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International Workshop Earthen Buildings in Seismic Areas

Conference Proceedings
Volume I

INTERNATIONAL WORKSHOP · EARTHEN BUILDINGS IN SEISMIC AREAS ·

The University of New Mexico

Intertect

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The National Science Foundation

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INTERNATIONAL WORKSHOP

EARTHEN BUILDINGS IN SEISMIC AREAS

PROCEEDINGS OF INTERNATIONAL WORKSHOP
held at the University of New Mexico,
Albuquerque, New Mexico, May 24-28, 1981

VOLUME I

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FOREWORD

The papers printed in these Proceedings of the International Workshop on Earthen Buildings in Seismic Areas represent the contributions of participants at the conference as well as other authors. Not all of the papers are original and have been presented, at least in part, at other forums. However, they were submitted for this publication, and we felt it of value to include them because they provided relevant background to the conference theme.

Assigning the papers to one of the five topics turned out to be somewhat difficult because of the overlap in the categories. We have attempted to use our best judgement in these decisions

Finally, in the interests of cost and time, it was not possible to reset the type nor to do more than a superficial job of editing the papers.

Gerald W. May
University of New Mexico

Frederick C. Cuny
Intertect

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John A. Blume, President
URS/John A. Blume & Assoc.

William O. Keightley
Professor of Civil Engineering
Montana State University

Aybars Gurpinar
Professor of Civil Engineering
Middle East Technical University
Ankara, Turkey

Roberto Méli
Professor, Institute of Engineering
Universidad Nacional Autonoma de Mexico

Haresh C. Shah
Professor of Civil Engineering
Stanford University

The following individuals acted as Session Chairmen:

Roberto Méli
Professor, Institute of Engineering
Universidad Nacional Autonoma de Mexico

William O. Keightley
Professor of Civil Engineering
Montana State University

Teddy Boen, Director
International Association for Earthquake Engineering
Jakarta Barat, Indonesia

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EARTHQUAKE RESISTANT CONSTRUCTION OF EARTHEN HOUSING

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Boen, T. Consulting Engineer, Jakarta, Indonesia

ABSTRACT

Earthen buildings are traditionally constructed since prehistoric times in all parts of the world. Yet there is practically no standardisation attempted so far. As usually constructed, they are weak and most vulnerable to complete collapse as observed during earthquakes in the past. An attempt has been made here to identify the main defects and structural weaknesses in such constructions. Then suggestions are given to improve their behaviour under normal conditions and to increase their resistance to earthquakes. It is recognised that no test results are yet available to evaluate such recommendations. The need to carryout properly planned investigations is therefore emphasised.

The recommendations for earthquake resistant construction of adobe buildings as made by IAEE Committee are reproduced in an appendix to the paper for ready reference.

INTRODUCTION

Earthen huts, consisting of walls built in clay mud and roofs made of thatch or tiles or clayey earth placed over wooden poles and bushes, have been constructed since prehistoric times in all parts of the earth. In spite of unprecedented technological advances made in the world, large proportions of populations, particularly in the rural areas of developing countries, still continue to live in such earthen huts. Many of these areas lie in moderate to severe seismic zones and the earthen houses pose a very severe earthquake hazard to the lives of the occupants and to whatever little belongings they have. By their very nature, these houses are also seriously threatened by the action of water whether through beating of rain or through inundation. Earthen walls softened by moisture penetration are left with little strength and even light ground shaking would be sufficient to cause their collapse in a heap of earth.

Another aspect of the earthen houses is their very small initial cost input, since the construction are usually done by the villagers themselves with the help of a village mason, the clay mud being obtained from nearby water ponds or fields, and wood and roof covering that are usually the only materials to be purchased. Therefore, any methods which should be suggested for improving their earthquake resistance capability must satisfy three requirements - firstly, the material to be used must be as cheaply available as used in making the hut; secondly, the total additional cost must be a small proportion of the cost of the hut; and thirdly, the technique should be such as can easily be adopted by the village masons and that most of the work can be done by unsupervised labor.

This paper outlines the main weaknesses of earthen houses leading to their collapse during earthquakes and presents simple and cheap techniques to reinforce them so as to make them reasonable stable.

BEHAVIOUR OF ADOBE BUILDINGS DURING PAST EARTHQUAKES

The performance of adobe, brick or stone buildings as observed during the earthquakes in India, Afghanistan, Iran, Chile, Italy, Turkey and elsewhere clearly shows that all unreinforced construction in clay mud mortar with any building units are extremely weak againt lateral loads. Even at moderate seismic intensities MM VII to VIII, a large percentage of adobe buildings, even to the extent of 30% are completely collapsed and another 30 to 40% become dangerously damaged which must be destroyed and rebuilt. The results presented in Table 1(7) and Figure 1 [6] based on studies on Chilean earthquakes are representative and indicative of the real situation about the earthquake vulnerabulity of the earthen buildings in relation to other non-engineered buildings. The main defects and structural weakness responsible for this poor earthquake behaviour are listed below.

MAIN STRUCTURAL WEAKNESS

1) Material Strength

There are no standards yet available for the compressive, tensile or bearing strength of earthen walls. It can, of course, be imagined that all these strength values would be very small. Also, since used in a non-standard fashion according to local traditions, the material strength will be widely variable.

Moreover, the strength of walls may vary from season to season during the year. The material would behave as 'hard' in dry weather and in arid climatic zones but relatively soft in moist or rainy weather and in wet areas. Due to the low strength values, only small size constructions, both in terms of span as well as height, could be safely built with earthen walls.

2) Shrinkage Cracks

The earth used to build walls is necessarily clayey so that it has enough cohesion to keep the various layers together. Associated with the cohesion is high shrinkage on drying which frequently results in vertical cracks particularly near the opening corners and junctions of long and cross walls. These structural cracks remain in-built in the walls although they may be plastered over on both faces and are a source of much weakness in their lateral as well as inplane strength.

3) Planning and Construction Defects

There are a number of planning and construction defects that can occur in earthen buildings such as the following and must be guarded against :

a) two storey construction is undesirable due to low strength of materials;

b) too high and too distant spacing of cross walls will pose stability problem in walls;

c) too large openings cause too much weakening of walls;

d) openings too close to corners of walls or too close to each other give rise to weak piers;

e) lack of proper foundation and firm plinth may cause spreading of wall at base when softened due to water;

f) too small bearing of door and window lintels may lead to crushing of jambs;

g) lack of proper bond between walls at right angles to each other may result in complete collapse of the building during ground shaking;

h) lack of proper bond between adobe units where such units are used with clay mortar;

i) poor quality of adobe units;

j) roof rafters directly placed on adobe wall create high stress concentration;

k) accessibility to water, wetting the wall near its base or rain water soaking into the walls from top, will cause large reduction in compressive and bearing strengths.

EARTHQUAKE RESISTANCE FEATURES

In order to achieve resistance to collapse of earthen buildings, new constructions should be planned and constructed in a manner that the defects pointed out above are avoided. Also some new features may be built into them for earthquake resistance as indicated below :

a) The earthen construction may be restricted to single storey. Where a pitched roof is adopted, the attic space only may be used for light storage purposes.

b) The uniform wall thickness should not be less than about 35 cm and its height not more than 8 times the thickness, that is the wall height may be restricted to about 2,8 m above plinth or floor level.

c) The length of wall between consecutive cross-walls may be less than about 10 times the wall thickness, that is about 3,5 m. In villages, where single room tenements are commonly adopted, the lengths are usually more than 3,5 m and may go even up to 6 to 7 m. In such cases, either buttresses should be built on the outside of long walls or a sort of partition in between may be used as shown in Figure 2.

d) The window and door openings in walls should be of small width and as centrally placed as possible. Larger widths reduce the wall strength appreciably and the lintel loads also become high. Doors and windows of about 0,9 to 1,0 m width should normally suffice.

e) The lintels over openings, which usually consist of wooden planks or half-sawn poles, should have a long bearing length on mud-walls to save them from crushing. A bearing length equal to about 40 to 50 cm should be adequate.

f) To avoid the crushing or splitting of walls under the concentrated loads of roof beams or rafters, their load should be distributed on the wall either through two courses of burnt bricks or through sawn timbers used as wall plates.

g) Suitable precautions should be taken for maintaining the walls in dry state, so that the strength of the wall is not lost.

h) For achieving box-like integral action of long and cross walls together, their mechanical connection is essential. For this purpose the following schemes are suggested :

(i) Wooden dowels may be inserted at all corners and junction of walls to go into all walls meeting at the junction by a minimum of about the wall thickness. Such dowels may be placed every 60 cm along the height and may consist of half sawn poles or bamboos (Figure 1.)

(ii) A collar beam should be placed going round over all the walls which may consist of timber of sufficient width with diagonal braces at all corners or two lumbers going round in parallel and well interconnected at the junctions. (See Fig. 5.5 of Appendix)

When the dowels are provided as in (i) above, the collar beam may be provided at top of walls and may serve as wall plate as well. If dowels are not used, the collar beam should be used at lintel level serving also as lintels over the openings and the wall plate used separately at the top of walls.

For economy half-split bamboos may be used instead of wood poles or sleepers. But it must be emphasized that since clay walls can be infested with white ants, that wooden element embedded in them must be suitably treated against termites. As an alternative to wooden dowels, expanded metal or welded wire fabric could be used where cost and availability would permit.

i) As a poorer alternative to the use of wooden members for reinforcing the walls, outside earther buttresses may be used to strengthen the corners and junctions of walls as shown in Figure 4.

j) The earthen construction will become much stronger if the dowels and buttresses could be used together where in the dowels pass through the buttresses as well as shown in Figure 4(b).

k) Another way to strengthen the wall against earthquakes is to use tapering wall thickness with about 60 cm at bottom and 35 cm at top.

l) In view of the limited wall strengths, the roof should be kept as light as possible. The thatched roofs are initially light but become heavy when soaked with water. Earth-covered roofs are naturally very heavy. Any kind of sheeted or tiled roofs would be preferrable.

DETAILED RECOMMENDATIONS

Detailed recommendations for construction of adobe houses are contained in 'Manual para la construccion de Viviendas con Adobe' prepared by Commision de Reconstruccion y Rehabilitacion de la Zone Afectada (CRYRZA) and proyects Experimental da Vivienda (PREVI) (Ministerio de Vivienda-Naciones Unidas)(5) which resulted from the observations, analysis and conclusions of National and Foreign Experts on the Seismic Effects in Peru on May 31, 1970, and the experience in adobe building put into practice successfully in other countries. Taking these and other information (2,3) into account, Committee II of International Association for Earthquake Engineering (IAEE) on Basic Concepts of Seismic Codes Non-Engineered Construction has prepared a chapter on "Buildings in Clay Mud or Adobe" as part of the total recommendations (4). This chapter is reproduced here in an Appendix to this paper for ready reference.

NEEDED STUDIES

Research investigations are needed to determine the earthen wall strengths, shrinkage properties and water soaking characteristics etc. which should also be related to the basic soil properties. Appropriate and economical admixtures are to be found which would improve the characteristics in a desired manner. The simple recommendations as presented in this paper are yet to be investigated by actual tests so as to determine their real value for earthquake resistance. Then only the real factors of safety of earthen buildings under severe earthquake conditions could be known.

CONCLUSIONS

Until actual test results become available, it is expected that the simple and very economical methods of construction and strengthening of the earthen houses suggested in this paper should go a long way in achieving safety against collapse of such houses in moderate earthquake intensities. These are strongly recommended for general adoption.

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4. "Basic Concepts of Seismic Codes" The International Association for Earthquake Engineering, 1980, Vol. I, Part 2, Chapter 5, pp. 83-89.

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7. Steinbrugge, K.V. and Flores R., "The Chilean Earthquakes of May 1960, A Structural Engineering View Point, "Bull. Seismological Society of America, Vol. 53, No. 2, Feb. 1963, pp. 225-307.

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TABLE 1

Comparative Study of Damage in Different Constructions (7,1)

Sl. No.	Type of Construction	Total Number of Dwellings	Repairable damaged %	Dangerous, must be dismantled %	Destroyed %	Total of Damaged ones %	Order of Usefulness with respect to Dangerous Destroyed
1.	Reinforced Brickwork	1781	8,3	1,4	0,8	10,5	2nd
2.	Reinforced Concrete Blockwork	5	20,0	0,0	0,0	20,0	1st
3.	Unreinforced Brickwork	1149	37,6	33,6	11,6	82,8	6th
4.	Unreinforced Concrete Blockwork	6	16,7	33,3	16,7	66,7	7th
5.	Combined reinforced and unreinforced brickwork	1334	37,7	20,8	3,5	52,0	5th
6.	Wood Frame with Masonry	147	53,0	19,7	3,5	76,2	4th
7.	Wood Frame	1516	24,8	8,0	1,9	34,7	3rd
8.	Adobe	187	17,0	52,5	23,0	92,5	8th
	Total dwellings considered	6125					

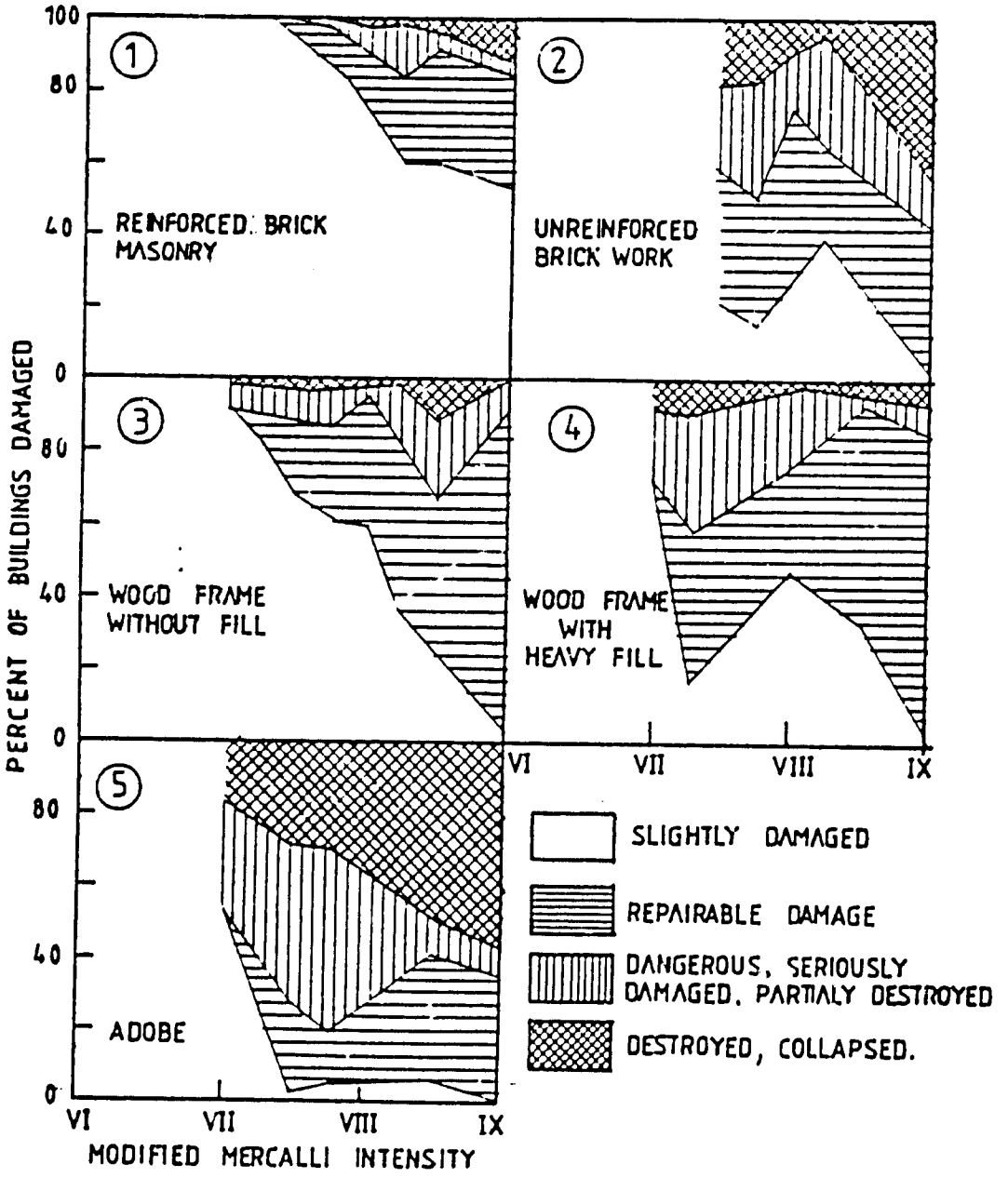


FIG. 1 _ DEGREE OF DAMAGE IN BUILDINGS

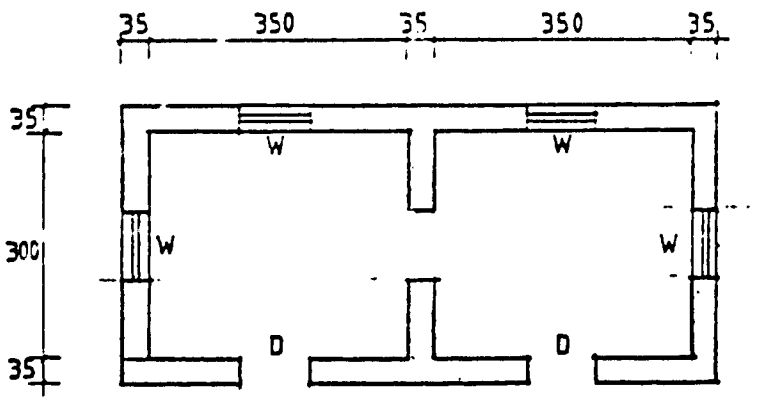


FIG. 2 _INTERMEDIATE PARTITION IN LONG ROOMS

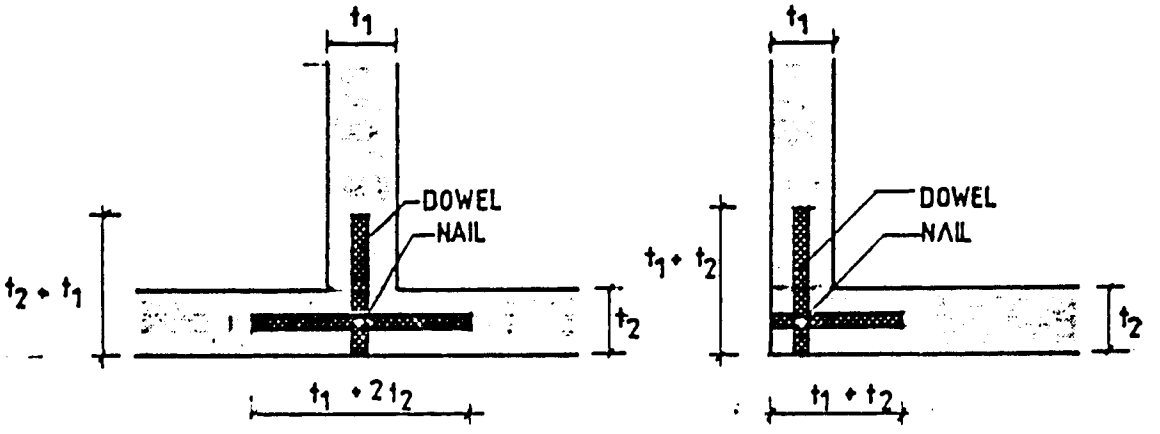


FIG. 3. DOWELS AT CORNERS AND JUNCTIONS OF WALLS

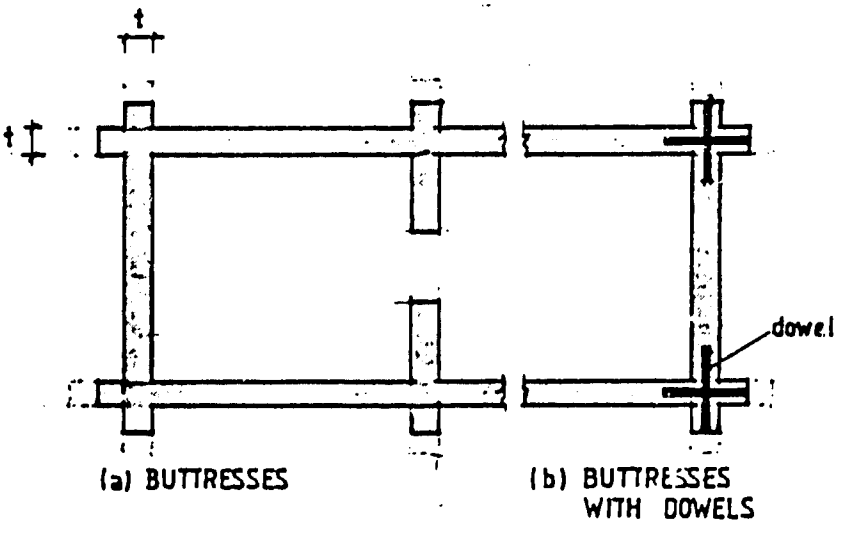


FIG. 4. ARRANGEMENT OF BUTTRESSES

CHAPTER 5

BUILDINGS IN CLAY MUD OR ADOBE

5.1 INTRODUCTION

There are many areas in the World where either the small buildings are constructed in clay mud; or unburnt sundried bricks are laid in mud mortar what is called as Adobe construction. Due to negligible tensile and shear strength and heavy weight such buildings are quite unsuitable in seismic zones A, B and C. Yet economic condition of the people may oblige them to continue to build their houses and cattle sheds in this way. Therefore, although the safety considerations in earthquake zones will demand prohibitation of such constructions, practical necessity of providing at least a shelter accomodation to the people will justify their continuation in future. With this view suggestions are given here to incorporate at least some earthquake resistance in such buildings.

Recognising that methods of forming, drying, stacking and transforting the adobe are peculiar to local conditions, recommendations are made here in those respects only which will have general application.

5.2 CAUSES OF FAILURE OF ADOBE BUILDINGS

The main causes of failure of adobe buildings in earthquake are briefly illustrated in Fig. 5.1.

5.3 DESIRABLE CONSTRUCTION FEATURES

5.3.1 Quality of Adobe

The earth used in mud houses and adobe (sundried bricks or blocks) should be of good quality as follows:

a) A mud paste made with small quantity of water so that the mud does not stick to hands should be capable of being rolled in the form of a thin thread between 5 and 15 cm long without cracking. If it cracks below 5 cm, clay is to be added; if it does not crack below 15 cm, sand is to be added.

b) Sufficient quantity of fibrous materials (straw, cane baggasse, horse hair, etc) should be added to the clay before making adobes.

c) After 4 weeks of sundrying the adobe it should be strong enough to support in bending the weight of a man (Fig. 5.2). If it breaks, more clay and fibrous material is to be added.

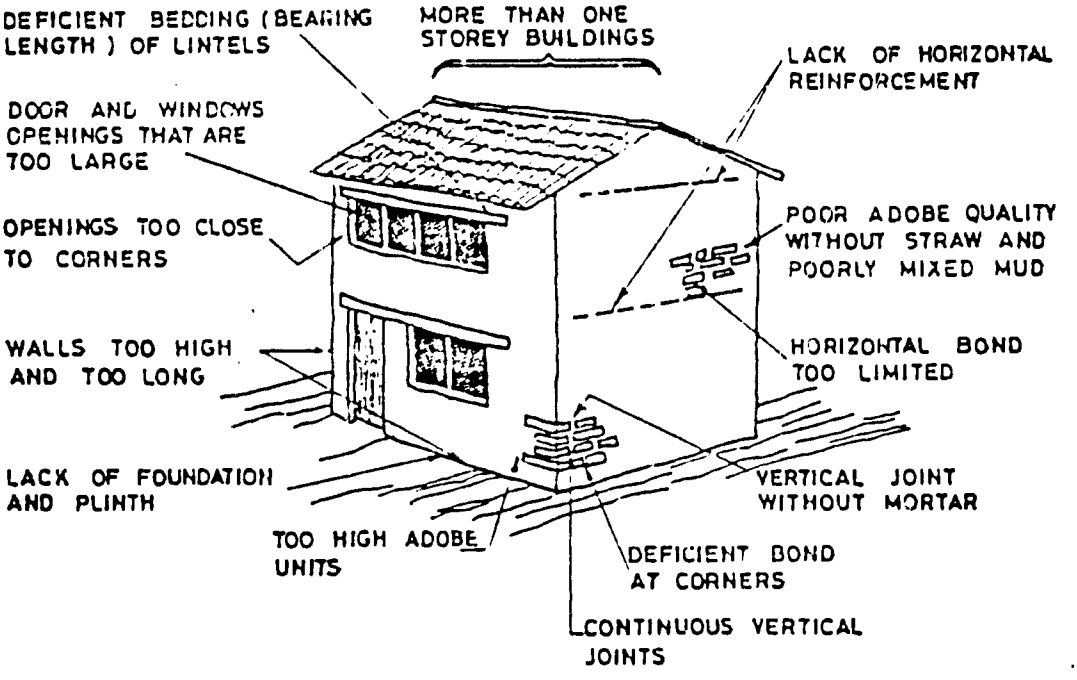


FIG. 5.1 - GRAPHIC SUMMARY OF CAUSES OF FAILURE

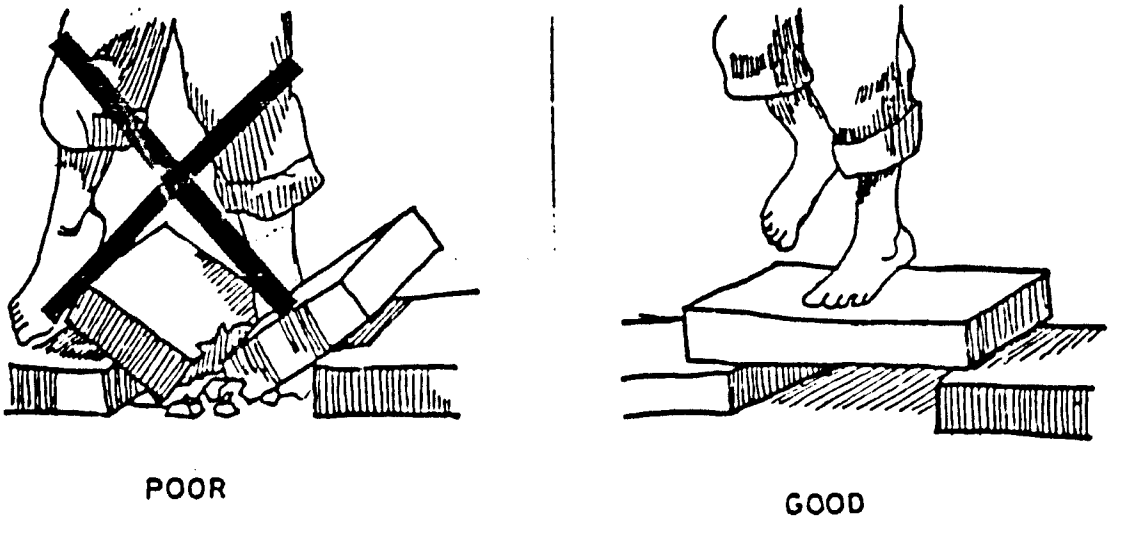


FIG. 5. 2 - TESTING STRENGTH OF ADOBE

5.3.2 Foundations

a) The strip foundation for the walls should have its width at least 1 1/2 times the thickness of wall and its depth a minimum of 40 cm below ground level.

b) The foundation should preferably be made in lean cement concrete with plums (cement:sand:gravel:stones as 1:4:6:10). Lime could be used in place of cement in the ratio lime:sand:gravel as 1:4:8.

5.3.3 Plinth Masonry

The wall above foundation up to plinth level should preferably be constructed from stone or burnt bricks laid in lime mortar 1:3 or clay mud. The height of plinth should be above the flood water line or a minimum of 30 cm above ground level. It will be preferable to use a water proofing layer (see 5.4.3b) at the plinth level before starting the construction of superstructure wall. If adobe itself is used, the outside face of plinth should be protected against damage by water by suitable facia or plaster. A water drain should be made slightly away from the wall to save it from seepage.

5.3.4 Construction of Walls.

The usual good principles of bonds in masonry should be adopted for construction of adobe walls, that is,

a) all courses should be laid level.

b) the vertical joints should be broken between two consecutive courses by overlap of adobes.

c) the clay mud should be the same as used in making the adobe.

d) the right angle joints between walls should be made such that the walls are properly joined together and a through vertical joint is avoided.

e) the walls should be covered with water repellent plaster on the outside by mixing bitumen cut-back in mud-mortar (See 5.4.3).

5.3.5 Dimensions of Walls

a) The length of a wall, between two consecutive walls at right angles to it, should not be greater than 10 times the wall thickness.

b) When a longer wall is required, the walls should be strenthered by intermediate vertical buttresses.

c) The height of the wall should not be greater than 8 times its thickness.

d) The thickness of load bearing walls may be kept one, 1 1/2, 2 or more

units of the adobe length depending on the desired length and height of wall. In the case of clay mud walls, parabolically tapering thickness will be seismically better (Fig. 5.3).

e) The height of the adobe building should be restricted to one storey plus attic only.

5.3.6 Openings in Walls

a) The width of an opening should not be greater than 1.20 m.

b) The distance between an outside corner and the opening should be not less than 1,2 m.

c) The sum of the widths of openings in a wall should not exceed one-third of the total wall length.

d) The bearing length (embedment) of lintels on each side of an opening should not be less than 50 cm.

5.4 SEISMIC STRENGTHENING FEATURES

5.4.1 Collar Beam or Lintel Band

A horizontal continuous reinforcing and binding tie should be placed coinciding with lintels of door and window openings in all walls. Proper connection of ties placed at right angles at the corners and junctions of walls should be ensured. These could be in the following forms:

a) Unifinished rough cut lumber in single pieces provided with diagonal members for bracing at corners (Fig. 5.4a).

b) Unifinished rough cut lumbers two pieces in parallel with halved joints at corners and junctions of walls (Fig. 5.4b). The lumbers may be half round.

c) Sawn lumber 5 x 10 cm in section placed in parallel as in b) above (Fig. 5.4b).

The whole assembly is to be covered with the clay mud and minimum two but maximum four courses of adobe laid over it before placing the roof.

5.4.2 Buttresses

Contruction of buttresses by projecting walls beyond the corner and T-junctions will help to retain the integral action of walls and facilitate the connection of collar beams with each other (Fig. 5.5).

5.4.3 Roof

a) The roof should preferably be of light material, like sheeting of any type.

b) If thatch is used for roof covering, it should better be made water proof and fire resistant by applying mud plaster mixed with bitumen cut-back on both surfaces of the thatch+.

c) The roof beams or rafters should preferably be rested on longitudinal wooden elements for distributing the load on adobe (Fig. 5.6). Preferably two top courses of burnt bricks may be laid instead of adobe for resting the longitudinal wooden elements.

d) The roof beams or rafters should be located to avoid their position above door or window lintels. Otherwise, the lintel should be reinforced by an additional lumber (Fig. 5.7.).

5.5 SUMMARY

The desirable features for earthquake resistance of adobe houses are briefly illustrated in Fig. 5.8.

+ Cut-back is prepared by mixing bitumen 80/100 grade, Kerosene oil and paraffin wax in the ratio 100:20:1. For 1.8 kg cut-back, 1.5 kg bitumen is melted with 15 grams of wax and this mixture is poured in a container having 300 millimetre Kerosene oil with constant stirring till all ingredients are mixed.
This mixture can now be mixed with 0.03 m^3 of mud mortar to make it both water repellent as were as fire protection of thatch.

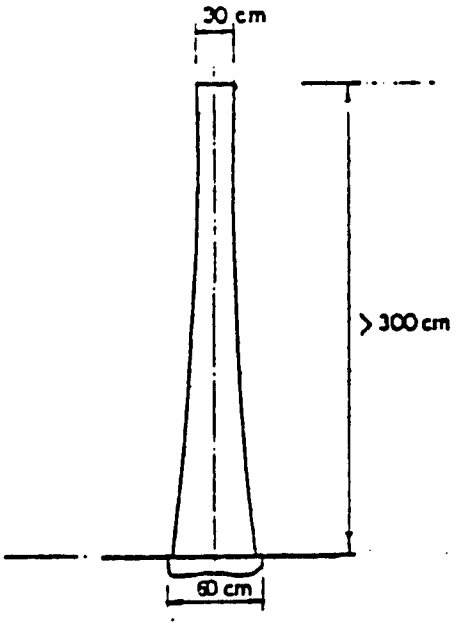
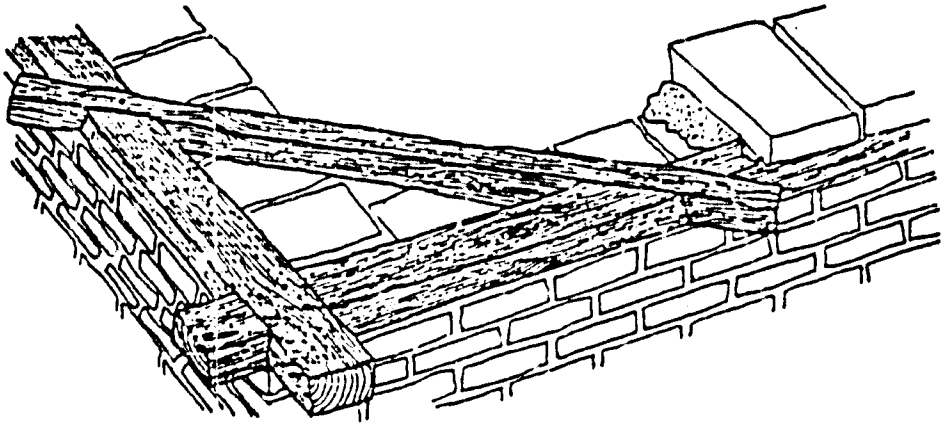
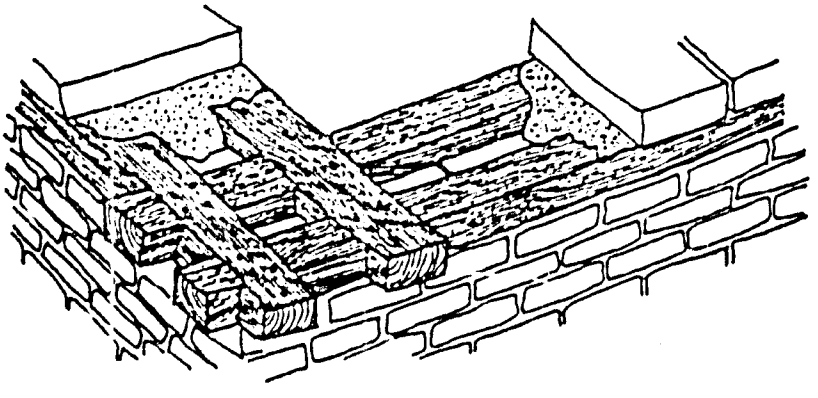


FIG. 5.3- CLAY MUD WALL



(a) ROUGH CUT LUMBER IN SINGLE PIECE WITH CORNER DIAGONAL



(b) ROUGH CUT LUMBERS IN PARALLEL

FIG. 5.4- COLLAR BAND IN WALLS AT LINTEL LEVEL

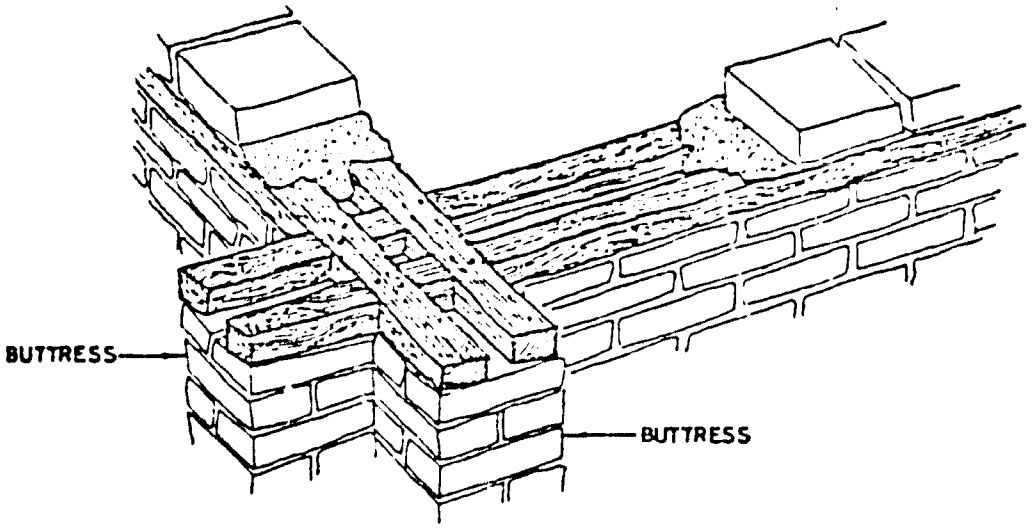


FIG .5.5 - USE OF BUTTRESSES

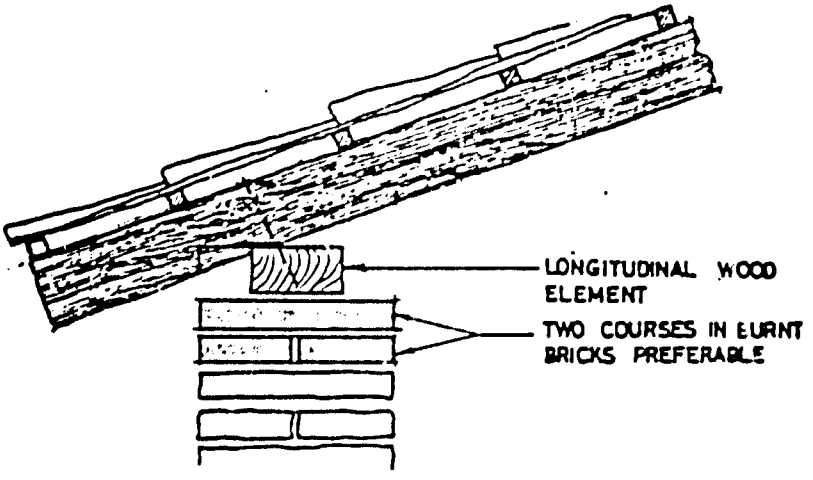


FIG. 5.6 USE OF LONGITUDINAL WOOD UNDER ROOF RAFTERS

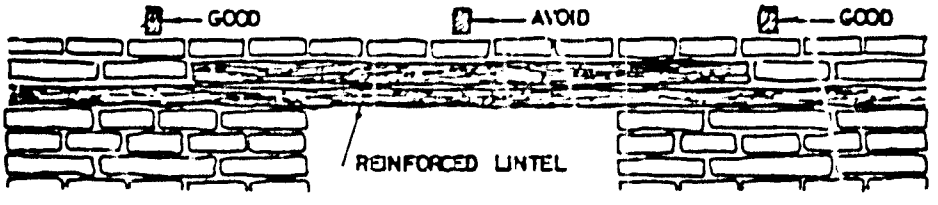


FIG .5.7 - REINFORCING LINTEL UNDER FLOOR BEAM.

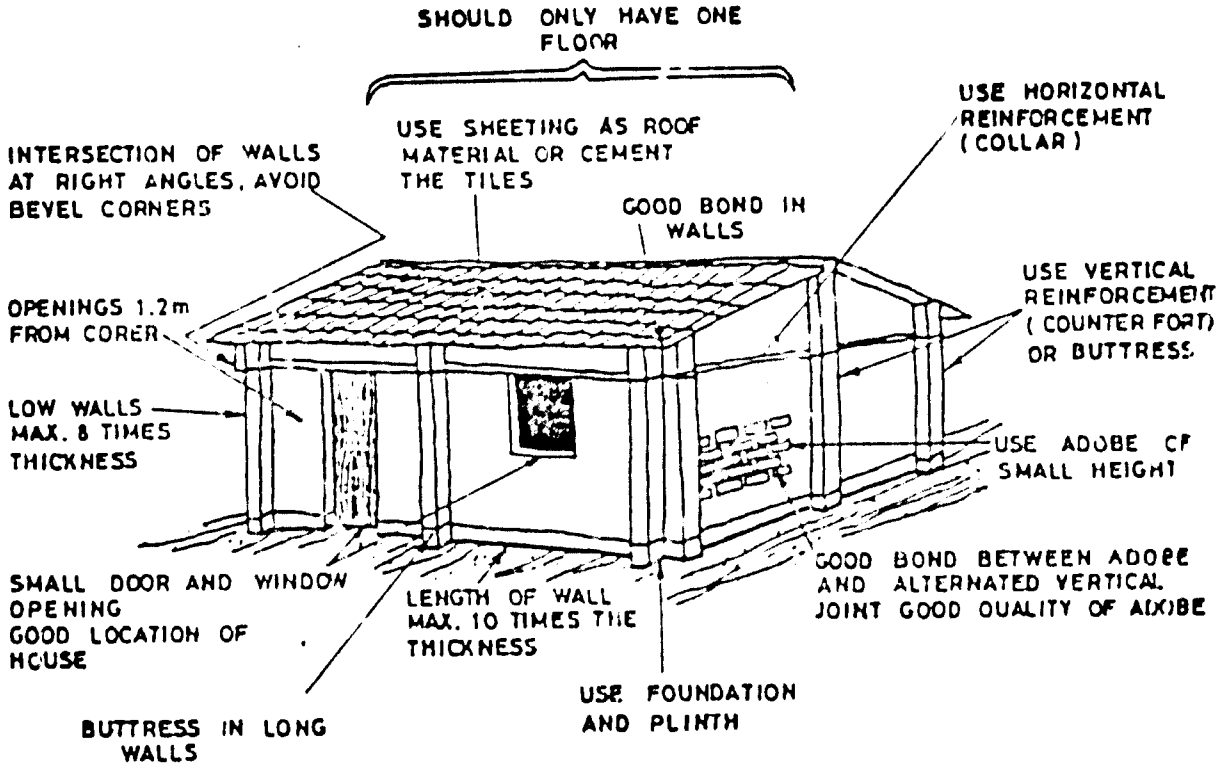


FIG. 5.8 - GOOD FEATURES OF EARTQUAKE RESISTANT CONSTRUCTION.

BEHAVIOUR OBSERVED IN EARTHEN BUILDINGS DURING FOUR DESTRUCTIVE EARTHQUAKES IN LATIN AMERICAN COUNTRIES

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ABSTRACT

In this paper, a revision is made of the behaviour noted by the authors in earthen buildings during four devastating Latin American earthquakes. They are: in San Juan, Argentina on 15th January 1944 and 23rd November 1977; in Lima, Perú on 3rd october 1974 and Guatemala, Central America on 4th february 1976.

Finally, some hints are given as to the improvement of the earthen buildings in zones of high seismic risk.

COMPORTAMIENTO OBSERVADO EN VIVIENDAS CONSTRUIDAS CON ADOBES DURANTE CUATRO TERREMOTOS DESTRUCTIVOS OCURRIDOS EN LATINOMERICA

RESUMEN

En este informe, se efectúa una revisión del comportamiento observado por los autores en las viviendas de adobes en cuatro terremotos destructivos latinoamericanos que son: San Juan, Argentina, 15 de enero de 1944 y 23 de noviembre de 1977, Lima, Perú, 3 de octubre de 1974 y Guatemala, C.A. 4 de febrero de 1976.

Finalmente se mencionan algunas recomendaciones para el mejoramiento de las viviendas construídas con adobes en zonas de elevado riesgo sísmico.

1- Introduction

Construction of adobe in Latin America is a tradition since spaniard colonization.

Because of the easiness of building and low cost, its diffusion was and still is very broad in human settlements all over the area, as well as in the most important cities.

For people of low means it shows advantageous characteristics for its building by themselves.

As a matter of fact, the row material can be obtained from the ground for nothing and with only the work of the person concerned adobes can be made and a house be built. Besides, in case of destruction by earthquakes it is possible to recover most of the materials thus facilitating the reconstruction.

It is evident that economic and social reasons will compel to continue using adobe, principally in rural areas. However, adobe-made houses built in the traditional way offer little resistance to earthquakes of a degree superior to VII of Mercalli's intensity scale and they have been the cause of the major amount of fatal victims occasioned by the earthquakes that affected Latin America.

The solution to this problem cannot be unbound from the socio-economical conditions of each country in particular. Consequently, many are the efforts perfomed in order to improve the seismic resisting behaviour of adobe-made buildings; however , this improvement must not lessen the value of its economic advantages and the possibilities of self-construction.

Adobe made buildings on which regulations have been applied for their better seismic resisting behaviour and that have been submitted to intensities of VIII and IX degrees of Mercalli's scale, have demostrated that it is possible to build economic houses made of adobe with and adequate resistance to earthquakes.

According to all the previously exposed, the need of prescribing regulations for the construction of adobe buildings, not with the aim of promoting them but to be applied in those cases that for socio-economical reasons their construction cannot be avoided, should be recognized.

2. The Earthquake of January 15th, 1944 - San Juan- Argentina.

General:

On Saturday 15th of January 1944, at 8 hours 50 min - local meantime - an earthquake with an epicenter located near the place known as La Laja, Department of Albardon, located 30 km

north of San Juan city, occurred. The magnitude of this seismic movement was estimated to be 7.8 in Richter's scale and its maximum intensity reached IX , in Modified Mercalli's scale , destroying nearly the whole city and causing from 8,000 to 10,000 dead. (Ref. 1).

On those days, the city of San Juan had about 110,000 inhabitants with a densely populated area covering approximately 135 city blocks. In its outskirts, four city districts were developing with a gradually decreasing building density, namely ; Concepcion in the north, Desamparados in the west, Trinidad in the south, and Santa Lucía in the east.

On the date of occurrence of this earthquake there were no regulations that prescribed seismic resisting provisions for buildings, though the city had been badly affected by another earthquake of greater magnitude than the commented one on October 27th, 1894.

Characteristics of buildings

When the earthquake occurred there were three kinds of buildings in the city, namely:

1- Reinforced concrete buildings with brick masonry, without seismic resisting provisions but well constructed, amounting about 2% of the city buildings. Most of them resisted the shake and were lately consolidated according to regulations prescribed by the National Council for San Juan Reconstruction, a national agency organized after the earthquake.

2- Brick masonry buildings, most of them imperfect because of the defective mortars employed (amounting aproximately the 8% of the city buildings). Many of these constructions collapsed and the remaining ones were demolished.

3- Adobe buildings (approximately the 90% of buildings).

Their behaviour is discussed in this paper.

Characteristics of adobe buildings

The edification in the urban area of the city of San Juan was distinguished by a predominantly 90% of adobe buildings characterized by being badly founded and having heavy roofs. In the outskirts, most of the buildings were made of adobe and there were even old houses built of "cast mud", called "tapia" in the local language, that were made by compacting mud in molds thus resulting walls with horizontal and vertical joints corresponding to each cast of mud.

The adobes used for building houses were made by mixing argillaceous loam, water and short straw and leaving the mix to rest for several days.

Then, the adobes being from 45 to 52 cm long, 22 to 25 cm long and 12 cm thick were casted and dried in the air. A dried adobe weighed about 20 kg and was laid on mud and sometimes on lime mortar prepared with greasy lime and fine grained sand.

The outer walls were made with adobes laid as a header (approximately 45 cm wide) and the inner ones by laying the adobes as stretchers (about 22 cm wide).

Nevertheless, it was frequent to find thicker walls made by building two walls with the adobes laid as a header separated 20 or 30 cm , this space being then filled with mud thus reaching a thickness of about 120 cm in order to thermically insulate the rooms.

In other occasions 120 cm wide walls were built massively in order to get some more strength, as it usually happened with churches.

In the inner walls of the houses it was frequently observed a lack of bond, the walls intersecting merely by contact and the corresponding joint being hidden by plastering and paint.

The foundations were of little depth and of bad quality since most of them were constructed using boulders cemented with mud, rarely lime concrete.

Their width usually was that of the wall. Since these foundations ended at ground level, moisture easily attacked the adobe walls disjoining the zone close to the ground and so reducing the cross section.

Sometimes the same phenomenon could be observed in foundations where the mud or mortar that cemented the boulders broke into bits.

The plastering of inner walls was made with mud mixed with water, adding a major amount of wheat straw than that employed when casting adobes in order to reduce the cracks caused by shrinkage when the argillaceous mud dried; they were then whitewashed and finally painted. Neither the outer walls nor the walls dividing estates were usually plastered.

In better finished houses, especially on their facades, plastering were made of lime and sand.

Adobe houses had only one storey. Their rooms were not less than 4,00 m. high,, usually 4,50 m and in some cases even up to 5.00 high. Excepcionally, heights up to 6.00 m. could be observed . (Photo 1). So high rooms and the exagerated thickess of the roofs were for the purpose of obtaining thermic insulation. The roofs were typical because of their construction and great weight. Poplar logs were rested on the upper part of the

walls, without anchoring, separated about 60 cm apart which in many distances did not rest on the whole thickness of the wall. The resulting system of beams was then covered with canes resting side by side and fastened with "tientos" , that is, narrow strips of wet leather which once dry become shorter and squeeze the knots.

In better perfomed constructions the canes were fastened with thin wire. On the so formed hurdle one or two beds of mud containing abundant cut straw, in a proportion even greater than that employed in the plasterings, were placed. Since these beds were replaced as time passed, the thickness of the mud frequently reached 40 cm and in certain cases a thickness of up to 60 cm has been measured.

This kind of roof was the preferred one by the inhabitants of the city of San Juan because of the continental characteristics of its climate and besides because it gave a good thermic protection against the heat if its long summer and the cold of its short but crude winter. Most of the houses were not given any treatment in their inner part being visible the logs as well as the hurdle. In better finished constructions they were covered by a ceiling made of Linen cloth or hardboard. In some public buildings, shops and confectioneries ceiling of stamping metal plates were observed.

In the center of the city the outlook of adobe constructions was improved by building a breast work over the roof which usually was more than one meter high. These walls were adorned with cornices which in spite of having a short projection caused eccentric loads. The greatest eccentric load was generated by the brackets that supported the aerial wires of the electrical system of the city and were embebed in the facades.

Observed damages.

The most affected area was the city district of Concepción since it had the oldest and worst construction and by being the closest to the epicenter. (Photo 2). Houses collapsed as well as walls separating estates made of cast mud. The stability against the earthquake of such walls proved to be limited since, though built of great thickness, there were no cohesion among the blocks resulting from each cast of mud. (Photo 3).

90% of the adobe buildings located in this city district collapsed. This result was caused by the weakening of wall bases generated by the wearing action of water, the lack of bond between interesting walls, the extremely high rooms and, mostly by the excessive weight of roofs.

The exaggerated thickness of the walls, sometimes as thick as 1,20 m or more, was of no help to the stability of buildings. (Photo 4).

Downtown and in the remaining three city districts of Desamparados, Trinidad and Santa Lucía, the degree of destruction observed in Concepción was not reached though many were the houses that collapsed because of the causes previously detailed.

In those adobe buildings that remained standing, it was observed, namely.

- A generalized collapse of breastworks and cornices due to the eccentric loads of the latter and those of the brackets supporting the electrical wires (Photos 5 and 6).

- Falling of roofs towards the interior of rooms because of the opening of walls and insufficient support of the logs resting on them (Photo 7).

- The prominent getting out of plumb of the facades.

- A generalized cracking of walls and damages in the upper corners of the openings, both caused by insufficient support of the logs by dintels.

- Falling of concrete dintels though the adobe wall remained standing.

- A negative influence of pipes embeded in the walls (pluvial drainage, ventilation of drains, etc.) that in some instances caused partial collapses or intensified the damages.

- Falling of plasterings due to lack of adherence.

- Falling of partitions because of lack of bond thus showing that they joined simply by contact. (Photos 8 and 9).

- Loosening of ceilings in most of the houses. Linen cloth or hardboard ceilings did not caused victims.

  On the other hand, in public buildings and confectioner's shops many were the dead and wounded caused by the loosening of rigid ceilings made of stamping metal plates.

- Changes made in houses, such as opening or closing of doors or windows, enlarging of rooms, etc, affected their stability manifestly and increased the magnitude of damages. In those cases where changes or enlargements had been performed using bricks, because of the lack of bond between both materials and their different behaviour, major damages resulted.

- Adobe masonry laid on lime-sand mortar collapsed because of the lack of adherence of the mortar with the adobes.

  This kind of buildings, that remained standing, were demolished in the days that followed the earthquake, the determination

based on safety reasons and the need of making ready the reconstruction, instituting the Council for San Juan Reconstruction.

Conclusions

The earthquake of 15 January, 1944, destroyed nearly completely the capital city of the Province of San Juan and its surroundings and caused approximately 8,000 fatal victims. The characteristic of disaster it reached was due to not only the violence of the movement but also to the extremely bad construction, mostly made of mud. This situation was somehow an amplified reprint of that noted after the 1894 earthquake already mentioned In that instance, what the earthquake pointed out was not taken into account, perhaps because in those days it was a small city. It is important to remark that the soil of San Juan is of good quality and it can bear much bigger buildings than the destroyed ones.

This is an important antecedent to affirm that the disaster was the consequence of the very worst quality of its construction, principally that one made of adobe.

3. The Earthquake of november 23rd, 1977 - Caucete-San Juan-Argentina.

General:

In the morning of 23 November 1977, at 6 hs. 28 min. local time, an earthquake of magnitude 7.3 in Richter's scale occurred which epicenter was located at about 100 km. east of the city of San Juan. It was distinguished by the large area affected reaching intensities of IX in Bermejo, from VIII to IX in Caucete, from VII to VIII in the city of San Juan and from VI to VII in the city of Mendoza. The city closest to the epicenter is Caucete, located 30 km. east of San Juan and being the center of a large rural area dedicated to the cultivation of vines and manufacture of wines (Ref. 2).

In the city of Caucete and surrounding districts, 75 dead resulted, a very small number if the large area affected and the population involved are considered.

This can be understood because the earthquake reached its great destructive power more than 20 seconds after its begining and, besides, because of the date and time of occurrence since it happened an hour before the begining of educational, industrial and commercial activities, but at daylight, so that the rural population had already left their houses.

The collapse of many adobe houses was responsible for most of the fatal victims and though damages were also important

in industrial and school buildings there were no dead in them because activities had not begun, as it was already mentioned.

Analysis of damages

In the city of Caucete, center of the agricultural area affected, the seismic intensity reached IX degrees in Mercalli's Scale.

It is important to mention that in a large area, covering more than 1,000 km^2, the phenomenon of liquefaction of fine-grained sands occurred and it caused a remarkable amplification of ground motion.

Such liquefaction arose some more severe effects on the constructions also accurring sinking, getting out of plumb and settling in buildings that in many instances made them useless.

The behaviour of constructions was th following:

a) Buildings with seismic-resisting provisions, made of reinforced concrete with ordinary brick, concrete block or hollow ceramic brick masonry. They resulted, in general, with minor damages. However, due to the combined effect of liquefaction of slimy soil together with constructive defects or inadequate structural design, several buildings collapsed or suffered severe damages, among which some school buildings can be mentioned.

b) Construction of old adobes built in the traditional way. They were destroyed or severely damaged and were the cause of nearly all the fatal victims (Photos 10, 11, 12, 13 and 14)

c) Adobe constructions built according to regulations prescribed by the Ex-Council for San Juan Reconstruction, in 1948, that as it was previously mentioned was the goverment department in charge of the reconstruction of the city of San Juan destroyed by the 1944 earthquake. The buildings of this kind located in Caucete suffered minor damages such as the falling of inner plasterings (Photos 15 and 16). Those ones located in the surroundings of San Juan city, where there was no liquefaction of soils and the intensity reached VIII degrees in Mercalli's Scale, suffered no damages.

Conclusions

Caucete earthquake has rendered possible a comparison of the behaviour of the different types of adobe buildings when shaken by seismic movements of great intensity, from VIII to IX degrees in Mercalli's Scale, with the following result:

On the one hand, total collapse of adobe constructions built in the traditional way, without seismic-resisting provisions, and on the other, with no damages or with economically

repairable damages those constructions built according to seismic resisting provisions in spite of soil liquefaction.

4. Lima (Perú) Earthquake of 3 October, 1974

General:

On October 3rd, 1974, at 9 hs 21 min - local time- a violent earthquake affected the city of Lima and its sorroundings. The epicenter was located by N.E.I.S. of the United States at 12.3° south latitude and 77.8° west longitude, 50 km south-west of Lima with a focus 13 km deep. The estimated magnitude, according to N.E.I.S. , varies from 6.6 to 7.6 , the former based on the volumetric waves (MB) and the latter on the superficial waves. This earthquake caused 78 dead, more than two thousand wonded, about 5.500 damaged buildings (Ref. 3) and affected a population of about four million inhabitants.

The most affected places were the following towns: Chincha, Chorrillos, Barranco, Imperial, Cañete and La Molina, having also been considerably damaged La Planicie, Pisco, Callao, Ica, Rimac, San Miguel and Barrios Altos. The most affected area covers approximately 60,000 km2, in which intensities as high as VIII degrees in Modified Mercalli's scale were observed, as stated in the Bulletin of the Geophysical Institute of Perú issued on 18 October, 1974.

Damages in buildings

The edification in the city of Lima combines different types of constructions: from old houses of adobe, some of them built during the colonial period, to modern buildings, several storeys high, with reinforced concrete structure and brick masonry walls.

The following types of constructions are distinguished:

a) Single storey houses of adobe.

b) Single and two storey houses made of adobe and "quincha".

c) Single storey houses of brick masonry without reinforcement.

d) Single and two storey buildings of brick masonry with little reinforcement.

e) Tall buildings with adequate reinforced concrete structure and brick masonry filling.

One storey high houses of adobe are numerous in the humble city districts of Lima, Barrancos, Chorrillos, Huaura, Huacho and Chancay. The adobe used measures approximately 10 x 20 x 40 cm and when laid as a header, walls 40 cm thick and from 3 to 4 m

high result. It was observed that such adobes are frequently moulded without straw and so they easily broke into pieces.

The roofs are even and formed with rafters or logs on which canes or boards are laid, covering them with one are more mud beds. Dintels are usually made of wood, occasionally of reinforced concrete. No one of the adobe houses had any kind of linking. As it happened in other earthquakes, many houses of this kind were damaged on October 3rd so causing most of the victims (Photos 17, 18, 19 and 20). Most of such houses have been affected by previous earthquaks and have later been repaired taking into account no kind of seismic resisting provision.

Those houses made of adobe and "quincha" usually have their outer walls built with adobes laid as a header (40 cm. thick) and they are from 3 to 4 meters high. The "quincha" walls are formed with poles, diagonals and pine beams all linked among them by means of horizontal rafters. Then, vertical canes are placed which are plastered with mud on both sides. The roofs are also even and built in a similar way that those ones of adobe houses. This type of construction is abundant in El Callao as well as in the old districts of Lima.

In general, the houses made of "quincha" and those of adobe and "quincha" were less damaged than the adobe ones (Photos 21 and 22).

Conclusions

Peruvian seismic-resisting regulations contain an appendix related to adobe constructions. Analyzing the observed damages it becomes clear that, if such regulations had been applied, those had been prevented.

5. Guatemala Earthquake of February 4th, 1976

General

On 4 february, 1976, at 10 hs. 02 min. 33 sec. GMT (03hs 02 min. 33 sec. local meantime) a violent earthquake affected the central area of the Republic of Guatemala causing about 25,000 dead, 77,000 wounded and copious damages to the physical and social structure. (Ref. 4).

The Republic of Guatemala has an area of about 108,889 km^2 and aproximately 5 million inhabitants. Its capital city, of about 1 million inhabitants, is located at Valle de la Ermita some 1,500 m. above sea level, the place being crossed by dells and surrounded by mountains having a few active volcanoes.

There are several types of construction in Guatemala, from the typical and humble single storey buildings of adobe, the

two and three storey buildings of adobe, the two and three storey buildings of bricks and blocks with little reinforced concrete structure, to the four to nine storey buildings, all of them of the framed sort with slabs enclosing the beams, and even, buildings of advanced construction with frames and reinforced concrete seismic resisting walls, these latter ones amounting more than two dozen.

The soil in Guatemala City, up to 10 to 15 meters deep, is formed by a clay bed that gradually turns into slimy sand. Under such superficial bed, and up to 100 meters deep, volcanic sand is found.

The bearing capacity value used for foundation calculations varies between 1 to 2 kg/cm2. A preliminary evaluation of damages was carried on by the General Secretariat of the National Council for Economic Planning. As far as it concerns to material damages, the sector mostly affected by this earthquake was the housing one. Practically one million inhabitants, one sixth the country population,lost their houses, since about 258.000 houses were damaged.

The main epicenter of 4 February earthquake has been found, by the United States Geological Survey, to be located near Los Amates, in Izabal, in the west area of the Republic of Guatemala, with an estimated magnitude of 7.5 Richter.

Observed damages

Speaking of old constructions of adobe, those located, in the outskirts of the capital city as well as the ones in country areas, it was observed that the "adobe" employed had been kneaded in such a way that it frequently contained pine fibres. The soil used for making mud contained little argillaceous components, thus resulting loose "adobes" that easily broke into pieces. Joints among the adobes were winder than they usually are in other Latin American countries , thus producing an inadequate linking among the elements. Besides, there is the rainy season, begining in May and lasting 4 to 5 months, so that the permanent moisture has worn out the foundations and the walls, the latter usually not plastered, leaving them in inferiority of conditions.

Nearly all of these houses with adobe walls and tile roofs, especially in the rural area, were destroyed and so caused most of the victims between the dead and wounded. (Photos 23, 24 and 25). In some of these houses with severe damages in their walls, it was detected that they had not collapsed if they had had an horizontal wooden frame on the upper end of the walls on which the rafters rested. Such wooden frame has evidently worked as an upper linking element of the walls causing them to perform as a whole and so preventing them from falling. (Photo 26).

Conclusions

The observed damages are basically due to the complete lack of seismic resisting provisions for constructions of mud , the very worst quality of the adobe employed and the inadequate way of building the houses, all these becoming worse because of weather effect.

6. Final conclusions

Humble constructions made of adobe that caused so many victims in case of occurrence of a destructive earthquake, are widely spread in Latin America and correspond to the present socio-economic conditions. They are a consequence of the cultural and technological development of the countries as well as of the raw materials available in each region, so that it becomes impossible to try to eradicate them definitely, but as a transition period, they can be improved in order to make them less dangerous.

Analyzing the behaviour observed in adobe houses during the four destructive earthquakes considered, it is deduced that when such houses have been constructed with faulty materials and according to traditional constructive ways, they have always collapsed because of the lack of seismic resistance.

In spite of this, for socio-economic reasons, still it will be necessary to build and rebuild adobe houses in Latin American countries (Ref. 5).

Because of this fact, it becomes necessary to face such a reality and, consequently, to dictate directions for the building of adobe houses in order to make them seismic-resisting enough as to support destructive earthquakes.

This is not an easy task since people to whom such houses are assigned usually are of less means and generally obstinate to change their traditional building techniques.

For this last reason, such rules shall be directed to a series of simple improvements both in their design as well as in their construction which, without lessening their advantages of self-construction shall give them enough seismic-resisting safety.

As it was previously stated, construction of adobe houses is imposed by the socio-economic conditions of each country. In Argentina, strong efforts are made to eradicate them from urban sites located in its seismic area. On the other hand, in rural areas an improvement of their seismic-resisting behaviour is attempted, especially in those cases where people, for the time being, have no other means than their own effort for their self-building.

7 - Analysis and structural design of adobe houses

From the analysis of damages observed in constructions of adobe caused by the four destructive earthquakes under consideration, the conclusion that, under certain conditions adobe houses can perfom a "satisfactory" behaviour in case of occurring severe earthquakes, is arrived to.

By "satisfactory" behaviour it is understood when the adobe house is capable of:

- Resisting minor earthquakes without being damaged.

- Resisting moderate earthquakes with slight structural and none-structural damages.

OOResisting strong earthquakes without collapsing and causing victims.

Failure of adobe houses my be attributed mainly to their little strength to tensile stresses and to the very little adherence between mortar and adobe.

Failure mechanisms are presented in Figure 1.

Consequently, those mechanical characteristics necessary to be known are:

- Tension strength.

- Bending strength.

- Shearing strength.

Though failures due to axial compression have not been detected, the knowledge of their behaviour under such stresses gives a good idea of the quality of their walls.

Figure 2 shows graphically the tests necessary to carry on to obtain the mechanical characteristics already mentioned. However, when such tests cannot be performed, the following stress values, somewhat conservative, can be adopted:

- Contact compression, 2.20 kg/cm^2

- Axial compression in walls, 1,8 kg/cm2

- Horizontal shear in walls, 0.10 kg/cm2

These allowing stress values have been obtained using a safety factor of five.

In short, those investigations and tests carried on by several researchers (mainly in Perú) presently allowed the structural analysis of adobe houses by rational mehotds based on the

materials resistance. Nevertheless, the good seismic-resisting behaviour of such houses is obtained when a series of provisions directed to the architectural design as well as to the building technique and the manufacture of adobes is applied.

In the following paragraphs some of such provisions are detailed:

a) Provisions for the architectural design:

- Symmetrical plants with a balanced distribution of walls, shall be obtained.

- The height of the walls shall be limited (8e, being "e" the thickness of the wall).

- The maximum length of the walls shall be limited (10 e).

- The openings for doors and windows shall be small (not wider than 1.20 m).

- The openings for doors and windows shall be located not less than 1,20 m far from the corners or, on the contrary at mid length of the wall.

- Adequate use of breastworks to improve the stability of walls. These can be located in the outer intersections of walls (minimum projecting length equal to wall thickness), in the center of a long wall or, coinciding with an opening for a door or window (breastwork total length, 3 e).

- Light roofs, preferably of logs covered with canes, mud (thickness ≈ 7 cm) and moistureproof insulation.

b) Building Details:

Walls: - 0.40 m minimum width, being bearing walls or not. Isolated walls without breastworks for their stability, are forbidden.

- They can be reinforced with stable materials in agreement with the wall material, for instance, canes or welded steel network.

Foundations and overfoundations:

- Minimum depth, 0,40 m.

- Minimum width, 0.40m , or that resulting according to bearing capacity of the soil.

- Minimum overfoundation, 0,20 m.

They will be made of:

- Cyclopean concrete with a minimum cement content of 160 kg/m3 adding 30% of boulders.

- Brick, concrete blocks or natural stone masonry on 1: 1/4 : 4 (cement-lime-sand) mortar and accordingly bond.

Upper enchaining beam:

- Each wall, in its upper end, will have an enchainment formed by two logs 0.10 m. in duameter or two rafters 0.10 x 0.10 m cross section, linked to each other every 70 cm by 2 x 5 cm wooden braces. At intersections and wall angles they will be half-thickness joined using five nails 4 x 120 mm size in each joint.
- An enchainment made of reinforced concrete having a width equal to that of the wall and being 15 cm high, with 4 10 mm steel rods and 6 mm braces every 20 cm; shall be preferred. Fig. 3.

- The roof structure shall be conveniently linked to this upper enchaining beam. Fig. 4.

Dintels:

When dintels of openings for doors and windows and the enchaining beams are made of reinforced concrete and they are less than 15 cm apart, it is convenient to unify them. Fig. 5.

Plasterings:

Walls shall be plastered with mud mortar containing abundant straw or cement-lime-sand mortar (1/4 : 1: 5).

Floors:

They could be made either of smoothed cement, calcareous floor tiles, or overbaked bricks. In all instances, once finished, the floor level shall be 10 cm below the overfoundation.

Pipings:

It is not advisable to embed any kind of piping in adobe walls. If necessary, the embedment shall be superficial.

Roof projections protecting external walls:

It is advisable the use of roof projections 0.50 m. deep in order to protect the external walls from rain wearing.

Stabilized Adobe:

With respect to this, the tests carried on in Perú are worth mentioning. The adobes stabilized with RC-250 asphalt remarkably im-

prove their behaviour under moisture, their strength and external appearance, to such extent, that it is not necessary to plaster them and can be just painted.

Horizontal and vertical reinforcements made of canes:

- Horizontal and vertical reinforcements made of canes remarkably improve the stability of walls. Vertical reinforcements need the use of a special kind of adobe to contain them. These vertical reinforcements shall be conveniently anchored in the reinforced concrete foundation and upper beam.

Adobe dimensions:

a) Traditional adobe 10 x 20 x 42 cm.

b) Square adobe 38 x 38 x 8 cm and halves 38 x 18 x 8 cm ; these ones being safer under seismic action.

Surrounding pavement:

An external pavement with a minimum 0.60 m. width made of smoothed concrete, shall cover all the perimetral length.

Separation between adobe houses:

- Every adobe house shall be located not less than 2 m. apart from any other existing building, the latter being made of adobe or not.

- Every adobe house shall be separated 1m , at the least, from estate-dividing walls.

Pluvial drainages:

Pluvial drainages of roofs shall be made of pipes with outer spillway or, on the contrary, by free downfall through pipes or grooves projecting, at least, 0,60 m from the outer walls.

Manufacture of adobe:

a) Selection of soil:

Clean soils, free of gravel or grains coarser than 5mm. These soils shall content clay or loam, this content amounting from 20 to 50% of the total weight and having a plasticity index between 5 and 10.

b) Test for selecting the soil

A cylinder, being approximately 2 cm in diameter shall be conformed with mud kneaded with little water and the length

it can reach without breaking shall be noted. If such length amounts to 5 to 15 cm , the soil shall be regarded as competent for adobe manufacture.

c) Preparation of mud

The selected soil, previously ground into small lumbs, shall be kneaded adding water and enough fibres, for instance dry straw. Then, the mixture shall be allowed to digest for not less than three days before casting the adobes, being kneaded once a day.

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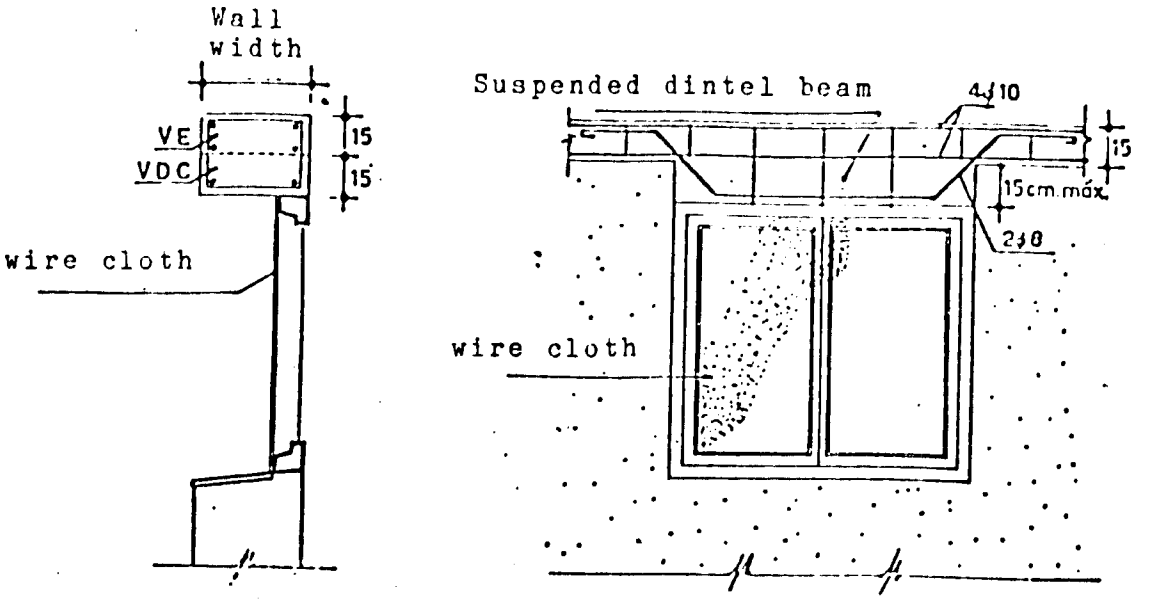
DINTEL - SOLUTIONS

WHEN THE SEPARATION BETWEEN WOODWORK AND UPPER ENCHAINING BEAM IS NOT GREATER THAN 15 CM , A DINTEL SHALL BE BUILT, UNIFYING IT WITH THE V.



WHEN THE SEPARATION BETWEEN WOODWORK AND UPPER ENCHAINING WALL IS GREATER THAN 15 CM THE WOODWORK SHALL BE PROTRACTED BY MEANS OF A STATIONARY WOOD OR GLASS PANE.

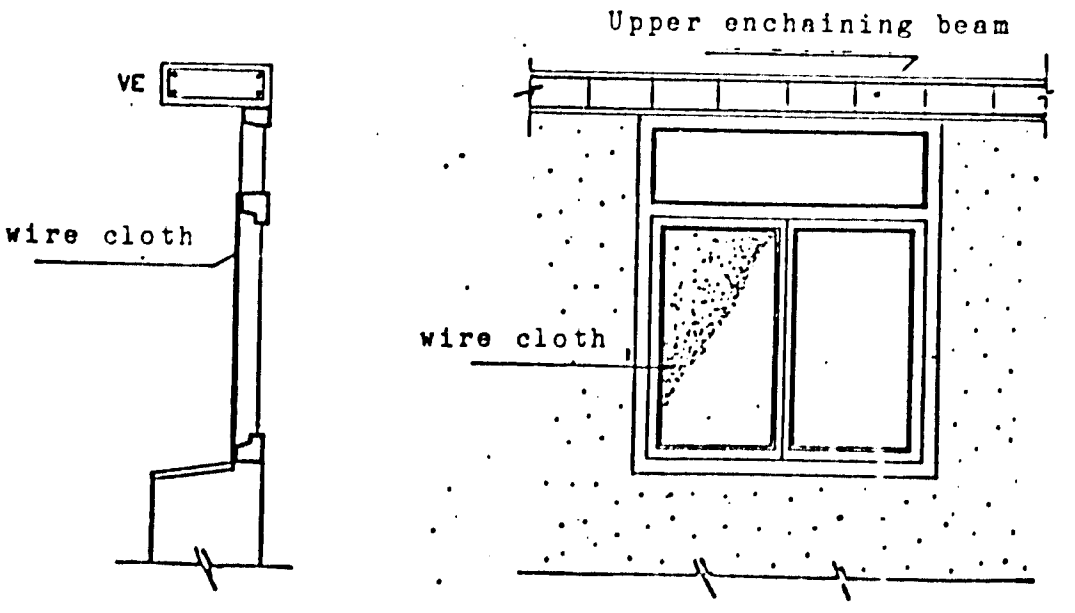
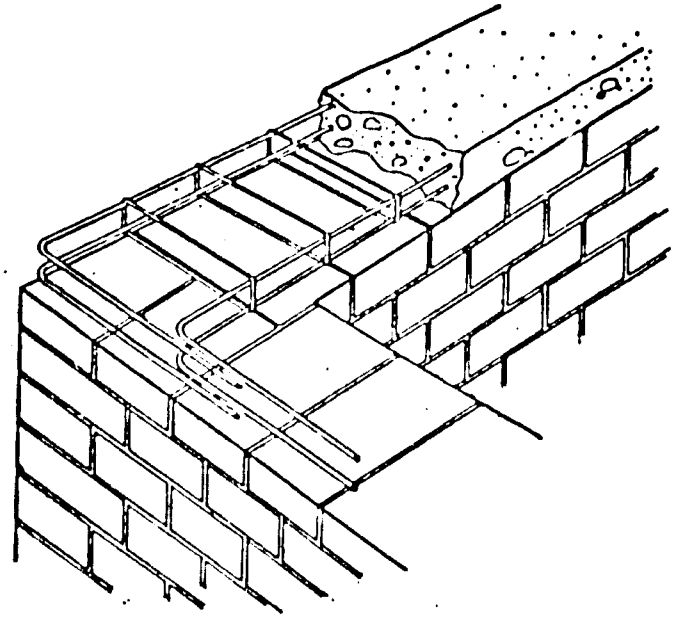


FIGURE 5

UPPER ENCHAINING BEAM

IN THE UPPER END OF WALLS, AN HORIZONTAL CONTINUOS REINFORCEMENT SHALL BE PLACED, THE SO CALLED UPPER ENCHAINING BEAM WHICH , AS POSSIBLE, SHALL COINCIDE WITH DOOR AND WINDOW DINTELS.



THE WHOLE SET SHALL BE SOLIDLY LINKED IN THE CORNERS TO AVOID UNFASTENING.

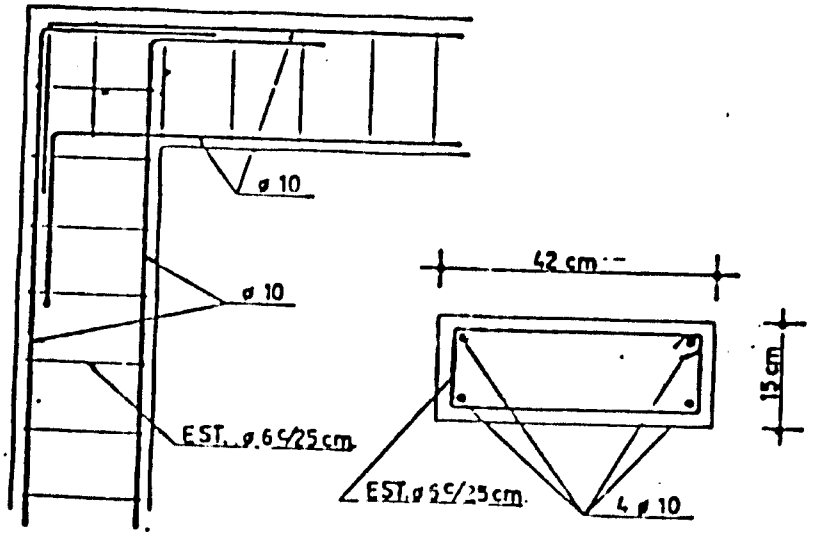
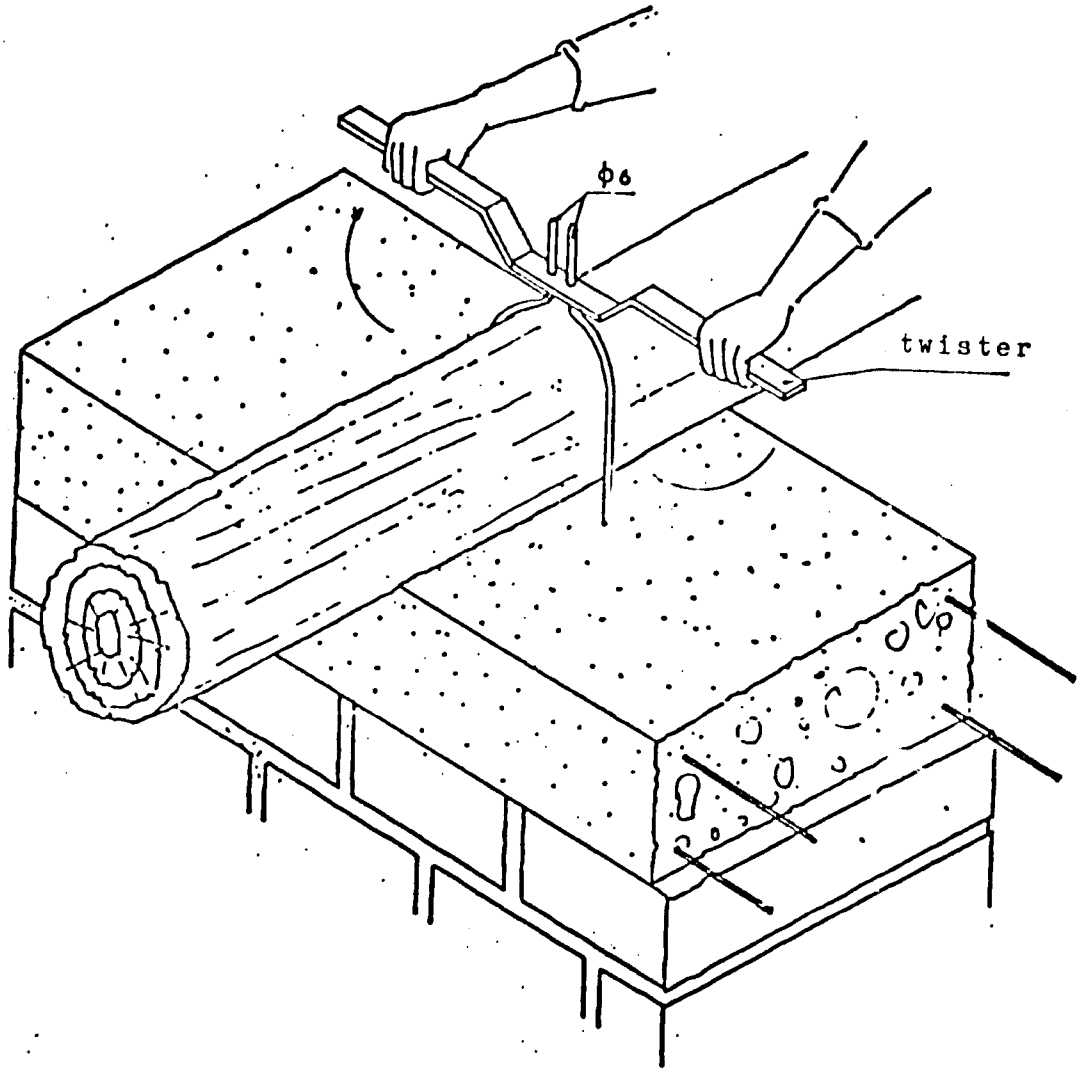


FIGURE 3

LOG ANCHORING



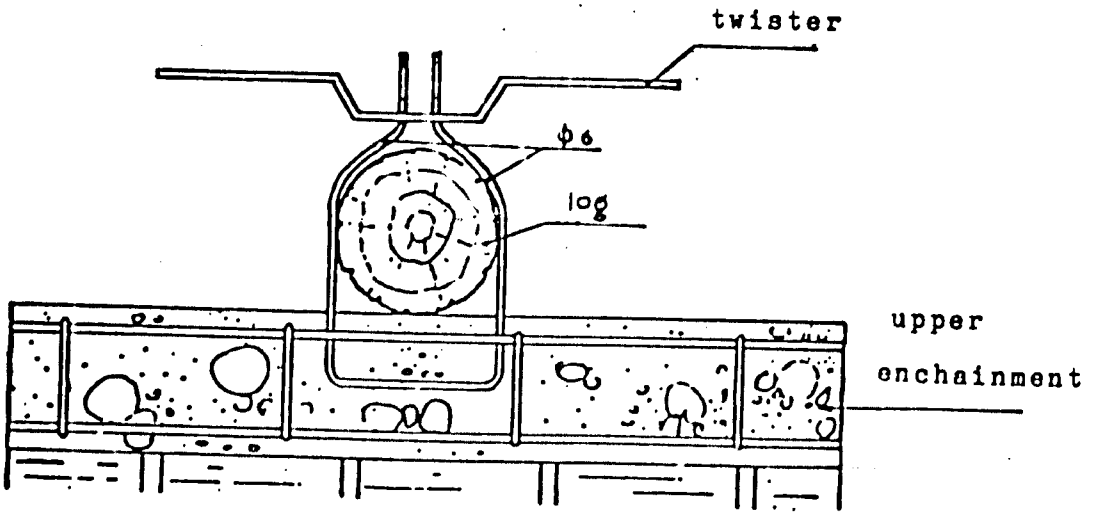
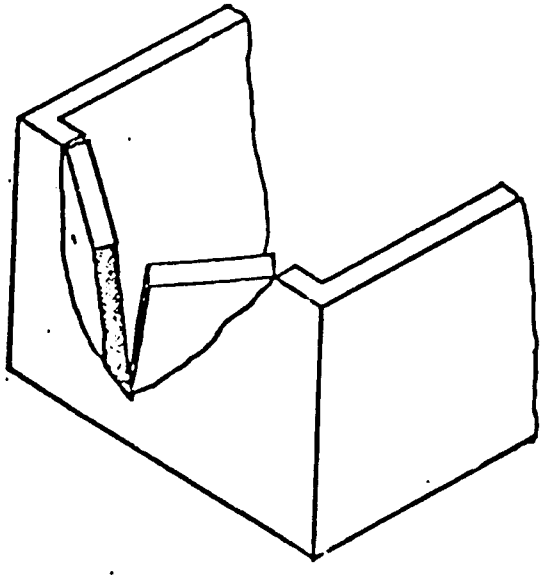
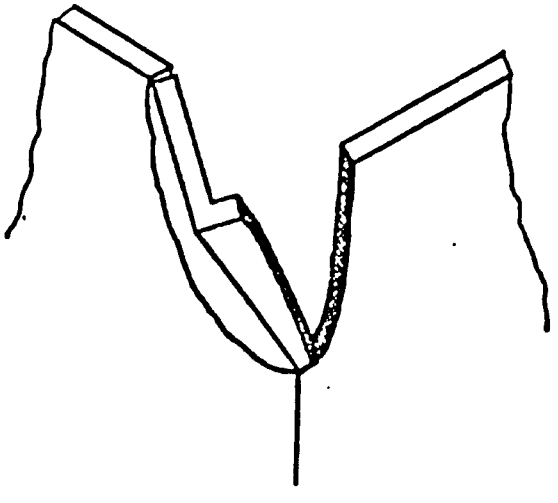


FIGURE 4

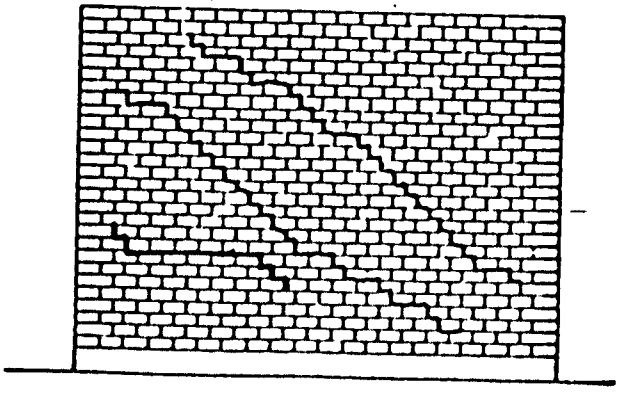
MECHANISM OF FAILURE



FLEXURAL FAILURE OF WALLS WITHOUT UPPER ENCHAINMENT



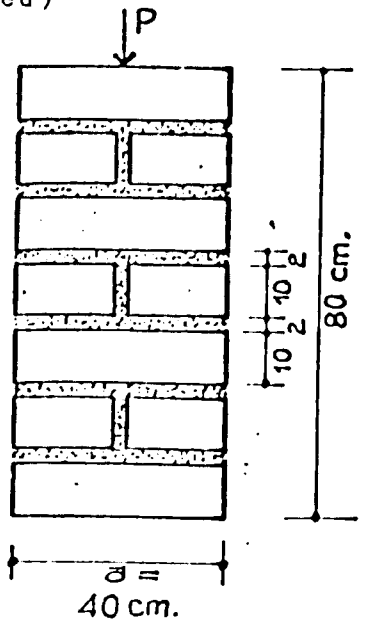
TENSILE FAILURE IN WALL INTERSECTION



SHEARING FAILURE FIGURE 1

TEST FOR DETERMINING ALLOWABLE STRESSES

(The mean value of not less than three specimens, shall be considered)

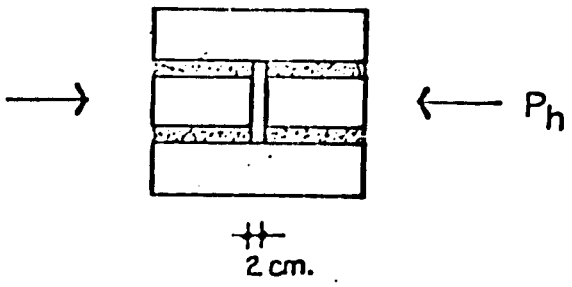


a) Axial Compression Test

$$\sigma_{rot} = \frac{P}{a \times a}$$

$$\sigma_{adm.} = \frac{\sigma_{rot}}{5}$$

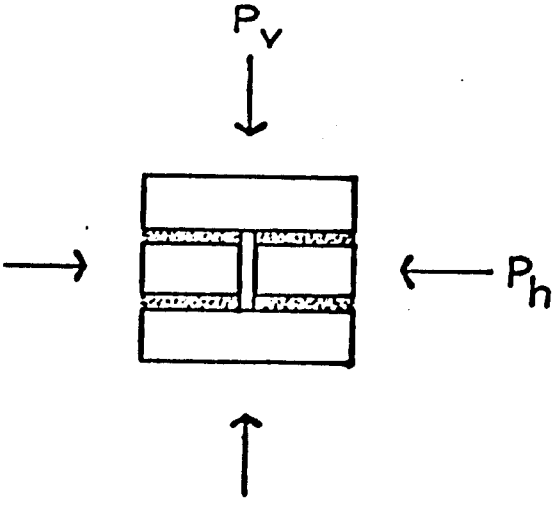
$$\sigma_{adm.} \text{ de contacto} = \sigma_{adm.} \times 1{,}25$$



b) Bonding Test (cohesion)

(without mortar and clean)

$$\mu = \frac{P_h}{2 \times (a-2) \times a} \quad \left[\frac{Kg.}{cm^2}\right]$$



c) Shear Test

$$\tau_{rot} = \mu + \frac{P_v}{2 \times (a-2) \times a} \cdot f$$

$$\therefore f = (\tau_{rot} - \mu) \frac{2 \times (a-2) \times a}{P_v}$$

FIGURE 2

LIST OF PHOTOGRAPHS

PHOTO N° 1 - Adobe house that collapsed during San Juan earthquake of 15-I-1944.

PHOTO N° 2 - Collapse of adobe houses, San Juan, 15-I-1944.

PHOTO N° 3 - Cast mud wall (Tapia), San Juan, 15-I-1944.

PHOTO N° 4 - Collapse of an adobe wall. 1,20 m thick, San Juan, 15-I-1944 (Concepción Church).

PHOTO N° 5 - Adobe walls collapse and falling of breatsworks and cornices, San Juan. 15-I-1944.

PHOTO N° 6 - Collapse and getting out of plumb of adobe walls, and falling of breastworks and cornices, San Juan 15-I-1944.

PHOTO N° 7 - Falling of roofs to the inside of rooms, San Juan, 15-I-1944.

PHOTO N° 8 - Collapse of partitions due to lack of bond, loosening of ceilings and falling of cornices, San Juan 15-I-1944.

PHOTO N° 9 - Adobe walls collapse and falling of cornices, San Juan, 15-I-1944.

PHOTO N°10 - Collapse of old adobe houses, Caucete, San Juan, 23-XI-1977.

PHOTO N°11 - Collapse of old adobe houses, Caucete, San Juan, 23-XI-1977.

PHOTO N°12 - Collapse of old adobe houses, Caucete, San Juan, 23-XI-1977.

PHOTO N°13 - Collapse of old adobe houses, Caucete, San Juan, 23-XI-1977.

PHOTO N°14 - Collapse of old adobe houses, Caucete, San Juan, 23-XI-1977.

PHOTO N°15 - Undamaged adobe house built according to regulations, San Juan, 23-XI-1977.

PHOTO N°16 - Undamaged adobe house built according to regulations, San Juan, 23-XI-1977.

PHOTO N°17 - Collapse of adobe walls, Lima, Perú, 3-X-1974.

PHOTO N°18 - Collapse of adobe walls, Lima, Perú, 3-X-1974.

PHOTO N°19 - Collapse of adobe walls, Lima, Perú, 3-X-1974.

PHOTO N°20 - Collapse of adobe walls, Lima, Perú, 3-X-1974.

PHOTO N°21 - House made od adobe and quincha, Lima, Perú, 3-X-1974.

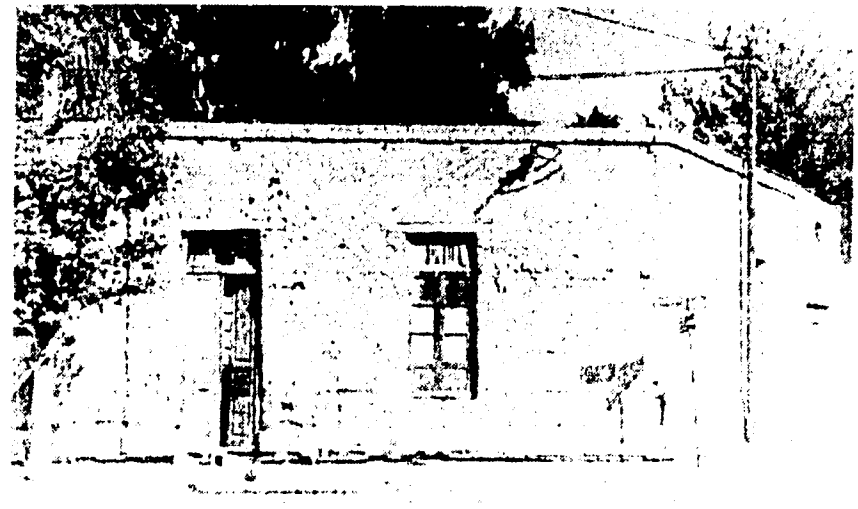
PHOTO N°22 - Partial collapse of a two storey house made of adobe and quincha, Lima, Perú, 3-X-1974.

PHOTO N°23 - Collapse of adobe houses, Guatemala, 4-II-1976.

PHOTO N°24 - Collapse of adobe houses, Guatemala, 4-II-1976.

PHOTO N°25 - Collapse of adobe houses, Guatemala, 4-II-1976.

PHOTO N°26 - Partial damages in adobe houses with upper wooden enchainment (collar), Guatemala, 4-II-1976.



P H O T O N° 1

P H O T O N° 2

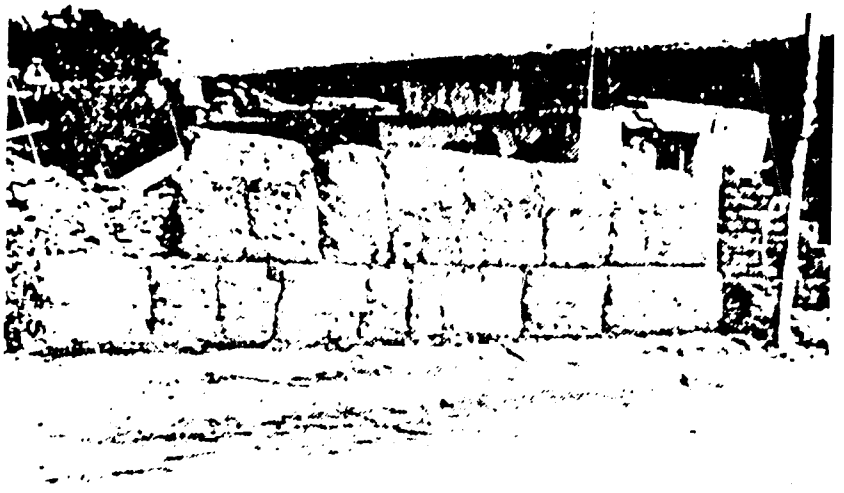


PHOTO N° 3

PHOTO N° 4

PHOTO N° 5

PHOTO N° 6

PHOTO N° 7

PHOTO N° 8

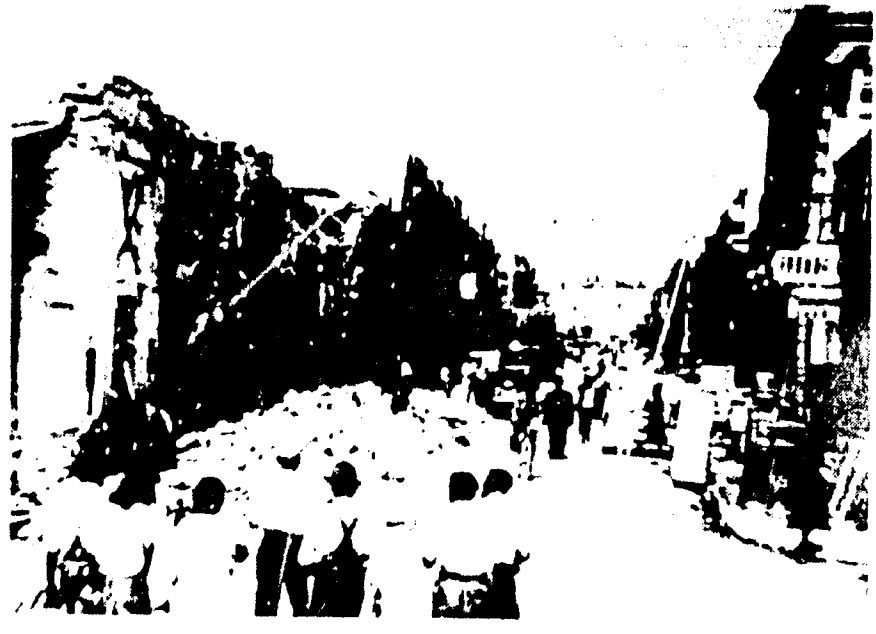


PHOTO N° 9

PHOTO N° 10

PHOTO N° 11

PHOTO N° 12

. P H O T O N° 13

. P H O T O N° 14

PHOTO N° 15

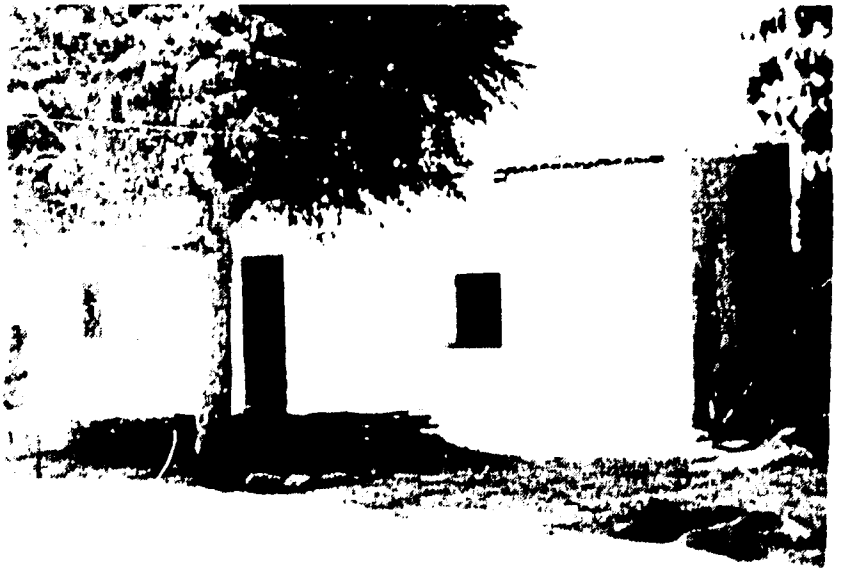


PHOTO N° 16

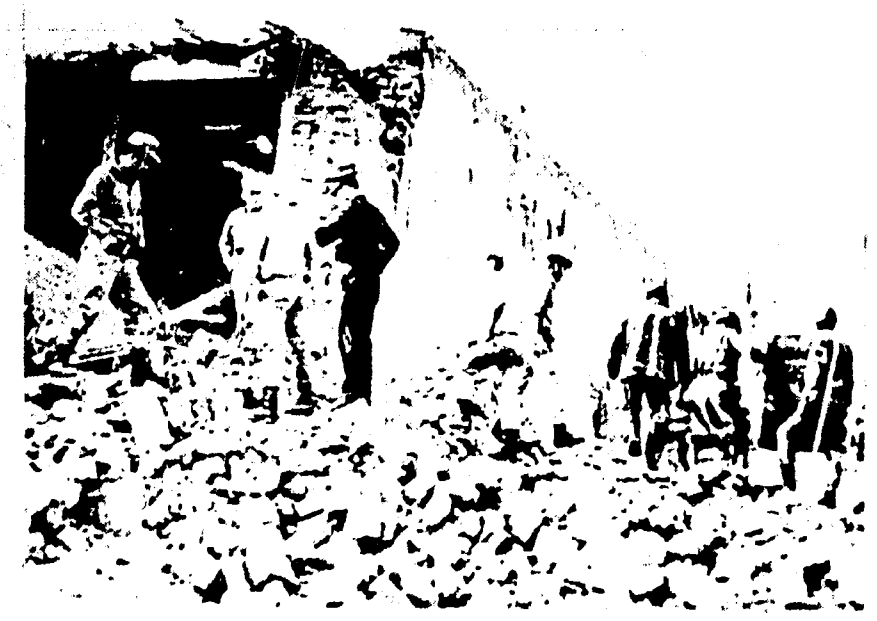
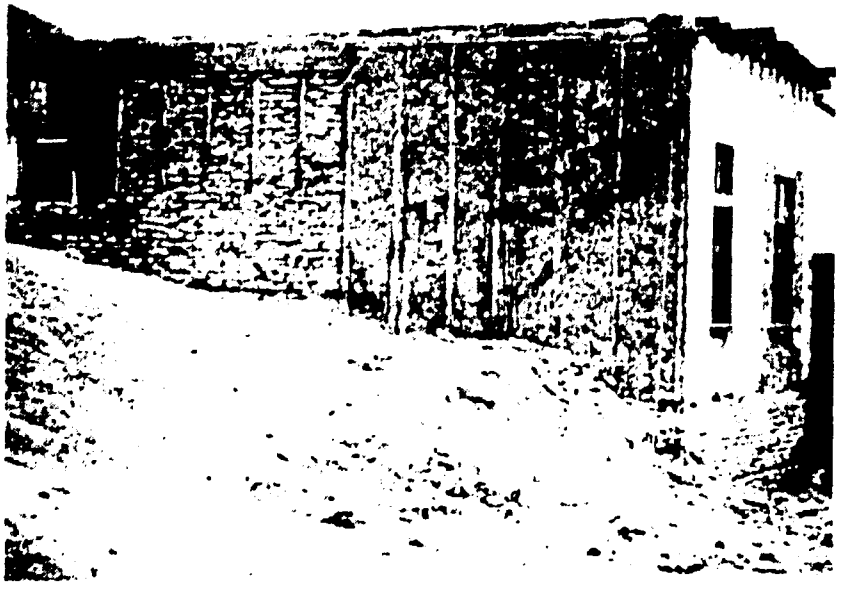


PHOTO N° 17

PHOTO N° 18

PHOTO N° 19

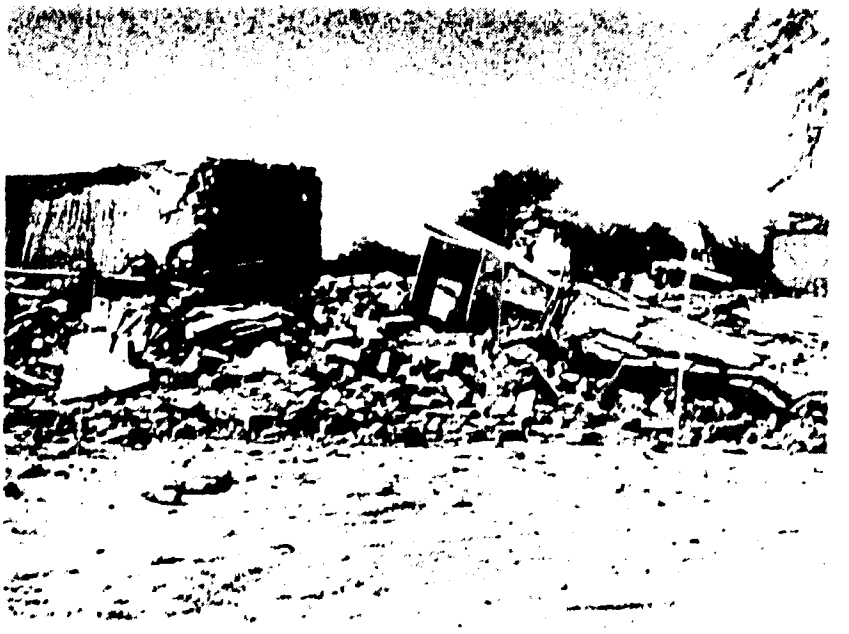
PHOTO N° 20



P H O T O N° 21

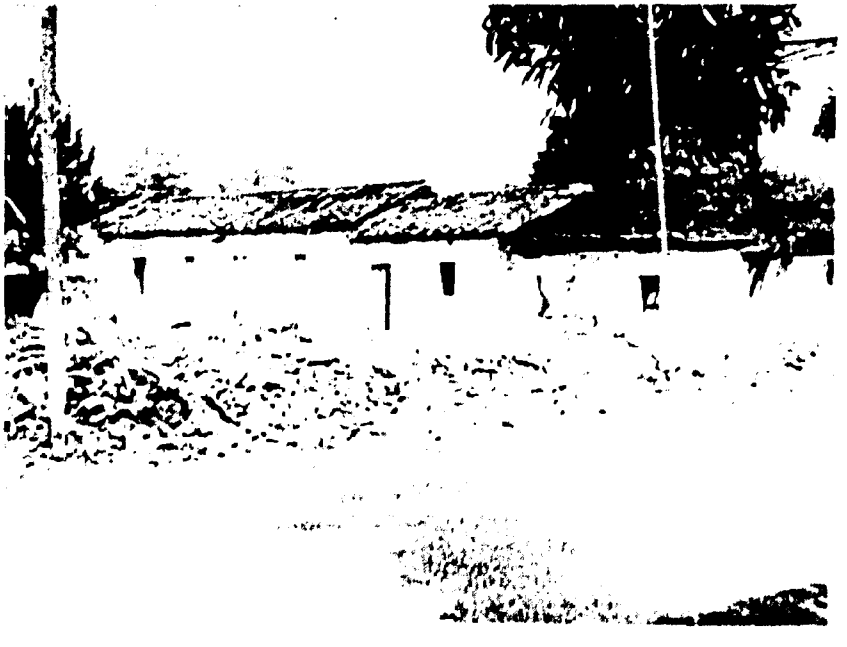
P H O T O N° 22

.PHOTO N° 23



.PHOTO N°24

. P H O T O N° 25



. P H O T O N° 26

BEHAVIOUR OBSERVED IN EARTHEN BUILDINGS DURING FOUR DESTRUCTIVE EARTHQUAKES IN LATIN AMERICAN COUNTRIES

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Ing. José Herrera Cano **
Ing. Hugo Giuliani **

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** Research workers of the "Ing. Aldo Bruschi" Seismic Research Institute of the Universidad Nacional de San Juan.

ABSTRACT

In this paper, a revision is made of the behaviour noted by the authors in earthen buildings during four devastating Latin American earthquakes. They are: in San Juan, Argentina on 15th January 1944 and 23rd November 1977; in Lima, Perú on 3rd october 1974 and Guatemala, Central America on 4th february 1976.

Finally, some hints are given as to the improvement of the earthen buildings in zones of high seismic risk.

COMPORTAMIENTO OBSERVADO EN VIVIENDAS CONSTRUIDAS CON ADOBES DURANTE CUATRO TERREMOTOS DESTRUCTIVOS OCURRIDOS EN LATINOMERICA

RESUMEN

En este informe, se efectúa una revisión del comportamiento observado por los autores en las viviendas de adobes en cuatro terremotos destructivos latinoamericanos que son: San Juan, Argentina, 15 de enero de 1944 y 23 de noviembre de 1977, Lima, Perú, 3 de octubre de 1974 y Guatemala, C.A. 4 de febrero de 1976.

Finalmente se mencionan algunas recomendaciones para el mejoramiento de las viviendas construídas con adobes en zonas de elevado riesgo sísmico.

1. Introducción

La construcción de adobe en Latinoamérica es una tradición que se remonta a la época de la colonización española.

Por la facilidad de su realización y por sus bajos costos su difusión fue y es aún muy amplia en los asentamientos humanos de la región, incluyendo también sus más importantes ciudades. Presenta para los sectores de bajos recursos características ventajosas para la autoconstrucción. En efecto, el material necesario se obtiene gratuitamente del suelo y con el solo empleo de la mano de obra del interesado se pueden fabricar los adobes y realizar su construcción. Además en el caso de su destrucción, por terremotos, es posible recuperar gran parte de los materiales facilitando la reconstrucción.

Es evidente que motivos económicos y sociales obligarán a continuar usando el adobe, principalmente en zonas rurales. Sin embargo, las viviendas de adobe construidas en la forma tradicional ofrecen poca resistencia a los terremotos de grado superior al VII de la escala de intensidad Mercalli y han sido la causa de la mayor cantidad de víctimas fatales que han ocasionado los terremotos que afectaron a Latinoamérica.

La solución a este problema no puede desligarse de las condiciones socio-económicas de cada país en particular. Consecuentemente, son muchos los esfuerzos realizados para mejorar el comportamiento sismo-resistente de las construcciones de adobe, mejoramiento que, sin embargo, no debe desvirtuar sus ventajas económicas y las posibilidades de la auto-construcción.

Construcciones de adobe en que se han aplicado normas para su mejor comportamiento sismo-resistente y que han sido sometidas a intensidades de grado VIII y IX de la escala de Mercalli, durante el terremoto de Caucete, San Juan (Argentina) del 23 de noviembre de 1977, han mostrado que es posible construír viviendas económicas y de adobe con adecuada resistencia a los sismos.

De acuerdo con lo expuesto se debe reconocer la necesidad de dictar normas para la ejecución de las construcciones de adobe, no con el objeto de promoverlas sino para ser aplicadas en los casos en que, por razones socio-económicas, sea ineludible su construcción.

2. Terremoto del 15 de enero de 1944 - San Juan - Argentina

Generalidades:

El día sábado 15 de enero de 1944, a las 20 hs. 50 min. hora local, se produjo un terremoto cuyo epicentro se

ubicó en las proximidades del lugar denominado La Laja, Departamento de Albardón, 30 kilómetros al Norte de la ciudad de San Juan. La magnitud de este movimiento sísmico fue estimada en 7.8 de la escala de Richter y su intensidad máxima en IX en la escala de Mercalli Modificada, destruyendo casi completamente a la ciudad de San Juan y ocasionando de 8.000 a 10.000 muertos.(Ref.1).

La ciudad de San Juan contaba a esa fecha con unos 110.000 habitantes y tenía un casco urbano densamente poblado de una extensión de 135 manzanas. En su periferia se desarrollaban cuatro barrios cuya densidad de edificación decrecía paulatinamente: al Norte Concepción, al Oeste Desamparados, al Sur Trinidad y al Este Santa Lucía.

A la fecha de este terremoto no había reglamento alguno que estableciera previsiones sismo-resistentes para la edificación de la ciudad, a pesar de haber sido severamente afectada el 27 de octubre de 1894 por un terremoto de mayor magnitud que el que se comenta.

Caracteristicas de las construcciones

Existían en la ciudad al momento del sismo, tres tipos de construcciones:

1 -Construcciones de hormigón armado con mampostería de ladrillo, sin previsiones sismo-resistentes, pero de buena ejecución que constituirán aproximadamente el 2 % de la edificación de la ciudad. Subsistieron en la mayor parte y fueron ulteriormente consolidadas conforme a normas que al efecto dictó el Consejo de Reconstrucción de San Juan, Ente nacional organizado con posterioridad al terremoto.

2 -Construcciones de ladrillo, en su mayor parte defectuosas por el empleo de mezclas deficientes (aproximadamente el 8% de la edificación de la ciudad). Muchas de estas construcciones se derrumbaron y las que quedaron en pié fueron demolidas.

3 -Construcciones de adobe (aproximadamente el 90% de la edificación de la ciudad). El comportamiento de estas construcciones se comenta en el presente trabajo.

Caracteristicas de las construcciones de adobe

La edificación del casco urbano de la ciudad de San Juan se caracterizaba por el predominio en un 90% de construcciones de adobe cuyas principales características eran los malos cimientos y pesados techos. En los barrios suburbanos casi toda la edificación era de adobe y hasta se encontraban antiguas viviendas construídas con "cajonadas de barro", llamadas "de tapia" en el lenguaje local, que se ejecutaban apisonando barro dentro de moldes por lo que sus paredes quedaban atravesadas por juntas horizon-

tales y verticales correspondientes a cada colada de barro.

Los adobes empleados en la construcción de las viviendas se fabricaban amasando limo arcilloso, agua y paja corta y dejando estacionar la mezcla durante varios días. Después se moldeaban con dimensiones que oscilaban entre 45 a 52 cm. de largo, 22 a 25 cm. de ancho y 12 cm de espesor y se dejaban secar al aire. Un adobe seco pesaba alrededor de 20 kilos y se asentaba generalmente sobre barro y a veces sobre mortero de cal preparado con cal grasa y arena fina.

Los muros exteriores se ejecutaban con adobes colocados de tizón (45 cm de ancho aproximadamente) y los muros interiores colocándolos de soga (22 cm de ancho aproximadamente). Sin embargo era frecuente encontrar muros de mayores espesores que se ejecutaban levantando dos muros de adobe de tizón, separados 20 o 30 cm, espacio que luego se rellenaba con barro obteniéndose un espesor total del orden de 120 cm. para aislar térmicamente los ambientes. En otras ocasiones muros de 120 cm. de espesor se construían macizos con la intención de obtener más solidez, tal lo que ocurrió frecuentemente en iglesias.

En los muros interiores de las viviendas se observaba con frecuencia falta de trabazón, interceptándose los muros por simple contacto y ocultándose la correspondiente junta con el revoque y la pintura.

Los cimientos eran de poca profundidad y de mala calidad, pues en la mayoría de los casos se construyeron con canto rodado unidos con barro, raramente con hormigón de cal. Su ancho, con frecuencia, no excedía al del muro. Como estos cimientos terminaban a nivel del suelo, la humedad atacaba fácilmente los muros de adobe, disgregando la zona próxima al suelo con la consiguiente pérdida de sección.
Igual fenómeno se observaba a veces en los cimientos, desmenuzándose el barro o el mortero que unía los cantos rodados del cimiento.

El revoque de los paramentos interiores se realizaba con barro amasado con agua, al que se agregaba paja de trigo en cantidad mayor que la que se empleaba para hacer los adobes, para atenuar las grietas de contracción que aparecían en el barro arcilloso al secarse; posteriormente eran blanqueados con agua de cal y pintados. Con frecuencia no se revocaban ni los paramentos exteriores ni los muros divisorios entre propiedades.

En viviendas mejor terminadas, especialmente en las fachadas, los revoques eran de cal y arena.

Las viviendas de adobe eran de una sola planta. La altura de las habitaciones no era menor de 4,00 m, generalmente 4,50m y en ocasiones hasta 5,00m. En casos excepcionales se observaban alturas de hasta 6,00 (Foto 1) La gran altura de los locales y el espesor exagerado de los techos obedecía al propósito de obtener aislación térmica. Los techos eran característicos por su cons-

trucción y por su gran peso. En la parte superior de los muros se asentaban, sin anclar, rollizos de álamo distanciados unos de otros 60 cm que, en muchos casos, no apoyaban en todo el espesor del muro. El envigado así formado se cubría con cañas colocadas una al lado de otra que se ataban con "tientos", que son tiras de cuero mojadas, que al secarse se acortan y aprietan las ataduras. En construcciones mejor ejecutadas las cañas se ataban con alambre delgado. Sobre el "cañizo" así formado, se colocaba una o dos capas de barro con abundante paja recortada, en proporción aún mayor que la que se usaba para los revoques. Como estas capas se reponían durante el transcurso del tiempo, el espesor del barro alcanzaba frecuentemente 40 cm. y en algún techo se ha medido hasta 60 cm. de espesor.

Este tipo de techo era el preferido por los habitantes de la ciudad de San Juan, por su clima de características continentales y dada buena protección térmica para el calor de sus largos veranos y el frío de inviernos breves pero rigurosos. En la mayor parte de las viviendas, no sufrían tratamiento alguno en su parte interior, quedando a la vista los rollizos y el "cañizo" que apoyaba sobre ellos. En construcciones mejor terminadas se ocultaba a la vista por un cielorraso de lienzo o de cartón prensado. Se observaron en locales públicos, negocios y confiterías cielorrasos de chapa de metal estampado.

En el centro de la ciudad de San Juan se mejoraba el aspecto de la edificación de adobe levantando por encima del techo un parapeto que generalmente sobrepasaba el metro de altura. Estos muros se adornaban con cornisas que, aunque fuesen de poco vuelo, ocasionaban cargas excéntricas. La mayor carga excéntrica era producida por las ménsulas que sostenían los cables aéreos de la conducción eléctrica de la ciudad y que se empotraban en los frentes de los edificios.

Daños observados:

La zona más afectada fue el barrio de Concepción por tener la edificación más antigua y de peor calidad y ser la parte de la ciudad más próxima al epicentro (Foto 2). Se derrumbaron completamente las viviendas y los muros divisorios construidos con "cajonadas de barro". La estabilidad al sismo de estos muros resultó escasa, pues aunque se construían de espesor considerable no existía cohesión entre los bloques formados por cada " cajonada de barro" (Foto 3).

Las construcciones de adobe que se ubicaban en este barrio, que como se dijo eran las más antiguas de la ciudad, se derrumbaron en un 90%. Influyó sobre este resultado, el debilitamiento producido en la base de los muros por la acción erosiva del agua, la falta de trabazón en los encuentros, la gran altura de los locales y por sobre todo el peso excesivo de los techos. Los espesores exagerados de los muros que a veces alcanzaban hasta 1,20 m. y aún más, no ayudaron a mantener la estabilidad de

los edificios (Foto 4).

En el casco urbano de la ciudad y en los tres restantes barrios circundantes de Desamparados, Trinidad y Santa Lucía , no se alcanzó el grado de destrucción observado en Concepción, aunque eran numerosas las viviendas derrumbadas por las causas anteriormente explicadas.

En los edificios de adobe que quedaron en pie se observó:

- Caída general de los parapetos y cornisas producida por la carga excéntrica de éstas y de las ménsulas que sostenían los cables de la conducción eléctrica (Fotos 5 y 6).

- Caída de los techos hacia el interior de las habitaciones a causa de la apertura de los muros y del insuficiente apoyo de los rollizos sobre éstos (Foto 7).

- Notable desplome de los muros de las fachadas

- Agrietamiento general de muros y daños en las esquinas superiores de las aberturas, ambas a causa del escaso apoyo de los rollizos en los dinteles.

- Caída de los dinteles de hormigón aunque el muro de adobe quedara en pie.

- Influencia negativa de los conductos empotrados en los muros (desague pluvial, ventilación de cloacas, etc.), que en ocasiones produjeron derrumbes parciales o intensificaron los daños.

- Revoques desprendidos por falta de adherencia.

- Derrumbes de muros interiores por falta de trabazón dejando al descubierto la unión de los muros por simple contacto (Fotos 8 y 9).

- Cielorrasos desprendidos en casi todas las viviendas. Los cielorrasos de lienzo y de cartón prensado no ocasionaron víctimas al desprenderse. Por el contrario, en los locales públicos, especialmente confiterías, donde se desprendieron cielorrasos rígidos de metal estampado se produjeron muertos y contusos por esta causa.

- Las modificaciones introducidas en las viviendas, apertura o cierre de puertas ó ventanas, ampliaciones, etc. afectaron notoriamente la estabilidad aumentando la magnitud de los daños. Estos resultaron mayores cuando las modificaciones o ampliaciones se ejecutaron con ladrillo, debido a la falta de unión entre ambos materiales y a su comportamiento diferente.

- La mampostería de adobe asentada sobre mezcla de cal y arena fina, colapsó a causa de su falta de adherencia a los adobes.

Estos edificios que quedaron en pie, con los daños anteriormente descriptos, fueron demolidos en los días posteriores al terremoto fundándose esta decisión en razones de seguridad y en preparar la reconstrucción, a cuyo objeto, se creó el Consejo de Reconstrucción de San Juan.

Conclusiones:

El terremoto del 15 de enero de 1944 destruyó casi totalmente la ciudad capital de la Provincia de San Juan y alrededores, con cerca de 8.000 víctimas fatales. El carácter de desastre que adquirió se debió no solo a la violencia del movimiento sino también a la pésima calidad de su edificación que en su mayor parte eran de barro. Esta situación fue una reedición ampliada de lo que se apreció luego del terremoto ya mencionado de 1894. En esa oportunidad sus enseñanzas no se tuvieron en cuenta, tal vez porque en esa fecha la ciudad era pequeña. Es importante mencionar que el suelo de la ciudad de San Juan es de buena calidad y puede sustentar edificios mucho mayores que los destruídos. Este es un antecedente importante para afirmar que el desastre fue la consecuencia de la pésima calidad de su edificación, especialmente la ejecutada con adobes.

3. Terremoto del 23 de noviembre de 1977 - Caucete - San Juan Argentina

Generalidades:

En la mañana del 23 de noviembre de 1977, a las 6hs. 28 min. hora local, se produjo un terremoto de magnitud 7,3 en la escala de Richter, cuyo epicentro fue ubicado a unos 100 km. al este de la ciudad de San Juan. Se caracterizó por la extensa zona que abarcó, alcanzando intensidades IX en Bermejo, VIII a IX en Caucete, VII a VIII en la ciudad de San Juan y VI a VII en la ciudad de Mendoza. La población importante más próxima al epicentro es la ciudad de Caucete, distante unos 30 km. al este de la ciudad de San Juan y centro de una extensa zona rural dedicada al cultivo de la vid y elaboración de vinos (Ref.2).

En la ciudad de Caucete y localidades aledañas se produjeron 75 muertos, cantidad reducida si se considera la extensa zona afectada y la población involucrada.

Esto se explica, porque el terremoto alcanzó su gran popoder destructivo a más de 20 segundos de iniciado y además, por la fecha y hora de su ocurrencia, ya que sucedió una hora antes de la iniciación de las actividades educativas, industriales y comerciales, pero con completa luz del día, por lo que la pobla-

ción rural ya había abandonado sus viviendas.

El derrumbe de muchas viviendas de adobe produjo la mayor parte de las víctimas fatales y aunque los daños fueron importantes también en establecimientos industriales y en escuelas, no ocurrienron víctimas en ellos por estar aún sin iniciarse las actividades, según se mencionó.

Analisis de los daños

En la ciudad de Caucete, el centro de la zona agrícola afectada, la intensidad sísmica alcanzó al grado IX de la Escala de Mercalli.

Es importante mencionar que en una amplia zona que abarcó más de 1000 km^2 ocurrió el fenómeno de licuación de arenas finas, lo que produjo una notable amplificación del movimiento del del suelo durante el sismo. Esta licuación originó efectos sísmicos más severos en las construcciones, ocurriendo además hundimientos, inclinaciones y asentamientos de edificios, que en muchos casos los inutilizaron.

El comportamiento de las construcciones fue el siguiente:

a) Construcciones con previsiones sismo-resistentes, de hormigón armado con mampostería de ladrillos comunes, bloques de hormigón ó bloques cerámicos huecos. Estas construcciones resultaron en general, con daños menores. Sin embargo por el efecto combinado de la licuación del suelo limoso, con los defectos constructivos o el diseño estructural inadecuado, varias construcciones sufrieron colapsos o daños severos, entre las que se destacan algunas escuelas.

b) Construcciones de viejos adobes, construídas a la manera tradicional. Resultaron destruidas o severamente dañadas y fueron la causa de casi todas las víctimas fatales (Fotos 10, 11, 12, 13 y 14).

c) Construcciones de adobe ejecutadas según recomendaciones dictadas por el Ex-Consejo de Reconstrucción de San Juan, en el año 1948, que según ya se mencionó fue el organismo que tuvo a su cargo la reconstrucción de la ciudad de San Juan destruída por el terremoto de 1944. Las construcciones de este tipo ubicadas en Caucete, sufrieron daños menores consistentes en caídas de revoques interiores (Fotos 15 y 16). Las ubicadas en zonas aledañas a la ciudad de San Juan, en donde no hubo licuación de suelos y la intensidad alcanzó el grado VIII de la Escala de Mercalli, no sufrieron daños.

Conclusiones

El terremoto de Caucete ha permitido comparar el comportamiento de las distintas construcciones de adobe, al ser sometidas a terremotos de gran intensidad, grado VIII a IX de la Escala de Mercalli, con el siguiente resultado:

Por una parte, colapso total de las construcciones de adobe ejecutadas según la tradición, sin previsiones sismo-resistentes y por la otra, sin daños o con daños económicamente reparables, las ejecutadas conforme a las recomendaciones sismo-resistentes, aún con el agravante de la licuación del suelo.

4. Terremoto de Lima (Peru) del 3 de octubre de 1974

Generalidades

El día 3 de octubre de 1974, a las 9 horas 21 minutos hora local, un violento terremoto afectó a la ciudad de Lima y sus alrededores. El epicentro del sismo fue ubicado por el N.E.I.S. de Estados Unidos en los 12.3° latitud Sur y 77.8° longitud Oeste, a unos 80 km. en dirección Sud-Oeste de Lima, con una profundidad de foco de 13 km. La estimación de la magnitud de acuerdo al N.E.I.S. varía entre 6.6 y 7.6, la primera según las ondas volumétricas (M_B) y la segunda según las ondas superficiales. Este terremoto causó 78 muertos y el número de heridos superó los dos millares, siendo alrededor de 5.500 el número de construcciones dañadas (Ref.3) y casi cuatro millones de habitantes la población involucrada.

Los lugares más afectados fueron las poblaciones de Chincha, Chorrilos, Barranco, Imperial, Cañete y La Molina, habiéndose también producido daños considerables en La Planicie, Pisco, Callao, Ica, Rimac, San Miguel y los Barrios Altos. El área más afectada cubre una extensión de aproximadamente 60.000 km^2 , dentro de la cual se observaron intensidades que alcanzaron el valor de VIII de la Escala Mercalli Modificada, según lo detalla el Boletín del Instituto Geofísico del Perú de fecha 18 de octubre de 1974.

Daños en las construcciones

La edificación de la ciudad de Lima comprende una gama bastante extensa de tipos de construcciones ; desde antiguas casas de adobe que datan algunas desde la época colonial (Lima antigua), hasta modernos edificios de varios pisos con estructura de hormigón armado y muros de mampostería de ladrillos.

Se distinguen los siguientes tipos de construcciones :

a) Viviendas de adobe de un piso.
b) Construcciones de adobe y quincha de uno y dos pisos.
c) Viviendas de un piso de mampostería de ladrillos sin reforzar.
d) Construcciones de uno y dos pisos de mampostería de ladrillo con algún refuerzo.
e) Edificios altos con estructura apropiada de hormigón armado y relleno de mampostería de ladrillos.

Las viviendas de adobe de un piso abundan en los barrios de menores recursos de Lima y en Barrancos, Chorrillos, Huaura, Huacho y Chancay. El adobe utilizado tiene dimensiones de 10 x 20 x 40 cm. aproximadamente y, colocado de cabeza, forma muros de 40 cm. de espesor que alcanza una altura de 3 a 4 metros. Se observó que frecuentemente estos adobes no tenían agregados de fibras de paja, por cuya razón se deshacen con facilidad. Los techos son planos y están formados por tirantes o rollizos de madera sobre los que se colocan cañas o tablas recubiertas por una o más capas de barro. Los dinteles son comunmente de madera y ocasionalmente de hormigón armado. Ninguna de las viviendas de adobe poseía algún tipo de encadenado. Como en otros terremotos, fueron numerosas las construcciones de este tipo que resultaron dañadas el 3 de octubre y en ellas se produjeron la mayor cantidad de víctimas (Fotos 17, 18, 19 y 20). Muchas de ellas habían sido afectadas por terremotos anteriores y luego reparadas sin haberse incluído ningún tipo de previsión sismo-resistente.

Las viviendas de adobe y quincha de dos pisos tienen, frecuentemente, los muros exteriores del primer piso construídos con adobes y colocados de cabeza (40 cm. de espesor), con una altura que oscila entre 3 y 4 metros. Los muros de quincha están formados por postes, diagonales y vigas de pino, todos arriostrados entre sí por listones horizontales. Después se colocan cañas verticales las que son revestidas con barro por ambos lados. Los techos son también planos y construídos en forma similar a las viviendas de adobe. Este tipo de edificación abunda en El Callao y en los barrios viejos de Lima. En general, las viviendas de quincha y las de adobe y quincha, resultaron con menores daños que las de adobe (Fotos 21 y 22).

Conclusiones

Las normas sismo-resistentes peruanas incluyen un apéndice dedicado a las construcciones de adobe. Analizando los daños observados se concluye que de haberse aplicado las normas, estos hubieran sido evitados.

5. Terremoto de Guatemala del 4 de febrero de 1976

Generalidades

El día 4 de febrero de 1976 a las 10 horas 02 minutos, 33 segundos GMT (03 horas, 02 minutos, 33 segundos hora local) un violento terremoto afectó a la zona central de la República de Guatemala, dejando como saldo alrededor de 25.000 muertos, 77.000 heridos y cuantiosas pérdidas en la infraestructura física y social (Ref.4).

La República de Guatemala tiene una superficie de 108.889 km^2 y alrededor de 5.000.000 de habitantes. Su Capital, de aproximadamente un millón de habitantes se ubica en el Valle de la Ermita a 1500 metros de altura sobre el nivel del mar, el que está cortado por cañadones y rodeado de montañas entre las que se incluyen unos pocos volcanes activos.

Las construcciones de la ciudad de Guatemala son de diversos tipos, desde las típicas y modestas construcciones de adobe de un solo piso, pasando por las de dos y tres pisos de ladrillos y bloques con una mínima estructura de hormigón armado y los edificios de cuatro a nueve pisos, todos del tipo aporticado con losas casetonadas que llevan incluídas las vigas, hasta llegar a los edificios de construcción avanzada con pórticos y tabiques de hormigón armado, de los cuales hay más de dos docenas.

El suelo de la ciudad de Guatemala hasta los 10 y 15 metros de profundidad está formado por una capa de arcilla que pasa gradualmente a arena limosa. Debajo de esta capa superficial y hasta los 100 metros se encuentra arena volcánica. La presión de cálculo de las fundaciones oscila entre 1 y 2 kg/cm^2.

En lo que respecta a las construcciones de la zona rural éstas eran de diversos tipos, predominando las de adobe sin ninguna clase de estructura antisísmica.

La evaluación preliminar de los daños estuvo a cargo de la Secretaría General del Consejo Nacional de Planificación Económica. En lo que respecta a los daños materiales, la mayor incidencia de este terremoto fue sobre el sector vivienda. Casi un millón de habitantes, la sexta parte de la población, quedó sin techo, ya que resultaron con daños alrededor de 258.000 viviendas.

El epicentro principal del sismo del 4 de febrero ha sido localizado por la United States Geological Survey (USGS) de E.U.A. cerca de Los Amates, en Izábal, en el oriente de la República de Guatemala, estimando su magnitud en 7,5 de la Escala Richter.

Daños observados

Refiriéndonos a las construcciones antiguas de adobe, tanto las ubicadas en los alrededores de la ciudad capital como en los pueblos del interior se observó que el adobe utilizado estaba amasado frecuentemente con fibras de pino en su interior. El suelo utilizado para amasar el barro mostraba en general pocos componentes arcillosos, por lo que el adobe resultaba desgranable y de fácil rotura. Las juntas entre adobes eran de mayor espesor que las que comunmente se hacen en otros países de América, resultando en la mayoría de los casos una traba inadecuada de los elementos. Debe agregarse también la temporada de lluvia que se inicia en el mes de mayo y que alcanza de 4 a 5 meses corridos, habiendo la permanente humedad, deteriorado los cimientos y los muros no revocados en su mayoría, erosionando sus espesores y dejando en inferioridad de condiciones a los muros.

Todas estas viviendas con muros de adobe y cubiertas de teja, en especial en zona rural, resultaron en su casi totalidad destruídas y fueron las que ocasionaron el mayor número de víctimas entre muertos y heridos (Fotos 23, 24 y 25). En algunas de estas viviendas con daños importantes en los muros, se observó que no se produjo el colapso cuando existía un marco horizontal de madera en la parte superior del muro sobre los que se apoyaban los largueros del techo. Es evidente que este marco de madera ha actuado como elemento de encadenamiento superior de los muros, haciendo que ellos trabajasen en conjunto e impidiendo su colapso (Foto 26).

Conclusiones

Los daños observados corresponden a la ausencia de previsiones sismo-resistentes para construcciones de barro, a la mala calidad del adobe y a la incorrecta ejecución de las viviendas, todo agravado por efecto del clima.

6. Conclusiones finales

Las modestas construcciones de adobe, que provocan elevado número de víctimas en caso de ocurrencia de terremotos destructivos, están ampliamente difundidas en América Latina y responden a condiciones socio-económicas imperantes. Son una consecuencia del desarrollo cultural y tecnológico de los pueblos y de los materiales disponibles en cada región, por lo que es imposible querer erradicarlas en forma definitiva, sin embargo, es posible, como etapa de transición, otorgarle mejoras para disminuir su peligrosidad.

De la revisión del comportamiento observado en las viviendas de adobe en los cuatro terremotos destructivos considerados, se deduce que cuando han sido ejecutadas con materiales deficientes y siguiendo formas constructivas tradicionales, han colapsado a causa de la falta de resistencia al sismo.

Sin embargo, por razones socio-económicas, en los países latinoamericanos será necesario todavía construir y reconstruir viviendas de adobe. (Ref. 5°).

Por ello, es necesario aceptar esta realidad y consecuentemente reglamentar la construcción de viviendas de adobe, a los fines de dotarlas de la capacidad resistente necesaria para sobrevivir a los terremotos destructivos.

Esta tarea no resulta fácil considerando que los destinatarios de estas viviendas son los sectores de población de menores recursos económicos, generalmente reacios a innovaciones en sus procedimientos constructivos tradicionales.

Por este motivo las reglamentaciones deben referirse a una serie de mejoramientos simples, tanto en el diseño de la vivienda como en su ejecución, que, sin desvirtuar las ventajas de la autoconstrucción, le dar suficiente seguridad sismo-resistente.

Como se ha expresado anteriormente, la construcción de viviendas de adobe está impuesta por las condiciones socio-económicas de cada país. En la República Argentina se trata de erradicar las viviendas de adobe en zonas urbanas de su área sísmica. En cambio, en zonas rurales se trata de mejorar su comportamiento sismo-resistente, especialmente en aquellos casos de pobladores rurales que no tienen por el momento otro recurso para levantar su vivienda, que su propio esfuerzo practicando la autoconstrucción.

7. Análisis y diseño estructural de las viviendas de adobe

Del análisis de los daños observados en las construcciones de adobe provocados por los cuatro terremotos considerados, se concluye que bajo ciertas condiciones las viviendas de adobe pueden ofrecer un comportamiento "satisfactorio" ante sismos severos.

Se entiende por comportamiento "satisfactorio" cuando la vivienda de adobe sea capaz de :

- Resistir sismos menores sin daños.
- Resistir sismos moderados con daños estructurales y no estructurales leves.
- Resistir sismos intensos sin colapsos y sin ocasionar víctimas.

Las fallas de las viviendas de adobe pueden atribuirse, fundamentalmente, a su poca resistencia a los esfuerzos de tracción y a su reducida adherencia entre mortero y adobe.

Los mecanismos de falla se ilustran en la Figura 1. Consecuentemente las características mecánicas que interesa conocer son:

- Resistencia a tracción.
- Resistencia a flexión.
- Resistencia al corte.
- Resistencia a la compresión.

A pesar de que no se han observado fallas por compresión axial, su conocimiento dá también una buena medida de la calidad de los muros.

La Figura 2 ilustra esquemáticamente los ensayos a realizar para obtener las características mecánicas señaladas. Sin embargo a falta de estos ensayos se pueden adoptar los siguientes valores, más bien conservativos:

- Compresión de contacto, 2,20 kg/cm^2
- Compresión axial en muros, 1,8 kg/cm^2
- Corte horizontal en muros, 0,10 kg/cm^2

Valores admisibles obtenidos con la aplicación de un coeficiente de seguridad igual a cinco.

En síntesis, los estudios y ensayos realizados por numerosos investigadores (especialmente en Perú) permiten, actualmente, el análisis estructural de las viviendas de adobe por métodos racionales basados en la resistencia de materiales. Sin embargo el buen comportamiento sismo-resistente de estas viviendas se obtiene por la aplicación de una serie de recomendaciones tanto en el diseño arquitectónico como en el proceso constructivo y en la elaboración de los adobes.

A continuación se detallan algunas recomendaciones:

a) <u>Recomendaciones para el diseño arquitectónico</u>:

- Se debe procurar plantas simétricas con distribución balanceada de muros.
- Limitación de altura de los muros (8 e, siendo "e" el espesor del muro).
- Limitación de la longitud máxima de los muros (10 e).
- Abertura de puertas y ventanas pequeñas (no mayor de 1,20m.)
- Los vanos de puertas y ventanas alejados por lo menos 1,20 m. de las esquinas ó de lo contrario en el centro del muro.

- Uso adecuado de contrafuertes para mejorar la estabilidad de los muros. Estos pueden ubicarse en los encuentros exteriores de los muros (longitud saliente mínima igual al espesor del muro), en el centro de un muro largo o en coincidencia de un vano de puerta o ventana (longitud total del contrafuerte, 3 e).

- Techos livianos, generalmente de rollizos de madera, con caña, barro (espesor e = 7 cm.) y aislación hidrófuga.

b) Detalles constructivos:

Muros:
- Ancho mínimo 0.40 m., sea o no portante.
- No se permiten muros aislados, sin contrafuertes para su estabilidad.

- Podrán reforzarse con materiales estables y que sean compatibles con el material del muro, por ejemplo cañas ó mallas metálicas soldadas.

Cimientos y sobrecimientos:
- Profundidad mínima, 0,40 m.
- Ancho mínimo 0,40 m., ó el que resulte en función de la tensión admisible del terreno de fundación.
- Sobrecimiento mínimo 0,20 m.

Se construirán de :
- Hormigón ciclópeo, con un mínimo de 160 kg. de cemento/m^3 y un 30% de piedra bola.
- Albañilería de ladrillo, bloques de hormigón o piedra natural asentados con mortero 1:1/4:4 (cemento-cal-arena) y convenientemente trabados.

Viga superior de arriostramiento:
- Todos los muros en su coronamiento llevarán encadenado formado por dos rollizos de 0,10 m., ó dos tirantes de 0,10 x 0,10 m. vinculados cada 70 cm. mediante tirantillos de 2 x 5 cm. de sección. En los cruces y encuentros de muros se empalmarán a media madera y con cinco clavos 4 x 120 mm. en cada unión.

- Es preferible el encadenado superior de hormigón armado de ancho igual al del muro y 15 cm. de altura, con 4 barras del 10 y estribos del 6 c/20 cm. Fig. 3.

- La estructura del techo se vinculará adecuadamente a la viga superior de encadenado. Fig. 4.

Dinteles:
Cuando los dinteles de aberturas de puertas y ventanas y las vigas de encadenado son de hormigón armado y están separados menos de 15 cm., es conveniente su unificación, Fig. 5.

Revoques:

Los muros serán revestidos con revoques de mortero de barro con abundante paja ó mortero de cemento-cal-arena (1/4:1:5).

Pisos :

Podrán ser de cemento alisado, mosaicos calcáreos ó ladrillo recocido. En todos los casos el nivel de piso terminado será 10 cm. por debajo del sobrecimiento.

Instalaciones:

No conviene embutir ningún tipo de instalación en muros de adobe, en caso necesario será solo muy superficial.

Aleros de protección de muros externos:

Se recomienda el uso de aleros de 0,50 m. en muros exteriores, obtenidos como prolongación de los techos, con el propósito de protegerlos del agua de lluvia.

Adobe estabilizado:

Las experiencias realizadas en Perú al respecto son dignas de especial mención. Los adobes estabilizados con asfalto RC-250 mejoran notablemente su comportamiento respecto de la humedad, resistencia y aspecto exterior a tal punto que puede quedar visto sin revoques y pintarse directamente.

Refuerzos horizontales y verticales de cañas:

Los refuerzos verticales y horizontales con cañas mejoran notablemente la estabilidad de los muros. Los refuerzos verticales requieren el uso de un adobe especial que permita el alojamiento de dichos refuerzos. Estos refuerzos verticales se anclan convenientemente en el cimiento y en la viga superior de hormigón armado.

Dimensiones del adobe:

a) Adobe tradicional 10 x 20 x 42 cm.
b) Adobe cuadrado 38 x 38 x 8 cm. y medio adobe 38 x 18 x 8 cm., brinda mayor seguridad ante el efecto sísmico.

Vereda perimetral:

- En todo el perímetro de la vivienda se deberá ejecutar una vereda exterior, de horimigón alisado y de un ancho mínimo de 0,60 m.

Separación entre viviendas de adobe:

- Toda vivienda de adobe debe separarse de cualquier otra construcción existente, sea de adobe o no, un mínimo de 2 m.

- Toda vivienda de adobe debe separarse como mínimo 1m. de los límites de la propiedad.

Desagues pluviales:

- Los desagues pluviales de los techos se deberán hacer con caños de bajada exterior o en su defecto por caída libre por medio

de caños o canaletas que sobresalgan como mínimo 0,60 m. del paramento exterior.

Fabricación del adobe:

a) Selección de la tierra:
Tierras limpias, sin gravas, ripios o g` .os mayores de 5 mm. Deben ser tierras que contengan arcilla y limo, pudiendo ser la proporción de arcilla entre el 20 y 50 % del total y cuyo índice de plasticidad esté comprendido entre 9 y 10.

b) Prueba para seleccionar la tierra
Se procede a formar un cilindro de aproximadamente 2 cm. de diámetro de barro amasado con poca agua y se observa el largo que puede alcanzar sin romperse. Si este largo está comprendido entre 5 y 15 cm., la tierra se considera apta para la fabricación de adobes.

c) Preparación del barro:
Previa trituración de la tierra seleccionada se amasa agregando agua y suficientes fibras como por ejemplo, de paja seca. La mezcla se estacionará no menos de tres días antes del moldeo de los adobes, dándole un amasado diario.

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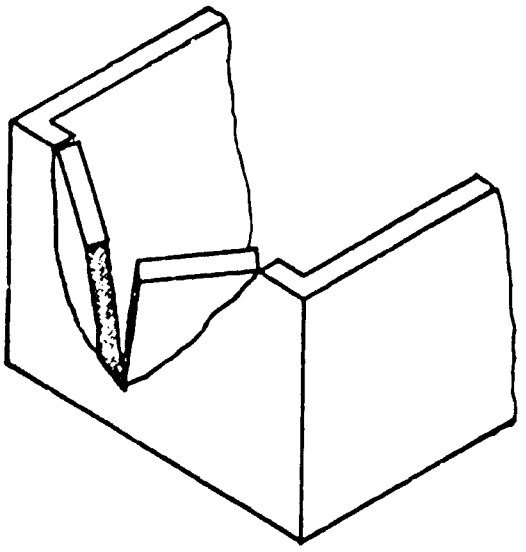
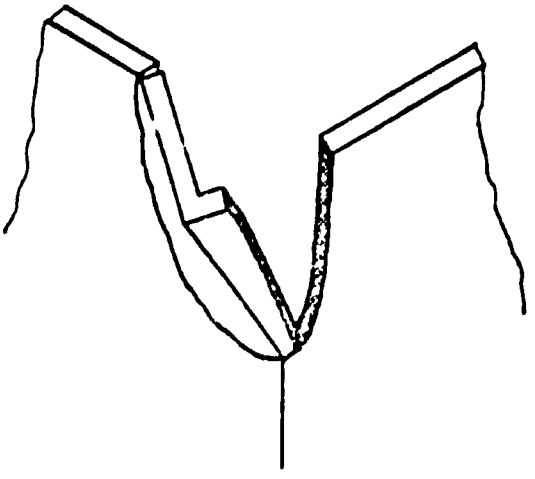
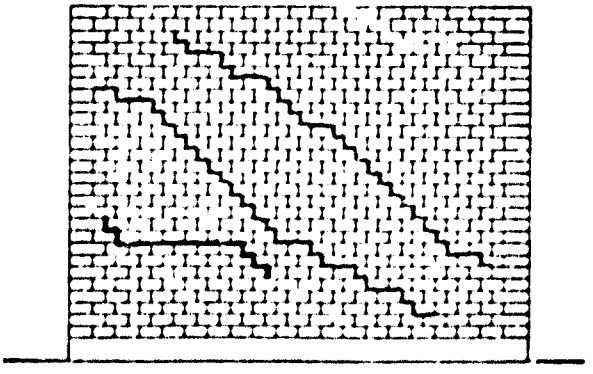
MECANISMO DE FALLA



FALLA POR FLEXION DE MUROS SIN ENCADENADO SUPERIOR



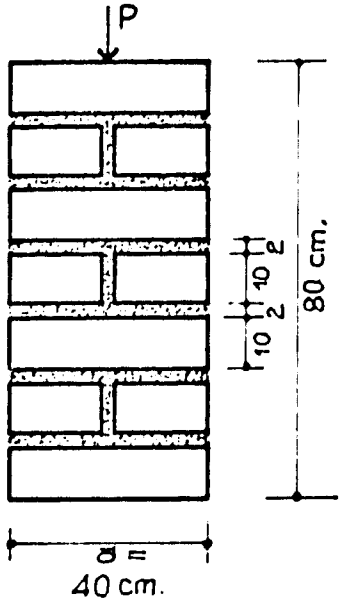
FALLA POR TRACCION EN ENCUENTRO DE MUROS



FALLA POR CORTE FIGURA 1

ENSAYOS PARA DETERMINAR ESFUERZOS ADMISIBLES

(Se tomará el promedio de no menor de tres especímenes)

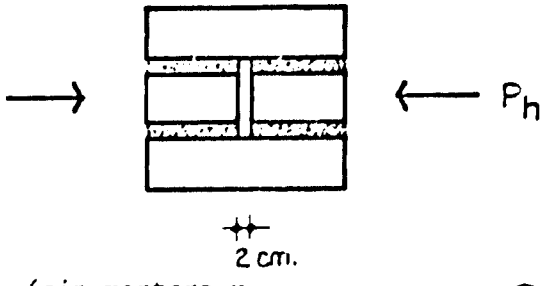


a) Ensayo de compresión axial

$$\sigma_{rot} = \frac{P}{a \times a}$$

$$\sigma_{adm.} = \frac{\sigma_{rot}}{5}$$

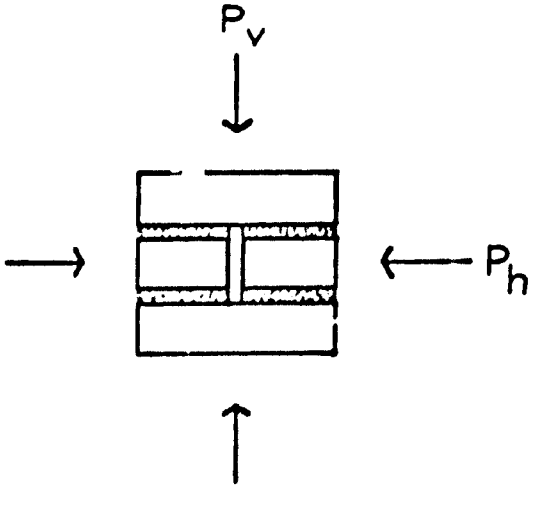
$$\sigma_{adm.} \text{ de contacto} = \sigma_{adm.} \times 1{,}25$$



b) Ensayo de adherencia (cohesión)

(sin mortero y completamente limpia)

$$\mu = \frac{P_h}{(a-2) \times a} \quad \left[\frac{Kg.}{cm^2}\right]$$



c) Ensayo de corte

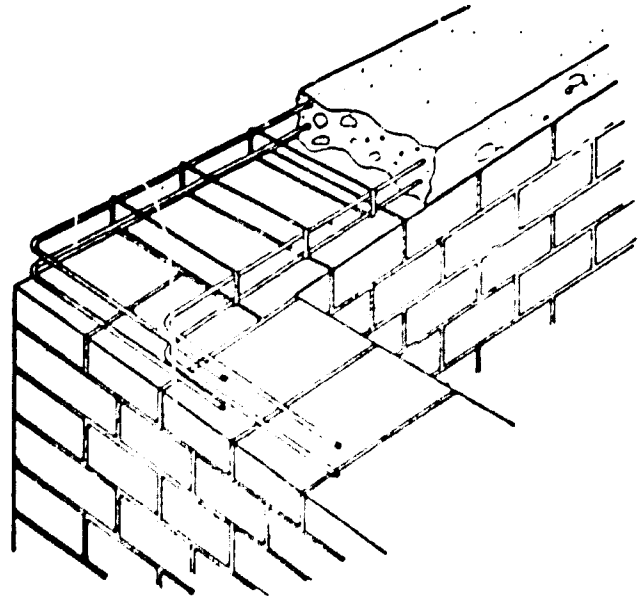
$$\tau_{rot} = \mu + \frac{P_v}{(a-2) \times a} \cdot f$$

$$\therefore f = (\tau_{rot} - \mu) \frac{(a-2) \times a}{P_v}$$

FIGURA 2

VIGA ENCADENADO SUPERIOR

EN LA PARTE SUPERIOR DE LOS MUROS, SE DEBE COLOCAR UN REFUERZO HORIZONTAL CONTINUO: LA VIGA DE ENCADENADO SUPERIOR QUE EN LO POSIBLE DEBE COINCIDIR CON LOS DINTELES DE PUERTAS Y VENTANAS.



TODO EL CONJUNTO DEBE IR FIRMEMENTE UNIDO EN LAS ESQUINAS PARA EVITAR QUE SE ABRA.

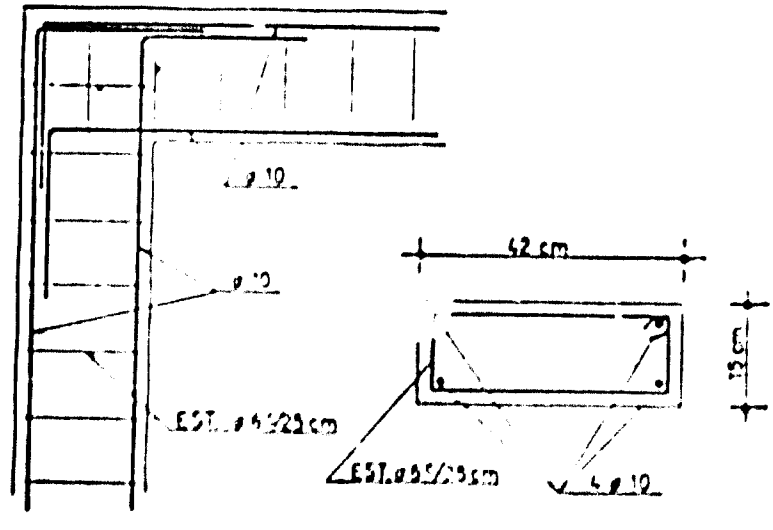


FIGURA 3

ANCLAJE ROLLIZOS

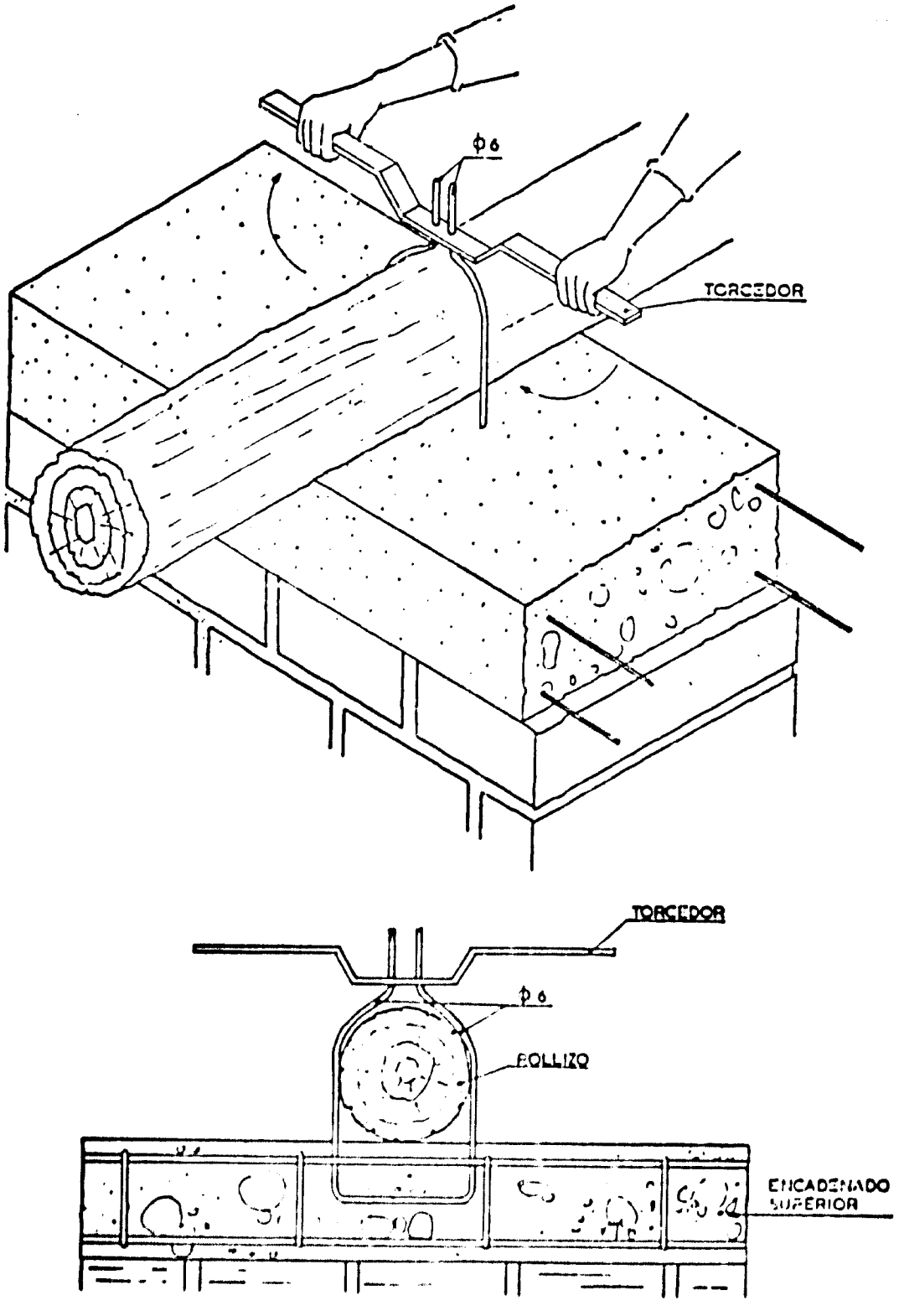
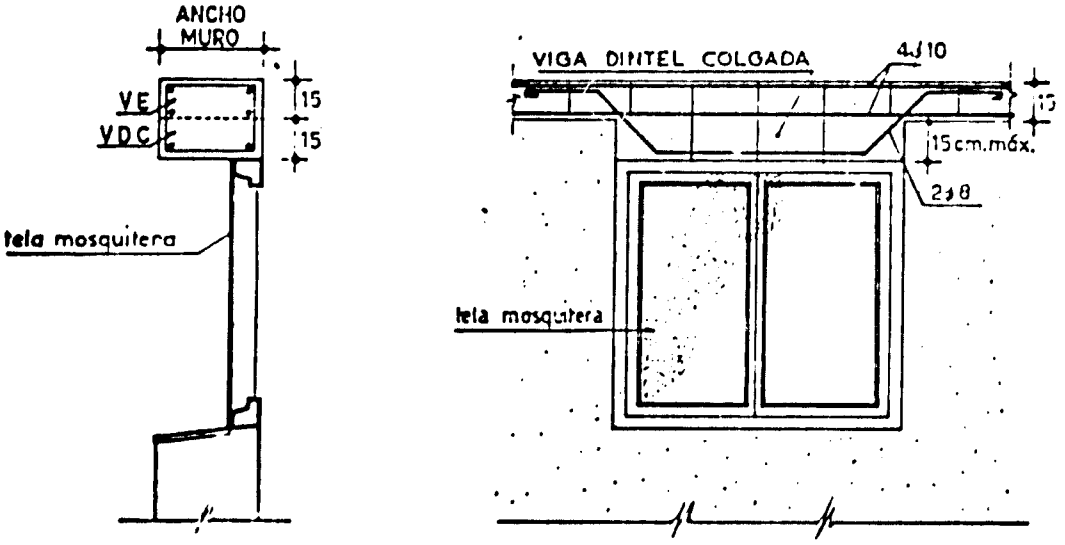


FIGURA 4

DINTEL - SOLUCIONES

CUANDO LA SEPARACION ENTRE CARPINTERIA Y VIGA DE ENCADENADO SUPERIOR ES COMO MAXIMO 15 CM , SE REALIZA UN DINTEL UNIFICADO CON LA VE.



CUANDO LA SEPARACION ENTRE CARPINTERIA Y VIGA DE ENCADENADO SUPERIOR ES MAYOR DE 15 CM , SE PROLONGA LA CARPINTERIA EN UN PAÑO FIJO DE MADERA O DE VIDRIO.

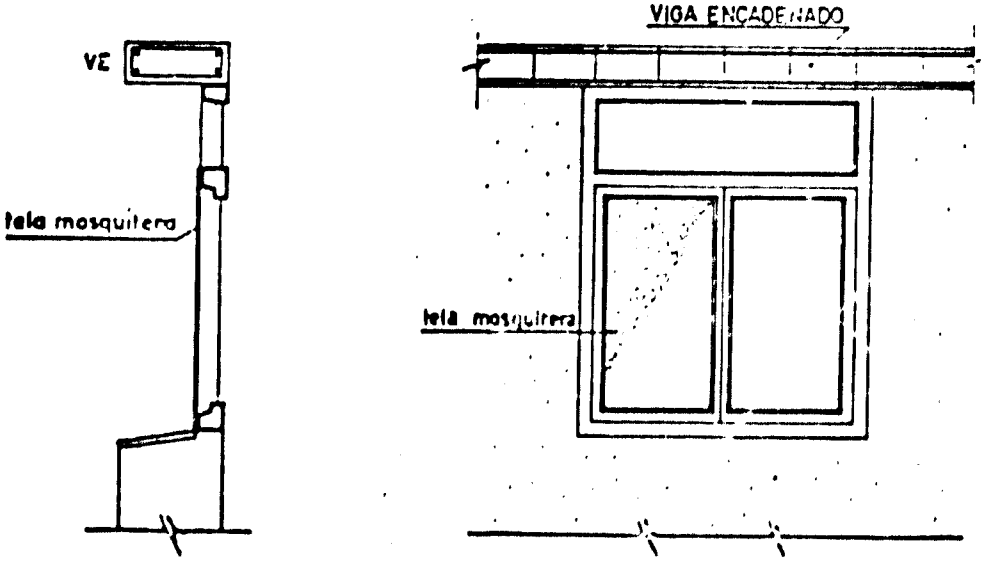


FIGURA 5

LISTADO DE FOTOS

FOTO N° 1 - Vivienda de adobe que no colapsó en el terremoto de San Juan del 15-I-1944.

FOTO N° 2 - Colapso viviendas de adobe, San Juan 15-I-1944.

FOTO N° 3 - Muro de barro colado (Tapia), San Juan 15-I-1944.

FOTO N° 4 - Colapso muro de adobe de 1,20m. espesor, San Juan 15-I-44 (Iglesia de Concepción).

FOTO N° 5 - Colapso muros de adobe y caída de parapetos y de cornisas ,San Juan 15-I-1944.

FOTO N° 6 - Colapso y desplome de muros de adobe, y caída de parapetos y cornisas , San Juan 15-I-1944.

FOTO N° 7 - Caída de techos hacia el interior de habitaciones, San Juan , 15-I-1944.

FOTO N° 8 - Colapso muros interiores por falta de trabazón, desprendimiento cielorraso y caída de cornisas,San Juan 15-I-1944.

FOTO N° 9 - Colapso muros de adobe y caída de cornisas, San Juan 15-I-1944.

FOTO N° 10 - Colapso de antiguas viviendas de adobe, Caucete San Juan, 23-XI-1977.

FOTO N° 11 - Colapso de antiguas viviendas de adobe, Caucete, San Juan, 23-XI-1977.

FOTO N° 12 - Colapso de antiguas viviendas de adobe, Caucete, San Juan, 23-XI-1977.

FOTO N° 13 - Colapso de antiguas viviendas de adobe, Caucete, San Juan, 23-XI-1977.

FOTO N° 14 - Colapso de antiguas viviendas de adobe, Caucete, San Juan, 23-XI-1977.

FOTO N° 15 - Vivienda de adobe sin daños construída conforme a normas, San Juan 23-XI-1977.

FOTO N° 16 - Vivienda de adobe sin daños construída conforme a normas, San Juan 23-XI-1977.

FOTO N° 17 - Colapso muros de adobe, Lima, Perú , 3-X-1974.

FOTO N° 18 - Colapso muros de adobe, Lima, Perú. 3-X-1974.

FOTO N° 19 - Colapso muros de adobe, Lima, Perú, 3-X-1974.

FOTO N° 20 - Colapso muross de adobe, Lima, Perú, 3-X-1974.

FOTO N° 21 - Vivienda de adobe y quincha, Lima, Perú, 3-X-1974.

FOTO N° 22 - Colapso parcial vivienda de adobe y quincha, de dos pisos, Lima, Perú, 3-X-1974.

FOTO N° 23 - Colapso viviendas de adobe, Guatemala, 4-II-76.

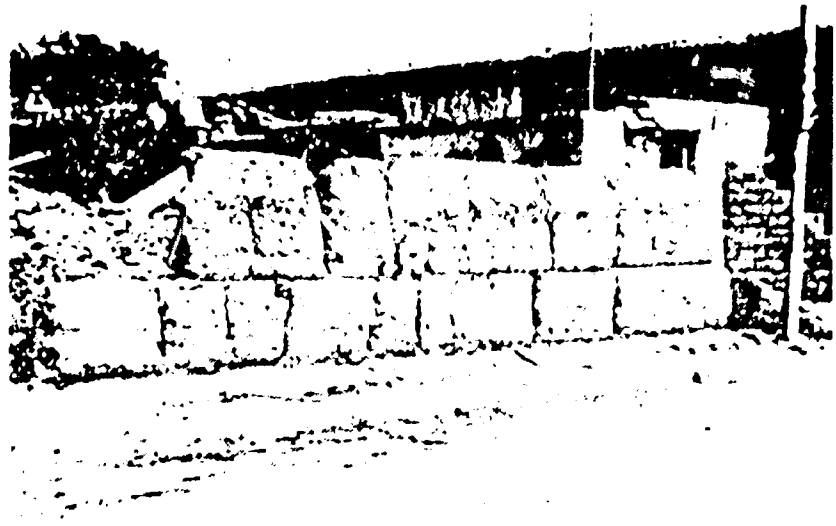
FOTO N° 24 - Colapso viviendas de adobe, Guatemala, 4-II-76.

FOTO N° 25 - Colapso viviendas de adobe, Guatemala, 4-II-76.

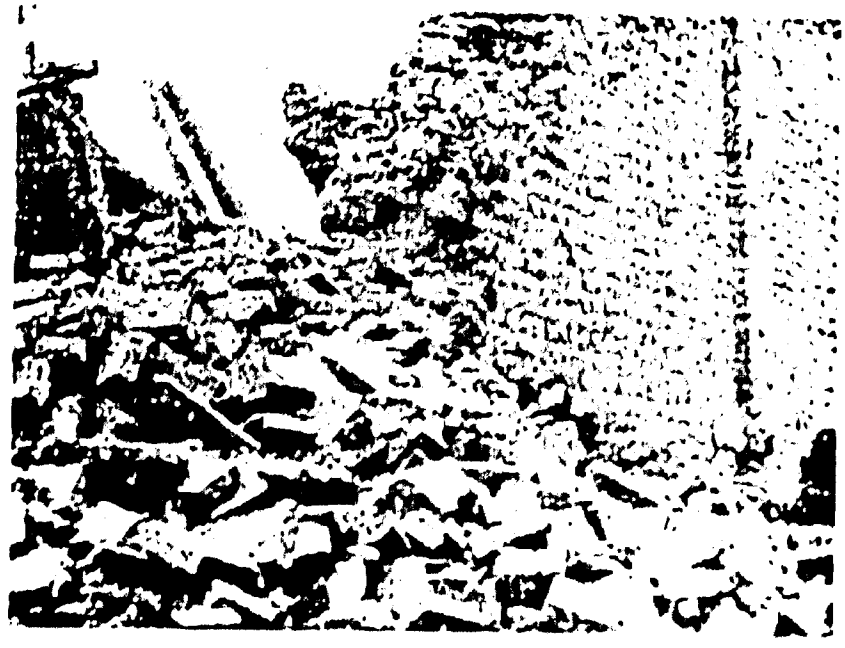
FOTO N° 26 - Daños parciales en viviendas de adobe con encadenado superior de madera (collarín), Guatemala, 4-II-76.

FOTO N°1

FOTO N°2



.F O T O N° 3



F O T O N° 4

F O T O N° 5

F O T O N° 6

FOTO N° 7

FOTO N° 8

FOTO N° 9

FOTO N° 10

·F O T O N° 11

.F O T O N° 12

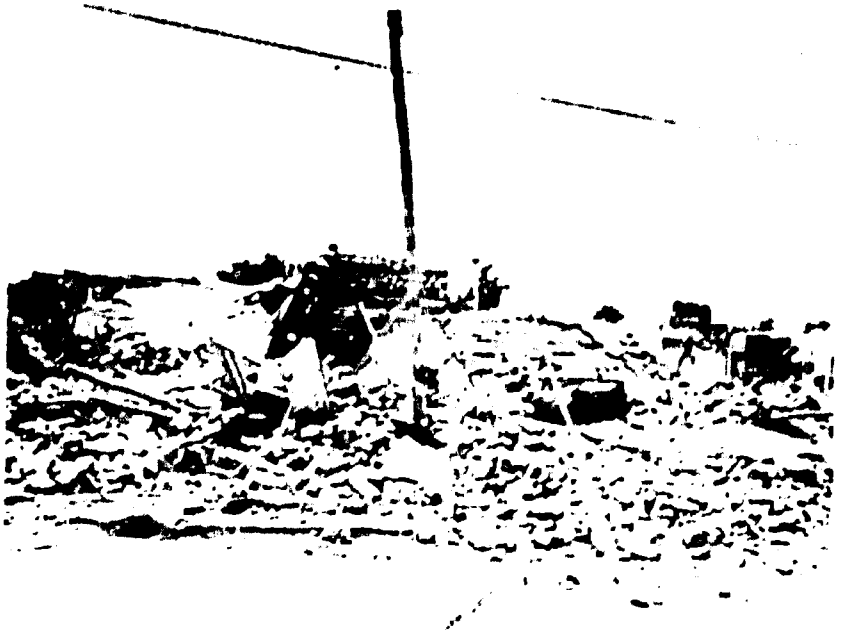


FOTO N° 13

FOTO N° 14

. F O T O N° 15

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F O T O N° 18

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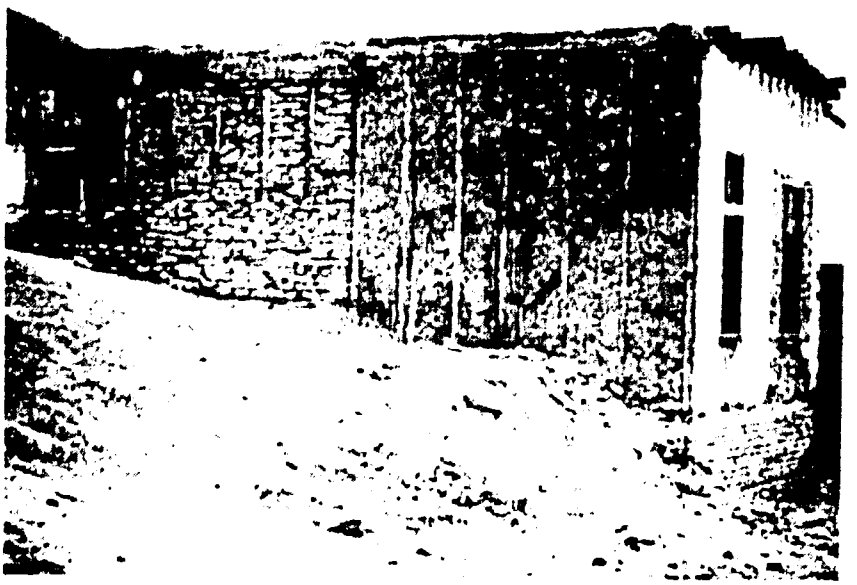
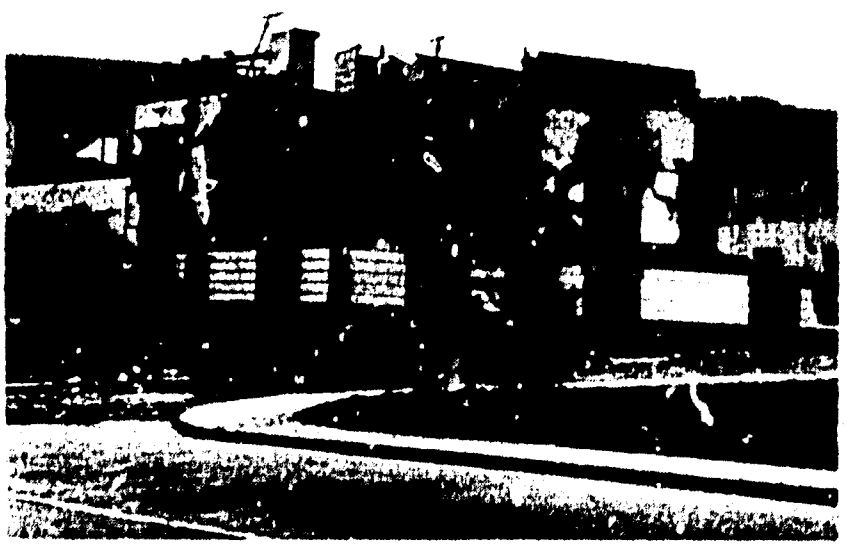
.F O T O N° 20



·F O T O N° 21



.F O T O N° 22

·F O T O N° 23

.F O T O N° 24

·F O T O N° 25

.F O T O N° 26

EARTHEN BUILDINGS AND EARTHQUAKES

John A. Blume
URS/John A. Blume & Associates, Engineers

ABSTRACT

The generally poor performance of earthen buildings in earthquakes is addressed but the position is taken that much of this damage could be prevented while still using, to a large extent, local materials and construction practices. Some simple requirements would be essential but they cannot be too drastic or increase the cost significantly. They do have to bring to bear reasonable compliance with certain laws of nature and of earthquake engineering. Models or prototype structures could be used for educational purposes. The major contributors to damage and collapse are listed as well as the major ways to prevent collapse. The challenge is great -- the reward is hundreds of thousands of lives in future decades.

Introduction

It gives me pleasure and encouragement to see the attendance at this important workshop and your interest in the subject. For many decades I have deplored the great loss of life in earthquakes, and I have noted that the non-engineered, natural-material residential and light commercial buildings have caused the greatest loss of life on a world-wide basis. Much of this can be prevented while still using natural materials! We have to examine and determine how this can be achieved without requiring some native farmer to engage an architect and an engineer and use a computer to build a structural steel or reinforced concrete frame. You know, and I know, that they simply can't afford that nor will they be able to in the future.

I have heard many engineers and others say the use of adobe, earth, rubble, even unreinforced burned masonry should not be permitted in seismic areas. Few of these authorities have visited the remote regions of countries throughout the world where shelters or housing have to be of absolute minimum cost, have to be "do-it-yourself" construction, and have to utilize to the maximum extent possible readily-available, natural materials including earth used various ways. Moreover, many of these authorities don't realize that any material with predictable properties can be made earthquake resistant.

It is my opinion as an engineer who has designed all types and sizes of structures in all types of materials including adobe brick, burned brick, and Arabian faroush, that the earthquake resistance of earthen buildings can be greatly increased with more attention to, and education about, proper materials properly used. Some new techniques may be needed as well as cartoons and models to demonstrate these techniques to untrained people. There may also have to be some simple standards and reasonable enforcement of those standards, but it can be done.

Local conditions such as climate, available materials, skills, traditions, poverty, etc., vary greatly not only from country to country but within a country. These will have to be allowed for in the improvement procedure I envision. Typical and simple designs could be developed for each major area. Models could be displayed in each area where construction is imminent. To the extent possible, traditional local procedures should be retained -- to expect radical changes to be successful would be folly in most places.

In addition to native residential construction I should note that some very fine homes and many large public and private structures have been built of adobe brick in earthquake regions of the United States and elsewhere. Earthen materials are by no means the exclusive property of the peasant in remote regions. Adobe has charm, warmth and insulation value to many people.

Types of Earthen Buildings

There are many types of earthen buildings which types I expect will be sorted out during this workshop. They vary not only in the materials used and in the combinations of materials used, but in the sophistication, if any, of design and construction. I suppose one could call a cave the most natural and oldest type of earthen building although caves are usually more rock than earth. This introduces the matter of definition, or of particle size applicable to this workshop. Buildings are made of rubble rock, of boulders, of chiseled rock, even of gravel. I shall presume unless corrected that our definition of "earthen" pertains to clays, silts, and some relatively small amount of sand; basically we are dealing with clay and silt somehow cast in place or molded into bricks which are dried in the

sun -- adobe bricks, often with straw and sometimes with waterproofing emulsions added to the wet mix. The masonry of which we are concerned has not been burned or fired in a kiln nor has it been made of concrete hollow blocks or bricks.

There are a great many ways in which earth as we have defined it has been used in building. The names of the construction types vary from place to place. Earth has been placed or rammed into wall forms; it has been plastered onto wood or rubble; it has been precast into sun-dried bricks and laid with various types of mortars (often simply mud); it has been mixed with cornstalks, wood, slats, logs, bamboo or branches in various ways; it has been used as the bearing material or simply as a filler material against the weather. Roof construction has included heavy earth fill or insulation and it has often consisted of beams or overhead arches of wood or old corrugated sheet metal with or without earth cover. Sometimes wood branches are used as reinforcement and -- in relatively few cases -- steel bars, wires, or mesh have been used as reinforcement. The earthquake record has been very bad where earthquake engineering has not been a consideration; it has been good in the few cases where good earthquake-resistant design has been employed. The general practice has been, unfortunately, after a damaging earthquake to rebuild in the same place with the same procedures, possibly with a trend toward less adobe and more wood if available and if the climate permits.

Properties of Adobe

Like concrete, concrete block, and burned brick masonry, adobe masonry is relatively weak in tension and in shear and strong in compression. Concrete and brick or block masonry under building code requirements are reinforced so as to compensate for their weakness in tension and shear. Adobe can be also, and has been, in a few cases.

Tests made by the USA National Bureau of Standards and also for the University of Washington Engineering Experiment Station show that adobe brick has unique resistance to impact, or great capacity to absorb energy. An example of this is the capacity to stop M-1 rifle bullets fired at a 50-yd (46 meters) range with only 3 to 4 in. (7.6 to 10.2 cm) penetration without fragmentation or spalling as for other materials. It is important that this valuable property -- ductility and energy absorption capacity -- be effectively utilized in building construction for seismic areas.

The Uniform Building Codes have been allowing 30 psi in compression for unburned clay masonry with Type M or S mortar and 8 psi for M mortar and 4 psi for S mortar in shear or tension in flexure respectively. These values can be increased by one-third under seismic conditions. Tests made years ago of stabilized adobe bricks laid in waterproofed 1:2-1/2 cement-sand mortar supervised by the writer gave considerably greater values. These tests also showed that lime or fire clay in the mortar weakened the bond.

Adobe that is not treated or plastered is subject to erosion by rain and ice formation. Unless any erosion is repaired the wall is weakened for earthquake resistance.

Earth rammed into wall spaces is subject to much shrinkage in place and this leads to cracks and weaknesses. Even the sun-dried bricks have small cracks but these are not generally harmful. Straw particles help to minimize the cracking.

The earth mix itself must be proper for walls or to make adobe units. Too much sand or too large particles can be detrimental. Sieve analysis and/or expert selection of materials is essential.

Contributors to Damage and Collapse

Earthquake weakness is caused by many factors, some of which are listed here, not necessarily in any order of importance:

1. Poor foundation conditions -- subject to liquefaction, rupture, settlement, sliding, flooding, or rockfalls from adjacent hills.
2. Heavy roof materials including tile, earth, etc.
3. Lack of bond between bricks and mortar or mud.
4. Sloped roof beams or arches (without cross ties) that thrust horizontally against the walls.
5. Walls too thin.
6. Walls with too many and/or too large openings.
7. No continuous bond beam at the top of the walls.
8. Exterior walls that are long without connecting interior cross walls; i.e., rooms that are too large.
9. No horizontal diaphragm or bracing at the level of the top of walls or in the roof plane.
10. Inadequate ties of roof construction to bond beam and of bond beam to walls.
11. Asymmetry of walls and of wall openings.
12. Unrepaired erosion or damage.
13. When used with wood framing, shrinkage or other gaps, and/or inadequate ties.
14. Lack of reinforcement where needed.
15. Inadequate foundations; too close to grade; not deep enough.
16. Poor selection and mixing of materials for adobe bricks.
17. Adobe bricks inadequately reinforced with straw or inadequately cured in the sun.
18. Adobe bricks laid without header courses.

Contributors to Reduced Risk

The elimination of all the above contributors to damage and collapse is a giant step toward a reasonable level of risk. To further reduce the risk there are also the following procedures not all of which would apply in all cases:

1. Analysis by relative rigidity of the building and its wall piers by structural engineers familiar with seismic design.

2. Site selection or investigation by geologists, soils engineers, seismologists.
3. Dynamic analysis of structures.
4. A reinforced concrete bond beam, well anchored.
5. A concrete or wood post and frame system.
6. Reinforced walls.
7. Cement-sand mortars; avoid lime and fire clay with waterproofed bricks and avoid mud mortar with all bricks.
8. Waterproof the adobe and the mortar.
9. Properly select and control the quality of the earthen materials and control the manufacture and curing of the bricks.
10. Provide inspection during construction; check masonry bond by tests.
11. Do not chop or chase out too much masonry for pipes, conduits, boxes, etc.
12. Design the roof system so that it is proper, of minimum weight, exerts no lateral force on any wall, is well tied to the bond beam, and acts as a rigid diaphragm.
13. Study earthquake-resistant code provisions; check the local code.
14. Provide for torsional motion.

In general, a small residential building tends to be rigid. It should therefore be made rigid, be well tied together at all connections of walls, roof and elements, it should be very strong, and as tough and ductile as possible. Adobe by its nature should be thick-walled, and thus provide thermal and noise insulation as well as strength. Reinforcement may not prevent all cracking in an earthquake but it tends to hold things together and prevent disaster even though some cracking occurs. There are many ways of reinforcing.

Static Analysis

The calculation of stresses in walls from assumed static lateral forces is a straightforward procedure. The top of the walls must be connected with a rigid horizontal member or bracing -- a rigid roof diaphragm well connected to a continuous bond beam is preferred. If this is not done, the structure lacks one of its most essential elements and is of doubtful seismic value. Assuming a rigid diaphragm and symmetry of walls and wall openings, the wall piers in the direction of the assumed force will be loaded in proportion to their relative rigidities. If there is no symmetry, the building will respond in torsion as well as translation and the forces and stresses will be increased over those forthe symmetrical layout. This too can be calculated.

Relative rigidity is a basic concept in structural engineering but is often overlooked by designers unfamiliar with seismic design. The stiffer the wall element relative to all other parallel wall elements, the more force it will attempt to resist. If it cracks in the attempt. the forces on the next cycle will be increased

and greatest for the next stiffest element. The stiffness, R, is the reciprocal of the deflection Δ:

$$R = \frac{1}{\Delta} \tag{1}$$

$$\Delta = \Delta_m + \Delta_v \tag{2}$$

where

Δ_m = deflection due to moment

Δ_v = deflection due to shear

R = rigidity

If the wall piers can be considered as "fixed" top and bottom (i.e., there is no rotation), then

$$\Delta_m = \frac{Ph^3}{12E_m I} \tag{3}$$

and

$$\Delta_v = \frac{1.2Ph}{E_v A} \tag{4}$$

where

P = horizontal force applied to pier, lb

h = height of pier, in.

I = moment of inertia = $td^3/12$, in.^{4}

A = area of pier = td, in.^{2}

E_m = modulus of elasticity, psi

E_v = modulus of shear = $0.4E_m$, psi

d = depth of wall parallel to force, in.

t = wall thickness, in.

E_m and t are linear in the equations; thus convenient values may be assumed to simplify and combine the equations. Let E_m = 1,000,000 psi. Then there is obtained

$$\Delta = \frac{P}{10^6(t)} \left[\left(\frac{h}{d}\right)^3 + 3\left(\frac{h}{d}\right)\right] \tag{5}$$

If the piers cannot be considered fixed at their tops, and are relatively free to rotate at one end, then

$$\Delta = \frac{P}{10^6 (t)} \left[4\left(\frac{h}{d}\right)^3 + 3\left(\frac{h}{d}\right)\right] \qquad (6)$$

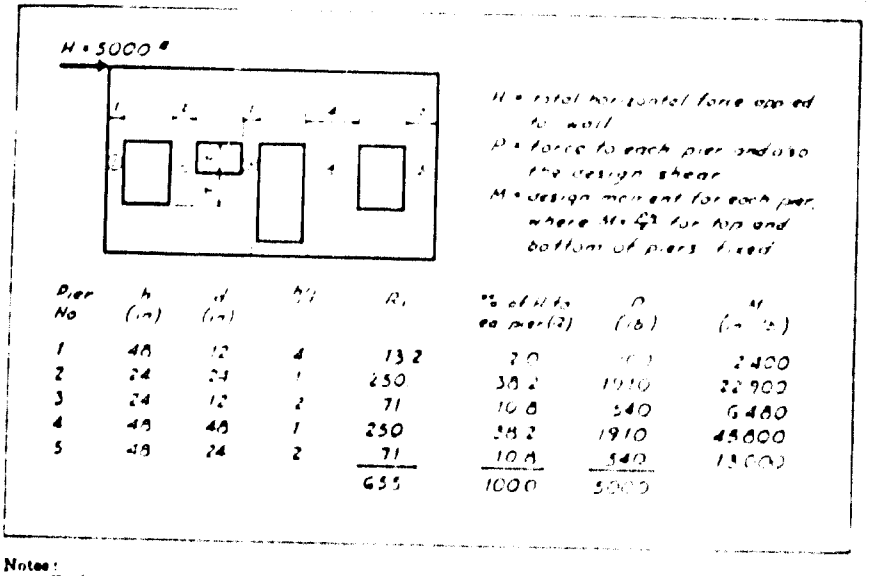
The condition expressed by Equation 5 is much more preferable for earthen buildings than Equation 6. Sometimes the situation falls between these two extremes.

Note that for the same h/d ratio, there will be the same Δ and R. Thus, a 2 ft x 2 ft square pier will be loaded as much as a 6 ft x 6 ft square pier and yet have but a fraction of the resistance to withstand that loading.

Table 1 shows the application of the above principles to a single wall with 5,000 lb assumed lateral force. From the P values, the unit shear can be obtained by dividing by 0.67 td for each pier and the flexural tension, f, can be obtained by dividing the moment, M, by the section modulus, S, which is simply $td^2/6$. Note that M = Ph/2.

TABLE 1

Distribution of Lateral Force to Piers of a Wall



Pier No	h (in)	d (in)	h/d	R_i	% of H to each pier (2)	P (lb)	M (in-lb)
1	48	12	4	13.2	2.0	[illegible]	2400
2	24	24	1	250	38.2	1910	22,900
3	24	12	2	71	10.8	540	6480
4	48	48	1	250	38.2	1910	45,800
5	48	24	2	71	10.8	540	13,000
				655	100.0	5000	

Notes:

a. Each pier is assumed to have full restraint top and bottom and relative rigidity values are taken from the corresponding curve in Fig. 5-1, page 15.
b. Wall returns at each end are assumed to be small and are neglected here.
c. Additional forces to be taken into account in the pier designs are those due to dead and live loads and overturning due to the lateral force P.
d. Note that the lateral force taken by pier No. 2 is the same as for pier No. 4 due to the same value of h/d, but the unit shear stress in pier No. 2 is double that in pier No. 4 due to the relative pier size.
e. Wall assumed to be of constant thickness and, therefore, the value of "t" need not enter into the computations for the determination of "P".

Assume t = 16" for the entire wall. Then for Pier No. 2, the shear, v, is

$$v = \frac{1.5P}{td} = \frac{(1.5)(1910)}{(16)(24)} = 7.46 \text{ psi}$$

But for Pier No. 4,

$$v = \frac{(1.5)(1910)}{(16)(48)} = 3.73 \text{ psi}$$

Pier No. 4 would pass UBC code requirements of 4 x 1-1/3 or 5.33 psi but Pier No. 2 would not.

Consider now the flexural tension on 2 and 4.

Pier No.	t (in.)	d (in.)	S (in.^{3})	M (in./lb)	M/S=f (psi)
2	16	24	1,536	22,900	14.9
4	16	48	6,144	45,800	7.5

There should be reinforcement at the jambs to take the excess flexural tension. Such bars should run from the foundations into the tona beams.

The calculations for a whole building include all pier and also torsional considerations. They are readily done by hand. They should be carried out with applicable forces for special structures and for typical buildings.

Forces Induced by Earthquakes

The lateral inertial forces induced by earthquakes depend upon many things and vary from insignificant to half or more of the weight of the building. Some of the variables are the earthquake magnitude, its location relative to the structure, its depth in the earth, the soil conditions at the site, and the strength and dynamic properties of the building. Close in to the epicenter the shaking is not much different for a rock site and a firm alluvial site. Far away, the alluvium may shake much more than rock, but with longer periods of motion which may not "tune in" to the building. An earthen structure close to a strong earthquake should be very strong to survive, but survival is possible with good design, materials, construction, and quality control of all three.

The forces prescribed by seismic codes are generally fictitious as the real forces could be much more. However, the real material values can also be much greater. Code forces, where applicable, should be considered as minimum forces and the structure should not only be strong but as tough and ductile as possible, and well tied together, everywhere.

Figures

Some figures are shown which were prepared by the writer during the initial phase of World War II when the excellent military properties of stabilized adobe were found by test. Although the testing work was done early in the conflict, the sketches shown were not released until later, due to war conditions. The optimum type of mortar for bond to adobe brick was found as well as other properties of the stabilized adobe brick. It is believed the figures, although old, are still applicable to stabilized (water resistant) adobe and mortar, and valid in essentially all respects to the current state-of-the art. If anything has changed it is an increase in respect for ground motion and lateral forces, thus values shown should not be considered as applicable to all conditions today. The allowable stresses have not changed.

Conclusion

Earthen buildings can be built to perform well in earthquakes but not by the more-or-less random control processes extent in many countries. Any material with predictable properties and predictable or controlled workmanship can be made to perform satisfactorily. This all indicates a measure of design and of quality assurance, as well as more attention to known basic principles, that is not now existing throughout the world. The risk can be evaluated and the structure, or at least a prototype or sample structure, can readily be analyzed. This can be done at a practical "down to earth" level with local conditions, materials, and traditions in mind but still introducing basic elements and procedures. Cartoons, models and/or prototypes can be used for educational purposes. The objectives are well worth striving for and are within the purview of this workshop. Hundreds of thousands of lives could be saved in future decades.

References

Plummer, Harry C. and John A. Blume, "Reinforced Brick Masonry and Lateral Force Design", Structural Clay Products Institute, Washington, DC, 1953.

Burr, G. D., "Rigidity of Masonry Piers and Walls", Civil Engineering, April 1936, p. 262-264.

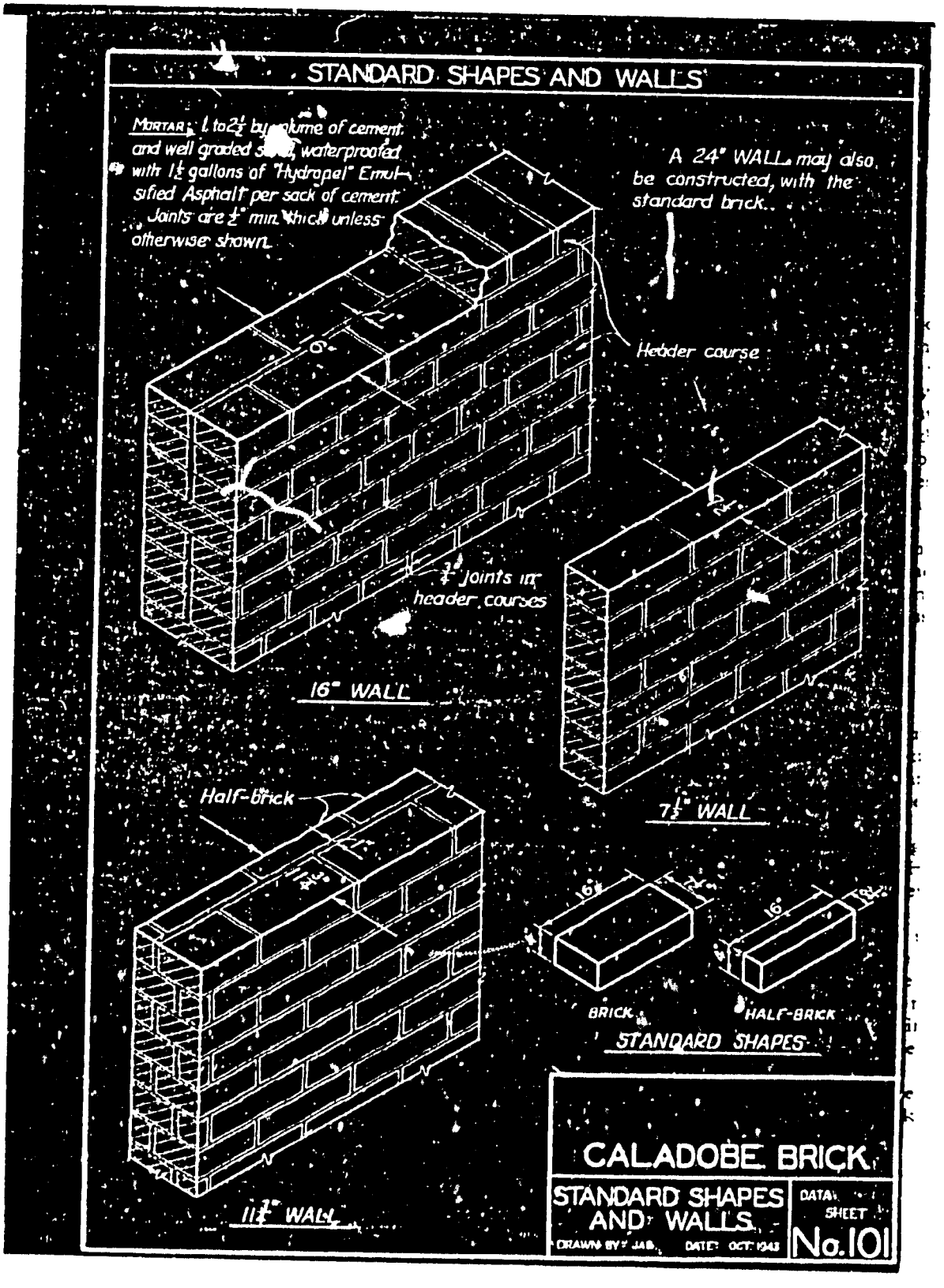
Uniform Building Code, International Conference of Building Officials, 1979 and prior editions.

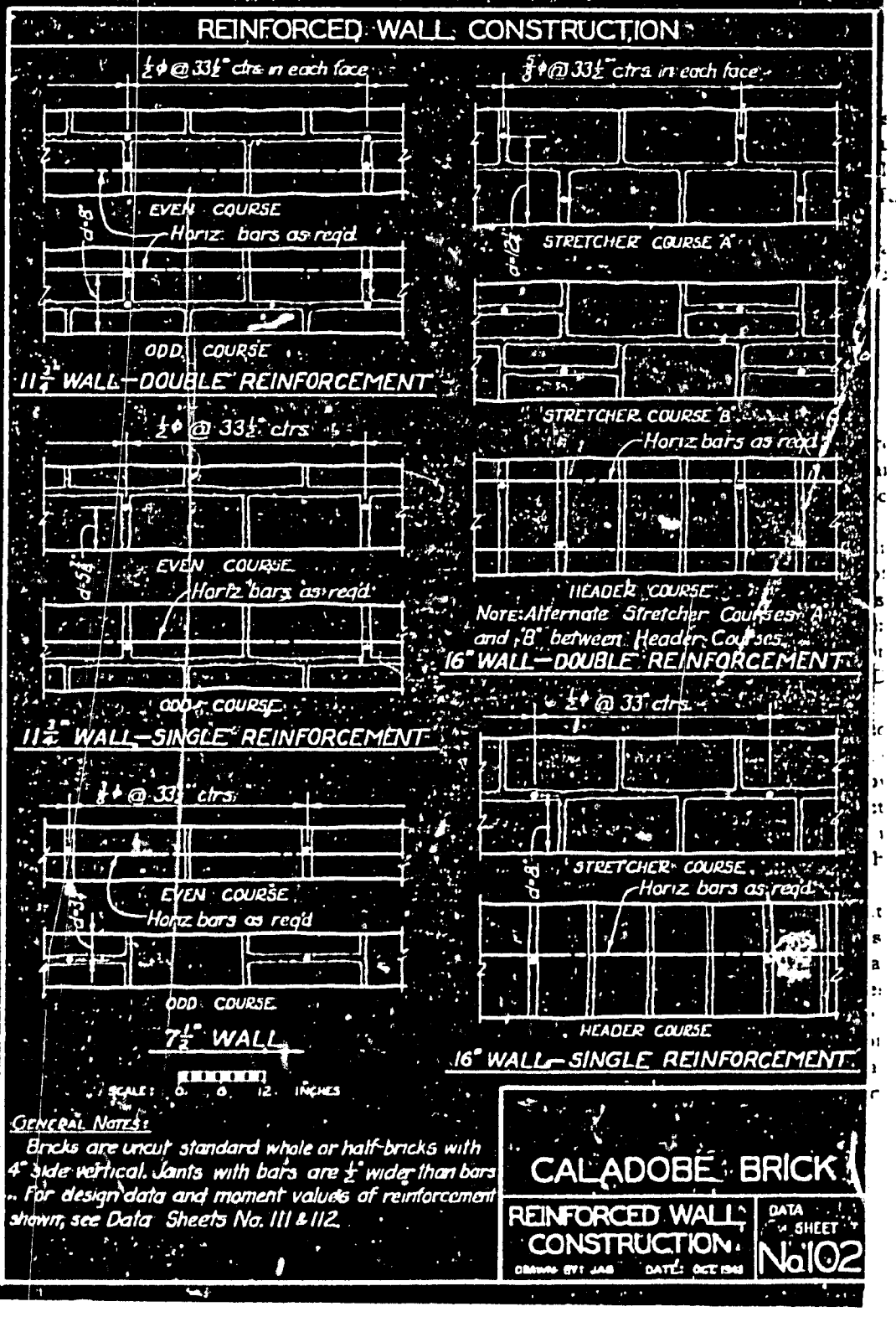
American Bitumuls Company, "Bitudobe - Treated Soil for War Uses and Civilian Defense", San Francisco, 1943.

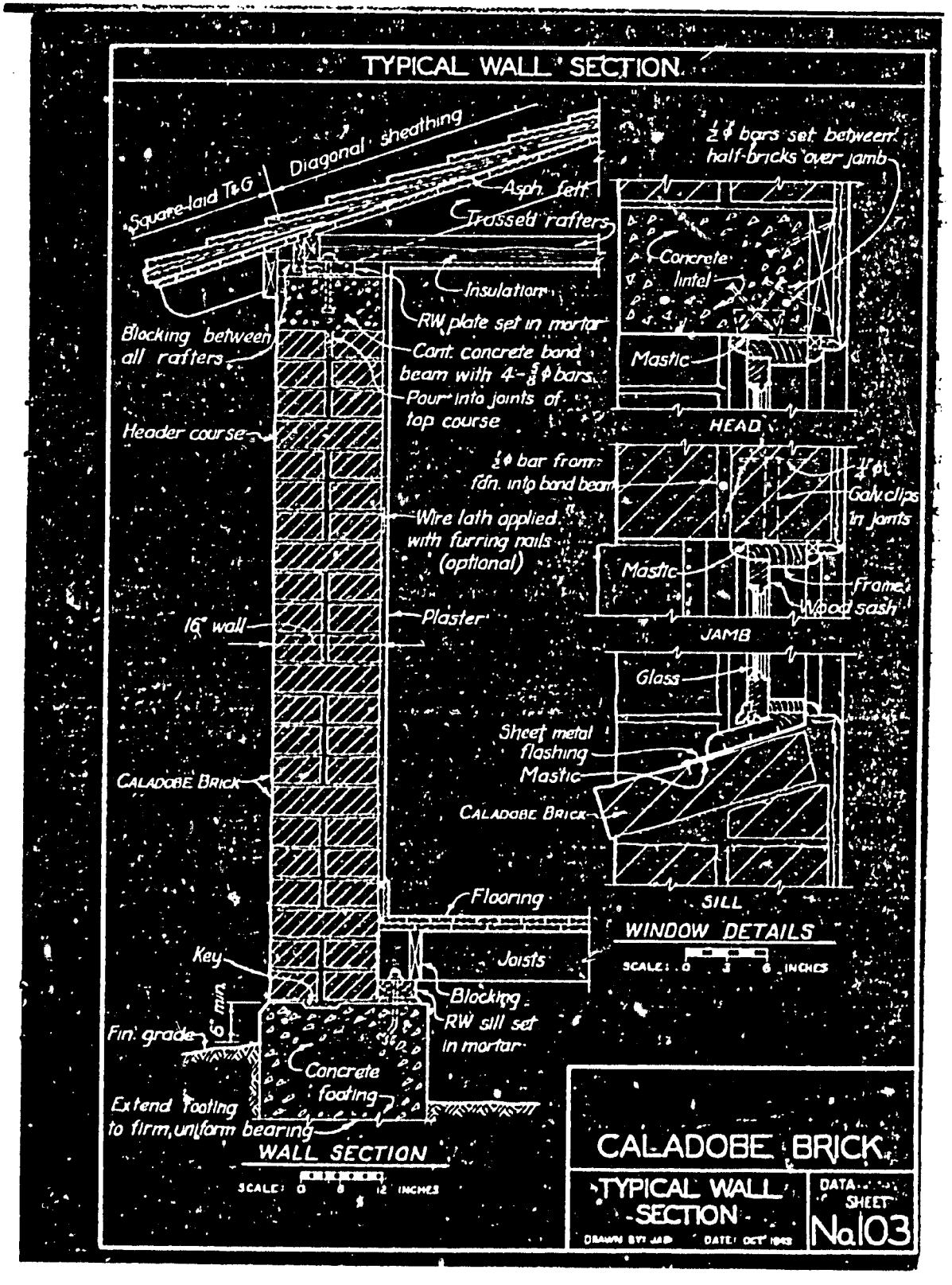
Blume, John A., Data sheets 101-112, "Build With Caladobe for Enduring Beauty", Foster and Kleiser Company, 1942.

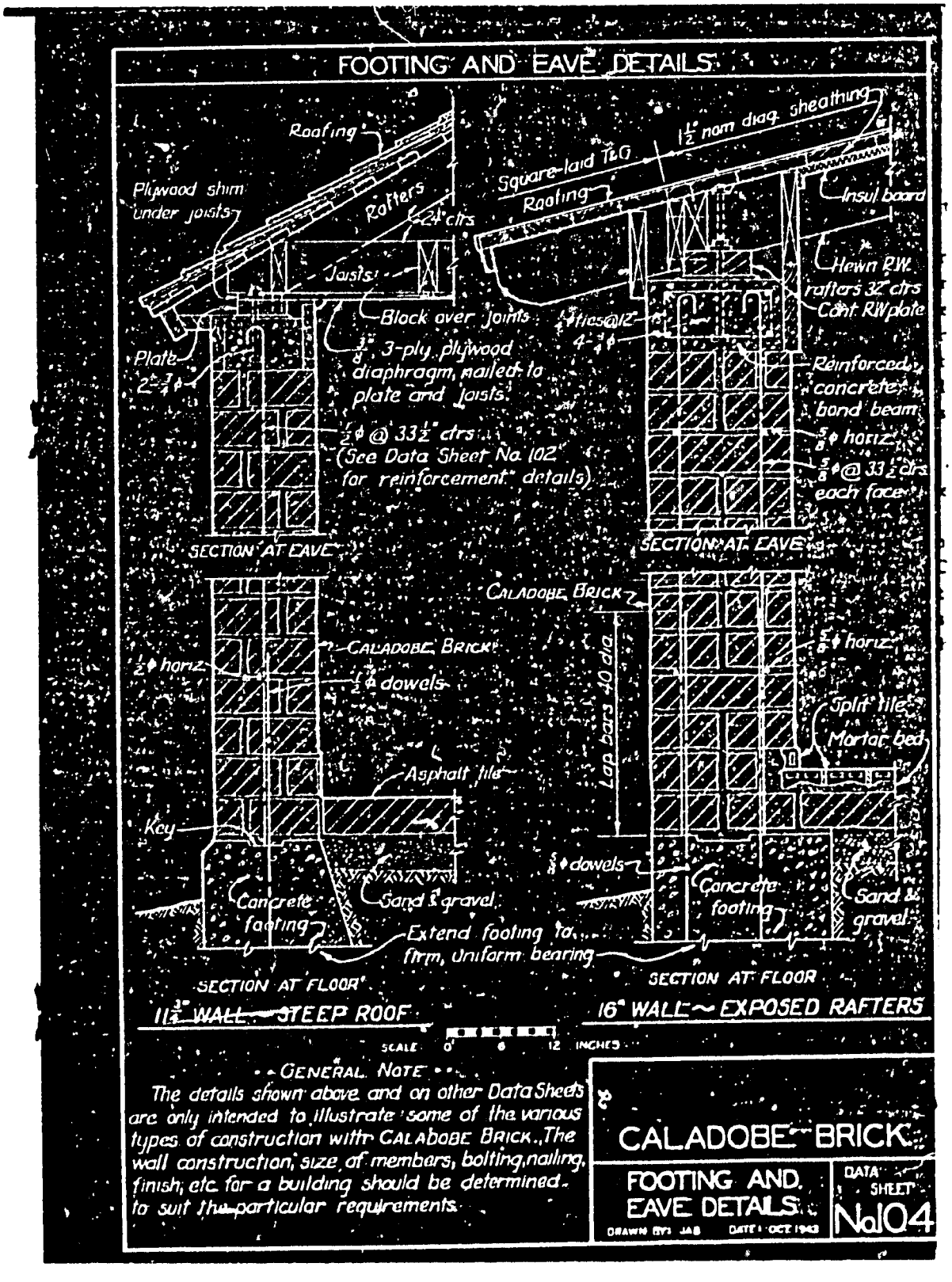
Blume, John A., "Structural Dynamics in Earthquake Resistant Design", Transactions, ASCE, 125:1088-1139, 1960.

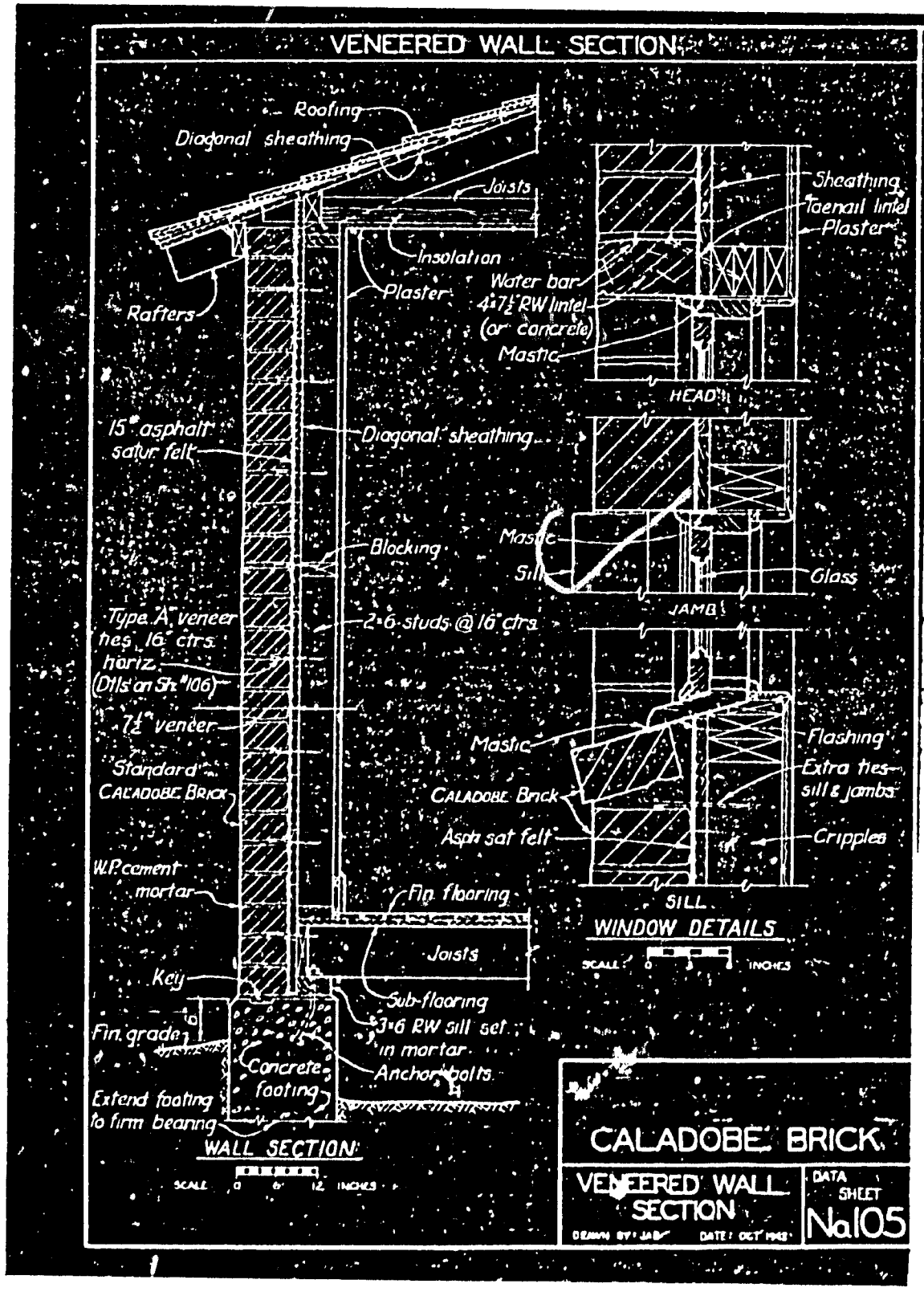
Portland Cement Association, "Analysis of Small Reinforced Concrete Buildings for Earthquake Forces", 1955.


STANDARD SHAPES AND WALLS
MORTAR: 1 to 2½ by volume of cement and well graded sand, waterproofed with 1½ gallons of "Hydropel" Emulsified Asphalt per sack of cement. Joints are ½" min. thick unless otherwise shown.
A 24" WALL may also be constructed, with the standard brick.
Header course
½" Joints in header courses
16" WALL
7½" WALL
Half-brick
11½" WALL
16"
BRICK
HALF-BRICK
STANDARD SHAPES
CALADOBE BRICK
STANDARD SHAPES AND WALLS
DATA SHEET
No. 101
DRAWN BY: JAB
DATE: OCT. 1943

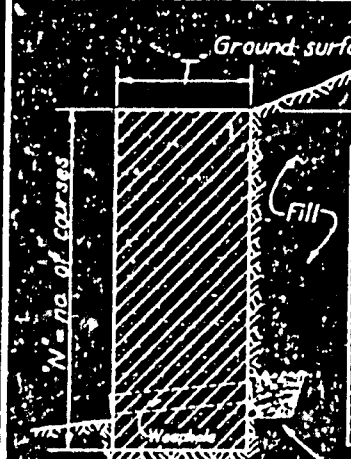

REINFORCED WALL CONSTRUCTION
½φ @ 33½" ctrs in each face
EVEN COURSE
Horiz. bars as req'd
ODD COURSE
11¾" WALL—DOUBLE REINFORCEMENT
⅝φ @ 33½" ctrs in each face
STRETCHER COURSE 'A'
STRETCHER COURSE 'B'
Horiz bars as req'd
HEADER COURSE
Note: Alternate Stretcher Courses 'A' and 'B' between Header Courses.
16" WALL—DOUBLE REINFORCEMENT
½φ @ 33½" ctrs
EVEN COURSE
Horiz bars as req'd
ODD COURSE
11¾" WALL—SINGLE REINFORCEMENT
⅝φ @ 33½" ctrs
EVEN COURSE
Horiz bars as req'd
ODD COURSE
7½" WALL
½φ @ 33" ctrs
STRETCHER COURSE
Horiz bars as req'd
HEADER COURSE
16" WALL—SINGLE REINFORCEMENT
SCALE: 0 6 12 INCHES
GENERAL NOTES:
Bricks are uncut standard whole or half-bricks with 4" side vertical. Joints with bars are ¼" wider than bars.
For design data and moment values of reinforcement shown, see Data Sheets No. 111 & 112.
CALADOBE BRICK
REINFORCED WALL CONSTRUCTION
DATA SHEET No. 102


TYPICAL WALL SECTION
Diagonal sheathing
Square-laid T&G
Asph. felt
Trussed rafters
Insulation
RW plate set in mortar
Cont. concrete band beam with 4-⅝ϕ bars
Pour into joints of top course
Blocking between all rafters
Header course
½ϕ bar from fdn. into band beam
Wire lath applied with furring nails (optional)
16" wall
Plaster
CALADOBE BRICK
Flooring
Key
Joists
Blocking
RW sill set in mortar
Fin. grade
6" min.
Concrete footing
Extend footing to firm, uniform bearing
WALL SECTION
SCALE: 0 6 12 INCHES
½ϕ bars set between half-bricks over jamb
Concrete lintel
Mastic
HEAD
¼ϕ Galv. clips in joints
Mastic
Frame
Wood sash
JAMB
Glass
Sheet metal flashing
Mastic
CALADOBE BRICK
SILL
WINDOW DETAILS
SCALE: 0 3 6 INCHES
CALADOBE BRICK
TYPICAL WALL SECTION
DATA SHEET
No. 103


FOOTING AND EAVE DETAILS
Roofing
Plywood shim under joists
Rafters
24" ctrs
Joists
Block over joints
3/8" 3-ply plywood diaphragm, nailed to plate and joists.
1/2φ @ 33 1/2" ctrs (See Data Sheet No. 102 for reinforcement details)
Plate 2-3/4φ
SECTION AT EAVE
CALADOBE BRICK
CALADOBE BRICK
1/2φ horiz
1/2φ dowels
Asphalt tile
Key
Concrete footing
Sand & gravel
Extend footing to firm, uniform bearing
SECTION AT FLOOR
11 3/4" WALL ~ STEEP ROOF
Square-laid T&G Roofing
1 1/2" nom diag. sheathing
Insul. board
Hewn P.W. rafters 32" ctrs
Cont. R.W. plate
Ties @ 12
4-3/4φ
Reinforced concrete bond beam
5/8φ horiz
5/8φ @ 33 1/2" ctrs each face
SECTION AT EAVE
5/8φ horiz
Lap bars 40 dia.
Split tile
Mortar bed
5/8φ dowels
Concrete footing
Sand & gravel
SECTION AT FLOOR
16" WALL ~ EXPOSED RAFTERS
SCALE 0' 6 12 INCHES
GENERAL NOTE
The details shown above and on other Data Sheets are only intended to illustrate some of the various types of construction with CALADOBE BRICK. The wall construction, size of members, bolting, nailing, finish, etc. for a building should be determined to suit the particular requirements.
CALADOBE BRICK
FOOTING AND EAVE DETAILS
DATA SHEET No. 104
DRAWN BY: JAB DATE: OCT. 1963


VENEERED WALL SECTION
Roofing
Diagonal sheathing
Joists
Insolation
Plaster
Rafters
15# asphalt satur felt
Diagonal sheathing
Blocking
Type "A" veneer ties 16" ctrs. horiz. (Dtls on Sh. #106)
2"x6" studs @ 16" ctrs
7½" veneer
Standard CALADOBE BRICK
W.P. cement mortar
Fin. flooring
Joists
Key
Sub-flooring
Fin. grade
3"x6" RW sill set in mortar
Concrete footing
Anchor bolts
Extend footing to firm bearing
WALL SECTION
SCALE 0 6" 12 INCHES
Sheathing
Taenail lintel
Plaster
Water bar
4"x7½" RW lintel (or concrete)
Mastic
HEAD
Mastic
Sill
Glass
JAMB
Mastic
Flashing
Extra ties sill & jambs
CALADOBE Brick
Asph sat felt
Cripples
SILL
WINDOW DETAILS
SCALE 0 3 INCHES
CALADOBE BRICK
VENEERED WALL SECTION
DATA SHEET
No.105

GARDEN WALLS



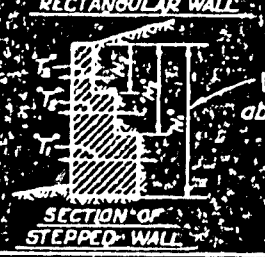
SECTION OF RECTANGULAR WALL

h	1	1½	2	3	4
θ	45°	33°40'	26°40'	18°30'	14°00'

VALUES FOR PLAIN WALLS

T	θ less than 15°		θ between 15° and 35°	
	Max. N	Ht. with ½" jts.	Max. N	Ht. with ½" jts.
7½"	4	1'-5½"	4	1'-3½"
11¼"	7	2'-7"	6	2'-2½"
16"	10	3'-8½"	8	2'-11½"
24"	14	5'-2½"	12	4'-5½"

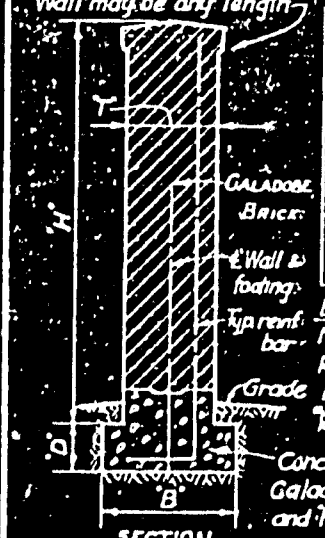
NOTE: The above table is based upon pervious, well drained soil. If the material is impervious or if considerable water is expected, provide drainage as indicated.
No seismic force is assumed.
Value of N_1 not to exceed that tabulated above for $T = T_1$; N_2 for $T = T_2$, etc.



SECTION OF STEPPED WALL

GARDEN RETAINING WALLS

"FENCE" WALLS WITH PILASTERS may be designed to withstand 20% gravity earthquake forces with slightly thinner walls than shown below.



SECTION

T	Plain Walls			Reinforced Walls			
	Max. H.	B	D	No. of curtains	Max. H	B	D
7½"	3'-6"	1'-4"	6"	1	5'-6"	2'-0"	8"
11¼"	4'-6"	1'-8"	8"	1 2	7'-0" 9'-0"	2'-6" 3'-0"	10" 1'-0"
16"	5'-6"	2'-0"	9"	1 2	7'-6" 11'-6"	2'-9" 4'-0"	1'-0" 1'-4"

BASIS OF TABLE: Static lateral force = 20% of wall wt. @ 120 lb/cu ft.
Max. net tension in plain walls = 5½ lb/sq in. "B" & "D" are for max. "H".
Reinforcement as on Data Sheet No. 102; f_s = 24,000 & f_c = 100 lb/sq in.
Max. O.T. Mom = 0.6 Res. Mom. Max. soil press = 1600 lb/sq ft.
RECOMMENDATION: Max. H = 8 T

"FENCE" WALLS WITHOUT PILASTERS

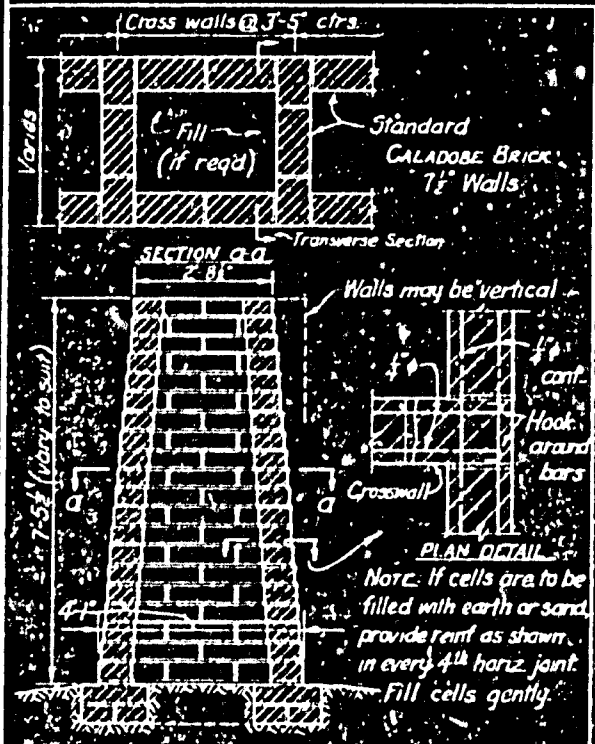
GALADOBE BRICK

GARDEN WALLS

DRAWN BY: J.A.B. DATE: NOV 1943

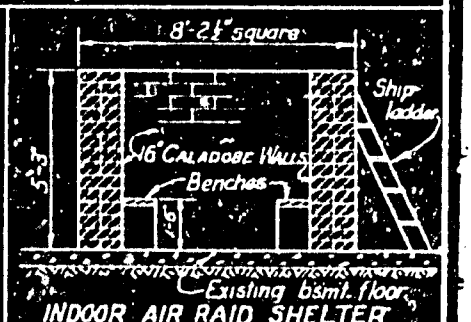
DATA SHEET No. 107

PROTECTIVE CONSTRUCTION



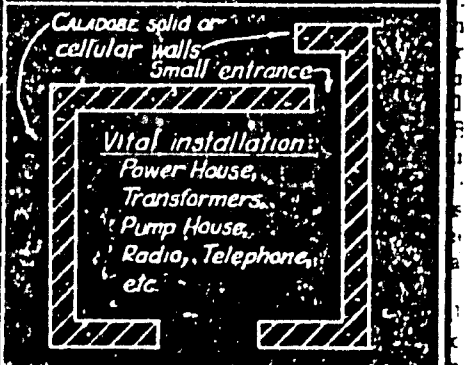
TRANSVERSE SECTION

CELLULAR TYPE BLAST WALL FOR THE PROTECTION OF VITAL INSTALLATIONS



INDOOR AIR RAID SHELTER

(For lateral protection from splinters)



PLAN

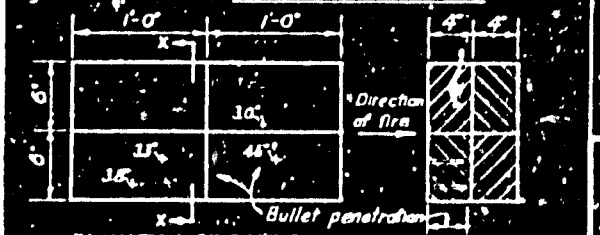
PROTECTION WITH BLAST WALLS

Data from University of Washington Engineering Experiment Station Bulletin No. 111, "Stabilized Earth Blocks for Protective Construction" by Robert Graham Hennes, July 1943:

Test Panel (Series C): 8 Bitudobe blocks as shown below. Joints filled with a paste of emul. asphalt & pulp.

Rifle: Garand, fired at 50-yard range.

Ammunition: std. M-1 ball, 0.30 calibre, 138 grain bullet, 50 grains of powder. Final condition of Panel: "Good".



ELEVATION OF TEST PANEL — SECTION X-X

GARAND RIFLE FIRE TESTS CONDUCTED AT FORT LAWTON

GENERAL NOTES

CALADOBE BRICK WALLS have all of the qualities desirable for revetments:

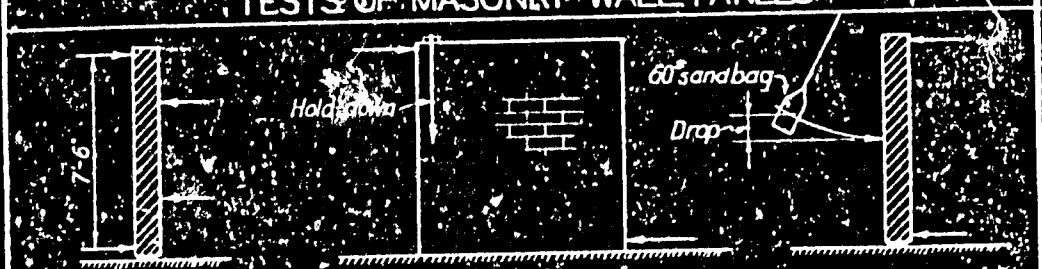
1. Resistance to penetration.
2. Energy absorption to prevent dangerous spalling and fracturing.
3. Strength.
4. Weather resistance.
5. Construction does not involve the use of critical materials or labor.

CALADOBE BRICK

PROTECTIVE CONSTRUCTION

DATA SHEET No. 108

TESTS OF MASONRY WALL PANELS



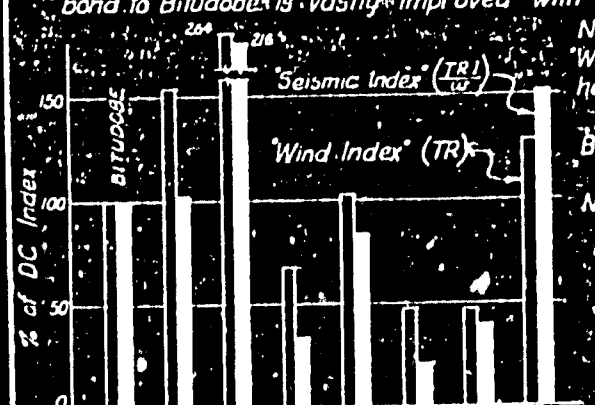
TRANSVERSE LOAD (T) RACKING LOAD (R) IMPACT LOAD (I)

NATIONAL BUREAU OF STANDARDS TESTS

PARTIAL TABULATION OF TEST DATA

From Report	Structural Symbol	Type of Wall	Wall thickness	Wt/sq ft (w)	Average Test Results T	R	I
			inches	lbs	lbs/sq ft	Kips/ft	Ft drop
BMS 78	DC	Bitudobe Block	11+	117	79.6	2.94	6.7
BMS 5	AB	Medium-Strength Brick Commercial workmanship	8 1/16	73.9	49.9	6.25	2.8
do	AC	Medium-Strength Brick Excellent workmanship	8 3/16	78.9	82.2	6.25	3.7
do	AD	Structural Clay Tile on End Excell. workmanship	8 1/16	42.6	38.7	4.02	1.2
do	AE	Structural Clay Tile on Side Excell. workmanship	8	38.9	63.9	3.74	1.8
do	AF	Stone Concrete Block Excellent workmanship	7 11/16	54.5	34.3	3.18	1.3
BMS 24	AU	Brick-Tile Cavity 2½" air space, steel ties	9 1/4	62.3	121.5	5.16	3.0
BMS 21	AX	Concrete-Block Cavity 2" air space, steel ties	10	44.1	49.8	6.01	3.0

*Specimens had not failed at end of tests - values made 7.5 for diagram below. Wall AX laid with 1:½:3 mortar, all others with 1:1:6 (by vol) cement-lime mortar. Subsequent tests by the American Bitumuls. Co. have shown that the bond to Bitudobe is vastly improved with more cement and no lime.



GRAPHICAL COMPARISON OF WALLS

NOTE: The Seismic Index and the Wind Index are arbitrary values used here for comparison purposes only. Bitudobe Block and Caladobe Brick are identical materials. Tests and BMS reports are by the National Bureau of Standards.

CALADOBE BRICK

TESTS OF MASONRY WALL PANELS

DRAWN BY: JAB DATE: OCT 1943

DATA SHEET No. 109

LATERAL FORCE DESIGN ELEMENTS

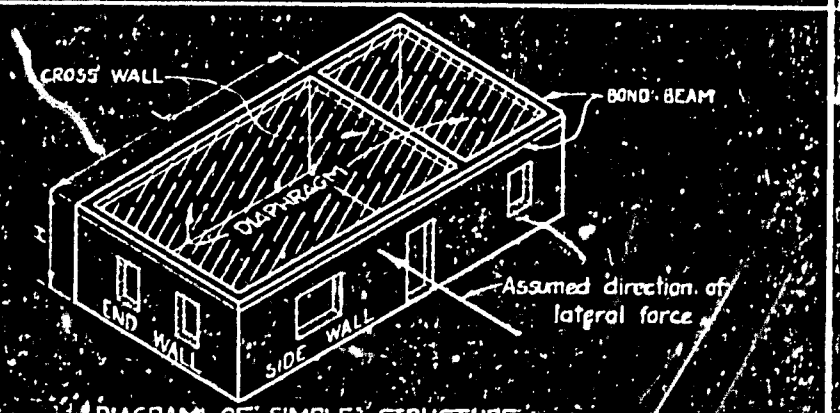


DIAGRAM OF SIMPLE STRUCTURE

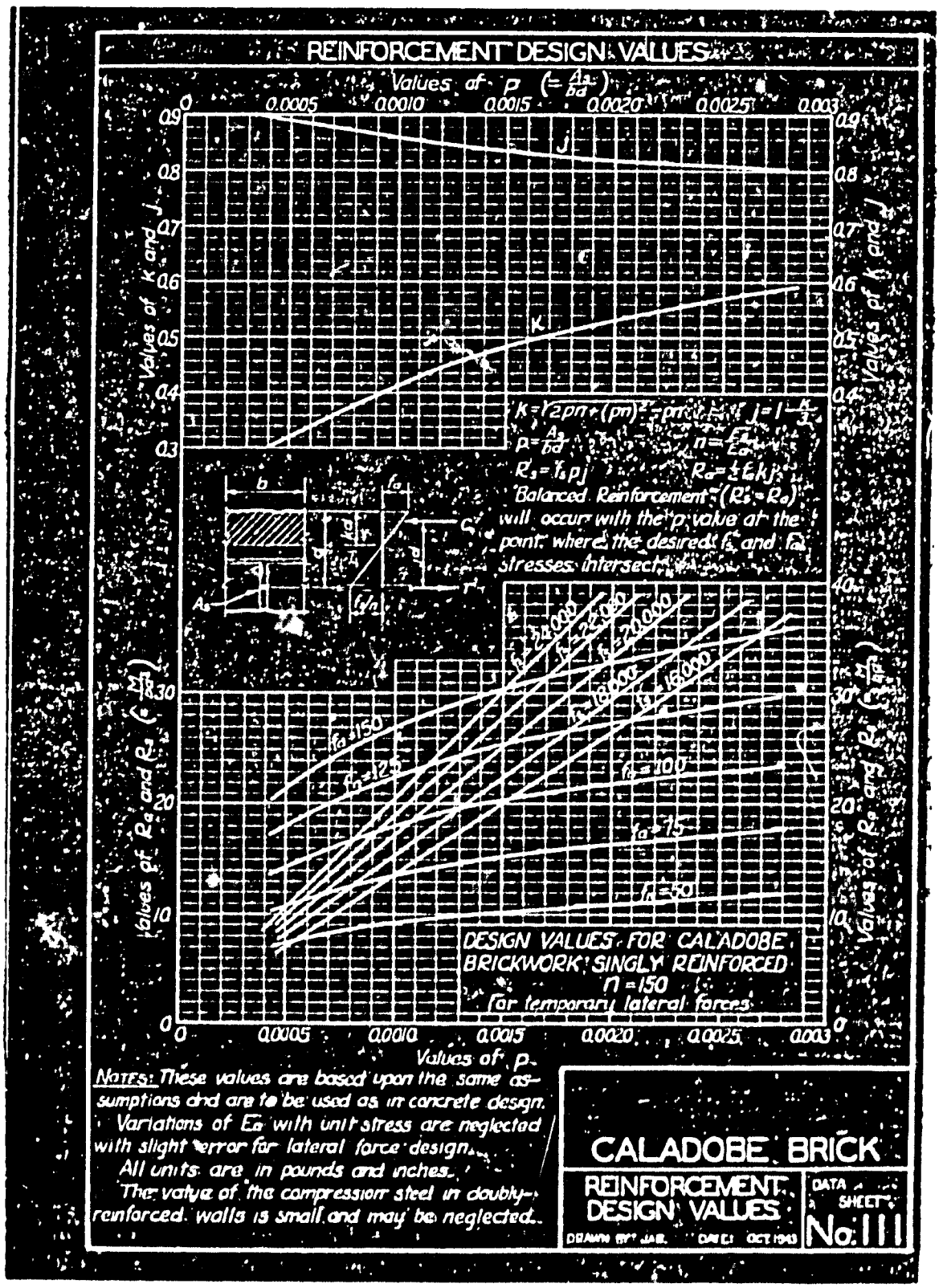
ELEMENT OF STRUCTURE	PRINCIPAL FUNCTIONS UNDER LATERAL FORCES	REMARKS ABOUT DESIGN AND CONSTRUCTION
DIAPHRAGM	To act as a horizontal girder or plate in distributing forces from roof, ceiling and sidewalls to the end and cross walls. To do this, and to relieve the side walls of carrying horizontal roof and ceiling forces as vertical cantilevers, the diaphragm must have rigidity as well as strength, and must be securely fastened to all the walls through the plate and bond beam.	If the roof is of 12% slope or flatter, its rafters may be diagonally sheathed to function as the diaphragm. Sheathed sheathing is generally too flexible to be effective. If the roof is steeper than 12%, accurate construction of well nailed plywood may be used. A deep roof with no ceiling necessitates a special analysis to make the bond beam and the walls self sufficient.
BOND BEAM	To act as a tie along the top of the walls, thus giving them considerable extra strength as vertical beams in resisting foundation settlements and other irregular or concentrated loadings. To give the walls additional lateral strength along their tops to resist normal forces and concentrated reactions from plate anchors, rafters, etc.	The concrete bond beam must have considerable tensile strength continuously around the top of all walls and corners, and it should be well bonded to the top course of masonry. A minimum area of reinforcement equal to 0.0007 times the entire area of the Cala adobe wall, section is recommended.
SIDE WALLS	To carry the normal forces down to the foundation, up to the bond beam and diaphragm, or sideways to the end and cross walls, depending upon the ratio of [illegible], the area and arrangement of openings, and the rigidity of the diaphragm. To resist torsional forces caused by the rotation of the building.	Design the structure as a whole for lateral forces in any direction equal to 10% of the dead weight. Design walls for 20% of their own weight as a loading normal to the face. Minimum thickness exterior walls [illegible]. Reinforcement is recommended. Concrete lintels are recommended. Wall openings should have a total width in any wall of less than 10% of wall length. Avoid corner windows. Ratio of height to width of piers between openings to be about equals [illegible]. All mortar to be 1 2½ cement and well graded sand mortar, waterproofed.
END WALLS	To receive the forces from the diaphragm, the bond beam, and the side walls and to transmit them down to the foundation. To resist torsional forces caused by the rotation of the building.	
CROSS WALLS	Same as the end walls except that the value in resisting torsional forces is usually small.	
PARAPET WALLS & CHIMNEYS	To carry themselves as vertical cantilevers.	Design and reinforce for horizontal force equal to their own weight.
FOUNDATION	To receive forces from the walls and to transmit them to the ground. To support the walls uniformly at all times so that no cracks develop with consequent loss of wall strength.	Extend to firm uniform bearing at proper intensity for soil. Provide key for wall mortar. Top and bottom horizontal reinforcement is recommended.

CALADOBE BRICK

LATERAL FORCE DESIGN ELEMENTS

DRAWN BY [illegible] DATE: OCT. 1943

DATA SHEET No. 110


REINFORCEMENT DESIGN VALUES
Values of p (= Aₛ/bd)
0 0.0005 0.0010 0.0015 0.0020 0.0025 0.003
Values of K and j
Values of Rₐ and Rₛ (= M/bd²)
Values of K and j
Values of Rₐ and Rₛ (= M/bd²)
j
K
k = √(2pn + (pn)²) − pn
j = 1 − k/3
p = Aₛ/bd
n = Eₛ/Eₐ
Rₛ = fₛpj
Rₐ = ½ Eₐkj
Balanced Reinforcement (Rₛ = Rₐ) will occur with the p value at the point where the desired fₛ and fₐ stresses intersect.
b
fₐ
Aₛ
fₛ/n
Rₛ = 20,000
Rₛ = 22,000
Rₛ = 18,000
Rₛ = 16,000
fₐ = 150
fₐ = 125
fₐ = 100
fₐ = 75
fₐ = 50
DESIGN VALUES FOR CALADOBE BRICKWORK SINGLY REINFORCED
n = 150
For temporary lateral forces.
Values of p
NOTES: These values are based upon the same assumptions and are to be used as in concrete design.
Variations of Eₐ with unit stress are neglected with slight error for lateral force design.
All units are in pounds and inches.
The value of the compression steel in doubly-reinforced walls is small and may be neglected.
CALADOBE BRICK
REINFORCEMENT DESIGN VALUES
DATA SHEET
No. 111

THE EXTENT OF THE PROBLEM OF EARTHEN BUILDINGS IN GREECE

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ABSTRACT

The present paper deals with "Earthen Buildings" that have a load carrying system of clay with various admixtures. The same term may also include structures with an initial wooden load carrying system filled in with clay. The clay is used either in the form of cast in place material or in the form of raw bricks.

Earthen buildings in Greece have been constructed since the protoneolithic period, and they have been considered superior than the baked brick wall construction, according to the use.

If well maintained and waterproofed, the earthen buildings show a very good earthquake resistance. There are cases that this type of buildings have suffered several strong earthquakes during their life, which in most cases reaches 100 years up to now.

Introduction

Terminology

In the present paper the term "Earthen Buildings" means the structures the main load carrying system of which is constructed out of clay with various admixtures. The same term may also include structures with an initial wooden load carrying system filled in with clay.

Extent of the problem in Greece

In Greece, a considerable number of people still use earthen buildings and in some cases serious problems may arise after damage of these type of structures due to an earthquake. During the last earthquakes a great percentage of this buildings were damaged.

There are no provisions for the aseismic construction of earthen buildings in Greece. There are provisions only for masonry (stone and brick) and reinforced concrete structures.

Earthen buildings have not been constructed in Greece in the last 30 years as main structures for habitation, and most likely this type of structures will not be constructed any more in Greece, according to the present state of practice.

The repair and strengthening of this type of buildings is a problem in most cases. There are also cases where alterations, additions and renovations must be done to earthen buildings. Due to various reasons (use, archaeological, traditional) and the required technology it is not well known.

In addition, the maintenance and waterproofing of the material of the walls of earthen buildings present considerable difficulties.

Historical Background

About the Protoneolithic age (6500 - 6000 b.C.) the inhabitants of Greece left the caves and settled in plains or on the shores of lakes, rivers and smooth bays. They wanted to have more permanent homes near the places of their work (pastures and farming fields), and they created the first communities in the plains of Thessaly, Argolis and Thrace.

Using techniques similar to those used for the knitting of baskets the early builders could create large spaces, of a rather circular form, for their houses using branches of trees driven into the ground. The branches were then smeared with mud on the outside. Later, clay (grayish or red) was used instead of mud and the houses were smeared with clay on the outside and even later on the inside as well.

Next, they used trunks or piles of wood for the skeleton of the houses and raw bricks to fill in the gaps between the wood. The piece of the wood that was driven into the ground was smeared with clay in order to protect it from humidity and other effects, Choremis (1981).

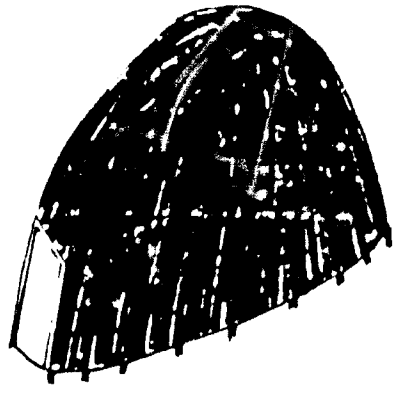

FIG. 1

The early builders created large round spaces, using branches and a cover out of mud.

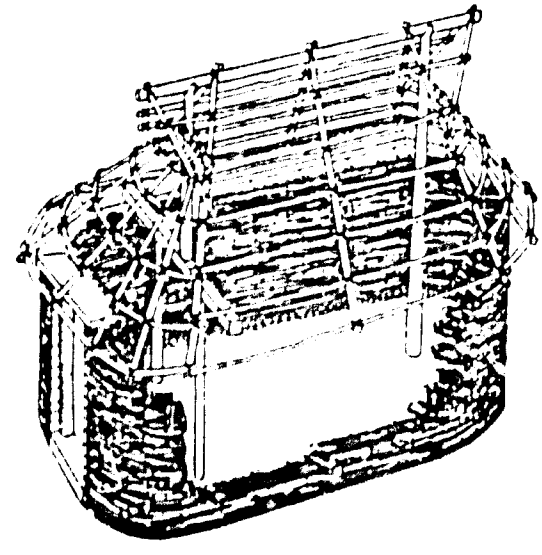

FIG. 2

Later, wooden frames and raw bricks were used, Schefold (1930).

Ruins of this kind of structures have been found in Sesklon-Thessaly-and in New Nicomedea. The houses had a rather rectangular shape with round edges, with partitions inside.

Various admixtures were used in the clay. according to the availability of local materials, the existing practice related to the construction of other similar objects (earthen casks etc), and the prevailing climatic and topographic conditions. These materials were: asbestos, sand, mica, and - what was very popular--the ground straw. In the island of Syros asbestos was used, although this mineral was not found in the island itself.

Bull's excrements or hair of animals were used, as an admixture to the mass of the clay, against high temperatures and as waterproof materials.

In some cases, instead of clay light (porous) and waterproofing material was used (Asia Minor, Spain Greece). This light material was very useful for the upper parts of domes.

The clay with the other admixtures was used as a material that was cast in place, as a mortar and for the construction of raw bricks.

The latter case is the most popular. Greeks, Babylonians, Egyptians, and Romans extensively used the raw bricks out of clay and ground straw. They did not yet know the baked bricks, but when the latter ones were discovered and used by the Babylonians and Persians, the Greeks and Romans believed the raw bricks to be better than the baked bricks and natural stones, because the raw brick walls were better in absorbing the impacts of the sieging rams, and thus they were more slowly deteriorating during sieges.

The effect of the water is ruinous. It is reported, Orlandos (1955) that in some cases, the ruinous effect of the water was used as a weapon by the besiegers. The walls of the city of Iionos and those of Mantinea were destroyed by the water of the nearby flowing rivers which were on purpose deviated by the besiegers.

The Babylonians used asphalt as gluing material between the raw bricks in the construction of walls. Elsewhere, smaller pieces of crushed stones or baked bricks for wedging the raw bricks among each other were used.

Many ancient writers like Plato, Xenophon, Herodotus, Aristophanes, Thucydides, Strabo and Vitruvius, referred to the way of preparation of the admixtures of the clay, the way of molding in order to form raw bricks, as well as the way of drying, transportation, and cost of the raw bricks. The bricks were made by specialized technicians and workshops. A kind of trade mark like a seal was usual among Ba-

bylonian raw brick makers, by which the date and place of construction was stated.

This was by law imposed on the Roman raw brick makers who should also indicate the name of the maker.

The shape of the bricks was in general that of an orthogonal parallelepipedon except in some rare cases were the base was a trapezoid (like in Delphi), Orlandos (1955).

The height of the bricks was relatively small, compared to the other dimensions. The height rarely was more than 10 cm, while the other two dimensions were more than 30 and 40 cm. The dimensions were, more or less, standard. The base had dimensions multiple of the "foot" in ancient Greece (= 0.308 m) The height was a multiple of the "finger" (= 1.92 cm), Smith and Tsivanopoulos (1890). Dimensions that were measured in ruins were 0.308 m in the walls of the city of Athens; 0.45 m in the walls of the sanctuary of Elefsis; 0.38 m in the walls of the city of Apollonia; 0.39 m in the walls of the houses in Olynthus, Orlandos (1955).

Half bricks were used in order to braid the bricks for better construction of the walls. It is interesting to notice here that the smaller dimension was less than the half of the other dimension in order to leave space for mortar.

The dimensions of the base of the bricks depended on the particular use. For private houses, for example, smaller dimensions were used, while for public works the larger dimensions were preferred, Smith and Tsivanopoulos (1890).

Interesting ruins in Greece are among others, Choremis (1981): The west gate of Eretria since 600 b.C. A part of the wall still remains, because the fire that turned the construction into ruins baked in the same time this part and made it more durable; The palace of Nestor in Pylos, built about 1250 b.C., was timbered. Its height was at least 2 stories. Thick plaster out of clay was placed on both sides of the timbered walls. The palace in the island of Santorini, that was destroyed from the eruption of the volcano at 1500 b.C., was timbered and plastered with clay and pumice.

A part of the walls of the city of Gela in South Italy was found intact, Choremis (1981), because it was buried in the surrounding sand and clay and the water could not destroy it.

Present Condition of Earthen Buildings in Greece

The various Governmental programs for rehabilitation of refugees (1920-1930) and of population striken by the war (1940-1949), although they were very big (about 200000 dwellings) and provided for a variety of relatively cheap building types, did not include the construction of buildings with earthen raw bricks, except in one or two settlements, where the earthen raw bricks were used as a filling material to the wooden load carrying system, Papaioannou (1975). This, in spite of the traditional reasons that might impose the construction of earthen buildings, was due to the relative difficulties for mass production of this type of buildings and to the high cost of their maintenance.

In the city of Kiation, noth Peloponnesus, a settlement of 100 one storied units has been constructed in 1930 within the frame of the habitation program for refugees. The load carrying system of each unit is a wooden frame with diagonal beams. The gaps are filled with earthen raw bricks, Fig. 3.

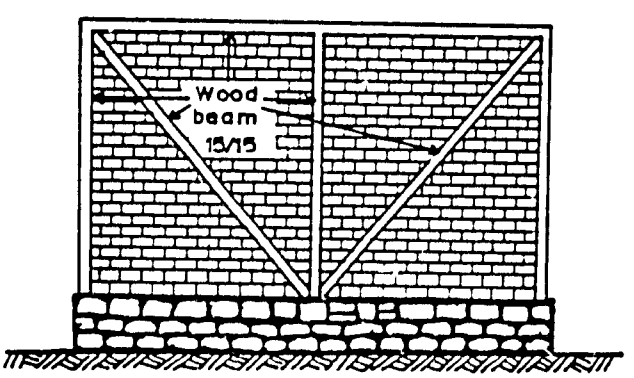

FIG. 3

Elevation of a wooden frame for houses. The gaps are filled with earthen raw bricks. The base is out of stone masonry.

All the well maintained buildings out of wood frame and earthen raw bricks in Kiaton withstood the various earthquakes quite well, Fig. 4. If we assume a rather strong shock every 20 ÷ 25 years that happens in this region, this type of buildings has been tested by the earthquakes two to three times quite successfully.

FIG. 4

Well maintained earthen buildings stand the test of time and of earthquakes very well.

Most of the buildings of this type, constructed in Kiaton, have been renovated and extended by adding more rooms in the horizontal and vertical direction using other materials, like stone or baked bricks and reinforced concrete. It has been observed that stone masonry structures and this type of structures of equal height had the same movement during the recent series of earthquakes of February 24 and 25, 1981. The same movement of adjoined buildings means same dynamic characteristics of these two types of structures. Many of this type of buildings have been demolished in order to build modern houses, propably, because the wooden frame and roof rotted.

In earthquake areas wood was used up to the late fifties as a strengthening element to the load carrying system, regardless of the material from which the latter was made. The wood is placed in the corners, in the sills of the windows, in the lintels, in any intermediate height if required, and under the roof. There are vertical, horizontal and x-braced wooden beams. In most cases they do not form any kind of frame.

In some cases, like in the island of Lefkas massive wooden corners were used to strengthen the corners of the buildings. These corners, each one of which was carved in one piece of root - usually of olive tree - were forming the end of

the corner of the building, Fig. 5.

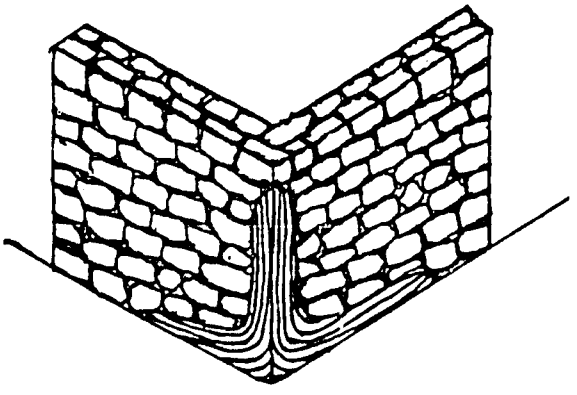

FIG. 5

Massive one-piece carved wooden corner
(island of Lefkas).

Some cities and villages in Greece have many one or two storied earthen buildings, with a load carrying system out of earthen raw bricks. Thise buildings are 80-100 years old. There are wooden beams as strengthening elements and for the distrubution of loads, Fig, 6.

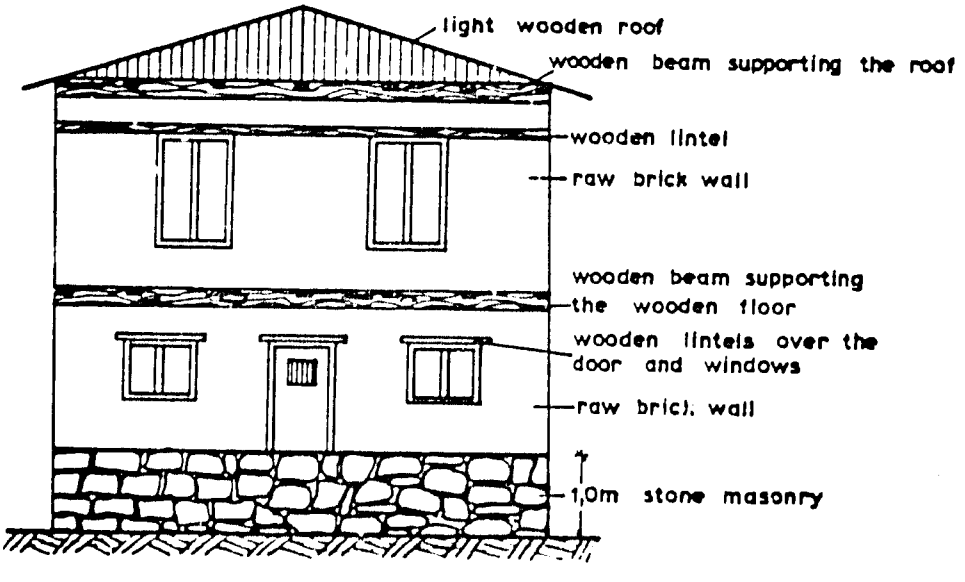

FIG. 6

Typical two storied earthen building

The "modern" raw bricks have dimensions 40*20*20 cm, and they out of clayey soil with ground straw.The pieces of straw have a length of 1-4 cm. Some times the clayey soil has small stones,fragments of tiles and sand.The same material is used

as mortar between the bricks.

In rare cases the mortar of the vertical joints between bricks is missing.

The thickness of the walls depends on the loads carried by them. Typical thickness for a bearing wall of a two storied building is 60 -70 cm.The internal partitions of the buildings are of a light timber construction (bagdhadi).

The percentage of earthen buildings in the various cities and villages in Greece constantly decreases. Table 1, for example, shows the results of relavant statistics for the city of Kiaton from 1920 up to this year.

TABLE 1

Year	Earthen raw brick masonry		Stone masonry		Wood.fr./raw brick fill.		R/C with baked brick fill.		Total
	Num.	%	Num.	%	Num.	%	Num.	%	Number
1920	500	100.0	-	-	-	-	-	-	500
1928	650	92.9	50	7.1	-	-	-	-	700
1940	1000	75.7	200	15.2	80	6.1	40	3.0	1320
1971	1300	56.6	470	20.4	30	1.3	500	21.7	2300
1981	1300	52.9	60	2.4	20	0.8	1080	43.9	2460

These statistics may be conidered as a typical example for other Greek cities that had also many earthen buildings in the past.

During the recent earthquakes 70% of the earthen buildings with raw brick masonry in the city of Kiaton were seriously damaged and have been condemned. This is attributed to: bad maintenance, due to which the water or the high humidity deteriorated the walls; damage of the roof; the rotten wooden beams that were initially used for strengthening; lack of or bad foundation; no, or inadequate repair of damages due to previous earthquakes. Numerous buildings almost 80 years old belong to the latter case. Some additional reasons for serious damages were the creation of big openings in the walls-resulting from a change of use mainly in the center of the old city- as well as the addition of more closed space with the constuction of reinforced concrete slabs and beams which are supported by the raw brick walls. Example of this type of mixed construction is the plan in Fig. 7, which, however, remained intact during the recent earthquakes.

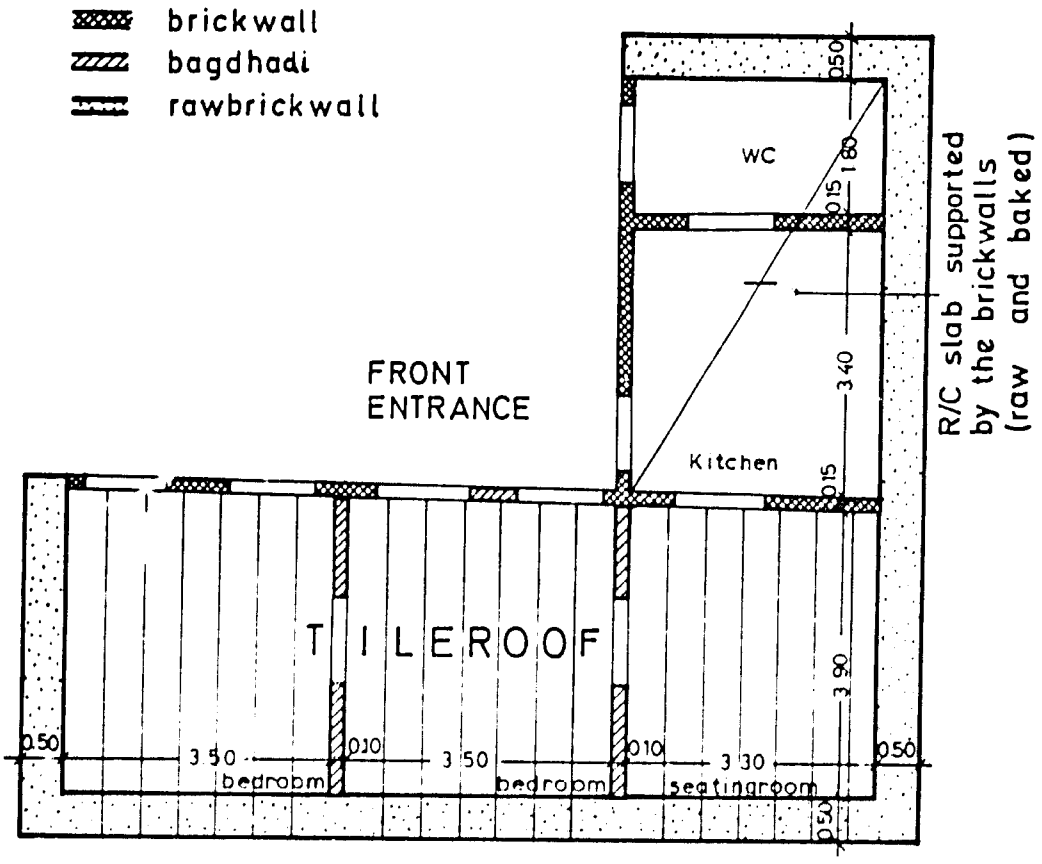

FIG. 7

One storied Earthen building since 1900, with new facade and partially new roof out of R/C, in Aghios Ioannis Rentis/Athens.

FIG. 8

Two storied earthen building in the center of the city of Aiaton. In the front of the first storey, a R/C construction replaces the existing wall: beam with balcony on slender columns. The building was seriously damaged by the recent earthquakes.

Other examples of renovations, additions etc, to this type of buildings are shown in Fig. 8 through 11.

FIG. 9

Two storied earthen building in the center of the city of Kiaton. Details of the construction of the roof and of the light partitions. Alterations in the front of the first storey.

FIG. 10

Two storied earthen building in the center of the city of Kiaton. Beam on columns out of R/C replaces the biggest part of the front wall of the first storey, for larger openings for the windows.

FIG. 11

An one storey old earthen building has been renovated with the addition of R/C columns and R/C beams, and of a second storey, out of R/C load carrying system and baked brick walls for partitions.

FIG. 12

A modern construction out of R/C and baked brick walls is added to an old two storied earthen building.

In Fig. 12 through 14 other damages of two storied earthen buildings are shown after the recent earthquakes in the city of Kiaton. These buildings have suffered several strong earthquakes. Most of them have not been repaired during the last 50 years.

FIG. 13

Old earthen building near the sea shore. The separation of the mortar is typical.

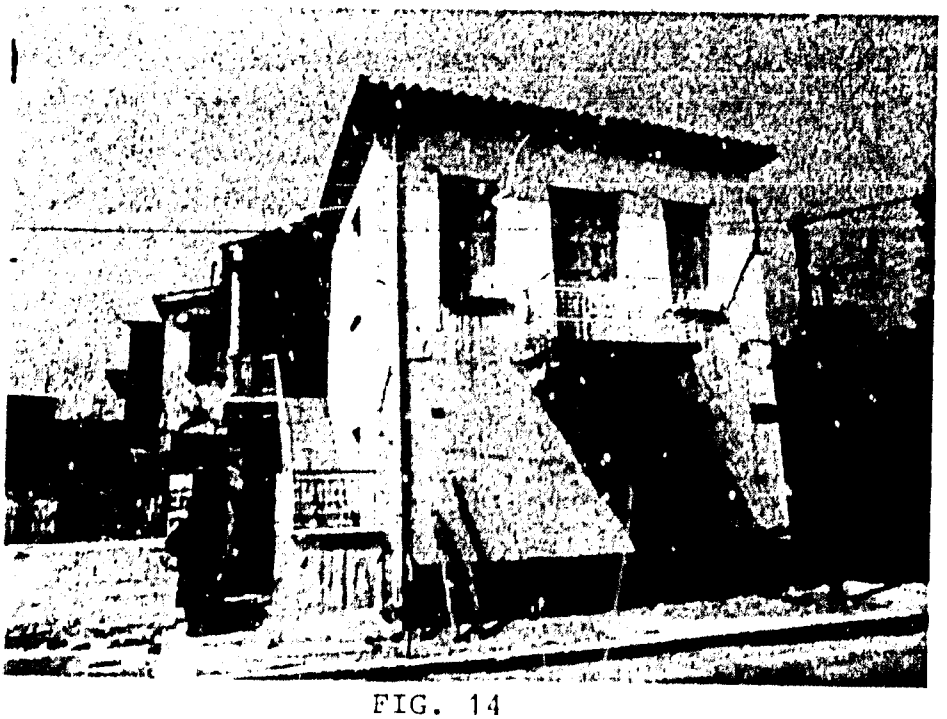

FIG. 14

A two storied earthen building, 100 years old. This building has suffered at least 3 strong earthquakes, while it was not repaired after the second one.

The rain water, the ground water or the humidity are destructive for the raw bricks. For this reason a waterproofing mortar is one of the best means to make the earthen buildings more durable.

The wooden beams which are put for strengthening the walls of earthen buildings are vulnerable to microorganisms, worms and insects.

FIG. 15

Humidity and ground water is coming from the body of the foundation. The uncovered raw bricks loose their strength. The wooden beams of the lintel and roof have been moth--eaten.

It is interesting to notice here that many earthen buildings collapsed slowly. The remaining parts did not move one in relation to the other, which means that during the collapse of the building there was no shock or any high acceleration of the particular parts. Some observers say that the buildings sat slowly on the ground.

FIG. 16

Collapsed two - storied earthen building

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CLOSE RANGE PHOTOGRAMMETRIC ANALYSIS OF EARTHEN BUILDINGS UNDER SEISMIC LOADING

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ABSTRACT

This paper describes an INTERTECT project to demonstrate the feasibility of a new analytical technique for evaluating the performance of earthen buildings and other non-instrumentable structures subjected to earthquake-induced loads. Close range photogrammetric equipment will be linked to, and triggered by, seismographic instrumentation to observe and record the performance of buildings during actual loading. If successful, the technique will provide a tool for observing adobe and other earthen buildings during seismic events. Successful development of this technique will give researchers and scientists a new tool for earthquake engineering research and will open numerous types of buildings and other structures such as earthen dams to observation, which have not previously been subject to complete analytical examination under actual or simulated loading conditions.

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BACKGROUND

Purpose of the Project

The purpose of this project is to develop a new analytical tool for examining earthen buildings and other structures which cannot be adequately instrumented. It is possible to instrument a number of buildings where certain properties of the materials used are known. However, for many types of structures, total instrumentation is not feasible, especially for those made of earthen materials (e.g., adobe and rammed earth buildings), and certain low quality masonry structures.*

Current earthquake engineering knowledge is based upon:

(1) Observation of damage to buildings

(2) Testing of scale models

(3) Calculation of component performance strength based upon known properties of the materials.

Much of this data is based on "before and after" comparisons, and there are few practical methods by which the actual deformation and collapse of buildings can be seen during an actual seismic event. Thus, a major gap exists in research methodology.

APPROACH

Photogrammetric engineering is the science of obtaining reliable information about physical objectives and the environment through the process of recording, measuring and interpreting photographic images and patterns. Close range photogrammetry is the application of principles of precision measurement to map (or measure) objects that are difficult to study in other ways. Data is derived from measurements and information obtained from photographs with optical analog instruments and/or analytic computations. Current applications include: observations of large-scale structures such as astronomic radio reflectors and bridges subject to environmental deformation; recording of measureable deformations in engineering models; and monitoring the manufacturing of other precision instruments.

Close range photogrammetry has many potential applications in earthquake engineering. Essentially, it is an analytical tool. Close range photogrammetry offers an analytical method for examining the response of non-instrumentable structures subjected to seismic loads.

(1) Close range permits observations of both full-scale buildings and model structures without direct contact

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*It has been estimated that as much as 60% of the world's man-made structures cannot be adequately instrumented and observed during earthquakes. This represents a sizeable portion of the buildings of concern in natural hazards reduction. Furthermore, the cost of fully instrumenting a large building can be enormous and, in poor quality buildings, such instrumentation is subject to damage in the collapse of the building.

(2) Close range can expand capabilities for observing structures and opens a new and wide range of structures to investigation.

An advantage of this project is that the proposed methodology makes practical use of existing technology. By doing so, a new tool can be added to the earthquake engineering field at minimal cost.

Methodology

This project proposes to develop a new technique for analysis of structures under seismic loading, by linking close range photogrammetric equipment directly to seismographic recording devices. The photogrammetric equipment will be placed in arrays surrounding the structure to be examined and linked directly to the recorders. When a seismic event occurs, a series of precision photographs will be triggered and, at the same time, localized ground motion will be recorded. The resulting data will record, in real time, the deformations of the building at specific loadings. This will enable researchers to conduct a precision analysis of the performance of buildings and specific components at various points in time during the seismic event.

RESEARCH ACTIVITIES

Major Elements of the Research Plan

Three activities will be initiated concurrently when the project begins. First, the photogrammetric array and mount will be designed. The mount will be built so that ground movement will not affect the position of the camera during a seismic event. It will be highly portable and able to be assembled rapidly on site.

Once the array has been built, the photogrammetric equipment will be linked to seismographic recording equipment via a triggering device activated by the seismograph. The equipment will then be ready for field use.

At the present time, it is proposed that the equipment be tested on site during a full-scale dynamic test. The University of New Mexico currently conducts periodic full-scale tests using explosive arrays to create ground motion similar to earthquake-induced ground motion. If such a test is conducted during the period of this project, the equipment will be placed on site to test this concept. If such a test is not conducted, the project will establish the photogrammetric methodology and the seismographic linkage independently, although a direct correlation will not be possible without an event where ground motion and structural motion both take place. A mount and frame will be tested under simulated ground motion conditions to establish the workability of the dampening system used for the mount. The actual selection of an alternative test facility will be made after it has been determined that a full-scale test is not possible. Research facilities utilizing shaker tables can also provide an opportunity for testing the photogrammetric methodology.

Detailed Description of Photogrammetric Methodology

The building's deformation in progress will be recorded by a pair of calibrated photogrammetric cameras. This imagery will then be developed and an analysis will be performed to determine the three-dimensional coordinates (X-Y-Z) of specific points before, during, and after deformation. These

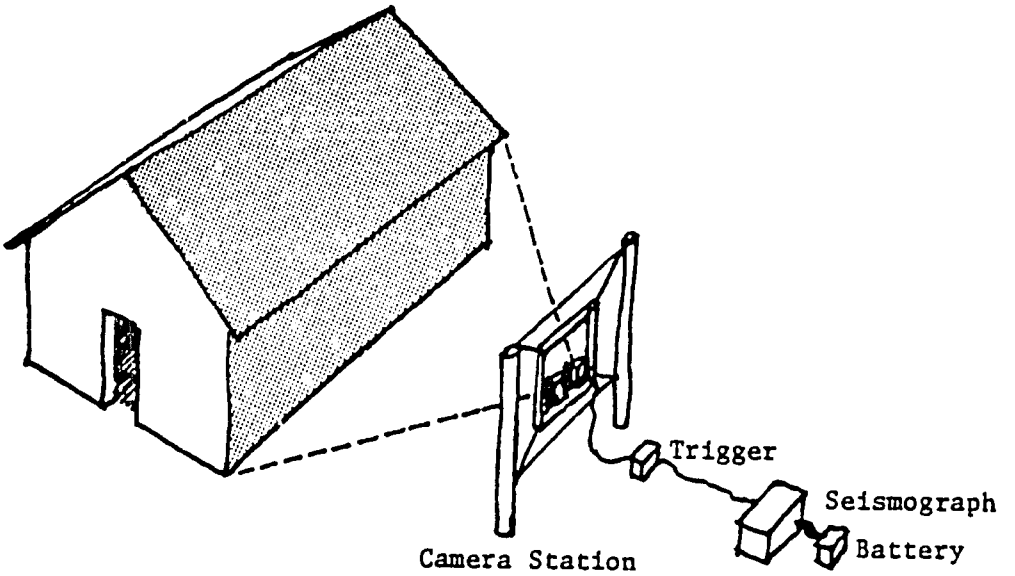

Figure 1
Basic Array

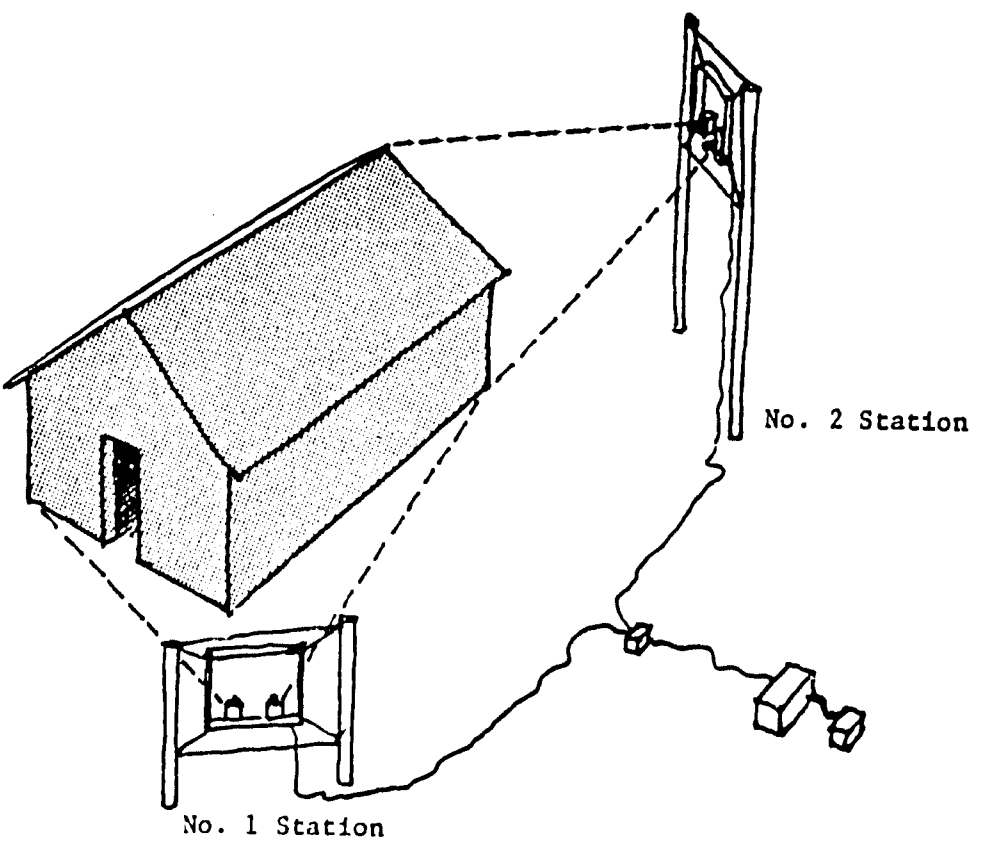

Figure 2
Comprehensive Array

precise coordinates will be used to compute the resultant vectors of deformation and will define the three-dimensional movement history of the seismic event.

The test site will consist of an example building constructed over a disposal emplacement of unexploded ordinance. At some distance (20-40 meters) a suspension system will be constructed to support a pair of photogrammetric cameras. Photographs will be exposed by both cameras before detonation to provide a priori control; photographs will be exposed during detonation to monitor deformation in progress (at three-second intervals, the cyclic rate of the cameras); and photographs will be exposed after the conclusion of the initial seismic shock and aftershocks to provide a posteriori control.

The suspension system will consist of a series of cables connected to poles in a line parallel to the front face of the building. Platforms for each of the two cameras will be suspended by wires attached to springs to minimize gross swaying and vibrations. Cameras with automatic winders will be synchronized with stroboscopic lights to freeze action, and will be triggered by a seismograph. Detonation of the explosives will have to take place after dark to allow the stroboscopic lights to provide all illumination without experiencing image smear due to other light.

The major concern of the orientation of the cameras during the event is to maintain the building within the field of view. This will be achieved by the suspension system. The differential movement of the cameras with respect to the building and to each other is immaterial because of the analysis technique.

There are basically two methods of performing an analysis by photogrammetry. The traditional method is to reconstruct the perspective bundles of light rays by analog equipment by replacing the light rays of conjugate imagery with mechanical rods. This presents difficulties for the proposed application because virtually everything in the field of view will be in motion and no stable reference points can be used to adjust and orient the instrument. The maximum accuracy attainable by the analog method is about 1/10,000th of the maximum dimension of the building face being imaged.

The other method of photogrammetric analysis is to reconstruct the perspective bundles of light rays by differential analytical geometry. Analytical photogrammetry is not constrained by variations in the orientation of cameras with respect to the building or to each other, because the computations include a provision to resect the perspective centers of the cameras based on conjugate imagery wherever it may appear in the photographs. After the initial estimate of the resection is performed, the computations intersect conjugate imagery to redetermine object space coordinates (the building), and the process iterates. When the differential change in the orientation of the cameras and the computed coordinates of the cameras and the building converge to some pre-specified criterion, a final intersection of the object space coordinates is performed and the results are output by the software. The mathematical model is based on rigorous least-squares, and the capability is present to include an error propagation analysis of the geometric dilution of precision for an accuracy determination of each and every coordinate computed in three-dimensional space. Under ideal conditions, analytical photogrammetry has attained accuracies better than 1/100,000th the maximum dimension of the object being measured. This test is not likely to provide ideal conditions, but the accuracy attained is expected to be a substantial improvement over the analog potential.

The analytical approach has the ability to successfully perform the project, and can provide the insight for the best equipment to utilize in a subsequent phase of the research. The methodology employed will be commensurate with the standard photogrammetric state-of-the-art, and will be feasible for utilization by other researchers that have access to a photogrammetrist. The physical facility for such a test is available at Sandia Research Laboratory, New Mexico, and the seismograph will be off-the-shelf equipment obtained from several commercial and academic sources.

The photogrammetric equipment, the cameras, are available from a number of commercial sources. Aerometric Engineering Inc. can provide the cameras and technicians for the photography.

In this project, only one face of a building will be studied. The accuracies attained will serve as a basis for determining necessary configurations of camera arrays for more extensive applications involving more than one face at a time.

Current technology in structural analysis involves finite-element techniques that define structures in a three-dimensional coordinate system. The photogrammetric approach to deformation monitoring and measurement presents data in a form completely compatible with the finite element approach to structural analysis. As the level of sophistication in finite-element techniques increases to include statistical analyses of the accuracies of the input data, the accuracy determinations of analytical photogrammetry solutions will be available for integration in the form of variance-covariance matrices solvable for eigenvector/eigenvalue parameters to define ellipsoids of error for X-Y-Z coordinate determinations and resultant space vectors of displacement due to deformation.

IMPLICATIONS FOR FUTURE RESEARCH

There are five significant aspects of this project:

(1) Buildings and other structures, which are not now instrumentable, can be evaluated;

(2) Full-scale buildings can be examined and evaluated without actual contact;

(3) The actual deformation and movement of the buildings can be recorded and linked directly to localized seismographic data during both real and simulated seismic events;

(4) There is no risk to the equipment due to failure of a particular structure;

(5) The method proposed utilizes existing off-the-shelf equipment currently available and in widespread use in other engineering disciplines. Successful development of the concept will add a significant new tool for researchers at relatively low cost.

Successful development of this technique will provide a tool that can be used for examining buildings under real earthquake conditions. As earthquake prediction becomes a reality, photogrammetric arrays can be placed on site prior to onset of a seismic event to record the performance of structures

under actual loading conditions. Thus the project not only will provide a precision tool useful for current research activities, but also, perhaps more importantly, it will provide an important tool for use when earthquake prediction techniques become more precise.

Substantial opportunities exist for linkages to existing earthquake research once the procedures have been developed and verified. There are a number of ongoing research programs funded by the National Science Foundation as well as by independent non-governmental foundations, research institutes, and private and state-supported universities that could benefit from these techniques.

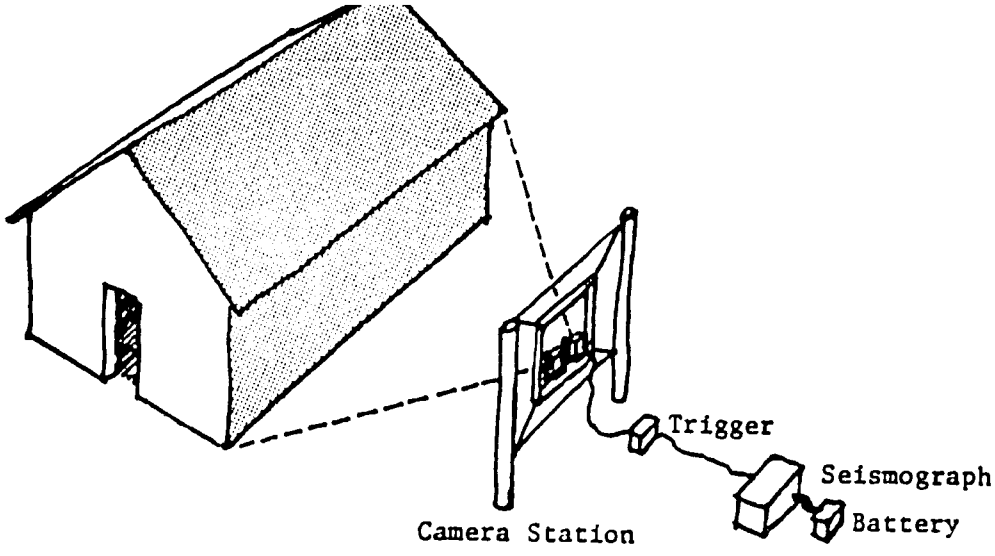

Figure 1
Basic Array

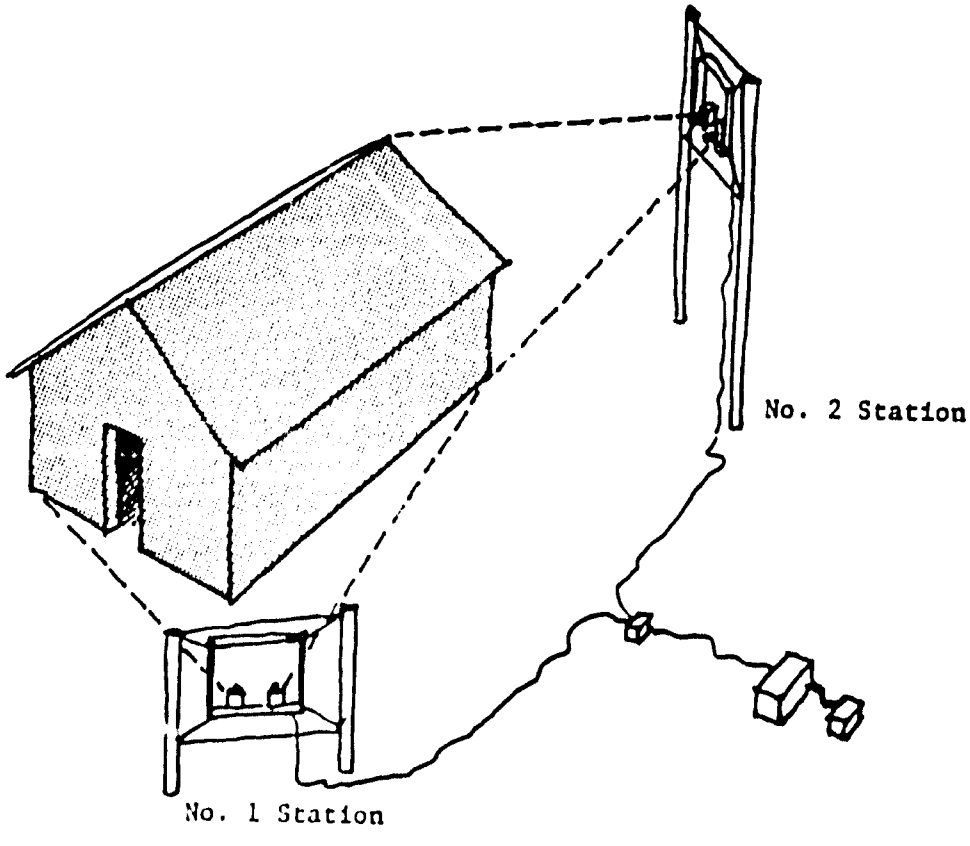

Figure 2
Comprehensive Array

INTERNATIONAL WORKSHOP ON EARTHEN BUILDINGS IN SEISMIC AREAS

KEYNOTE PAPER

SITING AND STRUCTURAL ASPECTS OF ADOBE BUILDINGS IN SEISMIC AREAS

by

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Preface

This paper is based on the experience of the Turkish National Committee on Earthquake Engineering (TNCEE) in research and implementations of earthquake resistant design practice of adobe structures in Turkey. The TNCEE comprises seventeen working groups of which two are called "rural structures" and "masonry structures". Both of these groups perform studies related to adobe structures involving different aspects of the problem.

The TNCEE is an organization having a wide base of membership including ministries, universities, government research institutions and private engineering firms. The ultimate aim of the studies performed by the working groups is the incorporation of their findings and experience into the earthquake resistant design code of Turkey. For adobe structures this is generally not sufficient and substantial public education programs are required for an effective implementation effort. Significant steps have been taken in this direction also, including preparation of explanatory posters, regional seminars, etc.

1. Introduction

In order to present a meaningful discussion on the subject of earthquake resistant behavior of adobe structures, a clear definition of an adobe structure is warranted. This is necessary for clarification of the context to be herewith employed.

In this paper "adobe structure" will refer to a structure in which the load bearing elements are constructed using adobe as material. In this sense, adobe structures are included in the general category of masonry structures. In contrast, wood frame structures where adobe is used as infill material will not be considered as adobe structure. Different use of adobe, i.e. both as load bearing and infill material, are common and Figure 1 shows the areas in Turkey where adobe is used most widely. Typical examples of the load bearing adobe structure and wood frame structure in which adobe has been used as infill material may be seen in Figures 2 and 3, respectively. As may be observed from these figures, the two structural schemes are essentially distinct and for this reason all aspects of structural behavior, including seismic, have profound differences. Structurally, the adobe bearing wall type buildings behave as masonry, not very different from stone or brick construction. On the other hand, the wood frame structure with adobe infill walls behaves as a "frame structure" regardless of the infill material.

This paper comprises various aspects of seismic behavior of adobe structures. Section 2 covers the adobe buildings in Turkey, in general. Section 3 includes a discussion on siting problems of adobe structures. Construction practices and different structural components making up the design of adobe buildings are presented in Section 4. In this section some of the common design errors encountered in existing adobe construction practice are also indicated. Experience from post-earthquake observations resulting in classification of damage of adobe structures is given in Section 5. Inspection and assessment of the state of existing structures are discussed in Section 6, whereas Section 7 presents the results and conclusions of laboratory and field testing of adobe structures. Synthesis of the preceding sections are presented in Section 8 where recommendations for repair and strengthening aspects are discussed. In Section 9 future research needs are indicated.

Turkish Standards and Codes on Adobe and Adobe Construction is covered in this workshop by Yorulmaz (1981) and will not be repeated in this paper.

2. Adobe Buildings in Turkey

Earth is one of the oldest building materials known to man and will be with us for a long time to come. In Turkish archeological excavations mud-brick is encountered in strata from Neolithic to the 6th Century. The timber reinforcement of the adobe walls has been employed in earthquake prone areas at the time of the Neo-Hittite states dating back many millenniums and is still employed today in an essentially unchanged format (Naumann, 1975).

In Turkey the most common application of earth as a building material is in the form of unburned clay bricks used in adobe masonry construction. In very limited areas walls are built by molding of the clayey earth mortar in 0.8 to 1 meter thick continuous horizontal courses and ramming successively. Other applications include the use of adobe blocks as infill material in wood frame structures (see Figures 2 and 3).

Structures in rural areas built with local materials and tradition without any engineering services are classified as "rural structures". Approximately 55 percent of the total building inventory in Turkey can be classified as rural structures amounting to about 4,900,000 units in 1980 estimates (DPT, 1979). As indicated in Figure 4, 75 percent of the rural structures are load bearing masonry out of which 32 percent comprise the adobe masonry. Thus, in Turkey, there are about 1,170,000 adobe buildings housing close to 6,000,000 people. The distribution of adobe structures in the seismic regions of Turkey are indicated in Table 1.

TABLE 1

Distribution of Adobe Buildings in Seismic Areas of Turkey
(After TNCEE, 1978)

SEISMIC REGION	NUMBER OF ADOBE BUILDINGS	PERCENTAGE OF ADOBE BUILDINGS
1. (I_o > IX MSK)	300,000	25
2. (I_o = VIII MSK)	170,000	15
3. (I_o = VII MSK)	350,000	30
4. (I_o = VI MSK)	230,000	20
5. (I_o < V MSK)	120,000	10

3. Siting

Siting of adobe structures is a subject which is part of the general problem of siting with respect to seismic hazard. It is also important to note that seismic hazard is only one factor which may influence siting considerations of adobe or other type of structures.

There are two major factors in siting considerations in terms of seismic risk. The first one may be represented by seismic zoning or contour maps indicating areas of equal intensity (or acceleration) for a given average return period or probability of exceedance in a specified duration of time. These are categorized as macrozoning maps and they indicate zoning of a region or the whole of a country based on the level of expected vibratory ground motion. This regional zoning (macrozoning) is used in determination of seismic design values for differenr type of

structures. Figures 5 and 6 present two examples. The first (Figure 5) is the official seismic zoning map of Turkey for building structures as published by the Ministry of Reconstruction and Resettlement in 1972. It is based on a compilation of felt intensity maps including historical earthquakes. As may be seen from this figure, Turkey is divided into five different zones, each corresponding to a different "design level" for building structures. For engineered building structures such as reinforced concrete, different zoning implies a different lateral seismic coefficient, to be used in design. For other types (non-engineered) of building structures including adobe, aseismic design is controlled by constructional requirements such as maximum number of stories, minimum wall thickness, etc.

The philosophy of design of adobe structures will be discussed in further detail in Section 3. Figure 6 (taken from Yarar et al., 1980) gives iso-acceleration contours for a 500 year average return period.

On the scale of these two maps, siting of adobe structures is not controlled by seismicity considerations. Use of adobe as a construction material generally results from lack or difficulty of other alternatives such as wood or good quality stone and associated workmanship. For this reason seismic macrozoning is not a factor in siting considerations of adobe structures.

On a local scale, however, siting considerations result from secondary effects of seismic hazards and not vibratory ground motion. These may be listed as follows:

- Surface Faulting
- Landslide
- Rockfall
- Liquefaction
- Fire

Localities of these hazards can be predicted quite accurately before occurrence of an earthquake and these should be considered as criteria for microzoning. In this sense, siting problems associated with adobe structures are no different from those of others.

The issue of surface faulting is the most controversial amongst the secondary effects of seismic hazards listed above. One of the reasons for this results from observations of cases in which new surface faulting occurred from earthquakes. One recent example of this was observed during the Çaldıran 1976 earthquake (MS = 7.2) in eastern Turkey (Gülkan et al., 1978) where surface faulting which had not been mapped prior to the earthquake caused the destruction of many adobe structures (Figure 7). However, another controversial point regarding this issue is the distance to surface rupture inside which destruction is imminent. Again during the Çaldıran 1976 earthquake several adobe houses remained intact although they were only about ten meters away from surface rupture (Figure 8).

Soil failures may cause extensive damage to all types of structures and recently this was observed to be the case in the Irpinia 1980 earthquake (Gürpınar et al., 1981). Especially in the towns of Calitri and Senerchia, landslides caused widespread damage (Figure 9) resulting in numerous casualties.

Fire is also an important secondary hazard associated with earthquakes. There are numerous documented cases where the fire caused by a toppled stove or a ruptured power line resulted in destruction of villages or sometimes parts of cities such as happened in the 1906 San Francisco earthquake. In 1970, fire also destroyed a part of the town of Gediz after a large earthquake (MS = 7.1). The old town of Gediz possessed a peculiar topography and for this reason most of the streets were narrow making rescue access very difficult. Coupled with the fact that most of the buildings were wood frame structures, the fire in Gediz became an uncontrollable menace.

After the earthquake and the ensuing fire, Gediz was relocated and the new town developed about 8 kilometers south of the old town and on the plains. The old town, however, was not evacuated and by 1976 its population had grown back to the pre-earthquake number of 6,000. A study was performed to decide whether or not the old town of Gediz was suitable for habitation as far as seismic hazard was concerned (Gürpınar, 1978). This study concluded that the expected level of vibratory ground motion at the old and new sites are the same (and in fact there are large cities in Turkey with higher seismic risk) and therefore this cannot be used as a siting criterion. The old town was microzoned such that the unstable slopes were left as green areas and restrictions on spacing between buildings and street dimensions were specified for fire protection.

Admittedly, fire may not be as big a menace to adobe structures as those of wood frame type but still the basic principle remains that it is a criterion for microzoning.

In summary, siting for adobe structures reduces to the problem of urban and/or rural planning for general hazards, especially soil failures.

4. Adobe Building Construction

The construction of a conventional Turkish adobe (kerpic) house involves the following production steps. The quantitative details of these steps and the relevant standards have been covered by Yorulmaz (1981).

4.1 Preparation of Adobe Brick and Mortar

4.1.1 Raw Adobe Material

Adobe blocks are made of clayey earth. This earth can either be obtained from the foundation excavation material or from suitable pits (kerpiclik) in the vicinity of the village. Based on years of experience, these pits are believed to provide competent material for adobe block production (Figure 10).

4.1.2 Preparation of the Mortar

The raw adobe material is placed in a pit of average dimensions 2x2x2x1 meter and mixed with appropriate amounts of water and straw. The amount of these additives is again based on the experience and vary from place to place. After mixing thoroughly the mortar is covered with a layer of earth and allowed to rest for one day (Figure 10).

4.1.3 Molding

After checking for proper consistency the mixture is hand-placed and pressed in wooden molds. The common dimension of the blocks are (25-30)x(30-40)x(11x12) centimeters for the "mother" (ana) and (15-20)x(30-40)x(11x12) centimeters for the "cub" (kuzu) units (Figure 11).

4.1.4 Drying

The molded units are placed on the ground in one layer and allowed to dry in open air with frequent turning to expose all sides. The drying period may vary between 5 to 15 days depending on the locality and material (Figure 11).

4.2 Building Construction

Most traditional adobe houses are single story structures with a mud-mortar stone masonry foundation and a heavy earth roof supported by unsawed logs.

Adobe wall foundations consist of 1.0 to 1.5 meters deep and 0.5 to 1.5 meters thick stone masonry walls usually built with the same mud mortar used for adobe blocks (Figure 12).

Adobe walls are built using the same clayey earth mixture as mortar in coursed ashlar bond with 2.5 to 3.0 centimeters thick joints. Wall thicknesses are: (1) 40 centimeters, using single "mother" units, (2) 60 to 70 centimeters, using "mother" and "cub" units, and (3) 80 to 100 centimeters, building the inside and outside faces separately and filling inside with rubble. Wall heights rarely exceed 3.0 meters (Figure 13).

Especially in seismic regions the use of wooden tie-beams is common. Tie-beams are usually placed under and above the windows and under the roof. In areas of very low seismicity, such as southeastern Turkey, there are many adobe structures having no tie-beams (Figure 13).

In 60 percent of the total adobe building stock heavy flat earth roofs are utilized. The roof is usually supported by unsawed timber beams, or peeled tree trunks of about 10 to 20 centimeters in diameter, spaced at intervals varying from 30 to 40 centimeters. These beams rest on the tie beam at the top of the walls. The bearing length of the beams on the wall may sometimes be limited to 10 to 15 centimeters. On top of these beams a layer of wooden board of about 1.5 to 2.0 centimeters thick or a layer of thin branches or straw mat are placed. A 15 to 20 centimeters thick coat of clayey earth topped by a 3 to 5 centimeters thick impermeable fine clay layer constitutes the main roof insulation.

After the removal of the first snow a new layer of finer material is added to the roof and the whole roof is passed over by a cylindrical heavy stone (log) thereby thickening the earth roof layer over the years to the unsafe limits, weighing up to 1.0 ton per square meter (Figure 14). The earthen terrace of the roof may have a surrounding stone cornice. In areas where timber is easily available and/or with post-earthquake experience the use of tiled or galvanized sheet metal covered timber roofs have become quite common. Plastering is usually applied to both faces of the wall 8 to 12 months after construction. A finer clayey earth mortar with more straw content is used. The final thin skin may either be clay or white wash (Figure 15).

Compared to the existing Turkish design specifications of adobe structures (Yorulmaz, 1981) the most common errors and deviations encountered in practice are as follows:

- Limited capacity and insufficient bearing area of roof beams on the walls.
- Increased thickness of the earth layer on the roof.
- Improperly tied walls at the corners.
- Non-existence or insufficiency of the horizontal tie-beams.
- Too many openings in the walls.
- Poor masonry practices.
- Poor water insulation.
- Poor quality adobe blocks.

In the near future, adobe construction will tend to continue as a craft rather than develop into an engineering practice that can accommodate rational design procedures. The relevant earthquake resistant design codes should attempt to synthesize the time proven practical construction procedures and sound engineering judgement into an applicable adobe construction guideline instead of prescribing the assessment and distribution of lateral seismic forces on adobe structures. Satisfactory performance of adobe structures have usually been witnessed when they were designed and constructed properly (Figure 16).

5. Earthquake Performance of the Adobe Buildings

Adobe, being an inherently rigid and brittle material, does not exhibit a wide spectrum of modes and degrees of failure. The official damage classification guidelines of the Ministry of Reconstruction and Resettlement identify three classes of damage for adobe structures:

- Light damage: thin plaster cracks, falling of plaster bits.
- Medium damage: widespread cracking of walls with reduced load carrying capacity.
- Heavy damage and collapse: gaps in walls, failure of tie beams, collapse of roof and/or walls.

Damage statistics of rural structures pertaining to earthquakes since 1966 are indicated in Table 2. The data is obtained from the official damage assessment reports of the Ministry of Reconstruction and Resettlement. Only intensity areas of VII MSK and larger have been considered.

TABLE 2

Earthquake Damage Statistics of Rural Structures

August 19, 1966 Varto Earthquake (MS = 6.9, I_o = IX MSK)

T.S.	T.P.	C.P.	M.D.P.	L.D.P.
Stone Masonry	85	75	20	5
Adobe Masonry	10	50	40	10
Other	5	70	25	5

July 22, 1967 Adapazarı Earthquake (MS = 7.2, I_o = IX MSK)

T.S.	T.P.	C.P.	M.D.P.	L.D.P.
Wooden Frame	85	55	30	15
Adobe Masonry	5	65	20	15
Other	10	20	25	55

March 28, 1970 Gediz Earthquake (MS = 7.3, I_o = IX MSK)

T.S.	T.P.	C.P.	M.D.P.	L.D.P.
Wooden Frame (Himis)	40	80	18	2
Wooden Frame (Bagdadi)	50	10	40	50
Adobe Masonry	5	30	50	20
Other	5	40	35	25

May 12, 1971 Burdur Earthquake (MS = 6.2, I_o = VIII MSK)

T.S.	T.P.	C.P.	M.D.P.	L.P.D.
Stone Masonry	40	55	30	15
Adobe Masonry	50	35	35	30
Other	5	40	40	20

TABLE 2
(Continued)

Earthquake Damage Statistics of Rural Structures

May 22, 1971 Bingöl Earthquake (MS = 6.9, I_o = VIII MSK)

T.S.	T.P.	C.P.	M.D.P.	L.D.P.
Stone Masonry	80	75	20	5
Adobe Masonry	15	40	50	10
Other	5	40	45	15

September 6, 1975 Lice Earthquake (MS = 6.9, I_o = VIII MSK)

T.S.	T.P.	C.P.	M.D.P.	L.D.P.
Stone Masonry	85	65	30	5
Adobe Masonry	10	50	40	10
Other	5	-	60	40

November 24, 1976 Çaldıran Earthquake (MS = 7.2, I_o = IX MSK)

T.S.	T.P.	C.P.	M.D.P.	L.D.P.
Stone Masonry	75	75	15	10
Adobe Masonry	20	60	30	10
Other	5	25	25	50

Legend:
T.S.: Type of Structure
T.P.: Percentage of the Type in Meizoseismal Area
C.P.: Percentage of Heavily Damaged or Collapsed Structures
M.D.P.: Percentage of Medium Damaged Structures
L.D.P.: Percentage of Lightly Damage Structures

These tables indicate that for site intensities of VIII MSK or greater about 45 percent of the adobe structues collapse or experience heavy damage, 37 percent experience medium damage and 18 percent experience light or no damage. The respective figures for stone masonry structures are 70, 22 and 8 percent. Although the number of adobe structures involved in these earthquakes are quite limited and some of them have timber roofs one can say, in general, that the earthquake performance of the adobe structures exceed that of the stone masonry structures (ERI, 1978; Arıoğlu et al., 1977). It should be noted that a considerable percentage of stone masonry rural structures include rubble stones with mud mortar.

The casualty statistics also endorse this finding. Unpublished studies of the Earthquake Research Institute of the Ministry of Reconstruction and Resettlement indicate that, on the average, 11 lives are lost per 100 collapsed and/or heavily damaged adobe structures with flat earth roofs. The respective figure for stone masonry with mud mortar and flat earth roof is 26.

The official damage statistics have also been compiled by the Earthquake Research Institute to indicate the damage of different rural structure classes in the meizoseismal area for different earthquake magnitudes. Two classes of rural structures are considered. The "Type A" rural structures encompass the adobe and mud-mortar stone masonry structures with heavy earth roofs and no tie-beams, whereas the "Type B" rural structures include stone masonry structures with lime or cement mortar and adobe structures both of them with thin earth or tiled timber roofs. Results are provided in Table 3.

The data indicated pertain to the structural damage statistics within approximately a 20-kilometer radius of the epicenter.

TABLE 3

Damage Statistics in the Epicentral Area of Earthquakes

MS	STRUCTURAL CLASSIFICATION	PERCENTAGE OF COLLAPSED STRUCTURES	PERCENTAGE OF STRUCTURES BEYOND REPAIR	PERCENTAGE OF STRUCTURES MEDIUM OR LIGHT DAMAGE
>	A	80	20	-
6.9	B	50	30	20
6.8	A	50	30	20
6.3	B	20	30	50
6.2	A	20	30	40
5.7	B	5	15	80
5.6	A	10	20	70
4.9	B	-	10	90
<	A	5	10	85
4.8	B	-	5	95

As may be seen from Table 3, the earthquake performance of adobe structures are mainly controlled by the weight of the roof and the presence of well constructed tie-beams.

Apart from the poor adobe masonry qualities, in general, the factors affecting the earthquake performance of adobe structures can be listed as follows:

- Limited bearing area of the roof beams subjected to heavy roof loads creating bearing and shear failure of adobe walls underneath (Figure 17).

- Insufficient connection of roof beams to the adobe walls. The roof cannot act as a rigid diaphragm and allows differential movement among walls leading to the collapse of the roof and/or walls. Out of plane walls behave like cantilever beams (Figure 17).

- Excessive wall openings leaving insufficient wall areas to resist lateral shear, leading to shear (diagonal tension) failures (Figure 18).

- Lack or improper construction of tie-beams and/or poor masonry practice of the corner connections of the walls causing separation of walls at the corners (Figures 19).

- Lack of structural symmetry either in plan or in the amount of openings.

- Deficient bedding of lintels above windows.

- Openings too close to the corners.

- Walls too high or too long between supports.

6. Inspection and Assessment of Existing Rural Structures

An ambitious project taken up by the Ministry of Rural Affairs and Cooperatives and the Ministry of Reconstruction and Resettlement with the guidance of the Turkish National Committee for Earthquake Engineering calls for a detailed assessment of the structural status of rural buildings within the primary seismic hazard regions of Turkey for the purposes of strengthening and/or rebuilding to increase their seismic performance.

A four-page questionnaire form was prepared and distributed to the local offices of the Ministry of Rural Affairs and Cooperatives. The personnel of these offices, already trained on the proper utilization of these forms, were instructed to visit the previously identified rural centers to fill out these forms. These forms supported with pictures of the typical rural structures will establish the basis of decision making on strengthening or demolishing and rebuilding. The type of strengthening is to be decided after the site visits of qualified engineers.

A sample questionnaire is presented in Appendix A.

7. Testing

Experimentation is probably the most powerful research tool for the study of the seismic behavior of adobe structures. This is due to the difficulty of developing analytical models for masonry structures in general.

Experimental research for masonry structures has recently developed in California, particularly at the Earthquake Engineering Research Center shaking table of the University of California, Berkeley (Gülkan et al., 1979). These tests were conducted to assess the reinforcement requirements for single story masonry houses through experiments on shaking table with simulated earthquakes. Although the buildings are quite different in many respects (concrete block or clay brick masonry units, timber roof structure, 16-foot square four-walled test houses), the following response characteristics of the unreinforced wall units are quite indicative:

(1) No cracking was observed in any unreinforced wall for tests with peak accelerations less than 0.2 g..
(2) Unreinforced out-of-plane walls continued to perform satisfactorily after cracking (but with excessive displacements) during tests with accelerations greater than 0.4 g.
(3) Two types of cracking were observed in the unreinforced in-plane walls: horizontal cracks in panels without openings and a diagonal crack extending downward from the window corner in the wall units with openings.

It should be noted that the important first finding is also supported by the results of the shaking table tests of model adobe structures (Meli et al., 1980) which reads: "Model 1, unreinforced, supported, without major damage, 50 percent of the actual intensity of the El-Centro record".

Experiments directed towards system identification methods have also contributed to research of dynamic behavior masonry structures. Mengi et al. (1981) have performed testing of brick masonry walls on the shaking table for purposes of identifying dynamic parameters related to the system. Some discussion on the preliminary results of this effort will be presented in Section 9.

Field testing can also be utilized as a tool for system identification. Field tests involving impact response measurements, ambient vibration measurements and forced harmonic vibration studies have been performed in Turkey on many rural adobe structures (Erdik and Tabban, 1978; Ohta, 1980). These experiments involve only very small strain levels and can give information only for the elastic behavior. Time history recordings and the accompanying power spectral densities are provided in Figure 20 pertaining to conventional rural adobe structures. In general, the frequency of free vibration of these structures vary between 5 to 10 Hertz, depending on the plan dimensions and the number of walls, with relative viscous damping values of 3 to 5 percent. It is thus clear that the seismic forces acting on these structures will be perfectly correlated and be, in fact, proportional to the maximum ground acceleration.

8. Repair and Strengthening

In order to identify the problems related to repair and strengthening of adobe structures, their dynamic behavior and damage patterns during earthquakes should be carefully assessed. Furthermore, decision has to be made for the allowable degree of damage for a given expected intensity of shaking. In Turkey, almost all adobe structures are used as dwellings in rural areas. Therefore their economic value can reasonably be represented by their construction cost. In other words, there are no secondary effects of adobe structure failures such as associated with dams, factories, power plants, etc. For this reason the prime function of the adobe structure is to protect the life of the inhabitant. The object of repair and/or strengthening of adobe structures is then to prevent the collapse of the heavy roof which is the most frequent cause of entrapment and loss of life. This may, in fact, be the first phase of strengthening and future improvements could include incorporation of other structural elements in design to increase the energy absorption capacity of adobe buildings. This would again involve public education programs to inform the builders about better utilization of other construction materials such as wood.

In the most simplified sense, adobe structures may be classified as box type structures where the primary lateral resistance against earthquakes is provided through the membrane action of the walls and the roof. Thus: (1) the out-of-plane walls should be able to resist their own inertia forces through flexural action as vertical beams, (2) the in-plane walls should be able to resist the lateral inertia forces developed at the entire roof and that from the top half of the out-of-plane walls through shear action as deep cantilever beams and (3) the roof structure must have sufficient strength and integrity to transmit the lateral inertia forces appropriately.

Although these conditions can be easily implemented during the construction phase the same does not hold true for strengthening of an already built one. The total cost of strengthening may even exceed that of a newly constructed house, thus making it economically infeasible except for the restoration work of historic monuments.

A rational approach for strengthening under adverse economic conditions should address to:

- decreasing of the roof inertia load by decreasing its mass.
- Increasing the integrity of the roof-wall connections through realization of a well constructed tie-beam (Figure 21).
- Avoiding the brittle and immediate collapse of the roof and thus entrapment through utilization of external columns to support the roof (Figure 22).

In summary, for the Turkish case, all activities should be directed to the betterment of the roof structure and avoidance of its premature and brittle collapse during earthquakes for all rural structures within the primary seismic hazard regions. Once the lives are saved, the rest is the resettlement and reconstruction activities for which specifically earmarked funds are officially available. The Turkish efforst on this issue are now in the assessment phase as outlined in Section 6.

For the new rural constructions a simple handbook is being prepared. The wall posters (Figures 23 and 24) are also of help for the site selection and construction of various rural structure types.

9. Future Research Needs

The imporance of field and laboratory testing, as well as post-earthquake field observations have been emphasized as research tools for the assessment of seismic performance of adobe structures. In this section the direction of analytical studies will be briefly discussed.

Although there is considerable research in the area of mathematical modeling of the earthquake response of steel and reinforced concrete frames it is also true that not enough research is directed towards developing dynamic models for masonry wall like structures. However, it should be realized that developing such a model is very important because it can provide valuable guidance in the design of earthquake resistant masonry dwellings.

A research project aimed at establishing a dynamic mathematical model for masonry wall like structures, has recently started with the cooperation between the University of California (UC), Berkeley, U.S.A. and the Middle East Technical University (METU), Ankara, Turkey. Experiments on masonry walls were performed using the shaking table of the Earthquake Engineering Research Center, UC, Berkeley. As a linear mathematical model, a model based on the theory of mixtures was chosen. This model differentiates the two phases of masonry, namely, brick and mortar phases, and takes into account the interaction between them. The model parameters are found by an optimization technique in such a way that an adequate match between model and experimental responses are obtained. It is found that the proposed two-phase model is capable of predicting the earthquake response of masonry walls accurately in the linear range. It is further found that the two-phase model is the only model which provides a good fit, for experimental response function over a frequency interval on which the major portion of this function is located.

Modifying the model to include debonding (between the mortar and brick phases) and non-linear effects are under investigation. The results of these investigations, both in linear and non-linear ranges, will be reported in detail shortly.

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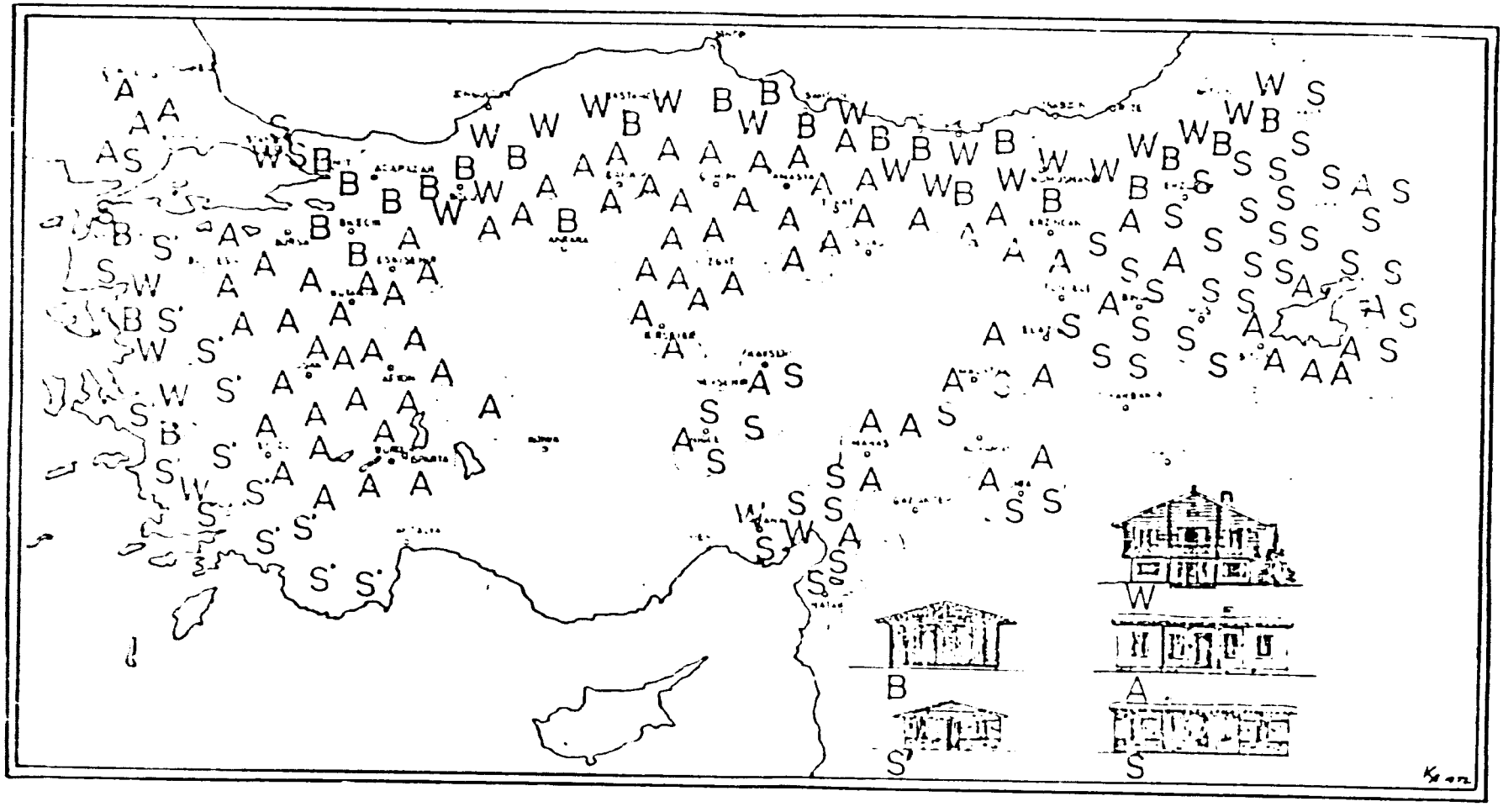
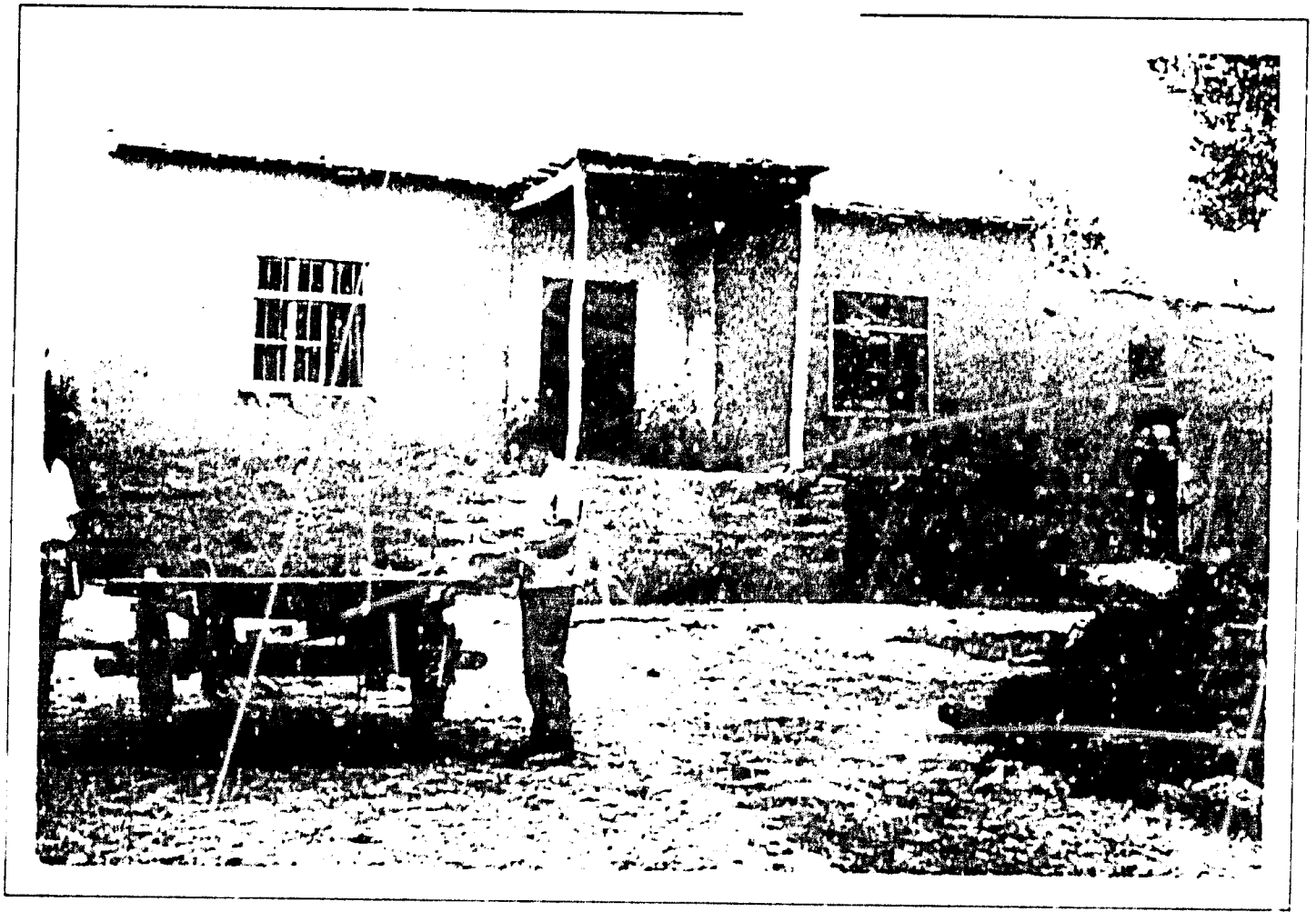


FIGURE 1



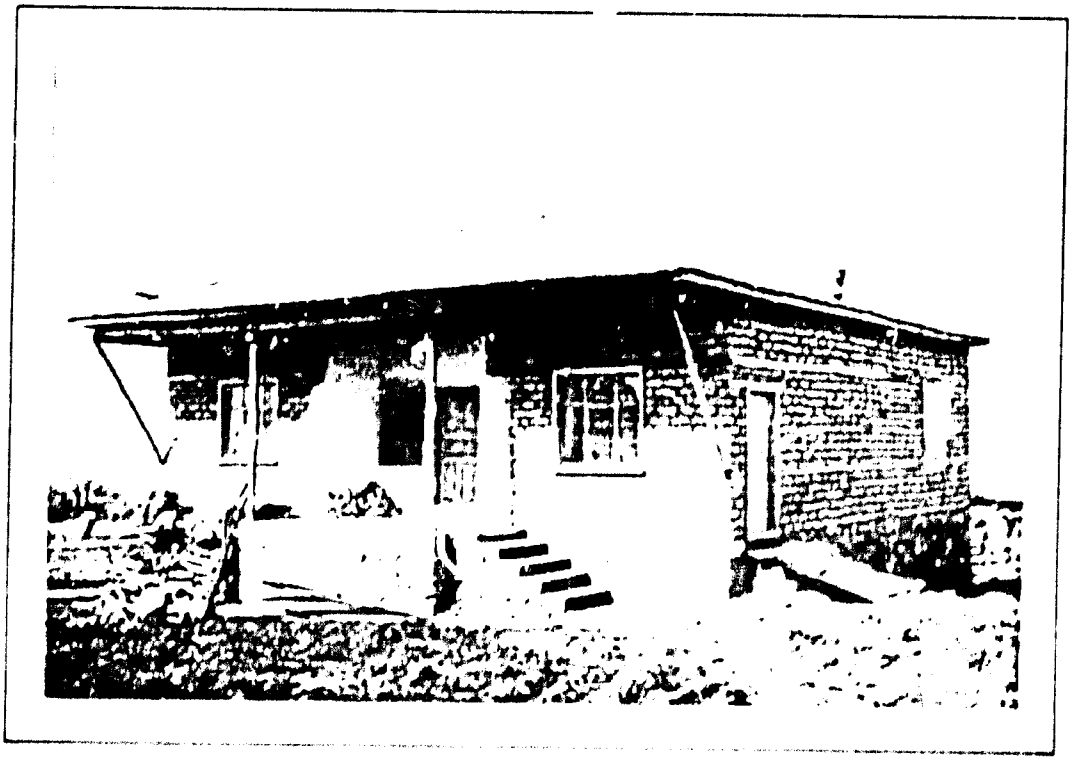
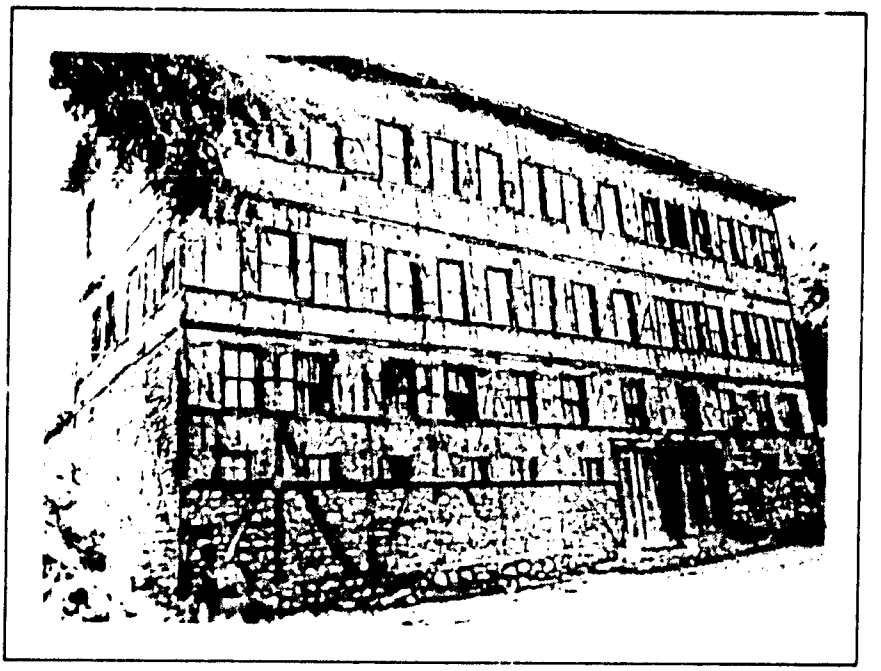


FIGURE 2



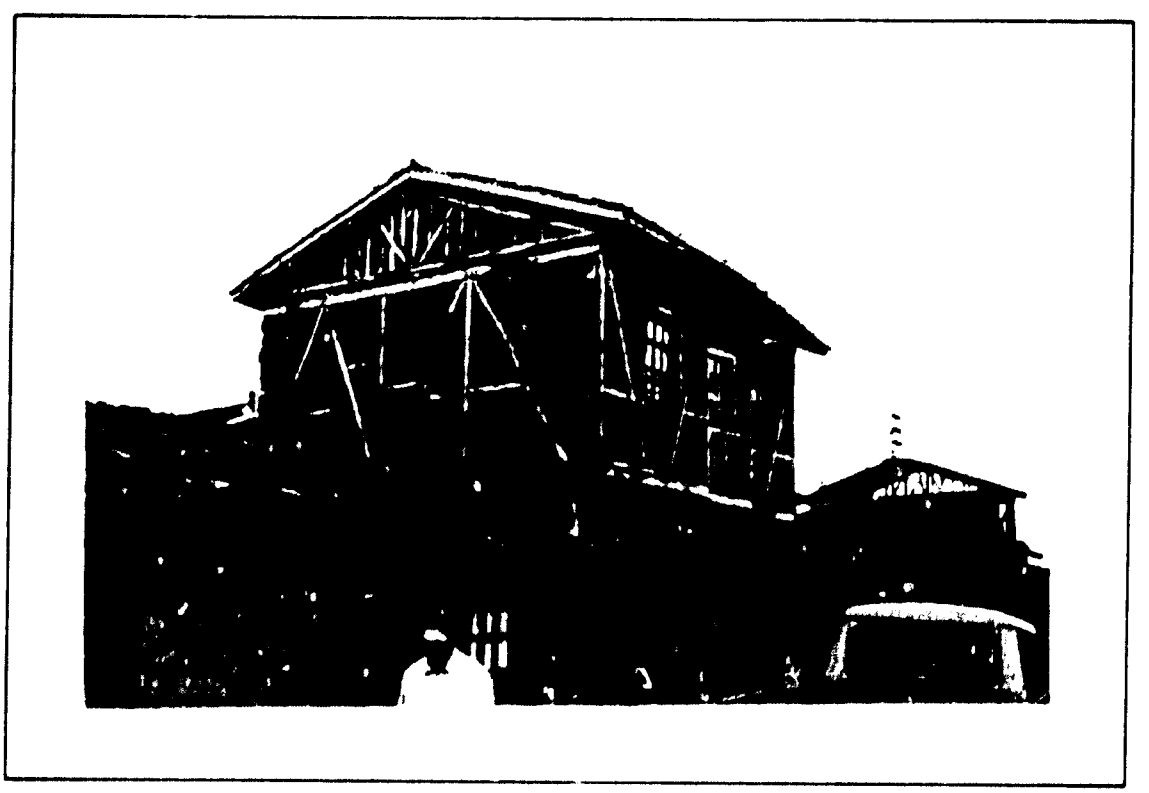


FIGURE 3

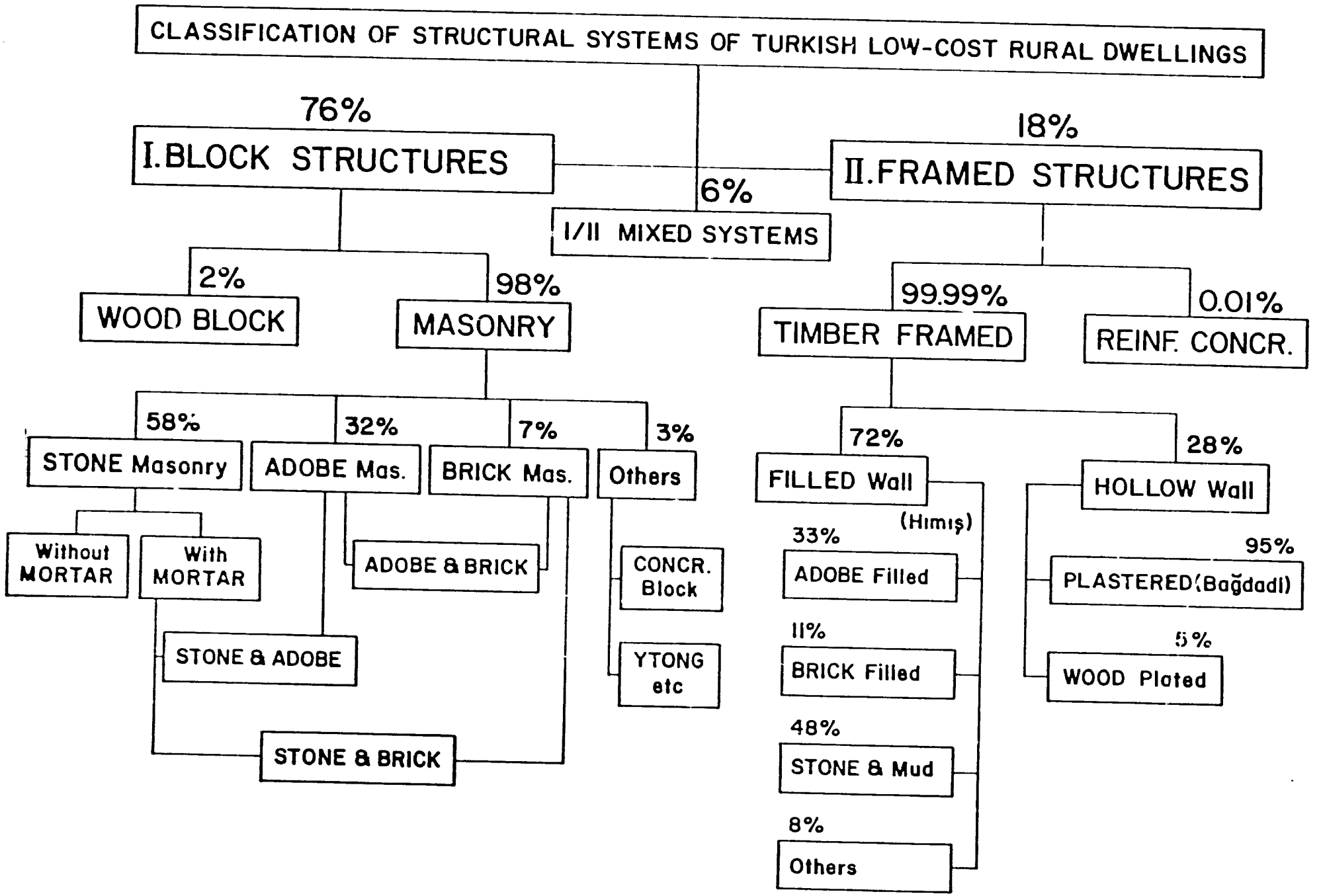

CLASSIFICATION OF STRUCTURAL SYSTEMS OF TURKISH LOW-COST RURAL DWELLINGS
76%
I.BLOCK STRUCTURES
6%
I/II MIXED SYSTEMS
18%
II.FRAMED STRUCTURES
2%
WOOD BLOCK
98%
MASONRY
99.99%
TIMBER FRAMED
0.01%
REINF. CONCR.
58%
STONE Masonry
32%
ADOBE Mas.
7%
BRICK Mas.
3%
Others
72%
FILLED Wall
28%
HOLLOW Wall
Without MORTAR
With MORTAR
ADOBE & BRICK
CONCR. Block
YTONG etc
(Himiş)
33%
ADOBE Filled
11%
BRICK Filled
48%
STONE & Mud
8%
Others
95%
PLASTERED(Bağdadl)
5%
WOOD Plated
STONE & ADOBE
STONE & BRICK

FIGURE 4

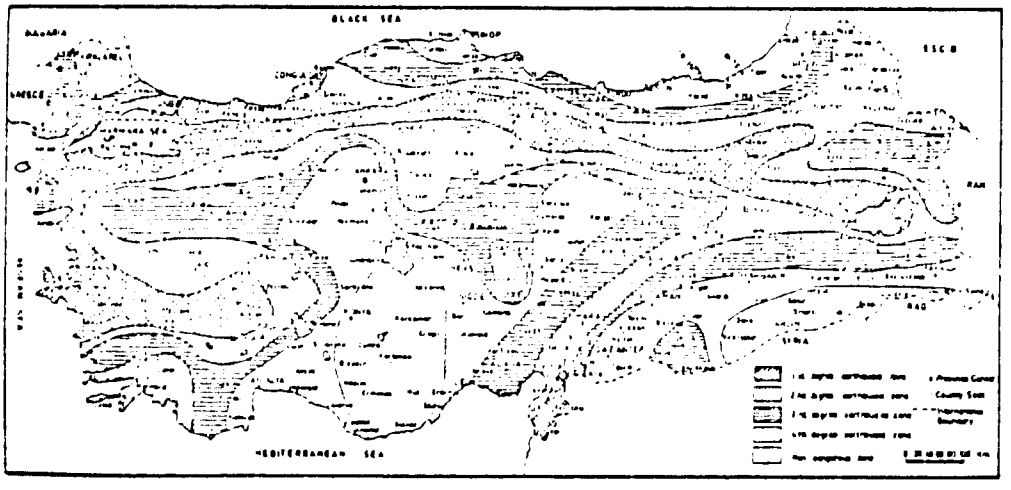


FIGURE 5

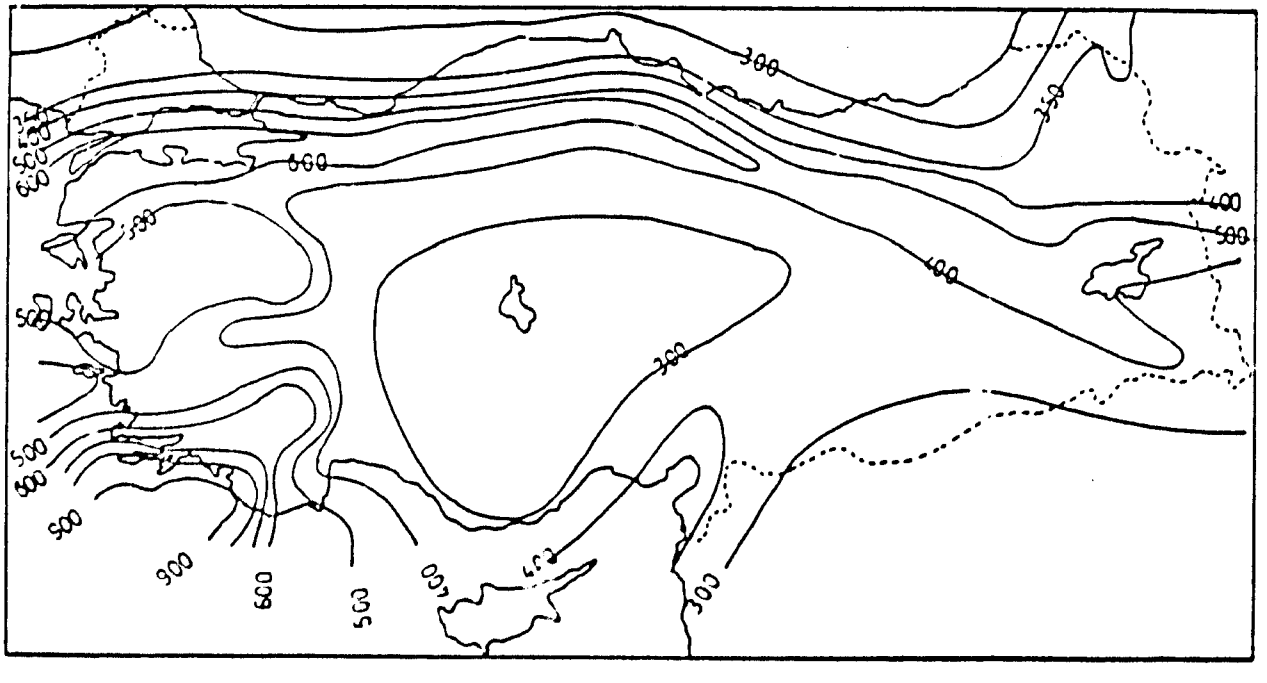


FIGURE 6

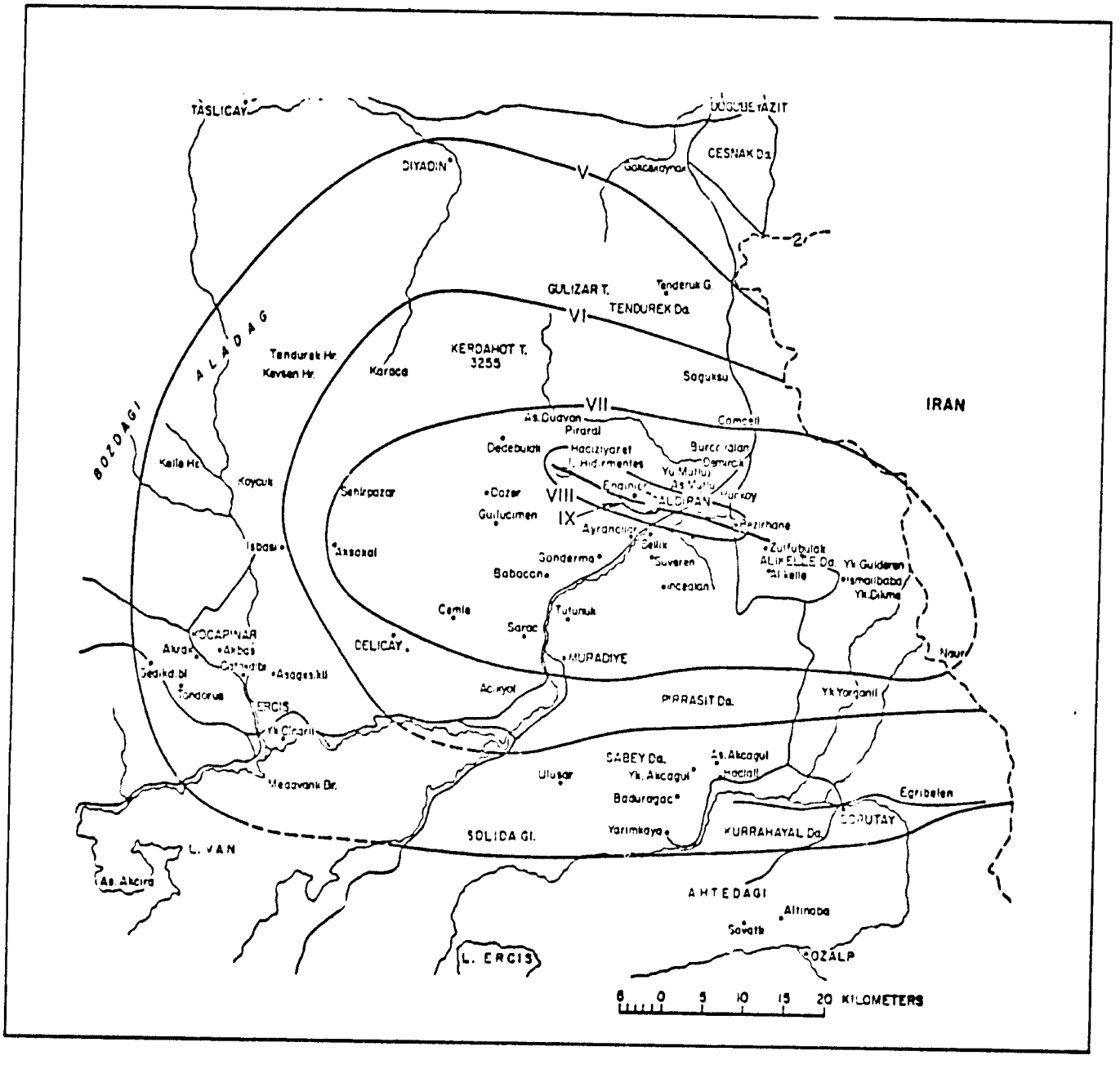

TASLICAY
DOGUBEYAZIT
CESNAK Da.
DIYADIN
V
GULIZAR T.
TENDUREK Da.
VI
KERDAHOT T.
3255
ALADAG
BOZDAGI
Karaca
Saguksu
IRAN
VII
Pirarat
Dedebulak
Hacıziyaret
Kaile Hr.
Koyculk
Sehirpazar
Dozer
Guluçimen
VIII
IX
Ayrancılar
Bezirhane
Isbasi
Aksakal
Sondermo
Babocan
Cemle
Tutunuk
Sarac
KOCAPINAR
Akrak
Akbas
DELICAY
MURADIYE
Naur
Acıkyol
PIRRASIT Da.
ERCIS
SABEY Da.
Ulusar
Baduragac
Egribelen
SOLIDAGI
Yarımkaya
KURRAHAYAL Da.
L. VAN
AHTEDAGI
Altınaba
Savatlı
L. ERCIS
SOZALP
0 5 10 15 20 KILOMETERS

FIGURE 7

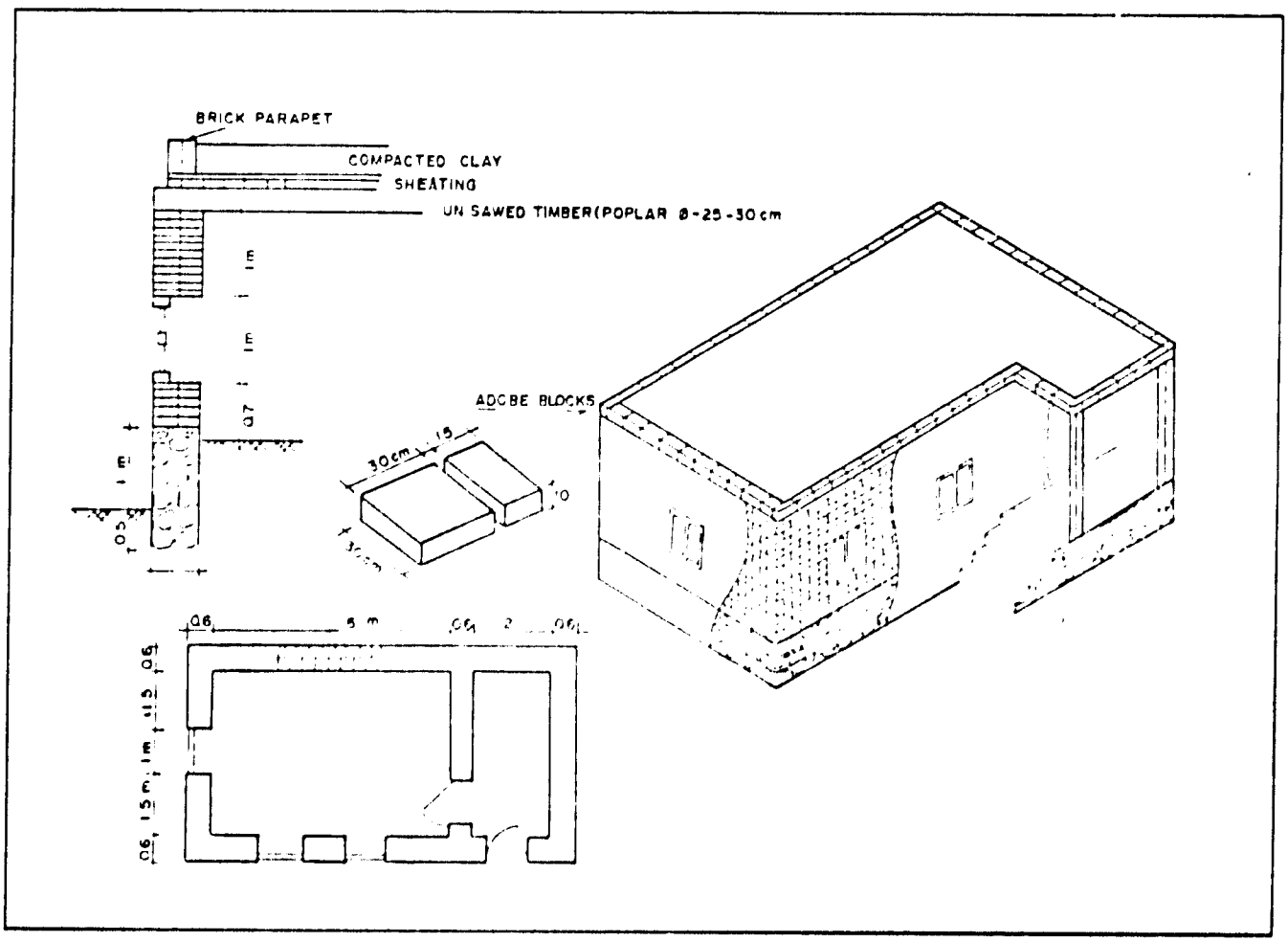

BRICK PARAPET
COMPACTED CLAY
SHEATING
UN SAWED TIMBER(POPLAR Ø-25-30cm
ADOBE BLOCKS
30cm
15
10
0.6
5 m
0.6
2
0.6
0.6
1.5 m
1 m
1.5
0.6

FIGURE 8

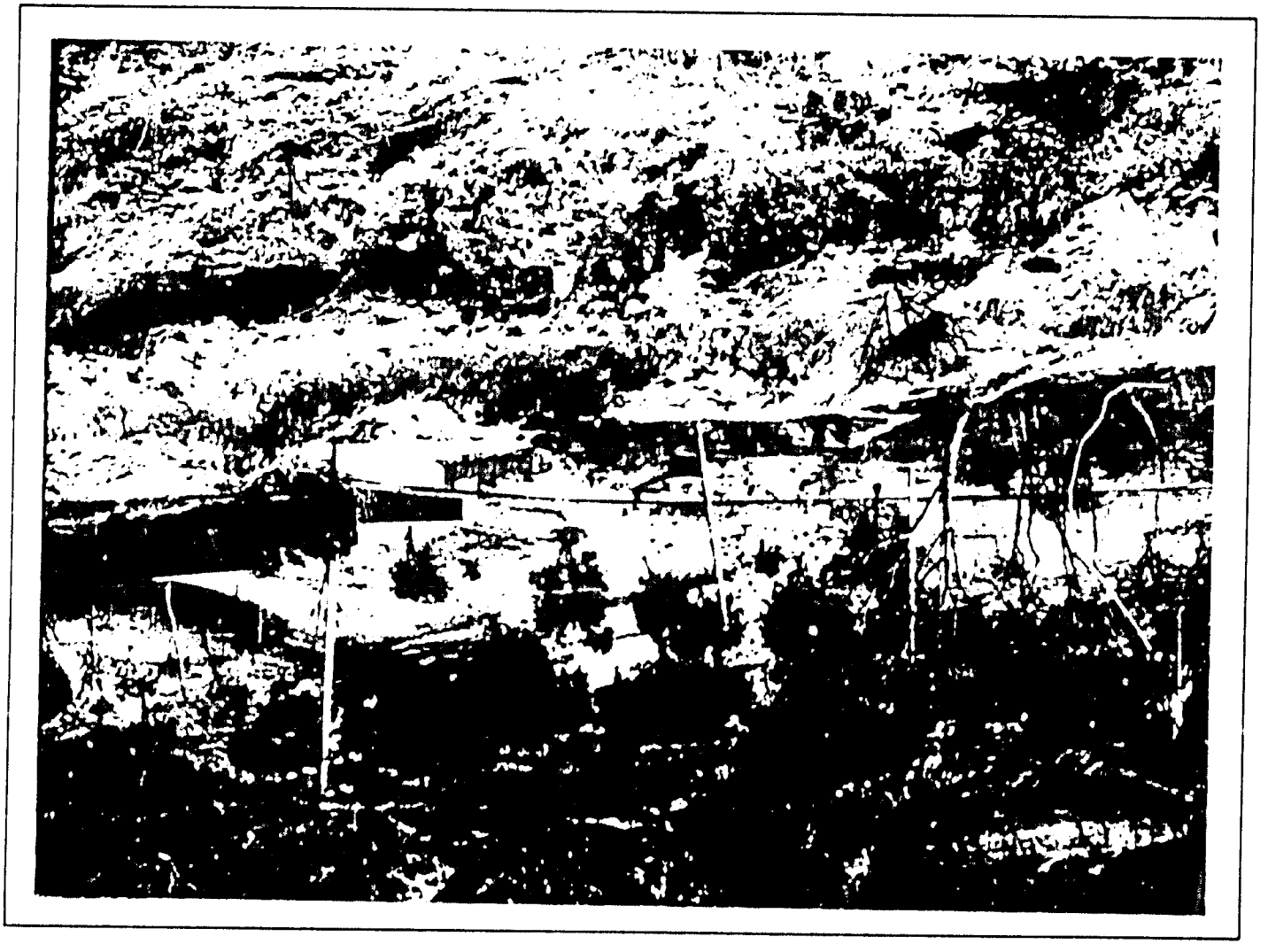
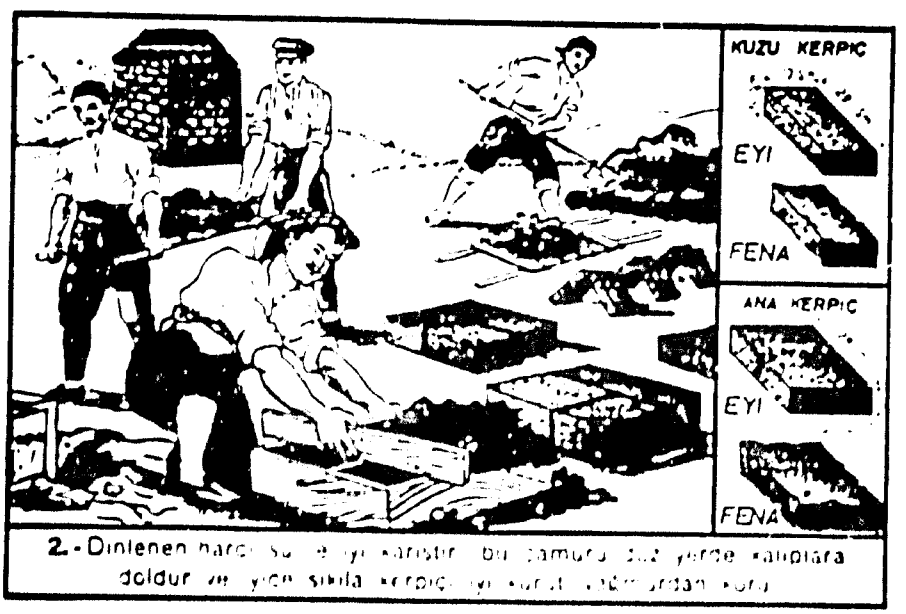


FIGURE 9

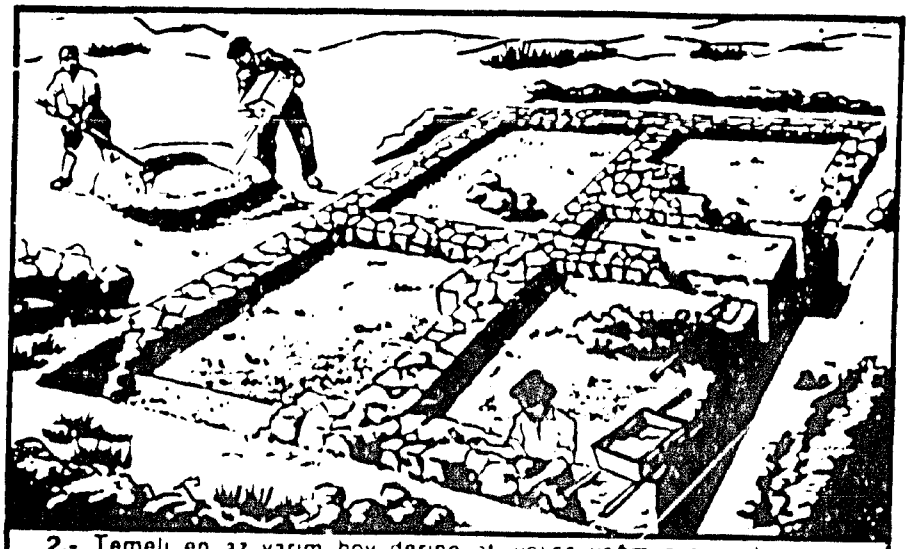
1. - Kerpiç için orta yağlı killi toprak hazırla. (Bir dıcu kum ve 5 dıcu kil karıştırsa orta yağlı olur.) 100 kalıp kerpiçlik toprağa 60 kilo da saman kat, su ile yoğur, bir tarafa yığ, asamian suıandır, iki gün beklet.

FIGURE 10

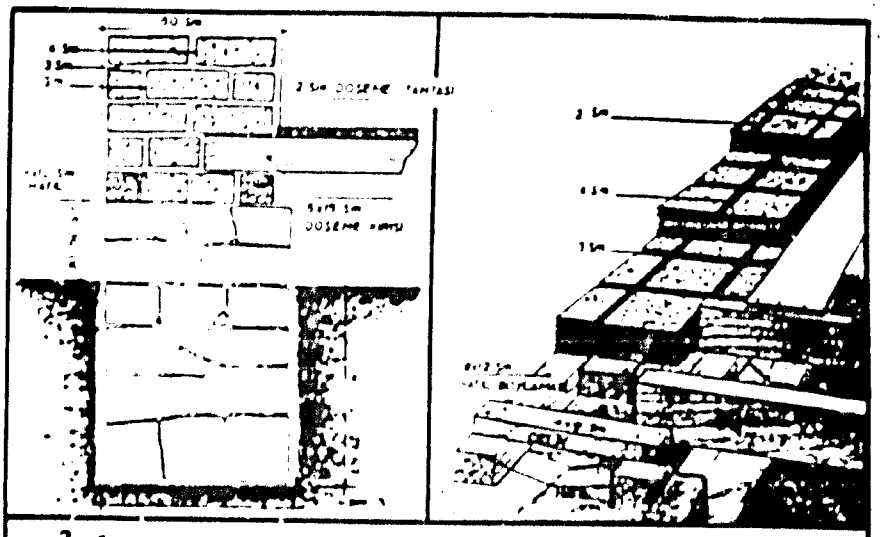


2. - Dinlenen harç su ile iyi karıştır, bir tamburu tuz yerde kalıplara doldur ve yeni sıkıla kerpiçleri iyi kurut, güneşten koru.

FIGURE 11

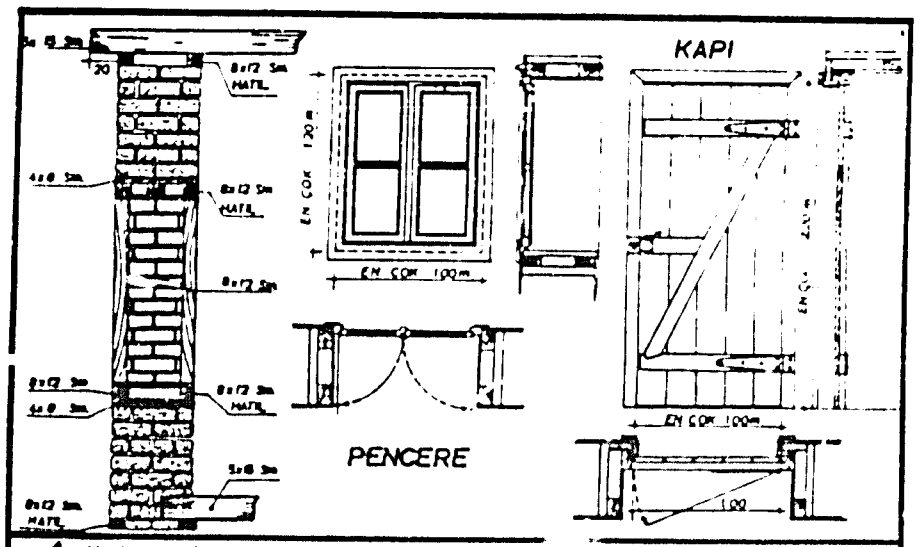


2.- Temeli en az yarım boy derine at yoksa yağmur suyu kar suyu tabana iner, toprağı gevşetir bu yüzden yapıda dayanıklı olmaz.

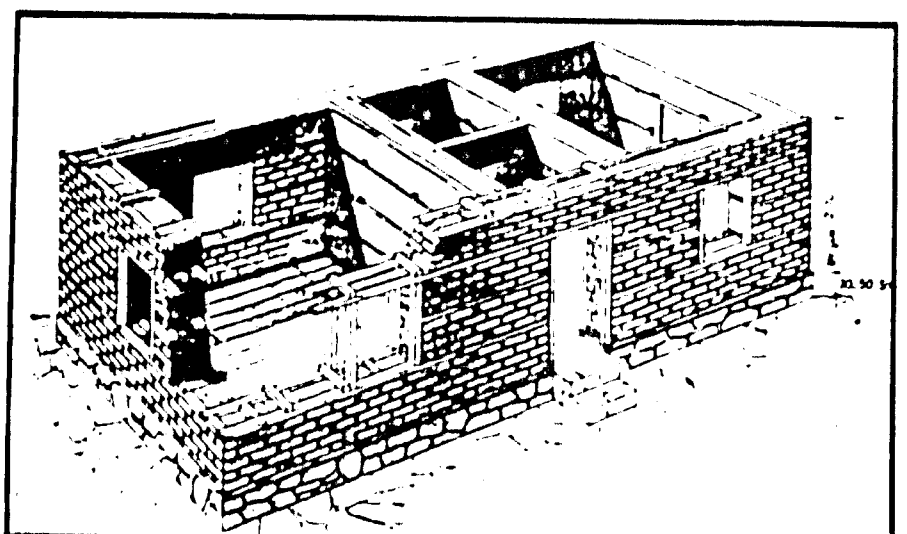


3.- [illegible]

FIGURE 12

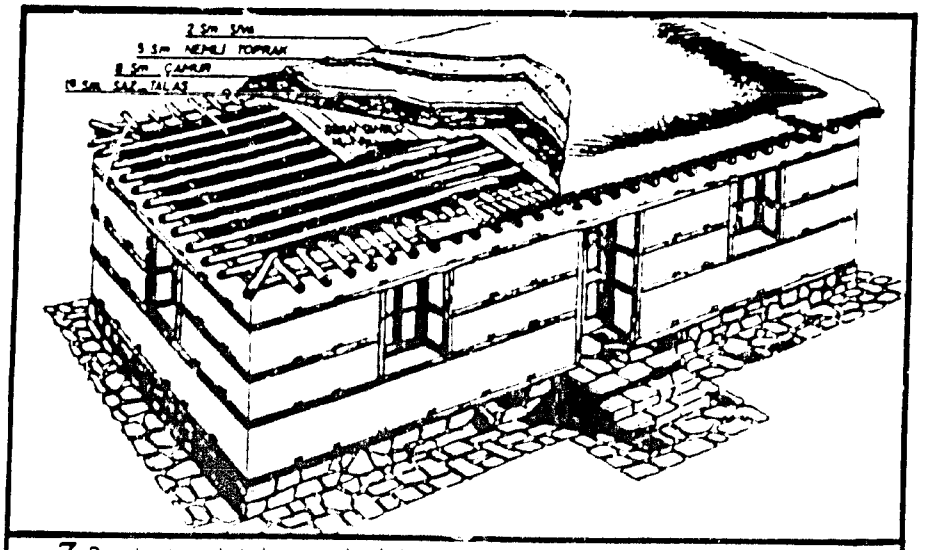


4.- Hatılsız duvarlar yersarsıntısına dayanamaz. Kerpiç duvarı resimde gördüğün gibi, duvar altından, pencereler altından ve üstünden çatı altından geçen hatıl ağaçlarıyla ve dikmelerle, kuvvetlendirmeyi sakın unutma. Kapı, Pencereyi resimdeki ölçülere göre yap

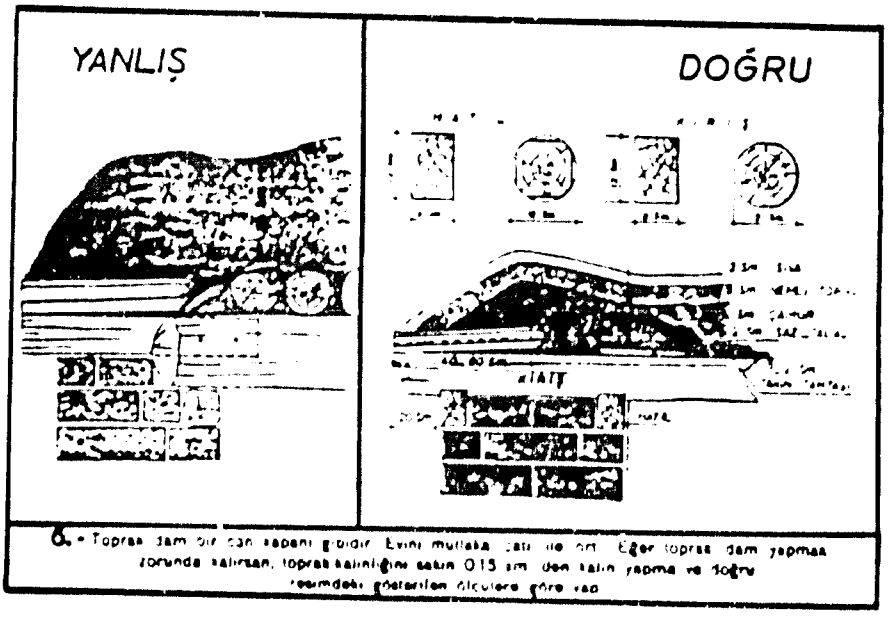


5.- Bu evdeki duvar işçiliğine hatılların sırasına bağlantısına, ölçülere dikkat et yapını buna göre yap

FIGURE 13



7- Dam kirişlerini birbirlerine ve hatıllarla iyi bağla, bu kirişlerin başlarını da diverlardan en az 0.20 sm aşır yoksa hafif bir sallantı damı çökertir.



6.- Toprak dam bir can sapanı gibidir. Evini muttaka çatı ile ört. Eğer toprak dam yapmak zorunda kalırsan, toprak kalınlığını asla 0.15 sm den kalın yapma ve doğru resimdeki gösterilen ölçülere göre yap.

FIGURE 14

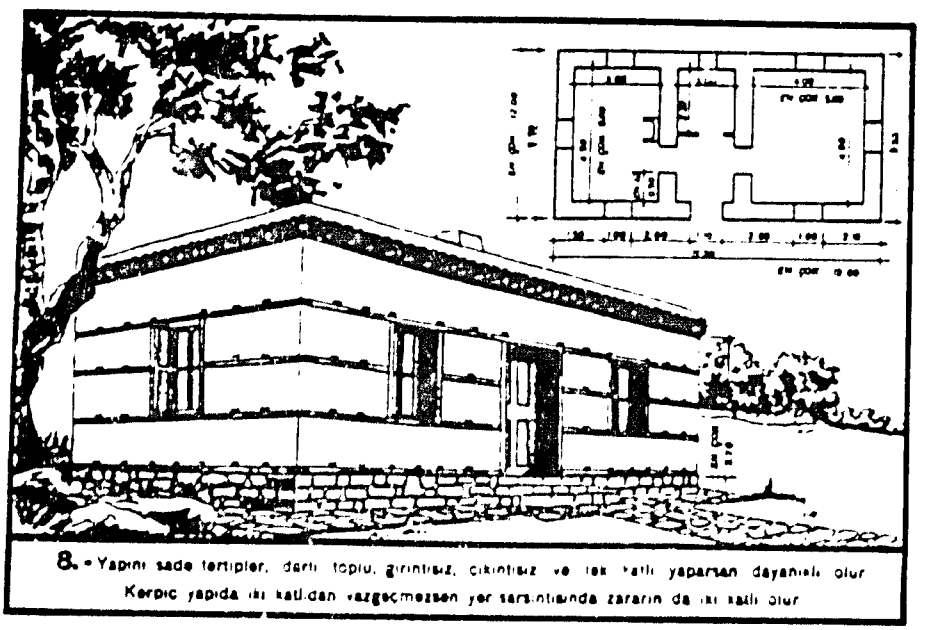
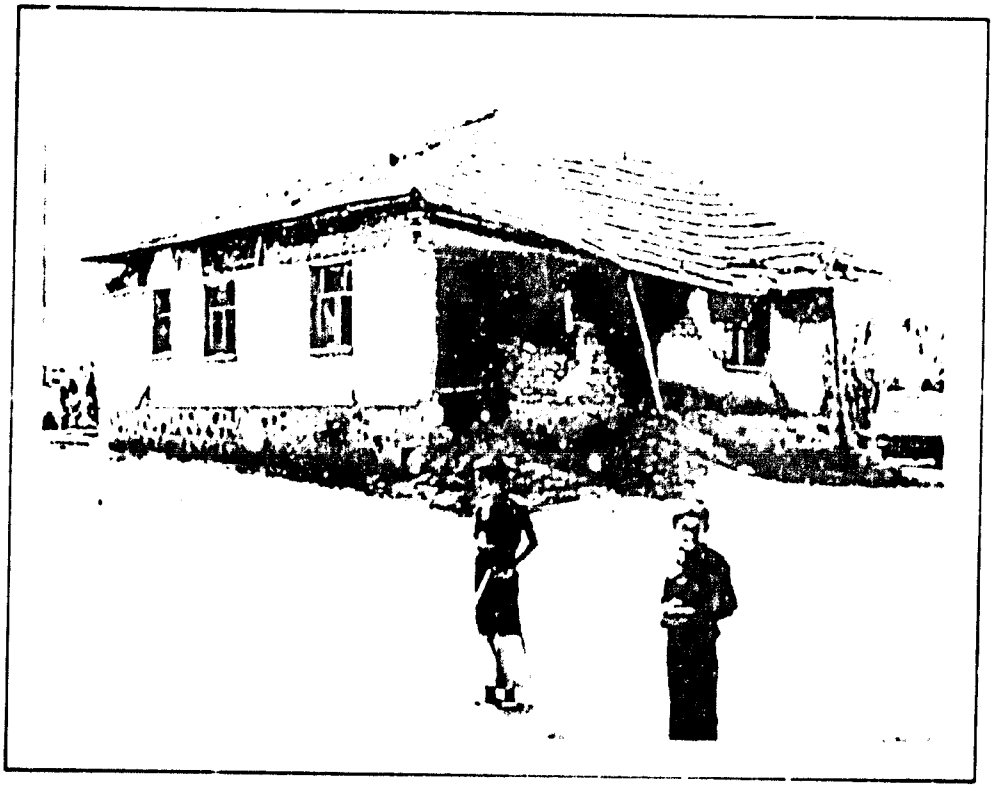

8. - Yapını sade tertipler, darlı toplu, girintisiz, çıkıntısız ve tek katlı yapılan dayanıklı olur
Kerpiç yapıda iki katlıdan vazgeçmezsen yer sarsıntısında zararın da iki katlı olur

FIGURE 15

FIGURE 16

FIGURE 17



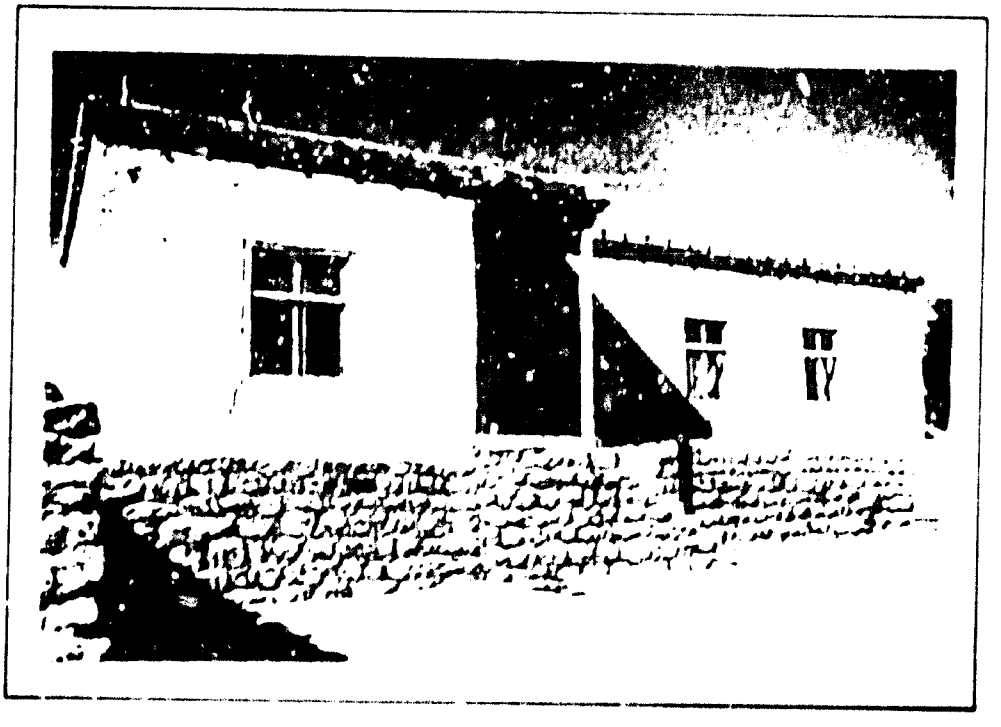
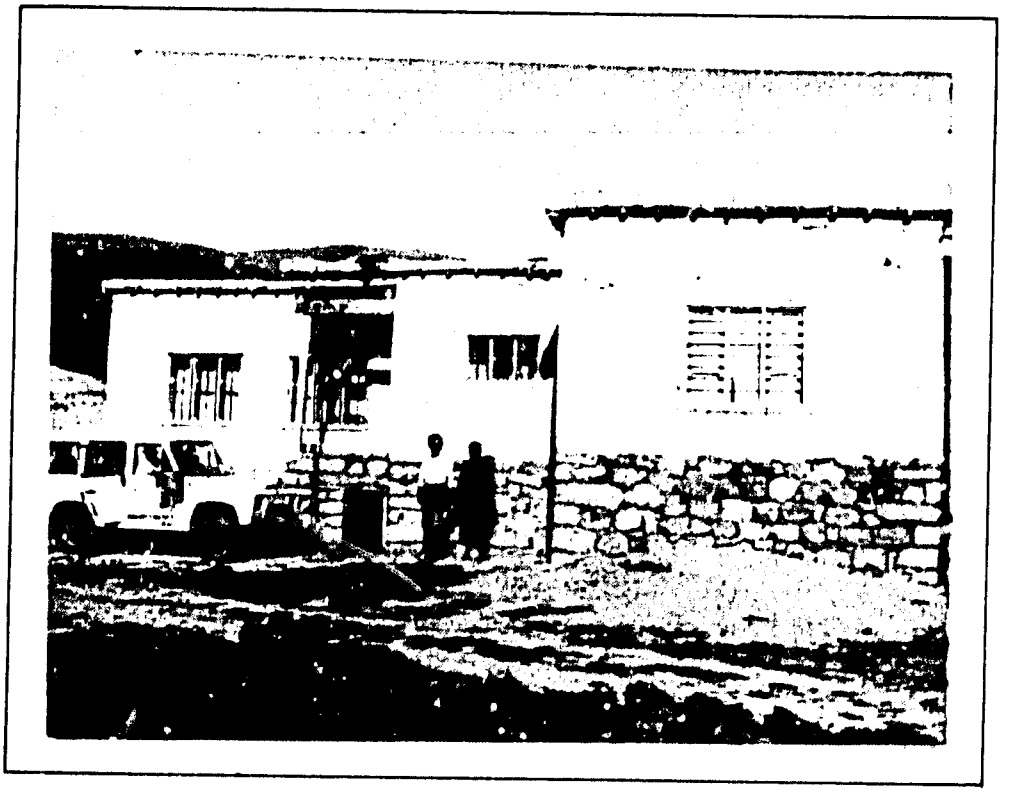


FIGURE 18

FIGURE 19



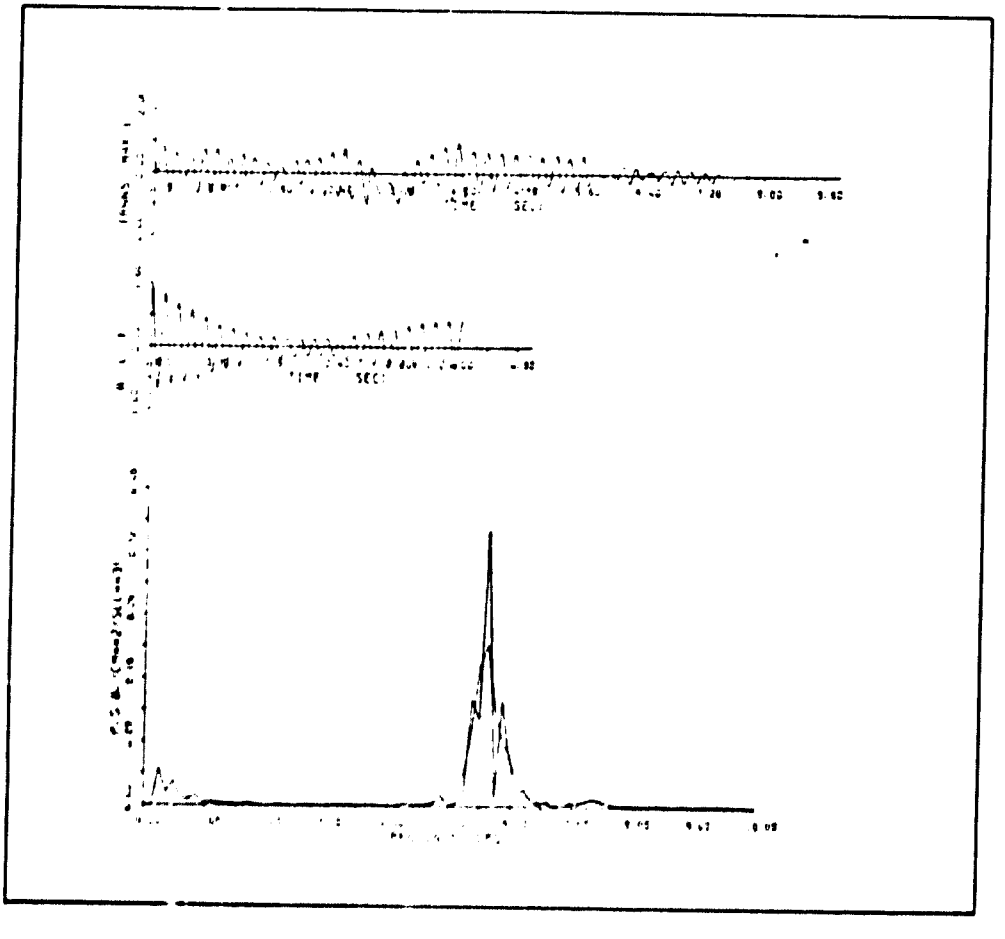


FIGURE 20

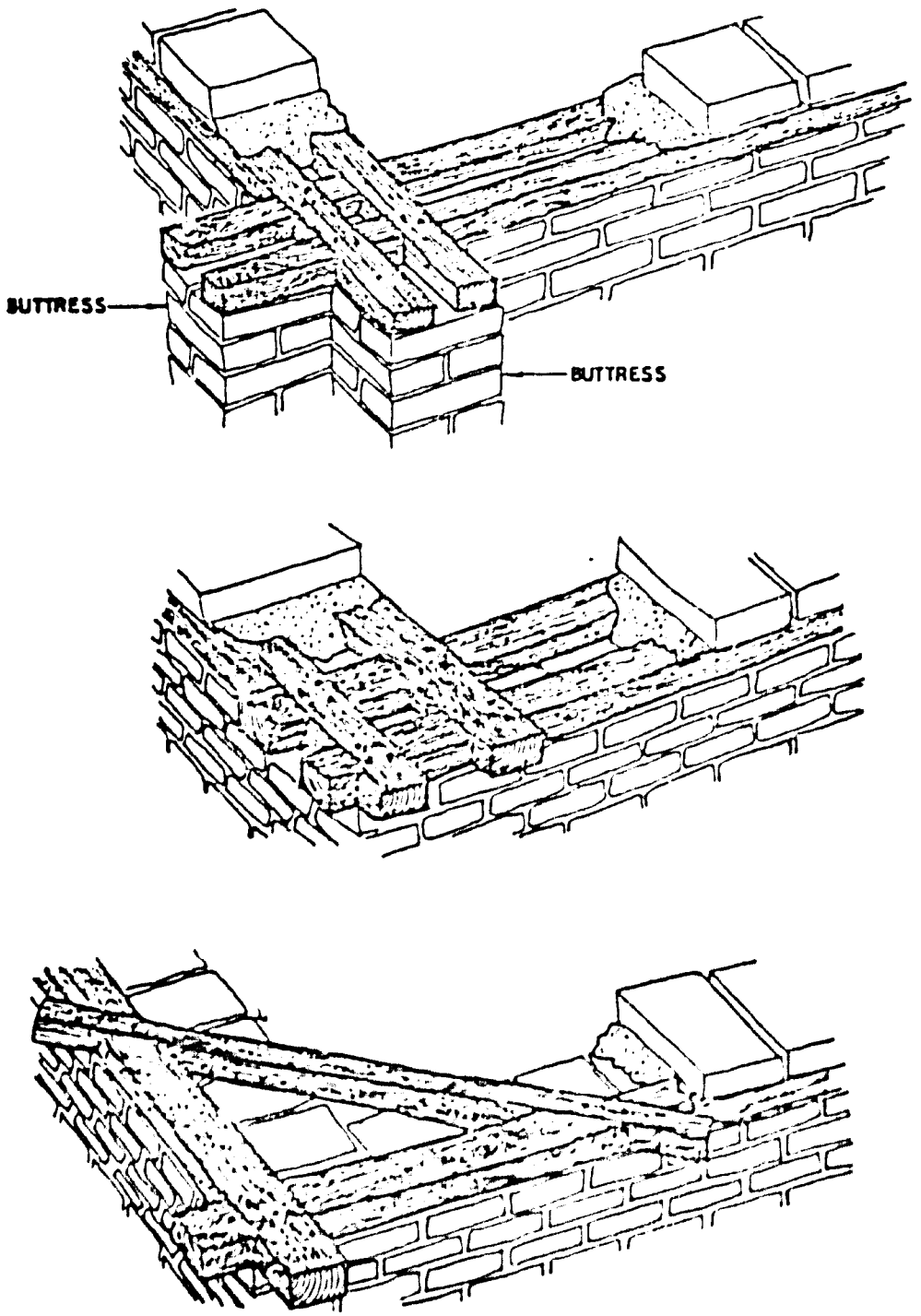


FIGURE 21

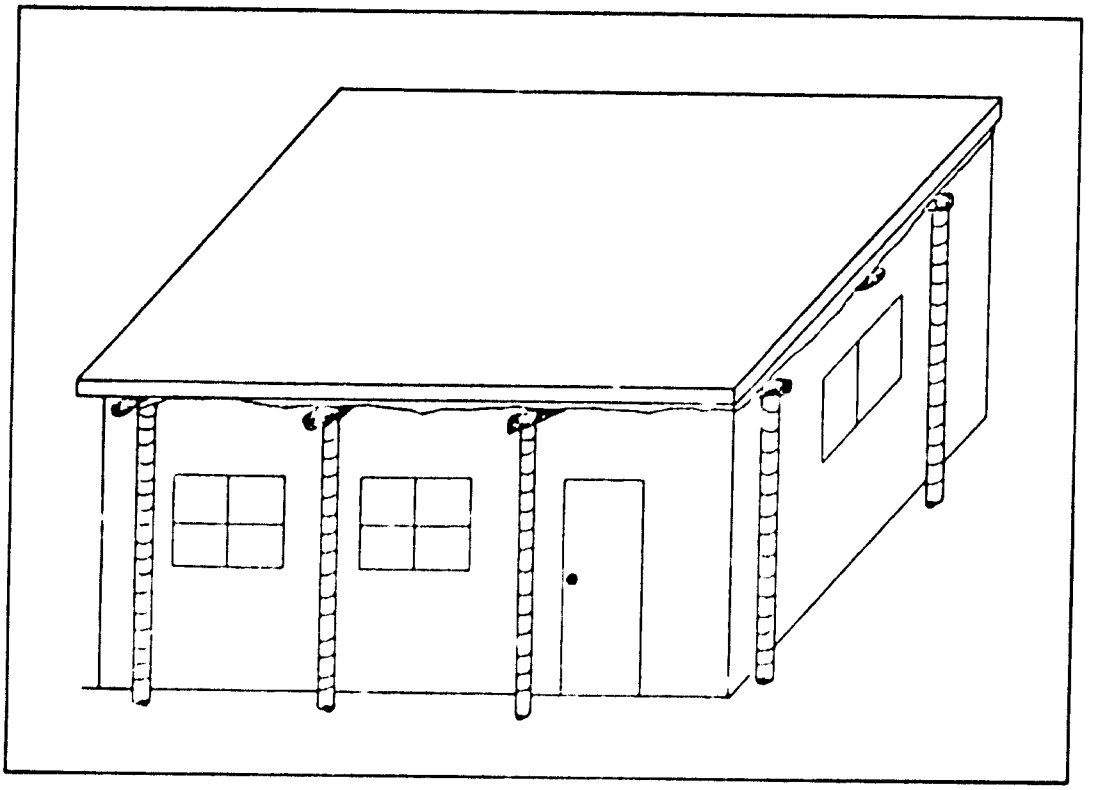


FIGURE 22

FIGURE 23

FIGURE 24

APPENDIX A

QUESTIONNAIRE FOR THE ASSESSMENT OF RURAL DWELLINGS IN HIGH SEISMIC ZONES OF TURKEY

(Prepared by the TNCEE for the Ministry of Rural Affair and Cooperatives)

T.C. KÖY İŞLERİ VE KOOPERATİFLER BAKANLIĞI DEPREM MÜHENDİSLİĞİ / TÜRK MİLLİ KOMİTESİ / KIRSAL KONUTLAR GRUBU

(Bakanlıkça Doldurulacaktır)

KIRSAL KONUT ANKETİ

1 – YÖNETİMSEL BİLGİLER

Köyün Adı : .....
Bağlı olduğu ilçe : .....
Bağlı olduğu il : .....

(Varsa eski adı) : .....
İlçeye uzaklık : .....km
İl'e uzaklık : .....km

2 – COĞRAFİ KONUM VE DOĞAL VERİLER

Köyünüzün yerleşme konumu

- ☐ Ovada
- ☐ Dağda
- ☐ Vadide
- ☐ Deniz kenarında
- ☐ Akarsu kenarında (İsmi .....)
- ☐ Ormanı içinde
- ☐ Orman kenarında

Zemin yapısı

- ☐ Kayalık
- ☐ Yumuşak
- ☐ Kumsal
- ☐ Diğer

Su kaynakları

- ☐ Kuyu
- ☐ Artezyen
- ☐ Akarsudan
- ☐ Diğer

Köyünüzün karşılaştığı doğal afetler, oluş tarihleri, yol açtığı hasarlar:

.....
.....
.....

Alınan önlemler: .....

3 – SOSYO - EKONOMİK BİLGİLER

Köyün Nüfusu :
Son sayımda : ..... Bu yıl : .....
Mahalle sayısı: .....
Hane sayısı : .....
Dağınık - Toplu olusu: .....

Köyün kuruluş yılı : .....
Kuruluş nedeni : .....

İlk okul varmı? .....
Kaç derslik? .....
En yakın orta okul? ..... km
En yakın lise? ..... km
Okuma yazma bilmiyen? ..... kişi

Sağlık ocağı varmı? .....
En yakın sağlık ocağı ..... km
En yakın hastahane ..... km

Köyde çalışan nüfus : .....
Kentte çalışan nüfus : .....
Yurt dışında çalışan nüfus: .....

Köylü Geçimini Daha Çok Hangi Yolla Sağlıyor?

Tahıl tarımı : % .....
Sebze - meyvecilik% .....
Hayvancılık % .....
Orman İşletmeciliği% .....
Küçük sanatlar % .....
Balıkçılık % .....
Ticaret % .....
Turizm % .....
Diğer % .....

En yakın İl yoluna ..... km
En yakın İstasyona ..... km
En yakın İskeleye ..... km

Köy yolunuz ☐ Asfalt ☐ Stabilize ☐ Ham yol
İl yolunuz ☐ Asfalt ☐ Stabilize

Köyde mevcut;

At arabası/Kağnı ..... adet
Kamyon /Kamyonet ..... adet
Traktör / Römork ..... adet
Binek Otosu ..... adet
Moto siklet ..... adet
Kayık ..... adet

Köyde Kooperatif Varmı? .....
Varsa Kooperatifin Adı? .....
.....
Katılan Ortak Sayısı? .....

4 – ENERJİ KAYNAKLARI

Köyde elektrik var mı?

Var Yok Yapım halinde

Köyde kaç TV var? .....

Köyde yaygın ısınma araçları: (% olarak)

Mangal % ..... Tandır % ..... Diğer

Soba % ..... Ocak % .....

Köyde akaryakıt istasyonu var mı?

Var Yok

En yakın akaryakıt istasyonu ..... km

En çok kullanılan enerji türü:

Isınmada: ..... Pişirmede: .....

5 – YAPI İŞÇİLİĞİ OLANAKLARI

Köyde mevcut inşaat işçisi : .....

Köyde mevcut inşaat ustası : .....

Köyde mevcut elektrik, tesisat ustası : .....

İnşaat işçisinin gündeliği : ..... TL/gün

İnşaat ustasının gündeliği : ..... TL/gün

Tesisat ustasının gündeliği : ..... TL/gün

6 – YAPI MALZEMELERİ OLANAKLARI

Köyde en çok bulunabilen ve kullanılan yapı malzemelerinin:

	NEREDEN TEMİN EDİLDİĞİ	B. FİATI		NEREDEN TEMİN EDİLDİĞİ	B. FİATI
Yuvarlak taş	:	.....	Eternit	:	.....
Köşeli taş	:	.....	Galvanizli saç	:	.....
Ahşap	:	.....	İnş. demiri	:	.....
Kerpiç	:	.....	Çimento	:	.....
Tuğla	:	.....	Kum/Çakıl	:	.....
Briket	:	.....	Diğer	:	.....
Kiremit	:	.....		.....	.....

7 – KIRSAL KONUTLARIN ÖZELLİKLERİ

Köydeki ortalama konut alanı ve yeni yapı:

Ortalama konut alanı ..... M^2

Son 5 yılı içinde yapılmış konut adedi ..... konut

Konutların kat adedi:

Bir katlı ..... konut

İki katlı ..... konut

Üç katlı ..... konut

Konutların temelleri

Taş/Çamur harçlı % .....

Taş/Kireç harçlı % .....

Taş/Takviyeli harçlı % .....

Kerpiç temelli % .....

Diğer temelli % .....

Yığma sistemli duvarların cinsi:

Yuvarlak taş % .....

Köşeli taş % .....

Kerpiç % .....

Tuğla % .....

Diğer % .....

Karkas sistemli duvarların cinsi (Himiş) :

Taş % .....

Kerpiç % .....

Tuğla % .....

Diğer % .....

Çatı örtü malzemeleri:

Kil - Toprak % .....

Kiremit % .....

Metal levha % .....

Diğer örtüler % .....

Duvarlarda sıva durumu:

	İÇTE %	DIŞTA %
Sıvasız	.....	.....
Kıtık sıva	.....	.....
Kireçli sıva	.....	.....
Diğer	.....	.....

Tarımsal işletme yapısı konuma:

Konuta bitişik % .....

Konutun altında % .....

Konuttan ayrı % .....

Yok % .....

8 – FOTOGRAFLAR

A – Köyü genel anlamda tanıtacak nitelikte, yükseklce bir yerden çekeceğiniz 9 x 14 kartpostal boyutlu bir fotograf,

B – Köyde en çok rastlanan konut türüne ait 6 x 9 kartpostal boyutlu bir fotograf,

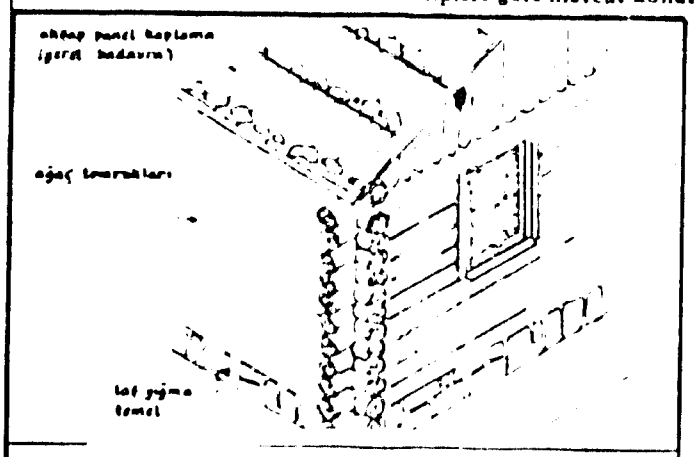
C – Köyde ikinci derecede yaygın konut türüne ait 6 x 9 kartpostal boyutlu bir fotograf,

D – Köy yakınında tarihi kalıntı vb. varsa onun son durumunu gösteren 6 x 9 kartpostal boyutlu bir fotograf,

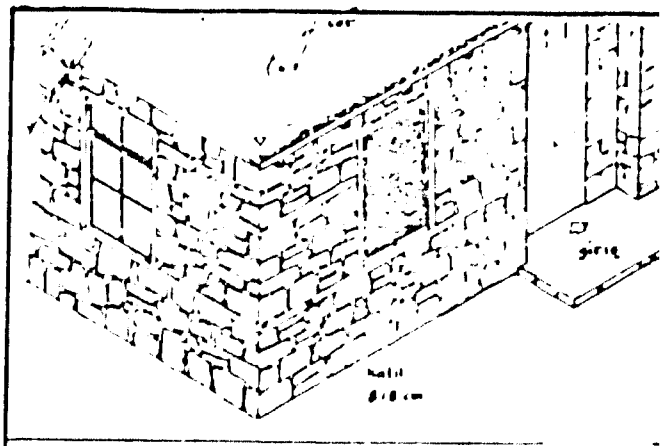
Arkalarına köyün adı ve bağlı olduğu il ve ilçe ile A, B, C, D, kod işaretlerini ve çekim tarihini yazmak suretiyle bir zarf içerisinde ankete ekleyiniz.

KIRSAL KONUTLARIN YAPI SİSTEMLERİ

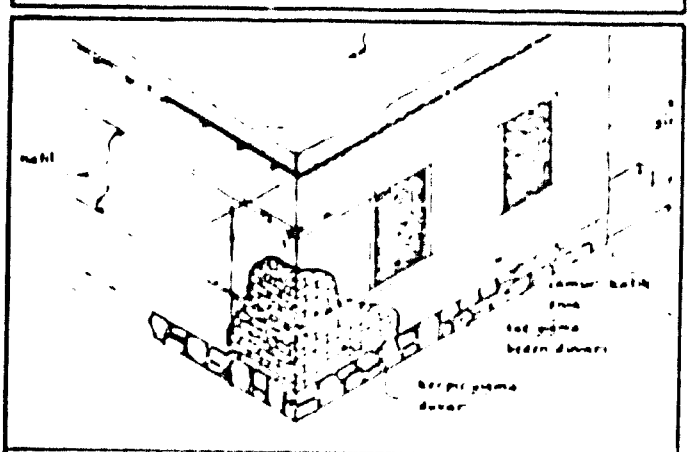
Köyde aşağıda belirtilen hangi yapı türü daha yaygındır?
Bu tiplere göre mevcut konut yüzdelerini hizalarında gösteriniz:



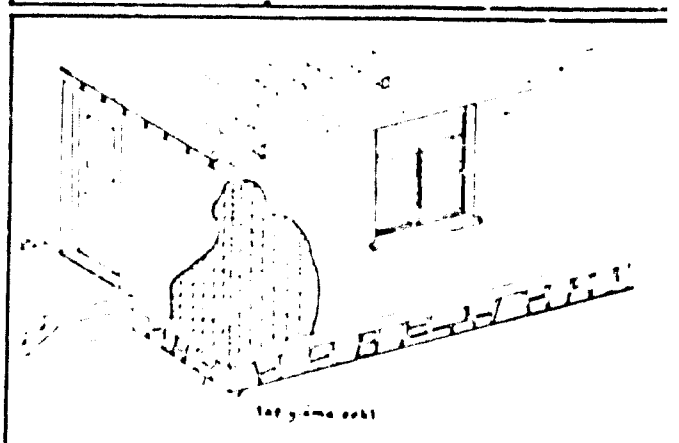
AHŞAP YIĞMA SİSTEMİ'DE % .....



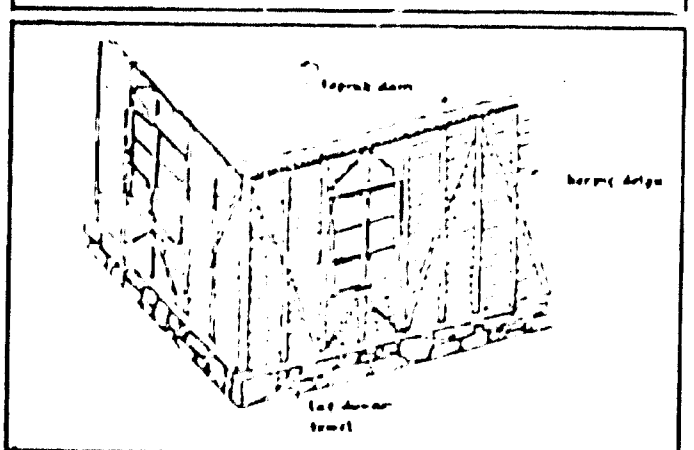
TAŞ YIĞMA SİSTEMİ'DE % .....



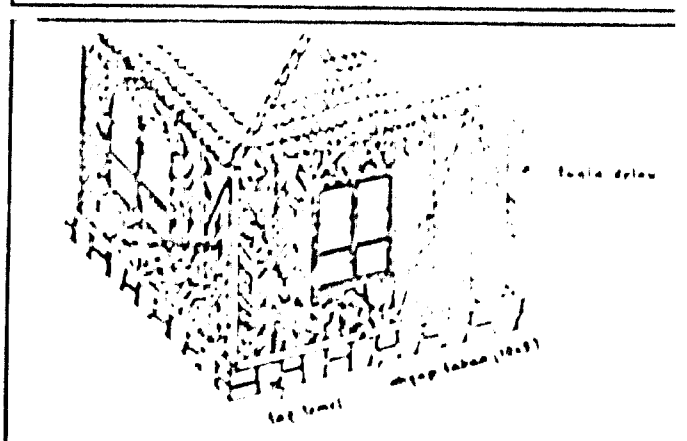
KERPİÇ YIĞMA SİSTEMİ'DE % .....



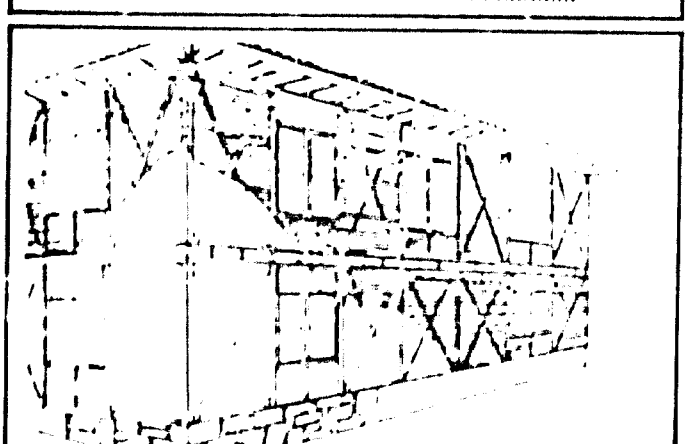
TUĞLA YIĞMA SİSTEMİ'DE % .....



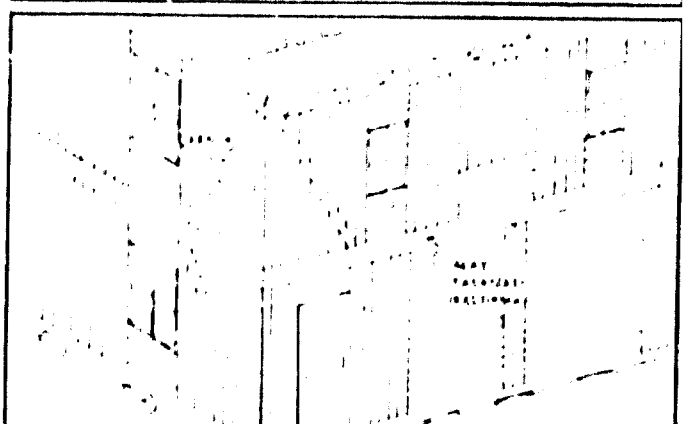
AHŞAP KARKAS (Himiş)
KERPİÇ DOLGU SİSTEMİ'DE % .....



AHŞAP KARKAS (Himiş)
TUĞLA DOLGU SİSTEMİ'DE % .....



AHŞAP KARKAS (Bağdadi)
ÇİTA ÜZERİNE SIVALI % .....



AHŞAP KARKAS
AHŞAP KAPLAMA SİSTEMİ'DE % .....

10 – KÖYÜNÜZDE ENÇOK UYGULANAN KONUT PLAN – ŞEMASINI ÇİZİNİZ

NOT : Her kare 1 metreyi göstermektedir, mahal isimlerini yöresel olarak yazınız.

II – DÜŞÜNCELER

I – Köyün sosyo - ekonomik durumu yönünden önemli bulduğunuz halde ankette belirtmediğiniz hususlara ilişkin gözlem ve düşüncelerinizi.

II – Köydeki konutların depreme dayanıklılığı yönünden önemli bulduğunuz halde ankette belirtmediğiniz hususlara ilişkin gözlem ve düşüncelerinizi:

ANKETİ DOLDURANLARIN KİMLİĞİ

Tarihi :

Adı Soyadı : ..... Görevi : ..... İmzası : .....

Adı Soyadı : ..... Görevi : ..... İmzası : .....

Adı Soyadı : ..... Görevi : ..... İmzası : .....

DESIGN, CONSTRUCTION, BEHAVIOR AND REPAIR PROBLEMS OF RURAL STRUCTURES IN GREECE

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ABSTRACT

Classification of different low-cost construction systems used in Greece is attempted.

Problems and possibilities of design, construction, seismic behavior and repair of rural structures in Greece, with either traditional or recent low-cost construction systems, are presented, with emphasis on observations and conclusions from recent destructive earthquakes (Volvi 1978, Magnissia 1980, Alkyonides 1981).

Need for practical design, construction and repair recommendations, easily available to rural population, is stressed.

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Introduction

Greece is one of the most seismically active countries in the world. Mean return period for M≥6,0 and M≥7,0 earthquakes is estimated to be 0,4 and 3,0 years respectively (4). During this century, Greece experienced at least 4 shocks stronger than 7,4R, while there is historical evidence of repetetive extremely destructive earthquake action in the past. No part of Greece can be considered as having a low seismicity. During the last four years, three destructive sequences of shocks took place:

(a) In 1978, in Northern Greece, near Thessaloniki (Volvi), 3 main shocks with magnitudes 5.8R (05.24.78), 6.5R (06.20.78) and 5.3R (07.5.78),

(b) In 1980, in Central Greece, near Volos (Magnissia), 3 main shocks with magnitudes 5.4R, 6.3R and 5.9R (07.9 .80), and

(c) In 1981, in Central Greece, near Athens (Alkyonides), 5 main shocks with magnitudes 6.8R (02.24.81), 6.5R (02.25.81), 6.3R (03. 4 .81), 5.8R (03. 5 .81) and 5.7R (03. 7 .81),

causing extensive damage in all types of structures, both in big cities and small settlements. Officially estimated total cost of repairs has been of the order of 1.5 billion dollars.

Urban development and construction tradition has been continuous since 3000BC in Greece, influenced by a variety of environmental resources and constraints, by frequent earthquake actions and by similar traditions of neighboring countries (Albania, Yugoslavia, Bulgaria, Turkey). A large number of different construction systems are still present in ancient, medieval and contemporary monuments, in still inhabited medieval and recent anonymous settlements, in modern villages and in big cities. In fact, a significant percentage of the population still lives in non-engineered structures, a great percentage of which can be classified as earthen structures.

Surprisingly at first, a great number of well constructed non-engineered structures withstood recent destructive earthquakes with more success than many modern seismic-resistant reinforced concrete (R.C.) structures. Moreover, the fact that low-cost is the main characteristic of non-engineered structures, does not necessarily mean that their architectural value is also low. On the contrary, many of them meet high architectural standards.

In spite of the above, there is a lack of reliable data con -

cerning the number and distribution over the country of the existing non-engineered structures,as well as on their seismic behavior. There is also a lack of simple Codes,recommendations and aids for effective methods of construction,repair and strengthening for this type of structures.

Traditional Construction Systems

A continuous 5000 year construction tradition,influenced by a variety of environmental resources and constraints,by frequent earthquake actions and by similar traditions of neighboring countries,produced a wide range of traditional construction systems and forms.

The predominant traditional systems that are still present in dwellings in Greece are classified in fig.1,according to their materials and to their structural use. Distinction is made among vertical,horizontal and roof systems,as well as among systems with surface and linear elements. The mass of the roof system influences materially the overall structural behavior during earthquakes,so,roof systems are classified according to their mass.

In table 1,the extent of use and the areas and types of structures in which the different systems are met are presented. Prevailing construction materials for dwellings and other rural structures are stone in mountainous areas and islands and adobe (and sometimes brick) in plains. Good quality timber is available only in certain areas in Greece. A large number of inhabited small villages and settlements are almost entirely built by traditional construction systems.

In table 2,cost-benefit parameters are given for the different traditional construction systems. Seismic behavior of a structure depends on the combination of its mass,stiffness,strength and ductility. Each system has its advantages and draw-backs,giving the best solution for certain cases. Knowledge of the construction methods for the different systems decreases with time,creating a problem for initial use,or repair and strengthening of these systems.

In figs.2-7,typical examples of applications and details of traditional construction systems are given. Excellent architectural

and structural results have been obtained using "poor" materials , but with the wisdom of a long tradition. Earthquake threat is always a consideration. Earthen structures are extensively used in the islands and in the plains of the mainland. Earth is also used in timber-framed structures, in areas where good quality timber is available.

Present Urban Development Policy and Practice

Today's urban development policy and practice in Greece have been strongly influenced by: (a) construction tradition, (b) frequent long periods of war during this century (1912-1913, 1917-1922, 1940-1949), (c) periods of building construction explosion in between and after war periods and (d) big population movements (Greek-Turk population exchange in 1922, refugee movements during the period of 1940-1949).

Right after 1922 and during the period of 1944-1949, big refugee settlements were hastly erected in and around big cities, almost exclusively with non-engineered structures. During the war period of 1940-1949, many of the existing buildings were completely destroyed due to war actions. Finally, the big demand for housing, as well as the effort for industrialization, created a constructuction boom during the last 30 years, both in big cities and villages.

At present, construction is officially permitted only on owned land, according to town plan, after official permit, under the supervision of a licensed Civil Engineer or Architect. Rural structures of secondary importance (stables, warehouses, etc) require only a gentarmery permit for construction. In cities (population greater than 5,000), the continuous building system prevails (individual buildings are erected in row without any seismic joint), while in villages (population less than 5,000), individual structures have to be independently erected. A large number of settlements has been declared preserveable and special permit is required to guarantee preservation of the nature of the settlement.

In spite of the official policy, a large number of low-cost non-engineered structures is erected everyday: (a) in the surrounding of big cities as squatter settlements, (b) in remote rural communities as dwellings, and (c) in most villages and small communities as secondary constructions (stables, warehouses, etc.).

Present Construction Policy and Practice

Predominant low-cost construction systems in use today are classified in fig.8,according to their material,structural use and frequency. A comparison between the data of fig.1 and table 1 on one hand and the data of fig.8 on the other,reveals that:

(a) Concrete,reinforced concrete,cement blocks,steel and perforated steel truss elements,are introduced as new materials,unreinforced and reinforced concrete being the most predominant.

(b) The use of brick has increased

(c) Stone,adobe and timber do continue to be used,although to a lesser extent.

(d) Traditional timber frame systems (bagdadi,tsatmas) and stone vault systems have practically disappeared.

New structures have to conform to the General Building Code (29), to the Loading Code for Structural Works (30),and to the Seismic Code for Buildings (31). No structural system except reinforced concrete is covered by a National Code. Recommendations for the EQ Safety of 1-story Rural Dwellings (20) and Recommendations for Construction of Aseismic Dwellings (25) give some guide-lines for low-rise rock and brick masonry construction in seismic areas.

Residential buildings in cities are constructed with R.C.wall, frame,or dual systems.

Rural dwellings are usually constructed with a mixed structural system,consisting of load bearing brick walls + a few reinforced concrete columns + reinforced concrete slabs and roofs. Due to financial problems,the structure is erected in several stages,usually with the houseowner's personal work and supervision. As expected, the end result is a structure of very low quality. Secondary rural structures (stables,warehouses,etc) in most cases do not cover any safety provisions,since least cost and effort is mainly sought at during their construction. Surveys of the type and quality of construction in small villages in Greece show that more than 3/4 of existing structures are either non-engineered,or of the mixed(brick masonry + RC columns) construction system. Non-engineered structures are usually built with stone,brick,or concrete block masonry with a light roof,or with adobe masonry and timber + tiles roof (fig.9).

Dwellings in squatter settlements follow the same general trend of construction,but since they are usually built in areas of poor soil conditions and in a big hurry (usually during night-time),they end to a still less efficient result. Materials mostly in use are reinforced concrete,and brick or cement block masonry (fig.10).

Construction tradition has been overwhelmed by the explosion of construction needs during the last 30 years. New people entered the construction business as technicians,without having enough time or opportunity to acquire the required knowledge and skill. Extensive use of reinforced concrete,which seemed as an easy to handle material,destroyed further the existing tradition. In this way,the long good construction tradition tends to disappear,without being replaced by an equally well known technique. Inflation,increased the demand for cheaper construction and the earthquake threat was forgotten. Finally,the mean quality of construction for low-cost structures seems to be lower than it was a few years ago with the traditional construction systems and materials. We have more and better materials,but we lost construction tradition and structural feeling.

Engineering Remarks from Recent Earthquakes in Greece

A lot of material concerning seismic behavior of traditional or contemporary low-cost construction systems comes into light during each strong earthquake in Greece. Unfortunately,to the writer's knowledge,no rational effort has been made until now for selection and evaluation of this data,mainly,due to lack of financial support. Existing data concerning seismic behavior of low-cost construction systems in Greece is scattered in a number of papers covering mainly seismic behavior of modern reinforced concrete structures.

Mean level of damage during the earthquakes of Volvi,Magnisia and Alkyonides is estimated to be rather high,compared with the observed intensities in the affected areas. This can be easily realised if one examines,not so much the overall damage statistics,but the damage of well constructed simple structures with traditional construction systems.

Well constructed and maintained old non-engineered structures with low-cost traditional construction systems survived the earth -

quakes with minor to moderate damage (figs 11,12,13). It is worth noting that many of these structures had already experienced at least one more severe earthquake in their lifes. This good behavior was specially prominent in the cases of lightly roofed adobe masonry structures and of hollow or adobe filled timber framed structures (bagdadi and tsatmas).

Poorly constructed and/or maintained old non-engineered structures with low-cost traditional construction systems,naturally,experienced severe damage during recent earthquakes (fig.14).

Seismic behavior of "modern" RC or mixed system "seismic-resistant" rural dwellings with the usual causes of overstress or understrength(structure to structure interaction,bad morphology,bad reinforcement detailing) was not better than that of bad old non-engineered structures (figs.15,16,17).

It seems that,for normal quality of construction,the percentage of severely damaged structures is higher for modern "low-cost" RC or mixed system rural dwellings,than for non-engineered dwellings with traditional construction systems,although the cost of the latter is much less. This surprising at first conclusion can be explained by the following reasoning:

(a) Good seismic resistance of RC structures can only be obtained through good design and construction,requiring higher knowledge and skills than old systems.

(b) RC gives the feeling of more freedom for overall form selection. This is of course true,provided that appropriate countermeasures will be taken during design and construction of RC structures with a bad morphology,which seldom is the case.

(c) Rural RC dwellings with bad morphology are not as simple structures to analyze and design as is usualy thought. This is especially true in cases of mixed construction systems comprising of brick masonry bearing walls + RC solumns + RC slabs,whose seismic behavior is to a large extent unpredictable.

(d) Heavy reinforced concrete slabs induce far more seismic strains to vertical structural elements,than light old roofs and timber floors induce to their non-engineered structures.

It is concluded that,usually despised non-engineered structures with traditional construction systems can be as good for seismic

protection as modern "low-cost" RC or mixed system rural structures. Since structures with traditional construction systems are much less expensive and can usually be self constructed, some thought has to be given to their re-use. Among the old traditional systems, adobe masonry offers the least cost and requires the least skill.

Lack of simple Codes, recommendations and guide-lines for repair and /or strengthening of moderately damaged non-engineered rural structures with traditional construction systems,has been observed during recent earthquakes in Greece,as well as a lack of knowledge of young engineers for relevant appropriate techniques of repair and/or strengthening.

Mass RC construction in cases of destructive damage of old settlements,in many cases led to a destruction of the environment (fig.18).

Conclusions

There is a large number of structures with different low-cost traditional construction systems in Greece. Most of them have passed successfully the tests of time and of more than one strong earthquake shock. Rational classification of these structures,survey of their distribution and careful study of their seismic behavior,will possibly lead to conclusions valuable not only for Greece.

Seismic behavior and architectural possibilities of adobe masonry,together with its low cost and ease of construction,make adobe masonry a very suitable construction system for low-rise,low-cost rural structures.

Simple and practical guide-lines for traditional systems construction, maintenance, repair and/or strengthening and cost-benefit comparisons between existing low-cost and traditional systems,both easily available to rural population are needed. In this respect,adobe masonry should be examined first,so that its use for low-rise,low-cost rural structures will be promoted. Knowledge of the behavior and guide-lines for maintenance,repair and/or strengthenir of the rest traditional systems found in Greece,will promote preservation of buildings,monuments and settlements of cultural value.

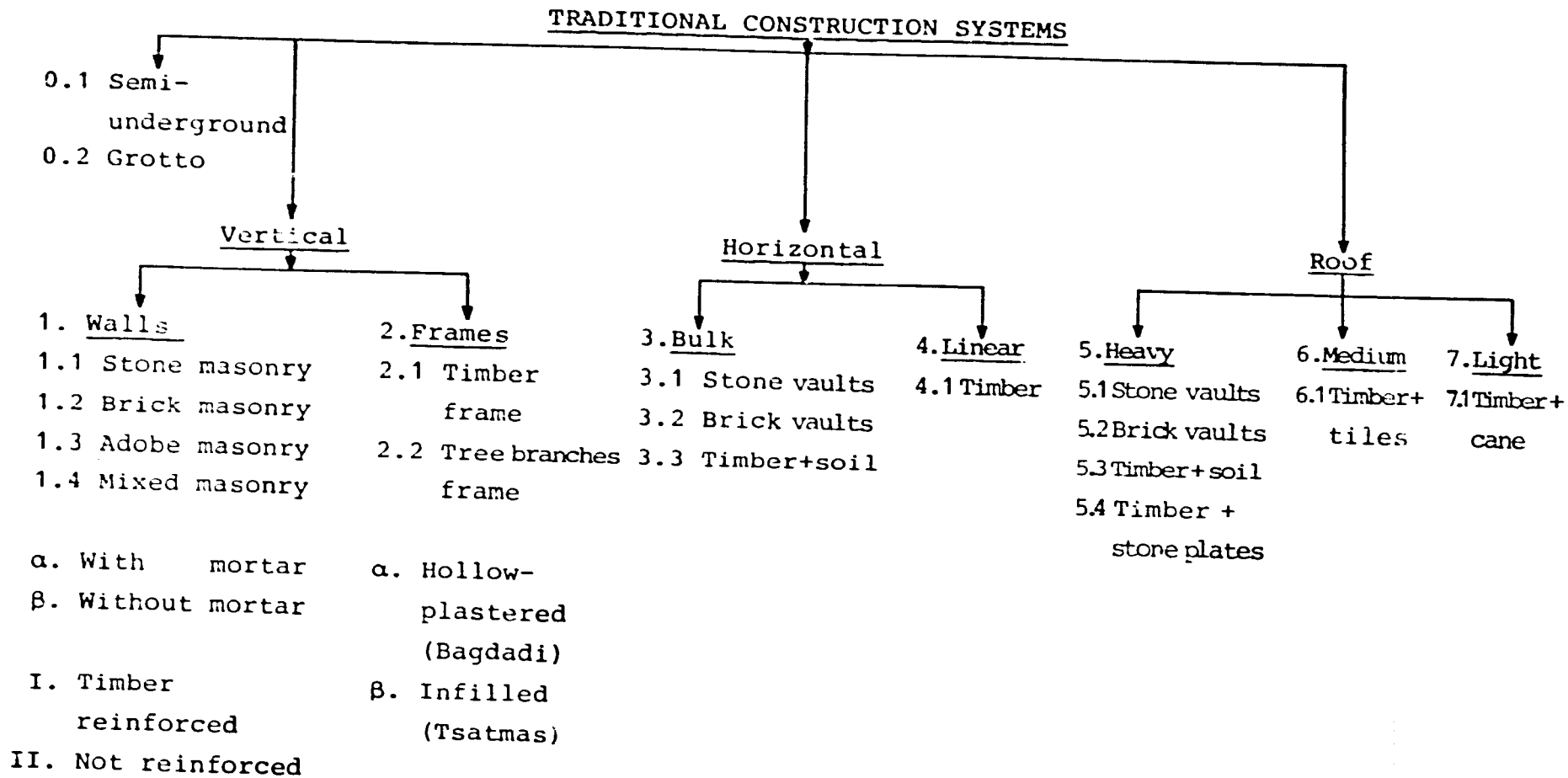


FIG.1 Classification of Traditional Construction Systems in Greece According to Material and Structural Use

TABLE 1

Use of Traditional Construction Systems in Greece

	System	Use	Areas	Type of Structures				
				Monuments - Churches	Traditional settlements	Squatter settlements	Rural (dwellings)	Rural (secondary)
0.1	Semi-underground	-	I		-			
0.2	Grotto	-	MI	-	-			
1.1	Stone	‡	MI	‡	‡	-	‡	+
1.2	Brick	‡	P	‡		+		
1.3	Adobe	‡	P		+		‡	‡
1.4	Mixed	+	MP	‡	-			
α	mortar	+	MP	+	+	+	+	
I	Timber reinf.	‡	MP	‡	‡		-	
2.1	Timber	+	MP		+		+	-
2.2	Tree branches	-	MP					-
α	Hollow	-	MP		-		-	
β	Infilled	+	MP		+		+	-
3.1	Stone vaults	+	MI		+			
3.2	Brick vaults	-	PI	+	-			
3.3	Timber + soil	+	I		+			
4.1	Timber	‡	P		‡		‡	
5.1	Stone vaults	+	MI	-	+			
5.2	Brick vaults	‡	PI	‡	+			
5.3	Timber + soil	+	I		+			
5.4	Timber + stone	+	M		+		+	-
6.1	Timber + tiles	‡	P		‡	+	‡	-
7.1	Timber + cane	-	P					-

Use: ‡ Extensive
+ Medium
- Small

Areas: I Islands
M Mountains
P Plains

TABLE 2

Characteristics of Traditional Construction Systems in Greece

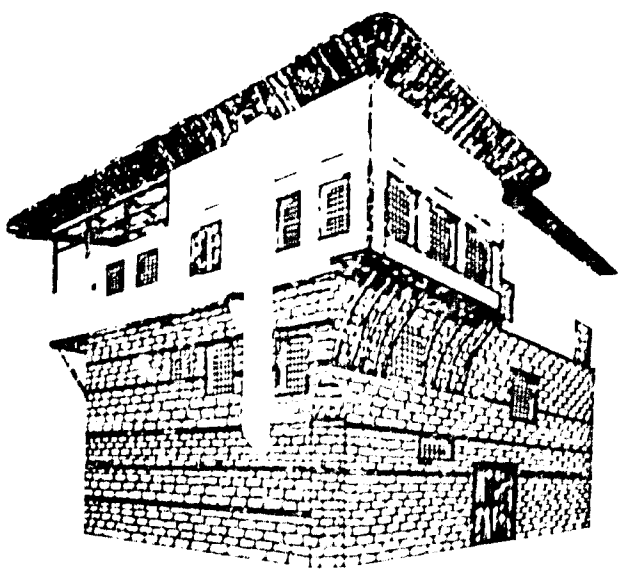
	System	Cost	Water proofing	Thermal insulation	Stiffness	Mass	Strength + ductility		Material availability	Knowledge of construction method
							Vertical loads	Horizontal loads		
0.1	Semi-underground	VL	VL	G						
0.2	Grotto	VL	L	G						
1.1	Stone	L	M	G	H	B	H	L-M	H	M
1.2	Brick	M	G	G	M	M	M	L-M	L-M	M-G
1.3	Adobe	L	L	G	L-M	M	L	L	H	M
1.4	Mixed	M	M-G	G	M-H	M-B	M-H	L-M	L-M	L-M
α	with mortar	(M)	(G)	(G)	(H)	(B)	(H)	(H)		(M)
β	w/o mortar	(L)	(L-M)	(L)	(L)	(L)	(L)	(L)		(H)
I	Timber reinf.	(M)			(H)		(H)	(H)	(L)	(L)
II	Not reinf.	(L)			(L)		(L)	(L)	(M)	(H)
2.1	Timber frame	M	L	G	L	L	M	M-H	L-M	L-M
2.2	Tree branches	VL	VL	M	VL	VL	VL	VL	H	L
α	Hollow	(L)	(L)	(M)	(L)	(L)	(L)	(M)		L-M
β	Infilled	(M)	(M)	(M)	(H)	(B)	(H)	(M)		L
3.1	Stone vaults	M-H				VB	H	M	H	L
3.2	Brick vaults	M-H				B	H	M	L-M	M
3.3	Timber + soil	L				VB	L-M	L-M	H	L
4.1	Timber	M				L	L-M	M-G	L-M	M-G
5.1	Stone vaults	M-H	M	M-G		VB	H	M	H	L
5.2	Brick vaults	M-H	M-G	G		B	H	M	L-M	M
5.3	Timber + soil	L	M-G	G		VB	L-M	L-M	H	L
5.4	Timber + stone	L	L-M	L-M		B	L-M	L-M	L-M	L
6.1	Timber + tiles	M	G	G		M	M	L-M	L-M	M
7.1	Timber + cane	VL	VL	M		VL	VL	VL	H	L-M

VL: Very low
L: Low
M: Medium

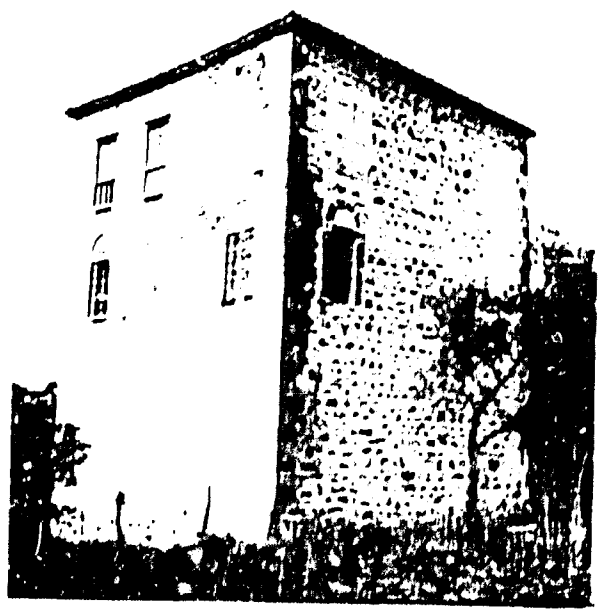
G: Good
H: High
B: Big

Astypalaia. Aegean Sea (9)

Monastery State of Mount Athos. Northern Greece



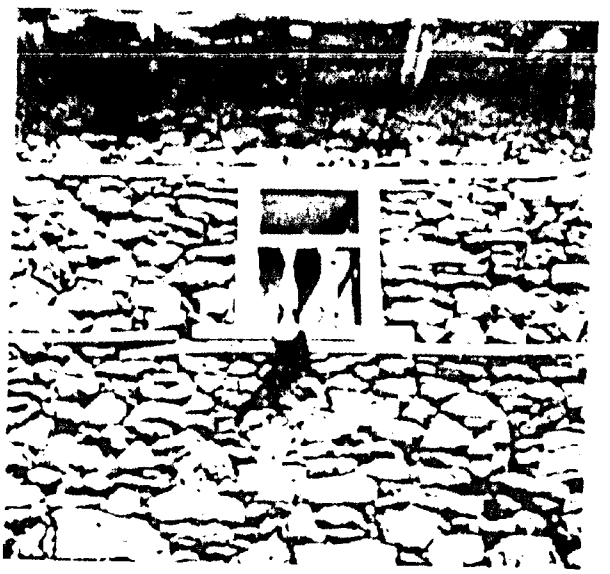
Verria. Northern Greece (22)



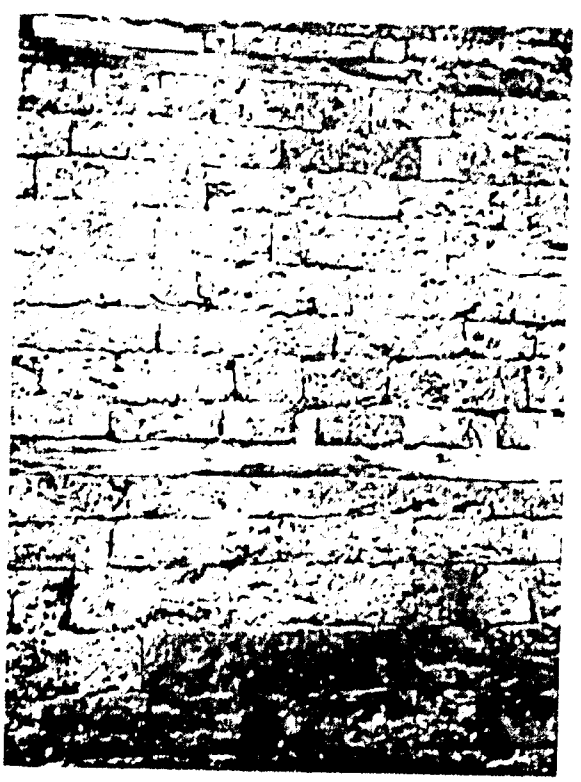
Mytilini. Aegean .

FIG. 2 Traditional Construction Systems. Stone Masonries. Excellent architectural and structural results with poor materials. Northern Greece and Aegean Islands

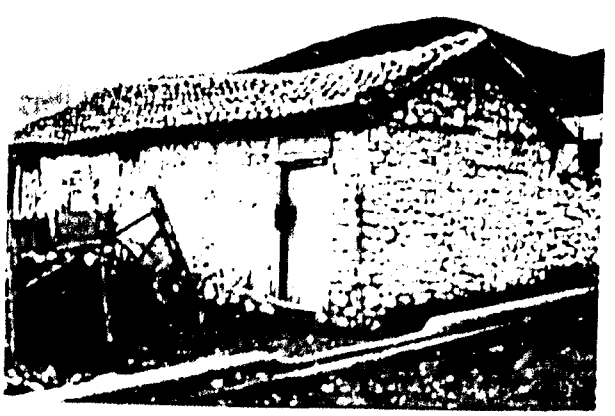
Stone masonry and chimneys in typical dwelling in Xalkidiki(23)



Stone masonry with reinforcement in Xalkidiki (23)



Stone masonry with timber reinforcement (22)



Poor stone masonry in rural structure near Xanthi

FIG.3 Traditional Construction Systems. Stone Masonries Northern Greece

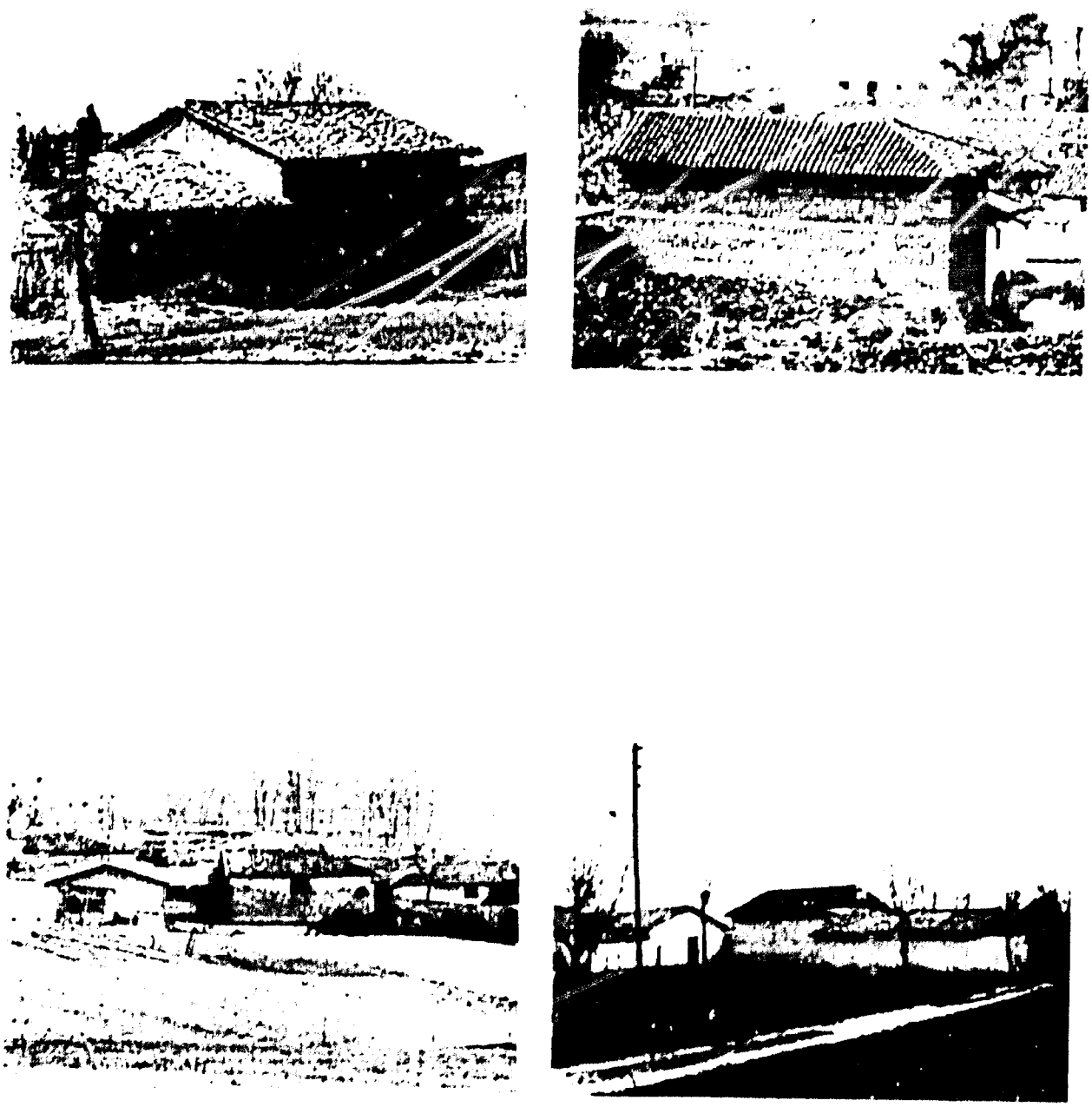
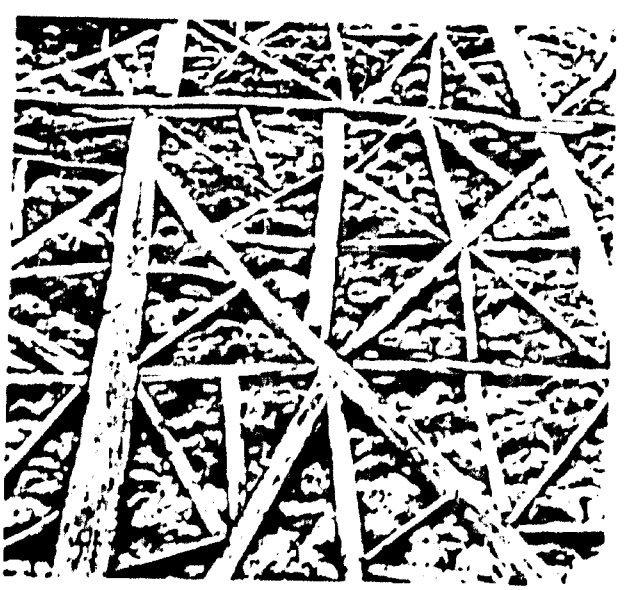


FIG.4 Traditional Construction Systems. Adobe masonries in small villages around Xanthi. Northern Greece

Bagdadi

Bagdadi

Bagdadi + Tsatmas (21)

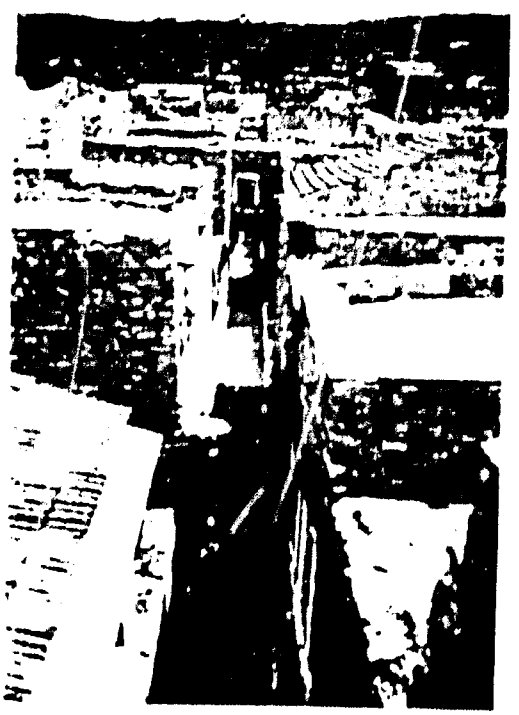


Tsatmas (22)

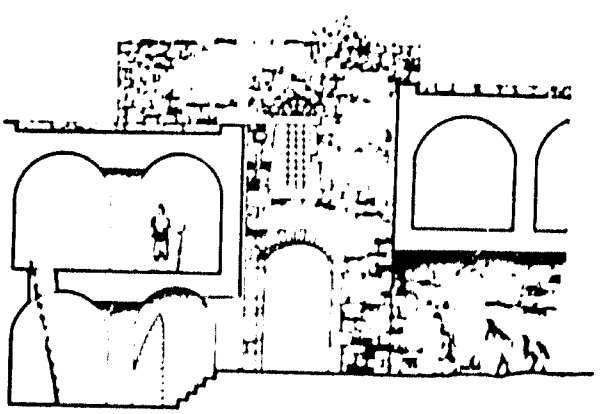
FIG.5 Traditional Construction Systems. Timber Frames. Northern Greece

Anabatos

Olympoi (9)

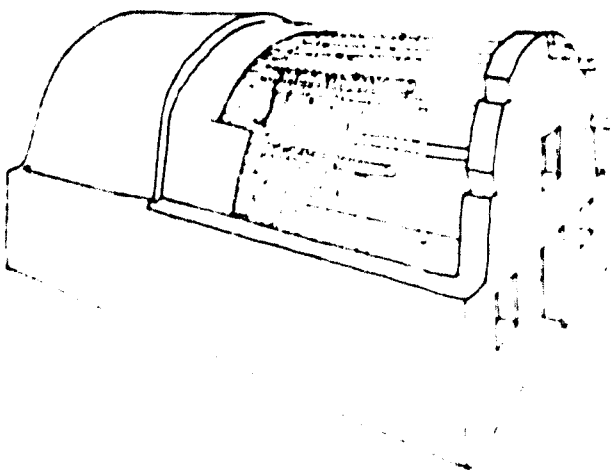


Olympoi. View of a street (9)



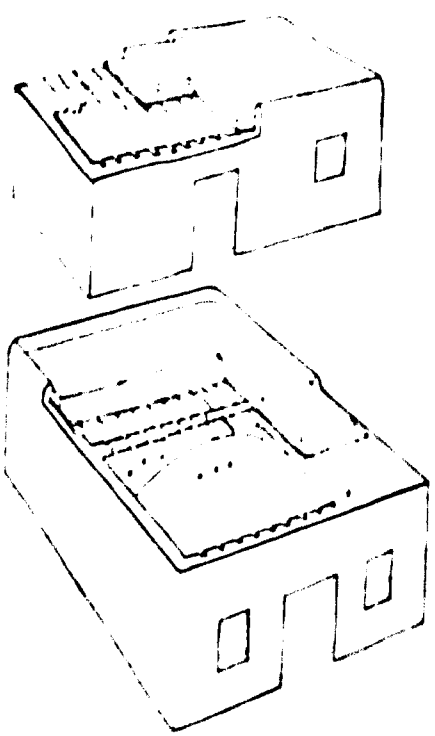
Detail of Construction System (19)

FIG.6 Traditional Construction Systems. Stone Vaults for fully fortified medieval still inhabited villages. Chios.



Timber + soil vault (9)

Timber + soil vaults. Santorini (9)



Timber + soil (9)

Brick vault + slates

FIG.7 Traditional Construction Systems. Roofs. Aegean Sea

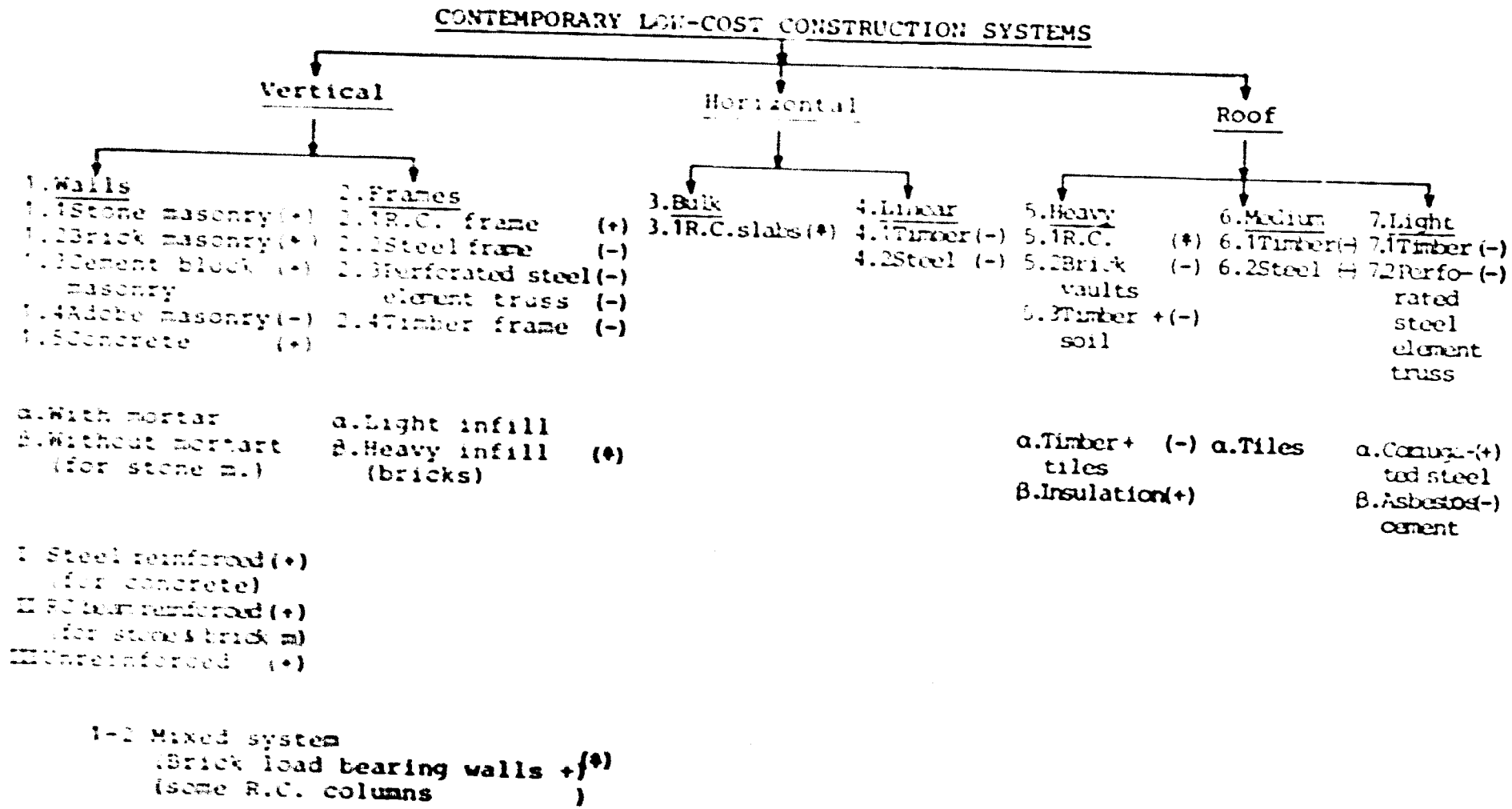
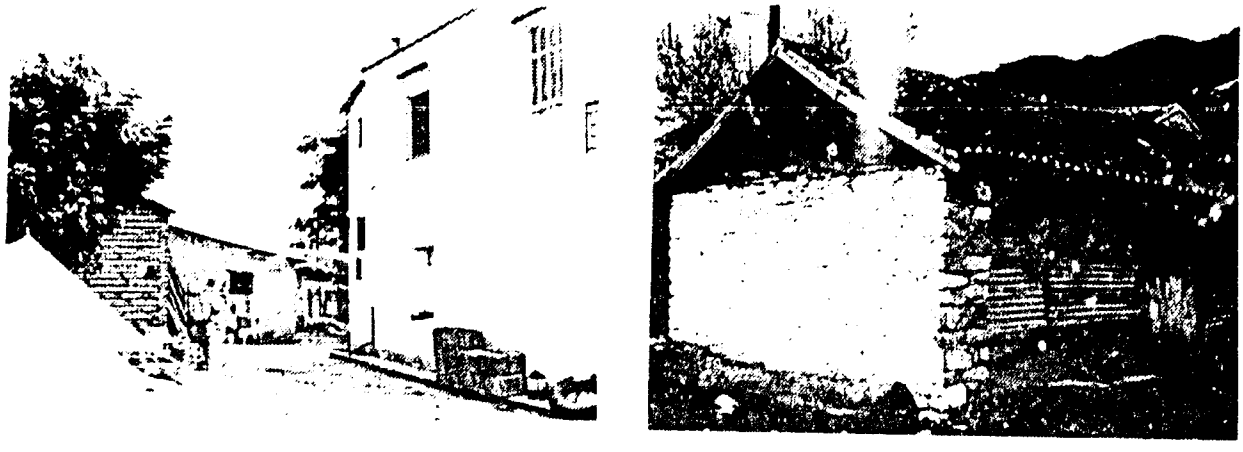


FIG.3 Classification of Contemporary Low-Cost Construction Systems in Greece According to Material, Structural Use and Extend of Use



Constructions of secondary importance near Thessaloniki

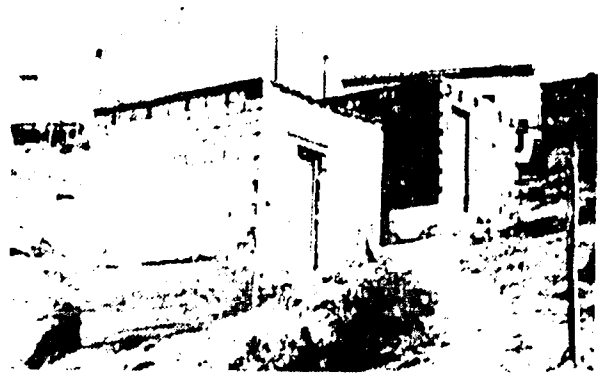
Adobe dwellings and constructions of secondary importance near Xanthi

FIG.9 Recent non-engineered structures in rural areas. Northern Greece

Ilissos settlement in Athens (9)

Dwellings in Ilissos settlement(9)

Dwelling in squatter settlement



Dwelling in squatter settlement(9)

FIG.10 Recent non-engineered dwellings in big cities (Squatter Settlements). Bad aesthetic and structural results

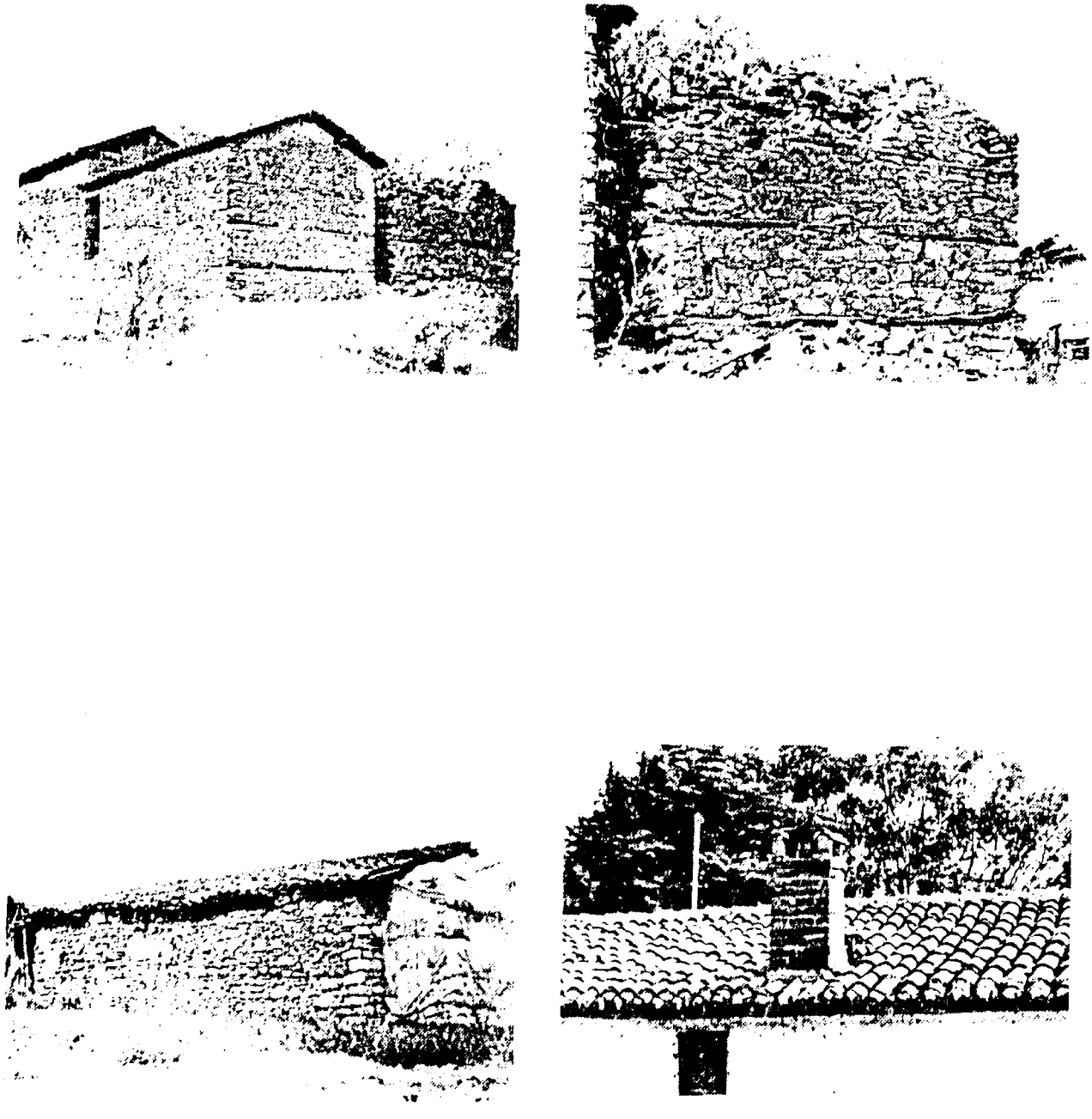
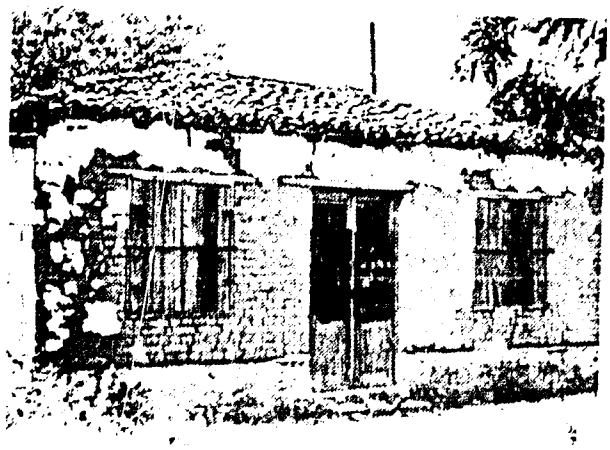


FIG.11 Well constructed stone masonries w/o mortar,and traditional chimney in the epicentral area of the Volvi 06.20.78 EQ. Many of them experienced no damage at all

Well constructed adobes experienced no damage at all



Poorly constructed adobes experienced moderate damage

FIG.12 Adobes in the epicental area of the Volvi 06.20.78 EQ

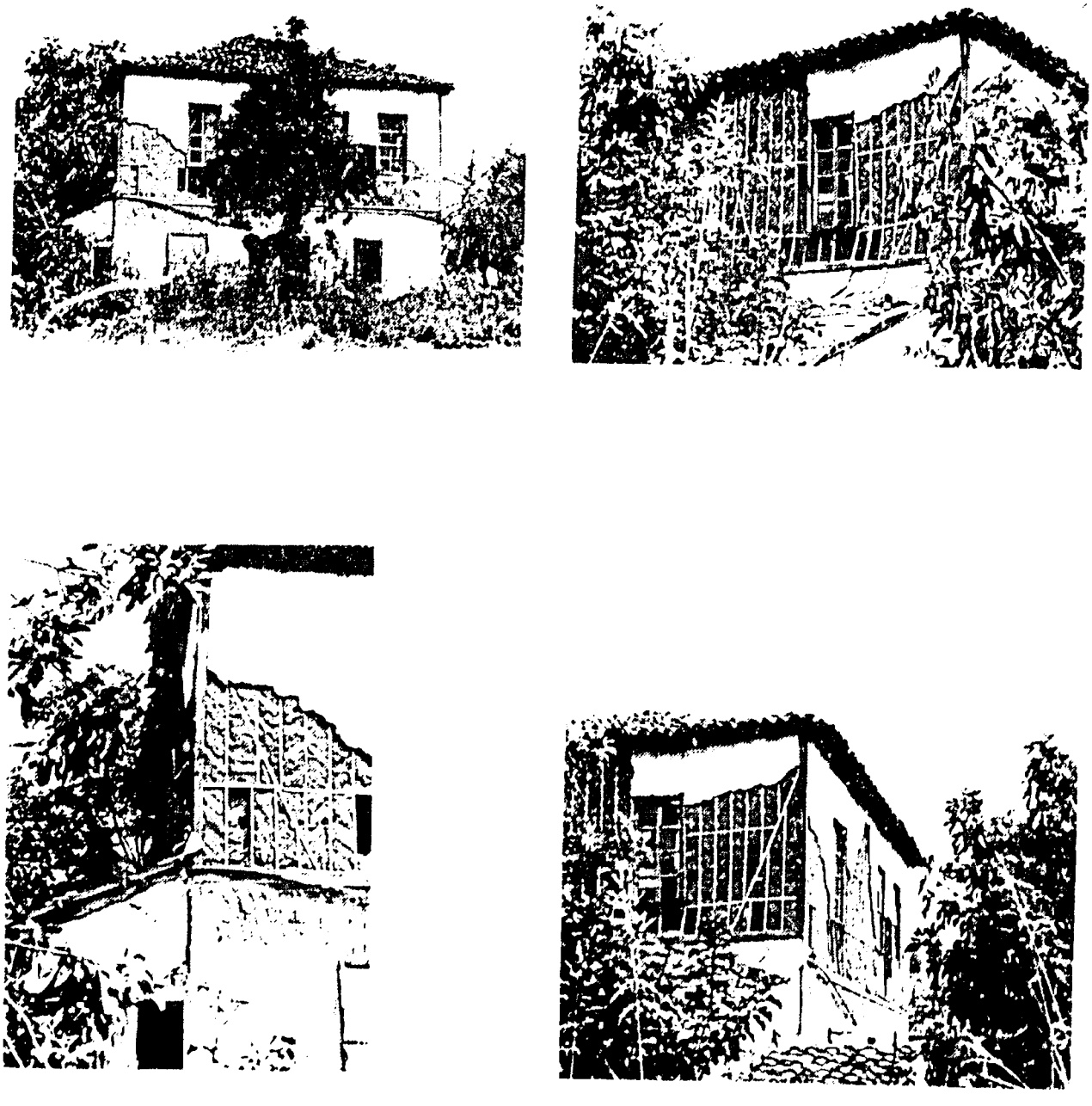


FIG.13 Adobe infilled timber framed dwelling in epicentral area of the Volvi 06.20.78 EQ. Many of them experienced only moderate damage

FIG.14 Traditional Construction Systems (Tsatma,Stone Masonry) of poor construction and/or maintenance experienced severe damage during recent EQs

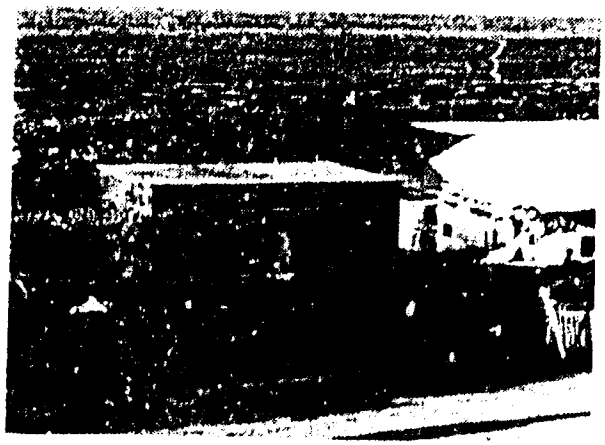
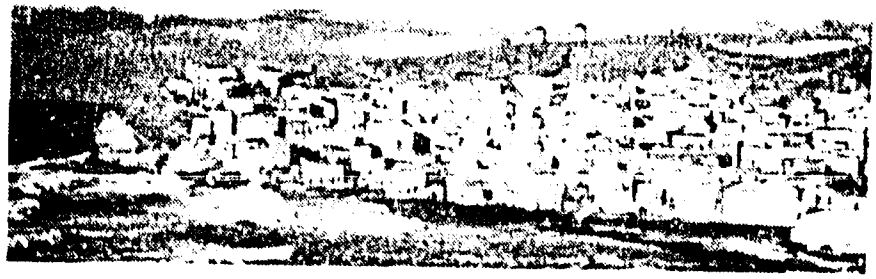


FIG.15 Modest brick masonry structure with light R.C. roof experienced no damage,while surrounding structures with mixed construction systems collapsed during the Alkyonides 03.4.81 EQ

FIG.16"Modern" rural dwellings collapsed,while well constructed "poor" structures with traditional construction systems survived with moderate damage during the Alkyonides 02.24.81 EQ

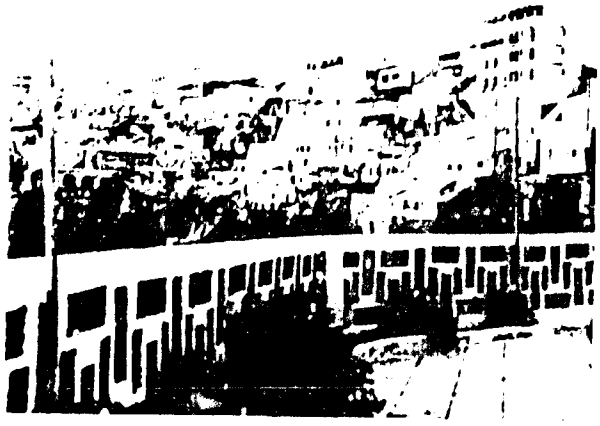
FIG.17 "Modern" rural dwellings with mixed (masonry + R.C.)construction systems experienced severe damage,while modest structures with traditional construction systems survived with moderate damage during the Volvi 06.20.78 EQ

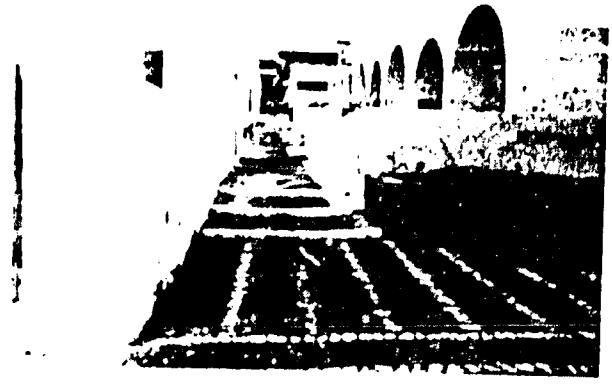


Before

After

Agios Efstratios before and after the 1968 EQ





Before After

Santorini before and after the 1956 EQ

FIG.18 Complete loss of the human scale and of the aesthetic effect during reconstruction of vernacular settlements after EQs

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PLANNED TESTING PROGRAM ON THE ROORKEE SHOCK TABLE

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ABSTRACT

A brief description is given of the shock table at Roorkee, India, which is capable of destroying 20-ton structures by imparting horizontal foundation shocks of up to 2g. A year's program of testing earth or low grade masonry structures on this table is planned. This paper lists a number of alternatives concerning how to test and what to test, from which the testing program will finally be determined. It is requested that readers transmit to the author their recommendations about the matters listed or other matters relating to the project.

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Introduction

The author is planning to work for one year at the University of Roorkee, Roorkee, U.P., India, testing structures of earth or of brick laid in mud mortar, on the railway wagon shock test facility there. This facility, illustrated in Figures 1,2, and 3, consists of a table 6m x 7m, mounted on a railway carriage which is pulsed by impacts, through springs, from other wagons which roll down inclines. An example of acceleration pulses is shown in Figure 4, and examples of damage to test structures are shown in Figures 5 through 8. The facility is capable of imparting rough half-sine uniaxial acceleration pulses of 0.15 sec. duration, up to 2g amplitude, to the base of 20- ton test structures. The pulses are widely separated in time, therefore resonance of the test structures cannot be developed. Table 1 shows a record of table and building performance experienced in the first use of the facility, in 1977, (1).

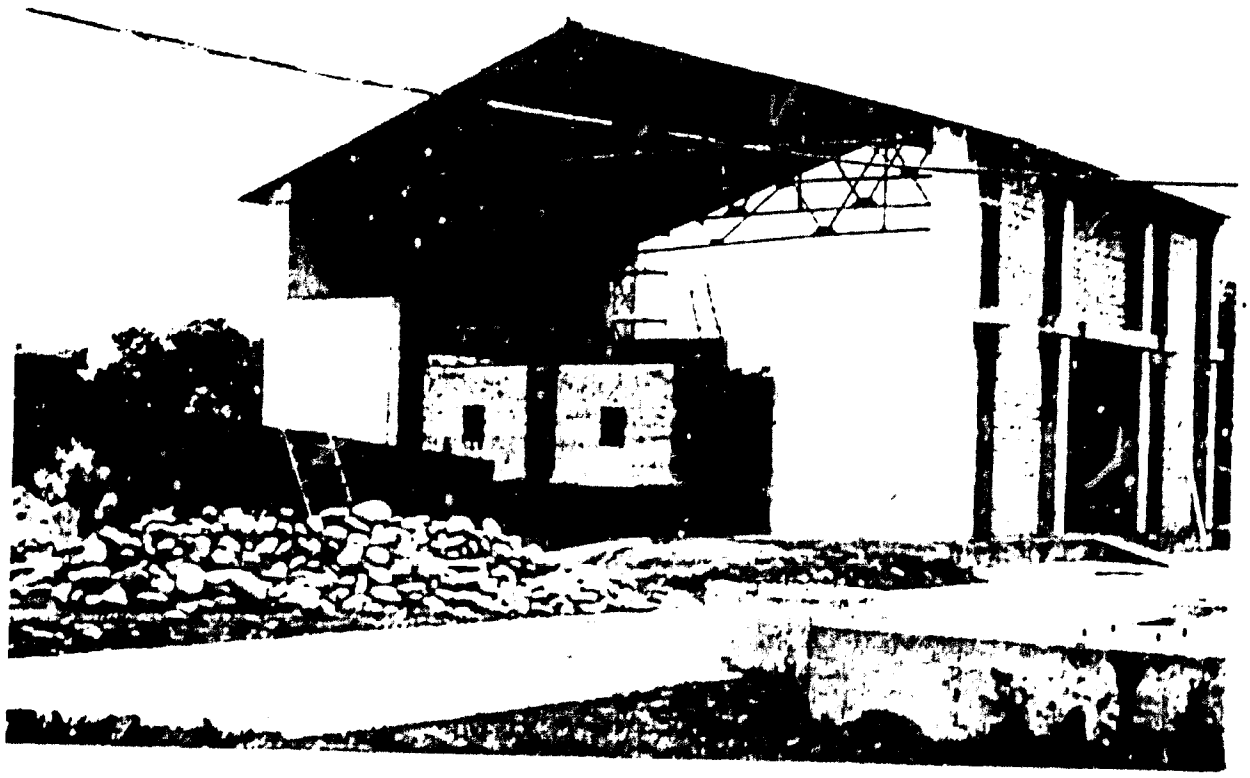
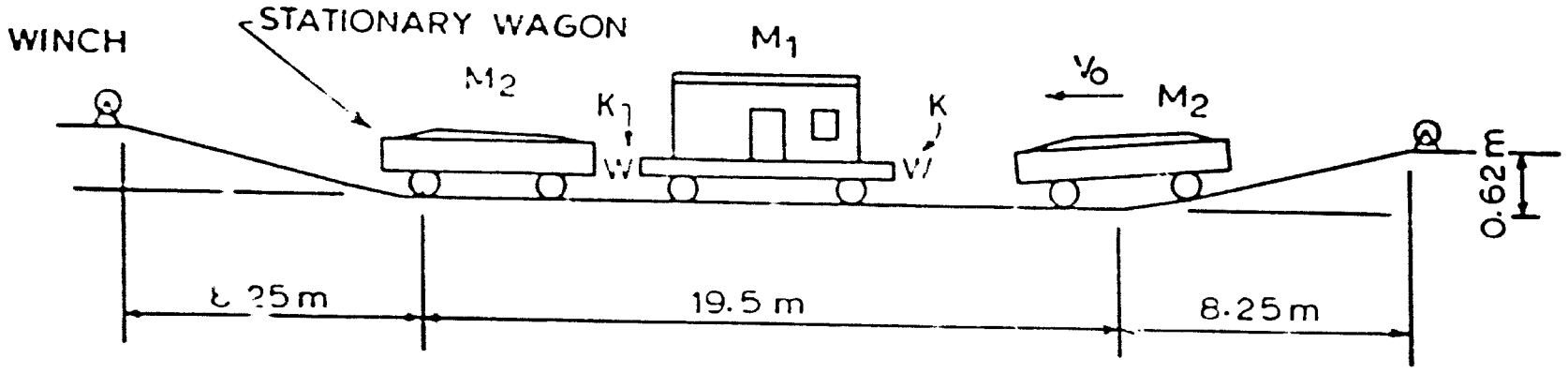
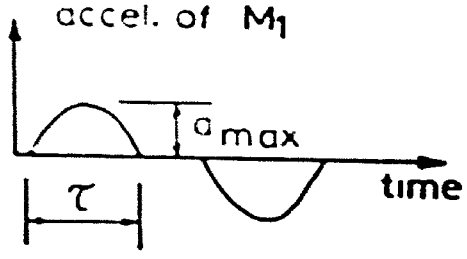


FIG. 1
The railway wagon shock test facility at the University of Roorkee, showing half scale one room structures on the table.

For best use of time, money, and equipment, researchers should be aware of what the others are doing, and to some degree should coordinate their efforts. This paper is to inform readers about a planned testing program, and to seek their advice as to certain aspects of the actual testing. It is hoped that the questions raised here and the suggestions offered by readers will stimulate thought and discussion among earth structure specialists, and result in optimum choices for this particular testing program, as well as influence plans for testing programs elsewhere. Of course, plans for this program must be discussed with and be approved by the host, the Department of Earthquake Engineering at the University of Roorkee.





Treating M_1 AND M_2 as rigid

$$\tau = \frac{\pi M_1 \sqrt{\alpha}}{\sqrt{K M_1 (1+\alpha)}}, \quad \alpha = \frac{M_2}{M_1}$$

$$a_{max} = \frac{\tau V_0 K}{\pi M_1}$$

FIG. 2.

Railway Wagon Shock Test Facility

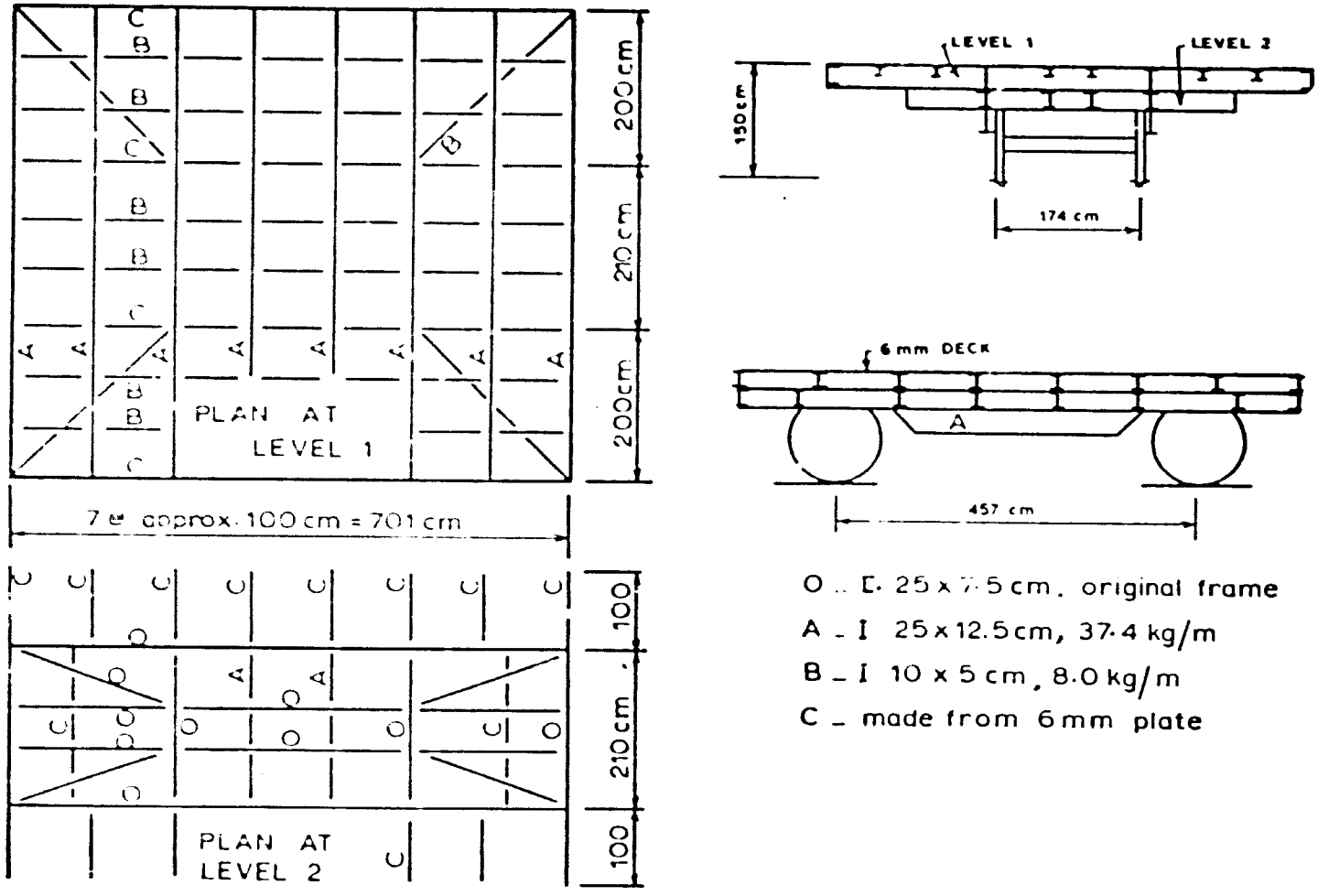


FIG. 3

Structural Details of the Shock Table

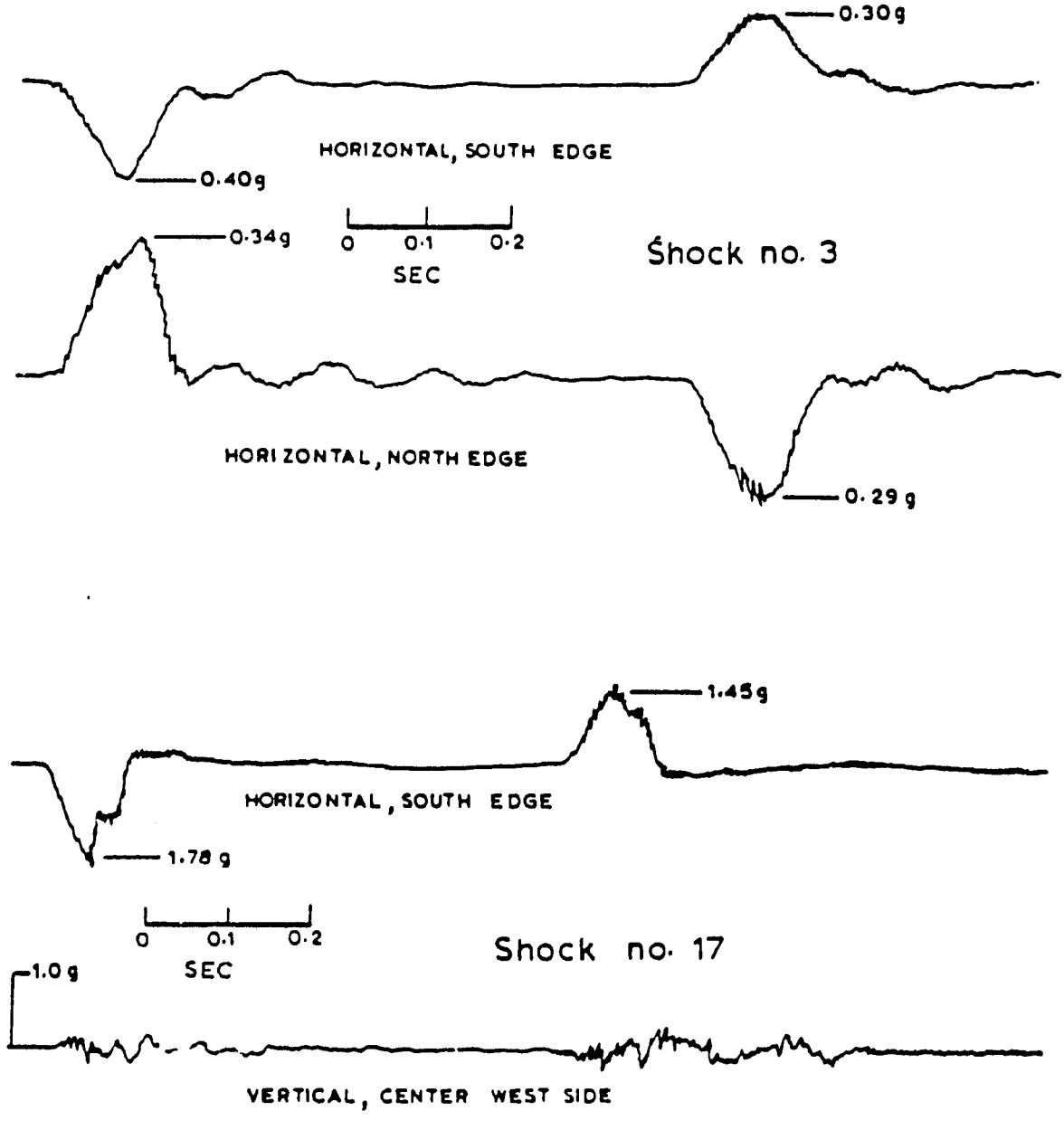


FIG. 4

Accelerations of the Shock Table

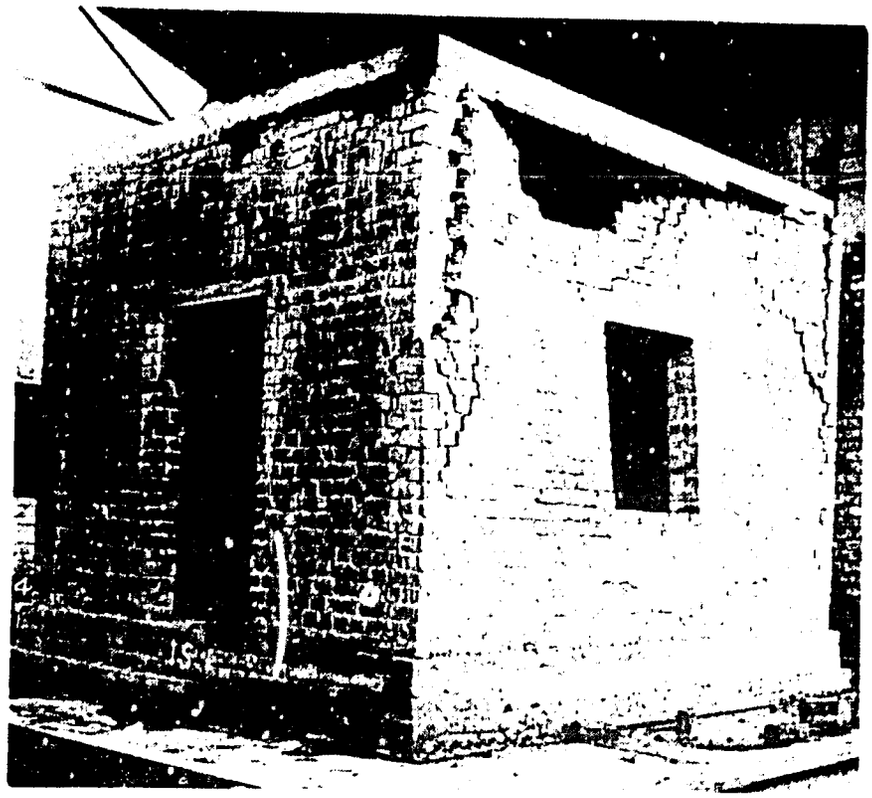


FIG. 5
Failure of unreinforced brick structure laid in mud mortar.

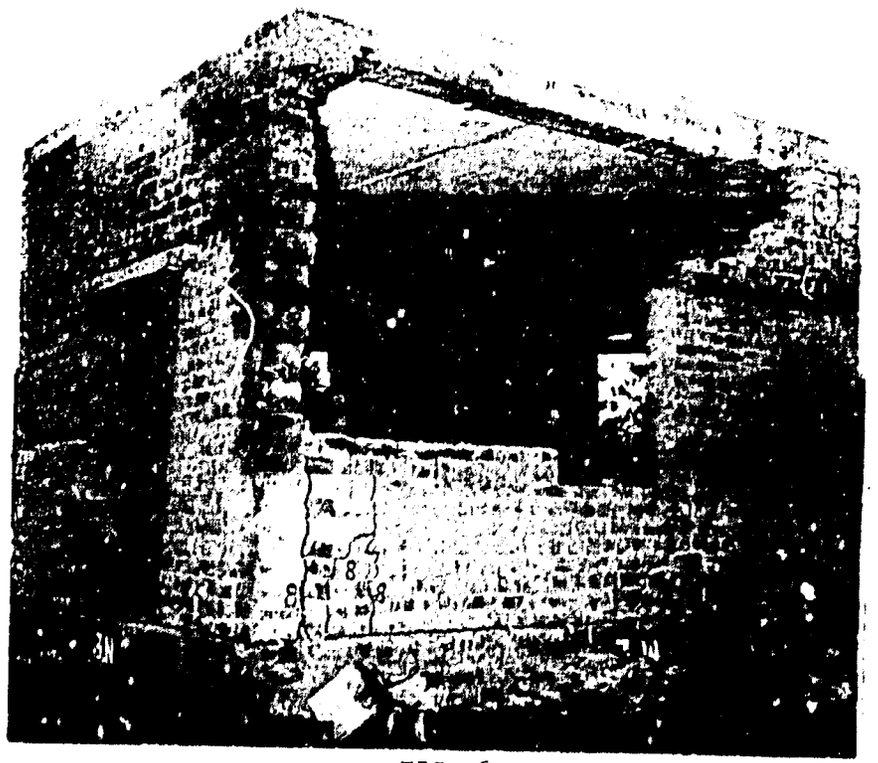


FIG. 6
Failure of unreinforced brick structure, 1:6 cement mortar.

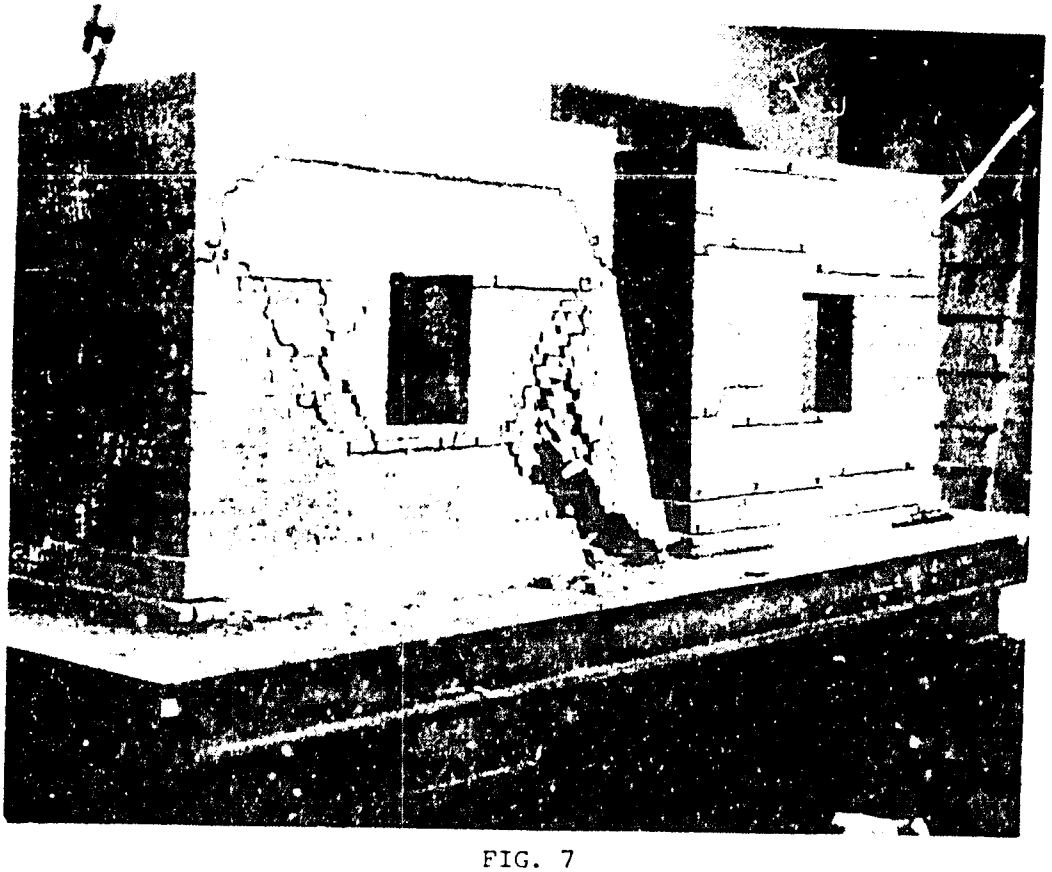


FIG. 7
Brick structure with mud mortar, bond beam, reinforced corners.

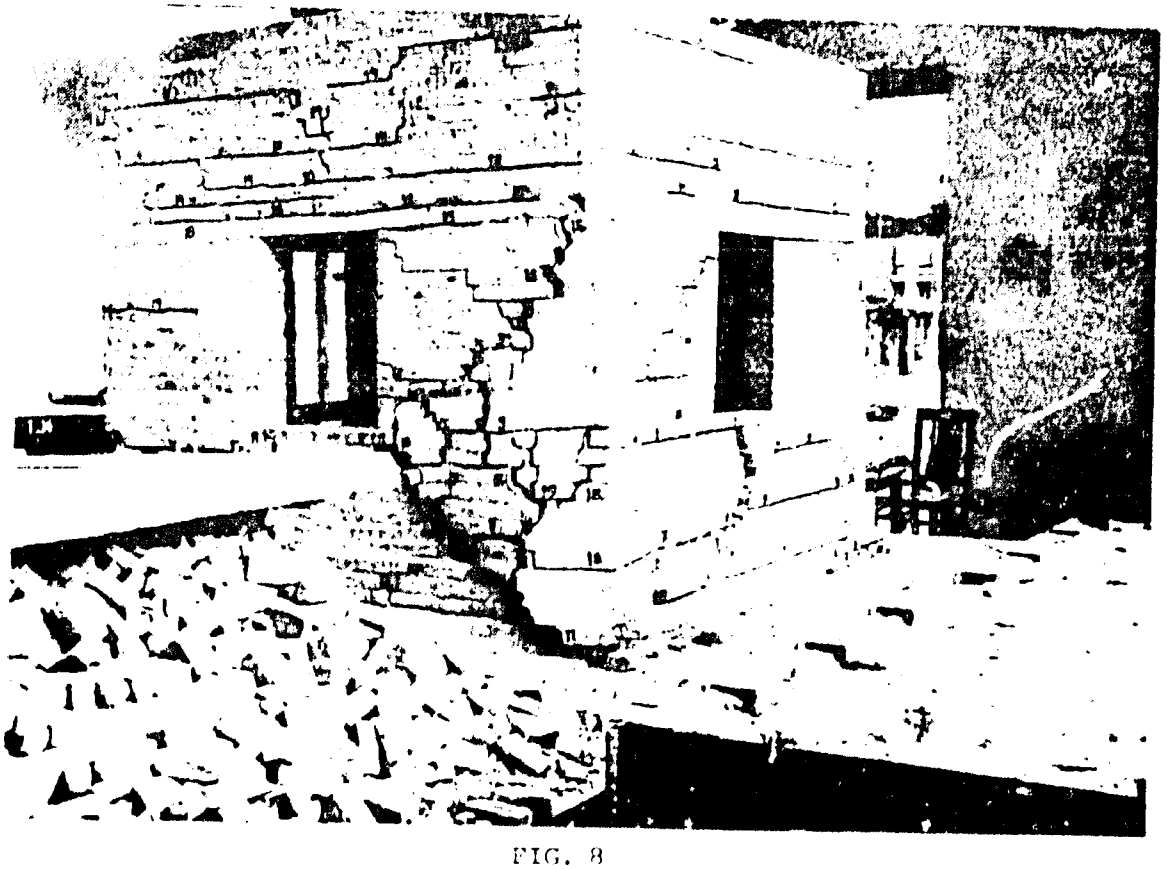


FIG. 8
Brick structure with cement mortar, bond beam, reinforced corners.

TABLE 1

Accelerations of the Table and Damage to Structures

Shock	Direction From	Dead Load Wagon Position	Maximum Horizontal Acceleration initial impact s. side	n. side	rebound s. side	n. side
1	E	14.5		negligible		
2	E	15.5	0.22 g	0.20	0.14	0.10
3	E	15.5	0.40	0.34	0.30	0.29
4	W	15.5	0.51	--	0.47	0.36
5	W	15.5	0.57	0.47	0.46	0.37
Transverse walls of PM cracked						
6	E	17	1.05	0.78	0.96	--
Base crack all around PC, shear wall cracks in PM, RM						
7	E	17	0.83	0.84	0.71	0.84
Transverse walls of PC bending, foundation cracks in RM						
8	W	17	Power failure			
PM demolished, small cracks in RC						
9	W	17	1.24	1.18	1.16	1.01
All walls of PC have wide cracks						
10	W	17	--	0.22 vert	--	--
PC demolished, large foundation cracks in RM						
11	W	17	--	0.19 vert	--	--
12	W	17	--	0.32 vert	0.97	--
13	W	17	1.26	0.36 vert	1.06	0.55 vert
14	E	18	1.30	1.27	1.30	1.46
RM demolished						
15	E	19	1.85	0.49 vert	1.40	0.31 vert
16	E	19	1.84	0.30 vert	1.52	0.30 vert
17	E	19	1.78	0.21 vert	1.45	0.18 vert
18	E	18	1.60	1.56	1.36	1.47
19	E	19	1.95	1.83	1.68	1.63
RC demolished.						

Mortars: PM: plain mud, PC: plain cement, RM: reinf. mud, RC: reinf. cement

Decisions To Be Made About The Testing

1. It is not presently possible with any testing facility to duplicate the tri-axial base input accelerations to a structure caused by an earthquake. Furthermore, all earthquakes are different, and the motions of future ones are unknown. The question of what should be the character of the input accelerations in a test facility will always be with us. The facility at Roorkee can provide only simple pulses, so the choices are limited, but the question must still be answered. How should the amplitude of the acceleration pulses be varied in the sequence of application? Should amplitudes be uniform, be steadily increased, or be held constant for several pulses and then be increased stepwise? In Figure 9 are shown examples of these possibilities.

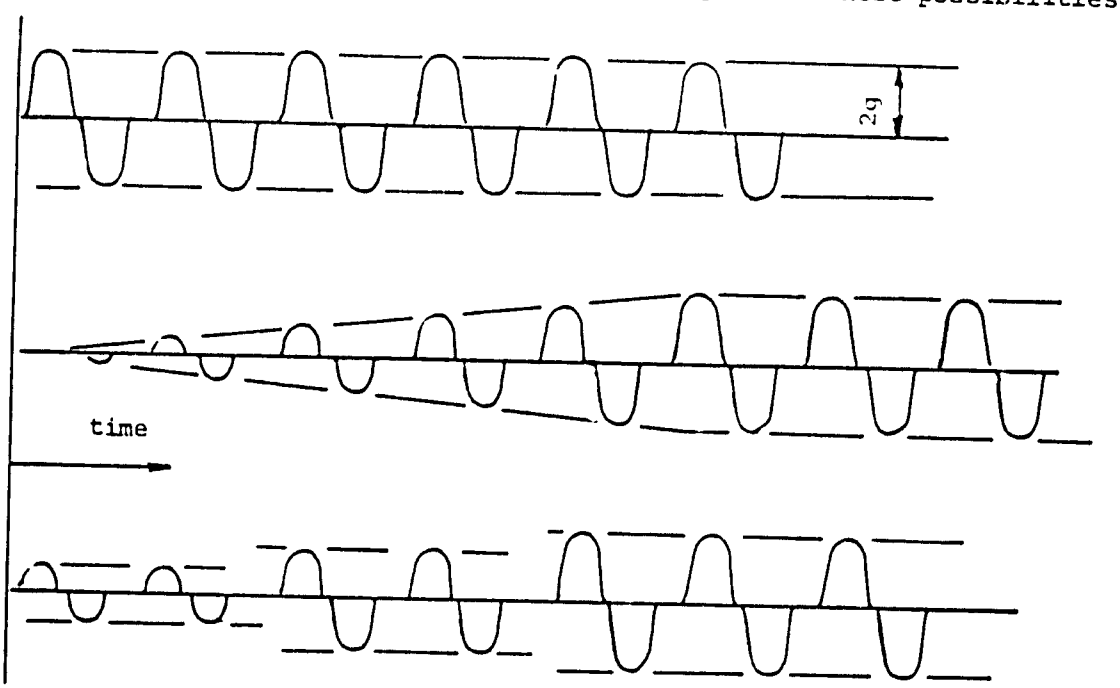


FIG. 9
Three possibilities for pulsing the structures.

2. How should damage be evaluated as a test progresses? Is there a way of realistically quantifying damage by measuring cumulative length of cracks, volume of cracks, permanent roof deflection, the ratio of roof acceleration/base acceleration, or some other condition or behavior?

3. What should be the size of the test structures? In the first test, in 1977, four structures roughly 2.0 m square were mounted on the table simultaneously as shown in Figure 10. Such an arrangement would permit 24 structures to be tested in one year, whereas only six could be tested if one structure filled the table. Do half scale models when tested at doubled acceleration behave the same as full scale models? Although the inertial stresses in the half scale models would equal those in the full scale models, the gravitational stresses in half scale models would be only half as large. Should the test

structures be oriented with the axes of the table, or at 45°, so that walls experience both inplane and out-of-plane forces?

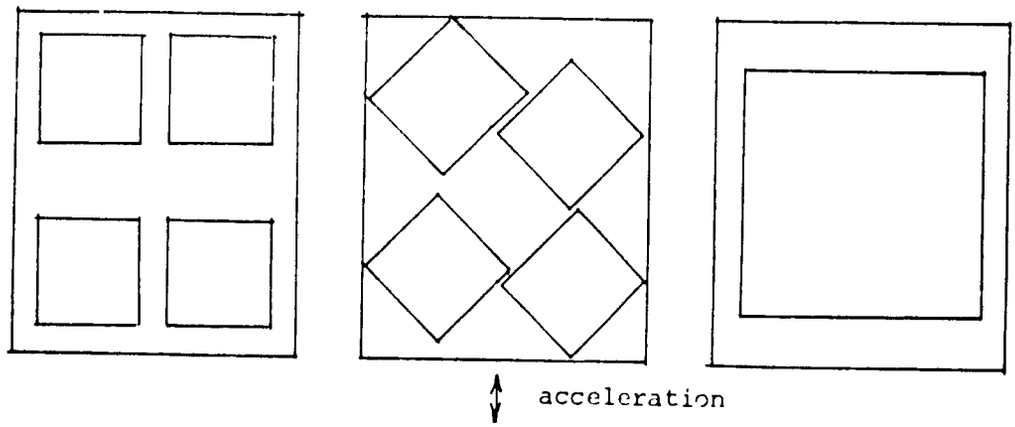


FIG. 10
Possible arrangements of structures on the table.

4. How much instrumentation should be employed? Surely, base accelerations will be measured. Is it worthwhile to measure roof accelerations, strains, or story deformations in order to attempt to describe structural behavior, or is it sufficient to simply assess damage after each pulse? Large amounts of instrumentation can be costly and time consuming, sometimes distracting the researcher from making more significant observations.

5. If one type of structure is tested several times, there will undoubtedly be a certain amount of scatter in the results, (2). How many repetitions of a particular test should be made in view of the fact that probably only six tests can be conducted in one year? If four structures are on the table each time, should one of them always be a "standard" structure, built the same each time?

6. What should be the layout of the openings in the walls of the test structures? In the first set of tests a door opening was put in a shear wall aligned parallel to the direction of the shocks, and a window was put in the center of each of the other walls, each opening occupying approximately 20% of the wall width. Should amount and position of wall openings be made variables?

7. What structural features should be tested? Since testing opportunities are limited, only the most important features can be considered. Below are listed features about which decisions will need to be made:

   (a) Solid reinforced concrete roof slab, or wood beams (parallel to pulses or perpendicular) overlaid with smaller cross pieces and a layer of clay, or a sloping roof of wood poles or trusses covered with clay tile or corrugated sheet steel?

   (b) Corners reinforced by buttresses (counterforts) built integral with the walls, and walls reinforced with pilasters (local thickening) at mid-length, or corners reinforced with wood columns fixed in the foundation, embedded in the walls, and attached to the roof or the bond beam, or

corners made of brick laid in cement mortar with steel reinforcing bars attached to the bond beam or to the roof, or unreinforced corners?

(c) Walls reinforced with vertical canes around which is poured a cement of some kind to bond the cane with the wall, perhaps a mixture of sand and clay slurry, the cane being wire tied to or embedded in the bond beam?

(d) Walls containing horizontal reinforcement in the form of barbed wire stretched between corner posts, if any, or small canes or other wood placed between courses?

(e) Walls reinforced with a skin, inside and out, consisting of wire mesh or jute cloth stretched over the wall surface and then coated with cement mortar or liquid sulphur, the skins being tied together by wires through the thickness of the wall, (3)?

(f) Walls reinforced with woven matting made of split cane, set vertically between the wythes?

(g) Bond beams placed at the top of the openings, or bond beams at the top of the walls, or bond beams at both places?

(h) Bond beams made of wood, or of reinforced concrete, or of reinforced masonry?

(i) Wood knee braces between walls and roof beams?

(j) A diagonally braced wood frame which supports the roof, infilled with earth between the bracing, or earth walls which support the roof?

(k) Walls made of fired brick laid in mud mortar, or walls of air dried mud brick? The use of fired bricks in mud mortar, common in India, would speed the work and reduce the cost because the fired bricks could be cleaned of mortar and be reused. A large supply of half scale fired bricks is on hand at Roorkee.

Concluding Remarks

It is seen that the many structural variations and reinforcements mentioned, and those not mentioned, will require a great number of decisions to be made. Should the testing work proceed slowly and methodically, examining the variables thoroughly, one by one, with the hope that additional years of funding will be forthcoming for this type of work, either in Roorkee or elsewhere, (funding for this proposed work is not yet definite), or should the work progress by leaps, testing a wide variety of the variables less thoroughly? Perhaps the answer to this question will be apparent after a few test results have been obtained. The author would appreciate the recommendations of the readers.

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EARTHEN BUILDINGS IN SEISMIC AREAS OF INDIA

Jai Krishna[1] & Brijesh Chandra[2]

INTRODUCTION

More than 100 million people in India live in earthen dwellings or buildings made of bricks in mud mortar having little tensile strength making them highly vulnerable to earthquake damage. Also, India has about 55% of its area as having moderate to severe seismicity getting earthquakes of magnitude greater than 5.5 (See Fig. 1). But realising that the earthen buildings can be damaged even by smaller shocks closeby, susceptible area may be as large as 75%. The problem of seismic resistance of such dwellings is therefore of considerable importance to India. Work done on brick buildings in different mortars has been published in references 1 and 2.

Earthen buildings are very suitable in view of their initial cost, low level skill for construction and excellent insulation against heat and cold, although they require heavy maintenance every year after rains. Such construction is in use traditionally since earthquakes are not so frequent, but when they occur they cause extensive damage, and if they occur after a rainfall, such dwellings simply collapse even in a small shock. Owners, therefore, tend to build in brick rather than adopt any methods of strengthening earthen buildings. That is why the studies planned to improve the resistance of such construction did not have the necessary incentive.

In hilly regions, which lie in 'severe' seismic zones, the usual form of construction is random rubble masonry put together generally without any mortar or at best mud mortar. Thus such dwellings are also hit badly during earthquakes. However since population density in hilly tracts is not as high as in plains, the total loss of life is small.

The present paper examines the dynamic behaviour of such buildings and suggests some economically feasible methods of improving them for seismic areas.

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DYNAMIC BEHAVIOUR OF EARTHEN BUILDINGS

Earthquake damage surveys have shown that the buildings made of earth, brick and random rubble have suffered because of their poor tensile resistance. There are numerous examples of complete collapse of such buildings in earthquakes of 1905 and 1975 in Himachal Pradesh, 1963 and 1980 in Jammu and Kashmir, 1958 and 1960 in Uttar Pradesh. At the same time there are some excellent examples of non-damage to other similar structures which incorporated some measures for improving seismic behaviour. A brick building built in Srinagar more than a century ago, has withstood many shocks which had caused considerable damage in the area. This building had horizontal wooden runners at plinth, lintel and window sill levels and it rested on soft alluvial deposit so that short period shaking got filtered before reaching it. Taking these observations as a base, a study was undertaken to examine means to improve the seismic behaviour of the traditional buildings built by common people. Some details of the work are briefly described here.

PROPERTIES OF MATERIAL

Since the seismic behaviour of a building is closely associated with the properties of material viz. tensile strength, shear strength, and damping characteristics, static and dynamic tests were carried out on such walls. It was seen that such testing is rather difficult since earthen wall strength is too small to permit any reliable measurements. Thus tests were conducted on brickwork in mud mortar which presented more uniform surface for load application and much better control on workmanship. For comparison, test results on brick walls and briquettes in 1:6 cement sand and 1:12 cement sand mortars (which came quite close to mud mortar) and brickwork in mud mortar are given below[3,4]:

Brickwork in Mortar	Tensile Strength psi	Shear Strength psi	Damping % of critical
1:6 Cement Sand	35	55	2 to 6
1:12 Cement Sand	5	30	4 to 8
Mud	4.5	25	5 to 10

It is further realized that in practice there would be a lot of variation in the strength of earthen walls since the methods of construction are 'non-standard'. Also as pointed out earlier, there would be a lot of variation when walls are wet, partially wet or dry. For this reason, the strength of such materials alone could not be relied upon to resist earthquake forces, and it is necessary to improve the structural system without changing the basic materials or form of construction.

IMPROVING EARTHQUAKE RESISTANCE

The traditional practice of building earthen walls consists of mixing earth with as much clay as possible to provide some cohesive strength and mix straw (about 1 to 2 lbs per cubic foot of earth) to improve tensile strength. The straw, of course, needs to be kept wet for a few days to improve workability. It is however difficult to assign any quantitative values to the increased strength by these 'admixtures', since workmanship and quality of materials makes considerable difference. Another step to improve the resistance of this form of construction is to waterproof the surface by coating it with bituminous mud plaster. This treatment cuts the maintenance cost also.

Strength of earthen walls can be improved by embedding in it split bamboo mesh as shown in Fig. 2, duly dipped in bitumen to protect it from rotting. This is an economical way of strengthening such walls against collapse. Where bamboo is not available, timber frame or only horizontal timber runners at lintel level with vertical members at corners could be used to strengthen the walls as shown in Fig. 3. It is sometimes recommended that at junctions of walls, timber dowels may also be provided at various levels as shown in Fig. 4 for tying the walls together.

Such walls necessarily have to have a roof as light as possible with their weight spread on the walls evenly. As far as possible openings should not be close to the junctions of the walls.

In buildings, made of brick or rubble masonry, the first step to strengthen them is to use either lime or cement mortar and the second stage consists of providing reinforcement at suitable places. The change of mortar alone increases the overall cost of construction by about 5 to 7% and provision of nominal reinforcement at corners and in lintel band as shown in Fig. 5 may add another 2 to 4%. These features increase the resistance of brick construction to about three times the strength when built in mud mortar without any reinforcement. Details of such recommendations are now available in IS:4326-1976[5] (Indian Standard Code of Practice for Earthquake Resistant Design and Construction of Buildings).

The above recommendations are based mainly on the experience and studies made at Roorkee, India. IAEE monograph[6] includes this work in detail.

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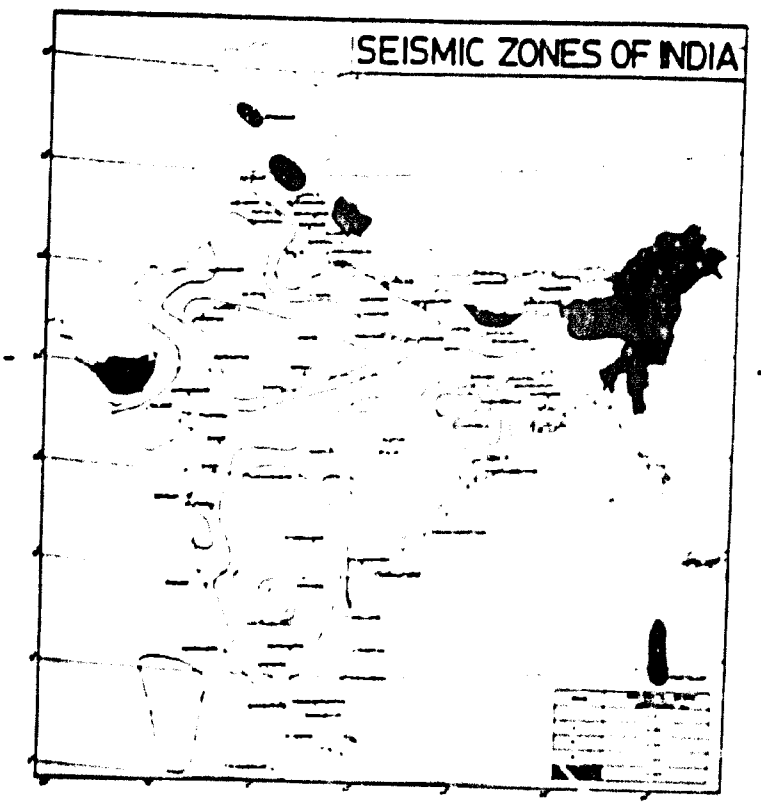


FIG 1 - SEISMIC ZONING MAP OF INDIA

FIG 2 - SPLIT BAMBOO WALL IN MUD WALL

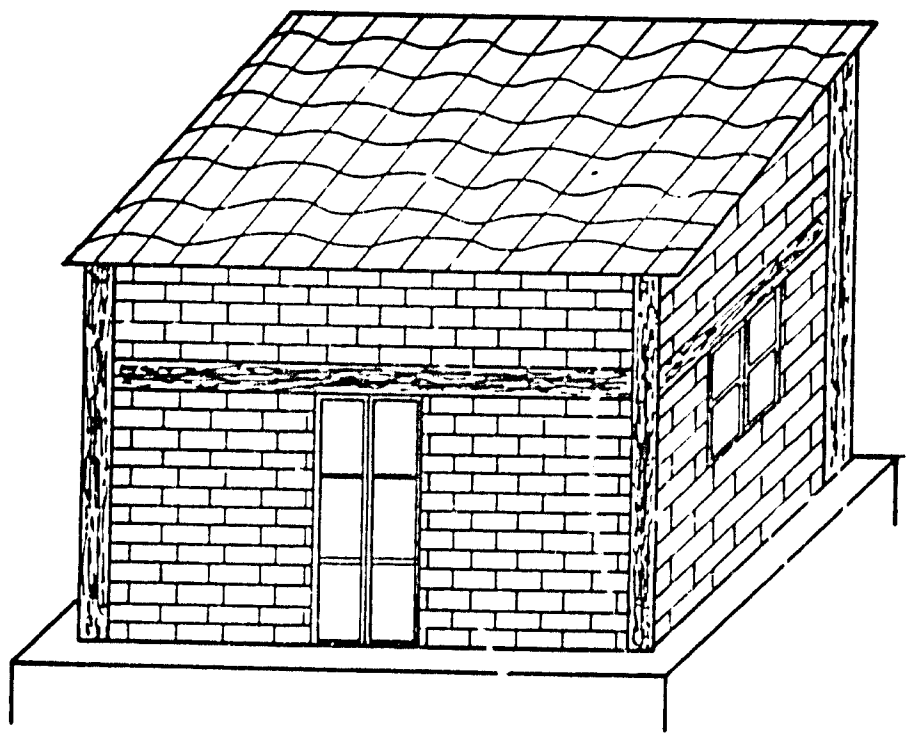
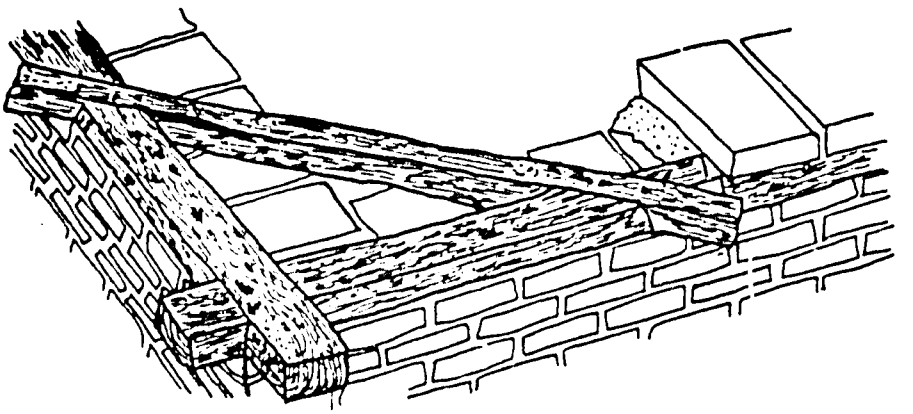
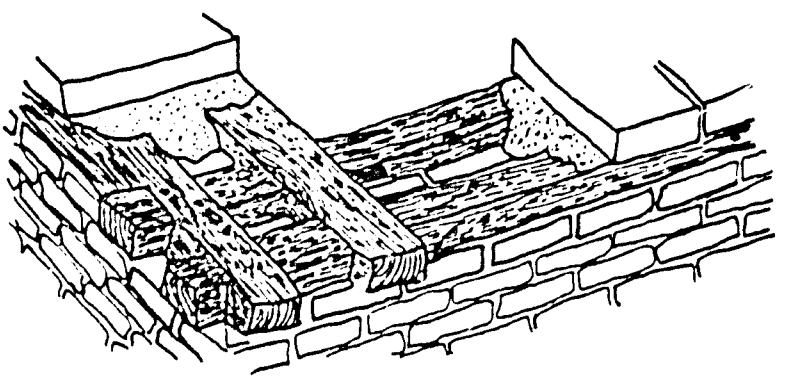


FIG. 3_ BRICK HOUSE WITH VERTICAL MEMBERS AT CORNERS AND HORIZONTAL RUNNERS AT LINTEL LEVEL IN TIMBER



(a)



(b)

FIG. 4 _ STRENGTHENING OF EARTHEN WALLS
(a) Diagonal Dowels at Corners
(b) Horizontal Punner in the Wall

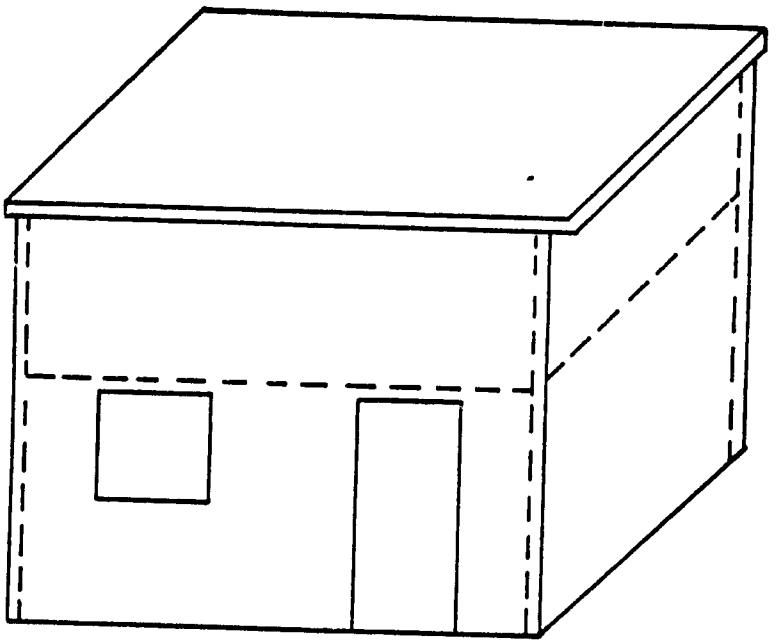


FIG. 5 _ REINFORCED BRICK HOUSE WITH LINTEL BAND AND VERTICAL STEEL AT CORNERS

THE WORK ON EARTH STRUCTURES IN THE DOM. REP. PAST AND PRESENT

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ABSTRACT: With a brief introduction the history of earthen buildings in the Dom. Rep. is described, with its uses and problems, both structural and socio-economic.
The main text deals with the work of the Foundation in adobe and rammed earth structures. Described is the soil stabilization technique, innovative formwork, design, roof structure, preservation methods, etc. and finally the future of earth construction in the Dom. Rep.

The Dom. Rep., in actuality, does not have a broad history of earthen structures. The original inhabitants were the Arawak (or Taino) Indians who were rarely known to live in earth houses basically because the island was so lush in vegetation. They had no need to use earth as a building material since there was always wood available. The island also had a high degree of rainfall which, according to the Spaniards, discouraged them from using earth since the rain tended to damage it. The Arawaks, in general, built their dwellings of wood and palm leaves.

TEJA - MANI

Around the middle to the end of the sixteenth century the Indians had all but disappeared creating thus a vacuum in the labor force. The French soon began to import African slaves to fill that shortage and at the same time importing their culture which still persists to date. At the same time, though much slower at first then accelerating rapidly in the last century and still more in this, the country was being deforested creating thus whole regions of dry hot climate. It was through necessity then, that certain people, not having the wood that was once very common, turned to earth as a building material. This change was accelerated by the fact that earth was a traditional building material of the original Africans. The technique that grew out of this necessity to use earth is called " teja-mani" and is now used in all of the Southern arid regions of the Dom. Rep. and in almost all of Haiti.

The method of construction is similar to "waddle-and-daub" and "bajareque" of Central America. The construction process begins with standing posts, approx. one meter on center, that become the structure's columns. These are connected at the top by a wood tie beam. Between the posts a panel of a weave of strips of small size wood (almost the size of twigs) is placed and to this panel wet dirt is applied. Their criteria for selecting the soil has more to do with the color of it than with its resistance to weathering. Upon examination we have found it to be a white silt with between 15 to 20% clay, just enough so that it adheres to the weave. There are no stabilizers used of any sort and no preservation techniques so naturally maintenance is high, and the life span short. The foundation, that I represent, is working on ways to improve this system for future construction and on ways to rehabilitate existing structures.)

COLONIAL BUILDINGS

The other early example of earth construction in the Dom.Rep. are the buildings of the Spanish Colonial Era. During this period all the important structures were built of earth and lime, and although after the middle to the end of the seventeenth century it was rarely used, today it is becoming the focus of a lot of attention. It should be noted that not long after the Spanish occupation of the Dom. Rep., began that the seat of the Viceroy was moved to Havanna and the country was largely ignored. During this period this method of construction using earth fell into disuse and wood construction replaced it.

However, the fact that these structures have stood almost five centuries withstanding tremendous hurricanes and earthquakes has begun, as recently as ten years ago, to impress the Dominicans. Because of their general lack of familiarity with earth construction their receptivity to it has been poor. The recent attention given to the colonial buildings has done much to help sway the public opinion in favor of earth structures.

The term given to this method of construction is "tapia", and it basically is a composite of clay, rubble, lime and bricks loosely compacted into a wall of approximately one meter thick.

SINVA - RAM

Recently there have been several attempts to implement housing programs using the SINVA - RAM to make earth blocks, and many of them have failed due to several reasons. One of the reasons of which I will talk more of later is the cultural taboo associated with earth structures. Another has to do with hurricane San Zenon of 1930 which literally devastated Santo Domingo with over 10,000 deaths. Most of the buildings of the Capital City were made of wood with roofs of zinc sheets, and these were precisely the structures that suffered the most. As a result of it, Rafael Trujillo, who came to power one year before the hurricane (1929) and remained there for 32 more years, instilled the idea in the Dominican mentality that cement and concrete block were the only building materials that could resist high winds and therefore the only materials worth building with. This erroneus concept has been the most difficult obstacle to change that we have had to overcome. The concept is so ingrained that for the average Dominican to have a house of concrete block is a status symbol, a measure of his position in society. In other words, cement is synonymous with progress. To try to convince the average Dominican of the necessity of using alternate construction materials has not been easy, but the economic situation is such that the price of a bag of cement went up 33% the last time it was raised.

Another problem with a couple of the SINVA - RAM programs has been the lack of thorough training so that what happened in some cases where the earth walls were not made to be water resistant the rains caused considerable damage. This has created a serious credibility gap .

Still yet another factor against earth construction has been the very color of the earth which in almost all cases has been red, the color of the most common clay on the island, laterite clay. According to the common misconception anything that is the color of dirt cannot have any structural value. (The obvious remedy in this situation is to finish the earth structure with lime or paint it thereby changing its color).

However, there have been several institutions successful in the past couple of years with the SINVA- RAM both of them on a small scale. One of them is the Institute for Development of the South (Instituto para el Desarrollo del Sur-IDESUR) which basically has worked at the level of individual buildings, houses, schools, etc. Their program is very new and so it is difficult to assess its re-

sults as of yet. The other organization working with the CIEVA-RAI now is a group of catholic priests in San Jose de Ocoa headed by Father Luis Quinn. They are constructing letrines, kitchens, sheds, etc, etc. with pressed earth block. The success of their program is due both to the receptivity of the population of San Jose de Ocoa, known traditionally to be very progressive, and to the dynamism of Father Quinn. As their structures are small and of minor importance their program has not yet really been put to the test. It will only be after they begin constructing larger buildings and living spaces that the full impact of what they are doing will be known. The success of their program, and really of any other program, will be measured more in terms of social acceptance than technical quality.

ADOBE

Adobe block construction has also been tried very little and when it has the results have been disastrous. On one well known occasion a housing program was tried in a region close to Haiti and rich in timber. This region is in the north where "teja mani" is not common. The result was that it was rejected because the houses resembled haitian houses, in that they were both made of earth, and the average Dominican rejects anything haitian as being primitive and anti-progressive. Also the region, being rich in timber, had no demand for earth structures simply because wood was so readily available. Perhaps if the project had been located in a deforested region the results would have been more positive.

Several universities also have experimented with adobe block construction but never have the results been implemented in the field. This situation is very familiar in the Dom. Rep. Too much has been done under laboratory conditions and too little (if anything) has been done in the field. Presently, adobe block construction is not being used by any major group or organization, to my knowledge, except the Foundation for Community Development, which I represent.

THE WORK OF THE FOUNDATION FOR COMMUNITY DEVELOPMENT

The work of the Foundation is concentrated primarily in the western part of the country close to Haiti in two areas, one of which is in Las Matas de Farfan to the South central and the other is to the north in Loma de Cabrera. The whole frontier is an extremely depressed and largely ignored region. At each of the two locations we selected, we are building schools for organic farming and appropiate technology (Centro de Agricultura Organica y Tecnologia Apropiada para la Comunidad- CAOTACO).

The principal buildings at both centers are being built of rammed earth, which I will discuss further on; but the interior partitions, letrines, sheds, and other minor structures are being built of adobe blocks. At first our only intention in using two different systems of earth construction was to enrich our own experience and also to expose the people to at least two types of construction. As it turned out the experience served as a basis for comparison demostrating both the pros and cons of each system.

based on this study we decided that any future extension work of the center would employ adobe or pressed earth block instead of rammed earth, of which we have more experience. The reason for this is that it resembles much more the method of construction of concrete block which is the most common and used everywhere in the Dom. Rep. We have found that rammed earth is too different from the systems used here and therefore it takes more time to train personnel. It also is easier to convince the people of the value of earth block construction than it is of rammed earth. As of yet there is only one extention project, that of a school in La Matas de Farfan, that we intend to built with earth block.

The center at Las Matas is in a semi-arid region. The people's reception here has been very positive because the system of construction of "teja-mani", that was described earlier, is common and wood is becoming difficult to obtain. In the year we have building the center we have detected no cultural problems that inhibit the acceptance of these earth structures, either rammed earth or pressed earth block.

The center in Loma de Cabrera is a different situation. As it is in a mountainous region rich with wood the people there have not yet accepted earth construction with the same zeal as in the South. Even though the cutting of trees for wood is against the law in the Dom. Rep., the inhabitants of that area do it constantly and use it to build their houses. We expected this; and though there probably will not be much extension building in the next six months, the goverment is becoming very strict with the anti-deforestation laws. This will obligate individuals, groups or organizations in that area to seek alternate building materials. Those who cannot afford the spiraling cost of cement, and there are many, will turn to earth structures.

RAMMED EARTH

The main buildings of both schools, six in each school or twelve in all, are being built of rammed earth. In neither case did we encounter problems in finding sufficient clay though both sources were found under the top soil. We selected clayey soils mainly because we found that was easier to add sand to clayey soils than it was clay to sandy soils. The proportions used were 3 parts clay, 3 parts sand, and 1 part lime. One of the basic ideas behind this project was that to design and build everything so that it would have a high degree of replicability in the field by the farmers. Immediately this made us discard cement as a stabilizer because of its cost, which at the frontier is about $5.00 a bag. Instead we used lime which is very common in almost all regions of the country. In Las Matas there is a lot of limestone, so we simply cooked it using a traditional technique taught to us by the inhabitants of that region. In this fashion we had an abundant supply of lime and at very reasonable prices. We found that although the 3:3:1 proportion was the guide, small variations did not considerably alter the quality of the construction.

What we were always careful to control was to add the correct amount of water to the mix, because if it were too dry it would not

compact well and too wet a mix created a mud. In the preparation of the mix we took great care to screen the clay, eliminating any balls of clay or gravel, them add the lime and wet it lightly. We found that by letting it sit for awhile the lime broke down the clay and thereby mixed with it better. After a day or so we added the required amound of sand, mixed it again and then again added water. At this state it was ready for compaction.

A good rule of thumb we established to help the workers determine the amount of mix they should compact at one time is that it should be about the height of a fist when they emptied it into the form. The height of a fist is about 4 inches which when compacted reduces to 2½ inches. The idea was to relate as many of the rules of thumb to elements they were familiar with such as a fist or as in another case we told the workers to raise the tamper to at least knee height before dropping it. In this case the rule of thumb was related to the knee which is something easily identifiable to them.

We found that the best type of tamper was one built of iron tube (6 ft. high and with and outside diameter of 2 in.) soldered at its base to an iron plate ½in. thick and 4 in. square. The 2in. diameter tube is optimun for long periods of time. If the weight of the tamper did not reach 20lbs. we would fill the handle with wet cement until it reached the desired weight.

At no time did we use any electric powered equipment such as air tampers or automatic mixing machines even though our work would have been easier because the intention in all cases was and is to enable even the poorest farmer to replicate what we were doing.

Our foundations were of cement and stone, using in both centers the abundance of field stone found on site. The soft terrain necessitated a strong foundation but in one experimental house built prior to the schools the rammed earth was set directly on a base of solid coral requiring thus no foundation. In effect the porous coral rock acted as the foundation for the house.

Our windows and doors were well braced using first a permanent frame of 1"x10" wood for the jamps and sill and a 2"x10" for the lintel. Inside this permanent frame was a temporary and reusable frame of heavier wood to prevent the collapsing of the 1"x10" 's. This bracing was essential as we discovered quickly that the ramming created tremendous pressure that on many occasion damaged not only the window and door frames but also the forms. The pressure also threw the window and door frames out of plumb.

FORMS

The forms we used to build the structures were totally our design and were determined by the system of construction we wanted. We decided that it would be best to ram a whole wall, from corner to corner, at one time thereby creating one whole monolithic section much stronger than if the wall were tamped in several parts. This decision was due in part to previous experience where we found that the only joint problems we had were vertical ones; and if the forms were short then the wall would have several vertical joints

between the rammed sections thus increasing the weakness of the wall. So we designed a form work system that was composed of sections that would fit together to create any length we wanted. In other words we designed a modular form system capable of creating any size space. This form can be put together so that it connects two corners of just about any distance from one another. At the same time it can subdivide the total wall or building into smaller spaces or rooms of any desired dimension by simply introducing a corner form at the desired location. From this corner form, in the shape of a "T", an interior wall, also of rammed earth, could begin.

Each full module is 90cms. (or three feet) long by 90cms. high and they are set 25cms. apart (or 10 inches") which is the thickness of the wall. A half module them is 45cms. (or 18 inches) long by 90cms. high. This creates a module of 18 inches and there are few activities not capable of being satisfied by multiples of such a small module.

There are several advantages to this type of system other than the fact that one can ramp a whole wall at the same time. One of these is that when one wall, from corner to corner, is finished one of the filled corner forms can be removed and located at the corner of a new wall and the rest of the forms can fill in the space between the two corners, one filled and one empty, thus creating a continuous system of forms. It is difficult to go wrong with such a system because it is versatile, and all the forms attach to one another. Another is that the individual modules are easy to handle because they are relatively small and light so that one can lift it up to the top of a wall two meters up.

The individual section along the same side of the wall are connected by metal hooks. The sections on different sides of the wall are held together at the top by an easily removable metal hook that prevents movement in either direction, and at the bottom by a metal rod that holds the forms together with the use of a nut that screw on one end of the road. The sections on one side of the wall are held in a straight line by guide bars.

The full height of the wall, to ceiling height, is achieved by ramping three rings around the structure. Considering that each form is 3ft. high and then subtracting a 4 in. overlap each time a form is placed over a previously built ring the total height of the wall when finished is approx. 8ft. In each of these three rings there are three layers of two strands each of barbed wire thus tying, horizontally, the whole building together.

ROOF

As the final ring is ramped reinforcing bars are set a foot down with one end sticking out at the top. The purpose of this is that the rebars hold the wood tie beam securely to the rammed earth wall. These rebars should not only hold the tie beam down but also should be spaced so that they coincide with the wood trusses or rafters thus tying those securely down also.

The center in Las Lajas was built to have shed roofs because

We knew it is the easiest type of roof to build. Though all the buildings there are built and look good, we decided that the roofs in Loma de Laurera should be gable roofs, because it was difficult for us to get beams the size and length we needed to cover the large spaces we had. In a gable roof one can use trusses that employ smaller sizes of wood and also easier to obtain. In a shed roof one wall has to be higher than the other, and in our case, because of the required slope of the roof, that wall was over 15 feet high, too high and therefore too unstable. In Loma de Laurera we are using a gable roof with a ridge beam supported at certain intervals by double trusses; then down the ridge beam we have rafters tying into the wood tie beam atop the earth wall. We designed this system specifically to save wood.

The roof itself is made of sisal-cement sheets that we construct on site. The principal is very similar to the sheet of asbestos-cement but in our case the fiber is sisal, a readily available raw material in the zone. The development of this roof is probably one of the greatest triumphs of our construction program because it can be made on site by the workers, is inexpensive, uses local materials, and is sufficiently strong to withstand the weight of any normal man.

WATERPROOFING - FINISH

There are several considerations to take into account with regard to the finish and weatherproofing of the buildings. One is that we knew that we could not leave the wall its natural color because it would be rejected by the people, and we also knew that if we applied any sort of weather proofing it would have to have an appealing finish and color to it. At first we tried treating the raw earth wall with liquid asphalt diluted with kerosene, but the result was not pleasing to the eye because the texture was rough and the color was black. There were other possibilities also such as using the sap from the plantain and other plants but these were not in sufficient quantity to warrant our recommendation for widespread use.

At one time we even liquid asphalt into the earth that we then ramped out for economy sake we rejected that method in favor of a surface weatherproofing that also served as a finish for the structure.

That we came up with something similar to that which the Spanish did to the colonial buildings that still stand today. They finished their structures with a combination of clay, sand and lime and considering everything it has weathered well. In our case, however, we used a mix of 6 parts sand, 2 parts lime and 1 part cement.

This finish is applied in the same fashion as any other finish using a float. Originally we tried to use a mix that did not have any cement in it, but we found that it did not adhere to the wall to our satisfaction. The final color and texture of the wall was pleasing. The resulting color was a light gray which we then either white washed with lime or painted with a water base paint. With a final coat of lime the buildings sparkled with a brilliant white.

We did several water tests to the finish and found that the mix that best resisted the force of a hose was that one that included at least one part in ten of cement.

DESIGN OF BUILDINGS

The design of the buildings was such that they not only adhered to the activities they were to enclose but also to a series of recommendations that would make them earthquake proof. Neither of these centers is in a hurricane prone zone so we only concentrated on making the buildings earthquake proof. We respected such criteria as making the basic shapes rectangular or square, locating windows on opposite walls just as doors were located on opposite walls, making the roof a complete integral structure not likely the break into pieces and collapse, locating columns along the walls at certain intervals, using barded wire keeping the windows and doors small and at a certain distance from the corner, tamping whole wall sections at a time, building interior walls that help brace the outer load bearing walls, etc. These caracteristics that we have observed give us enough confidence to be able to replicate this system in any extension project of the centers.

WORKING DRAWINGS

An easily understandable technique of working drawings developed out of the use of modular formwork. By drawing the wall showing the number and size of the forms the wall will take, the worker need only count them, lay his forms out accordingly, make sure they are plumb and start the ramming process. An attached drawing will better describe this. Here again we were trying to simplify all aspects of the total construction process so that any outsider, educated or not, could understand and follow it.

INTEGRAL COMMUNITY OF LA CIENAGA

On May 4 of this year the foundation began the initial stages of the construction of a community in La Cienaga located on the south west coast of the Dom. Rep. This project was designed by the National Housing Institute (Instituto Nacional de la Vivienda-INVI) a government institution but will be implemented by the foundation which is a private entity. This project is to be a model in two ways. First, it represents the first time that the National Housing Institute has provided the design of a project and then signed an agreement with the private sector for its implementation. This agreement is a model for future projects between the public and private sector. This project is the first in a series, and already the location of a second one has been selected, both of them representing two very different sets of conditions that exist in this country. La Cienaga is a coastal project, very vulnerable to hurricanes, with its particular economy, terrain, vegetation, culture, etc. The other site is Villa Vasquez, in the north, located in an arid region. This project is to respond to all the particular conditions of that region, such as its water problem, wood problem, food problem, etc. Each of these projects can be replicated, with some variations in the design, in the other areas of similar conditions. The community in La Cienaga is to be almost completely self-sufficient in food, health, energy, recreation, housing

education, and in sources of work. It will contain an area for the tree lucaena which will produce biomass, a communal organic farm, a market, a park, a school, a clinic, a communal latrine, an open space for sports and recreation, a communal center, 70 earthquake and hurricane resistant houses, and three small income generating businesses. All the structures will be made of pressed earth blocks using a machine we developed ourselves.

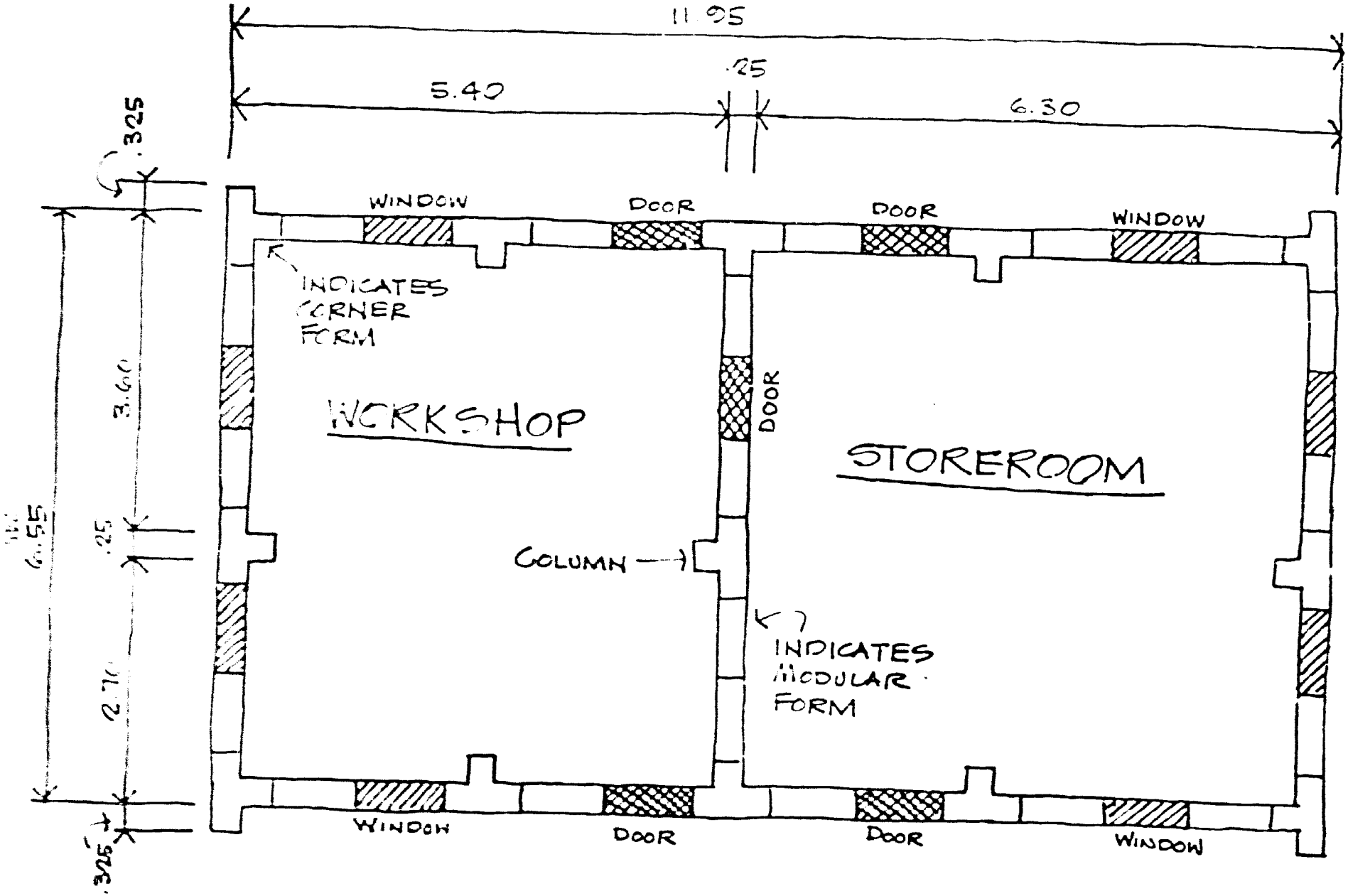
This project is a major landmark in the rural development of the Dom. Rep. and should set the standard for future projects, both of the public and private sector.

CONCLUSION

The Dom. Rep. has not been spared of the economic and energy crisis that is affecting the world. Change will inevitably come and we are fortunate to be in a position to help guide it where it should go.

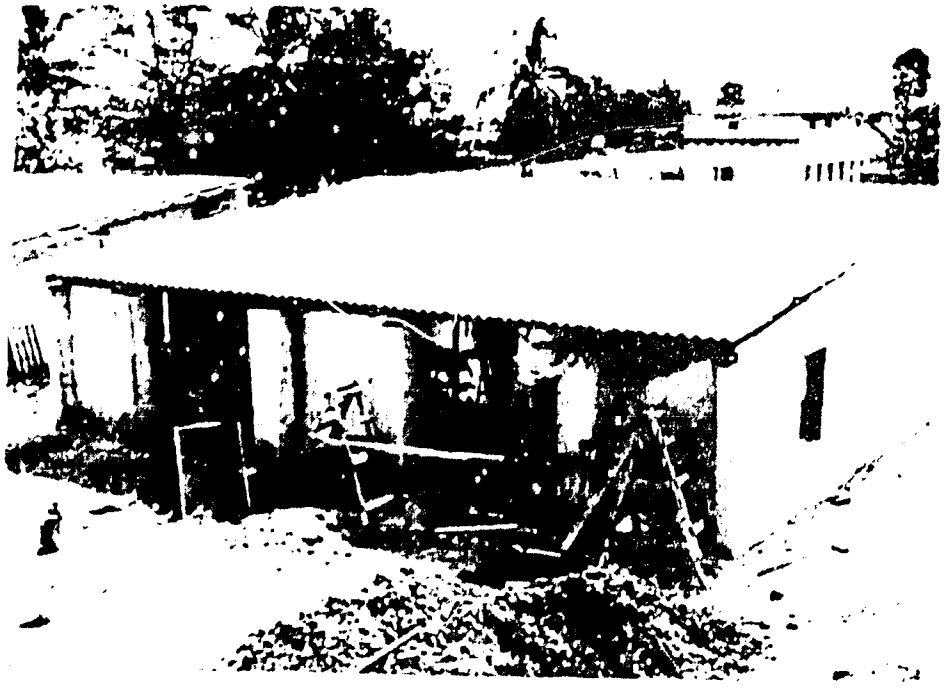
Such traditional construction techniques using concrete block and wood are becoming the exclusive property of only the rich. Even the unfamiliarity with earth construction will not be a barrier to its eventual use since economic factors and the ready availability of earth as a building material as compared to the slowly increasing scarcity of cement and wood have become a powerful argument.

Though the Dom. Rep. has been relatively [illegible] to the flow of new ideas perhaps this very isolation will permit it to create solutions all its own.

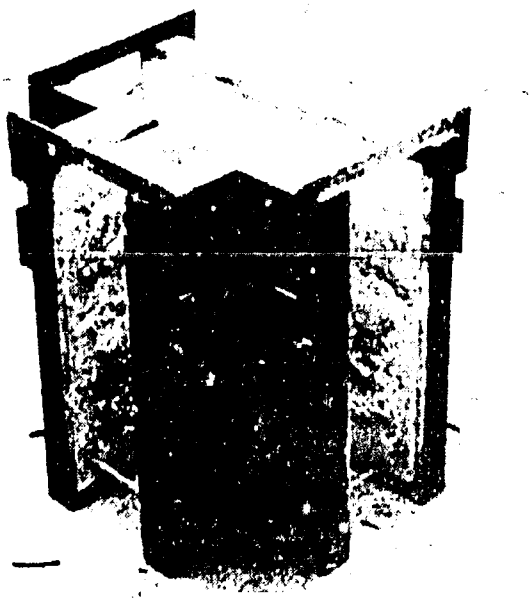


PLAN OF WORKSHOP - STOREROOM

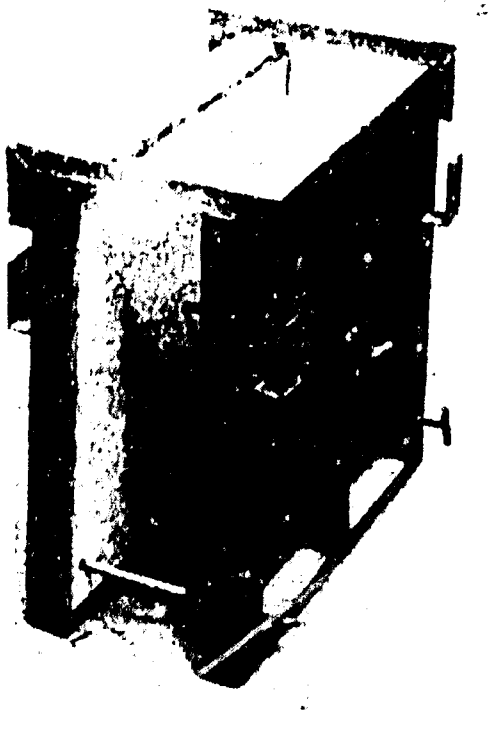
A "teja [illegible]" dwelling, very typical in both the [illegible] and Haiti. Notice how the earth has washed away from the weave.



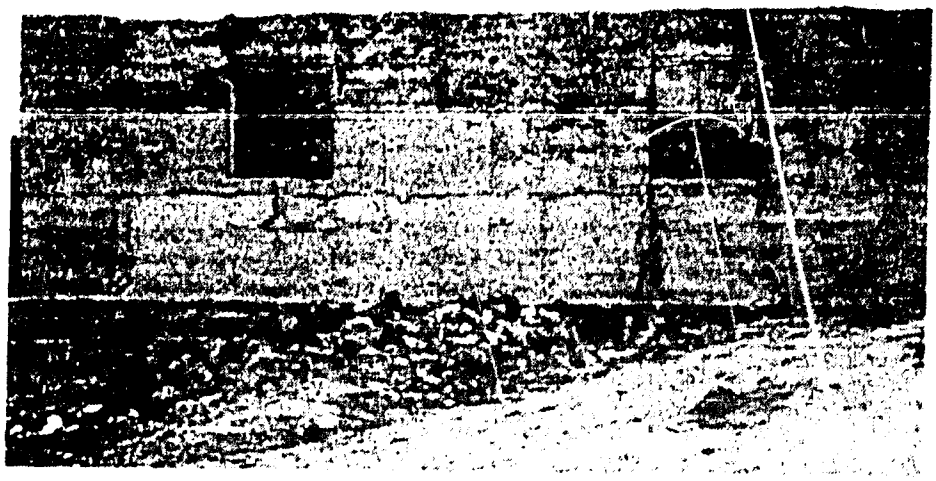
View of the classroom-dining room of the school in Las [illegible] de [illegible]. The walls are of rammed earth and the roof is of sisal-cement sheets.



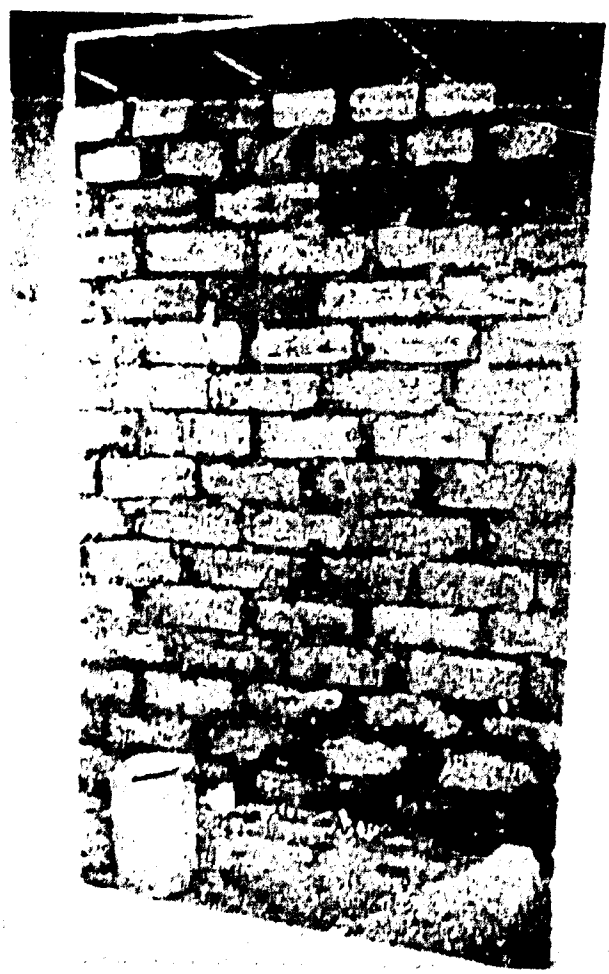
A corner form used in both centers. Notice the hooks on the top of the form holding it together.



A modular straight form that put together in series connects two corners. One can see the iron bars at the bottom that are removed when the form has been tamped full.



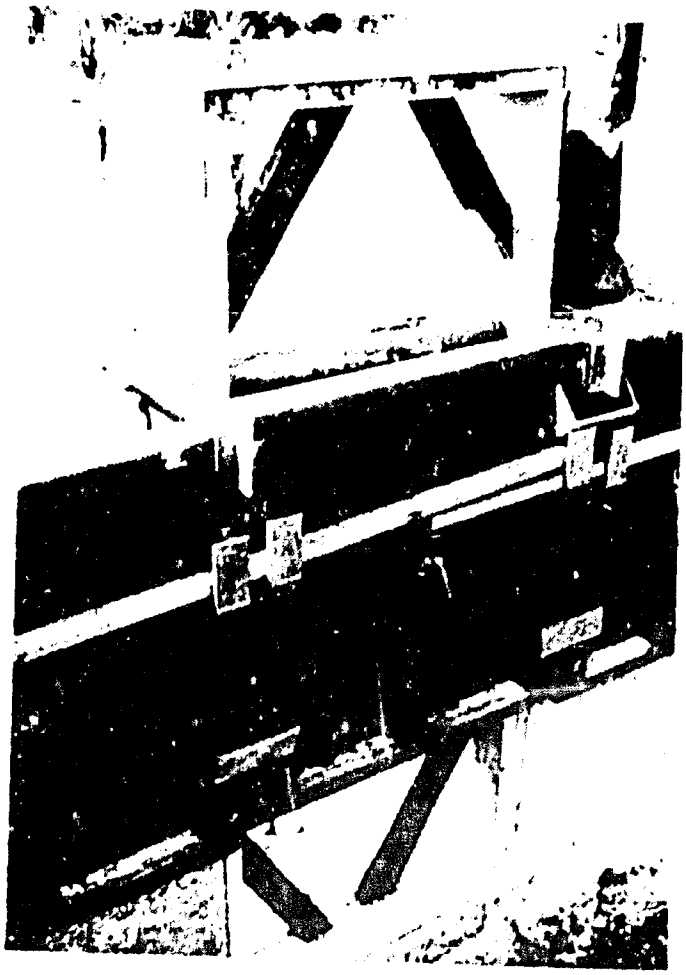
View of a whole wall tamped in three layers. This wall has not yet been finished or water proofed. On top the rebars that fix the wood tie beam to the earth wall can be seen.



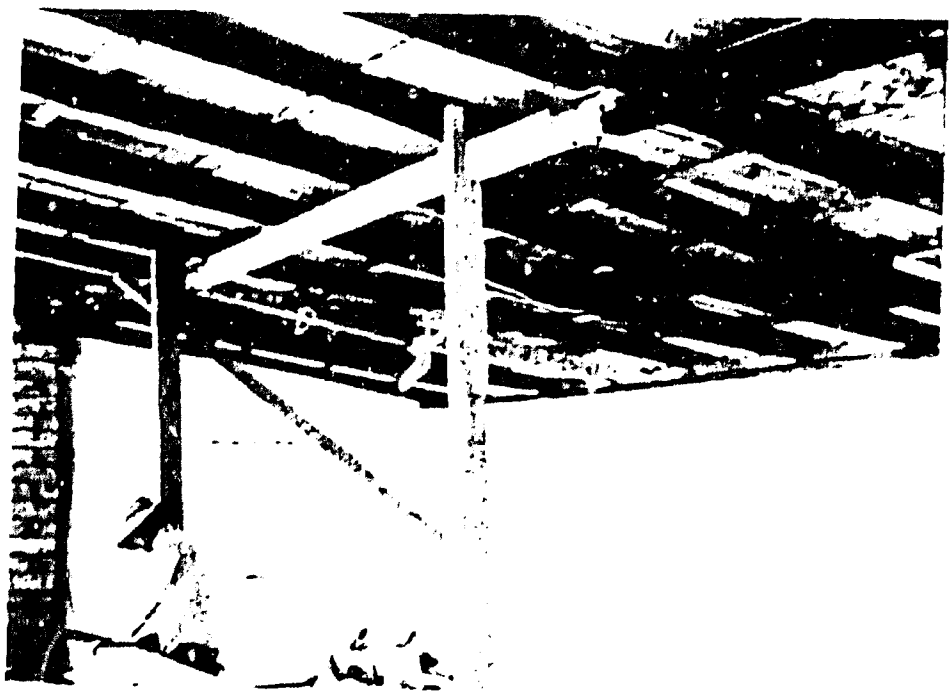
A view of an interior adobe wall shot through a window. This wall does not yet have a finish on it.

A corner form from above with the barbed wire reinforcing ready to be tamped. Notice how they are laid in two directions.

A view from above of the door frame at top held to the earth wall with barbed wire that is nailed to the wood of the frame.



Shows the joint between two modular forms with the metal tube keeping them in line. The door frame occupies exactly one form as is the case with a window frame. Notice the bracing of the door frame.



An interior view of the wood structure that supports the roof.

This paper was also presented at the 7th World Conference on Earthquake Engineering, September 8-13, 1980, Istanbul, Turkey and printed in the Proceedings of that conference, Vol. 4, p. 465-472.

STRENGTHENING OF ADOBE HOUSES FOR SEISMIC ACTIONS

Roberto Meli, Oscar Hernández and Marciano Padilla[I]

SUMMARY

In order to evaluate the efficiency of three strengthening methods for adobe houses, five 1:2.5 scale models were tested in a shaking table under the effect of the accelerograms of three major actual earthquakes. Mechanical properties of adobe masonry and structural behavior of adobe walls were also studied. The three strengthening methods evaluated were: a reinforced concrete bond beam at the top of the walls; a welded mesh nailed to both faces of the walls and covered by a mortar rendering; and steel rods tied to both faces of the walls in their upper part. The main objective of the reinforcement was to avoid separation of the walls in the corners and their subsequent overturning. Test results indicated that the seismic intensity that can be withstood without major damage is increased at least twice by any of the strengthening methods studied; the most efficient being the welded mesh reinforcement.

INTRODUCTION

In developing countries the main cause of loss of human lives and of economical damage following strong earthquakes is the collapse of small houses built of unreinforced masonry, mainly with adobes or stones bonded with mud mortar. One of the most dramatic examples is found in the Guatemala earthquake (1976), when due to the collapse of about 250,000 adobe houses more than 25,000 people died, this number representing about 98% of the total life toll.

Very little attention has been paid to the problem of increasing the safety of this type of construction and very few research programs have dealt with the subject. Perhaps one reason is the difficulty to transfer technological results to a medium where practically no technical personel is involved. Nevertheless, the magnitude of the problem demands both a number of efficient, practical and economical solutions and the actions of proper agencies in the field.

In the particular problem of adobe houses it is considered that, at least in Mexico, the cost involved in building new adobe houses with proper safety against earthquakes is at present higher than that of building brick or block masonry houses. Actually very few adobe houses are being built at present. The main problem is the lack of safety of many hundred thousands of unsafe adobe houses that exist in the seismic regions of the country. Considering this situation a research program has been undertaken at the Institute of Engineering of the National University of Mexico with the aim of evaluating different strengthening systems for single story low cost houses. The emphasis is placed on adobe houses but most results are valid for unreinforced masonry in general. Detailed reports on the research program can be found in the internal publication of the Institute (ref 1 and 2).

MODES OF FAILURE AND STRENGTHENING SYSTEMS

The weakness of adobe construction can only in part be ascribed to the poor

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quality of the material (unburnt earth brick) and to its degradation when subjected to the effect of the rain or to moisture changes. At least as important is the improper structural layout with low wall density, great height and great unsupported length of the walls; the large mass of the roof and the low restriction that the roof provides to the displacement of the walls normally to their plane contribute also to poor behavior. The aforementioned situation gives rise to the modes of failure illustrated in fig 1. The vibration of the longer walls normally to their plane induces bending moments that are maximum at their lateral ends and that produce vertical cracks that propagate downwards, in such a way that the upper part of the wall starts vibrating as a cantilever; overturning moments in the base of the cracked length become critical as the crack length increases and finally the wall falls generally outwards producing the collapse of the roof. When the laterally unsupported length of the walls is small, the in plane stiffness of the roof restricts the bending of the walls, or the shear strength of the wall is weakened by great window or door openings, the shear becomes critical and failure occurs by diagonal cracking (fig 1). Other failures are due to the collapse of the roof when its strength or its connections have been deteriorated by wheathering or to local problems as punching of the walls by a roof beam.

Being the flexural failure mode largely the most common, strengthening procedures have been focused mainly to achieve a proper connection between walls, to increase their strength and stiffness normally to their planes and to improve the connection between roof and wall and the in plane stiffness of the roof.

Perhaps the most widely proposed method of strengthening is the placement of a bond beam in the upper perimeter of the wall. The bonding element can be a wood truss as proposed in Chile, ref 3, or more commonly a concrete beam. With the last solution it is difficult to achieve proper bonding between adobe and concrete. Due to its large volume changes by shrinkage and moisture movements, adobe tends to separate from concrete and to loose the tightening effect of the beam. To overcome the problem a ribbed beam with a spur in the corner has been recently proposed and used in Mexico to strengthen adobe houses damaged by earthquakes (fig 2).

A much simpler procedure is the placement of horizontal steel ties, as in fig 3, which can be sligthly postensioned in order to precompress the wall. The procedure has been used to strengthen old stone masonry buildings damaged after Skopje and Friuli earthquakes (ref 4); its main advantage is that the roof does not need to be removed.

To achieve a more radical improvement of seismic behavior, vertical reinforcement is also needed. The concrete bond beam solution can be improved placing columns at the corners and at the ends of main openings, thus giving flexural strength in the plane of the wall and, more important, forming with the beam a concrete frame that provides confinement to the adobe walls, thus giving rise to a much more ductile behavior. The system is very efficient but rather complicated and expensive because the large wall thickness calls for very robust members; specials provisions must be adopted in order to ensure continuity between concrete columns and adobe walls. Systems with ties rods can be easily improved with vertical ties if there are stiff beams or footings at the foundation where the ties can be anchored; a system of this kind has been tested by Benedetti, ref 5.

A more comprehensive strengthening system has been proposed, ref 6, for

damaged adobe houses in Mexico. It consists in covering both faces of the walls with a welded wire mesh on wich a thick mortar rendering is placed. A composite section is formed which has good flexural and shear strength; additional bars in the perimeter of the openings and in the upper end of the walls give additional strength. Essential to the good behavior of the system is the continuity of the mesh in the corners and the fastening of both meshes through steel ties that cross the wall and avoid local buckling and separation of the mesh (fig 4).

The three systems have been designed and used in the field but an evaluation of their effectiveness was lacking.

MECHANICAL PROPERTIES OF ADOBE MASONRY

To study the properties that have more influence in seismic behavior of buildings, samples of adobes made in several regions of Mexico were collected. Their compressive and tensile strength was determined and, as expected, a wide range was found. The mean strength was 10 kg/cm^2 for the compression test and 3 kg/cm^2 for the tension test with 30% coefficient of variation in both cases. The aforementioned strengths correspond to dry and underteriorated adobes. When adobes were moisted to a 10% water content compressive strength was reduced to 3 kg/cm^2 and tensile strength to less than 1 kg/cm^2.

With adobes fabricated in the lab to have the same average compressive and tensile strength as the samples, small walls were built to study the properties of adobe masonry with different mortars. Results tend to show that the properties of a wall with mud mortar are similar to those of the adobe and that the wall behaves essentially as a monolithic element. Average properties for the laboratoı fabricated adobe masonry walls were a shear strength by diagonal compression of 1.3 kg/cm^2, modulus of elasticity of 2,500 kg/cm^2 and shear modulus of 700 kg/cm^2. Modulus of elasticity and shear strength were increased when cement mortar was used in the joint, whereas strength and stiffness were reduced when lime mortars were used.

Two full scale walls with mud mortars were also tested under alternating lateral loads; with vertical ties at the ends of the wall the flexural failure was avoided and a shear failure was obtained for an average shear stress of 1.1 kg/cm^2. As shown in fig 5, after the first diagonal cracking the capacity of the wall to withstand alternating lateral load was reduced practically to zero.

DYNAMIC TESTS ON A SHAKING TABLE

The study of the dynamic behavior of adobe, or unreinforced mansory structures, does not lend itself to simple tests, mainly because of the difficulty of applying loads to the structures without producing local failures due to weakness of the material. The shaking table of the laboratory of structural dynamics of the Institute of Engineering was used to test models of adobe houses. The table, ref 7, of 2.4 x 4.5 m in plan, can receive models weighting up to 15 ton and can reproduce ground motions in the long direction of the table only. A prototype house was chosen with the dimensions shown in fig 6, which are common in the rural areas of Mexico and Central America, the main differences being in the weight of the roof. In hot humid or mild climate zones roof tiles on wood trusses are used (total roof weight of about 50 kg/m^2) whereas in more severe climates earth roofs over closely spaced wood beams are common (roof weights up to 500 kg/m^2). Table size limitations required that only a part of the structure

be tested or that reduced scale models be used.

The second solution was favored and a geometric scale of 1:2.5 was chosen. Dimensional requirements for dynamic tests can be complied with if the weight of the materials is multiplied by the geometric scale factor or if their modulus and strength against any possible mode of failure is divided by the same factor. Any of the alternatives is difficult to accomplish for the type of structure considered. If none of these properties is modified, the dynamic behavior of the prototype can be reproduced by properly modifying the time and acceleration scales of the input, but the static stresses in the model due to the own weight of the structure are equal to those in the prototype divided by the scale factor. It was considered important to reproduce exactly the material and the joints, so adobe bricks were built in the lab with the same technique and materials as in the field. Different types of earth and straw contents were tried until the mean compressive and tensile strengths of the adobe sampled in the field were obtained. To obtain static stresses closer to those required, additional weights were distributed in the walls so as to increase the density of the material by a factor equal to the square root of the scale factor ($\sqrt{2.5}$). Thus, stresses in the model due to its own weight were 63% of those required. It was considered that this difference would not affect significantly the dominant mode of failure due to horizontal bending of the walls and that results would be slightly conservative regarding overturnuning and shear failures.

The records of three important earthquakes with high spectral amplitudes for low periods were selected, considering that this type of movement would be more critical for the adobe houses. The El Centro (1940) Managua (1972) and Oaxaca (1973) records were selected and had to be corrected according with dimensional analysis requirements; low frequency movements had also to be filtered in order to limit the maximum ground displacement to that allowed by the actuator of the shaking table (2.5 cm). The spectra of the original records and those calculated from the movement of the shaking table are compared in fig 5 for the three earthquakes. It can be seen that, except for very low periods in the El Centro and Oaxaca earthquakes, spectra of the recorded motions fitted acceptably well those of the original records.

The models reproduced the typical house shown in fig 6; scaled down roof trusses and tiles were placed only in the first test; in other tests equivalent masses were placed on steel channels simply supported on the walls, giving rise to a situation slightly less favorable than that in reality, as the beams imposed practically no restriction to the movement of the walls. Models were placed on the table in such a way that the movement of the latter was normal to the longest side of the house thus favoring bending failure of longest walls.

Five models were tested; three of them were built independently, two without reinforcement and one with a concrete bond beam; the two remaining models were obtained by strengthening the two unreinforced models after they were tested very near to total collapse.

In the first three models different table movements were applied and the type of roof was also changed. After recognizing that with the Oaxaca record more severe damages could be obtained, in the remaining tests only this record was applied increasing its intensity until reaching the collapse or the maximum capacity of the actuator. In order to obtain a measure of the amount of damage suffered by the models, after each level of seismic motion a free vibration test was performed measuring the period and damping of the movement in the four walls.

Six accelerometers were placed in different positions as shown in fig 6.

RESULTS OF SHAKING TABLE TESTS

A first objective of tests was to check the validity of using finite element dynamic linear elastic analyses for adobe houses. The fundamental period and the modal shape obtained in the models before being submitted to high amplitues of ground motions were very similar to the calculated one. These results demostrate that finite element analyses can be used to study the effect of a wide range of variables in the dynamic behavior, wherefrom simple rules for the design can be derived, as made in ref 2.

The amount of damage suffered by the models can be related with their loss of stiffness and consequently their increase in fundamental period, and with the increase in damping due to friction in the cracks. The variation of period and damping with the intensity of motion, shown in fig 8, allows to detect a drastic change that corresponds to major damage. To establish a basis for the comparison of the results of the different models it was considered as major damage that corresponding to an increase of 50% in period.

The behavior of the five models tested can be summarized as follows. Model 1, unreinforced, supported without major damage 50% of the actual intensity of the El Centro record. At about that intensity vertical cracks in the corners separated the walls; the length of the cracks increased in the following tests and for 90% of the intensity, the model was severily distressed; the total collapse did not occur, although the walls could be overturned with a slight push of one hand. It is believed that the elimination of low frequency motions from the original record canceled the large displacement that the structure would have suffered under the actual record; this prevented collapse.

Model 2, reinforced with a concrete bond beam, withstood without apparent damage 90% of the El Centro record and showed important distress caused by major vertical cracking below the concrete spur in the corners for 3.6 times the intensity of the Oaxaca earthquake. After testing, model 1 was reinforced by filling major cracks with mud and by placing the wire mesh and cement rendering in both faces as previously described. The house was tested again and identified as model 3. Starting at intensities approximately equal to the actual record, the mortar began to separate from the adobe, to crack and to fall down. Nevertheless the wire mesh nailed to the wall maintained the continuity of the structure, wich could withstood without collapse the maximum intensity that could be applied by the actuator, 4.6 times the Oaxaca record. Models 2 and 3 were subjected withouth major damage to the full intensity of El Centro and Managua records.

Model 4 was also unreinforced and was subjected to the Oaxaca record in order to establish a basis of comparison for the strength of the different models and to obtain a damaged structure to be strengthened by a different method. The mode of failure was similar to that of model 1 and it was considered failed at 1.35 times the intensity of the actual record. When reinforced with horizontal ties it withstood twice the intensity supported by the unreinforced model. Failure was due to severe vertical cracks in the corners and to horizontal flexural cracks in the long walls.

It is considered that the intensities withstood by the models cannot be quantitatively extrapolated to prototypes due to limitations of the tests: only

horizontal motion in one direction was applied, low frequency motion was eliminated and vertical stresses were not respected. Nevertheless the efficiency of the differents strengthening methods can be compared. It is concluded that the three methods enhance significantly the strength of the structure and that the efficiency of the concrete beam and steel ties methods is limited by the lack of vertical reinforcement, the beneficial effect of which is evident in the model reinforced with wire mesh.

CONCLUSIONS

The problem of strengthening existing adobe houses has to be faced with solutions that give rise to proper safety against earthquakes and that can be executed with simple techniques and at low cost. Use of wire mesh reinforcement is considered a very efficient method, as it not only enhances the seismic safety but also protects adobe from weathering. Nevertheless it requires a higher amount of steel than the other methods and for the proper placement of the mesh the roof needs to be removed at least by parts. From the point of view of cost and easiness of construction the reinforcement with steel ties is the most convenient one; to achieve a higher safety, additional vertical ties are needed in the corners and at the ends of the openings. Anchoring of vertical ties at a foundation beam or footing is needed. The efficiency of the concrete bond beam can also be singnificantly increased if it is tied to the foundation by vertical reinforcement.

The three strengthening methods cover only the more essential aspects of the reinforcement. Several additional details have to be considered to obtain proper safety: in plane stiffening of the roof to form a diaphragm; tying together of roof and walls, and placing of reinforcement around openings. Very good results can be obtained also by modifiying the house layout, as well as by reducing the weight of roof and the height and unsupported length of the walls.

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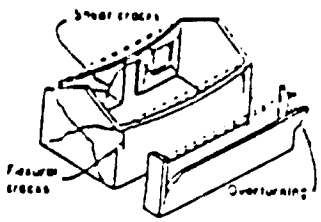

Fig. 1 Modes of failure of unreinforced masonry houses

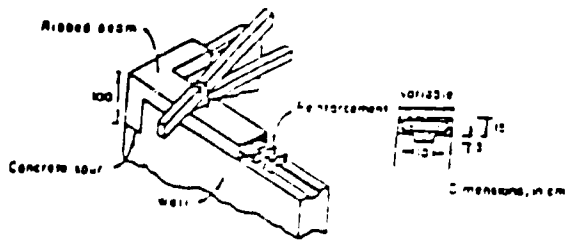

Fig 2. Strengthening with a concrete bond beam

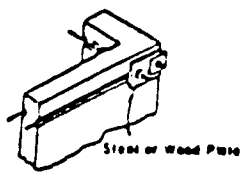

Fig 3. Strengthening with steel ties

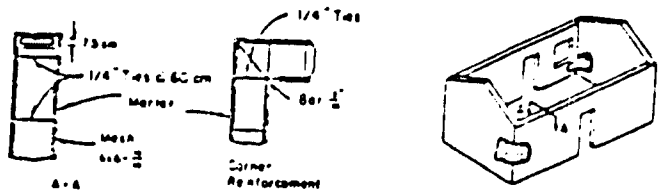

Fig 4. Strengthening with wire mesh and mortar

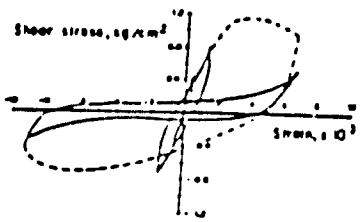

Fig 5. Hysteresis loop under lateral loads of an adobe wall

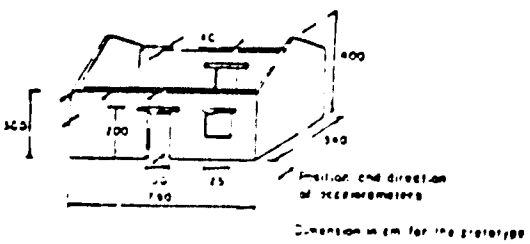

Fig 6. Typical adobe house tested on the shaking table

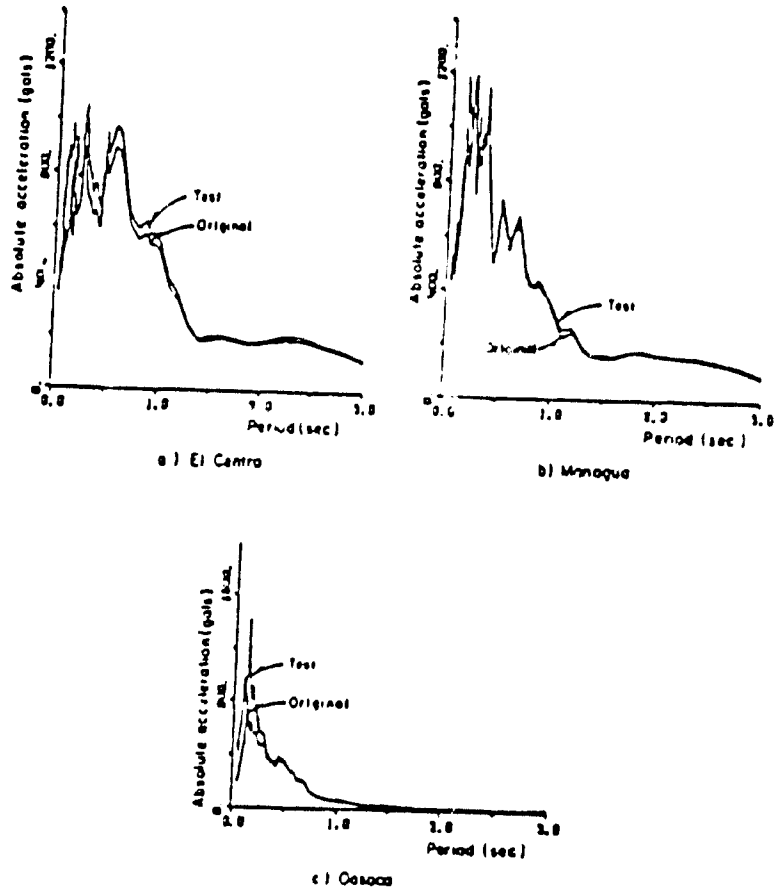

Fig 7. Spectra of the seismic motions used in the tests

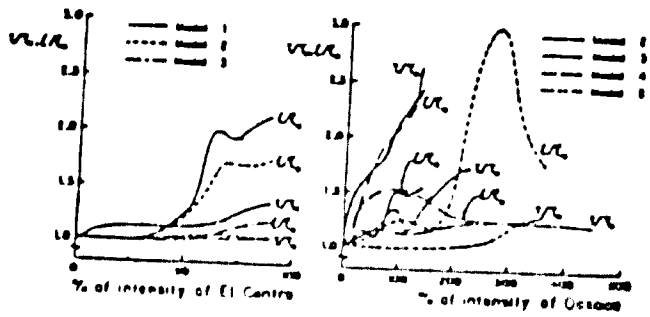

Fig 8. Variation of period and damping after tests with different levels of seismic excitation

MITIGATING ROOF COLLAPSE IN ADOBE DWELLINGS

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ABSTRACT

The main cause of earthquake deaths in adobe dwellings is the collapse of roofs. To mitigate collapse while staying within the constraints dictated by regional cultural and climatic factors, a plan is proposed for rural housing in desert regions of Iran. The plan provides for villagers to build their own housing, using local construction materials and traditional techniques.

Introduction

Earthquakes continue to be the most fearsome predator of human life in aspiring countries. In Iran alone, during the past fifteen years over fifty thousand people have lost their lives, while the total loss throughout the world is immeasurable. Most of these casualties are caused by the collapse of the heavy roofs of adobe dwellings, which are the common types of housing in the rural areas of most aspiring countries.

The evolution of adobe dwellings and their continuing dominance over other types of housing in rural areas stems from the fact that they depend exclusively on low-cost indigenous materials and skills, and they can easily be adapted to local climatic conditions.

The introduction of better quality construction material into rural areas, besides being costly, has not resolved the problem of roof collapse. In fact, field observation shows that in many instances [1], due to the lack of skilled manpower and proper supervision in the construction of buildings and due to the larger spans used, such buildings have collapsed during earthquakes and have caused many more casualties than traditional buildings would have.

Experience has also shown that construction of housing units in rural areas by government contractors has not materially contributed to the resolution of the problem and has actually introduced hitherto uncommon social and economic problems. The utilization of prefabricated housing is expensive and requires a relatively extensive infra-structure. Besides, since prefabricated housing generally does not conform to the traditional way of life in rural areas, it is usually not popular with people. So it may be concluded that due to traditional, cultural, economical and technological constraints, the use of adobe dwellings will probably continue for many more decades. This is a basic reason for continuing interest in the search for feasible and implementable solutions for improving the seismic resistance of future adobe dwellings.

Considering the undependable material properties of adobe, the erratic seismic behavior of the adobe structures, and the aforementioned constraints, design of earthquake resistant adobe dwellings is a very complex problem. Recommendations such as the introduction of various kinds of reinforcements in walls and their intersections and around the openings are not easily implementable due to cost and the quality of the workmanship available in rural areas [2].

One variable that still can be manipulated is the form of the dwellings. Recommendations such as conical and dome shaped dwellings with nontraditional plans have not been popular. After the 1978 Tabass earthquake in Iran, which killed over twenty-three thousand people, the author spent some time studying the plans and forms of the dwellings in the city of Tabass and its nearby villages and towns in the Kavir desert region. Based on this study, a plan for rural housing with two different types of roofs is proposed. One type of roof is the traditional barrel vault and the other type is made of wooden joists with mud covered straw mats. In the following sections the mechanism of adobe roof collapse, the basis of design of adobe dwellings to mitigate roof collapse, the available construction materials in rural areas, and the proposed plan are discussed.

Mechanism of Roof Collapse

In most cases the roofs of adobe dwellings are made of barrel vaults supported by bearing walls. The arches' lateral thrust is resisted by the transverse strength of the supporting walls. During shaking, the static lateral thrust is augmented by dynamic forces, the supporting walls move, and the roof collapses. Another failure mode is for the walls to fail first, but this is less common with this type of roof. In cases where the roofs are made of wooden joists resting on bearing walls and topped with mud-covered straw mats, the most common failure mode is the collapse of the roof due to insufficient bearing length. Another failure mode for this type of roof is the brittle failure of the adobe bearing walls, but this is not as common.

Design of Adobe Dwellings to Mitigate Roof Collapse

The design of adobe dwellings to mitigate roof collapse should meet constraints and embody principles which will be enumerated here.

A. Constraints

1. The plan of the adobe dwelling, besides satisfying the needs of its inhabitants and conforming to the local cultural and traditional way of life, should also be compatible with the geographical and climatic conditions of the region.

2. The adobe dwelling should have enough seismic resistance for its roof not to collapse during earthquakes with local intensities of the order of VII to VIII (MM scale).

3. The plan should be simple enough for villagers to build their own dwellings using indigenous materials and skills.

4. The construction cost of the dwelling should not be much higher than that of the dwellings currently built in these rural areas, and the total cost should be within the financial means of the rural population.

B. Principles of Earthquake Resistant Design for Adobe Dwellings

1. To minimize extraneous loads, the plan of the adobe dwelling should be as symmetric as possible. Mass and stiffness should be uniformly and symmetrically distributed. This will contribute toward a more uniform stress distribution during earthquake and consequently a higher earthquake resistance.

2. The height of the walls should be kept to a minimum.

3. Since sharp corners are more vulnerable to damage, the corners should be as open as possible.

4. The openings, i.e. doors and windows, should be located as far from the corners as possible. They should be symmetrically located, and their width should be as small as possible.

5. The roofs of adjacent dwelling units should be at the same height.

Available Construction Materials

The construction materials indigenous to most rural areas are:
1. adobe brick
2. river sand and stones
3. wooden joists*
4. bamboo, reeds and grasses, palm leaves
5. straw
6. clay and clayey soil
7. gypsum
8. lime

The proposed plan is based on the use of the above indigenous construction materials.

Field observation shows that the amount of damage in dwellings built of stone with mortar is more than that suffered by dwellings built of adobe brick with adobe mortar. This is because there is better adhesion of adobe mortar to adobe brick than there is of adobe mortar to stone.

There have been recommendations for the addition of stabilizers such as lime or gypsum to both adobe brick and adobe mortar in order to improve their strength

*wood is not as available and is costly.

properties. Also, the addition of hemp and straw has been recommended [3,4]. Implementing these recommendations is not easy, however, because in forming adobe brick and adobe mortar the basic tools used are the bare hands, and these stabilizers introduce problems such as workability of the materials and skin abrasions.

In general, therefore, in order to consider all the enumerated constraints, the ideal plan for adobe dwellings must give rise to minimum dynamic loads while simultaneously bestowing a higher resistance to the structure.

The Proposed Plan

In general, circular plans, due to their absolute symmetry, bestow more earthquake resistance to structures than other plans which have sharp corners. However, they do not conform to the traditional way of life in rural areas and have not been popular. Based on the following considerations, an octagonal plan (Fig. A1 to A3) is proposed:

1. The proposed plan is more symmetric than rectangular plans, and its center of mass and center of rigidity almost coincide.
2. The total length of the external walls of the proposed plan is about 10 percent less than the total length of the external walls of a square plan of equal enclosed area. The difference is even more than ten percent if a comparison is made between the proposed plan and a rectangular plan of equal enclosed area. This reduction in the total length of the external walls, besides contributing to the reduction of construction costs, also reduces the area exposed to the generally severe climatic changes of desert regions.
3. Compared to rectangular plans the length of the walls, especially bearing walls, is shorter. Field observations have shown that long adobe walls without lateral supports do not offer much resistance to ground motions.
4. Compared to rectangular plans the corners are more open. Experience shows that dwellings with sharp corners are more susceptible to damage during earthquake.
5. Rectangular plans have shear walls only in two directions, while the proposed plan has bearing shear walls symmetrically situated in four directions.
6. If the roofs are to be the traditional cylindrical arches, these arches may be oriented (Fig. A4) such that their horizontal thrusts at the top of bearing walls would cancel each other.
7. If the roofs are to be made of wooden joists, the proposed plan provides four wall supports for each joist (Fig. A5). This increase in the number of supports is an important factor in mitigating roof collapse. The earthquake-worthiness of this type of roof (with four supports for each joist) is expected to be better than that of the adobe arches discussed in 6 above.
8. Visits to cities neighboring Tabass after the 1978 Tabass earthquake showed that most of the dwellings are comprised of a small yard surrounded by several rooms opening to it. Due to desert climatic conditions, these rooms generally have no windows, and there is only a transom over the entrance door to let in some light. All these factors are considered in the proposed plan. Further, in conformity to rural traditions, the toilet is located

such that the access to it is through an open space which is not in direct sight.

9. The marking out of the proposed plan on the ground is very simple. It can easily be accomplished by the use of only two templates (Fig. A1).

Many buildings, including old mosques, shrines and mausoleums [5,6], which have survived earthquakes of local intensities of the order of VII to VIII (MM scale) without roof collapse have plans which are basically similar to the one proposed here. The survival of these buildings during past earthquakes offers true experimental evidence that the proposed plan should mitigate roof collapse.

Clusters of Adobe Dwellings

In general, separate units are preferable to adjacent units, because no lateral impacts due to out of phase motion of adjacent units are introduced. Also, the falling parts of one unit do not cause damage to other units. But to reduce the exposed surfaces in order to combat the effects of severe and quick climatic changes which are peculiar to desert areas, traditionally dwelling units are built adjacent to each other. To reduce the damaging effects of out of phase motion and falling parts, adjacent units should be designed to have similar stiffnesses and mass distributions and to have all roofs at the same level.

For the purpose of rural housing, two types of clusters are proposed. The units in one group have external yards to accomodate farm animals (Fig. A6). The units in the other group have no external yards and are more suited to rural towns (Fig. A7).

Construction Details

Since one of the provisions of the proposal is that the villagers be able to build their own dwellings using the local resources, i.e. materials, workmanship and traditional techniques, construction details such as the water proofing of roofs and collection and disposition of rain water are left to be carried out with customary slopes and in the traditional manner.

Remarks

Of course, one way to prevent collapse in any structure is to have a well designed and erected skeleton. If resources are available for construction of this type of housing in rural areas, then there is no need to limit the plans of the dwellings to what is proposed here. In any case, public buildings such as schools, pumping and communication stations should be designed and constructed with appropriate design, construction materials and supervision.

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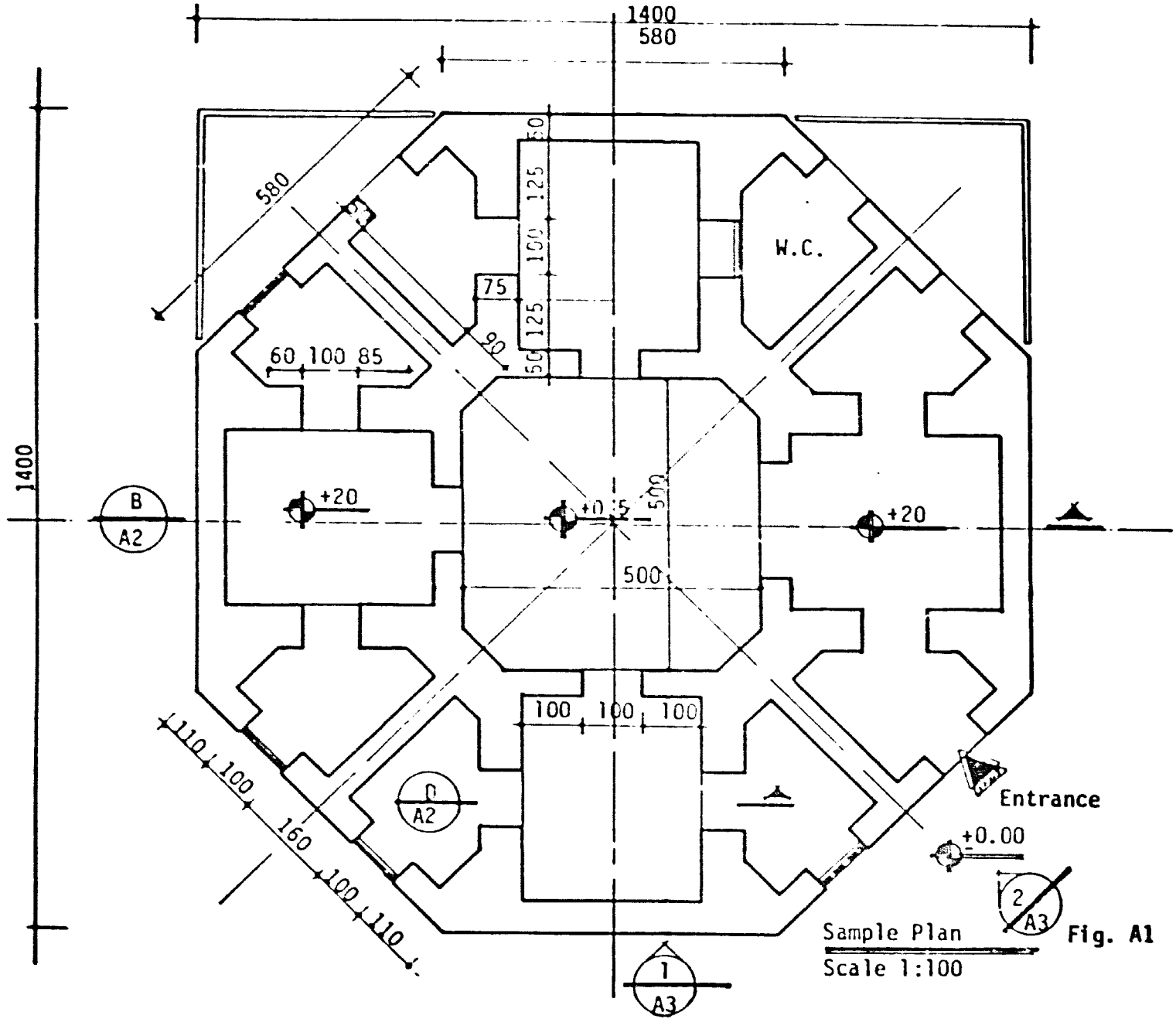
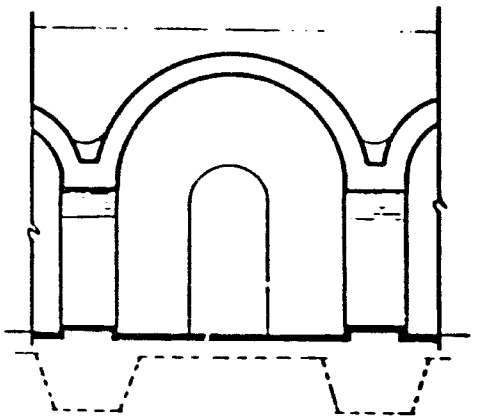


Sample Plan
Scale 1:100

Fig. A1



D / A1 Section
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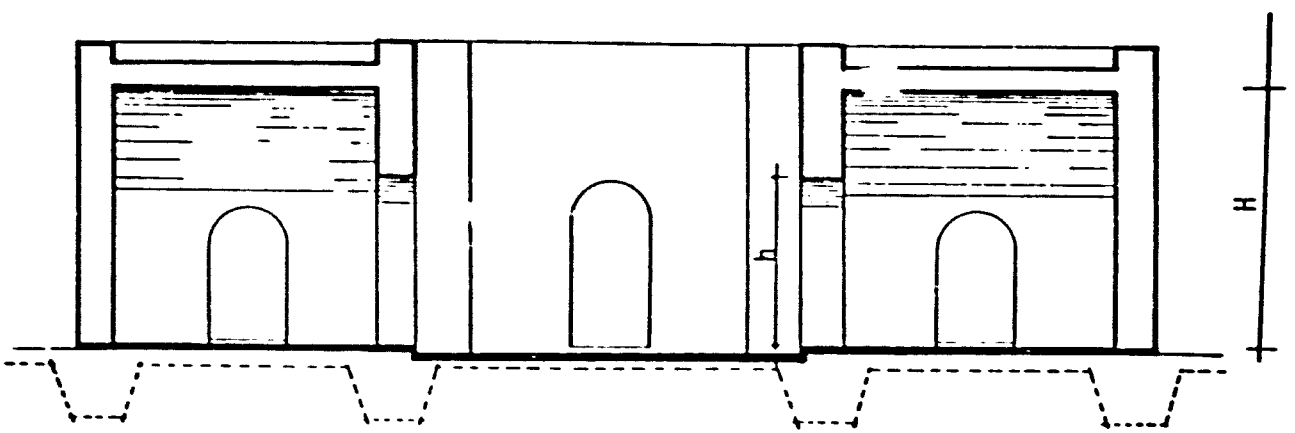
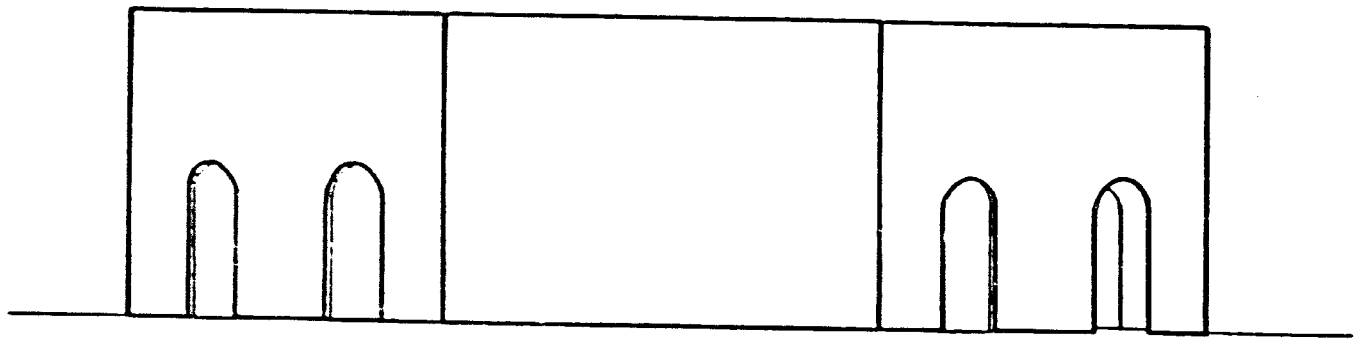


B / A1 Section
Scale 1:100

Fig. A2

Remarks:

i- The maximum heights H for barrel vaults $\leqq 3.5^m$
ii- The maximum heights h for doors $\leqq 2^m$
iii- The maximum heights for wooden roof $\leqq 2.7^m$



1 A1 Elevation
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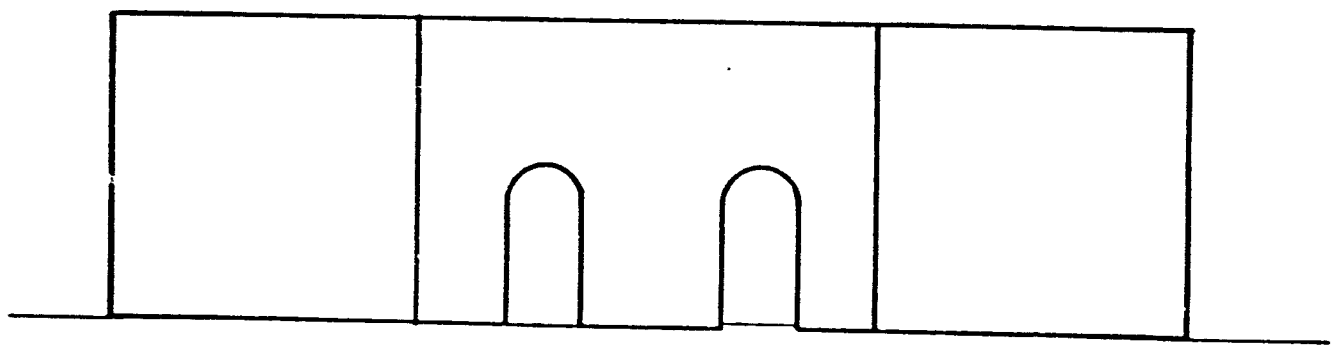

2 A1 Elevation
Scale 1:100

Fig. A3

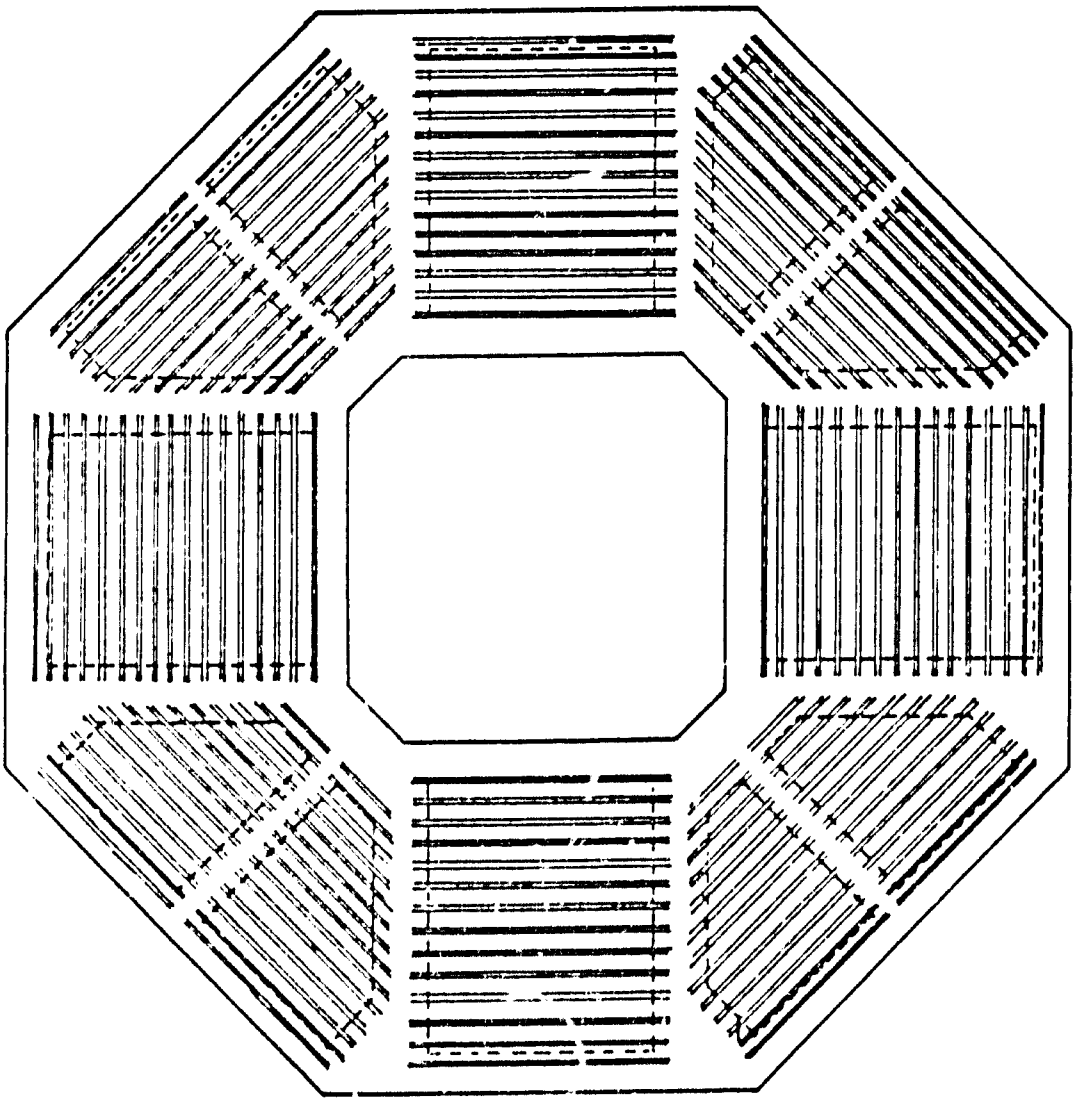

Fig. A4 Schematic View of Barrel Vaults

Scale 1:100

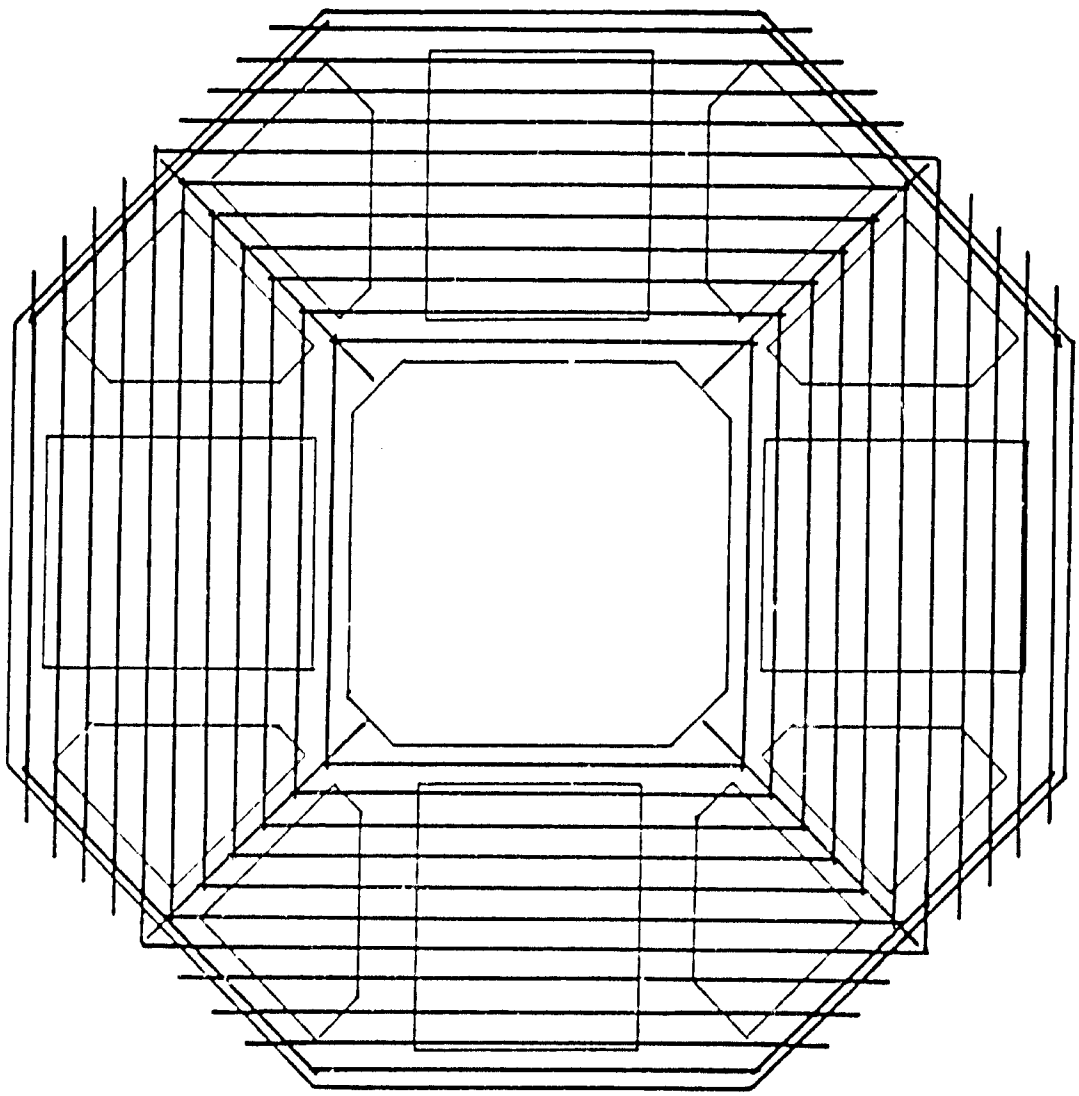

Fig. A5 Schematic View of Wooden Roof

Scale 1:100

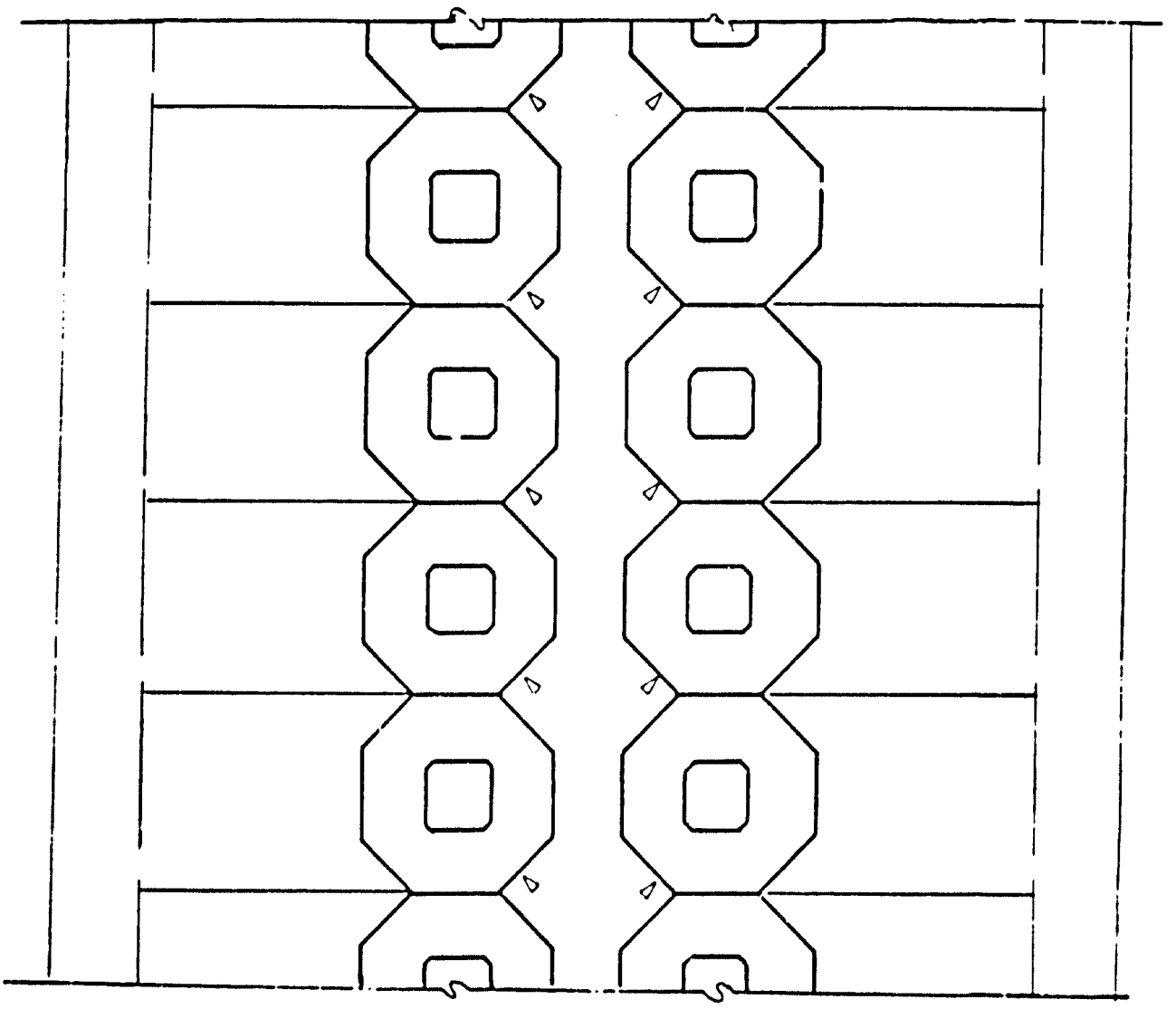

Fig. A6 Cluster Type 1
Scale 1:100

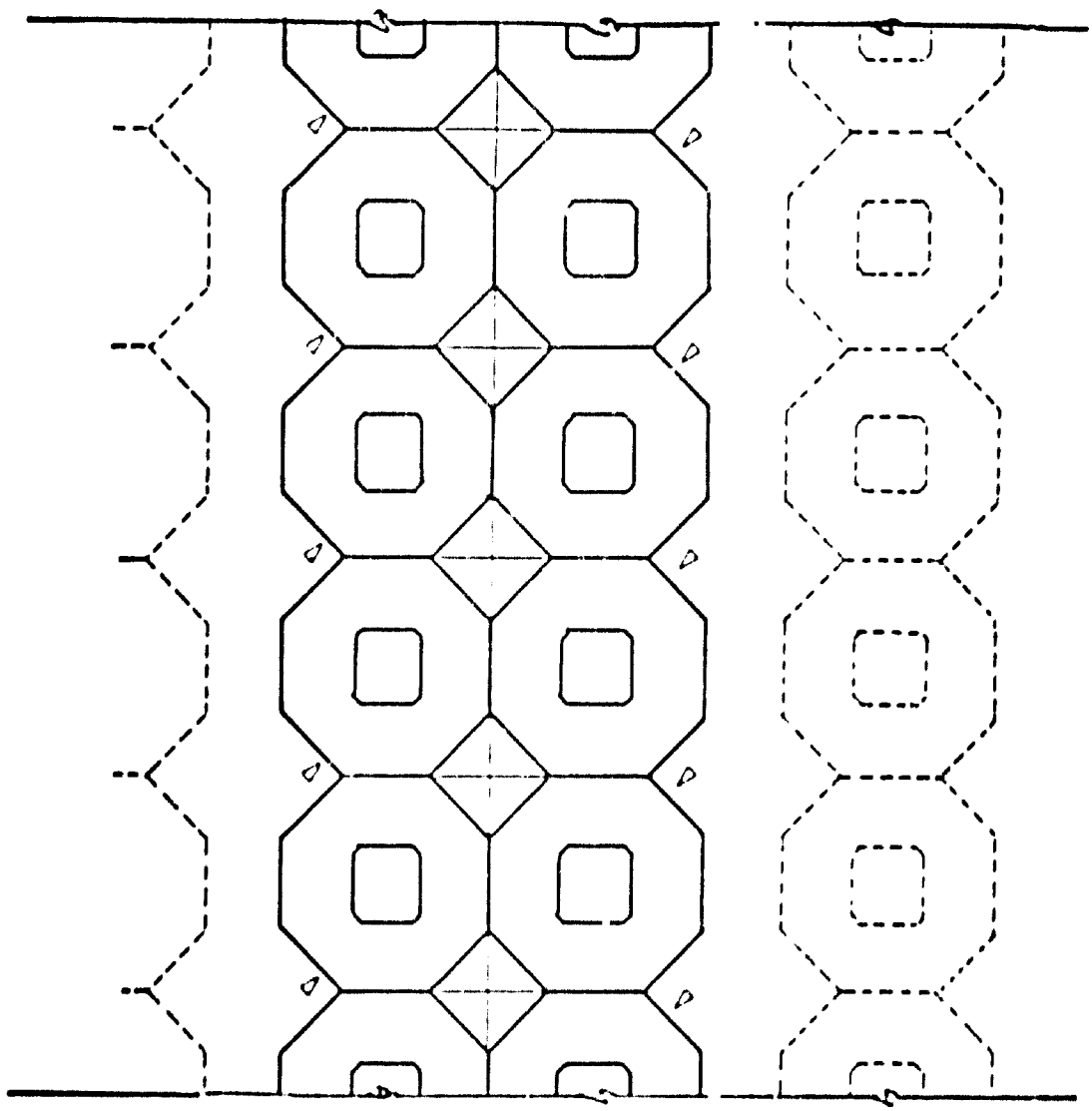

Fig. A7 Cluster Type 2
Scale 1:100

DEVELOPMENT AND UTILIZATION OF A "POURED ADOBE" BUILDING SYSTEM FOR SEISMIC AREAS

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ABSTRACT This paper describes the development, testing and use of a "poured adobe" building system made from on-site earth as a low-cost, energy-efficient building material for seismic areas. The method has been approved by California building officials, and has been used in the construction of a passive solar poured adobe home in Pacheco, California (eastern San Francisco Bay Area), which is in the Uniform Building Code Seismic Zone classification #4. The U.S. Department of Energy has awarded the Habitat Center a grant for further refinement of the method, as well as for seismic-related testing of several types of block and poured adobe building systems.

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The context for the development of the poured adobe building system described below differs from the one that predominated at the Workshop. While the concept, if not many of the specific components, of the system could be used in developing countries, Habitat's poured adobe system was developed as a response to the building technologies and the materials, labor and energy costs characteristic of industrialized countries, particularly the areas of high seismic activity in the Western U.S. In these areas, the issue is not how to build with earthen materials more safely, as might be the case in developing countries, but how to resurrect the use of earthen materials in a culture that has ceased to build with them at all for the last 100 years because it has not been "economical" to do so. Now, however, the economics of industrialized countries are shifting as well, and, particularly because of rising energy costs, are making it an appropriate time to reconsider the use of adobe.

Adobe as an energy-efficient building material

Adobe is an energy-efficient building material in several ways. First, it is energy-efficient in manufacture, since it is simply sun-dried rather than fired as is red brick, or produced in high-temperature processes such as cement; in his book Natural Solar Architecture, architect David Wright says "It takes over 300 times more commercial energy to produce a concrete block equal in volume to a sun-dried adobe block." (1) Adobe is also energy-efficient because it can be mined right on the building site, eliminating the energy and cost expended in the transport of building materials to the site.

Thirdly, and perhaps most importantly, adobe can be used to reduce energy costs for building heating and cooling throughout the lifetime of the structure if it is used in conjunction with energy conservation, passive solar heating and natural cooling principles in building design. The effective use of adobe for the "sun-tempering" of buildings has a long and well-established record throughout the world. The work of architect David Wright finally established the formal integration of passive solar heating and natural cooling design principles with the use of adobe for thermal mass. "Passive solar adobes" are now built routinely throughout the American Southwest. The energy savings on building heating and cooling can be significant in passive solar adobes, and not just in the clear, hot regions of New Mexico; the passive solar poured adobe home built by Habitat in Pacheco CA has not used any supplemental heating or cooling energy since the building shell was completed, and has consistently maintained a 57-77°F temperature range winter and summer.

Thus adobe has many energy-efficiency benefits. It is also a very low cost raw material. This should be good news to the U.S., where escalating energy, building and financing costs have created a tremendous building slump in many parts of the country, particularly in the Western U.S. So why aren't more adobes being built? The problem is with the labor-intensive nature of adobe construction, and the costs of that labor.

Adobe and labor-intensity

Even for standard wood-frame construction, labor costs represent a very significant part of the total (currently 54% labor to 46% materials cost in the San Francisco Bay Area) (2). However, for block adobe construction in the same area, the labor costs rise dramatically, pushing the overall costs of an adobe building from 10-30% higher than that of a conventional wood-frame building (3). As a result, there are no adobe developments and very few custom adobe homes being built outside of the Southwest.

For owner-builder situations, the cost of labor is not a factor, but the amount of time is. Few owner-builders have the amount of time required to invest in the required labor, particularly if it involves making their own adobe bricks. The result has been few owner-built adobes outside of the Southwest.

Thus there is a need to capture the benefits of adobe -- energy-efficiency and low materials cost -- while escaping the high labor costs and/or time commitments for contractors and owner-builders. It was in response to this need that the poured adobe building system described below was developed.

Basic poured adobe system concept

Habitat's basic concept was to create a poured adobe building system that would:

- provide the necessary structural integrity in a high seismic area
- provide for rapid construction to significantly decrease the labor time and costs involved for both production builders and owner-builders
- meet "buildability" requirements for both production builders and owner-builders (low cost and availability of materials & equipment for a range of project sizes)
- create effective building thermal mass for passive solar heating and natural cooling

The basic structural concept was to use a double layer of welded wire mesh or similar reinforcing fabric between which the adobe would be poured. This fabric would be embedded in the concrete foundation and also in the bond beam. Thus, in case of severe crumbling of the adobe under extreme lateral loading, the adobe would still be held within the "fence" of reinforcing mesh.

Our original plan was to use a load-bearing system in which the two parallel layers of mesh would be vertically connected. However, both local structural engineers and building officials indicated reluctance to approve such a load-bearing design for a seismic area in the absence of actual structural test data, since standard engineering handbooks are of little help in dealing with the structural characteristics of adobe. Rather than delay all work on poured adobe until we found the funding necessary for such testing, we decided to proceed with a non-load-bearing poured adobe application to work out the mix, delivery and forming aspects of poured adobe systems. The evolution of the non-load-bearing system design and components are described below. We expect to use the results from the seismic-related structural testing performed under our U.S. Department of Energy grant to obtain building permits for future load-bearing applications (see final section of paper).

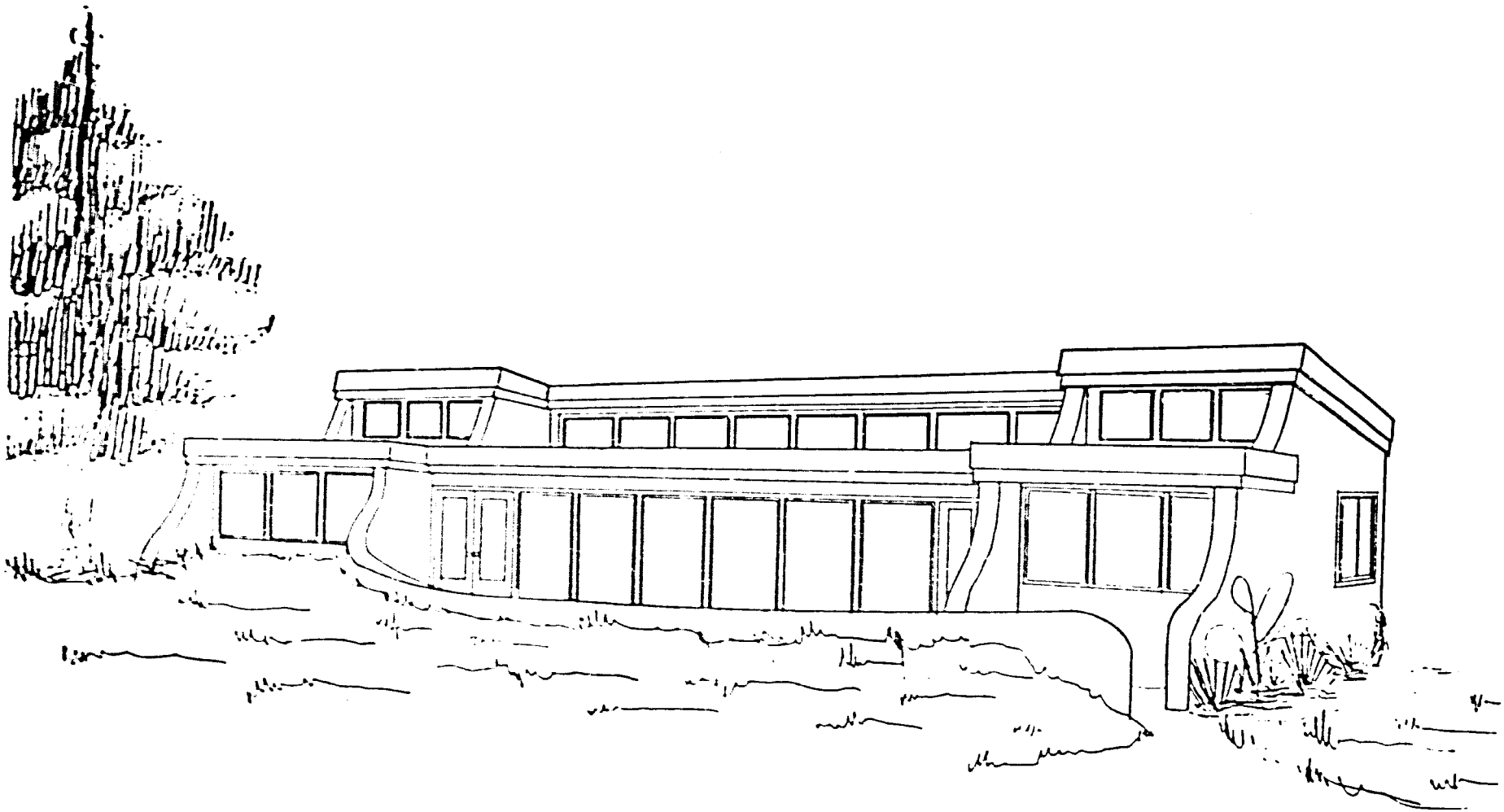
Poured Adobe Test Walls

To develop the specific poured adobe building system from the concept, we built a series of test walls on the site in Pacheco, California, where the passive solar poured adobe residence was to be constructed later. Although there were no previously successful full-scale adobe examples that we could use as a guide, the general advice we received from people in the field was (1) to use a stiff mix, (2) to use plywood or other solid wood forms, (3) not to try to pump the adobe into the forms -- that it wouldn't work, and (4) not to try to pour an entire wall height -- to use slip forms instead. As so often happens when theory meets practice, we found that none of these techniques worked and that in fact their opposites were the solution. We found that a stiff mix would not settle properly, and required so much tamping that the process began to resemble rammed earth. We found that using solid wood forms prevented the adobe from drying, causing slumping, and that drying occurred unevenly, producing severe cracking. We converted instead to forms made of expanded metal (commonly called "diamond lath") that would allow the water to evaporate quickly and evenly, and switched from a front loader (which requires too much space for maneuverability in an urban/suburban setting) to a standard concrete grout pump with a four-inch hose as the delivery system. We also poured test walls to a 6' height and found that the expanded metal forms could contain the wet adobe and withstand its weight. We found that the increase in wetness of the mix required for pumping did not result in significant cracking during the drying process. (The major determinant of cracking that we found was the size of the sand particles added to the clayey soil; the coarser the sand particles, the less the cracking.) We were also able to create a standardized modular forming system (described in more detail below) that could utilize all other elements of standard concrete forming such as snap ties, snap brackets, walers, etc.

Construction of the passive solar poured adobe residence

Based on what we learned from the poured adobe test walls, we moved on to the construction of an 1800 sq. ft. passive solar adobe home in Pacheco CA. The house design, which has received awards in both the California and the U.S. Department of Housing & Urban Development passive solar design competitions, is a non-load-bearing poured adobe application for building permit reasons (as previously discussed). A south elevation of the home (which has been closed in for the last year but has not yet received its final exterior plaster) in shown in the drawing in Fig. 1. A plan view of the forming and reinforcing system is shown in Fig. 2a, and a plan view of the finished poured adobe wall is shown in Fig. 2b. The overall poured adobe system and process used in the construction of this house can be summarized as follows:

The house is designed as a post-and-beam structure, with the poured adobe serving as non-load-bearing infill. The posts (in this case, pressure-treated telephone poles), were placed up to 13' on center, and extend about 4' down into the sandstone which underlies the site. The poles are set into steel rebar cages, levelled, and concrete is poured into the holes around the poles, forming caissons. 12-gauge welded wire mesh fabric is then stretched and attached on either side of the poles, forming an 8" "fence" into which the majority of the adobe is to be poured. The mesh is nailed to the poles, and extends 9" down into the foundation formwork. The concrete foundation is then poured through the welded wire mesh into the foundation forms, creating a substantial anchoring of the mesh in the reinforced foundation. For the perimeter walls, the 2" styrofoam insulation is then wired to the outside layer of welded wire mesh fabric.



PASSIVE SOLAR POURED ADOBE RESIDENCE

PACHECO, CALIFORNIA

Fig. 1

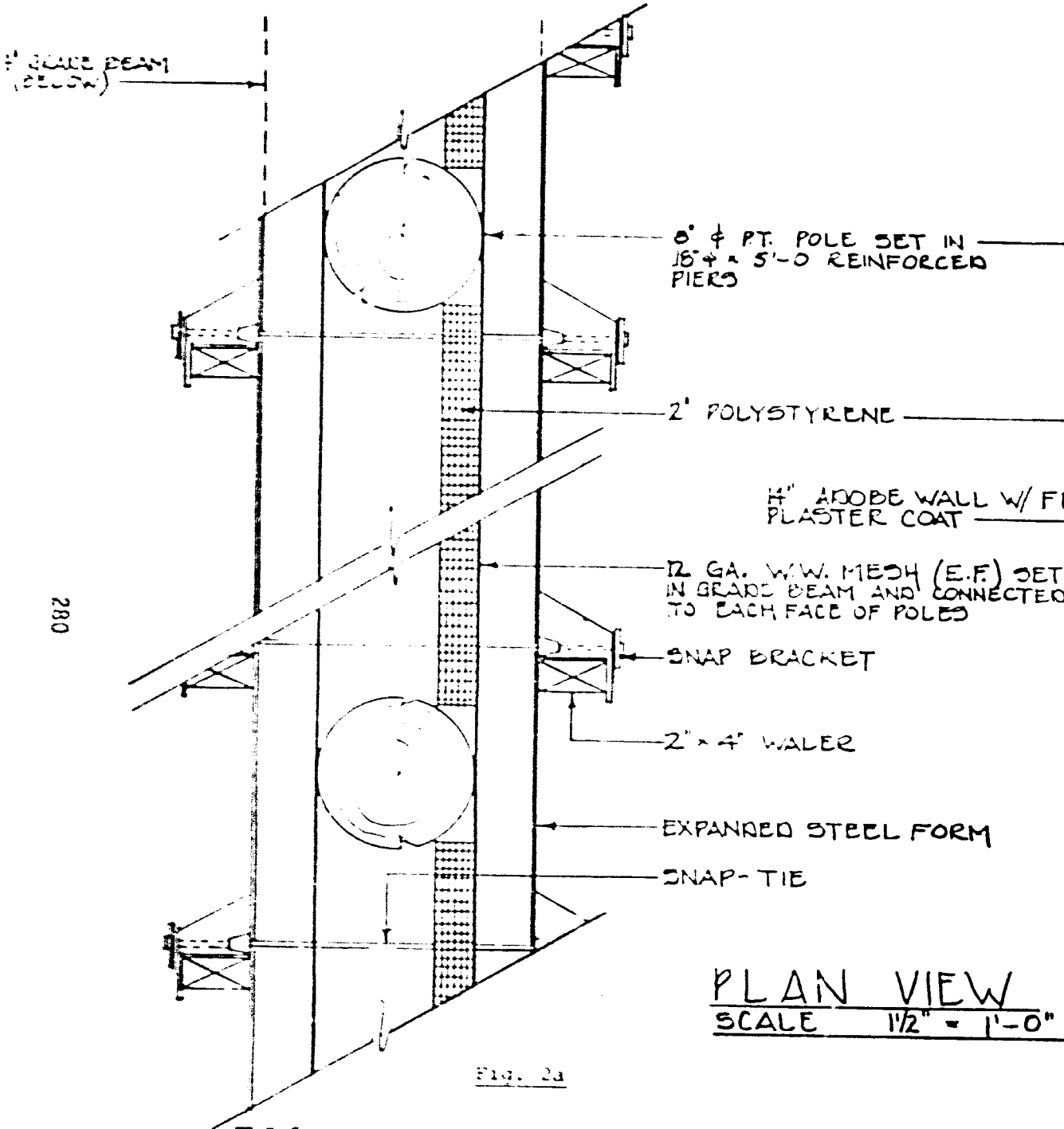


Fig. 2a

FORMING SYSTEM FOR POURED ADOBE WALL

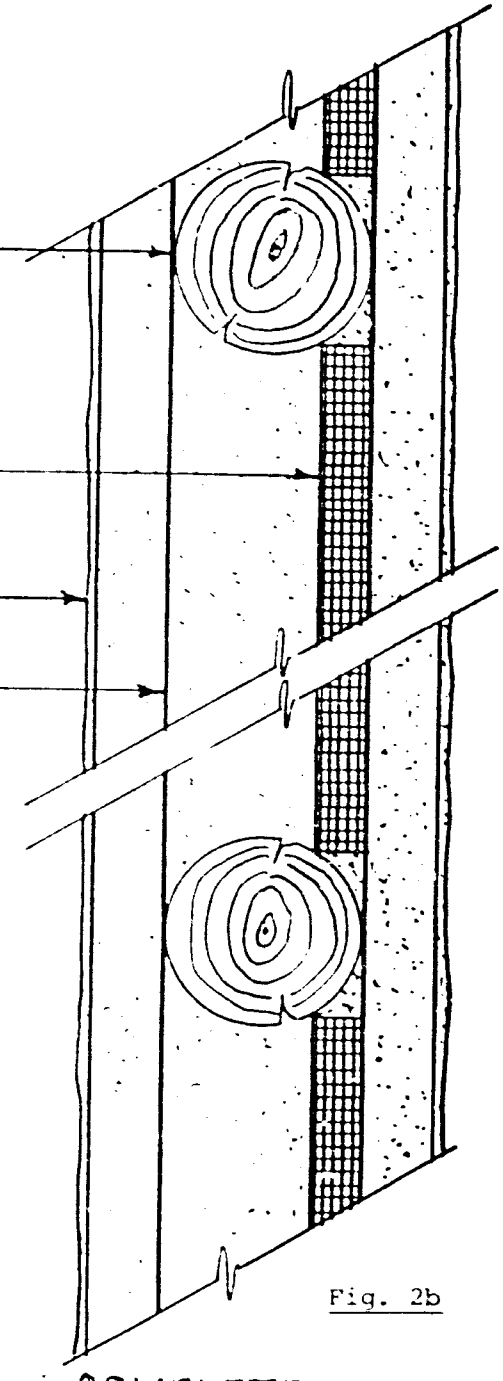


Fig. 2b

COMPLETED POURED ADOBE WALL

Once the foundation is set, the forms for the poured adobe are set in place. The forms are constructed of galvanized expanded metal or "diamond lath" which is nailed onto 2x4 frames to make standardized form modules of 4'x8' and 2'x8'. The forms are attached using standard snap ties, snap brackets, walers, stiffeners, etc., as in concrete construction. Note that since the forms are set even with the outside edge of the foundation, there is a 2" gap between the forms and the posts.

The actual process of excavating, mixing and pouring the adobe is mechanized. A medium-sized backhoe is used to excavate the on-site earth (which may be soaked if the soil is too clayey to break up lumps). A backhoe or front-loader is then used to dump the excavated earth into a gasoline-powered plaster mixer, and the stabilizer and straw are added. In larger-scale applications, the adobe can be batch-mixed in a pug mill or even a concrete truck with a pug mill or other type of paddle mixing attachment to make sure the waterproofing is adequately mixed (4). The mixed adobe is then dumped into the hopper of a concrete pumper and pumped into the walls. The pumped adobe flows easily through the welded wire mesh fabric and the 2" space on either side out toward the expanded metal forms, so that both the pressure-treated poles and the welded wire mesh are completely covered by the adobe. Suprisingly, very little of the wet adobe oozes through the expanded metal formwork. The inch or so of adobe that does get through at the bottom is simply scraped off with a trowel and put back into the forms.

The forms are then left in place for 2-3 weeks before removing, to enable the adobe to hold its shape without slumping when the forms are removed. The use of expanded metal for the formwork is critical is being able to remove the forms within such a short time; it allows the adobe to dry evenly, and reduces cracking.

Construction at the Pacheco site indicates that one assistant running the loader for mixing, one monitoring the mixer and the pumper, and one person on the hose can excavate, mix and pour the 9' high (average), 14"-wide adobe walls for an 1800 sq. ft. home (both interior and exterior) within two days.

Since not all finish work has been completed on the residence, exact cost figures cannot be given, but they appear comparable to frame construction and 30-40% cheaper than poured concrete or block adobe/concrete applications. These cost estimates are conservative because of the non-load-bearing nature of the structure (which increased costs for the posts, beams and connections), and the general overdesign of the structure to accomodate building officials wary of a "first-of-a-kind" design. These costs should drop dramatically when the design is converted to a load-bearing structural system, which will be developed and tested as part of our U.S. Department of Energy grant work.

A patent on the aforementioned poured adobe forming system has been applied for by Lynn Nelson of the Habitat Center.

U.S. Dept. of Energy Testing Program

Habitat has recently received a grant from the U.S. Department of Energy Appropriate Energy Technology Program, Region IX, for further refinements of the poured adobe building technology and for a structural testing program for both block and poured adobe building systems. The details of the testing program are still being finalized, but the overall program approach can be summarized as follows:

In order to determine structural behavior characteristics of reinforced poured adobe walls, several types of strength tests appear to be desirable. One of the purposes of the tests is to determine the influence of different variables on the strength of the walls. Another is to determine the correlation of simple laboratory tests such as compression, modulus of rupture and diagonal tension with strength behavior under combined stress conditions.

A comprehensive testing program would require major commitments of time and expense. Within the constraints of a limited budget, we have decided to focus our attention initially upon the combined shear and compression behavior in poured adobe walls. This testing program will determine the influence of adobe mix, compressive strength, modulus of rupture, diagonal tension strength and percentage of reinforcement on load-carrying capability. Simple lab tests including compression, modulus of rupture, and diagonal tension will be performed on specimens made from several different adobe mixes to determine its influence on these strength parameters.

Several combined shear and compression tests will then be performed on wallettes to develop an understanding of the relationship between shear strength and compressive stress. These tests will also indicate the influence of reinforcement on shear strength. The same simple strength tests will be made for each wallette tested and these strength parameters correlated with the shear strength behavior.

It is anticipated that a later testing program will address the subject of combined bending and compression behavior in order to determine out-of-plane load-carrying capabilities of poured adobe walls.

We invite discussion regarding our proposed testing program, and will make the results available through both the Habitat Center and the U.S. Department of Energy upon completion in 1983.

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LESSONS FROM RECENT EARTHQUAKES IN SOUTHERN ITALY AND OBSERVATIONS ABOUT THE PERFORMANCE OF BUILDINGS OF TRADITIONAL CONSTRUCTION IN THESE EVENTS

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ABSTRACT This paper discusses the lessons learnt from the most recent Italian earthquake in Campania/Basilicata of November 23rd 1980 and establishes a comparison with actions taken after the previous major earthquake in the South (Belice, January 14-15th 1968). The performance of buildings of traditional construction in these events is discussed with a comparison of the behavior of different building types and construction techniques. The description of damages to settlements is the starting point to review the strategies adopted, assessing pros and cons of involving the local component in self-help techniques

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Introduction

The scope of this paper is limited to the experience of earthquakes in Southern Italy (thus excluding Friuli) as the most recent disaster in Campania/Basilicata (second in magnitude only to those of Messina in 1908 and of Avezzano in 1915) has renewed debate on the slow reconstruction of Belice (1968) and in general on the inefficiency of public intervention in the impoverished and exploited South (which somewhat relates to Northern Italy as the "third world" to industrial nations).

In fact it is assumed here that the socio-economic context in which an earthquake occurs has a big influence both on the seismic performance of buildings (and thus the extent of damages, which is greater the lower the income) and on the choice of reconstruction strategies; therefore it seems relevant to compare the latest earthquake to the previous one in Belice (which have both affected a marginal economy where agriculture income is supplemented by receipts from emigration and welfare), while limiting the evaluation of the Friuli case (an economy which was entering the mainstream of industrial development just when the disaster occurred) to those policy lessons learnt at the national level which have been set as a reference for a course of action aimed at bringing Southern Italy closer to the North.

Belice

The earthquake that struck Belice (an inner hilly area in Western Sicily) on January 14-15th 1968 killed some 350 people and left approximately 50,000 homeless in the 15 communes most seriously damaged. The answer of the authorities has proved very centralized and "bureaucratic": the disaster victims have been either encouraged to emigrate from the region (providing them with passports and one-way tickets) or turned into passive recipients of an assistance which came from above completely by-passing the local administrations. Prefabricated units (at a cost then of 40β/m^2 and all produced outside Sicily) were provided as "temporary housing" for the homeless with big promises of industrial development, huge public works and fully subsidized permanent housing. The ad-hoc reconstruction law n° 441 approved in 1968 has since shown all its shortcomings:

- it overruled regional authorities granting most power to a special inspectorate for the earthquake areas;
- it set totally unrealistic goals for the economic development of the region trying to lure national corporations to invest in what are now known as "cathedrals in the desert";

- it distributed funds to as many as 136 communes instead of concentrating resources in the 15 worst hit villages;
- it entrusted with the whole planning and design task a national institute (which was obliged to appoint a horde of private professionals) instead than local authorities which would at least have become accountable to their communities and could have trained their permanent technical staff;
- it emphasized large-scale public works and infrastructure at the expense of small-scale residential development and facilities.

The result of this unfortunate law has been all imaginable delay in the planning and building process, which has created a "welfare mentality" among the local inhabitants and made them so frustrated to provoke a national scandal, when in 1976, i.e. 8 years later, the public opinion realized that the prefabricated units (for which 60 million $ had been spent between first costs and continuous maintenance) were still housing as many as 40,000 people and that only 1,500 permanent dwellings had been completed by the State (located in the middle of empty new towns removed from historical settlements and surrounded by oversize highways) for which estimated costs and times of completion had kept inflating by 4 or even 5 times.

Finally in May 1976 (just before the Friuli earthquake) a new law n° 178 changed the picture radically, limiting the allocation of public funds to the original 15 communes and granting them wide autonomy to subsidize private owners who would personally have their houses rebuilt; since then it must be admitted that residential reconstruction has proceeded at a much healthier pace and is now (13 years later) at least half-way through completion.

Campania/Basilicata

While the reconstruction experience in Friuli has been much more successful than in Belice, as the local authorities have been involved from the start and all programs are now due to be completed in 5 more years (10 after the disaster), the most recent earthquake has hit the regions of Campania and Basilicata with such widespread damages that the whole national policy of aid to development in the South has been questioned and the State put to a crucial test as to its efficiency in coordinating actions and its willingness to devolve powers to southern local authorities (which are considered the weakest in the country).

The earthquake of November 23rd 1980 in Campania/Basilicata can be seen as a turning point in the history of Southern Italy, were it only for sheer extension, having affected 5% of the national territory, including the whole metropolitan area of Naples which is the third largest in the country.

Before discussing the policy options which are currently considered for permanent reconstruction and development, it is worth describing the physical damages caused by the earthquake (which has killed nearly 3,000 people and left at least 150,000 homeless), limiting our observations to the area of the "epicentre" (200,000 hectares with a population of 240,000 people in 71 communes, as shown in the map in figure nº 1). This area is the only one which can be studied as a homogeneous entity, whereas all the outlying areas are very extensive and diverse (including Naples which is a case on its own), have been affected at different degrees but have in common the fact that the earthquake has just been the final detector of a progressive state of deterioration.

Of the 71 communes in the area of the epicentre, 18 can be called "destroyed" (with more than 50% of their building stock damaged beyond repair) and in several cases have to be relocated to a safer place, 16 can be termed "seriously damaged" and the other 37 "slightly damaged" (with less than 30% of the building stock affected). This assessment, resulting from a preliminary study of a research centre of the University of Naples in Portici which has not yet been officially endorsed, takes into account not only the effects of the 1980 earthquake but sees them compounded with the damages caused by the two previous earthquakes of 1930 (1,500 deaths) and 1962 (50,000 houses damaged), although with different epicentres, proving that this area is a place of "continuous hazard".

Our study area (lying in the 3 provinces of Avellino, Salerno and Potenza) is quite mountainous and among the most marginal and poorest of Italy, but nonetheless its urban structure is deeply rooted as it dates back to the medieval times and there is no question about the cultural and historical identity of all its settlements (in spite of a temporary loss of population due to the heavy emigration of the last 30 years).

Performance of structures

The survey carried out by the University of Naples in the area of the epicentre has considered over 38,000 buildings in 41 communes: 69% of the housing stock is built in masonry, 20% in concrete and 11% is in "mixed" construction (typically with walls

in either stone or tufa and concrete slabs, the use of timber being limited to trusses in the older structures. As far as tenure is concerned, more than 80% of the dwellings are considered "owner occupied" although many of them were empty at the time of the earthquake (which explains the limited number of casualties) as they belong to emigrants who invest their income in real estate in their home-towns for future security.

As far as damages are concerned, the worst collapses have happened at the two extremes of the age spectrum: 50% in structures built before 1945 (which is explained mainly by their old age and poor maintenance) and another 34% in houses built after 1952 (which reveals the irresponsible use of modern techniques made by speculative local builders). The pattern of damages although very uneven on the territory (which can be only explained by a thorough geophysical and geological survey) shows a greater vulnerability in hilly villages densely built (where land slides have been added by the tremors) versus more recent settlements in the plains and rural isolated houses.

The worst damages can be found in town quarters made of all masonry small structures or of new concrete multistory apartment-houses, whereas one-story recent single-family homes (whether in masonry, concrete or mixed construction) built directly by or on behalf of their owners have proved the most resistant: this is especially true of farms, in which case only 1,000 out of a sample of 10,000 need major repairs. This evidence confirms that old age and poor construction (both related with low income) are the main causes of collapse.

From the technical point of view, the bad performance of concrete buildings is chiefly due to the wrong positioning and the insufficient quantity of reinforcing iron bars as well as to the poor quality and cohesion of the cement aggregate itself, and the low resistance of buildings of mixed construction is due to the fact that their perimetral walls are made of real stones only as an outside layer but are filled on the inside with all sorts of incoherent material which crumbles with time and allows the water to infiltrate. In this case the most worrying cracks can be observed near the corners of walls and at the junctions between walls and joists (heavy roofing often with concrete trusses and with tile covering being the cause of most casualties).

The best seismic performance is shown by small one- or two-story houses of traditional tufa construction having a compact box like shape, generally with timber trusses under a roof of slates, which have a shorter-period oscillation: they are more common in rural areas than in towns, where they have either been

substituted by buildings hastily erected in modern techniques or have been joined by additions in other materials which have undermined their original stability.

Reconstruction policies

As of April 1981, the most hopeful event for the reconstruction of the earthquake hit zones of Campania/Basilicata can be considered the appointment of Giuseppe Zamberletti as special government commissioner for the emergency phase, a man who has acquired a unique first-hand experience working in the same capacity in Friuli and who is a strong advocate of devolution of powers to local authorities. His efficiency in coordinating aid after a first week of undeniable chaos and unpreparedness, is proved by the completion in the first four months of well equipped camps of caravans and containers (with just a few tents) as close as possible to damaged sites. After this first emergency phase he seems now determined to limit the provision of second phase housing (i.e. some 15,000 rather expensive prefabricated units with an expected life of 10 years) by next September only to the worst hit 34 communes, where the extent of needed reconstruction is so great that it will take no less than 10 years to plan a new settlement and rebuild it following all the adequate regulations.

The debate on reconstruction policies, especially in the light of the previous quite opposite experiences of Belice and Friuli is now at its peak (while an ad-hoc law is being discussed in Parliament) between those who favor centralization claiming that local authorities in the South cannot be trusted and those who advocate devolution. So far the most interesting event from the point of view of "decentralization" has been the direct involvement for the first time of the most efficient local authorities from Northern and Central Italy (regions as well as communes) which have each "adopted" a town and have set an example of cooperation at the local level which can become promising if it continues throughout reconstruction as a transfer of technical know-how and administrative experience.

Whether the lesson from Belice has been learnt - i.e. that an excess of government involvement hinders instead of helping the permanent recovery - will be witnessed in the very area of the epicentre, which has been hit at a time of great social weakness (with the lowest percentage of men in working age due to emigration and a further immediate loss after the earthquake of a quarter of its population) but which has now a chance to attract back its labor force and start investing locally.

Besides the general policies which are being debated, there are a few local initiatives which, were they to be generalized, could become useful examples for other similar situations:

- the creation of a cooperative housing society in Castelgrande (based on the example and with the direct help of similar cooperatives in Friuli) to coordinate public and private intervention and maximize the use of local labor and resources;
- the first experience of legitimate self-help in Buccino with fast timber-frame reconstruction of 100 houses and the start of training programs of the locals in this technique;
- the special emphasis given in Sant'Angelo de' Lombardi to the preservation of the local historical heritage and the creation of a workshop for restoration and training of students;
- the involvement by faculty and students of Italian and British Universities in the reconstruction of Salvitelle to turn it into a case study of users' participation in the process.

Conclusions

The last Italian earthquake, which has simply been sketched here given the complexity of its issues (historical, social and economic far beyond the sheer problem of housing) has a chance to become a vital laboratory of different approaches to a more participatory and effective reconstruction, and even set a useful example for some developing nations.

Italy is at a crucial turning point in her history, as a growing percentage of her resources will have to be devoted to protection against natural hazards. This is announced in the just completed survey by the National Research Council (known as the "geodynamics project" started just before the Friuli earthquake): it has published a complete risk map of the country which shows that 35% of the Italian population of 57 million lives in earthquake prone areas and that as much as 40% of the country's housing stock can be in danger.

It is presently estimated that at least 40 billion $ would be needed to reinforce Italy's buildings according to anti-seismic regulations. Such an enormous effort of prevention (which is already turning the national building industry to rehabilitation and to the use of more labor-intensive methods) will entail the need to train a new generation of planners, designers and builders who are expected to work in closer contact with communities and show a greater understanding of local traditions and of time-honored techniques.

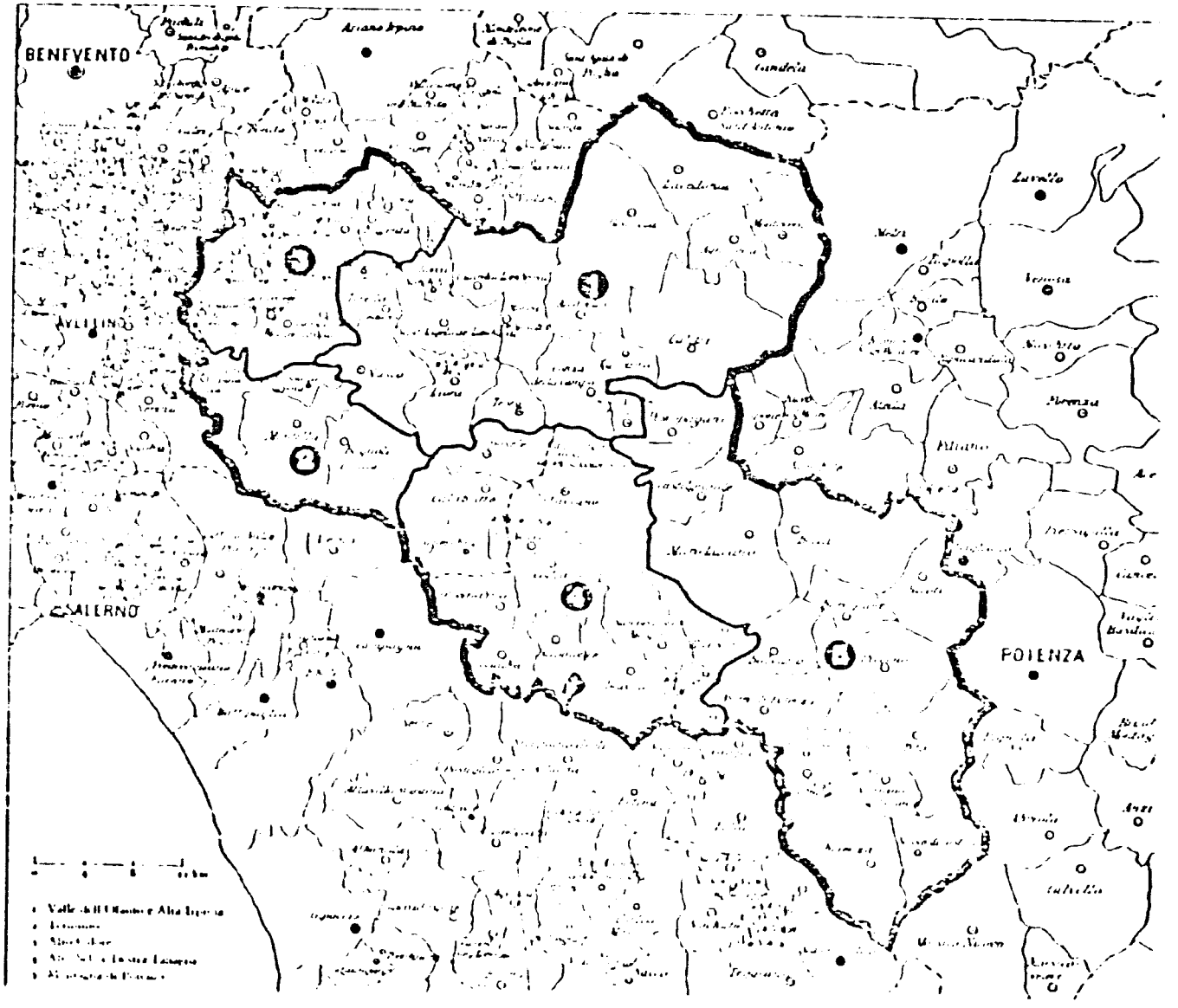

Figure 1: The 71 communes in the area of the epicentre

ADOBE CONSTRUCTION AND ITS PERFORMANCE IN SOUTHERN CALIFORNIA

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ABSTRACT

This paper presents a discussion on the construction and performance of two adobe structures in Southern California. First, a discussion on the San Fernando Mission, the largest adobe structure in California, is presented relative to its adobe construction details and its performance and rehabilitation during and after the 1971 San Fernando Earthquake. Second, an adobe home located near Oceanside, California is discussed regarding its method of construction and performance under weathering and earthquakes since its construction in 1964.

General History and Description

On September 8, 1797, the Mission of San Fernando Rey de Espana (the Mission San Fernando) was founded by Padre Fermin Lasuen, founder of eight other California missions. This was the 17th of the 21 missions to be founded by the Spanish priests along the coast of California. The mission was located in the oaken valley so named by the Spaniards in 1769, but known to local Indians as Achois Comihabit. The mission grounds are approximately 25 miles north of downtown Los Angeles which is presently known as the San Fernando Valley.

The first chapel was completed in 1799. The third chapel was completed in 1806 and was damaged extensively by the 1812 earthquake. The 1971 San Fernando Earthquake damaged the adobe walls to the extent that a decision was made to demolish the damaged chapel and reconstruct an exact replica.

The Mission San Fernando from its beginning flourished and grew. The various buildings were made from adobe and tile decorated by artwork of both Spanish and Indian cultures. As the mission grew, it became known for its leather, cloth and iron goods. In the early 19th Century, it became a trading center for what is now the San Fernando Valley. The mission continued to prosper until the 1830's when the missions were secularized. By the time of the Civil War, this and many other California missions were no longer used and its buildings deteriorated.

The mission grounds consisted of numerous buildings as shown in Fig. 1. The present chapel is the mission's fourth chapel which is an exact replica of the third chapel. The chapel is 166 ft. long and 35 ft. wide with tapered walls over five ft. thick (at some locations over 8 ft. thick) at the base and tapering to over three ft. at the top. The wall taper gives the impression that the walls are leaning inward. Due to the severe winds from the Mojave Desert, no windows were placed on the north-facing wall of the building.

Much of the chapel's current interior artwork is original. Of all the wall murals, most are original although in some damaged areas the murals were repainted. The statue over the alter of St. Ferdinand III, the Spanish king for whom the mission was named, and the painting of St. Francis of Assisi are both original artworks from the 19th Century chapel. Also located throughout the chapel are French lithographs and some modern statues.

Southwest of the chapel is located the Convento Building which took 13 years to construct. The one-story adobe building is 243 ft. long and 60 ft. wide, making it suitable for long strings of living quarters. The building has 21 Roman arches along the exterior walkway and Moorish arches on the windows and doors. The walls were constructed of 4 ft. thick adobe bricks decorated with Indian wall decorations.

The Convento Building houses many different rooms. The largest of the rooms is the Sala or Reception Room. It's ceiling, unlike the chapel ceiling where beams rest on corbels, rests on square beams and fasten to the walls directly. Rawhide thongs were used to fasten members together since iron

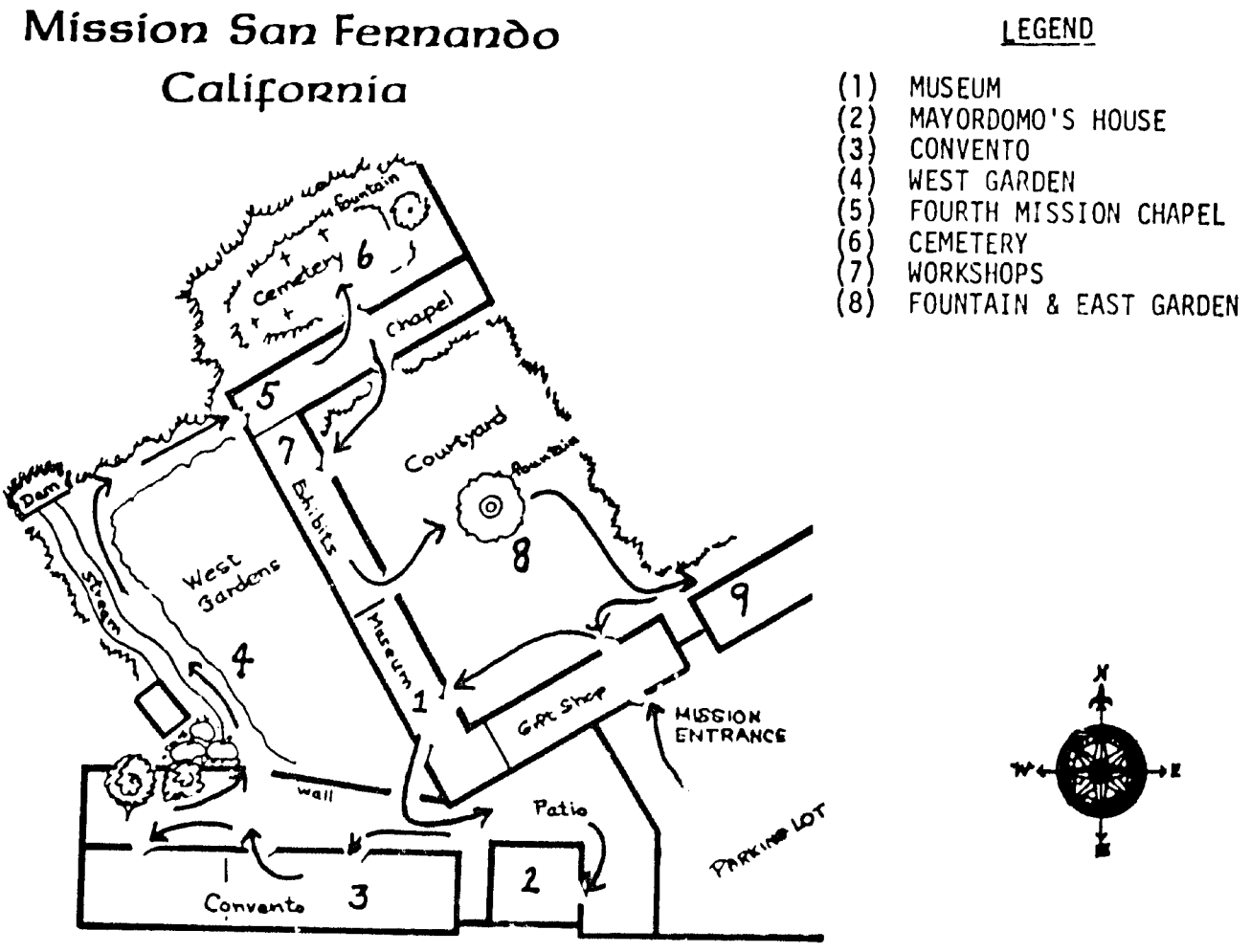

FIG. 1

San Fernando Mission Grounds

shortages existed around the mission. Indian murals depicting the Indian point of view decorate the Reception Room.

The Convento also contains dining rooms, mission offices, a wine cellar where wine was made, a library, a governors' room for prominent visitors, the bishop's room, a kitchen, a smokehouse, and the Valley's first hotel known as the "hospice". In addition, many of the rooms are presently being used to house a museum which has many of the mission carvings, paintings and old vestments.

Located adjacent to the Convento is the Mayordomo's house. It housed the foreman of the mission ranch which was 121,542 acres and had over 21,000 head of livestock at one point. The house, built in 1801, is a three-room building. By 1900 it was in ruins and was finally restored in 1949. The house is presently decorated to depict the look of an overseer's home.

The remaining buildings all of adobe construction on the mission grounds were used for various functions required to operate the mission in the early part of the 19th Century. As a self-sustaining mission, workshops for such trades as carpentry, saddlery, pottery, weaving and blacksmithing were vital to the survival of the mission. All shops were of one-story construction with numerous rooms and doors. A colonnade, or patio, in front of the workshops was supported by large plastered rectangular columns made from adobe brick. This part of the mission deteriorated rapidly after the 1850's and by the early 1900's, it became a pile of rubble. The adobe bricks varied in size since restoration occurred over a period of 150 years. The adobe bricks were manufactured primarily with soil, water and minimal amounts of straw. Asphalt stabilizers were not used until after 1930 in the construction of the adobe bricks.

The mission grounds also consist of a large cemetery, central courtyard of exotic gardens and a large fountain. The cemetery contains the remains of more than 2,500 Indians and early settlers. The gardens were and still are planted with rare trees, beautiful flowers, cacti and fruit bearing trees. The main fountain is located at the center of the courtyard as illustrated in Fig. 1. The courtyard, once the center of the mission's everyday work-life, is now planted with grass, trees and shrubs.

The mission is located at the northern end of the San Fernando Valley about 10 miles from the Pacific Ocean. The climatic conditions are typical of the temperate and pleasant weather conditions for which Los Angeles is recognized. The temperatures since the founding of the mission have probably varied from a low of about 40°F during the winter month evenings to over 110°F during the hot summer days. Since 1900 the annual rainfall for the Los Angeles Basin varied from a low of about 2 inches to a high of more than 30 inches with an average of about 10 inches. Prevailing winds are from the West (the Pacific Ocean) and the East (Mojave Desert). The combination of neglect, wind, and rain over the period of nearly 180 years resulted in virtual disintegration of the adobe construction.

In relationship to seismic activity, the San Fernando Mission is located in UBC Seismic Risk Zone 4. Fig. 2 provides the location of the mission in relation to the epicenter of the 1971 San Fernando Earthquake. Within a 0.5 mile radius of the mission two concrete structures were severely damaged.

6 miles to epicenter ●

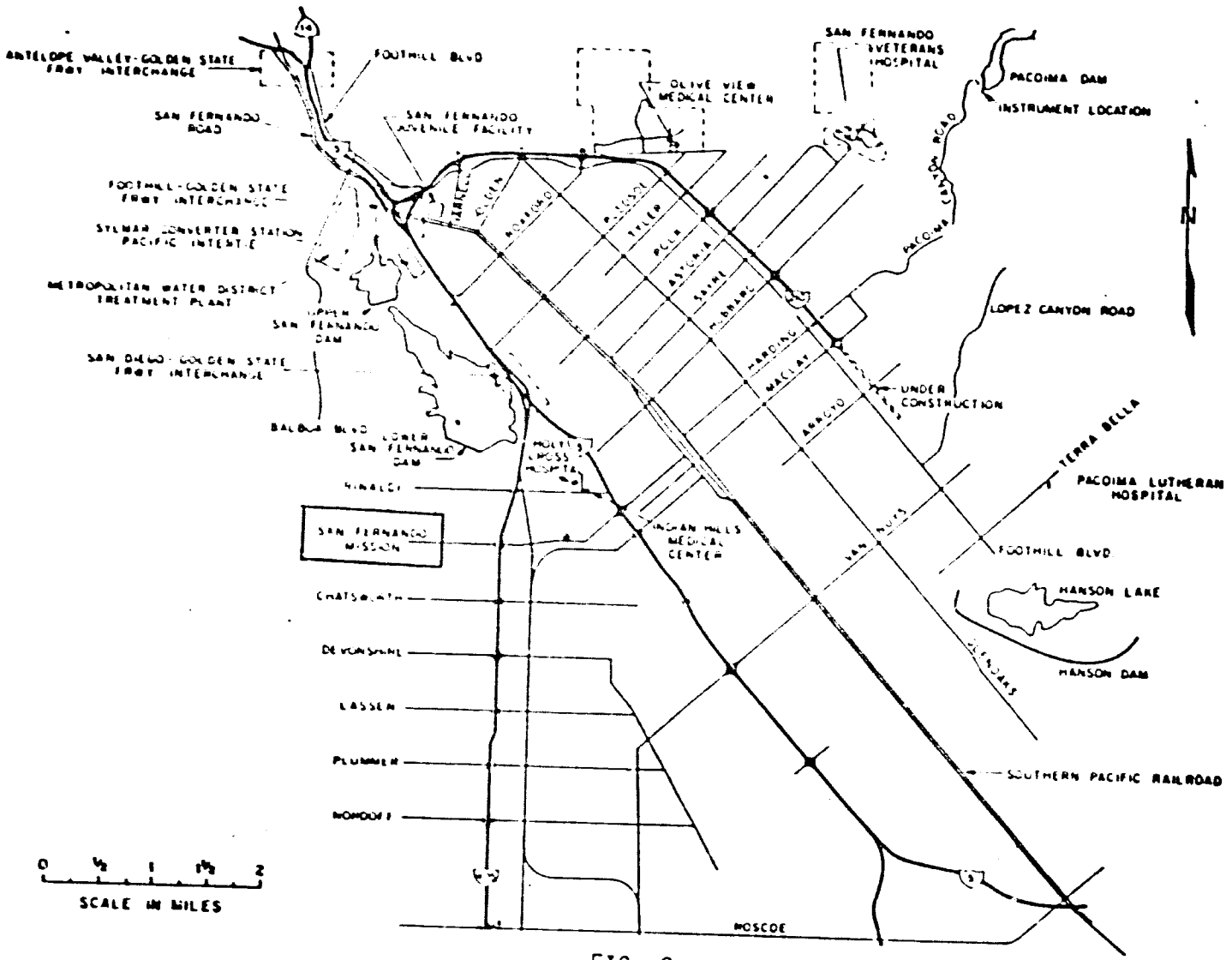

FIG. 2

Mission Location Relative to Epicenter of 1971 San Fernando Earthquake

The four-story St. Mary's Hospital was damaged to the extent that repair was not feasible and, as a result, it was demolished in 1973. The eight-story Indian Hills Medical Center suffered extensive damage, but repair in the form of epoxy injection was feasible.

Restoration Prior to 1971 San Fernando Earthquake

San Fernando Mission was secularized in 1834 and for the next 28 years it would be used as a stage station. In 1862, President Lincoln restored by order the mission and the grounds to the Catholic Church. Thereafter, the mission was used for various religious and educational purposes. Through neglect and deterioration, most mission buildings became a pile of rubble by the end of the 19th Century. Restoration was attempted at least on four different occasions; 1879, 1912, 1926 and 1930. Due to the lack of funds and possibly a lack of restoration technology, all four of these restoration attempts were unsuccessful. After World War II, William Randolph Hearst established the Mission Restoration Fund and endowed it with sufficient funds to restore the mission and its grounds to the beauty and authenticity of the early 1800's when the mission flourished and prospered. The nature of this restoration involved placement of concrete bond beams, reconstruction of the workshop area using new adobe bricks and replastering both the interior and exterior wall surfaces of the chapel and other buildings.

Damage of Mission Buildings Due to 1971 San Fernando Earthquake

The chapel suffered the most severe damage of all the mission buildings, primarily due to large open areas not common to other buildings where many interior walls provided resistance to the seismic loads. The most severe seismic damage to the chapel occurred at the choir loft and near the base of the exterior walls. Despite such damage, the adobe chapel survived the earthquake without collapse.

Figure 3 shows the damage suffered by the adobe walls due to load transfer from the wooden beams of the choir loft. These wooden beams were apparently embedded into the adobe walls to a depth of only about 18 inches. As a result, at least one course of adobe brick peeled away from the adobe wall and collapsed as shown more vividly in Fig. 4. This portion of the church suffered the most severe damage.

The east wall represents the front of the chapel. Fig. 5 provides a general interior view of the east wall, the altar and portions of the north and south walls. Extensive damage to the interior plaster included both cracking and spalling. At least one course of adobe brick peeled from the north wall in several regions near the pulpit. Other portions of the interior surfaces of the adobe walls were damaged primarily in the form of cracking

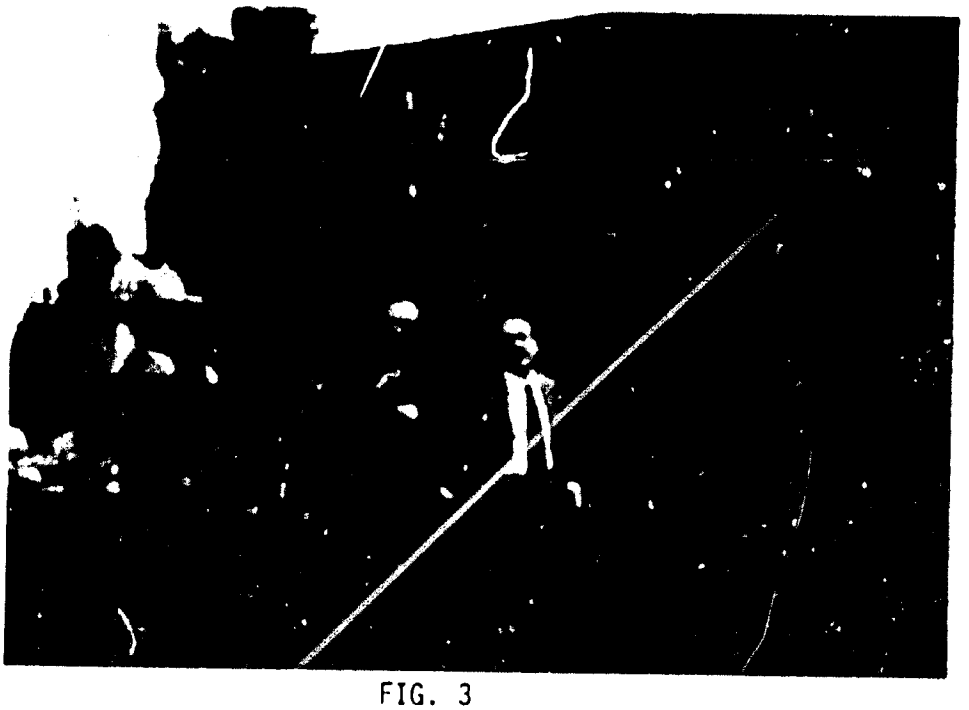

FIG. 3

Damage Due to Inadequate Embeddment of Beams of Choir Loft

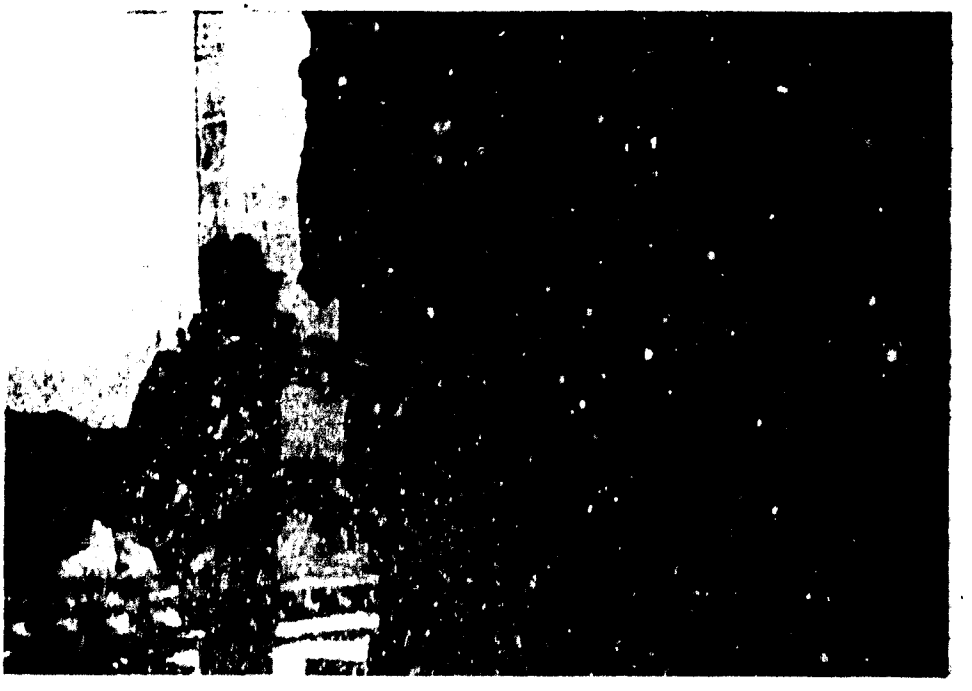

FIG. 4

Adobe Brick Collapse at Choir Loft

and peeling plaster with surprisingly small damage to the adobe brick itself.

The damage to the exterior of the chapel was similar to that of the interior. Extensive cracking and peeling of the plaster was visible on many walls. The most severe damage occurred at the base of the walls where one or more courses of adobe brick peeled off. The Spanish style tile roof neither collapsed nor suffered major damage.

The remaining adobe buildings at the mission were not severely damaged by the 1971 San Fernando Earthquake. Damage to stone lintels as shown in Figure 6 and cracking and minor peeling of the plaster on both interior and exterior wall surfaces was common to many of the adobe structures. The minor damage experienced by one and two-story buildings was probably due to the lateral stiffness provided by the numerous interior and exterior adobe shear walls.

Repair and Rehabilitation After The Earthquake

The damage suffered by the chapel's adobe walls was limited as described earlier. However, the Los Angeles Building Department ordered the chapel building vacated on the basis that the unreinforced adobe construction was a hazard to public safety. After approximately one year of engineering studies, it was concluded that repair and/or strengthening of the chapel's adobe walls was not economically or structurally feasible. The chapel's dimensions and aesthetic features were totally documented and the chapel was demolished including the foundation. In 1973, construction was started on a new chapel which would be an exact replica of the demolished chapel but with greater sesimic resistance. The new structure of the chapel consisted of a steel frame with interior and exterior surfaced plaster to duplicate the original chapel. All details of the earlier chapel, even the sag in the roof, were meticulously reconstructed for the sake of maintaining the originality of the new chapel. The new chapel interior is shown in Fig. 7 including the altar and the elaborate paintings on the walls.

The other structures on the mission grounds were not severely damaged by the 1971 Earthquake as discussed earlier. Damaged or cracked plaster was repaired. Two transverse adobe walls in the Convento Building were replaced with new reinforced concrete block walls and bond beams were added to increase the seismic resistance.

Conclusion

Through extensive efforts by many people involved with the San Fernando Mission and the generous financial aid provided by William Randolph Hearst, the San Fernando Mission today stands as a living monument to the Spanish

FIG. 5

Earthquake Damage on East Wall of Chapel

FIG. 6

Damge to Stone Lintels

priests and American Indians who originally built it. The architecture and the beauty of the mission have been preserved for future generations through duplication of even the smallest details of the original mission.

FIG. 7

View of East Wall After Rehabilitation

DESIGN, CONSTRUCTION AND PERFORMANCE OF A MODERN ADOBE HOME IN IN SOUTHERN CALIFORNIA

Introduction

In 1964, Mr. Walter Jakway began construction of an adobe home near Fallbrook, California. Due to his love of Mexican-Indian culture, he decided to construct the home utilizing adobe materials and workmanship common to the Indians near Mexico City during the early part of the 20th Century. The home was completed after approximately 1-1/2 years of construction work. In the attempt to duplicate both the materials of construction and workmanship of the Mexican Indians, Mr. Jakway acted as the construction foreman. He employed five members of the Mexican-Indian tribe with which he was familiar since Mr. Jakway lived and toured Mexico on many occasions. This paper briefly describes the construction details of this adobe home and its performance under Southern California-type climatic conditions and earthquakes.

Design of the Adobe Home

The home is located in an unincorporated area of Southern California, hence the design and construction procedures were approved by the Building Department of San Diego County. According to the 1979 UBC Seismic Risk map of the United States, this region is located in Seismic Zone 4. Since the home was constructed prior to the 1971 San Fernando Earthquake, the design of the home apparently involved only a simple set of calculations for the roof beams and girders. The adobe walls were approved on the basis of their overwhelming thicknesses ranging from 18 in. to 24 in. The home is located 70 miles directly south of the epicenter of the 1971 San Fernando Earthquake and approximately 60 miles west of the southern portion of the San Andreas Fault as shown on Fig. 3 and 30 miles west of the San Jacinto fault. The extensive damage to buildings and bridges produced by the 1971 San Fernando Earthquake resulted in major changes in various building codes in regards to seismic design. Hence, if this adobe home were to be constructed under the current code requirements, additional calculations and different construction practices would be required since unburned clay brick walls must be stabilized with emulsified asphalt and compressive and shear stresses must exceed 30 psi and 8 psi, respectively (1979 UBC).

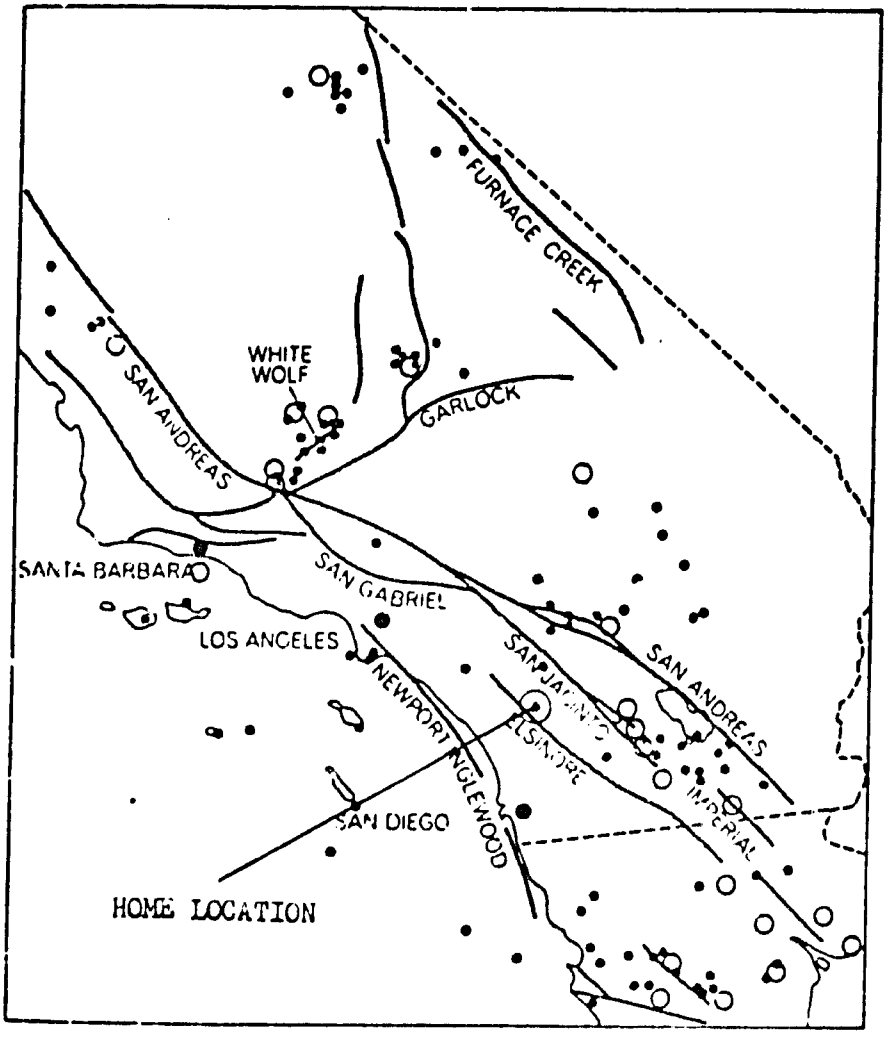

FIG. 8

Thirty-six year earthquake record shows the epicenters of all events of magnitude 5 or greater recorded in Southern California and in the northern part of Baja California from 1931 through 1969. The epicenter is the point on the earth's surface above the initial break. Dots show earthquakes between 5 and 5.9 in magnitude. Open circles indicate earthquakes of magnitude 6 or greater. The hypocenter, the point of the initial break in the earth's crust, is often many miles below the surface in thrust-type earthquakes, a type frequently observed in this region. In the 36-year period Southern California and adjacent regions experienced more than 7,300 earthquakes with a magnitude of 4 or more. Earthquakes are about 10 times more frequent in this area than they are in the world as a whole.

The home consists of two bedrooms, 1-1/2 baths, large family room and a spacious kitchen and dining room. The L-shaped home has floor dimensions of 70 ft. by 25 ft. The total floor area is about 1,800 sq. ft., including a two-car garage. Due to the thick adobe walls, insulated roof, and relatively low window glass area, the energy consumption for heating and cooling are minimum. The temperatures outside the home vary from a low of about 30°F during winter nights to over 100°F in the summer. However, without the benefits of air conditioning or heating, the home inside temperature varies between 60°F to 75°F throughout the year.

Preparation of Adobe Brick

The soil surrounding the adobe home has a distinctive reddish clay appearance. For aesthetic purposes and in keeping with the Mexican-Indian customs most adobe bricks were manufactured with on-site soil and on-the-job site. The bricks were manufactured in wooden molds to a finish size of approximately 4" x 12" x 18". The mixture used for the adobe bricks was as follows: 15 shovels of soil, one quart of asphalt stabilizer, a minimal amount of straw and sufficient amount of water to produce a mix which would yield about a comparable 3-inch concrete slump. The soil used to make the adobe bricks was graded with large sieves. The final soil mix consisted of about 30% passing the number 200 sieve and nearly 100% passing the number 4 sieve. The soil, water, stabilizer and some organic straw were mixed with a typical 1/2 cement sack mixer. Some small lumps of soil can be seen in the finished brick due to lack of mixing. The final adobe bricks were dried in the sun for a period of about two months. Sample bricks were sent to testing laboratories for compression strength, shear strength, water content and stabilizer content. The test results were approved by the San Diego County Building Department.

Foundation and Wall Construction

The foundation for this adobe home consists of concrete with minimal amount of reinforcement. All existing floors consist of unreinforced concrete pads about 4 inches thick poured after the foundation had been placed but before the walls were constructed. The exact cross-sectional dimensions for the foundation are unknown with the exception of the depth of 15 inches to 18 inches.

All walls were constructed with adobe brick discussed earlier resulting in 18-inch wall thicknesses. Oval pilasters at the house corners were about 24-inches thick. The mortar consisted of the same adobe mix used for the fabrication of the brick. Each adobe brick layer was completed before the next layer was begun in order to permit each mortar joint to gain sufficient strength to avoid settlement. The mortar joint thickness varies

from a minimum 3/8-inches to about 5/8-inches in order to compensate for irregular dimensions of the adobe brick.

The interior of the walls was plastered with about a 1/2-inch to 3/4-inch thick gypsum plaster base coat followed by a 1/8-inch thick interior finish gypsum coat. The resulting interior wall surfaces were smooth and were painted periodically with common water based paints. Peeling of paint has not been observed. However, as a result of moisture accumulation near windows and doors, blistering and effervescence appear to be a continuous problem.

The exterior of most walls was neither plastered nor treated with admixtures or surface coatings. However, as a result of weathering, the exterior walls have been painted about every 10 years with the adobe type coating mix.

Due to lack of tooling or precise workmanship, the Mexican-Indian adobe homes built near Mexico City were constructed with slightly crooked walls. Such wall crookedness was duplicated by Mr. Jakway in his adobe home shown in Fig. 9. The slight curvature in the walls provides an aesthetically appealing view without providing a sense of insecurity. All door and window frames were cut from hewed logs and set flush into the walls. The windows were constructed from iron bars and glass set into a soft lead sodder. Thus, the windows cannot be opened.

Roof Construction

The roof has a pitch of approximately 1/2-in. per foot and sloping in one direction only. The beams, girders and slats were hewed from local spruce pine trees using a small hand ax as was common practice of the Indians. The roof tile consists of a local fired clay product. The roof tile is attached to the 2-in. by 2-in. wooden slats by a tongue and groove type of construction. The slats rest on beams and were placed diagonally as shown in Fig. 10. Small clearances and embedment into the adobe walls prevent movement of the slats.

The beams and the girders are embedded into walls. Nails were sparsely used in the roof construction primarily for the purpose of beam and girder alignment during the construction. All beams and girders were erected with pully systems and manpower. The slats, beams, and girders were cut to length utilizing a cutting tool similar to a saw that was common to Mexican-Indians during the early years of the 20th Century. The beam spans range from 5 ft. to over 8 ft. with cross-sectional dimensions of 4 in. by 8 in. The girders span lengths of up to 22 ft. with varying cross-sections.

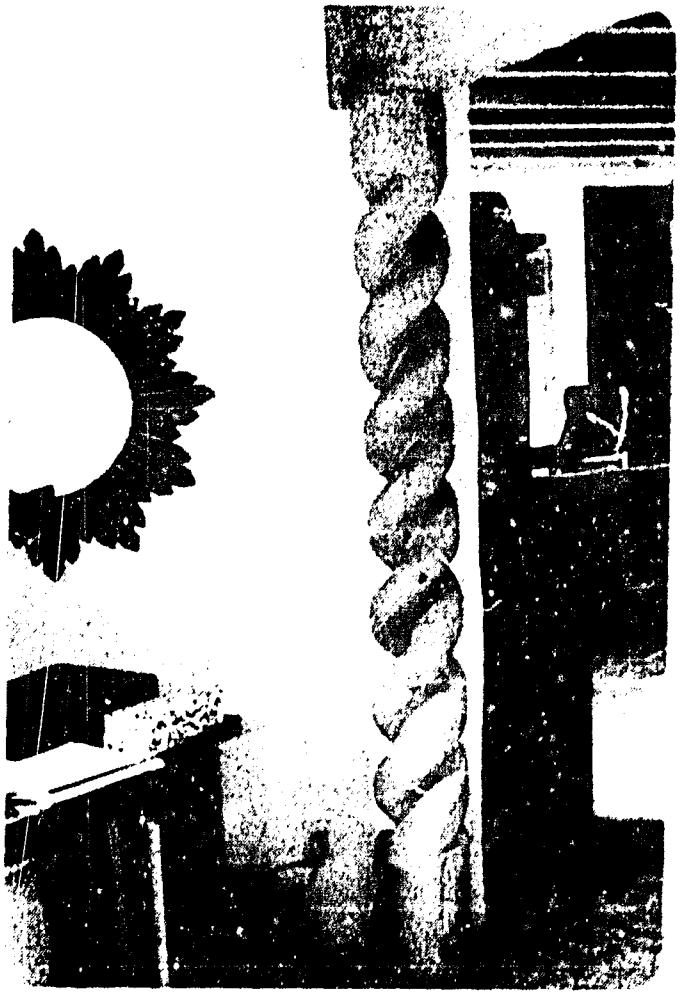

FIG. 9

Crooked Wall and Spiral Wood Column

FIG. 10

Roof Beam Construction

FIG. 11

Seismic Damage to Pilaster

Performance Under Weathering

The climatic conditions near and at the adobe home are typical of the mountainous coastal regions of Southern California. The annual rainfall varies from less than 10 inches to over 30 inches in 1980. Freezing temperatures do occur during winter nights, however, snow accumulations have been very minor during the past several decades. The home is located on a hill at the end of a narrow valley which acts as a funnel for the Southwesterly winds. As a consequence, the wind speeds vary from gentle breezes to speeds exceeding about 60 mph at least once or twice per year. The weathering of the adobe bricks after 16 years of the above-described climatic conditions appears to be minimal. The edges and corners of nearly all the adobe bricks have been blunted on the outside wall surfaces. The adobe brick surfaces may have lost about 1/4-inch in thickness and loose straw is visible on some bricks. The mortar joints have deteriorated in localized regions where moisture accumulation is higher. Re-striking the joints has been performed on several occasions using adobe mix similar to that used for the adobe brick. As discussed in an earlier section dealing with the preparation of the adobe brick, the presence of localized lumps of clay and rain probably produced the spherical voids present in some adobe bricks especially in regions of high moisture accumulation.

An interesting phenomenon of adobe construction is its vulnerability to attack by animals. Boring wasps have on several occasions built their nests in the adobe walls by boring deep holes about 3/8 in. diameter into the adobe brick. It appears that asphalt stabilizers do not deter such behavior by wasps or other animals that scratch or dig into the adobe.

Performance During Earthquakes

Since 1964, the cities and towns adjacent to the San Andreas Fault extending from Los Angeles to Imperial Valley (see Fig. 8) have been subjected to more than two dozen earthquakes with magnitudes about 4.5 on the Richter scale. Except for the 1971 San Fernando Earthquake, most of the remaining earthquakes along the southern San Andreas and San Jacinto faults occurred in the Imperial Valley near the cities of El Centro, Brawley and Calexico. These cities are approximately 50 miles south of this adobe home and suffered considerable damage during past earthquakes. Seismic activity such as shaking, was physically observed at the adobe home on numerous occasions. The extent of damage due to seismic activity has been minor to the adobe home. Cracking at the junction of the pilasters and the adobe walls has been attributed to the seismic activity as illustrated in Fig. 11. Settlement and lack of a mechanical connection may also have been partially responsible for such cracking.

The embedment of the roof beams and girders into the adobe walls has been sufficient to result in diaphram action during seismic activity. This is evident by the presence of minor cracking in the adobe bricks and mortar joints at and near the location of beam or girder embedments.

Special Ornamental Features

Most doors, both interior and exterior, were hand-carved utilizing aesthetic features common to the Mexican-Indians. The door hinges were made from malleable iron rods and shaped according to the colonial Spanish and Indian traditions as illustrated in Fig. 12. The hardware on all doors was handmade.

The centerpiece in many Mexican-Indian and colonial Spanish homes was one or more spiral-shaped columns illustrated in Fig. 9. The columns were generally carved by hand from native wood and located in the kitchen and/or dining room area. Mr. Jakway carved the column from spruce pine utilizing several carving knives and a small hatchet.

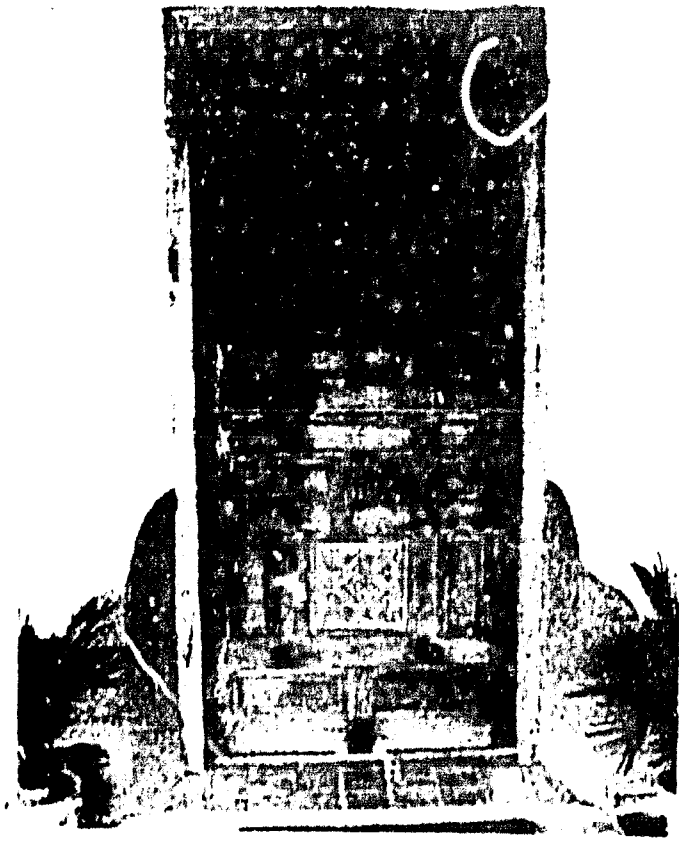

FIG. 12

Typical Handmade Doors and Hinges

A REVIEW OF THE SEISMIC BEHAVIOR OF EARTHEN HOUSING IN NICARAGUA

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ABSTRACT : Earthen construction is typical in the rural areas of Nicaragua. Two types are identified: The Taquezal and the Adobe which seem promissing for low cost massive housing. However, their vulnerability to earthquakes and other environmental risk had limited their use.

The paper describes efforts to make earthen construction safer, appropriate for energy conservation and suitable for using alternate forms of energy.

Acknowledgement

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Introduction

Earthen construction is typical of low cost rural housing in Nicaragua. There are two types: Taquezal widely used in the Central and Northern part and along the Pacific Coast; and adobe used in the Northen and Central regions. Both types are vulnerable to earthquakes and other environmental risks and had suffered serious damages and even collapse under seismic loads.

Until recently, nobody seems concerned with their safety and the only regulation which appears in the Building Code prohibited their use. However, this type of housing is widespread in the rural and semiurbans areas where people have identified themselves with them.

An analysis of the economic situation of construction materials and the construction patterns shows, that earthen houses will be difficult to erradicate from the construction habits of the Nicaraguan rural people. This, and the fact that earthen houses are suitable for energy saving, have good thermical and accoustical insulation properties, makes them a very attractive low cost housing solution, if properly protected against seismic events.

This paper will review the typical earthen construction in Nicaragua, the progress made to make them safer since the 1972 earthquakes and the experimental work being done to take advantages of their design for energy saving and as receptors of alternate forms of energy.

A brief review of the existing taquezal and adobe construction follows.

Taquezal Construction

Earthen construction is the Nicaraguan answer to low cost rural housing. Their construction patterns although very diversified have changed very little, in spite of earthquakes, volcanic eruptions and other events.

Nicaragua, the largest country in Central America, has an extension of 130.000 Km.2 and about 2.6 millions inhabitants. It is bounded by the Atlantic and Pacific Ocean at the East and West respectively and by the Republics of Honduras and Costa Rica at the North and South respectively. Most of its inhabitants are Spaniard and Indian descents and were precisely the Spaniards who introduced earthen construction to the country.

Fig. 1 and Table 1 show the distribution of Earthen housing in Nicaragua. The major concentration exists in the Northen part, but the construction along the Pacific Coast, a high seismic risk zone, is also considerable. From the earthen houses listed in Table 1, it is seen that taquezal is most popular than adobe construction, in the urban and rural areas.

FIG.I TAQUEZAL AND ADOBE HOUSING IN NICARAGUA.

TABLE 1. EARTHEN HOUSING IN NICARAGUA

MAJOR CITIES	ADOBE WALLS				TAQUEZAL WALLS			
	URBAN AREA		RURAL AREA		URBAN AREAS		RURAL AREAS	
	UNITS	%	UNITS	%	UNITS	%	UNITS	%
EL PAIS	11,016	100	8303	100	15825	100	13949	100
CHINANDEGA	[illegible]	2.44	526	6.33	751	4.75	1478	10.60
LEON	2103	18.10	371	4.47	1750	11.06	1182	8.47
MANAGUA	2449	21.10	324	3.90	7677	48.51	314	2.25
MASAYA	911	7.84	60	0.72	695	4.39	61	0.44
GRANADA	1616	13.91	83	1.00	963	6.09	52	0.37
CARAZO	133	1.14	25	0.30	101	0.64	75	0.54
RIVAS	307	2.64	80	0.96	120	0.76	62	0.44
CHINANDEGA	337	2.90	430	5.18	168	1.06	396	2.84
JUIGALPA	550	4.73	2167	26.08	243	1.54	540	3.87
MATAGALPA	814	7.01	2108	25.35	879	5.55	2080	14.91
JINOTEGA	216	1.86	339	4.08	355	2.44	521	3.74
ESTELI	175	1.51	492	5.92	675	4.27	2138	15.33
MATAGALPA	317	2.69	353	4.25	879	5.55	2294	16.44
NUEVA SEGOVIA	1367	11.77	905	10.89	559	3.53	2513	18.02
RIO SAN JUAN	5	0.04	13	0.16	8	0.05	18	0.13
BLUEFIELDS	37	0.32	34	0.41	2	0.01	225	1.61

SOURCE : NATIONAL HOUSING SURVEY, 1971.

NOTE: Earthen Housing in Managua was practically destroyed by the 1972 Earthquake. Therefore, the data presented may not be representative.

The taquezal construction is characterized by a system of earthen walls, shaped by a wood frame and sometimes reinforced by small stones,pieces of clay tiles, straw and wood. It has no resistence to shear loads and vibrations.

As an illustration and to describe the taquezal system, a typical house located in Northen Nicaragua is shown in Fig. 2.

The site where the house is located is flat, but high and dry; it receives 600 cm. of rain annually.

The house appears to have been built in one stage although, it is possible that the wood bedrooms and the store room may have been built as an addition after the rest of the house was finished and occupied for a time.

The transfer load mechanism is provided by a wood framework composed of wood posts and wood tie beams. The wood posts, four on each eave side, are buried in the ground up to about a yard and tied to the crown beams at the top. The framing is appropriated to transfers vertical loads, fairly well; however, it has no ability to take lateral loads, as is the case of the earthen walls of the taquezal system.

Walls and Foundations

Foundations are a vital part of earthen construction. Those corresponding to the house considered,are obtained by filling ditches connecting the columns by rocks (Fig. 3c). Although this is not a usual practice in earthen houses, rock foundations are a good low cost footing solution as they absorb surface waters, thus protecting the earthen walls against damage and even collapse. The construction of a poor cement concrete beam on top of this base will strengthned the wall. Other improved solutions known as "minifaldas" consist in extending the beam foundation up to 2 - 3 ft. height.

The main feature of a taquezal wall is a double face framework or mold designed to be filled by a mud like mix. The frame is obtained by buring in the ground additional poles 2 - 3 ft. apart and tying or nailing horizontal "lath" sticks or wattle to both sides of these posts.

The wattle can be sticks, bamboo, caña brava and others. Sticks of 1" x 2" of sawn lumber are a common type used.

The mud filling is obtained by mixing a clayey soil with water and adding stones or pieces of clay tiles and sometimes straw or cow manures. The practice of mixing straw, small branches, dry corn leaves and similar materials is harmful as it diminished the compressive strength of the dried earthen mix. Furthermore the organic material rotten or decomposes easily and dries out, loosing volume and propiciating further cracks.

A better earthen mix should be one of stabilized soil using the appropriate stabilizer with the local soil, to meet the minimum allowable stresses. It follows that, this type of construction will be attractive when the

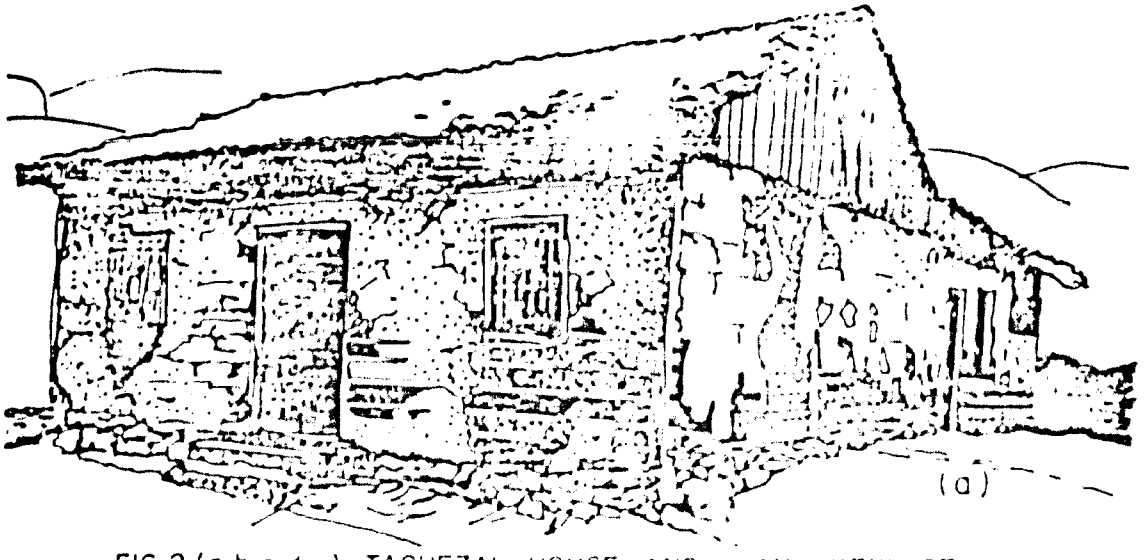
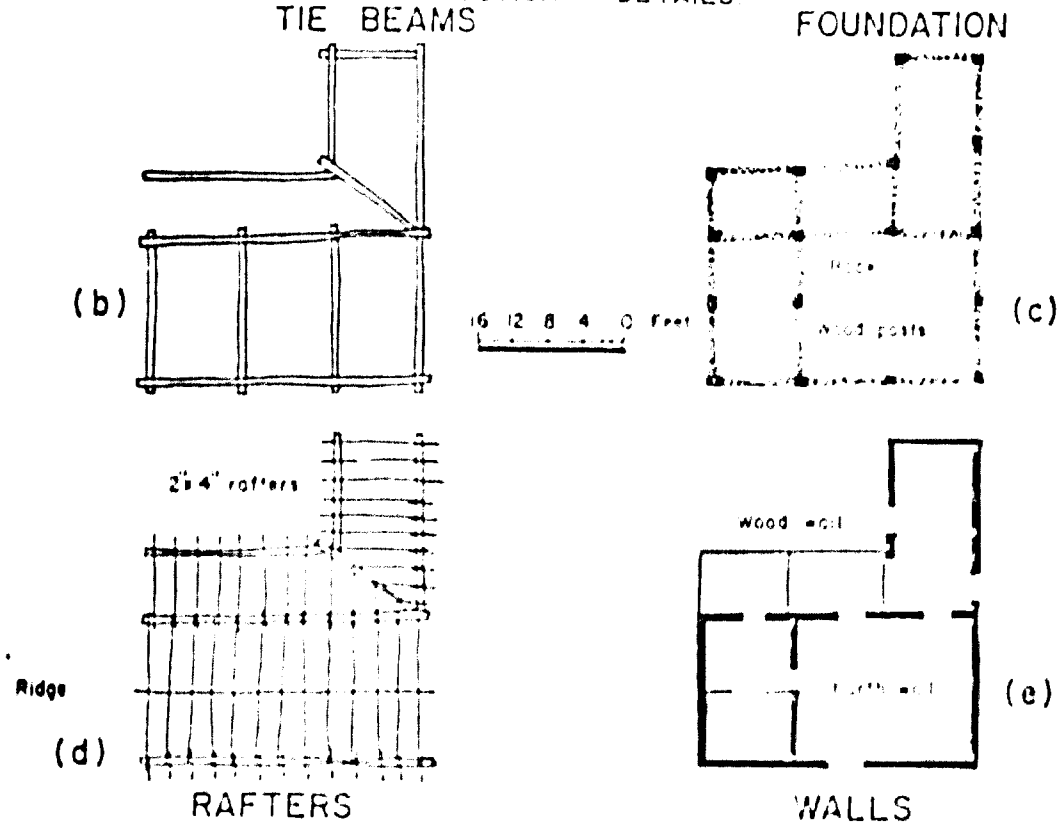


FIG.2 (a,b,c,d,e) TACUEZAL HOUSE AND PLAN VIEW OF CONSTRUCTION DETAILS



appropriate soil and stabilizer are in location, or nearby. Otherwise, transportatio cost could be a decisive factor. Climate, humidity and local soil conditions are important factors to be considered.

After the filling has dried, the wall is finished with a mud plaster and painted with a mixture of spend carbide and water. Other paints used are limewater solutions. A common problme in earthen houses is the spalling off of the finish. This can be corrected with a soil-cement mix using a percentage of cement higher than that used in the walls.

Roofing

The roof framework, was constructed by assembling rafters and tie beams to the wall framework Fig. 3(b and d). The 2" x 4" rafters about 2 feet on center, are laid with the slope of the roof and the 1" x 2. purlins, on which clay "teja" tiles are laid, are nailed across the rafters, at 6" spacing.

Hand made teja tiles are about 12" long, they provide a roofing attractive and economical. However, as a heavy roof cover it increases the danger during earthquakes, specially if they are not fixed properly.

The conventional way to laid teja tiles is in rows, overlaping one another like the scales of a fish. The last row at the top is fixed to the ridge by a mortar. Figs. (3a, b) show two typical roof-details used in Nicaragua. Fig. 3(a) indicates a load bearing ridge, while Fig. (3b) shows a non-load bearing ridge rafter, where the resulting thrust will require a tie beam.

The floor of this house is packed earth. New improved floor solutions have been worked out and will be presented later.

The urban areas use more sophisticated taquezal construction, filling the double wood frame with a mix of soil, water, cement and lime and adding large stones, pieces of clay tiles and the like as filling. It was the popular type of construction in Managua, before the 1931 and 1972 earthquakes.

Both earthquakes demostrated the dangerous behavior of this construction. Most of the taquezal building, collapsed burying thousands of people under the rubble. The failure was mainly caused by a weak and a rotten wood framework or a badly deteriorated by termites. Housing in Managua went from taquezal to reinforced concrete, wood, reinforced or confined masonry. Secondary cities and small towns have conventional taquezal houses of one and two stories. However, this type of construction could be improved by increasing the strength properties of the earthen mix and by establishin methods of design and construction for seismic safety.

A serious objection to the taquezal system is the heavy weight of the walls which generates high seismic forces. As a result, the walls will deform beyond the permissible limit loosing its capacility of resistence.

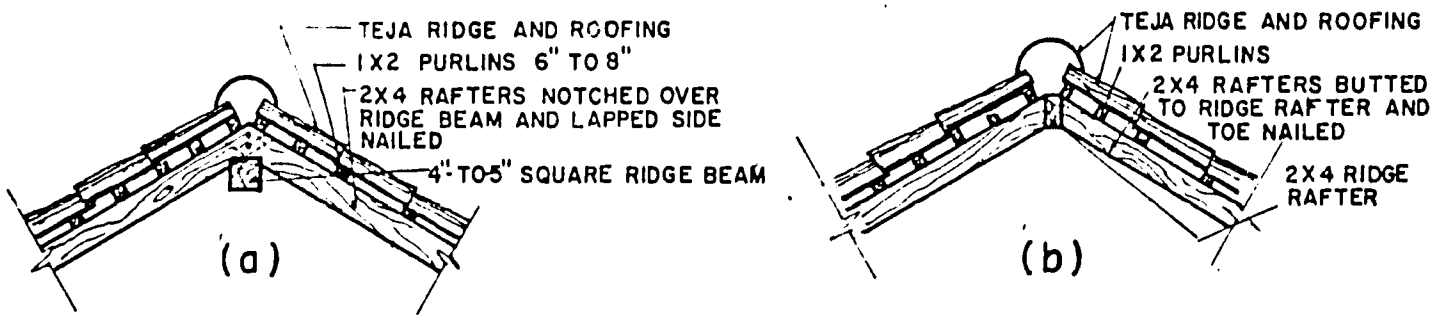


FIG. 3 (a,b) ROOF DETALLS FOUND IN EARTHEN HOUSES

As a first solution approach, one may considered the possibility of having the taquezal wall works as a shear wall. This requires an integrated wall, which is not the case under the actual methods of construction.

However, by designing a filling with different sizes of stones to minimize voids and to keep contact which each other, a network stress transmission can be created, establishing a good force resistant system.

A filling of the residual voids with soil cement mix would set the basic supporting system. To integrate the framework to this system, such that the hybrid structure behave mononilitically, the wood studs, of the frameword can be coated with a glue-cement mix, that will give a good bond with the filling. The coating will also protect the wood against termites, fire and humidity.

Another alterantive would consist in designing the framework to resist the lateral forces. In general, taquezal framework have behaved satisfactorily under seismic loads. Failures have occurred when the base of the columns have rotten or deteriorated by termites or other insects. The behavior of the frames will improve considerably if a treated column base, is fixed to a concrete foundation.

Another objection to traditional taquezal construction, has been the use of heavy weight roofs, since they generate lateral forces that can not be transmitted to the framework due to the lack of adequate connection. By designing good connections between the roof system and the framework an integral behavior of the structure can be achieved.

Adobe Housing

To review existing adobe construction, consider the house shown in Fig. 6 (a,b). The supporting frame is a 9 wood posts of 6 sq. inc. sections tied at the botton by a 6" x 4" concrete grade beam built directly over the ground. This beam is reinforced with two strands of barbed wire stretched between the columns.

A better foundation is found in some adobe houses, where trenches connecting the columns have been dug and filled with large river rocks. The grade beam is then pour on top of this base.

As before, the wood posts are embedded up to 1 yd. in the ground. To complete the wall framing, the columns are fixed to a wood beam at the top. The roof frame is then build, placing the teja tiles, sometimes before the construction of the walls.

The adobe walls are built using adobe bricks of about 3" x 5" x 10" giving a wall thickness of 5 inches. The bricks are laid within the wood frames with thick mortar joints of about 1 inch until the height of doors and windows is reaches. A second concrete beam reinforced by barbed wire to withstand stress concentrations is placed at the height of doors and windows. The wall is completed withthe last row placed under the tie beam. If any gap is left, it is filled out with a mortar.

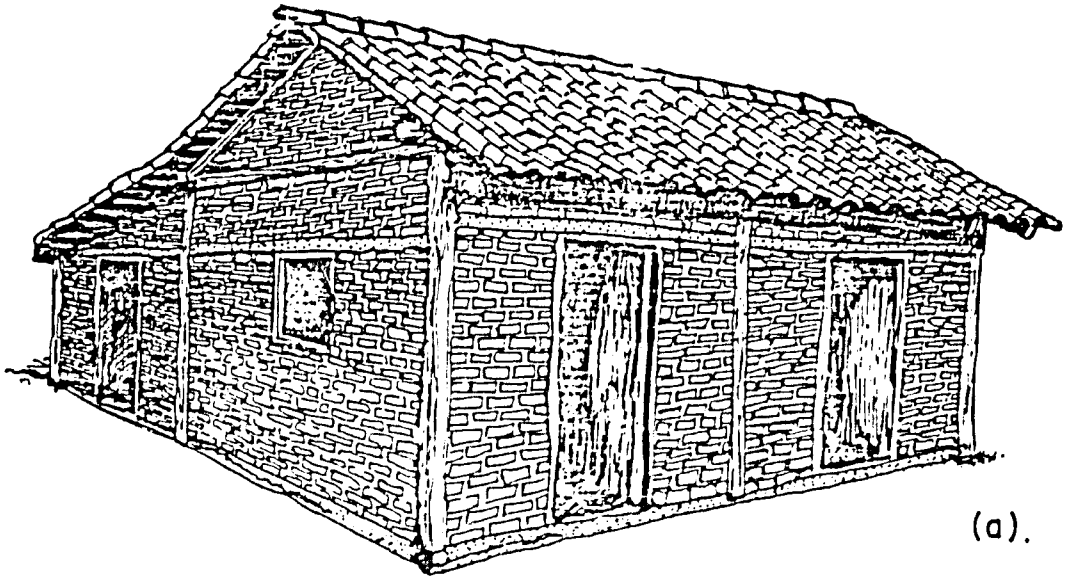
Other details of the house are similar to the previously described. A combination of taquezal and adobe walls is also used in the rural areas of Nicaragua.

The taquezal and adobe housing shown, are inadequate to resist lateral loads such as those from earthquakes or winds being taquezal the most critical.

In order to improve the performance of earthen construction during a seismic event, work is being carried out on various aspects of earthen materials and their technology for construction.

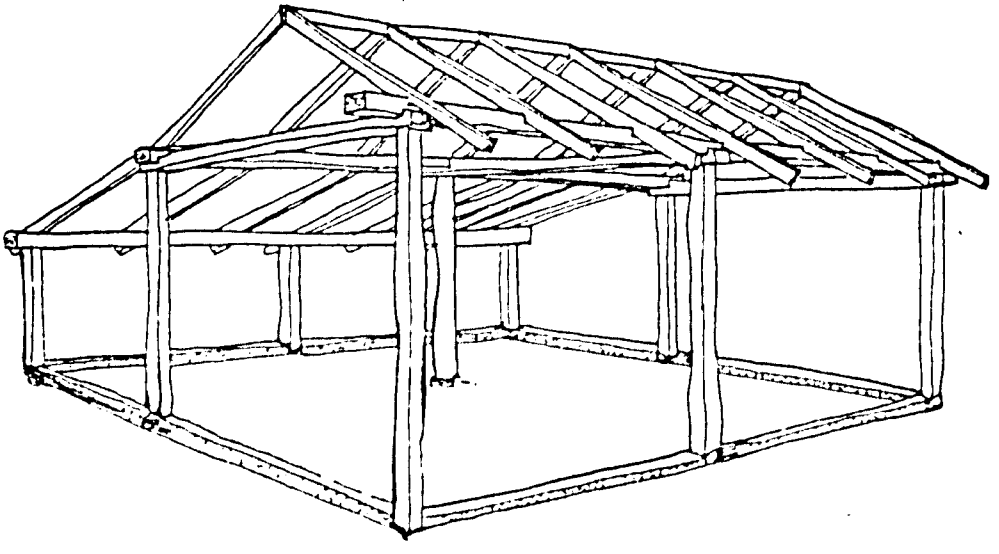
Materials: Adobe

This material, generally understood as a mix of soil and water subjected to a natural process of drying, has been in use for several centuries around the world. Although the behavior of adobe is complex, technical specifications can be established for its rational use in construction. Adobe in Nicaragua is characterized for its row material disponibility, low cost, easy fabrication and construction, good thermical and accoustical properties and a resistance to termites and fire. It sounds like an ideal material, however, it has serious disadvantages such as poor behavior under weathering conditions, low compressive strength and noticeable cracking due to high soil contraction.



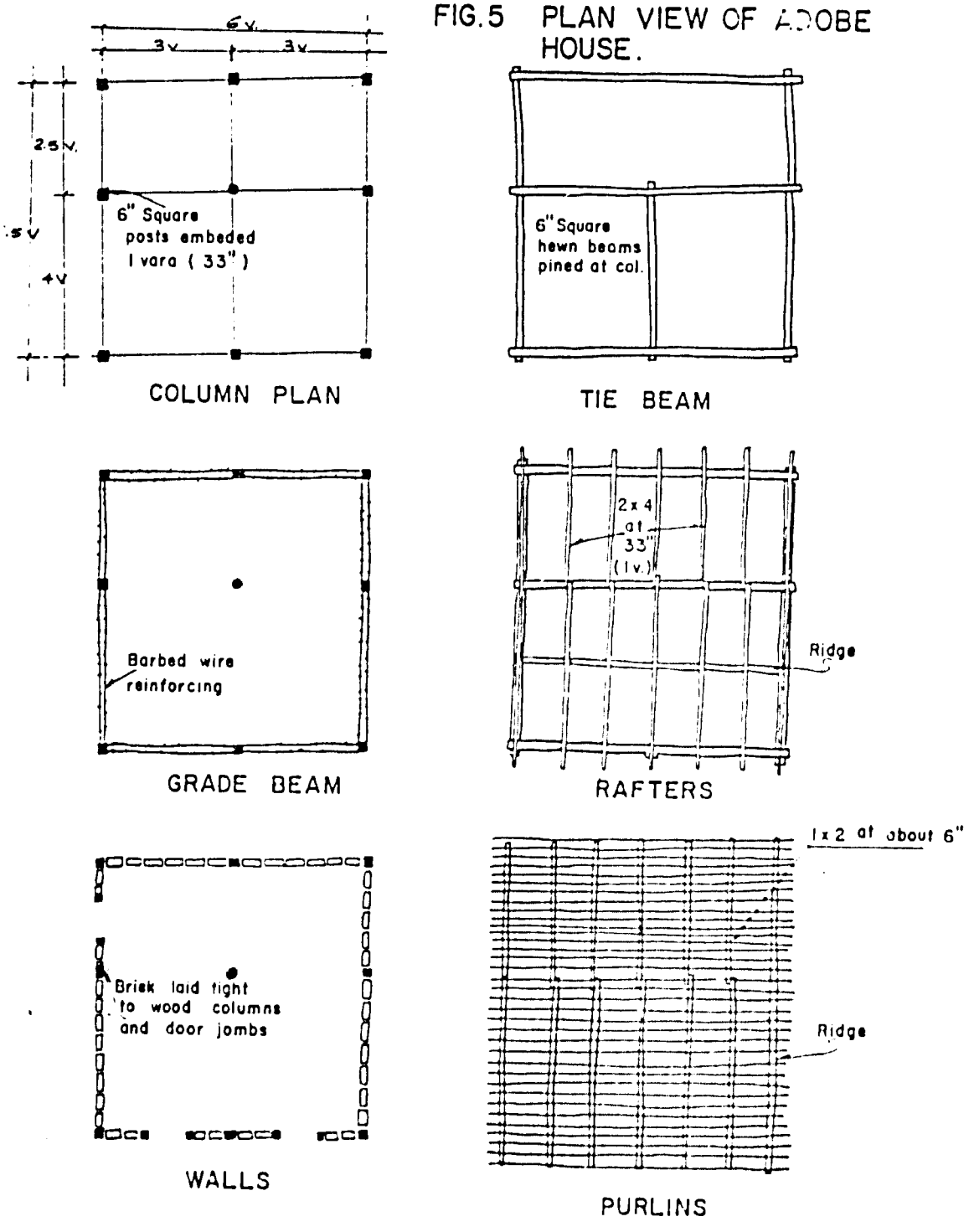
(a).

FIG. 4. (a,b) ADOBE MASONRY HOUSE AND FRAMING SYSTEM.



(b)

FIG.5 PLAN VIEW OF ADOBE HOUSE.



The conventional process of making adobe, consists in selecting the appropriate soil, mix it with water and let the mix sits for a day. The mix is then poured into wood molds, where it will dry in the natural environment for about three weeks. However, the 24 hours sitting of the mix is not necessary as it have been proven elsewhere that during this time, no organic decomposition can take place.

In some places, straw, grass and others are added to the mix, but this is not a good practice as it diminished the resistant properties of adobe. Furthermore, the inclusion of organic materials will increase the tendency of adobe to crack.

A first study, intended to optimize the stabilization of adobe in Nicaragua, was carried out by using clayey soils and stabilizers which can be found or produced locally, such as Portland Cement, Puzzolana, Lime and others. The results can be described briefly as following:

a) The combination of Lime & Puzzolana as a stabilizer is a good economical solution for the appropriate soil, if puzzolana natural deposits are nearby. Otherwise, the costs my be prohibited since the cost of obtaining the required fine puzzolana, must be included. Natural puzzolanas of volcanic origin are found in Nicaragua in the form of pumice.

   The workable time for adobe stabilized with lime and puzzolana may be extended up to 2 1/2 hours.

b) For the samples of soils studied and considering several factors, such as weathering performance, cost, impermeability and mechanical properties, it was concluded that a 5% of cement as stabilizer and the combination of 15% lime and 15% of puzzolana were the optimum for such soils.

c) Weathering test were carried in stabilized and non-stabilized soils. A cube of 2" x 2" x 2" of non-stabilized soil lasted only 4 minutes in static water, while one stabilized with 5% of cement may be desintegrated in 3 years.

d) For the soils considered the compressive strength of stabilized adobe using lime and puzzolana showed higher values.

e) Tests for measuring the tensile strength were also performed on stabilized and non-stabilized adobe samples of 2" x 2" x 2". The tests indicated results about 8% of the corresponding compressive strength.

The above work was mainly oriented toward the chemical properties of the stabilization process.

As a first study in Nicaragua is invaluable, but due to the severe limitations at that time, the results obtained should be examined very carefully.

Further work is needed along these lines. Since extensive work on the stabilization of soils, has been done elsewhere, it was decided to use soils stabilization to Nicaraguan soils.

Adobe Stabilized with Cement

To further the previous work and to enhance the practical applications for construction, a program for stabilized adobe with cement, oriented toward housing was carried thoroughly.

The objective of the program is to technify the use of adobe, its physical-mechanical properties, the methods of fabrication and construction for low cost housing, safe and adequate for the different regions of the country.

The program started with the study of the physical properties of soils in the vecinity of prospective housing projects. Samples from the Departments of Managua, Rivas, Nueva Segovia, Leon, Chontales and others were obtained, keeping in mind that the best soils for the stabilization of adobe bricks with cement, are those with a 75% of sandy material and a 10 - 15% of clay. Table 2 lists the physical properties of the soils.

Bricks can be fabricated by hand or by machine. The first type is the traditional one, using wooden modls. The fabrication by machine implies the use of the CINVA-RAM.

As one of the objectives of the program, is the study of adobe masonry construction, a series of static tests to determine the mechanical properties of small assemblazes was carried out.

Compressive Strength Tests for Adobe Bricks

The size of bricks considered is 30 x 15 x 10 cms., with the following properties; fine texture, weight of 5.5 Kgs., compressive strength of 60 Kg/cm2, and 31% of absorption in 24 hours.

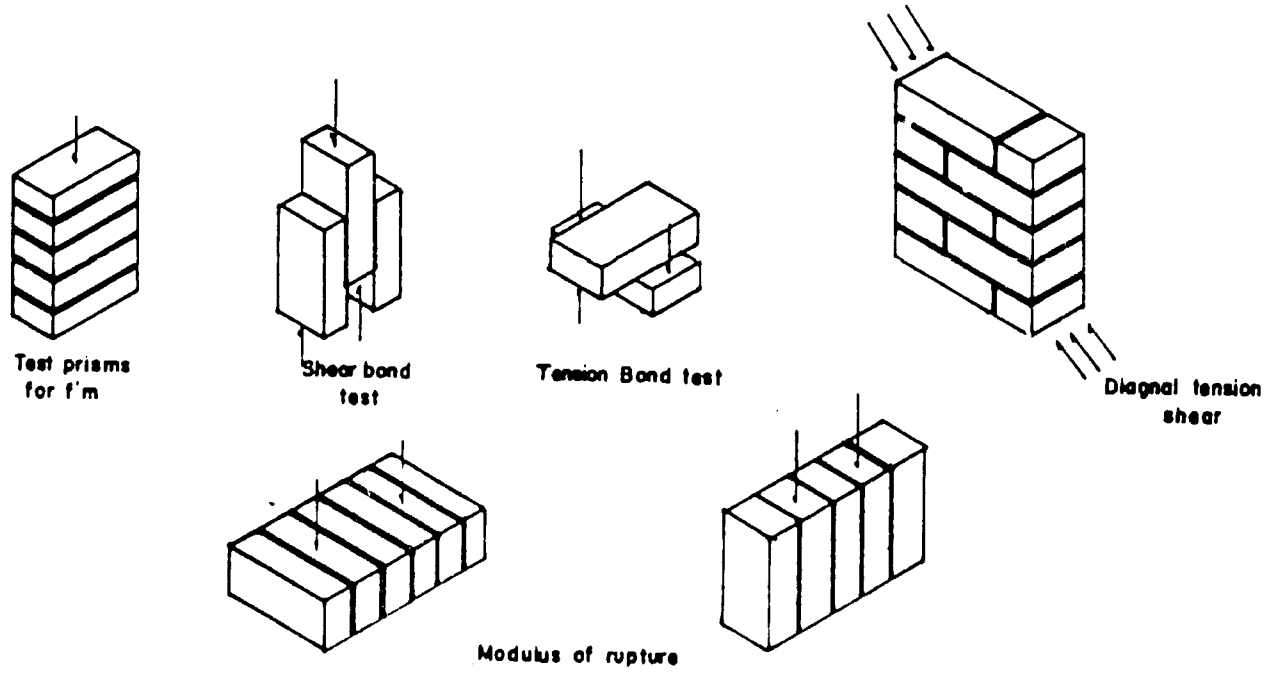
The ultimate compressive strength was obtained by testing the units after 28 days of fabrication and have them submitted to a process of 7 days of curing.

Several mix proportions of soil-cement varying from 8:1, 17:1 were tried. However, the ration 10:1, was the optimum with regard cost and structural behavior.

The results show that the mechanical properties of bricks fabricated by machine, are higher than those made by hand.

TABLE 2.- PHYSICAL PROPERTIES OF STUDIED SOILS

LOCATION PROJECT	BORING No.	DEPTH Mts.	LIQUID L. (%)	PLASTIC L. (%)	PLASTICITY INDEX (%)	MAX.UNIT WEIGHT (Kg/m^3)	OPTIMUM MOISTURE CONTENT (%)	CLASSIFICATION U.S.C.S.	CLASSIFICATION H.R.B.
Luis I. Gómez, Managua.	1	1.0	47	40	7	--	--	M.L.	A-5
Luis I. Gómez, Managua.	2	1.5	37	33	4	--	--	S.M.	A-2-4
Ingenio Benjamin Zeledón, Rivas.	1	--	--	--	-	1300	36.2	O.H.	A-7-5
" "	2	--	--	--	-	1284	28	O.L.	A-6
" "	3	--	N.P.	N.P.	N.P.	1670	19.2	S.M.	A-2-4
Nueva Segovia, Ocotal (yellow)	1	--	27	15	12	--	--	S.C.	A-2-6
" (red)	2	--	28	13	15	--	--	G.C.	A-2-6
San Juan del Río Coco.	1	--	28	18	10	--	--	S.C.	A-2-4
Sta. Tomás, Chontales.	1	--	45	14	31	--	--	O.L.	A-7-5



FIG·6 LABORATORY SPECIMENS IN MECHANICAL PROPERTIES TESTING

The average compressive strength for hand made bricks was 29 Kg/cm2. while the machine made was 60 Kg/cm2.

Tables 3 and 4 show the results of the compressive strength tests in hand and machine made adobe bricks stabilized with cement.

Flexure Tests

As it can be seen in Fig. 6, the arrangement used for the flexure tests, would give bending stresses normal to the joint. The maximum span length considered was 18" and the soil-cement mortar joint used a 10:1 mix proportion. The average bending stress, was found to be of 2.95 Kg/cm2.

Bonding Tests

The tests to develop the maximum bonding stresses were designed, considering the texture and thickness of the units, the flowing and mix proportion of the mortar and the absorption of the assemblage. The tests were carried on machine made adobe bricks and the assemblages used can be seen in Fig.6

TABLE 3.- BRICKS COMPRESSION STRENGHT

Hand made

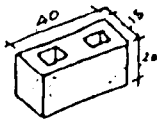
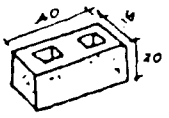
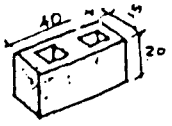
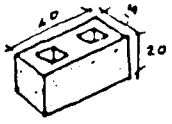
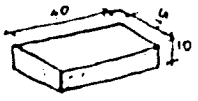
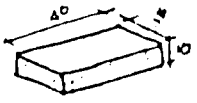
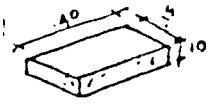
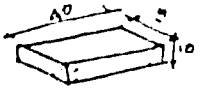
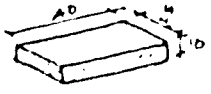
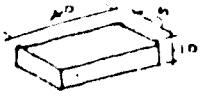
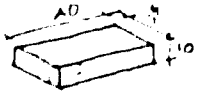
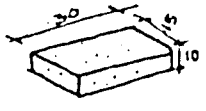
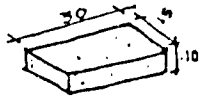
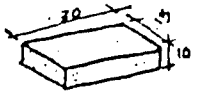
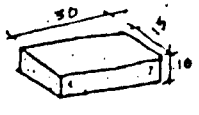
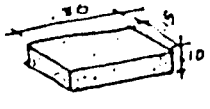
SOIL CEMENT PROPORTION	GEOMETRY IN CMS.	COMPRESSION STRESS Kg/cm^2	NOTATIONS
8:1		8.0	Soil from Rivas (A-6)
8:1		23.01	Soil from Rivas (A-7-5)
10:1		15.06	Soil from Rivas (A-6)
14:1		3.75	Soil from Rivas (A-6)
17:1		30.7	Soil from Rivas (A-2-4)
10:1		30.41	Soil from Ocotal (A-2-6)
17:1		20.42	Soil from Ocotal (A-2-6)
10:1		32.88	Soil from Totogalpa (A-2-6)
12:1		28.8	Totogalpa
12:1		28.6	San Juan del Río Coco (A-2-4)
12:1		27.3	San Juan del Río Coco

TABLE 4.- BRICKS COMPRESSION STRENGHT

Machine manufactured

SOIL:CEMENT PROPORTION	GEOMETRY IN CMS.	COMPRESSION STRENGHT Kg/cm^2	NOTATIONS
10:1		55.46	Soil from Dolores, Rivas (A-2-4)
12:1		56.84	Soil from Dolores, Rivas (A-2-4)
10:1		17.67	Soil from Chinandega, Paredones (A-7-5)
13:1		61.19	Soil from José Isaías Gómez (A-2-4)
10:1		76.7	Soil from San Pedro de Lóvago, Chontales

(a) PRISMS COMPRESSION STRENGTH

ADOBE BRICK STABILIZED WITH CEMENT	f_e Kg/cm^2	PROPORTION OF MORTAR	f_b Kg/cm^2	f'm Kg/cm^2	f'm/f_e
José I.Gómez	61	1:10	16	19.26	0.31
" "	61	1:10	16	25.4	0.41
" "	61	1:10	16	23.3	0.38

(b) SHEAR BONDING TESTS

SOIL CEMENT BRICK	MORTAR	f_b Kg/cm^2	STRESS Kg/cm^2
José I. Gómez	8:1	16	1.47
" "	10:1	16	2.06

(c) TENSION BONDING

SOIL CEMENT BRICK	MORTAR	f_b Kg/cm^2	STRESS Kg/cm^2
José I. Gómez	8:1	16	3.31
Sn. Pedro de Lóvago (Chontales)	10:1	16	1.01

(d) DIAGONAL TENSION SHEAR

SOIL CEMENT BRICK	MORTAR	h/l	f'm Kg/cm^2	V_c Kg/cm^2	$V/\sqrt{f'm}$
José I. Gómez	1:10	1.0	19.26	2.69	0.61
" "	1:10	0.67	19.26	2.97	0.67

TABLE 5

A summary of the results of the experimental program, follows:

a) The average compressive stress of machine and man made adobe bricks stabilized with cement were respectively, 60 Kg/cm2. and 20 Kg/cm2.

b) The average f'm found, using a mortar joint of 10:1 proportion and machine made bricks was 22.65 Kg/cm2.

c) The average shear bond stresses found, without considering confined normal stresses was 2 Kg/cm2, while the average tension bond stress obtained was 1.5 Kg/cm2.

d) The diagonal tension mode of failure was verified, by cracks crossing the brick and mortar simultaneously. The average diagonal tension shear stress was found to be 2,8 Kg/cm2.

e) The average bending stress normal to the joint was 2.95 Kg/cm2.

To complement the above experimental study, dinamic tests should be performed.

Adobe Construction for Cooling Passive Solar System

An experimental work is underway using adobe construction for cooling passive solar systems, in tropical areas.

A 2.8 mt. x 3.5 mt. model was built, using poured in place cement stabilized adobe bricks of 7.2" x 11" x 32". The structural system and roofing details are shown in Fig. 7.

Wind valves were localized at the botton and top of the walls facing wind currents. The combination of earthen material thermal insulation properties, convenction currentes inside the model and the inverted roof system, force the inside temperature to be lower than outside.

The results seems promissing for cooling low cost housing.

Seismic Zoning for Adobe Housing

To improve the safety of adobe construction against seismic events, a study was carried out to find the maximum dimension values to be used in adobe housing according to the seismic zones established by the Nicaraguan Building Code. The results appear in the form of recommended values, shown in Fig. 8.

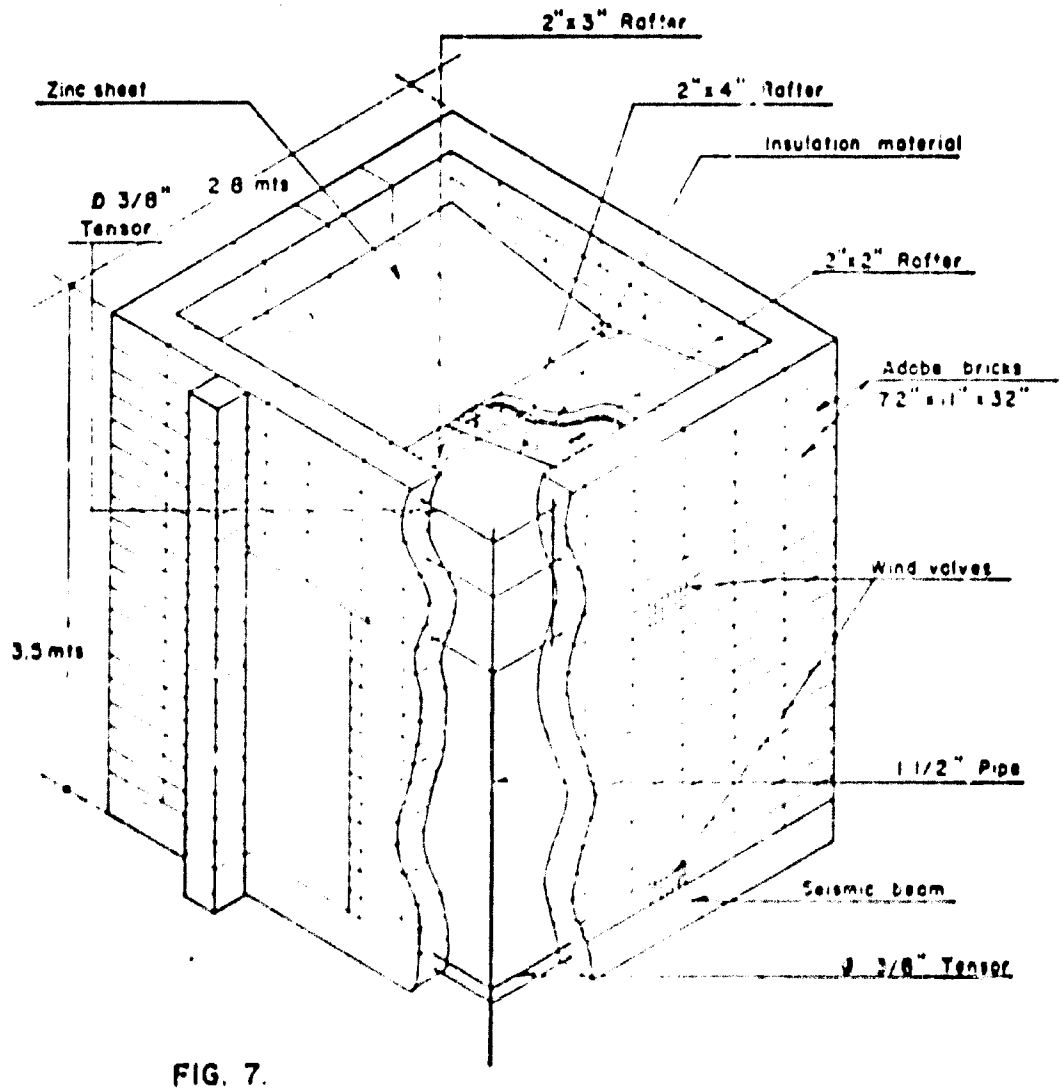


FIG. 7.
ADOBE CONSTRUCTION IN A COOLING PASSIVE SOLAR EXPERIMENTAL MODEL.

Maximum values of l and h for stabilized adobe housing

Seismic zone	Wall thickness	Max. length	Max. height
Zone 1 Zelaya northen Jinotega	t= 0.15 t= 0.20 t= 0.30	6.21m (5.45m) 7.19m 8.79m	4.78m (2.96m) 5.51m. (3.95m) 6.75m (5.92m)
Zone 2 Central region	t= 0.15 t= 0.20 t= 0.30	4.46 m. 5.15 m 6.31 m	3.43m (2.96m) 3.95 m 4.84 m
Zone 3 Chinandega, Rivas and others	t=0.15 t= 0.20 t= 0.30	3.20m 3.70m 4.53	2.46 m 2.84 m 3.48 m
Zone 4 Leon, Jinotepe and Granada	t=0.15 t=0.20 t=0.30	2.91 m 3.36 m 4.12 m.	2.24 m 2.58 m 3.16 m
Zone 5 Masaya and others areas of the pacific	t=0.15 t=0.20 t=0.30	2.83 m. 3.26 m 4.00 m	2.17 m 2.51 m 3.07 m
Zone 6 Managua	t=0.15 t=0.20 t=0.30	2.48 m 2.86 m 3.51 m	1.91 m 2.20 m 2.69 m

Effects of wind on l and h for the Atlantic coast and for the central region are shown in parenthesis

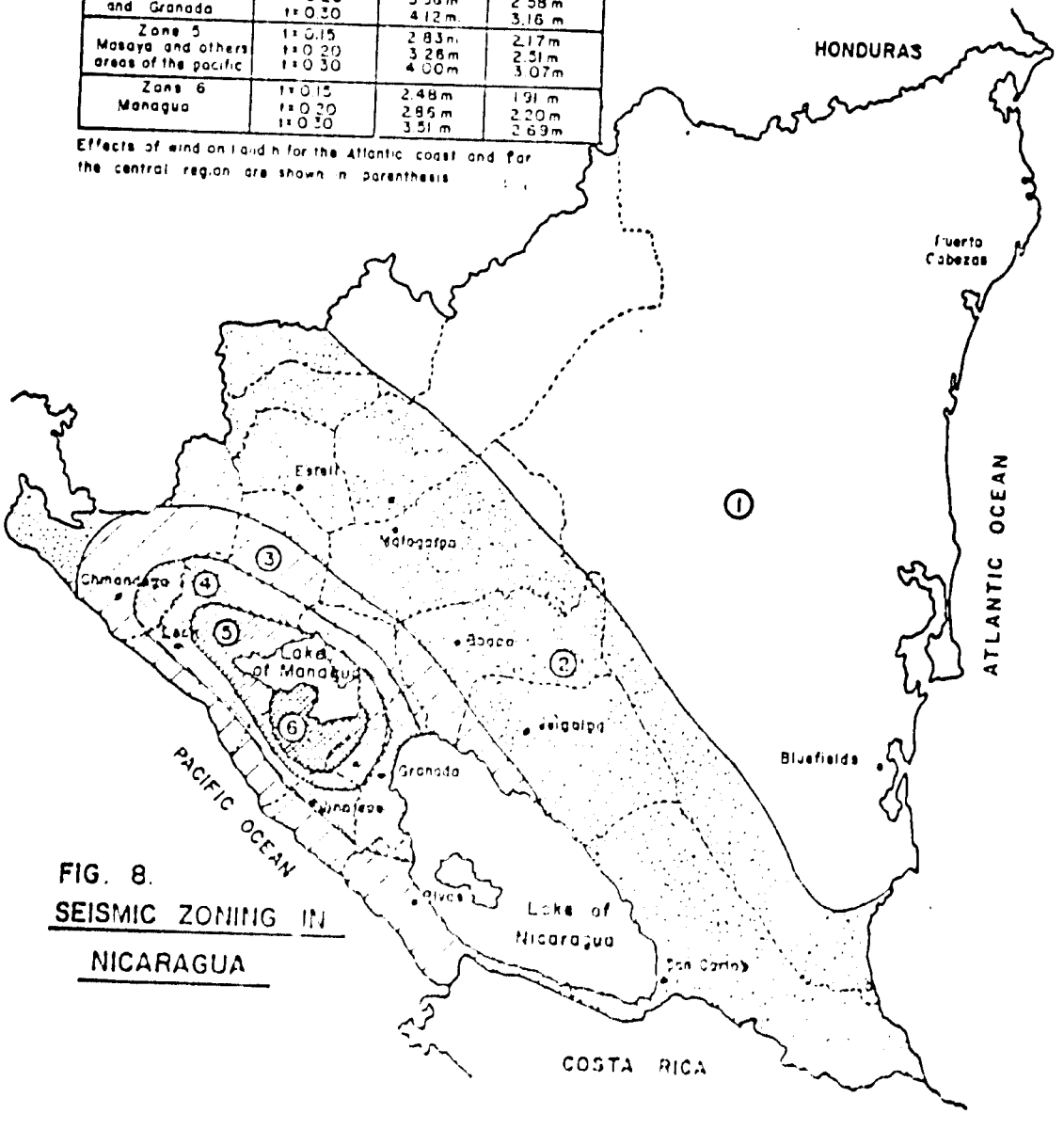


FIG. 8.
SEISMIC ZONING IN NICARAGUA

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SITING OF ADOBE STRUCTURES IN EARTHQUAKE PRONE AREAS

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ABSTRACT

Adobe and mud structures, used widely for housing in earthquake prone areas throughout the world, will fail, even in the presence of good design and workmanship, if they are built on poor sites. Structural and seismic factors, topographic factors, and lithologic factors are all important in selecting geologically safe construction sites away from fault zones, cliffs, unstable slopes, or areas with deep alluvial or man-made fills.

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Introduction

Adobe or mud structures are widely used for low cost housing and public buildings in regions where wood or other building materials are not available because of either high cost or scarcity. Throughout many of these regions, e.g. along the western margin of the Western Hemisphere or in the Middle East, earthquakes are a frequent occurrence. The use of mud as a building material in seismically active (i.e. earthquake prone) areas has resulted in hundreds of thousands of human deaths and billions of dollars in property losses in recent years as reflected by the following single report from the Earthquake Information Bulletin—typical of many each year.

> "Southern Peru experienced a destructive earthquake on February 16 (1979). The magnitude 6.7 earthquake was located about 100 km northwest of Arequipa, where at least 14 persons were reported killed, many were injured, and damage to adobe-type homes was extensive" (1).

Many of these deaths and some of the property losses are preventable, even if adobe (one of the weakest building materials in terms of earthquake resistance) is used as a building material (2).

Preventable deaths resulting from earthquakes occur every year somewhere in the world. On the average, 10,000 people lose their lives in earthquakes annually (3). In some years, for example in 1976, the number of fatalities totals hundreds of thousands. Ultimately, prevention of such deaths will be possible when we develop an earthquake prediction capability and implement worldwide earthquake warning systems. Implementation of such systems will take years. In the interim, the number of earthquake related deaths can be significantly reduced through appropriate design and construction of structures on <u>relatively safe sites</u>.

Property losses can also be reduced. Between 1926 and 1950, UNESCO estimated an average annual property loss of $400,000,000 (US) (3). These annual losses are increasing with increasing development. Single earthquakes now may cause similar amounts of property loss. For example, the 1960 Chilean earthquakes cost $300,000,000 (U.S.) in housing along (4), the 1964 Alaskan earthquake resulted in $310,000,000 (U.S.) worth of property damage (3), and the preliminary estimates of damage in the 1976 Guatemalan earthquake totaled $1,100,000,000 (U.S.) (5).

Many countries in seismically active regions have initiated programs to reduce losses of life and property. One early step in such programs is to develop seismic risk maps, maps showing areas of relatively high and low risk with respect to potential earthquake damage (6,7,8). In addition, detailed maps may be prepared for areas of special concern (e.g. major cities or seaports) (9). These maps provide a base for the detailed geological and engineering studies necessary for thorough site selection analyses.

The value of seismic and earthquake engineering studies, especially in less developed countries (LDC's), was underscored by Flores (4). Earthquakes can create damage worth the equivalent of the national budget of an LDC. Flores indicates that regulation of construction in Chile prior to the 1960 earthquakes resulted in a 25% ($100,000,000 U.S.) decrease in damage relative to pre-regulation projections. Had all houses conformed to applicable standards,

losses would have been reduced by 75% or $300,000,000 U.S.

Damage to the spirit of the people can also be prevented through reduction of losses in property and life. A loss of morale can critically influence development efforts, reconstruction and economic growth of a country and should not be ignored. In this paper, I delineate criteria for selecting safe building sites in seismically active areas, as one facet of an approach to reducing property damage, loss of life, and resultant loss of morale. Safe siting is particularly important where adobe is used in building, because adobe fails readily under the influence of ground shaking and other effects of earthquakes.

Both pre- and post-earthquake siting projects are feasible. However, the inertia to change limits the impact of pre-seismic siting, as such projects usually influence only new structures. Post-earthquake projects, as part of disaster relief programs, may have wide impact, as the population is open to change and is in need of reconstructed buildings. In either case, site selection is critical to development of earthquake resistant buildings.

Damage Produced By Earthquakes

The wide range of geological effects of earthquakes have been reviewed by many authors (3, 10, 11, 12). Among the most important effects are ground rupture, landslide, earth lurch, liquifaction and settling of soil, and flooding.

Ground ruptures result from several causes. First, surface faulting may produce a series of discontinuous cracks (13). The surface may be offset along such cracks in both vertical and horizontal directions. Such offsets may range from a few centimeters to several meters. Ground rupture also occurs in cases of lurching and landsliding. Some of the most spectacular cracks developed by the 1976 Guatemalan earthquake were developed at the heads of landslides, where cracks more than a meter across and several meters deep, with vertical offsets of several meters, created a greatly disrupted terrain.

Landslides develop where slopes are oversteepened, either for natural or artificial reasons. Where streams undercut slopes, especially where minor faults and joints are present in the bedrock, the landslide potential is significant. Road construction, home and building construction, and other human activities may also result in undercut slopes. Both natural and human activities led to landslides in the 1970 Peruvian earthquake and the 1976 Guatemalan earthquake (11, 13).

Weak soils and alluvial deposits especially those saturated with water as a result of heavy rains or a shallow water table, may give way to produce landslides on steeper slopes or they may liquify in flat-lying areas. In addition, loose materials may be consolidated by shaking during an earthquake and settle.

Floods may develop both upstream and downstream from landslide dammed rivers and streams. The upstream floods are local and result from the lake which forms behind the dam. The downstream floods may be catastrophic and widespread, if a weak, landslide dam collapses releasing the water trapped in the lake. In addition, debris added to streams by landslides can lead to increased sedimentation and related problems during flooding.

Damage to human constructions as a result of shaking and the various geological effects ranges in extent from widespread in major earthquake (magnitude >7) to local in smaller earthquake (magnitude 3.5-5). Damage may affect large and small structures of modern or ancient design and may range from simple cracks to total collapse. Figure 1 shows typical failure lines in an abode structure. Both adobe and modern steel-reinforced buildings will suffer damage, if weaknesses in design, workmanship, materials, or siting exist.

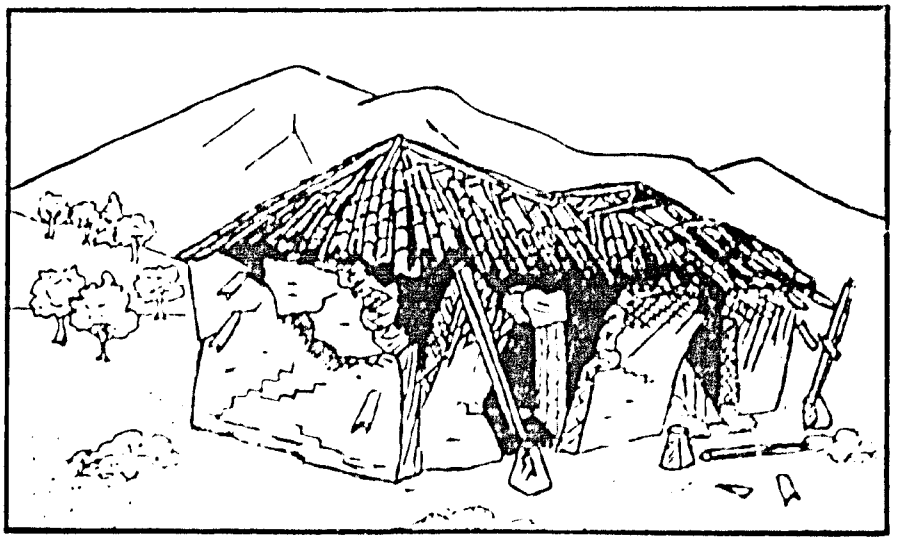

FIG. 1

Sketch of earthquake-damaged adobe house showing typical failure including diagonal cracks fallen tiles, and partially collapsed roof (after Raymond et al. in ref. 2).

Site Selection Factors

Factors important in selecting safe construction sites, whether they be sites for single houses or sites for entire towns, may be categorized into three groups — structural and seismic factors, topographic factors, and lithologic factors. In long range programs of construction or reconstruction, all factors from each group should be evaluated by a team of geologists and engineers. Where this is not possible, paraprofessionals, trained by a

knowledgeable instructor, may use a set of detailed guidelines to select sites which are devoid of obvious flaws (14).

Structural and Seismic Factors

The seismicity of an area, both recent and historical, is of critical importance in site selection. Studies of recent earthquakes can provide evidence for evaluation of: (a) the location of active faults; (b) the maximum ground acceleration (shaking) expected in a given area; (c) the type of damage (Mercalli intensities) expected on different foundation materials and for different structures for earthquakes of varying magnitude; and (d) the short term frequency of damaging earthquakes. These recent data can then be combined with historical data to provide a historical record of damaging earthquakes and, with geological data, an estimate of the design earthquake, the earthquake which would give the most severe shaking at a given site (3).

Seismicity should not be estimated solely on the basis of historical earthquake activity, however (15, 16). Topographic, lithologic, and structural data can reveal pre-historic (Holocene and Quaternary) activity on faults. The data expand the seismic record for an area and allow a more thorough analysis of seismic risk, as virtually all large earthquakes (Magnitude > 6.0) occur on faults recognizable through field studies (16). Thus, active faults may be recognized on the basis of geological, as well as geophysical evidence.

In the United States, the Nuclear Regulatory Commission has defined "capable faults." These are faults thought to be "capable of causing movement at or near the ground surface or generating high vibratory ground motion" (17). The recognition of a capable fault depends on seismic and geological evidence, as capable faults are defined as those faults with recurrent movement history in the past 500,000 years and/or tectonic activity within the past 35,000 years (17). Because historical records extend for only a few hundred or thousand years, geological studies, based on field work, clearly contribute to thorough seismic risk analyses and site selection.

Geological field studies reveal a multitude of important features. For seismic risk studies, evaluation of length of fault rupture is important in estimating Richter magnitude (3, 18). Offset stream channels, faulted alluvial and other Quaternary deposits, fault scarps, and sag ponds provide evidence of recent and potentially active or capable faults and should be included in the seismic risk analysis.

In terms of site selection, data indicative of an active or capable fault are important in evaluating the geological structure of an area. Such evidence should be summarized on a geologic map, which, like the seismic risk map, provides a basis for detailed site selection studies. The geologic map should also include data on the age of rock units offset by faults and careful plots of all landslides.

Using the seismic risk and geologic maps as a basis, the geologist and engineer can evaluate the area in which a site is to be selected. Structural features that should be evaluated in the local study include faults and joints. Recognition (and mapping) of the exact location of active or capable faults in the area, location of older faults and their related features, and evaluation of joint systems are all aspects of a thorough analysis. Active or capable faults and the associated zones of crushed rock must be avoided as building sites, as rupture may occur anywhere within the fault zone, destroying structures built on the line of fracture (e.g. 12). In addition, the crushed rock materials along the zone provide poor foundations. Dead or inactive faults should also be avoided, as these fault zones also contain weak foundation materials. Furthur, some faults, such as the San Andreas fault of California, have a long history of movement (19) and others have presumably been reactivated during later tectonic events (e.g. 20).

Criteria useful for the recognition of faults have been summarized by many authors, including Billings (21). Structural features of note include:

(a) offset rock layers;
(b) truncated rock layers;
(c) slickensides; and
(d) zones of gouge, breccia, mylonite, or "horses".

Zones containing such features must be rejected as building sites (Figure 2).

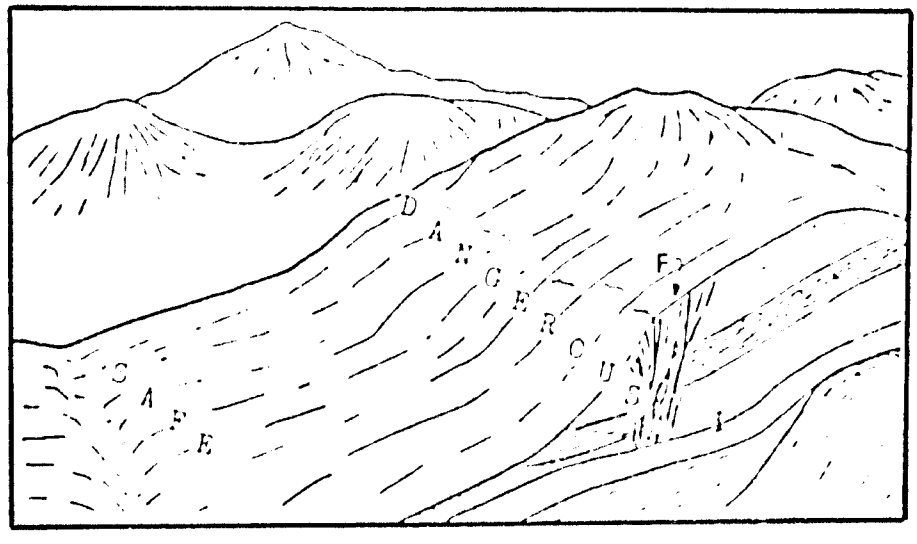

FIG. 2

Sketch showing dangerous building sites along a fault zone (F).

Joints are fractures along which no significant movement has occurred. However, highly jointed bedrock does not provide a strong foundation for a structure. In addition, where joints are arranged so as to weaken slope materials, they may lead to landslides. Consequently, it is important to examine potential sites for flaws imparted by jointed rock.

Topographic Factors

The topography—the relief, contour, and slope of the land—can provide many clues to the relative safety of a site. Topographic factors relate to site safety in two ways. First, many topographic features reflect underlying faults. Second, certain sites are unsuitable for construction in seismically active areas because of the topographic considerations alone.

Underlying faults are expressed in the topography by a variety of features. These include offset stream valleys and ridges, truncated ridges (spurs), fault scarps and fault-line scarps (localized steep linear slopes), linear series of springs, linear groups of marshes or ponds (sag ponds), visible zones of surface cracking or offset of man-made objects (e.g. roads or canals), and topographic lineaments such as unusually straight stream or river valleys. Prospective sites should be examined for such features and sites along the line of any group of such features should be avoided.

In addition to the topographic factors listed above, i.e. those that reflect underlying faults (or joints), sites in certain topographic situations should be avoided for reasons of their own. The Guatemala earthquake of 1976 produced thousands of landslides, many of which resulted in loss of life and property. In Peru, the potential hazard posed by landslides is well known, in part as a result of the Huascaran debris avalanche that buried Yungay (11). Therefore, sites immediately above, within, or below presently developed landslides should be avoided. In addition, sites should be avoided where the landslide potential is great as a result of structural factors (e.g. extensive faulting or jointing), stratigraphic factors (e.g. jointed resistant rock masses overlying weak rock masses that are tilted towards a valley), and topographic factors (e.g. oversteepened slopes).

Relief and slope are critical factors to evaluate in relation to the potential for earthquake generated landslides at a site. In Guatemala, many lives were lost where structures were erected adjacent to cliffs, very steep slopes, or large gullies (barrancas). For example, at Estancia de la Virgen near San Martín, reportedly eleven families were carried with their homes into the Rio Pixcayá when the cliff adjacent to the river collapsed during the earthquake. In Guatemala City, residential areas adjacent to barrancas suffered more intensive damage than surrounding areas, probably as a result of amplified ground motion. Here, some individuals lost their lives as a result of landsliding. As a general rule, construction adjacent to cliffs or barrancas or on or near slopes steeper than 35° (75% grade) should be avoided (Figure 3).

Sites on high and especially narrow ridges should also be avoided. High and narrow ridges are known to experience ground shaking amplified up to three or more times that of adjacent valleys (22,23,24), which results in greater damage. In addition, narrow ridges are subject to landslides on both sides, a condition developed during the 1976 Guatemalan earthquake in Las Venturas (San Martín), along the San Martín-Chimaltenango road, and along the El Tablon-Las Flores road.

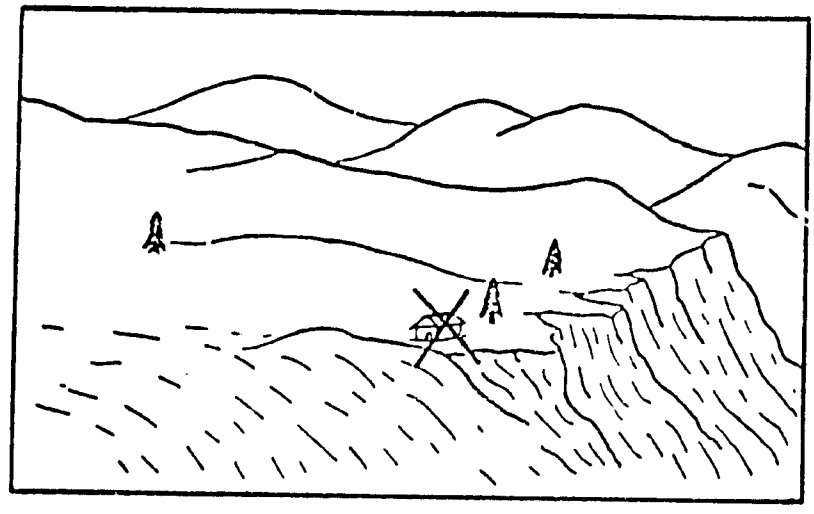

FIG. 3

Sketch showing unsafe building site (X) along cliff face.

Valley bottoms may also be hazardous. The hazard at such sites is only indirectly related to the topography. Landslides from above provide one type of hazard, especially in narrow, steep walled valleys. The second type of hazard is related to the lithology of the rock or soil in the valley bottom. It is well known that poorly consolidated materials lead to increased earthquake damage (12,25,26). Ground shaking on alluvial materials, as reflected by accelerations, may be increased up to 4.3 times, versus accelerations on adjacent bedrock (27). Thus lithologic factors must be evaluated at such sites.

Valley bottoms may also be subject to flooding. For example, the 1976 Guatemalan earthquake produced landslides that dammed at least four major rivers. The 1970 earthquake produced a similar phenomenon in Peru (11). Landslide dams produced flooding upstream and, if they subsequently collapse, flooding also occurs downstream. Although accounting for the flood factor is difficult because of the many potential sites for landsliding along major rivers and streams, where nearby slides or areas of potential sliding occur, they should be taken into account during the site selection process.

Lithologic Factors

The importance of the lithology of the foundation material at building sites is very important. Solid bedrock provides the best foundation for structures. That damage increases with decreasing strength and cohesion of foundation materials has been revealed by numerous post-earthquake studies (28-31). Therefore, a thorough site selection study should include a civil engineer's or soil scientist's study of the soils and/or a geologist's evaluation of the bedrock, depending on local conditions.

Hard crystalline rock types provide much firmer foundations than poorly consolidated sediments or pyroclastic rocks. Many of the landslides in Guatemala occurred in weak pyroclastic materials which crumbled on shaking. Glaciofluvial and other similar deposits of the Rio Santa Valley of Peru are subject to similar failure (11). Granitic rocks, gneiss, metasandstones and similar rocks are preferred as foundation materials to sedimentary rocks. In general, poorly consolidated, weak, wet, organic-rich soils or alluvial deposits should be avoided.

Where sites must be selected in alluvial materials, thin, well compacted dry soils with silty layers provide better foundations than the wet, poorly consolidated soils. Thixotropic clays and highly saturated sands, even at considerable depth below a building site, will make the site unstable and subject to settling or sliding. Turnagain Heights, Alaska, where a whole section of houses slid towards the sea, was constructed in an area with underlying thixotropic clay (10).

Conclusion

Safe building sites will allow well constructed adobe structures to survive earthquakes without total collapse. A thorough investigation of proposed alternative building sites should be used to eliminate sites from consideration that occur along fault zones, on highly jointed and/or steep slopes, along cliffs or roadcuts, in areas of previous or potential landsliding, along narrow ridges, in areas of extensive natural and man-made fill, and along narrow valleys near large cliffs or landslide prone slopes. If adobe structures are constructed using proper design, good workmanship, and good materials on safe bedrock sites lacking these flaws, loss of life and property will be minimized.

Site analysis is best carried out by trained engineering geologists. However, in LDC's there is often a shortage of trained personnel. Under such circumstances, locals trained as paraprofessionals (using graphics and simple rules) may make site evaluations for adobe structures that will eliminate the worst sites from consideration.

Acknowledgements

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EARTHQUAKES AND RESIDENTIAL CONSTRUCTION IN JAPAN

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ABSTRACT

While much effort has been spent on analysis of individual structures, building class seismic damage estimators for earthen buildings in seismic zones, of value in disaster planning, code-writing, city planning, national hazards policy formulations etc., have been little investigated. First, details of the typical construction in Japan incorporating earthen elements are presented, with emphasis on those providing lateral resistance. Next, based largely on data from Sendai City, Japan in the 12 June 1978 Miyagiken -oki earthquake (M_L-7.4), estimators of seismic damage for low-rise buildings in urban Japan have been determined, based on damage to over 60,000 buildings. Damage ratios for onset of damage and collapse and for cost of damage are found to correlate best with response spectra at 0.75 s. Using published test data and average building properties, a seismic damage model explains the low-rise building behaviour and permits examination of the effect of structural changes on the estimated damage.

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Introduction

Although Japan is usually associated with earthquakes, its association with building construction is usually that of wood rather than that of earthen buildings. This is due to the well-known superb joinery of the typical Japanese house, as well as the abundant forests and prominent part wood plays in the architectural aesthetics of Japan. Closer examination however, reveals that earthen construction is actually a significant part of the typical Japanese house, and vis-a-vis earthquakes, provides a considerable portion of the lateral resistance. Thus, a review of typical Japanese residential construction is appropriate in any discussion of earthen buildings in seismic zones. The purpose of this paper is to briefly present an overview of Japanese urban regions and seismicity, to outline typical residential construction and then to present some research results of the author quantifying such construction's seismic resistance.

Within the overall seismic risk problem, one of the less researched topics has been that of regional damage estimation, although the aggregated damage that a region sustains in an earthquake is probably society's greatest concern, vis-a-vis earthquakes. One of the reasons for this lack of activity has been the lack of damage estimators (also termed damageability performance, or vulnerability functions) for the various classes and sizes of structures in today's urban regions. Even though extensive research has been devoted to the response of specific individual structures, little effort has been devoted to the average response of these classes of structures. While the value of the study of the response of individual structures goes without saying, the value of building-class seismic damage estimators in such fields as land-use and city planning, microzonation, building code evolution, natural hazards insurance, disaster planning, etc. is also very great, when faced with the problem of estimating the damage to tends of thousands of low-rise and hundreds or thousands of mid- and high-rise buildings. To adequately serve these fields' needs, damage estimation functions should nt only be descriptors or predictors of damage given ground motion but should also relate the response or damage tothe structural system in sufficient (and yet not too much) detail such that the effects of modifications to the structural system are readily apparent, thus permitting the application of cost-benefit analysis or other decision-making methodologies.

Such damageability functions are especially mandated in situations like Japan, with one of the highest degrees of urbanization in the world. In urban regions, such as Tokyo-Yokohama, Osaka. Nagoya, Hiroshima, etc., low-rise buildings, especially of wooden construction, constitute the great majority. In Osaka (the second largst city in Japan), of 408,000 buildings 80.4 percent are wood, 90 percent one or two storey and only 0.124 percent are 10 storeys or higher.

The primary reason for the high degree of urbanization of modern Japan is the fact that mountainous areas constitute about 90 percent of 142,706 square miles, thus forcing her approximately 112,000,000 people onto recent (in geologic terms) alluvial plains, such as the great Kanto plain of Tokyo.

Coupled with economic, transportation and other constraints, the result is that much of Japan's population is housed on deep, recent, alluvial deposits in an area of high seismicity. This seismicity is among the world's highest for a densely populated country, and is basically due to the subduction of the Pacific plate under the Asian plate along offshore Japan to the east, complicated by the convergence of the Philippine plate near Tokyo. The result is great, deep offshore and large, shallow inland earthquakes with relatively high frequency of occurrence. An idea of the hazard can be gained in Fig. 1, which estimates motions for Japan for 75 years.

Thus, we find in Japan a high degree of urbanization on deep alluvial fans in an area of high seismicity, so that we have a high expectation of strong ground motion of long duration and long period.

Typical Residential Construction

The structure of the typical wooden low-rise in Japan has changed very little in this century (see Engel (2) for a detailed description). Fig. 2 shows a typical view of a nearly completed house in which the main elements are clearly discernible. These are heavy tile roofs (unlike many other localities, in Japan the tiles are seated in a bed of about 7 cm of mud, which adds enormously to the weight of the roof) supported on a vertical post and lintel constructions which carries the roof and second floor to the foundation. The foundation in the past consisted of stone or concrete seats and usually now are low perimeter concrete walls. Due to this feature, these structures are especially sensitive to ground movement. The vertical posts, being of wood joined into the sill or roof beams, provide virtually no lateral resistance due to the inability of the connections to develop any moment capacity. Thus, the lateral resistance is due solely to the walls and, if existing, bracing. Traditionally and until very recently, bracing was not typical, although now being increasingly mandated by code. In Fig. 2(a) some diagonal bracing can be seen, while the side wall, more clearly shown in Fig. 2(b), has no diagonal bracing and relies for lateral resistance solely on the mud infilled wall between vertical posts.

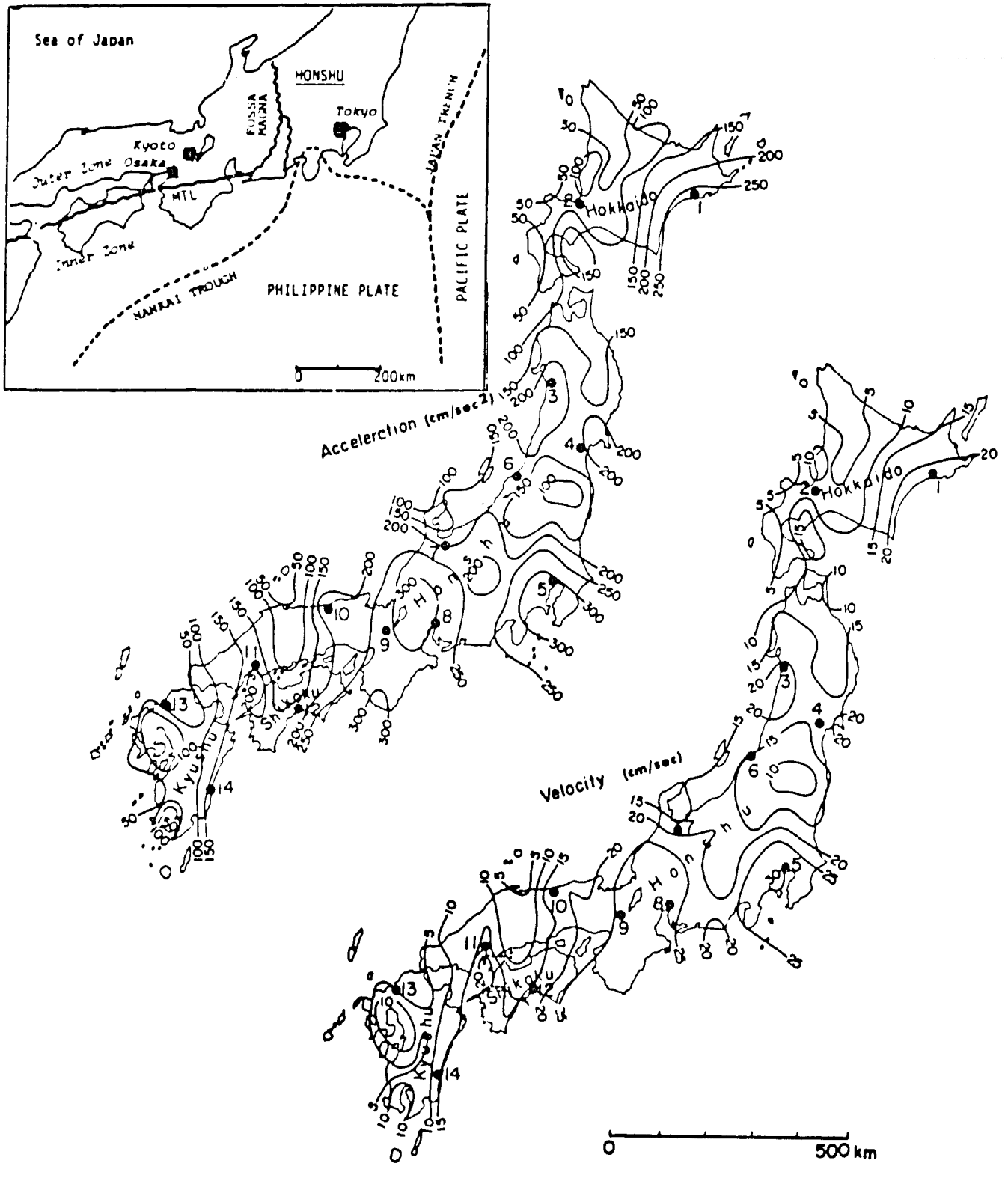


Fig. 1 Seismic map for the Expected Value of the Maximum Ground Motion to occur in 75 years (after Goto and Kameda (1)). Insert shows tectonic plates near Japan.

The construction of these walls is of some interest. The first step is usually the assembling on the ground of the pre-fabricated main posts and lintels, and tilting these up into place. By this method, the main posts and heavy roof timbers, Fig. 3, can usually be entirely erected in a day, with temporary bracing. This is followed by the installation of bamboo lath first on a coarse grid (labeled mawatashi-dake in Fig. 5) and then on a finer grid (komai-dake) tied to the coarser grid. Fig. 4 shows a close up of this, prior to applications of the mud, while Fig. 5 is a schematic, with Japanese terms, etc.

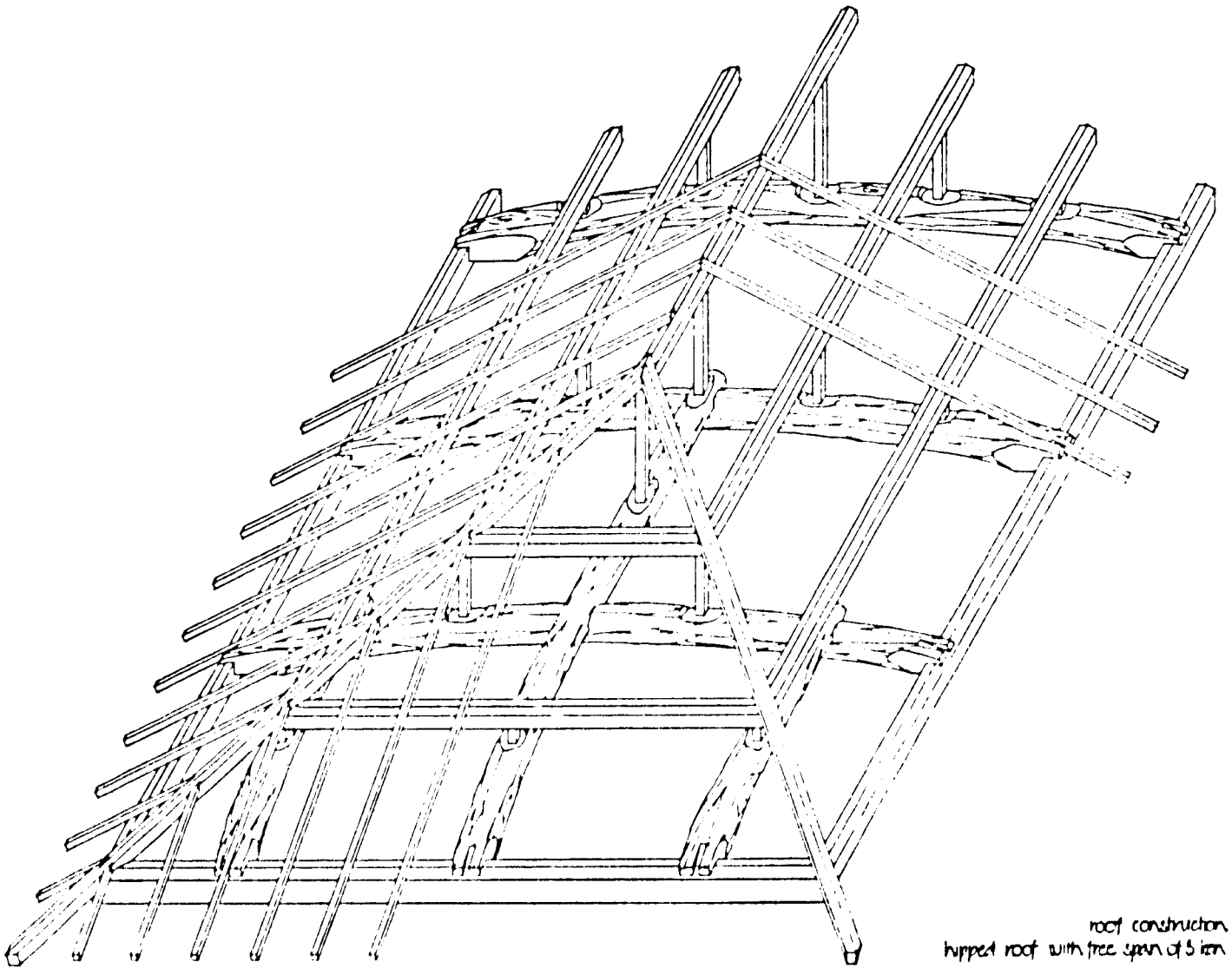


Fig. 3 Hipped-roof construction (after Engel 2)).

Fig. 2(a). Nearly-completed typical Japanese house - front view

Fig. 2(b). - side view

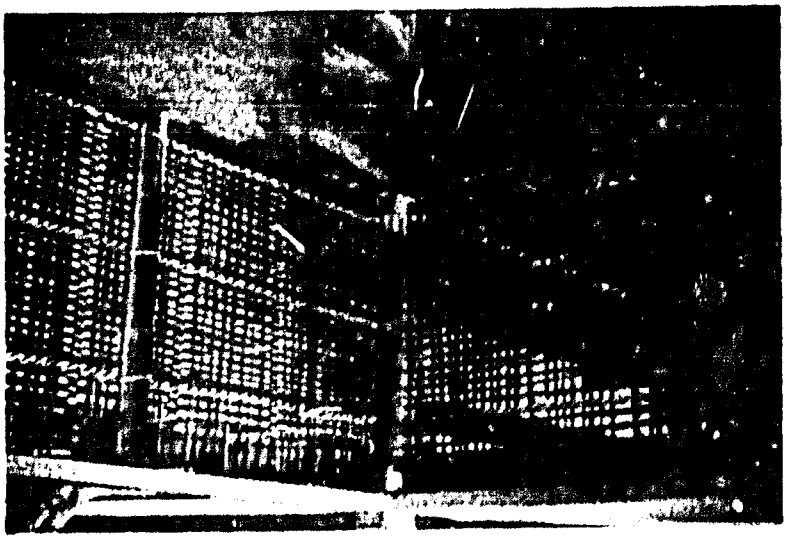


Fig. 4 Close-up of bamboo lath, showing tying of various elements and setting into the eaves beam.

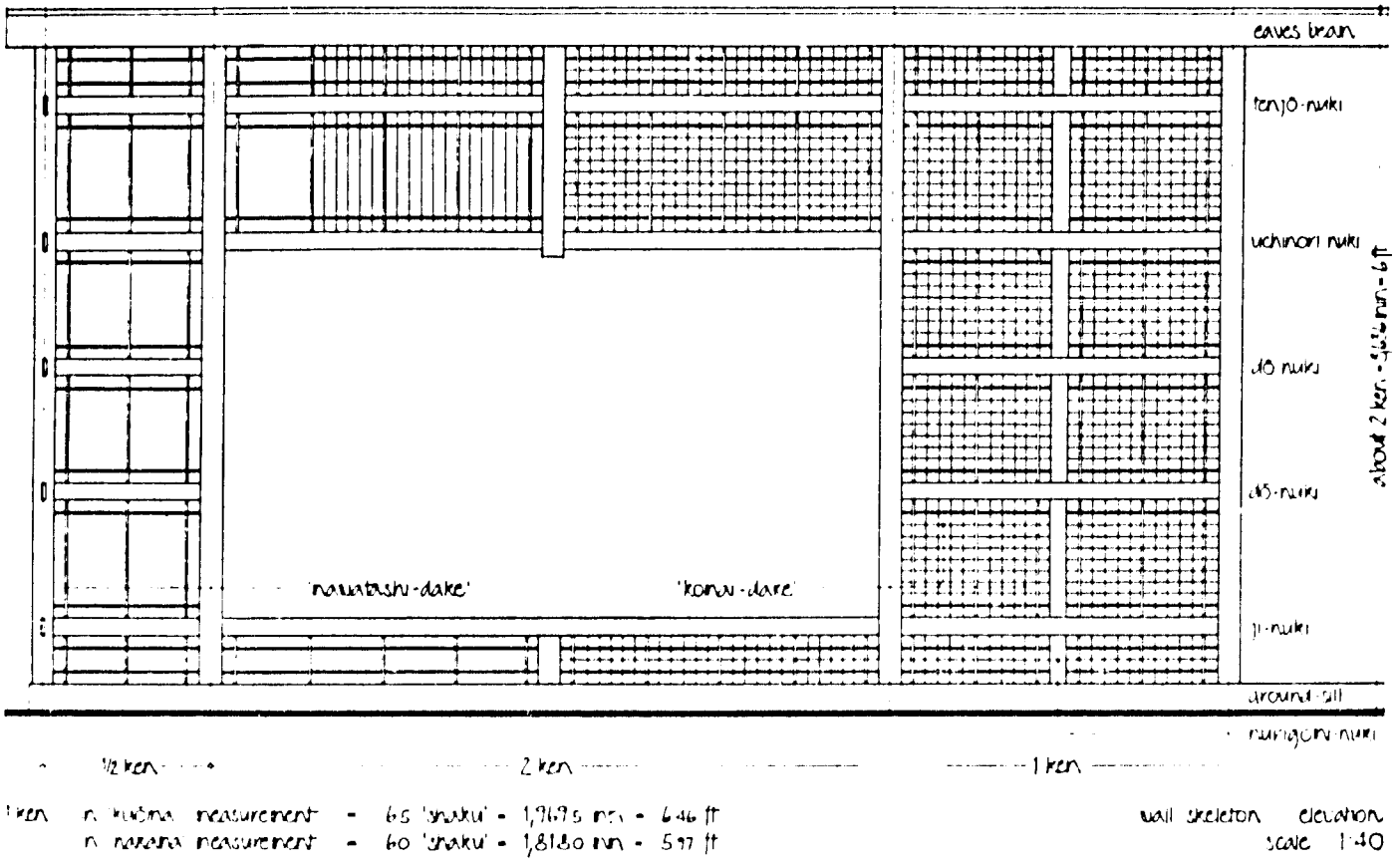


Fig. 5 Details of wall-skeleton construction (after Engel (2)).

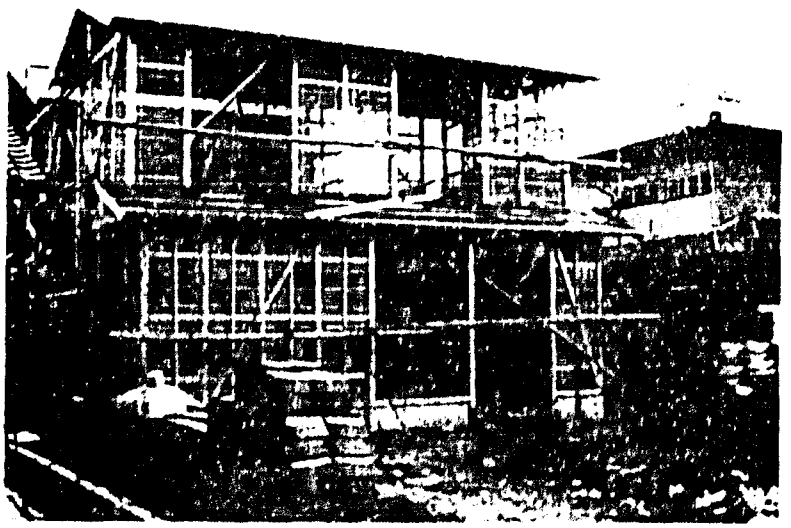
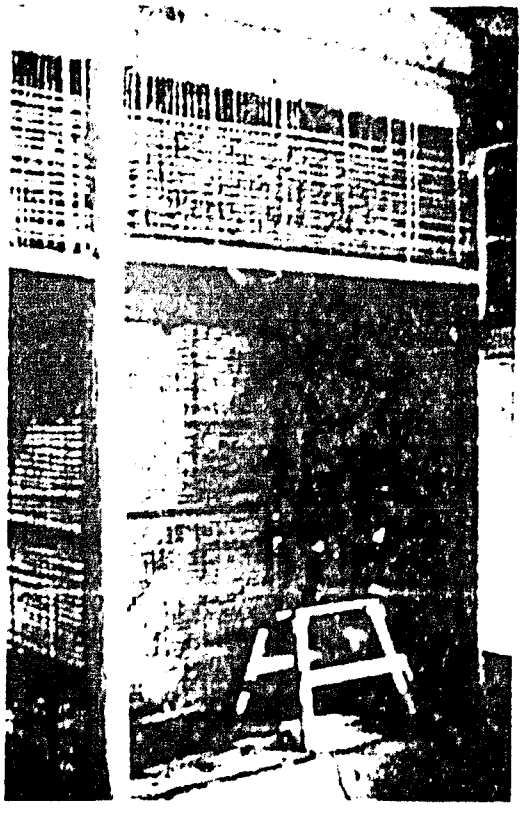


Fig. 6 Framed-up house with lath installed, prior to application of mud. Note roof tiles in foreground.

The result is shown in Fig. 6, which is a framed-up house, with temporary and some permanent bracing, prior to the application of the mud to the installed bamboo lath (note the heavy roof tiles in the foreground). Application of the mud, which is a common clay-sand mixture with chopped straw mixed in, is by simple troweling to the bamboo lath, Fig. 7, one side at a time. Note in Fig. 7 that lath and mud are used over doorways so that a weak frame action can be accomplished (this shall later be referred to as a "pierced wall"). Fig. 8 shows the reverse



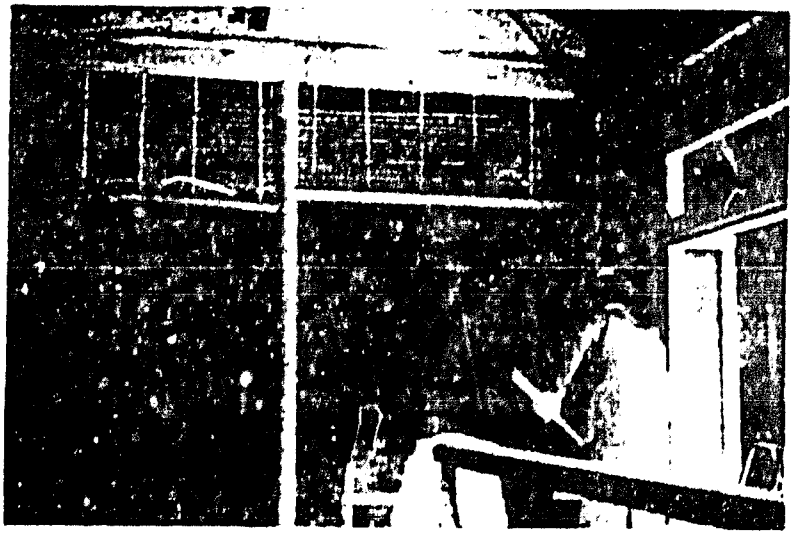


Fig. 7 Application of the mud to the bamboo lath.

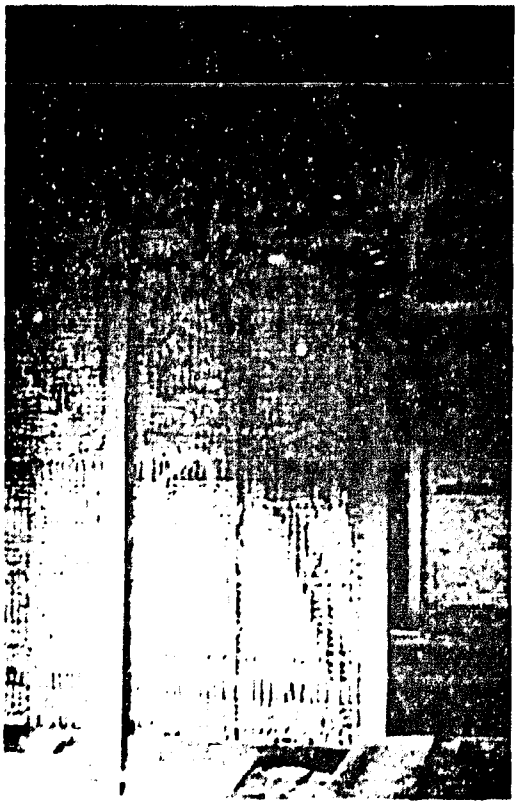


Fig. 8 Mud applied to one side of bamboo lath.

side, after troweling on one side. The final result is as shown in Fig. 2. This type of wall is termed, in Japanese, shin-kabe. There is another, somewhat less common type, termed okabe, Fig. 9, which employs a larger wooden lath over which a chicken wire-like mesh is placed and then a thin coat of stucco applied.

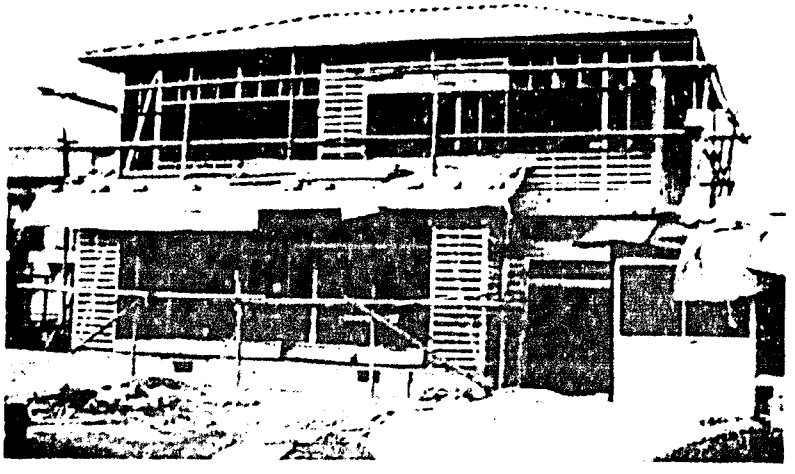


Fig. 9 Okabe type wall, prior to application of stucco.

Seismic Damage Characteristics

In what follows, it is useful to first define several terms:

Definitions

The term Damage Ratio for Buildings Damaged, DR_{BDMG}, is defined:

$$DR_{BDMG} = \frac{\text{Number of Buildings reporting Damage}}{\text{Total Number of Buildings}} = \frac{BDMG}{NB}$$

Here BDMG is number of buildings reported damaged and NB is total number of buildings, for a given area. Damage is, in the above, loosely defined and includes structural or non-structural, large or small, corresponding to the number of buildings claimed damaged. The term Damage Ratio for Buildings Destroyed, DR_{BDST}, is similarly defined:

$$DR_{BDST} = \frac{\text{Number of Buildings Destroyed}}{\text{Total Number of Buildings}} \quad \frac{BDST}{NB}$$

where Destroyed means collapse during, or razing after, the earthquake. Lastly, the damage Cost Factor, DCF, is defined:

$$DCF = \frac{\text{Damage Repair Cost of the Building}}{\text{Replacement Value of Building}}$$

While there exist problems regarding how small the damage can be and yet be included in DR_{BDMG}, or how long after the earthquake razed buildings should be included DR_{BDST} (or even which earthquake, in the case of aftershocks), or how accurately Damage Repair Cost is reported for DCF (and under what incentives, for example the degree of disaster relief aid), these definitions are sufficient for many aspects of damage estimation, and will be used herein as defined above.

The Miyagiken-Oki Earthquake Of 12 June 1978

Much of the following analysis is based on data from the Miyagiken-oki earthquake of June 12, 1978 which occurred at 17:14 local time, with an epicentre at 142°10' East, 38°09' North, focal depth of 40 km. and magnitude M_l = 7.4 (USGS M_s = 7.5)[7]. The earthquake and its damage have been well reported[3,4] and only certain aspects will be mentioned here. Figure 10 is a regional view showing Sendai City and its relation to the epicentre, aftershock area and regional geology. Sendai City sustained a majority of the building damage in the earthquake (e.g. 55 per cent of the destroyed buildings, 61 per cent of damaged buildings), most of which was concentrated in the softer alluvial portions of the city. Sendai is typical of most Japanese urban regions in that it is located partly on a soft alluvial plain adjacent to the sea, partly on an intermediate zone of firm uplifted older alluvium (in Japan termed diluvium), this zone continuing to hills or mountains. The distance from the epicentre to the centre of Sendai is approximately 110 km which, given the earthquake's magnitude, resulted in surprisingly large accelerations, peak ground accelerations being on the order of 0.25 g. Since, for the purpose of this study, response spectral accelerations, velocities and displacements are required for various locations and soils in Sendai, and few records were available, use of Trifunac's 5 per cent damped response spectral attenuation function[5] was made, which was modified with satisfactory results, see Figure (11). This modification has been previously reported[6] and will not be dealt with in detail here, but basically consisted of using a 'virtual epicentre' shifted towards Sendai from the epicentre of record (see Figure 10), in the attenuation function, instead of the epicentre of record.

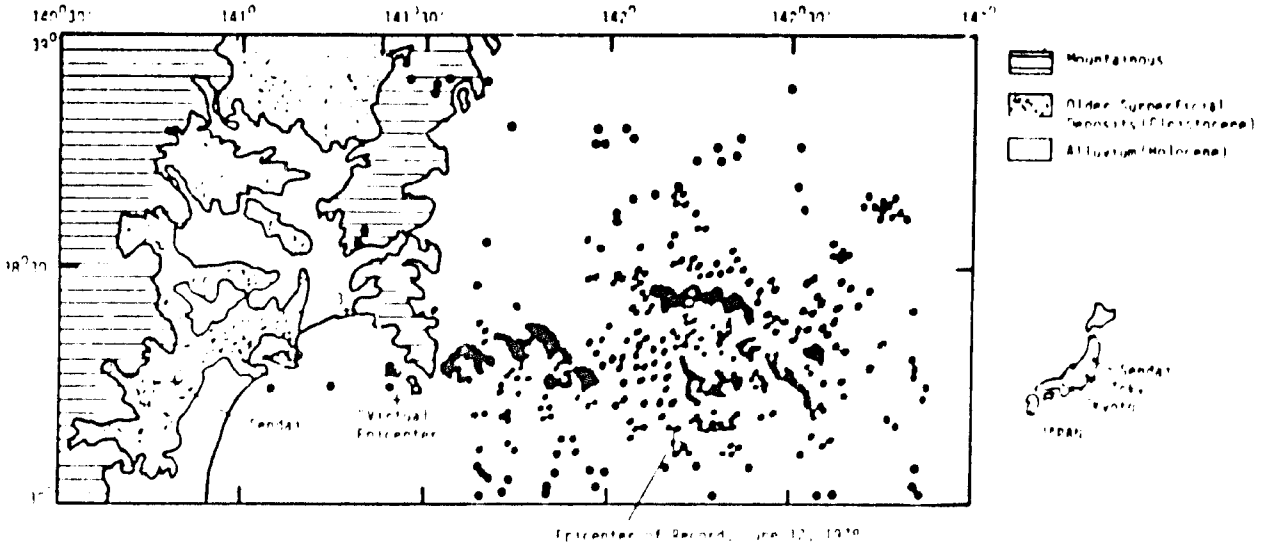


Fig 10 Regional view of Sendai, showing geology and aftershock area for period June 12 - Aug. 31, 1978.

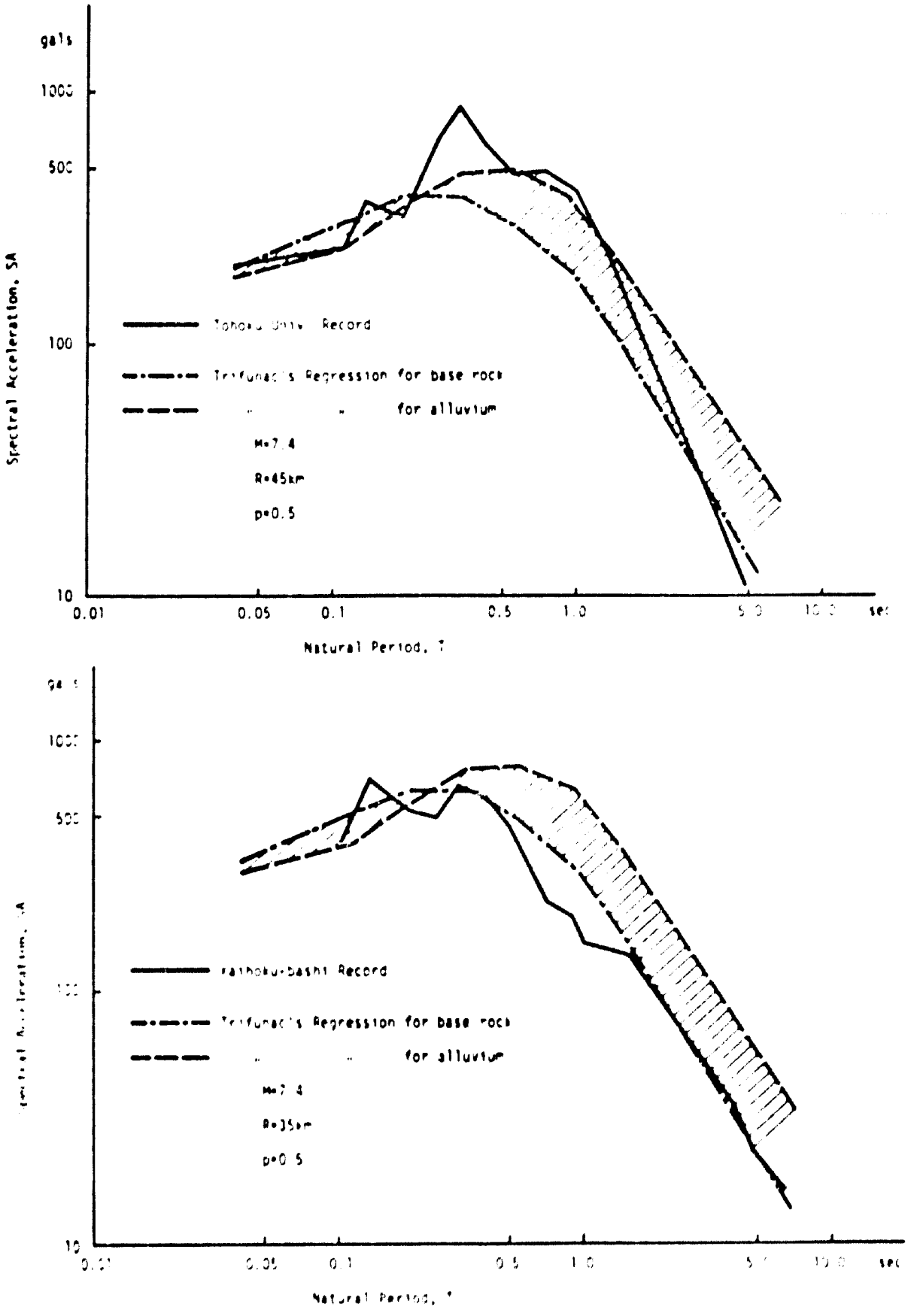


Fig 11 Response Spectra for (above) Tohoku Univ. and (below) Kathoku bathi, compared with Trifunac's regression and 'virtual' epicentre.

Statistical Analysis of Low-rise Building damage in Sendai

This section, the statistical analysis, summarizes previous findings[6] and is included for the sake of completeness. Figure 12 is a map of Sendai showing DR_{BDMG} and DR_{BDST} by political subdivision experienced in the Miyagiken-oki earthquake (the political subdivisions were of sufficiently small size to be adequately categorized by a single soil type -- hard, intermediate or soft). The data in Figure 12 were regressed against the 5 percent damped spectral accelerations generated by the modified attenuation functions, described above. After examing various types of equations (linear, log-log,etc.) and different spectral acceleration periods, a correlation of log-log form for spectral accelerations 0.75 s was found to be best. These correlations are (number of observations is 17):

$$DR_{BDMG} = 1.813(SA_{0.75})^{1.744}, \quad r = 0.75, s = 0.00345 \qquad (1)$$

$$DR_{BDST} = 0.020145(SA_{0.75})^{2.525}, \quad r = 0.69, s = 0.0001 \qquad (2)$$

where $SA_{0.75}$ is the response spectral acceleration at 0.75 s (in g), r is

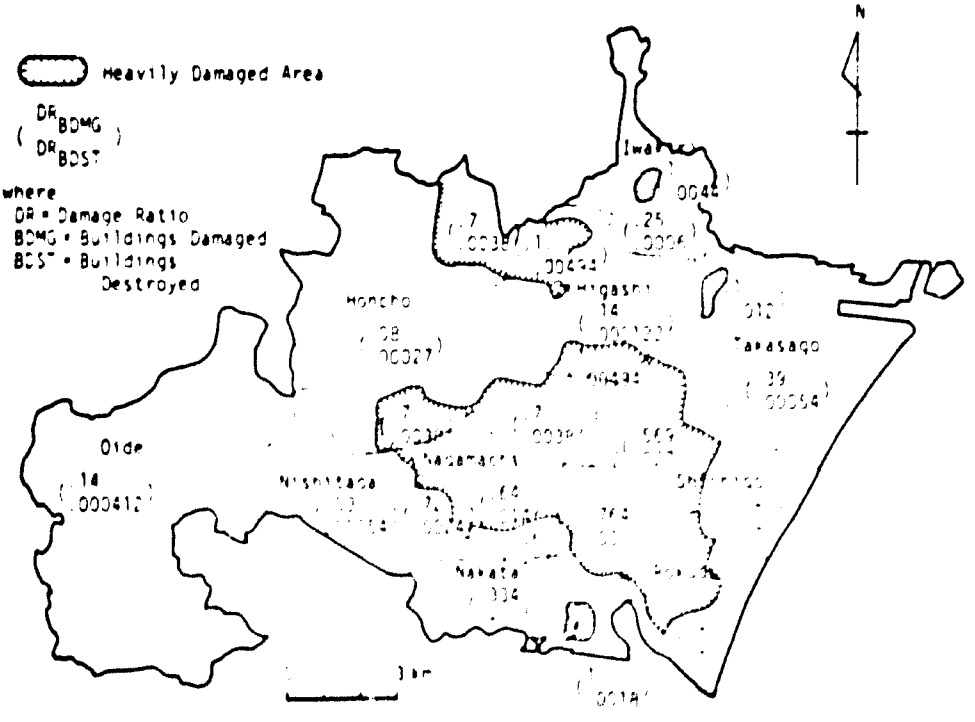


Fig 12 Sendai City political subdivisions, showing damage ratios resulting from June 12, 1978 earthquake.

the correlation coefficient and is the conditional standard deviation. Relation (1) was modified to include data from other Japanese earthquakes[7] which resulted in

$$DR_{BDMG} = 1.208(SA_{0.75})^{1.324}, \quad r = 0.69, \quad s = 0.00325 \tag{3}$$

Damage costs were reported in Sendai[8] from which the following relation was determined:

$$¥ = 0.5+0.434BDST+0.0053BDMG, \quad r = 0.998 \tag{4}$$

where ¥ is 1978 Japanese Yen (x 10^8). From the above relations, assuming an average value per building of 10^7 Yen, the damage cost factor was determined[6]:

$$DCF = 0.0756(SA_{0.75})^{1.7} \tag{5}$$

the variance of which can be approximated by

$$V_{DCF} = 0.000115+\frac{170}{(NB)^2} \tag{6}$$

The above relations permit damage estimates for low-rise buildings in Japanese regions to be made, when use is made of various response spectral acceleration attenuation regressions, which was illustrated in Scawthorn et al[6]. However, they do not in themselves explain the damage or permit any estimation of the effects of changes in the buildings' structures on the damage (for example, what would be the effect of an increase in the required bracing ratio?). For this, a physical model is necessary.

Seismic Damage Model For Low-rise Buildings

Lateral resistance in the average low-rise Japanese building was discussed above and seen to derive from three elements: (1) solid walls of either shinkabe (older, bamboo lattice-mud) and/or okabe (newer, similar to stucco on lath), (2) pierced walls of the same materials and (3) walls of the above materials with diagonal wood bracing. Items (1)-(2) are usually considered non-structural, while (3), if existing, is considered structural. Takeyama et al[9] conducted static and dynamic tests of elements representative of items (1)-(3) from which force deflection cur es the form:

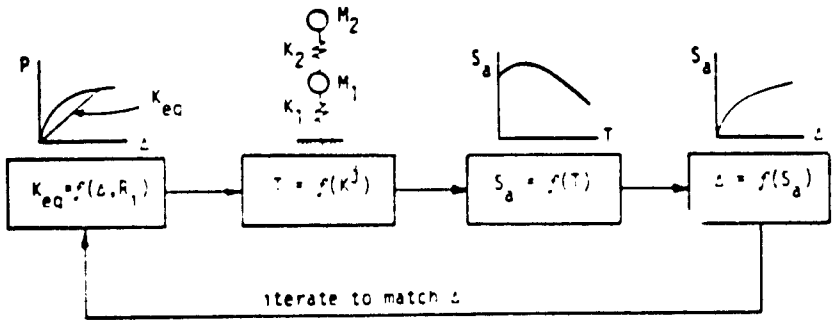


Fig. 13 Schematic representation of iterative technique used in determining natural period and displacement considering non-linear behaviour of low-rise building elements

was used here because it had previously been found to be the best correlative with damage, in the above statistical analysis. The reason for this can now be seen since, on average:

$$T_1 = 0.33\Delta^{0.335} \quad \text{and} \quad T_2 = 0.55\Delta^{0.28} \tag{10}$$

(where T_1 and T_2 are the fundamental periods of one-or two-storey buildings, respectively, determined by the iterative technique and the equivalent linear

Table II

	Heavy Roof		Light Roof	
Building	e	f	e	f
1 storey	15.6	1.56	10.6	1.68
2 storey	26.7	1.28	24.2	1.32

$$P = a\Delta^b \quad \Delta \leqslant 1 \text{ cm} \tag{7a}$$

$$P = c + d\log\Delta, \Delta \geqslant 1 \text{ cm} \tag{7b}$$

may be determined, where P is the horizontal load acting at the top of a one-storey wall panel (kg/cm), is the deflection of the top of the panel (cm) and a - d are constants, Table 1. Building storey equivalent linear stiffness per unit building horizontal projected area, K_j, may then be expressed:

$$K_j = \frac{1}{\Delta_j} \sum_i R_{ij} P_i \tag{8}$$

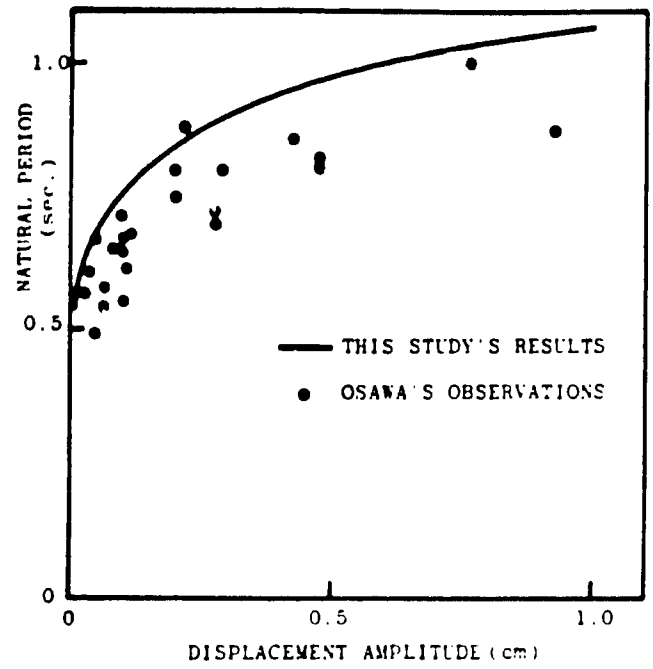
Table 1 Force-deflection characteristics for low-rise buildings
$P = a\Delta^b, \quad \Delta < 1\text{cm}$
$P = c + d\log\Delta, \quad \Delta \geqslant 1\text{cm}$

Type	Specimen	$\Delta<1$cm a	$\Delta<1$cm b	$\Delta\geqslant1$cm c	$\Delta\geqslant1$cm d	R_{ij} (m/m^2)
Wall:						
Shinkabe	SB-6	37.1	0.70	36.9	136.0	0.134
Okabe	OC-6	88.6	0.35	95.2	97.9	0.035
Pierced Wall	SA-6	9.8	0.73	1.5	53.1	0.334
Wall with bracing	OD-6	135.4	0.88	143.6	663.9	0.086

where j indicates first or second storey, i = items (1)-(3) and R_{ij} is the ratio of wall length in metres per square metre of floor area. Using equation (8) modal frequency, modal shapes, response to spectral acceleration, etc. were obtained using a step-wise linear iterative technique in which the K_j are based on a value of the storey displacement $_j$, which is then determined from the spectral acceleration and K_j and thence used as the next input value in the iteration, see Figure 13. Natural periods calculated using this method were compared with published test results [10, 11] Figure 14 with good agreement. Using average R_{ij} determined from standard building plans [12] shown in Table I, as typical of present-day low-rise buildings, and response spectral shapes typical of Sendai in the Miyagiken-oki earthquake (described above), responses of average low-rise buildings were determined:

$$\Delta = e(SA_{0.75})^f \tag{9}$$

where e and f are given in Table II, and indicates deflections of the eave line with respect to the ground of either one- or two-storey buildings). $SA_{.075}$



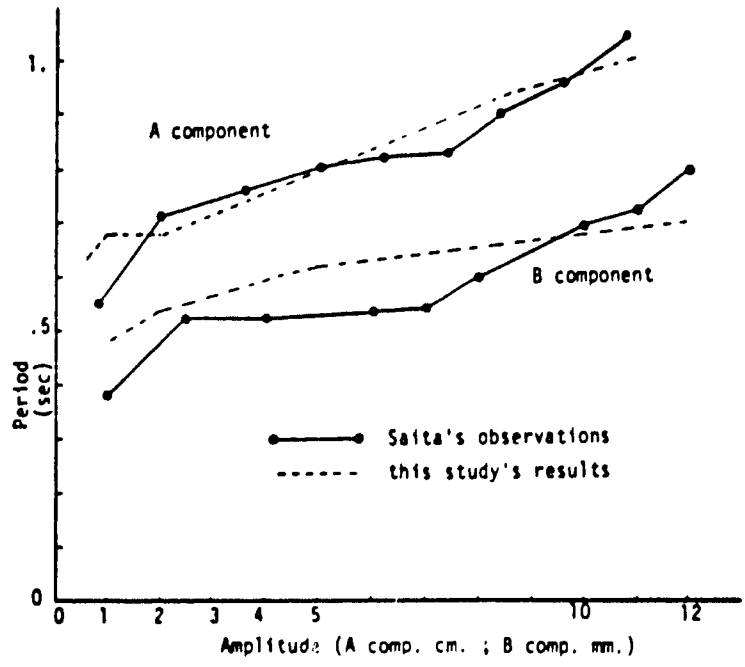


Fig. 14 Comparison of this study's results with Osawa's (above and Saita's (below) test observation of a typical low-rise buildings

stiffness, equation (8)) and Sendai experienced average $SA_{0.75} \approx 0.45$ g, which implies average eave-line building displacements of about 9 cm (2 storey) and 3 cm (1 storey) and periods of 1.0 s (2 storey) and 0.5 s (1 storey). Since the numbers of one- and two-storey buildings in Sendai were about equal, 0.75 is nicely bracketed explaining its better correlation when compared with spectral acceleration periods of 0.32 s, 0.55 s etc. This is not to imply that 0.75 is exactly the best correlative but that response spectral accelerations around 0.75 s provide better correlations with damage than much smaller or larger periods, for Japanese low-rise buildings. Equation (10) also expresses an oft-noted fact, that the period of low-rise Japanese buildings depends on displacement, (11) which can be seen in Figure 14. By definition, the DR is that portion of the building population exceeding some damage threshold. Since the above damage model has been for an average building and equation (3) is the mean damage relation, we can say (assuming normal distribution for Δ):

$$DR_{BDMG} = 1.208 SA_{0.75}^{1.324} = 1.0 - \Phi\left[\frac{\Delta_{DMG} - \bar{\Delta}}{s_{\Delta}}\right] \tag{11}$$

where Φ is the cumulative distribution function of the normal distribution, Δ_{DMG} is the eave-line displacement at which damage reports commence and $\bar{\Delta}$ is the displacement as determined by equation (9). The method of least squares was used to determine Δ_{DMG} and s_{Δ}, resulting in

$$DR_{BDMG} = 1.0 - \Phi\left[\frac{6.9 - \bar{\Delta}}{3.4}\right] \tag{12}$$

The damage threshold determined herein is 6.9 cm which is somewhat larger than Takeyama's [9] observation of cracking at about 4 cm. This difference is not great, however, when it is considered that Takeyama's observation was for the beginning of cracking and was based on static tests whereas this study's 6.9 cm is based on the observed damage claims of Sendai in an actual earthquake. It should also be noted that these values are for deflections at the top of a 3 m wall. Similarly, a destruction threshold can be determined:

$$DR_{BDST} = 1.0 - \Phi\left[\frac{66.0 - \bar{\Delta}}{21.1}\right] \tag{13}$$

Lastly, due to floors and roof sustaining damage only at comparatively large deflections, a damage cost function of the form

$$DCF = 0.5\left(\frac{\Delta_1}{60}\right)^2 + 0.5\left(\frac{\Delta_2}{60}\right)^2 \tag{14}$$

(where Δ_1 is the storey deflection of the first floor and Δ_2 that of the second storey) gives good agreement with the previously determined statistical relation, equation (5), in the range of observed accelerations.

Use of the Low-Rise Building Damage Model

As an example, suppose it is proposed to double the amount of bracing presently used, in the first floor only. Using the model, the resulting increase of stiffness is calculated to only be about 1/3 (since doubling the bracing only doubles item (3), whereas the 'non-structural' elements, especially the walls, still contribution significantly). Scaling the Miyagiken-oki response spectra, calculations show that at moderate accelerations the number of damaged (i.e. DR_{BDMG}) buildings would be cut almost in half, while at higher accelerations the decrease in DR_{BDMG} would be very small or negligible. The damage cost and number of buildings destroyed, however, at all acceleration levels would be cut by about 1/3.

Closure

The purpose of this paper has been to briefly present an overview of the situation in Japan regarding the typical construction incorporating earthen elements vis-a-vis earthquakes. After detailing the method of construction using earthen elements, the results of some researches were presented. Basically, these were the development of a building-class damage estimation, which would permit prediction of and scenario-review for damage in urban Japan, as well as providing weight into the physical behaviour of these buildings. Damage was dealt with in the form of average damage ratios, applicable to individual or groups of buildings, relating this damage to damage thresholds in terms of displacement. The correlation of low-rise building damage with response spectral acceleration in the statistical analysis section of this paper is, due to the use of average properties and natural periods for the entire low-rise building inventory, equally correlation with spectral velocity and displacement. Thus, the spectral displacement corresponding to the mean damage threshold (for DR_{BDMG}) can be found directly from equation (1), its value being 6.67 cm, corresponding to natural periods for one- and two-storey buildings (by equation (10)) of 0.62 and 0.94 s, respectively. The use of average properties and damage ratios for low-rise buildings is justified, we think, by the anticipated applications to urban regions where tens or hundreds of thousands of such buildings are aggregated. The data derives from the earthquake in one region, with the exception of the incorporation of other damage ratio data (for DR_{BDMG}) in the low-rise building section, and the results must be used with some caution due to this limitation. The analysis also relies on synthesized response spectra (based on the 'virtual epicentre' modification of Trifunac's attenuation

regression) although this does not appear to be too serious drawback, based on the match obtained with the existing records. The technique of regressing damage against various structural or ground parameters has been extensively used herein. The lowest correlation coefficient determined was 0.69 for 17 observations. While this coefficients could be much higher, it satisfies at the 1 per cent confidence level the hypothesis that there exists dependence between the correlated variables.

The applicability of the results to regions outside of Japan is unclear. While the architecture of the Japanese house is unique, the basic techniques and perhaps some of the results could find application in parts of China, India, Central America, etc, where mud-on-wood-lattice walls are used.

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THE VULNERABILITY TO EARTHQUAKES OF LOW-STRENGTH MASONRY STRUCTURES

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ABSTRACT The paper reviews the work of a newly-formed multidisciplinary group to consider ways of reducing the vulnerability of buildings of traditional construction in seismic areas. The problems of assessing vulnerability are discussed, and the preliminary results of recent field studies in Northern Pakistan and Southern Italy are summarised.

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In the great siesmic belt which stretches from the Mediterranean across Turkey and Iran to the Himalayan mountains, the vast majority of people live today in buildings of moderate or high vulnerability to earthquakes. Traditional building types have developed from three primary constraints:

(1) Arid or semi arid climates, in which the difference between day and night temperatures is considerable, so that massive roofs and walls are needed to create comfortable indoor conditions.

(2) A severe shortage, and often complete absence of timber, or indeed any other building material capable of carrying tension.

(3) Economic deprivation and sometimes extreme poverty, which dictate that only local materials and 'self-build' methods can be used.

Throughout this area, dwellings consisting of massive but weakly bonded masonry walls of adobe or random rubble stonework, and supporting heavy mud or tiled roofs, are the rule. And since the structures of such dwellings are inherently unable to resist more than a very limited amount of shaking force (and indeed in many cases would by the standards of industrialised countries be considered statically unsound even under their normal gravitational loading), the occurrence of an earthquake is liable to cause a major disaster in which many thousands of buildings are destroyed and large numbers of people are killed by or trapped under falling masonry. Even without considering the irreplaceable nature of these losses, cost of the relief operations and of the economic disruption caused by such events make it necessary for all administrative and financing agencies involved to consider whether there are not ways in which these vulnerable communities could not be provided with protection against earthquakes, in a manner analogous to those used for other natural hazards, such as flood or erosion protection measures.

Although this is an old problem, it is one which surprisingly little progress has been made in recent years, particularly when compared with the considerable advances which have been made in the engineering theory of earthquake-resistant design. One of the reasons for this lack of progress has been the large gap between what engineers have deemed the minimum adequate standards of earthquake protection, and what the recipients of that protection have been able to afford, or at least willing to pay for it. Meanwhile the increasing economic marginalisation of rural populations everywhere in the region and the diminishing availability of traditional building materials appears to be creating conditions of increasing vulnerability for these populations.

It was against this background that a multi-disciplinary working group was recently formed in the U.K. to look for new approaches to this problem. Recognising that technical measures would be no more

likely than before to provide adequate solutions without an understanding of the wider social and economic context, the membership of the group included specialists in social sciences (anthropologists and geographers) as well as engineers and architects, and maintains strong links with seismologists and geologists.

One of the underlying convictions of the group is that ancient societies have been more aware of the earthquake risk than is generally recognised, and that many of the traditional building techniques used in seismic zones in different parts of the world (notably those of China, Japan and South East Asia) have proved themselves over time to be very well adapted to earthquakes. The group therefore believe that one hitherto little explored way of making more progress in design of low-cost buildings to resist earthquakes is to study and learn from these techniques, to find ways in which they could be modified to improve their performance or adapted for use elsewhere in the world. This problem is discussed in more detail elsewhere (1).

A second conviction of the group is that there is still a severe dearth of experimental work on the performance of small buildings, particularly data which is based on field observation. Progress in understanding the behaviour of small buildings in earthquakes and hence earthquake resisting design can only be made if the response of buildings to known ground movements can be observed. This can be done in a broad way by the observation of the performance of buildings in earthquakes, but the most useful observations will be made where the local ground movements have been measured by strong motion instruments, of which there are still very few in the areas being discussed. A second approach is the modelling of structures for testing in the laboratory. Although further considerable modelling difficulties present themselves (which have been discussed elsewhere (2)), the group intends to work towards linking field study with laboratory study of existing structural form. Laboratory models could then be used to study the effectiveness of various possible design modifications on earthquake resistance; successfully tested modifications could then become the basis for design guides for local builders in modifying and strengthening buildings in seismic areas.

A third conviction is that neither laboratory nor field studies should be undertaken in isolation from the question of developing appropriate programmes for the implementation of the results of these studies; the economic and administrative problems of implementation of modification programmes have in the past invalidated research work to such an extent that it is now believed vital at all stages to consider these problems in devising technical investigation programmes.

The initial stimulus for the formation of the group was an invitation from the Royal Geographical Society to take part in its 1980 Karakoram Project, a large scientific expedition to the Karakoram region of North Pakistan, recently made accessible by the Karakoram highway. This region presented an ideal opportunity for a field study since it experiences a relatively high frequency of damaging earthquakes (most recently in 1974), and has an interesting variety of vernacular building types using combinations of stone and timber, some of which have been reported as being

resistant to earthquakes. The working group spent 2 months studying vernacular building types and the earthquake risk (as well as other hazards) between June and September 1980.

A second field study was carried out in March 1981 by the [illegible] group in Campania, Southern Italy, on the effects of the November 1980 earthquake in that region. Again the effects of the earthquake on vernacular building types was one of the main interests. The engineering aspects of both of these studies were financed by the Science Research Council, and both will be described in greater detail in papers to be published in due course. This present paper presents a brief interim review of the main objectives and activities and some preliminary conclusions of each of these studies.

Field study in Pakistan

The principal objective of this study was to examine traditional or vernacular building types, and to investigate what relationship there was between the existing forms of buildings and settlements and the vulnerability of these settlements to earthquakes and natural hazards; at the same time it was intended to look at local awareness of these hazards, and the extent to which the people themselves would be willing to modify their traditional houseforms to make them less vulnerable.

Two settlements in the region were chosen for detailed study. One of these settlements, Pattan in Kohistan on the Indus, had been very seriously damaged in the earthquake of Dec 28, 1974, and the report of the UNESCO mission (3) had stated that some of the buildings had been built using traditional techniques which made them less vulnerable. A second settlement chosen, Barculti in the Yasin valley, had not itself experienced a recent earthquake, but was in an area of known seismic activity; buildings in this area were built according to the Chitrali tradition, which anthropological writers (4) had suggested included earthquake-resisting features. Two more settlements were visited for shorter periods, Thorharabad on the slopes of the Indus valley at an altitude of 3,000m, more inaccessible and using building techniques different from either of the other two settlements; and Karnish in the Hunza Valley. In neither of these two places is there a recent history of seismic activity. Fig. 1 shows the location of each of these settlements.

In each of these settlements detailed observations and measurements were made of the settlement forms and their location in relation to possible rock falls and flooding, and of the form of construction of typical individual buildings.

The house types will be described in detail elsewhere (5). One example, the typical form of dwelling in Barculti is shown in figs. 2 and 3. The standard living room is almost square, approximately 6m across, surrounded by low windowless walls of thick random rubble masonry: the main living space is defined by four large square timber columns, which support the primary beams which in turn carry the roof. An important feature of these columns is that their bases rest on horizontal timber base-plates, and the primary beams rest on them without any form of connection other

than that provided by friction. Resting on the primary beams are a series of smaller transverse beams spanning laterally to the side walls, and also, over the centre space, a pyramidal structure of diagonally placed beams which define the only opening to the space, a smoke-hole. The roof structure is covered with a layer of mud between 300 and 500mm thick.

Very similar structures are found in the Chitral Valley, further west, geographically and ethnically related to the Yasin Valley, and have been described by Hassan ul Mulk and Staley (4) who write "the Chitralis claim that this combination of wood and stone is particularly resistant to earthquake shocks," and that "when there is an earthquake the women run to the Cher-o-tun (Chiri-Dung fig. 2) and cling to it as the safest place in the house."

However, it was one of the most strongly formed conclusions of this study that, in the Yasin Valley certainly, there is very little awareness of the risk of earthquakes. In relation to the other hazards faced by the people of these valleys, (of flooding, rock falls or mudslides and of soil erosion) which derive from the unstable and rapidly changing landforms - the earthquake risk is perceived as being very remote, in spite of the occurrance during the last 50 years of two earthquakes large enough to cause damage in nearby valleys. In consequence there is little awareness of the need for or demand for earthquake-resistance in local house forms. Such earthquake-resistance as these house-types do possess is presumably then rather accidental than conscious, being in all probability the result of the introduction at some earlier time of house forms derived from the cultural and physical requirements of the Chitral valley. A further study of the earthquake-awareness of that region would have been valuable, but unfortunately the current Afghanistan-Pakistan border situation made it impossible.

In the absence of any data on the performance of this Yasin building type in past earthquakes, the extent to which these structures would in practice prove to be earthquake-resistant could not be deduced from the field study; and one of the objectives of the study was to obtain a sufficiently detailed structural description to enable them to be modelled for subsequent theoretical analysis, or experimental analysis using small-scale models. In addition to the detailed surveys, descriptions and samples of building materials, it was also decided to attempt direct measurement of the dynamic response characteristics of selected buildings. This was done by means of a controlled frequency vibrator, attached to the roof structure, the response of which was measured at various points by suitably placed accelerometers.
By this means it was possible to determine directly the natural modes of vibration, natural frequencies and damping characteristics of these buildings, and also to observe the degree of connection between the structural elements (roof structure, walls, columns, etc). The method is not new; it has recently been used by the U.K. Building Research Establishment for studies of the wind response of tall buildings (5). But it may be the first time that it has been applied to buildings of this type. The method is of course subject to the severe limitation that only very small vibration responses can be studied, which, although it may give useful information about the conditions prior to material breakdown in earthquakes, gives little clue to the response of the

structure in major shaking once irreversible structural changes have occurred. It is also subject to the severe practical limitation that householders are inclined to be reluctant to offer their houses for such testing, which at best is an inconvenience, but also requires confidence in the ability of the engineers to ensure that it proves as non-destructive as they claim it to be. In the event it was possible to find enough time and develop enough confidence to test only two houses and a number of walls, all in Barculti Village.

The results of these tests are interesting and will be described in detail in a forthcoming paper (7). Very clear resonance peaks for the buildings, were identifiable at frequencies in the range 0.10 to 0.15 secs for vibration in the longitudinal plane of the primary roof structure; and it was also observable that even at small amplitudes there is a clear separation between the motion of the column-supported roof and the longitudinal walls. These observations suggested the possibility of the modelling of the structure as a simple column-beam system, in which the columns are not connected either at their head or base, but are free to 'rock' under lateral earthquake loading; and a study of this system is in progress.

Field study in Italy

The general objective of this study was to examine damage in a number of the settlements affected by the earthquake of November 23 1980. The survey was planned to take place during March 1981 at a time when immediate relief needs were largely met, but before substantial demolition and rebuilding had been carried out.

As in Pakistan, it was proposed to study vernacular building techniques, (both traditional and more modern) but also, in this case, to assess the performance in the earthquake of different building types in areas affected by ground motions of different levels.

More than this, it was also intended to obtain some assessment of the relative significance of age and condition of the structure, of orientation, of subsoil conditions and of topography on the degree of damage caused to buildings; and to look also at the damage to other structures, towers, roads, embankments etc.

Some basis for this work was provided by the intensity mapping already carried out by [illegible]), see fig. 1, and potentially even more significant, by the records of 10 strong motion instruments of the [illegible] network which were triggered by the earthquake [illegible]. It was intended to use the positions of these strong motion instruments as the centres for localised damage surveys, so that building performance could be directly compared to ground movement. It was considered important to restrict these surveys to the very immediate locality of the strong motion instruments, in order to limit any effects from the variation of ground and topographical conditions.

However, investigation showed that none of the instruments was located in the epicentral region (MSK intensity X, fig. 4) and only one was in the region of MSK intensity IX. Moreover, the instruments were placed in electrical substations, and they were in most cases removed from the old town centres to places on the outskirts of the towns, where there were fewer, more recently constructed buildings, and where damage was rather light.

The damage surveys actually carried out therefore consisted of

(a) Localised surveys of all buildings within approximately 250m of the strong motion instruments, at six stations located near the epicentral region (Auletta, Brienza Bagnoli, Irpino, Bisaccia, Calitri and Sturno)

(b) More extensive damage surveys in two towns; Salvitelle, approx. 40km from the epicentre, and assigned MSK VIII by the CNR survey, and Lioni, very close to the epicentre and assigned MSK X by the CNR. In both of these surveys a substantial representative sample of the buildings in the town was surveyed, there being insufficient time for a complete survey.

The damage classification system used was a 7-point scale using crackwidths as an indicator, based on that devised by the Building Research Establishment for classification of damage due to foundation settlement in the U.K. The Scheme is shown in Table 1. For each building surveyed the information recorded also included data on its situation and orientation, form and materials of construction, age and condition, and assessments of its serviceability and ability to withstand aftershocks; and in the case of masonry buildings a sketch of the pattern of cracking.

Table 1. Damage classification scheme.

Damage level	Interpretation
0	No damage
1	Light, superficial non structural damage
2	Small cracks < 5mm. width
3	Cracking 5mm. < max. width < 10mm.
4	Cracking > 10mm.
5	Partial collapse
6	Total collapse

Altogether 416 buildings were surveyed in the 8 surveys. More than three quarters of all buildings surveyed fell into one or other of two categories. By far the largest number (58.5% of all buildings surveyed) were 2 or 3 storey buildings of random rubble masonry construction, with either timber or steel joist floors, and with tiled roofs supported on timberjoists.

In 1858, following the great Neopolitan earthquake of the previous year, Robert Mallet was sent by the Royal Society to investigate. His account (10) begins with a description of the building methods of the region part of which is quoted below:

> "The general style of construction of walls, even in first class buildings, consists of a coarse, short-bedded, ill-laid rubble masonry with great thickness of mortar joints, very thick walls, without any attention to thorough bonding whatever... The floors are formed of joists of fir timber.. from 6 to 9 inches in diameter, placed about 3 feet apart. The ends are inserted some inches into the walls but are neither bedded on nor connected by any bond timbers, none of which are ever placed in the walls... The roofing also usually consists of round fir timber. The framing is of the simplest character. It consists commonly of principal rafters at 3 to 5 feet apart connected by a rude collar brace, of round fir also, trenailed or bolted to the rafters. The feet of the rafters sometimes rest on a wall plate of squared or half round timber, but often bed directly on top of the wall".

The form of construction which was described by Mallet is still very largely prevalent in the region today although with some modifications:

(1) many of these buildings have, without strengthening of the supporting structure, had additional third or even fourth stories added in newer materials.

(2) the timberfloors described have, in many cases been removed and replaced by concrete floors supported by steel joists and ceramic planks; but, as before connected neither to the wall nor bonded laterally to make the floors monolithic.

There is little doubt that these modifications have generally weakened an already weak structural system; accordingly this type of building is every bit as vulnerable as those which were condemned by Mallet in 1858.

The second major type of building is that of more recent construction. This type (12.5% of buildings surveyed, is of 3 to 4 stories and has a reinforced concrete frame. The frame consists of columns of 300 to 400mm diameter supporting in-situ floor slab of ceramic plank filler construction, and usually a pitched reinforced concrete slab roof. The walls are infilled after the construction of the frame and commonly consist of two skins of ceramic blocks not bonded to each other or to the frame. In this type of construction there are no shear walls, and lateral strength is provided only by flexural strength of the connection of column to

the floor structure. It is not designed for any seismic forces.

The remaining 24% of buildings were a mixture of masonry buildings mostly of more recent construction, and some including r.c. floor or roof slabs.

Histograms of damage for the random rubble masonry buildings in Lioni and Calvitelle are shown in fig. 5. A striking feature of these histograms is the very considerable spread of damage, even within one building type. This means that many factors other than location and building type need to be considered in explaining damage levels. It may be as Mallet claimed in his 1857 report, that the orientation of a masonry building to the main direction of the shock affects its performance. It is certain also that not only subsoil conditions but also topography have a strong affect on the degree of shaking experienced. There were remarkable examples in several towns of a complete change in the pattern of damage as subsoil conditions changed from hard rock to soft rock or alluvium. In Calvitelle, however, a similar variation in damage could not be clearly attributed to a change in subsoil conditions or building types; but considerable variation (by a factor of 5) was observed in the peak readings of 5 seismometer recordings of the same minor after shock all within an area of 250 m of each other: this suggested the possibility of a strong topographical effect on damage distribution, which merits further investigation.

For rubble masonry buildings the level of damage in terms of percentage of damaged buildings (damage 2 or above) for all the surveys is shown against the intensity level assigned to that town in the CNR survey (*) in fig. 6: the correlation between assigned intensity and damage is surprisingly poor, and damage levels are on the whole lower than would be expected for this class of masonry at the MSK intensity levels assigned (11).

Further analyses of the data for the Italian survey, including comparisons with the strong motion instrument records, are in process of being carried out, and will be reported in due course.

Conclusions:

Tentative conclusions for the Pakistan and Italian field studies are :

1. In both Italy and Pakistan, buildings of random stone masonry without independent structural frames are highly vulnerable to earthquakes.

2. In both areas, low income and lack of awareness of the earthquake risk are severe obstacles to any major or rapid

reduction in vulnerability; even buildings built of more modern materials have been shown to be very vulnerable, because of poor construction techniques and a lack of understanding of the basic principles of anti-seismic construction.

3. In Pakistan, there is some evidence that an independent timber roof support system reduces vulnerability, but the effectiveness of this not yet clear.

4. It is possible to obtain information on the dynamic characteristics of buildings of traditional construction under small vibrations using a simple portable vibrator and accelerator, but such tests can be difficult to organise in the field.

5. The usefulness of damage surveys to obtain information on vulnerability of traditional construction is limited by inadequate knowledge of ground movement. Intensity level is a very crude measure, and is subject to considerable error. Strong motion instrument records are potentially more valuable, but even in Italy, which has one of the most extensive networks, the density and positioning of stations is inadequate as a basis for damage surveys.

6. The methodology of damage surveys needs to be further refined so that they can be used for :

   (a) Studies of a wide variety of traditional building types

   (b) Studies of the effect of modifications in traditional technologies

   (c) assessment in quantitative terms of damage distribution, so that vulnerability of similar building types can be predicted

   (d) identification of the major factors (e.g. orientation, ground, topography etc.) affecting building damage

   (e) constructing theoretical and laboratory models of typical buildings

   (f) comparison with strong motion instrument records to identify the characteristics of earthquakes which best correlate with damage.

7. There is great value in undertaking field studies with a multi-disciplinary team comprising engineers, architects, anthropologists, geographers, geologists and seismologists; lack of any one of these perspectives on the earthquake phenomena would have greatly reduced the value of the studies undertaken. But there is also much to learn about the successful management of such an interdisciplinary group in the field.

Acknowledgements

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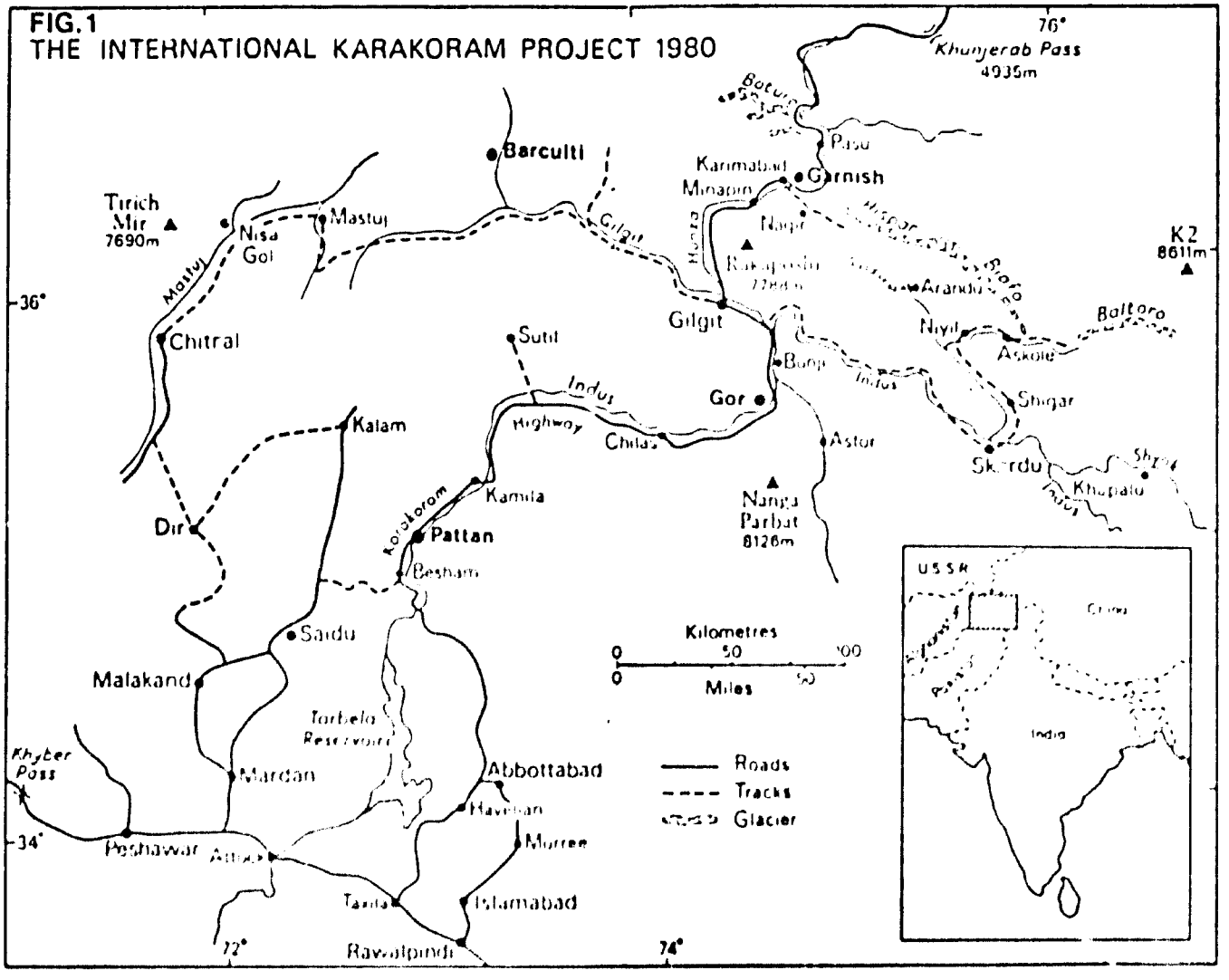
FIG. 1
THE INTERNATIONAL KARAKORAM PROJECT 1980



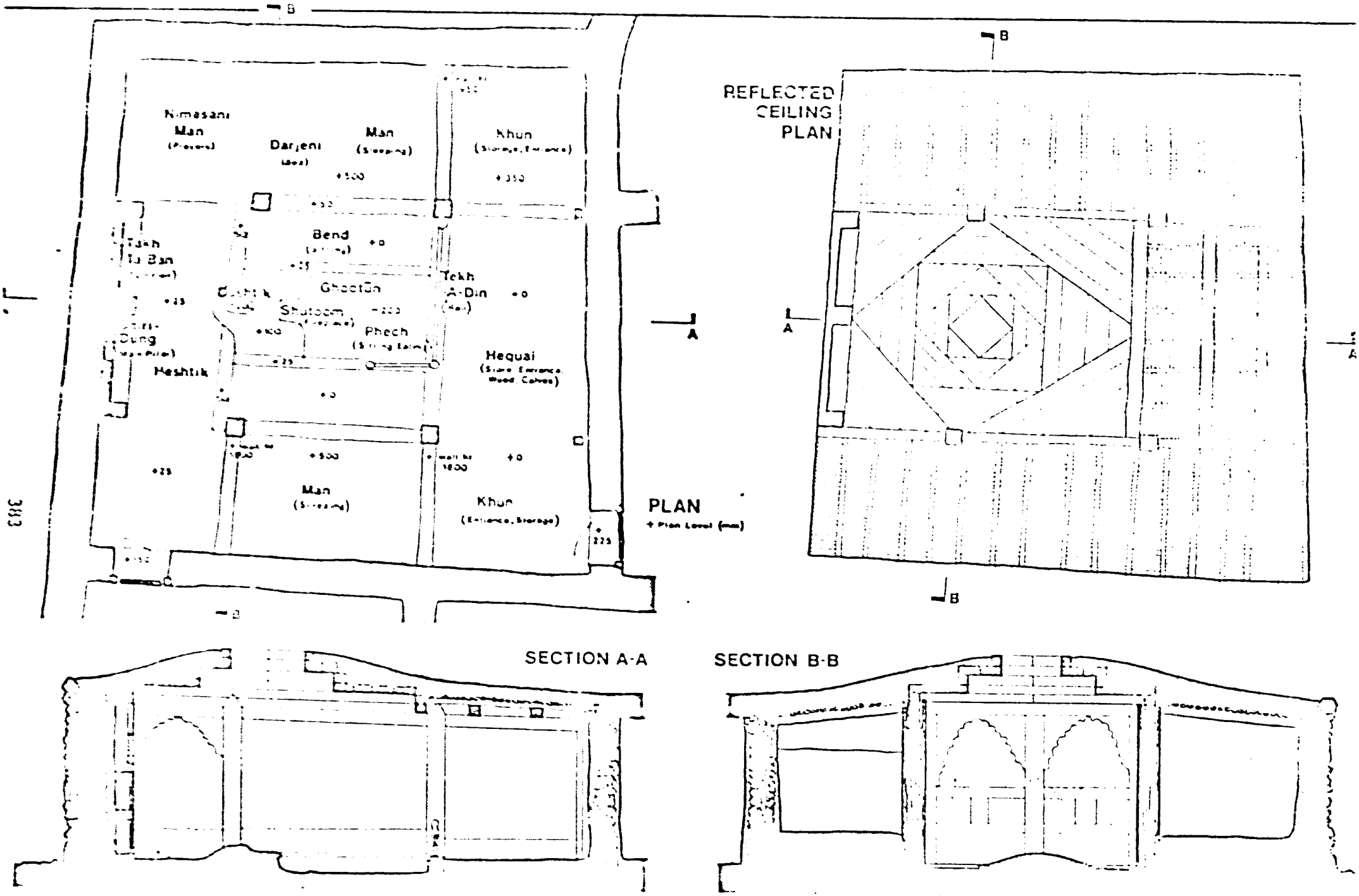


FIG 2 Study of Room 1, BAIPASH S., Barkoiti

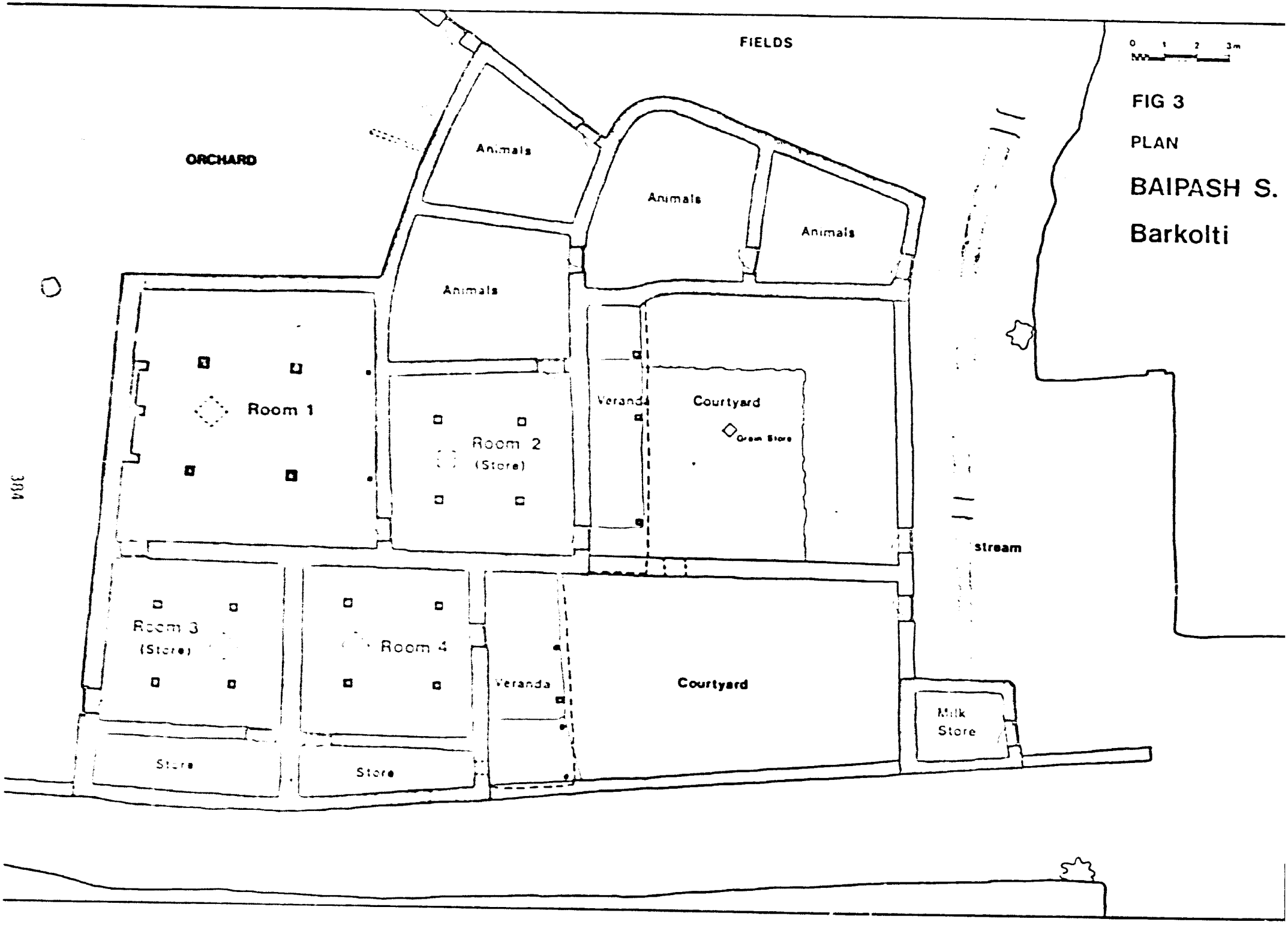


FIG 3

PLAN

BAIPASH S.

Barkolti

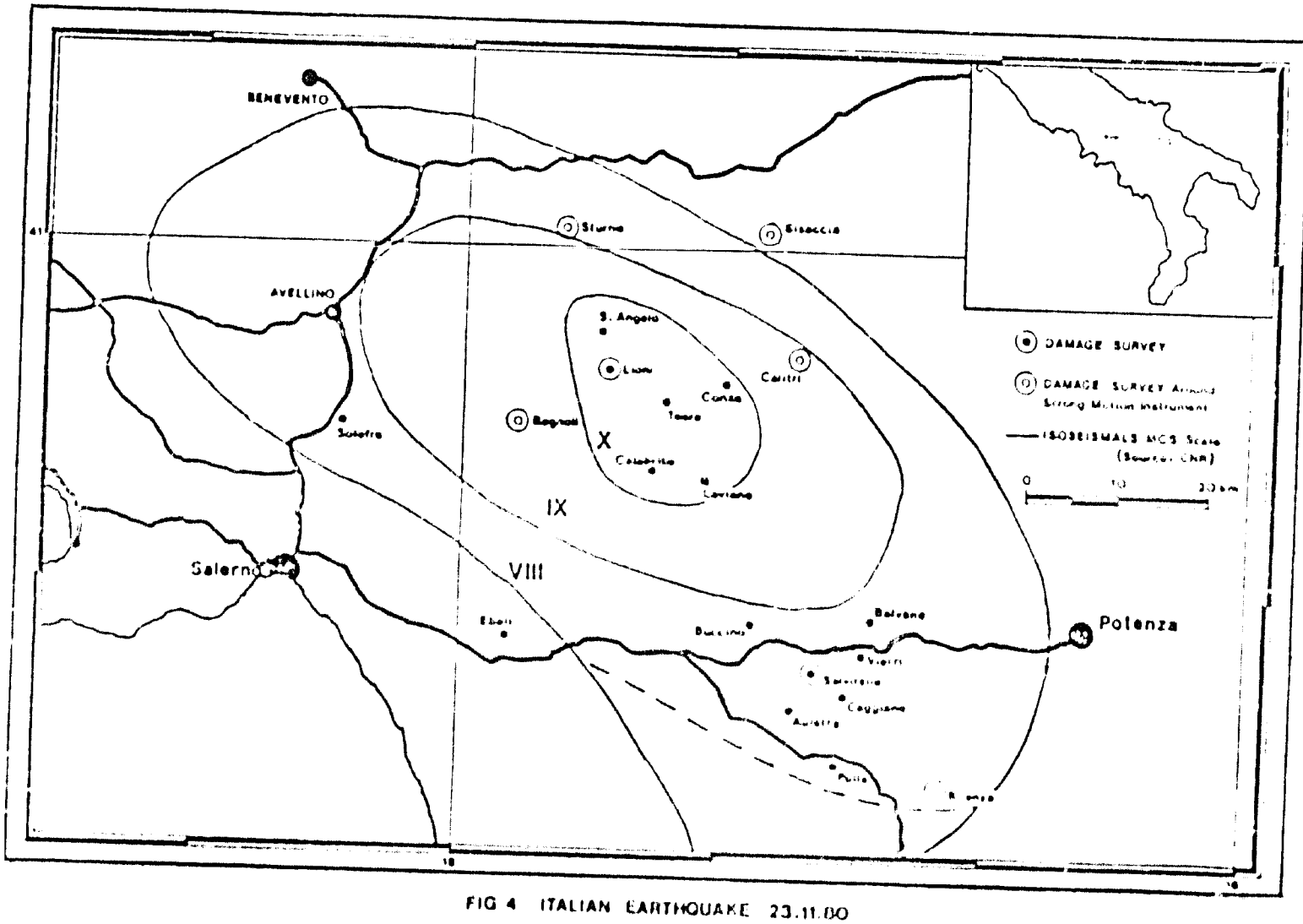


FIG 4 ITALIAN EARTHQUAKE 23.11.80

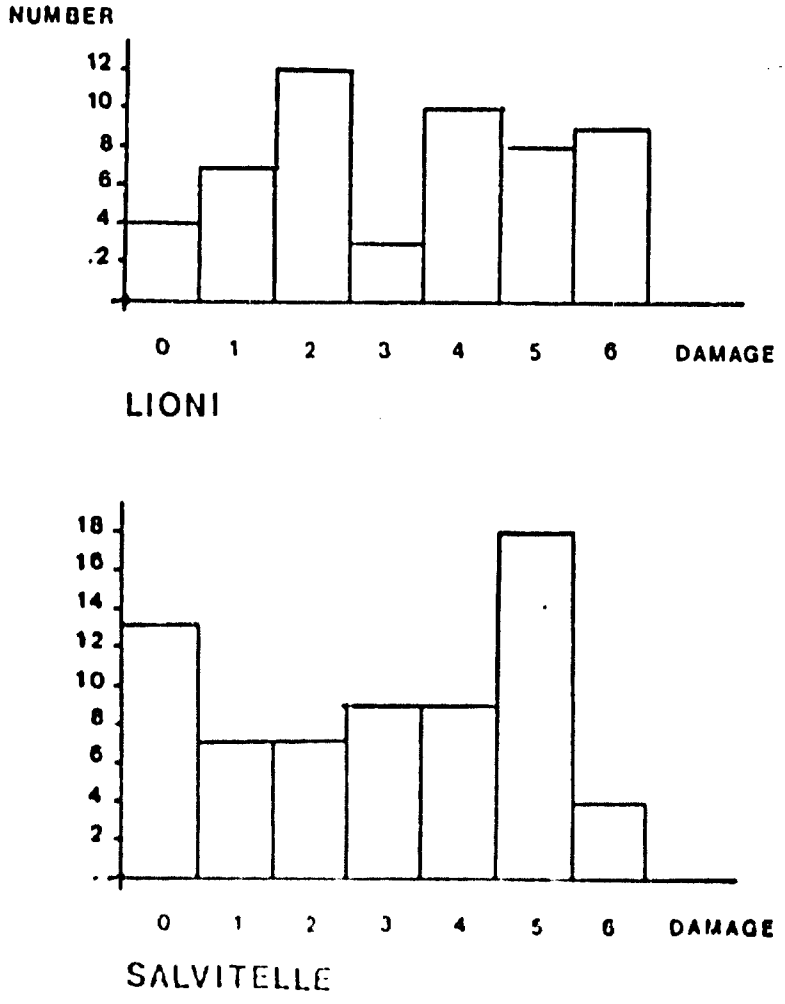


FIG.5 DAMAGE DISTRIBUTION
Masonry buildings in Lioni and Salvitelle

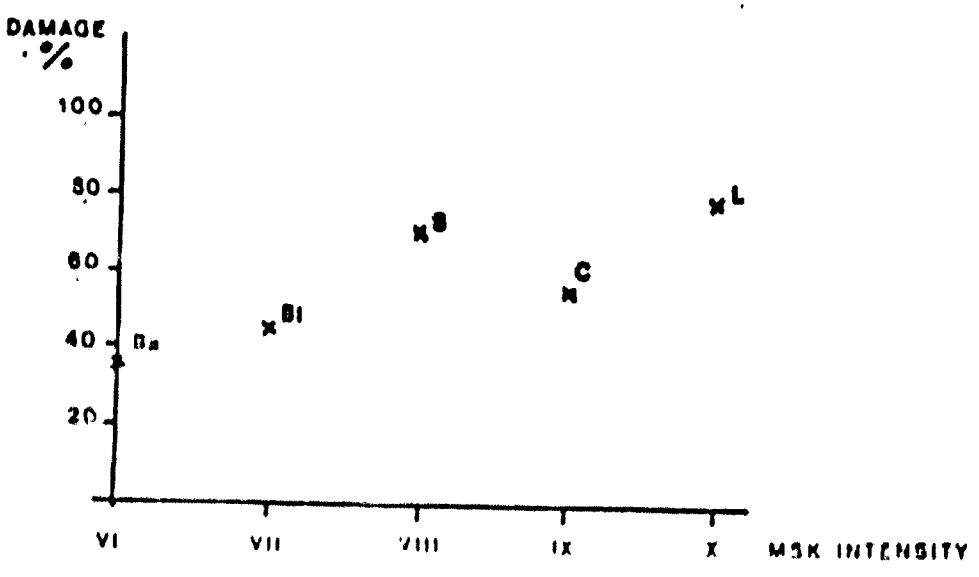


FIG.6 MASONRY BUILDINGS
Damage at each assigned intensity
(percentage of buildings with damage level>2)

" ESTUDIO SISMICO DE CONSTRUCCIONES DE ADOBE DE DOS PISOS

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Profesores del Departamento de Estructuras y Construcción
Universidad Nacional de Ingeniería

LIMA -PERU

"ESTUDIO SISMICO DE CONSTRUCCIONES DE ADOBE DE DOS PISOS"

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ABSTRACT

This study is the continuation of the research work done at Universidad Nacional de Ingeniería since 1971 and whose results have been partially published.

A method to determine compression, shear and flexure stresses in two story adobe dwellings produced by seismic effects is presented. Besides, a study for two-story structures used in low cost housing is included, taking into-account seismic zonation, type of soil and materials characteristics. Finally, recommendationes for seismic design and future research work in adobe structures used for low cost housing are proposed.

ABSTRACT

Este trabajo es continuación de las investigaciones realizadas en la Universidad Nacional de Ingeniería desde el año 1971, cuyos resultados parciales han sido publicados.

Se presenta una metodología para el estudio sísmico de construcciones de adobe de dos pisos, a fin de determinar los esfuerzos de compresión, de corte y de flexión.

Además se ha realizado un estudio de viviendas económicas de adobe de

dos pisos teniendo en cuenta la zonificación sísmica, el tipo de suelo, y el tipo de material. Finalmente se propone recomendaciones para el diseño y construcción de las viviendas económicas de adobe

INTRODUCCION

En el Perú la mayoría de viviendas rurales y de algunos centros urbanos son de adobe, siendo muchas de ellas de dos pisos. Dada la modesta capacidad económica de la mayoría de nuestra población, es evidente, que se seguirá construyendo con materiales de bajo costo, como es el adobe; además en muchos lugares es el único material de construcción disponible.

Esta realidad plantea un reto a la Ingeniería Civil, lo que hace imperativo el aporte de el esfuerzo y dedicación de sus miembros para mejorar mediante investigaciones y estudios el comportamiento de este tipo de viviendas frente a solicitaciones sísmicas severas. En la Universidad Nacional de Ingeniería, conscientes de esta realidad, en el año 1970 se inició un "Programa de Investigación de Construcciones de Adobe , con el auspicio del Ministerio de Vivienda y Construcción. Posteriormente en 1972 bajo los auspicios del mismo Ministerio y con la participación de la Agencia Internacional para el Desarrollo (A.I.D), en la Universidad Nacional de Ingeniería se realizaron estudios, en los que se utilizó bloques de suelo estabilizado con asfalto (COBE). Los objetivos de estos estudios fueron el desarrollo de una tecnología para la fabricación de bloques, el desarrollo de procedimientos de construcción, la determinación de una serie de características del material que permitieran el diseño racional dela construcción para resistir adecuadamente los movimientos sísmicos. Estos objetivos se han alcanzado prácticamente en su totalidad para construcciones de un piso.

La experiencia de los sismos recientes muestran que bajo ciertas condiciones las construcciones de adobe pueden ofrecer un comportamiento satisfactorio ante sismos severos; estas condiciones se expresan por medio de factores, tales como la sismicidad regional, las características locales del suelo y el tipo de construcción.

En este trabajo se presenta un estudio para el análisis de viviendas económicas de adobe y bloque estabilizado de dos pisos. El estudio se concreta en el desarrollo de una metodología en el diseño para cargas de gravedad y para fuerzas sísmicas actuando en el plano del muro y perpendiculares a éste. Además se estudia este tipo de viviendas teniendo en consideración la sismicidad regional y el tipo de suelo.

Finalmente se está planteando recomendaciones para continuar investigaciones acerca de las construcciones de adobe de dos pisos.

ESFUERZO ADMISIBLE POR COMPRESION EN MUROS

En el diseño de muros para cargas verticales es necesario determinar un esfuerzo permisible de compresión que considere en forma implícita la influencia de los otros factores actuantes. Matemáticamente el esfuerzo admisible de compresión puede expresarse :

$$f_m = \phi_r \, \phi_c \, \phi_e \, \phi_l \quad f'_m$$

donde :

f_m = esfuerzo admisible

f'_m = esfuerzo de rotura nominal

ϕ_r, ϕ_c , ϕ_e , ϕ_l = coeficientes de reducción por variabilidad de la resistencia real, variabilidad de las cargas, y por la excentricidad y la esbeltez, respectivamente.

A continuación se hace una evaluación de estos coeficientes, principalmente por similitud con los valores correspondientes en estructuras de concreto.

1. Variabilidad de la Resistencia Real (ϕ_r)

El coeficiente ϕ_r depende principalmente de la diferencia entre el tamaño del especimen y el prototipo (ϕ_{rt}), y de la variabilidad de la resistencia de material (ϕ_{rn}).

$$\phi_r = \phi_{rt} \; \phi_{rn}$$

El factor ϕ_{rt} para el caso de columnas estribadas y muros de concreto se considera igual a 0.7; en muros de adobe la relación de tamaño entre el prototipo y el modelo o probeta de ensayo es prácticamente la misma, por lo tanto se adoptará - ϕ_{rt} = 0.7

El factor ϕ_{rn} para el caso de columnas de concreto se considera igual a 0.85; en muros de adobe la variabilidad de la resistencia del material es menor que en el caso de concreto, por lo tanto se adoptará conservadoramente ϕ_{rn} = 0.9 en construcciones de dos pisos .

Finalmente, ϕ_r = 0.7 x 0.9 = 0.63

2. Variabilidad de las Cargas

En construcciones de viviendas económicas de adobe típicas, la relación entre la carga viva y la muerta generalmente es menor que 0.15. Para esta relación el factor de mayoración ponderando para obtener la carga de rotura es :

$$\frac{1.4\ CM + 1.7\ (0.15\ CM)}{CM + 0.15\ CM} = 1.41$$

El coeficiente ϕ_c será 0.70

3. Excentricidad de la Resultante

En base al estudio realizado de excentricidades reales en una vivienda típica de adobe de dos pisos, ver anexo 1, se asumirá que la resultante de las cargas en el muro actúe en el vértice del núcleo central. Para esta condición el esfuerzo máximo es igual al doble del esfuerzo nominal, de lo que resulta.

$$\phi_e = 0.5$$

4. Esbeltez

Para un elemento en compresión elástica la carga crítica, es $P_{cr} = \pi^2\ E\ I/(kl)^2$

donde :

kl = longitud de columna biarticulada equivalente

E = módulo de elasticidad, que puede expresarse como :

E = α f'm (f'm = esfuerzo de compresión en rotura)

I = momento de inercia por metro lineal de muro

t = espesor del muro

$$I = \frac{t^3}{12}$$ (depreciando la influencia del módulo de Poisson)

El esfuerzo crítico, $f_{cr} = \frac{P_{cr}}{t \times 1} = 0.822\ f'm\ \alpha/(kl_t)^2$ (I)

Considerando una transición gradual de esta expresión, hasta el valor límite ϕ f'm; que puede lograrse pasando una parábola de eje vertical con vértice en $(\frac{kl}{t})^2 = 0$, y fm = ϕ f'm, y que además pasa por el punto $f_m = 0.5\ \phi\ f'_m$ Para este valor obtenemos $\frac{kl}{t} = 1.282\sqrt{a}$

Pasando la parábola por éstos dos puntos obtenemos finalmente :

Para $kl/t > 1.282\sqrt{\alpha}$: $\dfrac{fm}{\phi f'_m} = \left(\dfrac{0.908}{kl/t}\right)^2 \alpha$ (De Ec.1, haciendo $fm=f_{cr}$)

Para $kl/t < 1.282\sqrt{\alpha}$: $\dfrac{fm}{\phi f'_m} = 1 - \left(\dfrac{0.551\ kl}{\sqrt{\alpha}\ t}\right)^2$ (Ec. Parábola)

Estas ecuaciones expresadas gráficamente pueden verse en la figura 1.

5. Valores Recomendables para k.

El coeficiente k del muro depende de las restricciones en sus extremos para cada nivel, que se expresa por : $\dfrac{\Sigma\ (EI/h)col.}{\Sigma\ (EI/L)vigas}$

Para la determinación de los valores de Ψ , se han supuesto una construcción típica de adobe de dos plantas con altura de piso 2.65 m., espesor de muros 0.40 m; para los techos se ha supuesto viguetas de madera de 2" y 8" espaciadas entre si 0.50 m. Así se encontró para el piso superior, de arriba hacia abajo Ψ =1.8, 3.6 y para el piso inferior, de arriba a abajo Ψ = 3.6, 1.0. Con estos valores y teniendo en cuenta que la construcción experimenta desplazamiento lateral se encontró : k = 1.75 para el segundo nivel, y k = 1.6 para el primer piso.

Para fines prácticos de diseño es recomendable considerar k = 1.5 para el primer nivel, y k = 1.75 para el segundo nivel.

6. Resumen

De lo anteriormente desarrollado, se asume que el esfuerzo permisible por compresión en muros de adobe, para viviendas económicas de dos pisos, está dado por :

$$f_m = \phi_r\ \phi_c\ \phi_e\ \phi_1\ f'_m = (0.63)\ (0.70)\ (0.5)\ \phi_1\ f'_m$$

$$f_m = 0.22\ \phi_1\ f'_m$$

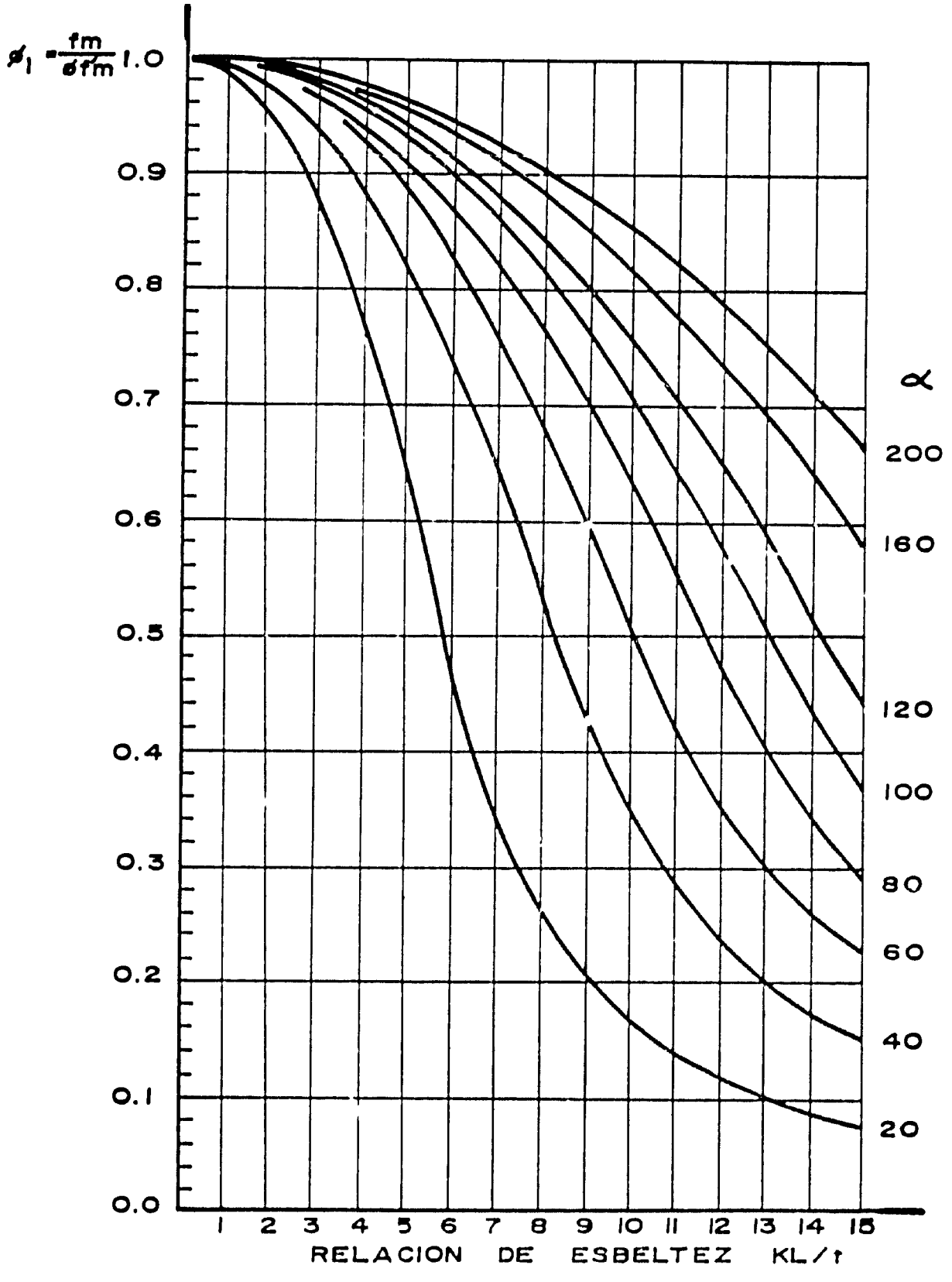

FIG. 1

CURVAS PARA LA DETERMINACION DE ESFUERZOS ADMISIBLES EN MUROS PORTANTES

MUROS CON CARGAS HORIZONTALES EN SU PLANO . - ESTUDIO DEL ESFUERZO CORTANTE

Cuando se considera fuerzas sísmicas en la dirección del muro, el esfuerzo más importante es el de corte paralelo a las hiladas. En la determinación de la fuerza de corte que toman los muros consideramos dos casos extremos :

1. Caso de Techo Rígido

Al considerar techo rígido, la fuerza sísmica se reparte entre los muros de acuerdo a sus rigideces laterales.

Las rigideces se calculan con la teoría elástica para muros, ignorando la rotación de la base. Se advierte sin embargo, quela rotación de la base tiene una influencia importante, si se trata de suelos compresibles.

Para el cálculo de la fuerza sísmica y su punto de aplicación se considera que la fuerza es proporcional a la masa y que el techo es infinitamente rígido.

1.1 Rigideces de los Muros

La rígidez de cada elemento de un muro específico se determinará con las expresiones (1) :

$$\left.\begin{array}{lll} k_i = \dfrac{k_{si}}{\frac{4}{3}\,(h_i/l_i)2 + 1} & \text{(Fórmula General} & \text{(a)} \\ k_i = k_{sl} = \dfrac{1}{3}\,E\,\dfrac{tli}{h_i}\,; \text{ para } & (l_i > 4\,h_i\,) & \text{(b)} \\ k_i = 0.25\,(l_i/h_i)^3\,Et\,; \text{ para } & (l_i < \dfrac{hi}{3}\,) & \text{(c)} \end{array}\right\} \quad (1)$$

En la deducción de las ecuaciones (1) se ha considerado un factor de forma de 1.2 y un módulo de elasticidad por corte (G) igual a 0.4E. Para el cálculo de las rigideces se ha considerado una deformada de voladizo.

Las expresiones (1b) y (1c) representan las rigideces por corte y flexión - respectivamente. Los intervalos indicados han sido obtenidos considerando una diferencia del "valor real" por defecto menor de diez por ciento. Pa

ra fines prácticos esta simplificación se considera suficiente.

2. Rigidez Equivalente para Muros en Paralelo

$$k_e = \sum_{i=1}^{n} k_i$$

3. Rigidez Equivalente para Muros en Serie

$$k_e = \frac{1}{\sum_{i=1}^{n} (1/k_i)}$$

4. Caso de Techo Flexible

La fuerza cortante que toma cada muro depende únicamente de la masa situada - dentro de su área de influencia.

MUROS DE CARGAS PERPENDICULARES A SU PLANO

Un muro sometido a cargas sísmicas perpendiculares a su plano se comporta como una losa.

En el diseño para este tipo de solicitaciones es recomendable seguir el procedimiento desarrollado en la Universidad Nacional de Ingeniería, referencia (3)

ESTUDIO DE VIVIENDAS DE ADOBE DE 2 PISOS PARA DIVERSAS CONDICIONES DE SISMICIDAD Y DE TIPO DE SUELO

1. Coeficientes Sísmicos

Usando los resultados del apéndice 2 en la determinación de las fuerzas sísmicas, se ha obtenido los coeficientes sísmicos para las 3 tres zonas sísmicas y los tres tipos de suelo que especifica el reglamento peruano de diseño sismo-resistente, los cuales se muestran en la tabla 1.

TABLA 1

VALORES DE COEFICIENTES SISMICOS

Zona sísmica / Tipo de Suelo	1	2	3
Tipo 1	0.267	0.187	0.080
Tipo 2	0.320	0.224	0.096
Tipo 3	0.374	0.262	0.112

2. Esfuerzos Admisibles de corte usados en el Estudio

En este estudio se han considerado tres tipos de construcción : Adobe común con mortero de barro, bloque estabilizado con mortero de cemento-arena en la proporción de 1 a 8, y bloque estabilizado con mortero de suelo-asfalto. Con los valores de la adherencia, μ , y del coeficiente de fricción, f, indicados se han calculado los valores del esfuerzo admisible de corte (V_{ad}) en la cabeza y pie de los muros del primer y segundo nivel. Los valores se encuentran en la tabla 2 y obtenidos con la siguiente expresión $V_{ad} = 0.45 \ (\mu + f\sigma)$

TABLA 2

ESFUERZOS ADMISIBLES DE CORTE USADOS EN EL ESTUDIO

Material	Mortero	μ	f	V_{ad} (2°nivel) kg/cm2)	V_{ad} (1°Nivel kg/cm2)
Adobe común	Barro *	0.15	1.09	0.13 (0.29)	0.31 (0.52) ***
Bloque estabilizado.	cemento** arena 1:8	0.36	1.07	0.21 (0.38)	0.40 (0.60)
	Suelo-asfalto*	0.25	0.90	0.16 (0.29)	0.32 (0.49)

* Dato obtenido de la referencia (4)

** Dato obtenido de la referencia (2)

*** Los valores entre paréntesis corresponden al pie del muro.

3. Esfuerzos cortantes actuantes (V_a)

Para el modelo considerado en el apéndice 2 se han obtenido los valores de los esfuerzos de corte actuantes que se muestran en la tabla 3

TABLA 3

VALORES DE ESFUERZOS CORTANTES ACTUANTES

(V_a) en kg/cm2, en Primer y Segundo nivel

zona sísmica / Tipo de suelo	1	2	3
Tipo 1	0.39 (0.20)*	0.27 (0.14)*	0.12 (0.06)*
Tipo 2	0.47 (0.24)	0.33 (0.17)	0.14 (0.070)
Tipo 3	0.55 (0.28)	0.38 (0.19)	0.16 (0.080)

* Los valores entre paréntesis corresponden al 2°nivel.

4. Discusión de los Resultados

La discusión final de los resultados se resume en las tablas 4,5 y 6. Para el estudio se ha considerado una variabilidad de los esfuerzos actuantes de 20% para estructuras ubicadas en suelos tipo 1 y 2 y de 50% para las ubicadas en suelo tipo 3.

TABLA 4

ADOBE COMUN

zona sísmica / Tipo de Suelo	1	2	3
Tipo 1	SI	SI	SI
Tipo 2	NO	Si	SI
Tipo 3	NO	NO	Si

TABLA 5

BLOQUE ESTABILIZADO CON MORTERO DE CEMENTO ARENA (1: 8)

Zona sísmica / Tipo de Suelo	ZONA 1	ZONA 2	ZONA 3
Tipo 1	Si	SI	SI
Tipo 2	NO	Si	SI
Tipo 3	NO	SI	SI

TABLA 6

BLOQUE ESTABILIZADO CON MORTERO SUELO-ASFALTO

Zona sísmica / Tipo de suelo	ZONA 1	ZONA 2	ZONA 3
Tipo 1	SI	SI	SI
Tipo 2	NO	SI	SI
Tipo 3	NO	NO	SI

ANEXO 1

ESTUDIO DE EXCENTRICIDADES REALES EN VIVIENDAS DE ADOBE DE DOS PISOS

Se considerará viguetas de madera de 2" x 8" espaciadas a 50 cm.

CARACTERISTICAS MECANICAS

(POR METRO DE CONSTRUCCION)

Muros : $f'_m = 15\ kg/cm^2$; $E_m = 20000\ kg/cm^2$

$I_m = 533,300\ cm^4$; $E_m\ I_m/h_m = 4.03 \times 10^6$ kgxcm.

Techo : $E_t = 150,000\ kg/cm^2$ (MADERA)

$I = 6030\ cm^4$; $EI/l = 2.3 \times 10^6$ kgxcm.

CARGAS

	Techo 1a. Planta	Techo 2a. Planta
Peso propio	30	30
Acabados	70	120 (Teja)
Sobrecargas	200	100
	300 kg/m²	250 kg/m²

MUROS

2°piso $P = 250x2.20=550$ kg (Extremo superior)

1°piso $P = 300x2.20+2.65x0.4x1600+550 = 2906$ kg.

(Extremo superior)

VERIFICACION DE ESFUERZOS EN MUROS

Para el primer nivel se ha estimado un momento en los muros de 170 kg.-m

P $P = 2906$ kg.

$e = \frac{M}{P} = 0.06$ m.

$e/t = 0.146 < \frac{1}{6}$: Conforme

$\sigma = \frac{2906}{100x40}(1 \pm 6x0.146) = \begin{cases} 1.36 \\ 0.09 \end{cases}$ kg/cm²

Es probable que el muro no se agrieta

Si se considera conexiones rígidas en el segundo nivel, entre el muro y el techo, el momento en el muro sería de 235 kg-m ; pero como en la práctica las conexiones de apoyo no son rígidas, asumiremos un momento en el muro igual a la mitad del obtenido .

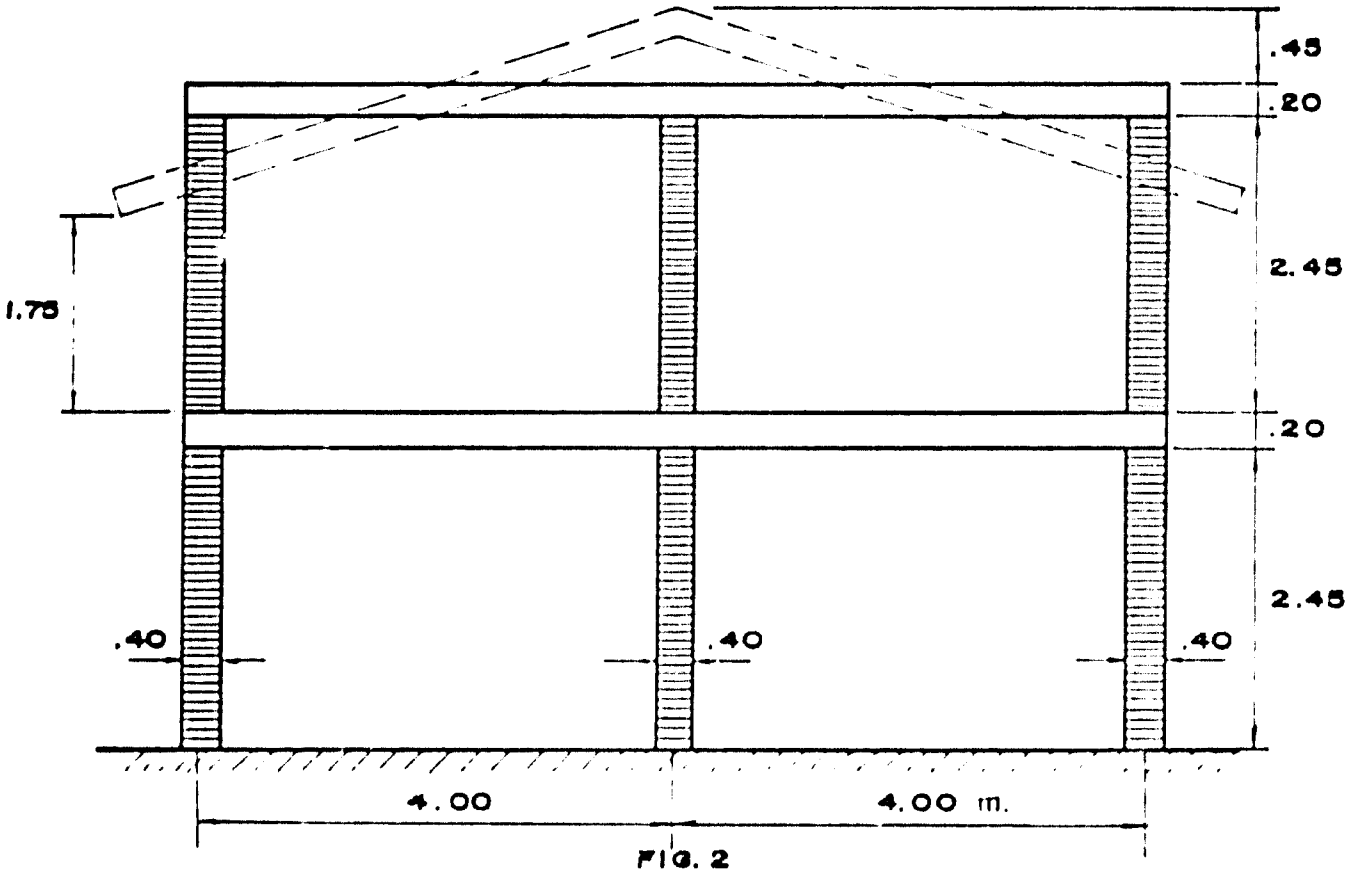

FIG. 2

ELEVACION TIPICA DE VIVIENDA ECONOMICA.

$$M = 235 \times 0.5 = 117 \text{ kg.-m}$$
$$P = 550 \text{ kg.}$$
$$e = 0.21 \text{ m.}$$
$$e/t = 0.53 > \frac{1}{6}$$
$$\sigma = \frac{550}{100 \times 40} (1 \pm 6 \times 0.53) = \begin{Bmatrix} 0.57 \\ -0.30 \end{Bmatrix} \text{ kg/cm}^2$$

Es probable que el muro se agriete.

Es necesario que el muro tenga en su cara externa un elemento que pueda absorber las tracciones (refuerzo de caña, adobe con paja, refuerzo metálico u otros)

CRITERIO DE DIMENSIONAMIENTO PARA EL ESPESOR DEL MURO

Generalizando para un muro de espesor, t, y luz de techo, l, se tiene :

$$P = 2.50 \left(\frac{l}{2} \times 1.1\right) + 300 \left(\frac{l}{2} \times 1.1\right) + 2.65\, t \times 1600$$
$$P = 302.5\, l + 4240\, t$$
$$M = 0.43 \frac{w l^2}{12} = 0.43 \times 300 \frac{l^2}{12}$$
$$M = 10.73\, l^2$$

Para :

$$\frac{e}{t} = \frac{1}{6} ; \qquad \frac{10.73\, l^2}{(302.5\, l + 42.40 t)\, t} = \frac{1}{6}$$
$$t^2 - 0.0713\, lt - 0.0152\, l^2 = 0$$
$$t = 0.092\, l$$

Para fines prácticos se asumirá, $t = 0.1\, (l)$

Además, es recomendable tomar para el espesor del muro $t > \frac{h}{6}$, donde h es la altura de piso.

ANEXO 2

ESTUDIO DE PERIODOS DE VIBRACION DE VIVIENDAS ECONOMICAS DE ADOBE DE DOS PISOS. DETERMINACION DE LAS FUERZAS SISMICAS

En este estudio se ha considerado un modelo constituído por un ambiente de planta cuadrada de 4m. x 4 m.; dos pisos de 2.65 m. de altura; muros de 0.45 de espesor, y techos de madera.

Se ha tomado dos modelos dinámicos extremos, el primero con masas concentradas en los niveles de techo, y el segundo con masas uniformemente distribuída a lo alto de la edificación.

MODELO DE MASAS CONCENTRADAS

$$k_s = \left(\frac{1}{3} \quad \frac{E + t1}{h}\right) 2 \quad \left(\frac{1}{3}\right) \qquad \frac{(2\ \text{Ton/cm}^2)\ (45\ \text{cm.})\ (400\ \text{cm.})2}{265\ \text{cm.}}$$

$$k_s = 90.6\ \text{Ton./cm}$$

$$k = \frac{k_s}{\frac{4}{3}\ (h/1)^2 + 1} = 57.2\ \text{Ton./cm.}$$

$$W_1 = 35.3\ \text{Ton.}$$

$$W_2 = 17.7\ \text{Ton}$$

Resolviendo la ecuación de frecuencia :

$$\left|\underset{\sim}{k} - w^2\ \underset{\sim}{m}\right| = 0, \text{ se tiene :}$$

$W_1 = 24.55$ rad/seg. $\qquad T_1 = 0.26$ seg. < 0.30 seg.

$W_2 = 64.35$ rad/seg. $\qquad T_2 = 0.10$ seg.

MODELO DE MASAS UNIFORMEMENTE DISTRIBUIDA

$m = \frac{qh}{g}$ = Masa total

q = Peso por unidad de altura

α = Factor de forma = 1.2

G = 0.4E

Considerando deformación por corte y flexión se tiene

$$\delta_T = \delta_s + \delta_b = \frac{\alpha q h^2}{2AG} + \frac{1}{8}\frac{q h^4}{EI}$$

Asumiendo la primera forma de modo correspondiente a la deformación estática , se tiene :

$$k_s = \frac{qh}{\delta_s} = \frac{2AG}{\alpha h} = \frac{E\,t\,1}{1.5\;h}$$

$$k_b = \frac{qh}{\delta_b} = \frac{8EI}{h^3}$$

Reemplazando valores, se obtiene :

k_s = 90.6 Ton/cm ; k_b = 51.6 Ton/cm,

de estos valores, resulta k = 32.9 Ton/cm

La frecuencia circular w_1 , será :

$$w_1 = \sqrt{\frac{k}{m}} = \sqrt{\frac{32.9 \times 980}{35.4}} = 30.2 \text{ rad./seg.}$$

y el período fundamental será de T_1 = 0.21 seg. < 0.3 seg.

Puede observarse que para viviendas típicas de dos pisos, en ambos modelos el período fundamental es del mismo orden de magnitud y menor de 0.3 seg.

En consecuencia para viviendas típicas de adobe de dos pisos, se justifica usar un coeficiente sísmico elástico, C, de 0.4 que corresponde a estructuras cuyos períodos de vibración son menores o iguales a 0.3 segundos.

DETERMINACION DE LAS FUERZAS SISMICAS

Considerando para el modelo presentado ;

Z = 1.0 ; U = 1.0 ; S = 1.0 ; C = 0.4 ; R_D = 1.5, y aplicando el Reglamento Peruano de Diseño Sismo-Resistente :

$$H = 0.267\,P = 0.267\,(52.99)$$
$$= 14.15 \text{ Ton.}$$
$$F_2 = 7.07 \text{ Ton.}$$
$$F_1 = 7.08 \text{ Ton.}$$

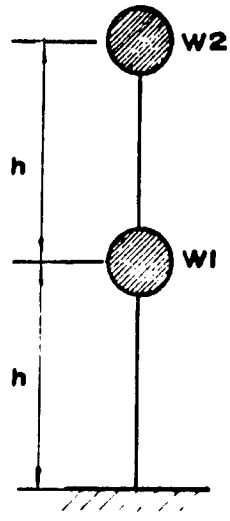

FIG. 3
MODELO DE MASAS CONCENTRADAS

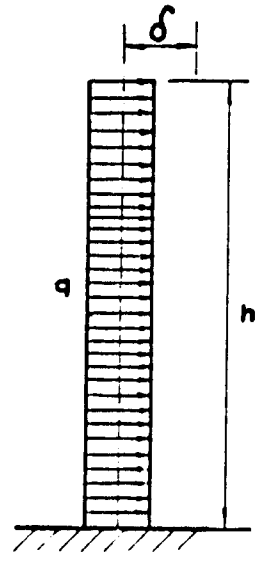

FIG. 4
MODELO DE MASA UNIFORME

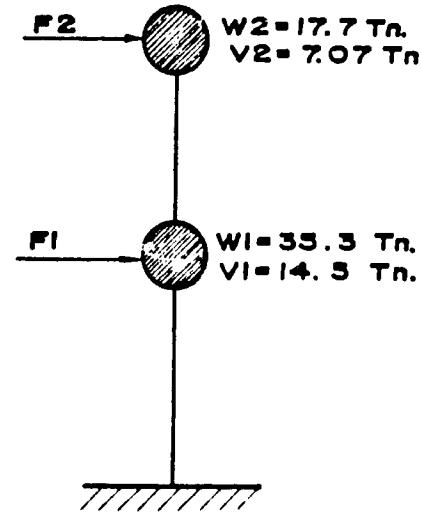

FIG. 5
FUERZAS SISMICAS

RECOMENDACIONES

1. Realizar investigaciones en muros a escala natural para determinar en forma más precisa los esfuerzos admisibles de compresión promedio y sus desviaciones. Estas investigaciones tendrán además, por finalidad encontrar :

   - El factor ϕ_r de variabilidad de resistencia del prototipo al modelo (especimen). Estas experiencias se realizan en muros a escala natural, tratando de simular las condiciones reales de apoyo, confinamiento, cargas, etc.
   - El factor ϕ_e de variabilidad por excentricidad del prototipo al modelo. Estas experiencias tendrán por finalidad encontrar este factor representativo del grado de restricción de los techos en sus bordes y la influencia de la excentricidad de las cargas en el agrietamiento.
   - El factor ϕ_l de variabilidad por esbeltez. Se deberán programar una serie de experiencias con la finalidad de determinar este factor.

2. Efectuar experiencias con la finalidad de determinar en forma más precisa los esfuerzos cortantes admisibles promedio y sus desviaciones en los muros de viviendas de adobe de dos pisos.

3. Realizar construcciones típicas de adobe de dos pisos, en diferentes regiones sísmicas del país y ubicadas sobre diferentes tipos de suelo. Estas experiencias tendrán, por finalidad fundamental conocer más la influencia de estos factores en la respuesto sísmica de estas construcciones.

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"INVESTIGACIONES EN ADOBE"

Por: Ing. Julio Vargas N. (*)
Ing. Gianfranco Ottazzi P. (**)

RESUMEN

El trabajo consta de dos partes. En la primera se presenta recomendaciones para construcciones de adobe en base a ensayos a escala natural.

En la segunda se presenta los resultados y conclusiones de ensayos de pilas a compresión axial y muretes a compresión diagonal y a corte.

"RESEARCH ON ADOBE"

ABSTRACT

The work is divided in two parts. The first presents the recommendations for the adobe constructions based on natural scale tests.

The second part presents the results and conclusions of tests of short columns with axial compression and of walls with diagonal compression and with shear.

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"Investigaciones en Adobe"

INDICE

Parte I

Programa de elementos a escala natural para viviendas rurales.

1. Introducción
2. Definición del Programa
3. Observaciones sobre los ensayos
4. Conclusiones

Parte II

Programa de elementos de mampostería.

1. Ensayos de compresión axial
2. Ensayos de compresión diagonal
3. Ensayos de corte directo

INTRODUCCION

La primera etapa de este programa experimental, consistió en el ensayo de 8 módulos de vivienda de 4 x 4 m (h = 2.40 m) sobre mesa rebatible, 16 muros verticales a corte de 2.40 x largo variable (generalmente 4.0 m), 10 muros verticales a flexión (2.4 x 4.0 m), 3 muros horizontales a flexión, 5 muros verticales a volteo, 23 pilas a compresión de 8 adobes, 10 muretes a compresión diagonal y otros ensayos en bloques o unidades (compresión, tracción, flexión). Los resultados de estos ensayos han sido publicados en abril de 1978 bajo el título "Investigación sobre vivienda rural", como informe final al Ministerio de Vivienda y Construcción, quien financió parte de los ensayos. Paralelamente se publicó un resumen de dicho informe, bajo el título "Vivienda Rural en Adobe" (publicación DI-78-01).

En esta primera etapa se definieron algunas herramientas básicas para el diseño de viviendas de adobe (parámetros elásticos) así como se definieron algunas técnicas de análisis para muros verticales bajo cargas horizontales en su plano y perpendicular a él.

Sin embargo, se hacía evidente la necesidad de lograr un segundo paso, cual es la ductilización de las viviendas a través de un adecuado refuerzo con materiales rurales. Este es uno de los objetivos fundamentales de la segunda etapa. Adicionalmente, a través de los mismos ensayos, se ajustaría los resultados anteriores a la luz de una mayor información. Este es otro objetivo importante del programa.

Para obtener dicha ductilización, se limitó los refuerzos a materiales rurales. Se definió como "materiales rurales", a aquellos que dentro de la realidad peruana, se consiguen en el lugar o llegan hasta los lugares más remotos del campo, ellos son la madera, la caña, el alambre y los clavos (la limitación se reduce al material transportable a caballo o en burro, si es que no es del lugar).

2. Definición del Programa

El programa de ensayos consistió en 18 muros de 2.40 x 4.00 m ensayados a corte, 5 muros de las mismas dimensiones ensayados a flexión y 4 módulos de 2.40 x 4.0 x 4.0 m. con muros de .20 m. de espesor. Las técnicas utilizadas son las mismas que las de la primera etapa y han sido descritas con detalle en las publicaciones mencionadas.

De los muros ensayados a corte, 10 fueron confeccionados sin refuerzo, aunque con variaciones que permiten complementar la información de la primera etapa. Así, se ensayó dos muros en aparejo de soga (Ma y S2) adicionalmente a los cuales, se hicieron las siguientes variaciones:

- 1 muro en aparejo de cabeza (e = .40) (S1)
- 2 muros en aparejo entrecruzado (e = .40) (SAA1 y SAA2)
- 4 muros en aparejo de soga con sobrecargas de 165, 860, 975 y 1750 Kg/m (MS1, S4, S3 y S6).
- 1 muro en aparejo de soga ensayado con deformación lineal impuesta. (S5)

Todos estos ensayos fueron evaluados y sumados a la anterior información, para ajustar la expresión empírica que relaciona el esfuerzo cortante máximo que resiste un muro de esas dimensiones, en relación al esfuerzo unitario de compresión que actúe simultáneamente.

Seis de los restantes muros ensayados a corte, tuvieron refuerzo de caña. Dos de ellos con sólo refuerzo horizontal cada dos hiladas (RC1 y RC2), otro con caña horizontal cada cuatro hiladas más 4 líneas de refuerzo diagonal, amarrado al anterior en los encuentros (SC6), otro tenía refuerzo horizontal de caña cada 4 hiladas y adicionalmente refuerzo vertical de cañas enteras exteriores amarradas a las horizontales (a-111-I) y finalmente dos idénticos tenían una malla de re-

fuerzo de caña al interior del muro (horizontal y vertical) (MRE1 y MRE2).

En general se comprueba que estas disposiciones de refuerzo de caña, distribuyen en mayor área el esquema de fisuración, lo que implica una redistribución correlativa durante su proceso de formación, concediendo la posibilidad de aceptar mayores deformaciones con algo más de capacidad resistente. (Ductilidad).

Sin embargo, si se tiene en cuenta que en un ensayo de corte (carga lateral concentrada), se solicita cada sección horizontal a una misma fuerza cortante independientemente de su altura, la colocación de sólo refuerzo horizontal no influye demasiado en el control de las deformaciones posteriores a la fisuración. La colocación de refuerzo horizontal es conveniente para controlar el desplome de los muros transversales pero no mejora por si sola las características de ductilidad, al menos significativamente.

Por lo anterior, se planeó los ensayos con otras disposiciones de refuerzo adicional al horizontal.

Las capas de refuerzo diagonal dieron resultados aceptables, pero el procedimiento constructivo es demasiado complejo como para justificarlo. Por otro lado, el refuerzo vertical exterior, sólo trabaja a estados de deformación muy avanzados y entonces el control de la fisuración resulta tardío.

Así se llegó a la malla interior, que dió resultados satisfactorios pues aunque complica en algo el procedimiento constructivo, lo compensa con creces al brindar buena ductilidad al conjunto.

Finalmente, se ensayó dos muros con vanos centrales de 1 m^2 con refuerzo de madera en la parte superior del alféizar y en la parte superior del mismo (RM1 y RM2). Se pretendía controlar de alguna manera las fisuras que se inician en las esquinas del vano.

Los ensayos de flexión tuvieron como misión ayudar a comprender cualitativamente el comportamiento de los muros reforzados, sometidos a cargas perpendiculares a su plano.

Los dos primeros tenían dos soleras de madera a la altura del alféizar y en el tope superior (RM3 y RM5). Se pretendía observar la adherencia entre madera y adobe bajo diferentes niveles de compresión de confinamiento, cuando actúan cargas que flexionan al muro.

Los tres restantes correspondían a tres de los tipos de refuerzo de caña que se utilizaron en los ensayos de corte:

- Caña horizontal cada dos hiladas (a.111.III)
- Caña horizontal cada cuatro hiladas más refuerzo vertical (a.111.II)
- Caña horizontal cada cuatro hiladas más refuerzo diagonal (SF5)

Adicionalmente, se ensayó cuatro módulos con las siguientes características principales:

- Refuerzo de caña horizontal cada dos hiladas, con los encuentros cocidos. (módulo # 22).
- Refuerzo de caña horizontal cada seis hiladas, con cuartones verticales de madera a los extremos de los muros longitudinales. (módulo # 23).
- Refuerzo de caña horizontal cada tres hiladas, más cuatro líneas de refuerzo de caña diagonal. (módulo # 24).
- Refuerzo de caña horizontal cada cuatro hiladas y vertical embutido cada 25 cm., amarradas entre sí y rellenos de barro en los vacíos del aparejo utilizado. (módulo #24). Ver figura 2.

3. Observaciones sobre los ensayos

Ya mencionamos anteriormente que como conclusión de la primera etapa, se presentó una expresión para evaluar el esfuerzo unitario cortante de fisuración (τ), en función del esfuerzo unitario de compresión (σ) que actúe simultáneamente.

Así, la expresión original obtenida con alrededor de 25 ensayos.

$\tau = .09 + .55\sigma$ (Kg/cm^2) quedaría ajustada a

$\tau = .1 + .55\sigma$ (Kg/cm^2) expresión algo más simple

para su uso en diseño o comprobación.

Para efectos de comparación posterior con muros mejor reforzados, conviene anotar que el orden de magnitud de las deformaciones de fisuración, a la altura de la mitad del muro (parte superior del "muro efectivo") es de 3 mm, variando desde 1 mm. hasta 5 mm.

En la definición de la nueva expresión se han considerado también una serie de ensayos de muros reforzados, cuando existía la seguridad de que el refuerzo no variaría la carga de fisuración (por lo general, el refuerzo sólo trabaja posteriormente a la fisuración y su misión primordial es controlarla). De manera que es posible afirmar que está basada en más de 50 ensayos de muros a escala natural, la mayoría de los cuales mantuvo una relación de alto a largo de 0.6. No se encontró mayor influencia en el tamaño de los adobes, ni en el aparejo de colocación ni en el espesor del muro. Edades de secado de 1 a 3 meses tampoco son influyentes en este tipo de ensayo. En general la altura de la carga y los dispositivos de ensayo han sido invariables. Existe buena correlación entre los resultados de estos ensayos y los de los módulos, a pesar de la variación de solicitación que pasamos a explicar:

En el caso de la carga superior concentrada, el corte en cualquier sección es constante e igual a la carga. En el caso de mesa rebatible, la carga es constante (si la masa también lo es) y el corte en cualquier sección va en aumento conforme disminuye la distancia al suelo. Este último caso es más parecido al real pues suponiendo una forma lineal de vibrar, las fuerzas de inercia variarían linealmente (a masa constante) creciendo con la altura y el corte acumulado sería una ley parabólica. (Ver figura 1).

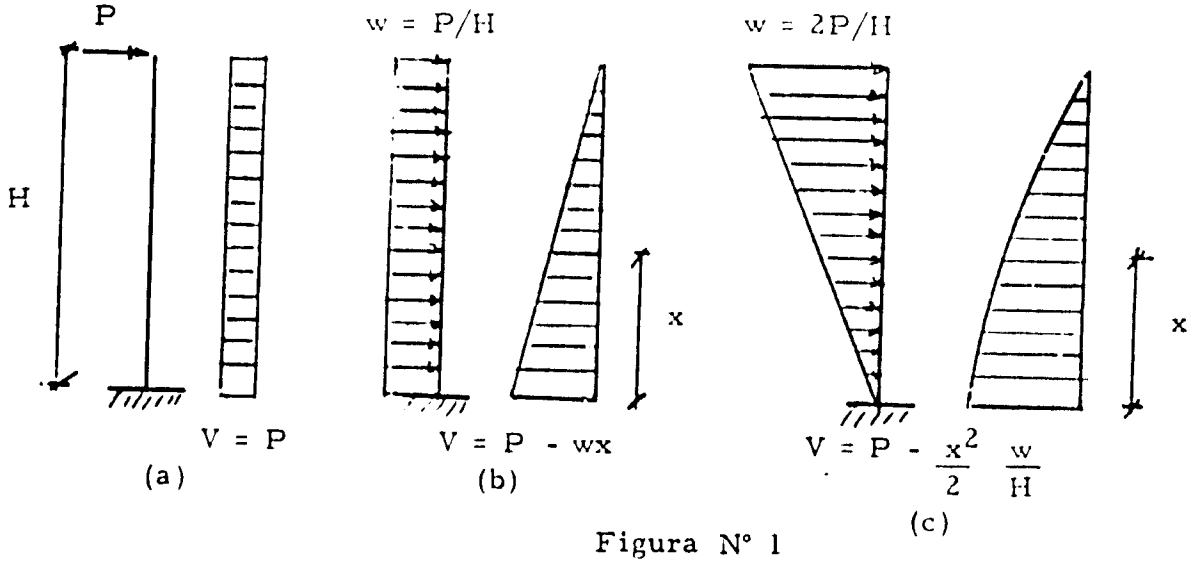


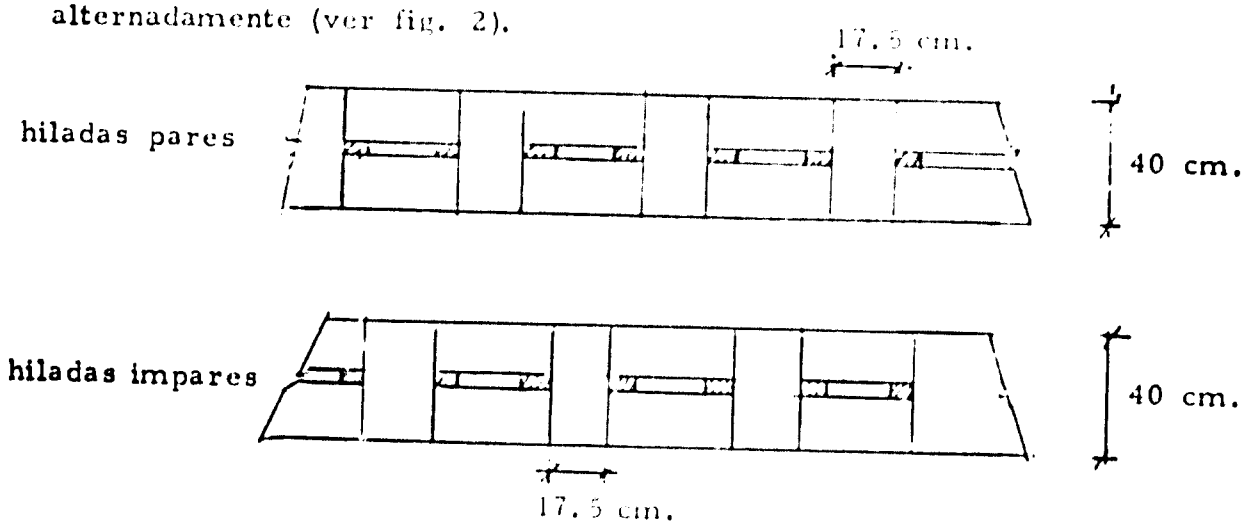
Figura N° 1

Respecto al tipo y material de refuerzo para conceder ductilidad a las construcciones de adobe, cabe mencionar lo siguiente:

- El refuerzo con piezas de madera no es muy económico, tanto por el costo de la misma, como por el del necesario amarre de alambre para lograr su participación como un elemento integrado al adobe. No habiéndose encontrado otra manera eficiente de integrarlo, debe limitarse su inclusión a los elementos indispensables, tales como dinteles y cadena superior.

- La utilización de la caña tipo carrizo como refuerzo, es muy conveniente siempre que se asegure el cocido en los encuentros, se proporcione la cantidad de refuerzo necesario según la intensidad

esperada de la solicitación y se disponga de manera de formar mallas cocidas que puedan controlar efectivamente las fisuras propias del esfuerzo cortante (caña horizontal y vertical en el interior del muro). Mientras que la caña horizontal puede ir en las juntas, las caña vertical hay que ubicarla en espacios libres dejados exprofesamente con un aparejo especial entrelazado en base a bloques en soga y cabeza alternadamente (ver fig. 2).



Los espacios achurados son rellenados con barro luego de colocar en ellos la caña vertical. Las dimensiones del bloque son 8 x 17.5 x 40 cms.

Fig. 2

- El alambre colocado para unir la cadena superior con el cimiento corrido y con cierta tensión, tiene un doble efecto favorable para el comportamiento de los muros: mejora la resistencia al corte al incrementar el esfuerzo unitario de compresión y concede ductilidad.

Debe prestarse especial cuidado al problema del control periódico de la tensión, ya que los alambres tienden a aflojarse y también al de la oxidación del alambre. Estos inconvenientes son serios para un ambiente rural.

La ductilidad que se consigne con estos refuerzos sólo ha sido comprobada bajo pruebas estáticas con cargas monotónicas y por tanto, debe considerarse que los resultados son preliminares, hasta no realizarse ensayos cíclicos y dinámicos.

Como demostración de la gran ductilidad alcanzada dentro de las limitaciones anteriores, en la fig. 3 se observa la comparación de deformaciones ocurridas en los muros S1 y MRE2 de dimensiones semejantes, pero el primero sin y el segundo con refuerzo de caña vertical interior y horizontal cada 4 hilacas.

4. Conclusiones

- Es posible dimensionar las construcciones rurales de adobe en base a los lineamientos mencionados, considerando un comportamiento elástico y apropiados coeficientes de seguridad (referencias 1, 2, 3 y 4).

- Adicionalmente, es indispensable concederles una apropiada ductilidad en base a refuerzo de materiales rurales, habiéndose obtenido hasta el momento buenos resultados con caña tipo carrizo, dispuesta como ha sido descrito.

- Es necesario continuar con investigaciones de elementos a escala natural sujetos a excitación dinámica, para poder evaluar cuantitativamente el factor de ductilidad y ajustar adecuadamente los coeficientes de seguridad para el diseño (Ref. 5 y 6).

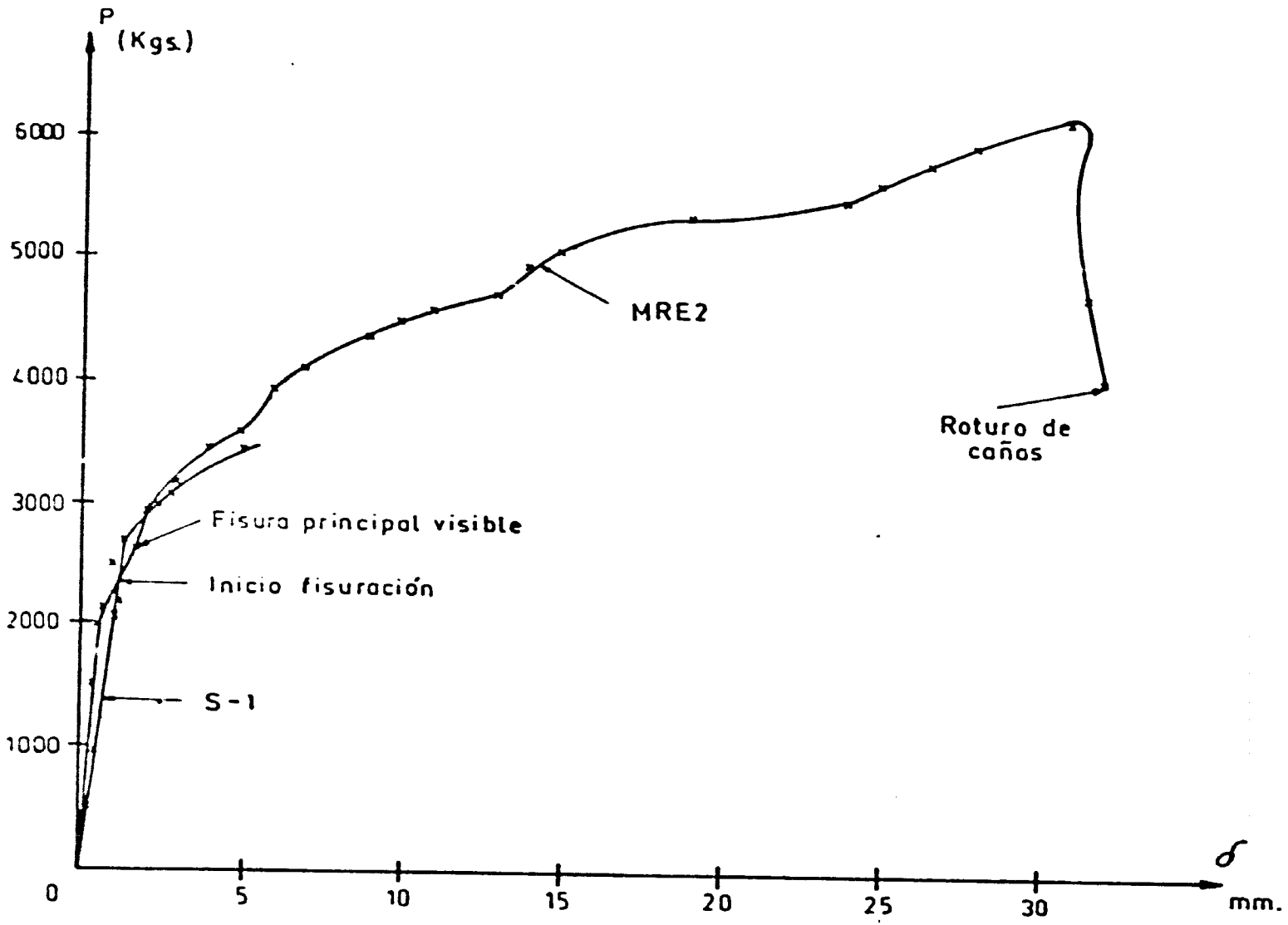


FIG - 3

CURVA CARGA - DEFORMACION LATERAL MUROS MRE2 Y S-1

TABLA I

I. ENSAYO DE MUROS A CORTE

Clave	Ensayo	Deformación	Dimensiones	Refuerzo	Observaciones	Fecha	Foto N°
SC6	Carga P_1 = 1590 Kg P = 3200 Kg	δ hasta 12 mm	.20 x 2.4 x 4.0	Caña diag. y horiz. cada 4 hiladas	Redistribución de esfuerzos hasta más allá de muro efectivo	10.78	
S1	Carga P = 3600 Kg	δ~5.13 mm	.40 x 2.4 x 4.0			08.77	1
S2	Carga P = 1900 Kg	δ~3.24 mm	.20 x 2.4 x 4.0			08.77	2
S3	Carga P = 3500 Kg	δ~3.9 mm	.20 x 2.4 x 4.0		s/c ~ 975 Kg/m. alambre	08.77	3
S4	Carga P = 3500 Kg	δ~2.3 mm	.20 x 2.4 x 4.0		s/c ~ 860 Kg/m. probetas	08.77	4
S5	Carga P = 4100 Kg	δ~13 mm	.20 x 2.4 x 4.0		Deformación uniforme	09.77	5
S6	Carga P = 6000 Kg	δ~5.6 mm	.20 x 2.4 x 4.0		s/c ~ 1750 Kg/m. alambre	09.77	6
MA	Carga P = 1900 Kg	δ~3 mm	.20 x 2.4 x 4.0			07.77	7
SAA1	Carga P = 3200 Kg	δ~5.5 mm	.40 x 2.4 x 4.0		Amarre americano	10.77	8
SAA2	Carga P = 3200 Kg	δ~1 mm	.40 x 2.4 x 4.0			10.77	9
RM1	Carga P = 1650 Kg	δ~4.5 mm	.20 x 2.4 x 4.0	Madera	Vano 1.0 m no interviene en la rotura	09.77	10
RM2	Carga P = 1200 Kg	δ~2.0 mm	.20 x 2.4 x 4.0	Madera	Vano 1.0 m carga arriba 1/2 ventana	09.77	11

Clave	Ensayo	Deformación	Dimensiones	Refuerzo	Observaciones	Fecha	Foto Nº
RC1		δ hasta 9.2 mm	.20 x 2.4 x 4.0	Caña horiz. c/ 2 hiladas	Redistribución de fisuras	11.77	12
RC2	Carga P = 2430 Kg	δ hasta 5 mm	.20 x 2.4 x 4.0	Caña horiz. c/ 2 hiladas	Redistribución de fisuras	11.77	13
a.111.I	Carga P = 1720 Kg	δ = 1.5 mm	.20 x 2.4 x 4.0	Caña entera vert. y horizontal c/ 4	No trabajó bien caña vertical	03.78	
MS1	Carga P = 3000 Kg	δ = 1.3 mm	.20 x 2.4 x 4.0		s/c = 165 Kg/m	07.77	14
MRE2	P_f = 2400 Kg P = 6180 Kg	δ hasta 30 mm	.40 x 2.4 x 4.0	Caña vert. interior y horiz. cada 4 hiladas	Gran ductilidad	04.79	

NOTA: P_f = Carga de fisuración

P = Carga última

TABLA 2

II. ENSAYO DE MUROS A FLEXION

Clave	Ensayo	Deformación	Dimensiones	Refuerzo	Observaciones	Fecha	Foto N°
RM3	carga 1370 Kg	----	.20 x 2.4 x 4.0	2 cadenas de madera	----	09.77	15
VF1	carga 705 Kg	----	.20 x 2.4 x 4.0	----	mortero yeso-barro 1:4	08.78	16
FM2	carga 865 Kg	----	.20 x 2.4 x 4.0	----	mortero cemento-arena 1:3	09.77	17
SF5	carga 865 Kg	----	.20 x 2.4 x 4.0	Caña c/4 hil. + diagonal	----		18
a.111.II	carga 960 Kg	----	.20 x 2.4 x 4.0	Caña c/4 hil. + vertical	----	04.78	19
a.111.III	carga 1360 Kg	----	.20 x 2.4 x 4.0	Caña c/2 hil.	----	07.78	
RM5	750 Kg	----	.20 x 2.4 x 4.0	2 cadenas a 1 y 2.10	----	10.77	20

TABLA 3

III. ENSAYO DE MODULOS

Clave	Ensayo	Deformación	Dimensiones	Refuerzo	Observaciones	Fecha	Foto N°
Módulo 22	∢ 28.5° Coef. ≃ .4	δ ~ 3.2 mm	.20 x 2.4 x 4 x 4	Caña c/ 2 hiladas cocidas	Resistencia = q' c/4 hiladas	03.78	21
Módulo 23	∢ 30° Coef. ≃ .5		.20 x 2.4 x 4 x 4	Caña c/ 6 hil. cadena sup. + postes de madera	Se separa el marco	04.78	22
Módulo 24	23° resbala hasta 20° 27° 30' 26° 30'		.20 x 2.4 x 4 x 4 Impacto pared frontal, paredes dorsales	Caña c/ 3 hil. cadena sup. caña diagonal	Fisuras prematuras en caña diagonal Accidente Impacto	10.78	23
Módulo 25	No se rompió hasta 37°		.40 x 2.4 x 4 x 4	Caña horiz. y vert. entre adobes amarre americ. cañas amarradas	Gran performance	03.79	24

∢ : Angulo de inclinación de la mesa rebatible en el instante de la falla.

Coef. : Coeficiente sísmico equivalente

Parte II

PROGRAMA DE ELEMENTOS DE MAMPOSTERIA

1. Ensayos de Compresión axial

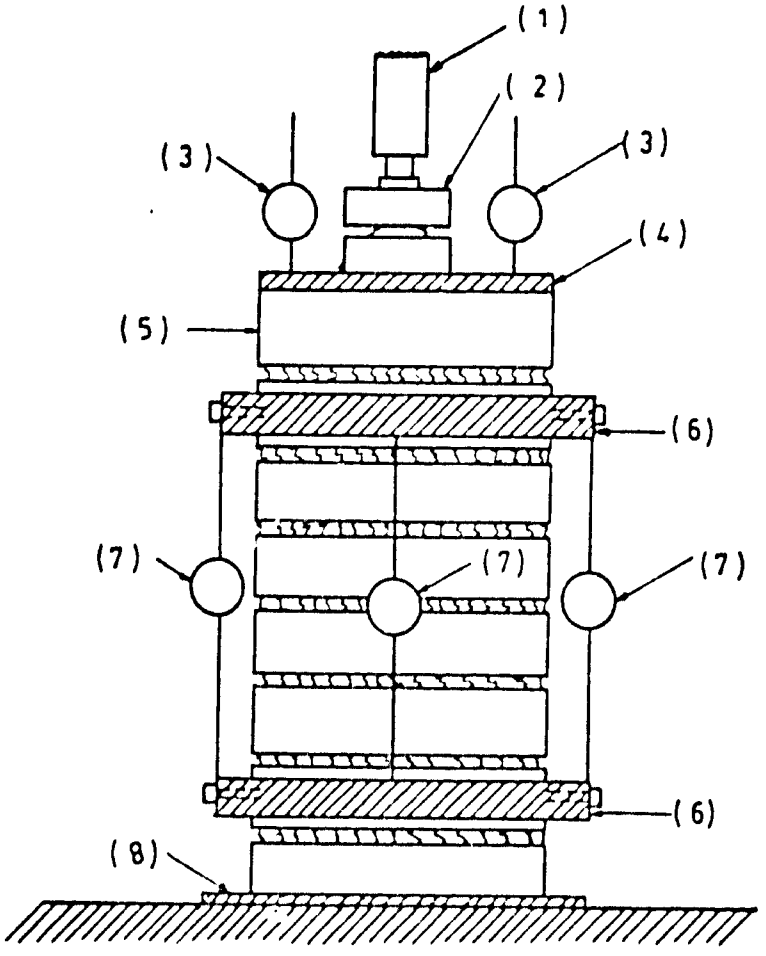
El objetivo de esta serie de ensayos es conocer el comportamiento de los muretes de adobe (pilas) bajo solicitaciones de compresión pura.

Se estudió la influencia de diversas variables en la resistencia a compresión de las pilas, las principales fueron:

- Esbeltez de las pilas (Relación entre la altura de la pila y la menor dimensión).
- Calidad del mortero. Se estudió la influencia de diversos tipos de mortero en la resistencia a compresión.
- Espesor de las juntas.
- Tiempo de secado.

En la figura 4 se muestra el esquema de los dispositivos empleados en este ensayo. Nótese que se colocaron 6 flexímetros para registrar las deformaciones del especímen durante el ensayo.

A continuación se presenta el resumen con los principales valores obtenidos en todos los ensayos de compresión axial.



1.) Gata hidráulica operada manualmente.

2.) Rótula.

3.) Fleximetros superiores.

4.) Plancha de acero para repartir la carga.

5.) Adobe nivelado con mortero de cemento.

6.) Marco de medición.

7.) Fleximetros laterales (4 en total).

8.) Base de madera para el transporte.

FIG - 4 ESQUEMA DE LOS ENSAYOS DE COMPRESION AXIAL

RESUMEN ENSAYOS DE COMPRESION AXIAL

Serie	Mortero	Esbeltez	Edad	(1) $\bar{P}$ Max	(2) $\bar{\sigma}$ Max	(3) S	(4) C.V.	(5) E_L	(6) E_s	N° de Especímenes
J	Barro	1:1 (2 adobes)	1 mes aprox.	9,413	11.77	0.69	6	----	210	8
I	Barro	1:1.5 (3 adobes)	1 mes aprox.	6,820	8.53	0.41	5	----	220	10
H	Barro	1:2 (4 adobes)	1 mes aprox.	6,297	7.87	0.87	11	595	320	10
G	Barro	1:3 (6 adobes)	1 mes aprox.	6,425	8.03	0.52	6	690	450	9
C	Barro	1:4 (8 adobes)	1 mes aprox.	6,398	8.00	0.57	7	1,000	755	12
K	Barro	1:5 (10adobes)	1 mes aprox.	6,180	7.73	0.36	5	1,300	680	10
BY	Barro 4 Yeso 1	1:4 (8 adobes)	1 mes aprox.	8,645	10.81	0.66	6	1,720	----	9
ACY	Arena 5 Cemt. 1 Yeso 1/2	1:4 (8 adobes)	2 meses	12,355	15.44	0.94	6	4,565	----	10
ACY	Arena 5 Cemt. 1/2 Yeso 1	1:4 (8 adobes)	8 meses	11,840	14.80	0.64	4	4,720 S=830 C.V.=18%	1,175	6
ACC	Arena 5 Cemt. 1/2 Cal 1	1:4 (8 adobes)	10meses	14,140	17.68	0.11	0.6	5,450 S=250 C.V.= 5%	----	6
CPJ	Barro	1:4 (8 adobes)	11meses	9,620	12.03	0.73	6	3,740 S=260 C.V.= 7%	----	7
CMB	Barro	1:4 (8 adobes)	7 meses 11meses	9,760	12.20	0.84	7	1,950 S=215 C.V.=11%	840	23

(1) Carga máxima promedio (Kg.)

(2) Esfuerzo último promedio calculado con el área bruta (20 x 40) (Kg/cm^2).

(3) Desviación Estándar calculada para los esfuerzos máximos.

(4) Coeficiente de variación en % calculado para los esfuerzos máximos.

(5) Módulo de elasticidad calculado para los flexímetros laterales (Kg/cm^2).

(6) Módulo de elasticidad calculado para los flexímetros superiores (Kg/cm^2).

OBSERVACIONES

La inclusión en el mortero de materiales tales como el cemento, la cal, o el yeso, mejoran notablemente la resistencia en compresión y el módulo de elasticidad (mayor rigidez) de las pilas.

La esbeltez de las pilas no fue una variable influyente tal como se pensaba inicialmente. La resistencia de las pilas se mantiene prácticamente constante en un rango bastante amplio de esbelteces (desde 1:1.5 hasta 1:5). Desde el punto de vista de una normalización de los ensayos, la esbeltez 1:4 (pilas de 8 adobes) es adecuada, ya que los especímenes son manejables (transporte) y es posible colocar flexímetros laterales. Además el número de juntas es adecuado para representar el comportamiento de los muros bajo este tipo de solicitación.

El tiempo de secado parece ser una variable importante, ya que en los ensayos efectuados se observa que la resistencia en compresión y el módulo de elasticidad aumentan con el tiempo. Sin embargo, no se cuent. con suficientes ensayos para establecer claramente la influencia de este parámetro.

El uso de juntas gruesas produce especímenes muy difíciles de manejar (transporte) y reduce la resistencia de las pilas.

Es conveniente calcular el módulo de elasticidad en base a los registros de los flexímetros laterales, ya que existen diferencias importantes con respecto a las lecturas de los flexímetros superiores. Estos registran todos los acomodos de la pila dando como resultado módulos de elasticidad más bajos.

El mecanismo de falla en estos especímenes bajo este tipo de solicitación es bastante complejo y difícil de precisar. Generalmente debido a las deficiencias de las pilas, al equipo de ensayo y a la heterogeneidad del adobe, se presentan fenómenos de flexo-compresión que complican el esquema de falla. En general se ha podido observar un esquema de fisuras verticales tanto en el adobe como en el mortero que preceden a la falla. Además como el material es frágil la falla es violenta y hay fenómenos de aplastamiento en el adobe y mortero. (Ver fotografía N° 25).

Para evaluar la resistencia en compresión de los bloques de adobe, se hicieron ensayos sobre 20 prismas (8 x 8 x 9 cm.) cortados de un adobe y nivelados con capping de yeso. El esfuerzo de compresión máximo promedio fue de 15 Kg/cm^2 con un coeficiente de variación del 14%.

2. Ensayos de Compresión Diagonal:

Las cargas laterales provenientes de la acción de un sismo sobre una estructura, inducen esfuerzos de tracción diagonal que pueden causar la falla del muro. Este tipo de falla se reconoce porque la grieta diagonal que se produce atraviesa el muro con una trayectoria aproximadamente recta. De allí la necesidad de estudiar el comportamiento de los muros de adobe bajo este tipo de solicitaciones. Un tipo de ensayo sencillo y fácil de ejecutar es el de compresión diagonal sobre un murete cuadrado (60 x 60 x 20 cm), al que se aplican las cargas en las esquinas a través de unos ángulos que distribuyen las concentraciones de esfuerzos en una zona pequeña. La deducción teórica de las fórmulas se encuentra en la Ref. (7) y (8).

En una primera etapa los muretes se construyeron horizontales con el objeto de ensayarlos in situ evitándose así el manipuleo (ver foto 26). Para minimizar la fricción entre la probeta y el suelo, se asentaron sobre bolsas vacias de cemento. Sobre el murete se fijaron bases de medición para un elongámetro que servían para obtener deformaciones en las diagonales.

Posteriormente y como parte de otro programa de investigaciones, se ejecutaron nuevos ensayos de este tipo con mejores dispositivos (ver foto 27), tanto para aplicación de carga como para medición de deformaciones.

A continuación se presentan los resultados de las dos series de ensayos:

Especímen	τ máximo (Kg/cm^2)	G (Kg/cm^2)
D-1	0.30	670
D-2	0.30	194
D-3A	0.33	250
D-3B	0.24	158
D-4	0.27	170
D-5	0.27	907
D-6	0.27	110
D-7	0.27	906
D-8	0.27	171
D-9	0.24	246
CDPM-1	0.32	500
CDPM-2	0.26	340
CDPM-3	0.27	403
CDPM-4	0.19	---
CDPM-5	0.17	518
CDPM-6	0.13	467
CDPM-7	0.25	358
Promedio	0.26 C.V. = 7.6%	398 C.V. = 61.4%

τ = $\dfrac{\text{Carga máxima}}{\text{Area de la diagonal}}$

$\tau = \gamma' G$

G = Módulo de Rigidez al esfuerzo cortante

$\gamma' = |\varepsilon_c| + |\varepsilon_t|$

ε_c = Deformación unitaria en la diagonal comprimida

ε_t = Deformación unitaria en la diagonal traccionada.

OBSERVACIONES

En general los resultados obtenidos para la primera serie de ensayos, en lo referente a deformaciones no son muy confiables, debido al sistema de mediciones que se utilizó. De allí la alta dispersión obtenida, sin embargo en la segunda serie donde se mejoró el sistema de mediciones, se puede observar que la dispersión es bastante menor.

Hay que anotar que la falla siempre fue por las juntas (escalonada), de allí el valor bajo que se obtiene para la resistencia, comparado con similares ensayos realizados en México (5).

3. Ensayos de Corte Directo:

Este tipo de ensayo está propuesto en el Reglamento Nacional de Construcciones (8.3), y sirve de base para establecer el esfuerzo admisible de los muros en corte sometidos a fuerzas sísmicas. La expresión propuesta es la siguiente:

$V_r = u + f\sigma$ = Resistencia al corte (Kg/cm^2)

σ = Compresión unitaria normal al plano de corte

u = Cohesión

f = Coeficiente de fricción aparente

Donde los parámetros u y f se determinarán a partir de ensayos de corte directo. A falta de información específica, se usará el siguiente esfuerzo admisible:

$$V = 0.45\ V_r = 0.054 + 0.03\sigma \quad (A)$$

A continuación resumimos los principales valores obtenidos de los ensayos de corte directo:

Serie	N° especímenes	σ (Kg/cm^2)	V_r (Promedio) (Kg/cm^2)	
EC	8	0.00	0.1305	C.V. = 15.9%
E-15	6	0.20	0.393	C.V. = 26.7%
E-25	4	0.40	0.550	
E-30	4	0.50	0.640	C.V. = 7.7%
E-40	5	0.70	0.926	C.V. = 6.2%
E-28	5	0.28	0.401	C.V. = 7.7%

OBSERVACIONES

Con los valores señalados se efectuó un ajuste por mínimos cuadrados (regresión lineal), dando como resultado la siguiente expresión:

$$V_r = 0.13 + 1.09\sigma \quad (Kg/cm^2) \quad (B)$$

$$V = 0.45\ V_r = 0.059 + 0.49\sigma \quad (C)$$

Ensayos similares hechos por otro investigador (9) sobre un total de doce especímenes dieron como resultado:

$$V_r = 0.15 + 1.09 \quad (Kg/cm^2) \qquad (D)$$

Comparando las expresiones (A) y (C) se observa que no existe ninguna concordancia en el valor de f, lo cual hace pensar que la expresión (A) tiene algún error (podría ser en el punto decimal).

Actualmente, se están procesando los resultados obtenidos de un total de 70 especímenes, ensayados en corte directo, con cargas de confinamiento que varían entre 0.2 y 2.0 Kg/cm^2 y con espesores de junta variables.

4. Referencias Bibliográficas

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(5) Refuerzo de Vivienda Rural en Zonas Sísmicas, O. Hernández y R. Meli 1978. UNAM, México.

(6) Seguridad ante sismos de casas de adobe. Estudios Analíticos. E. Bazán, M. Padilla y R. Meli 1978. UNAM, México.

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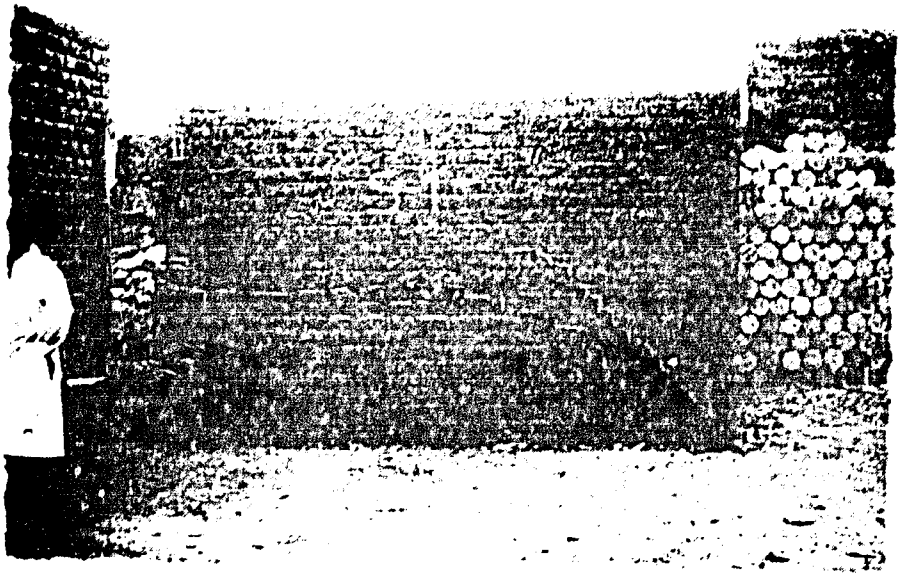
I. ENSAYO DE MUROS A CORTE



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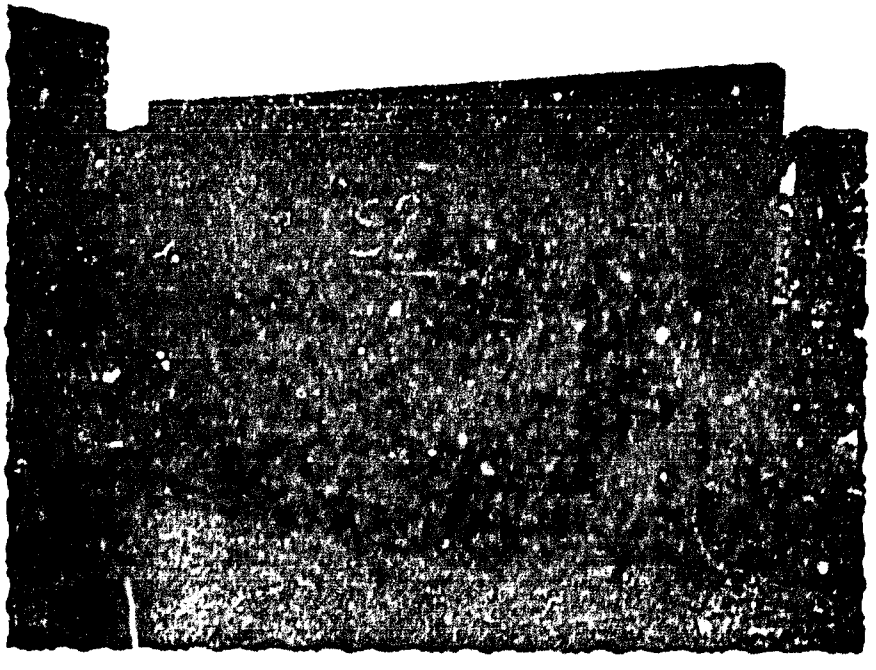

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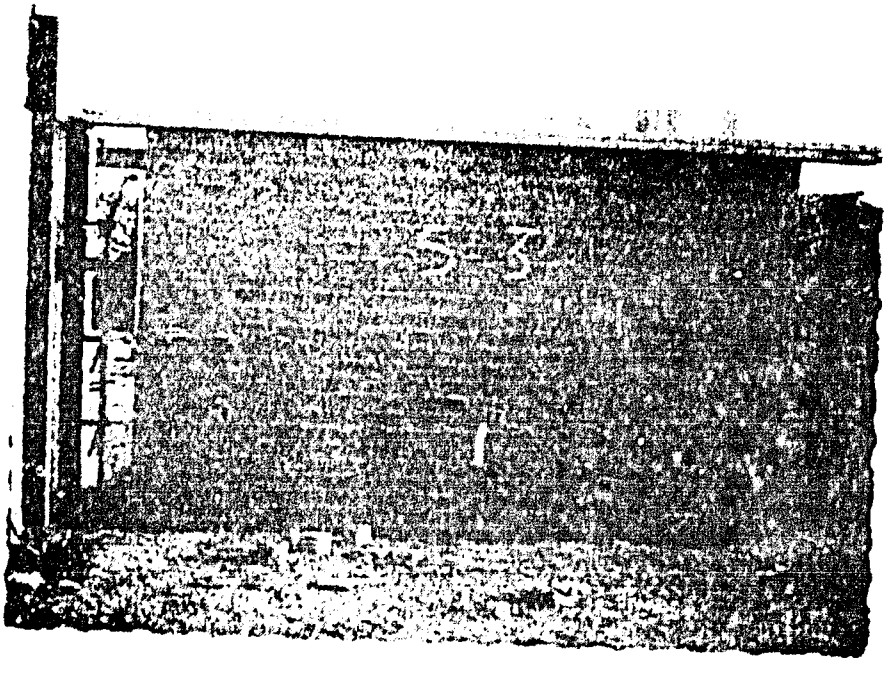

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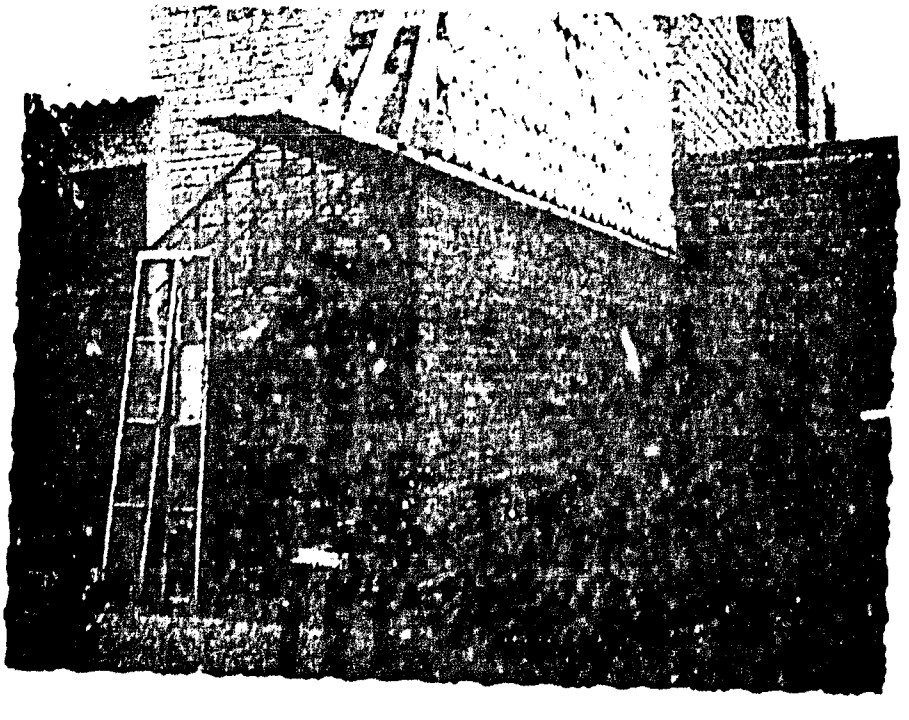

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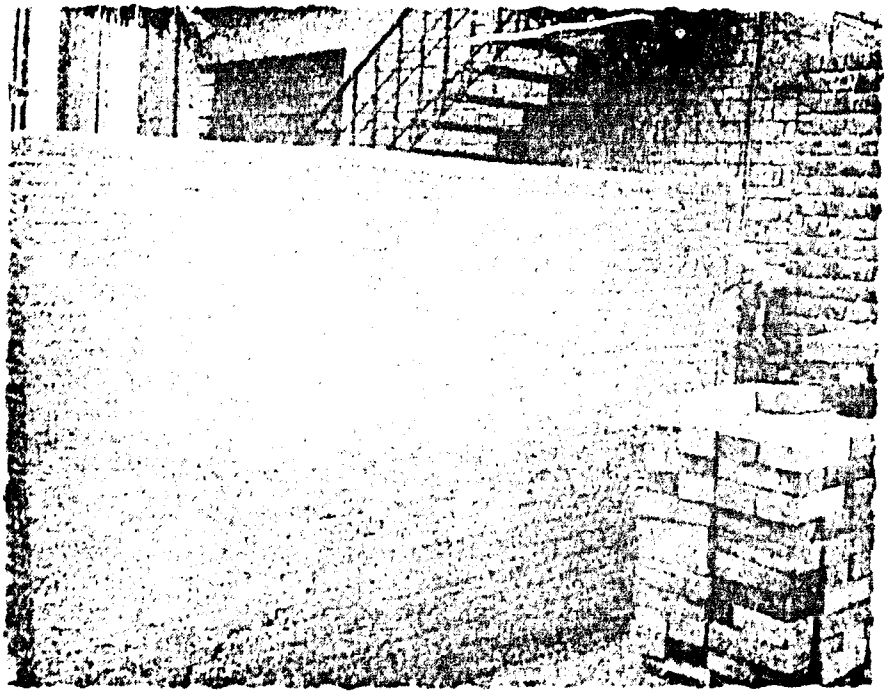

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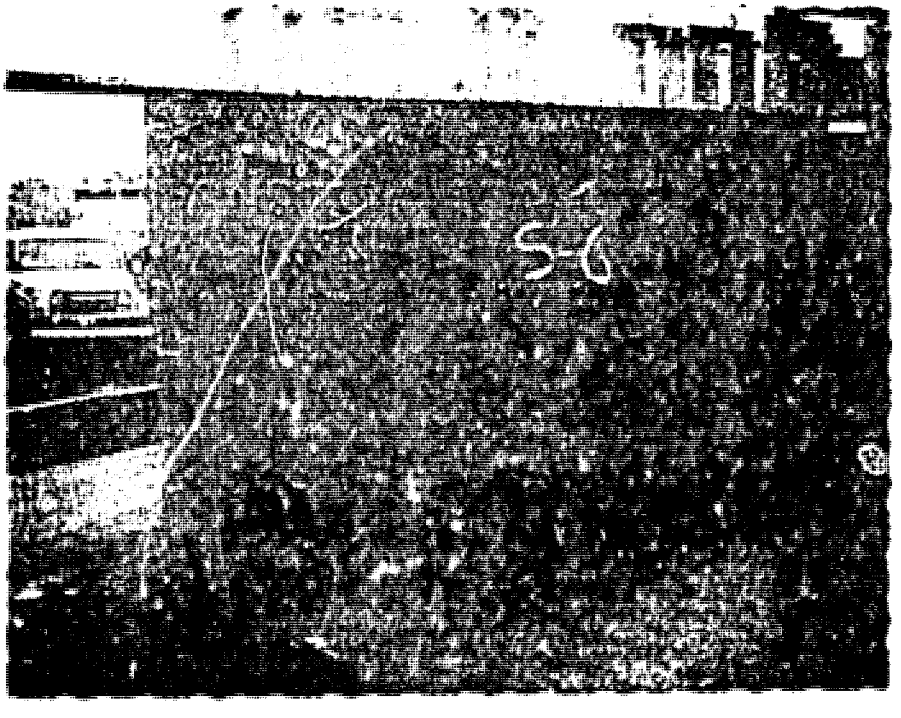

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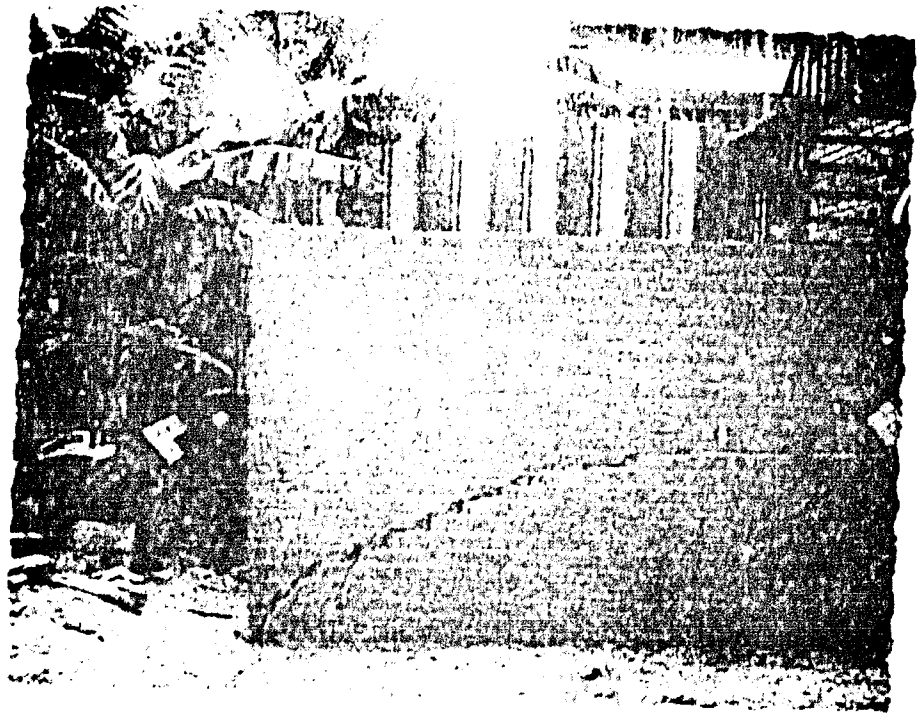

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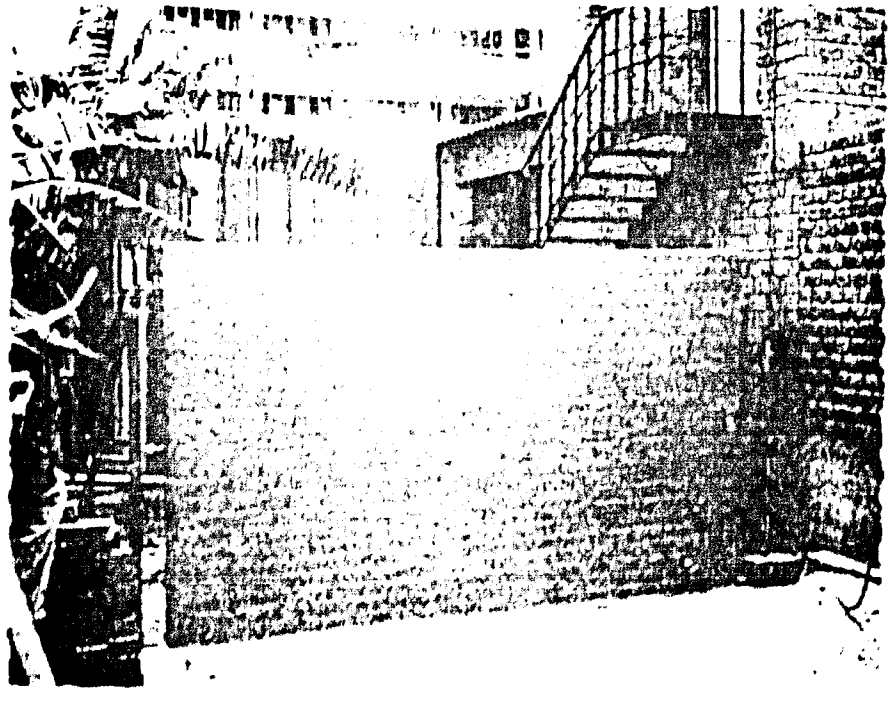

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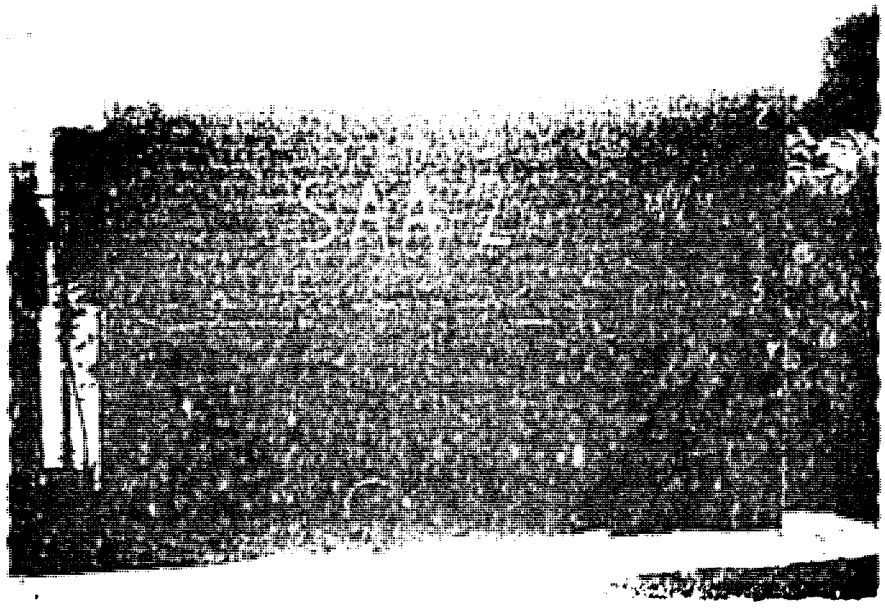

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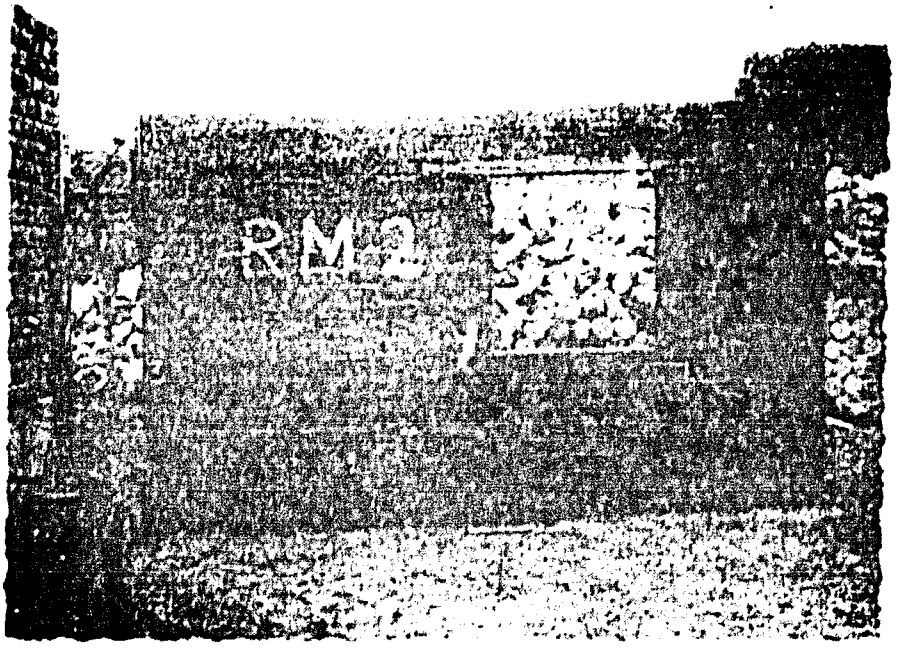

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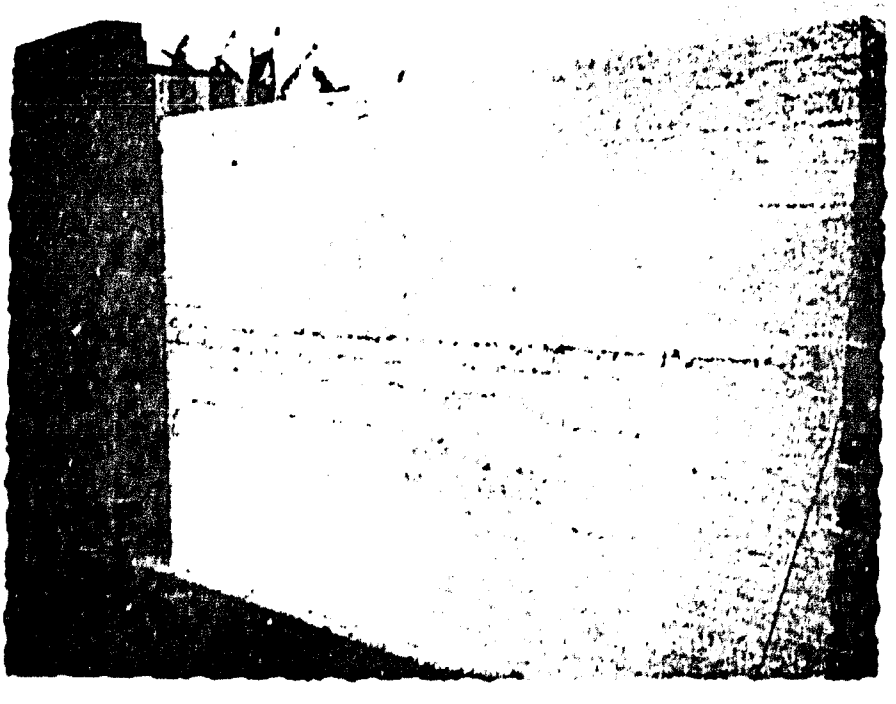

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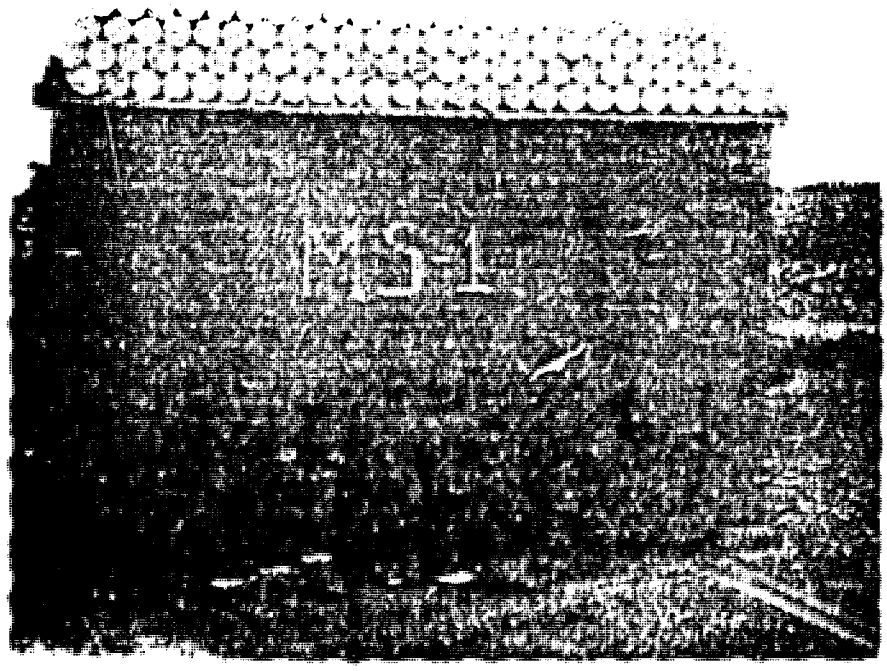

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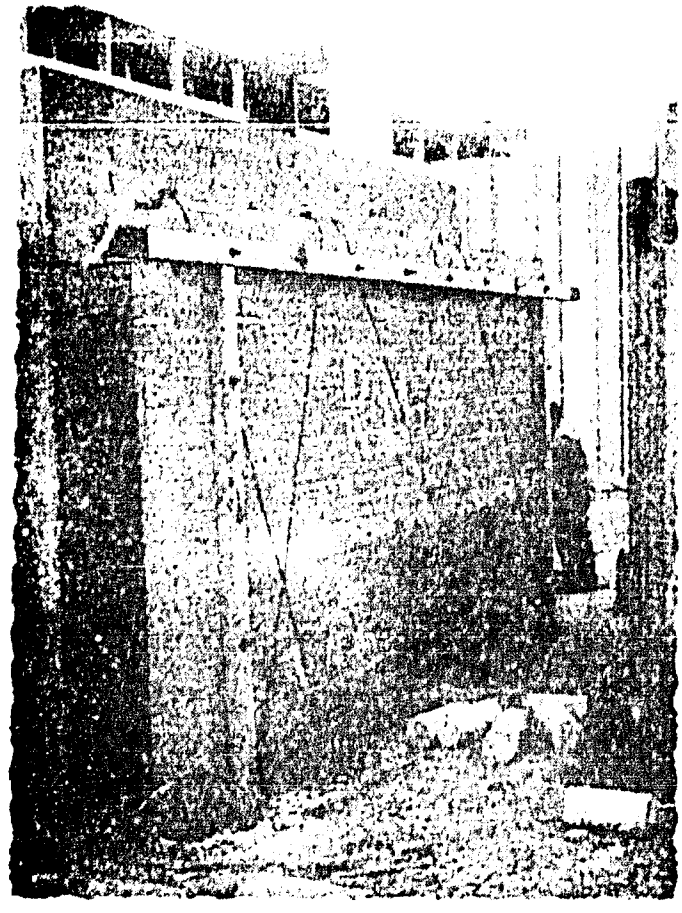

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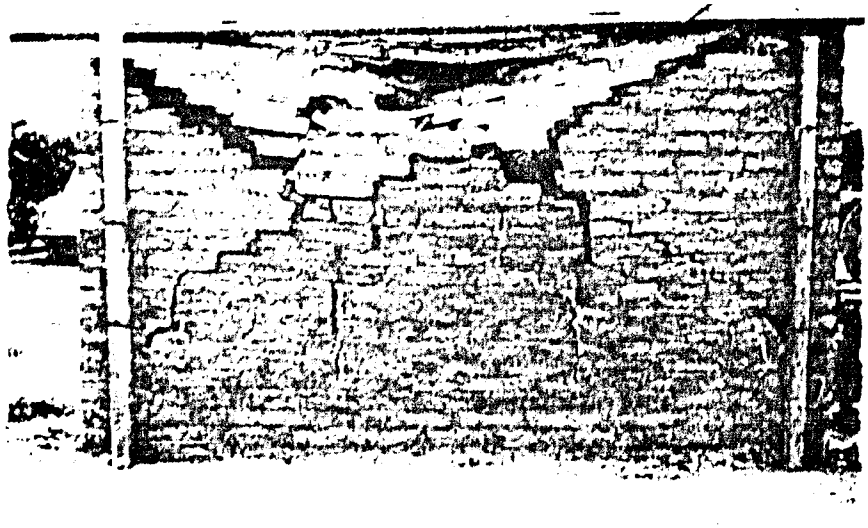

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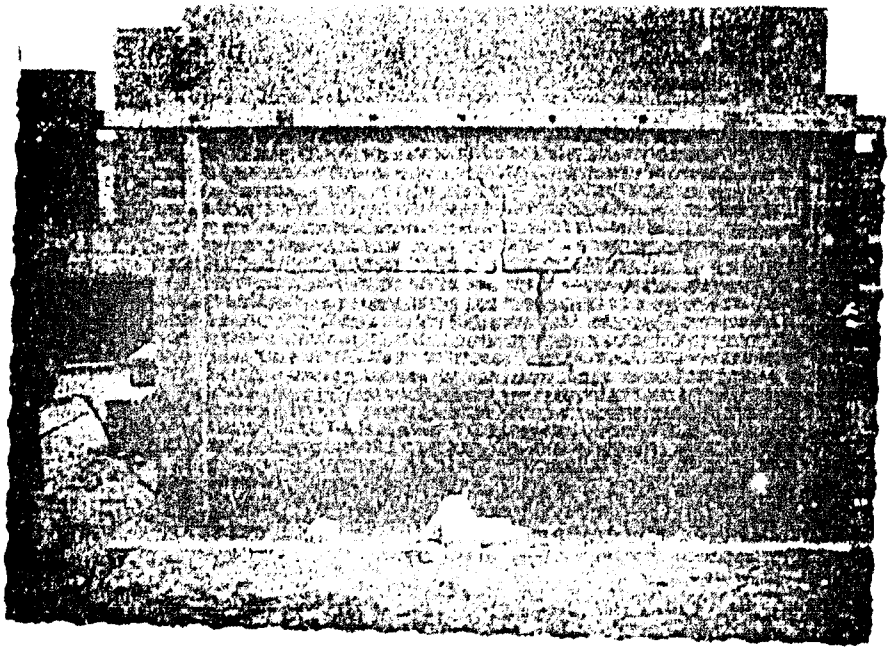

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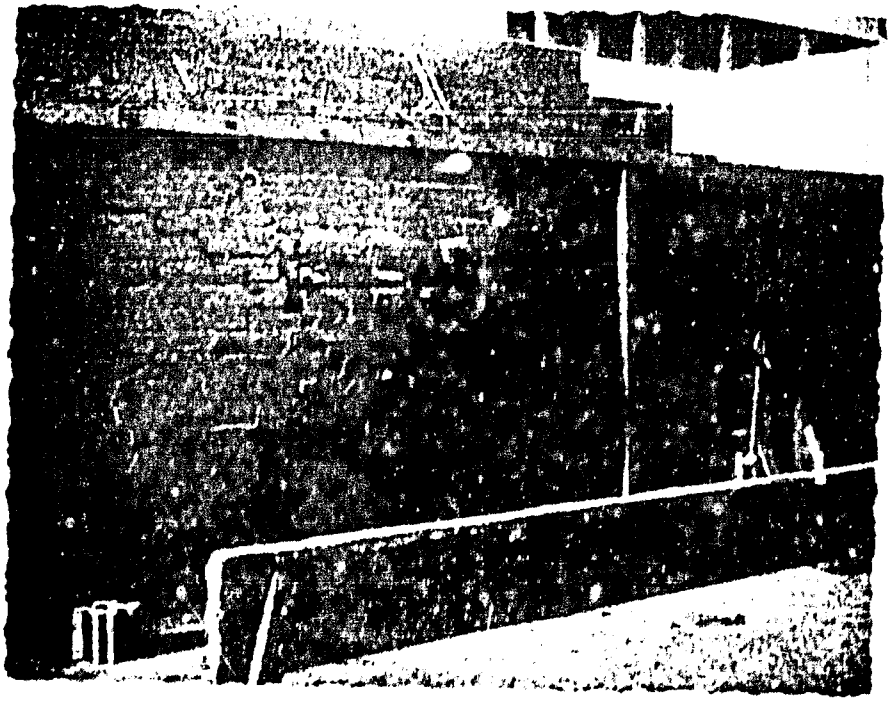

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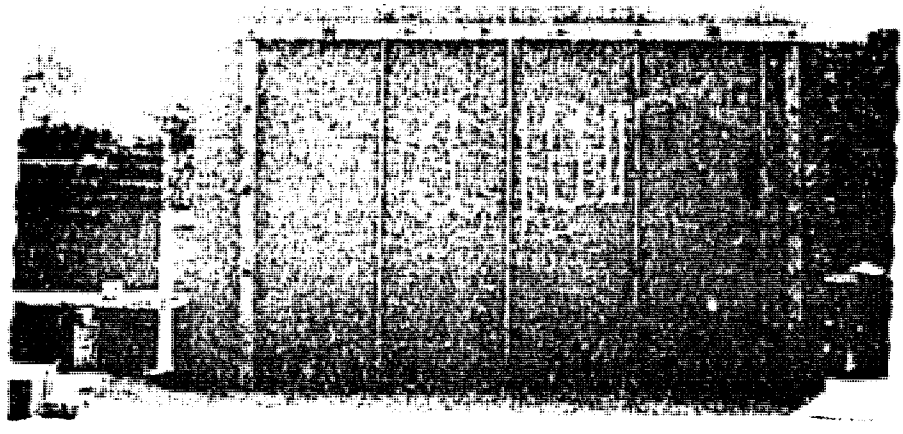

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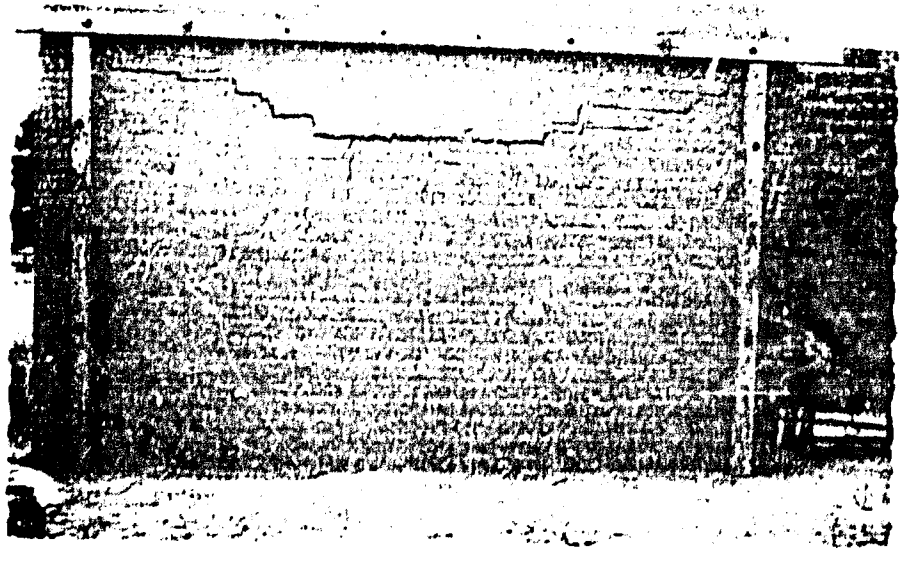

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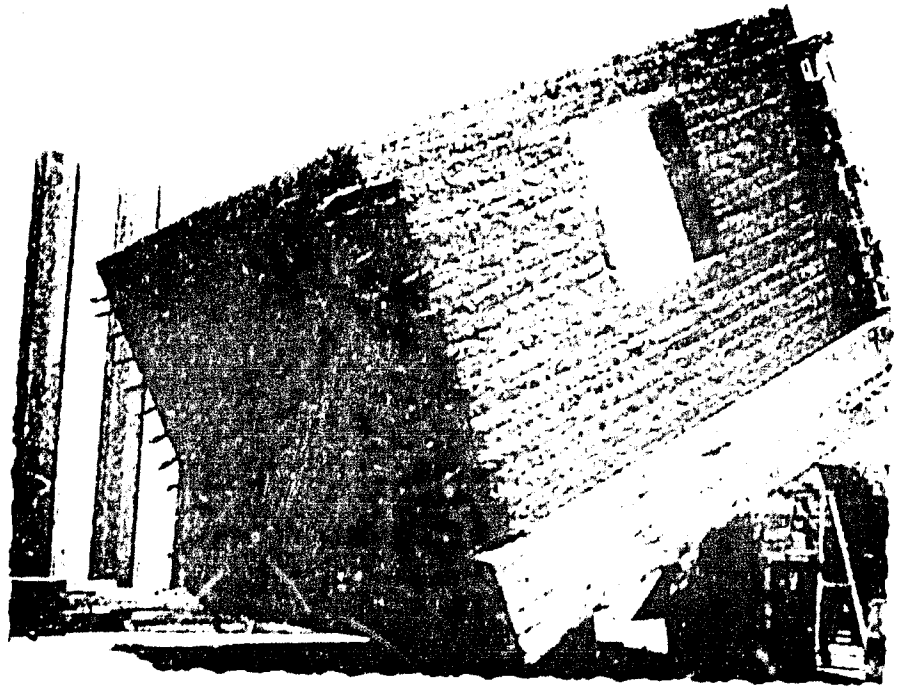

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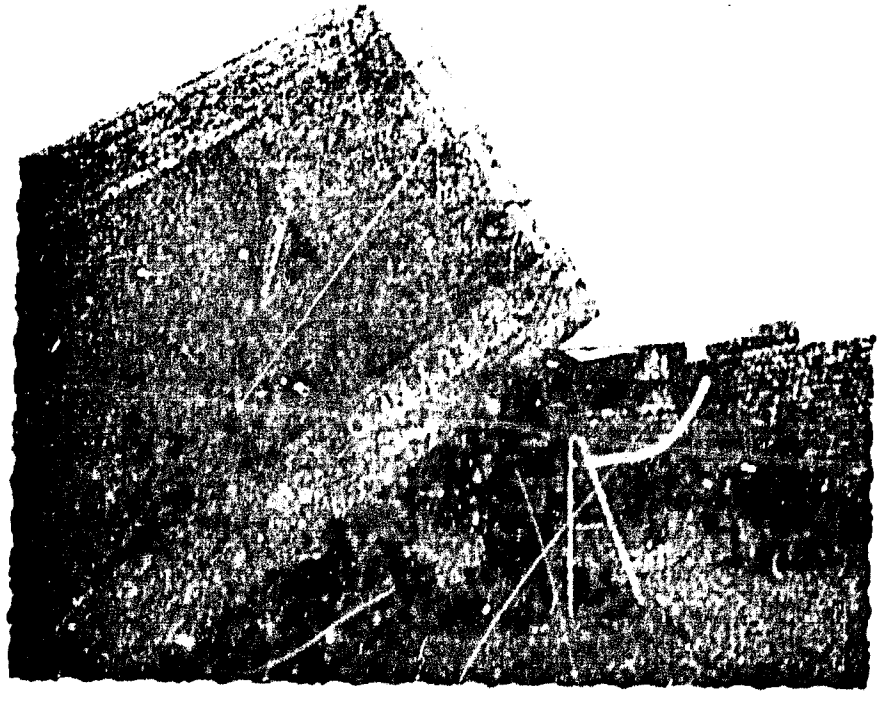

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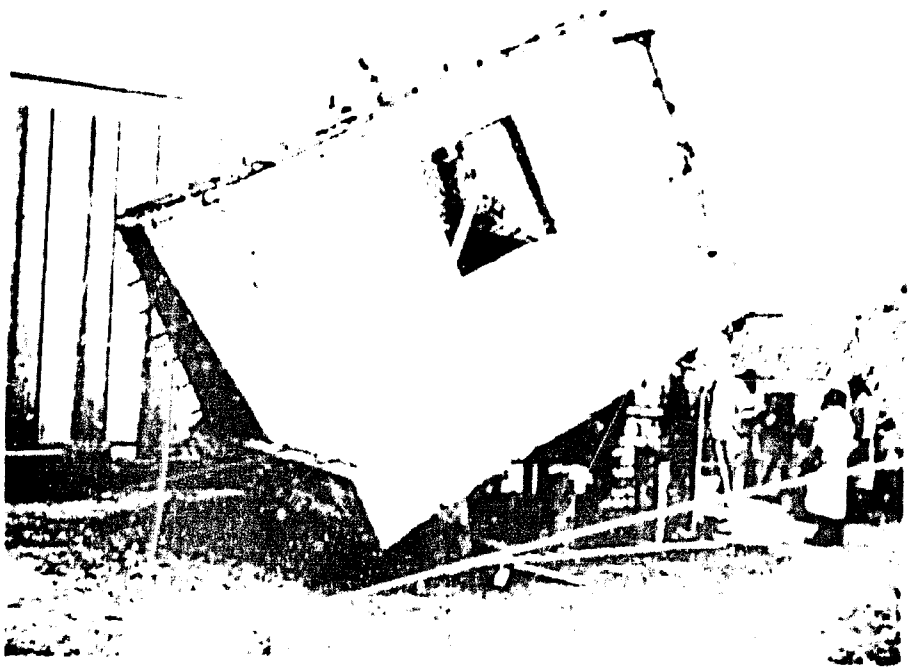

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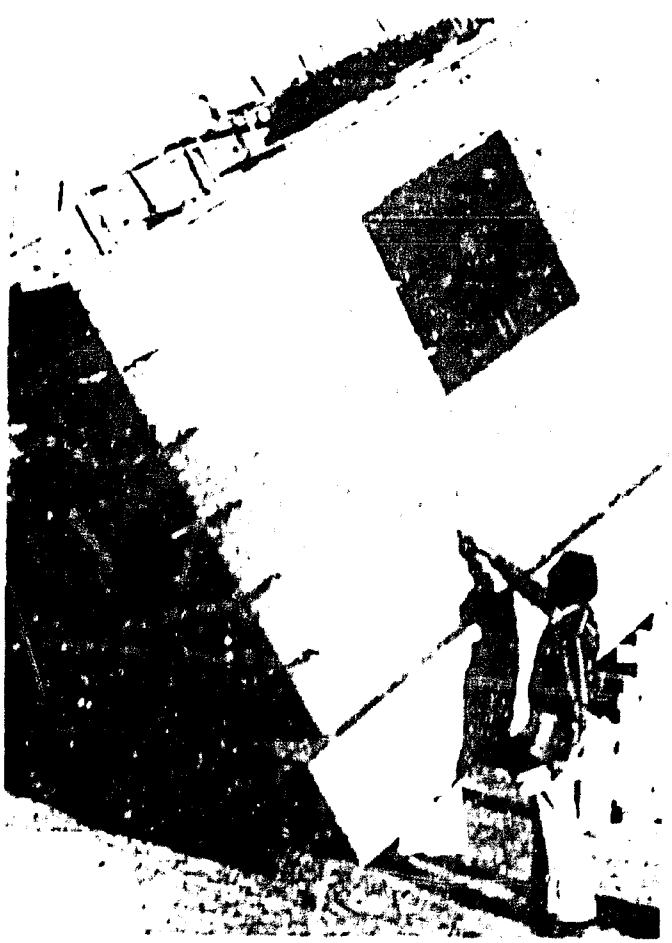

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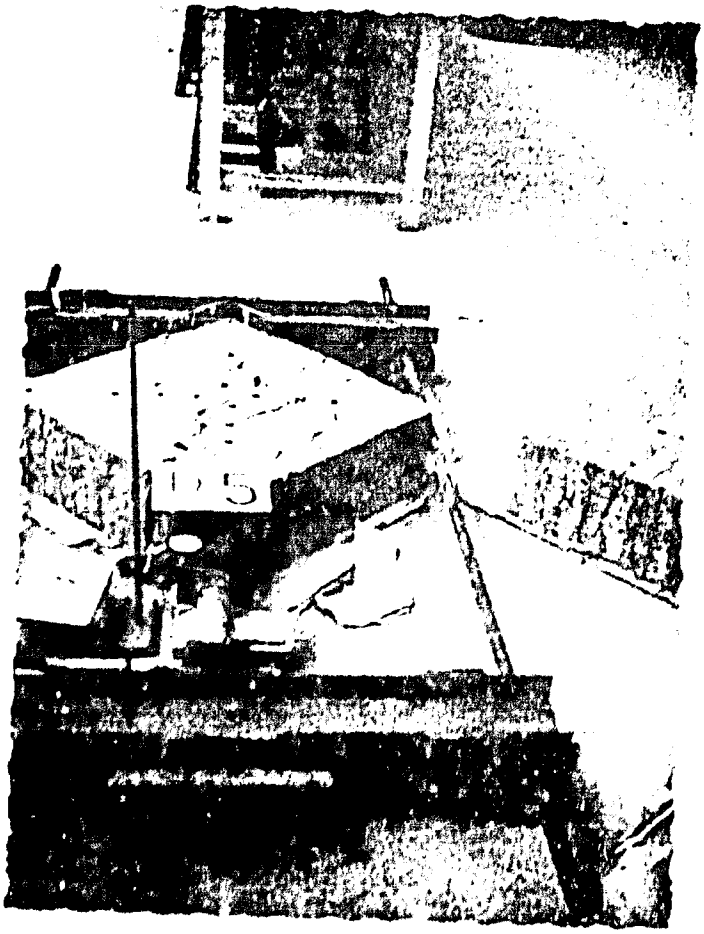
ENSAYOS COMPRESION AXIAL

Fotografía N° 25

ENSAYOS COMPRESION DIAGONAL



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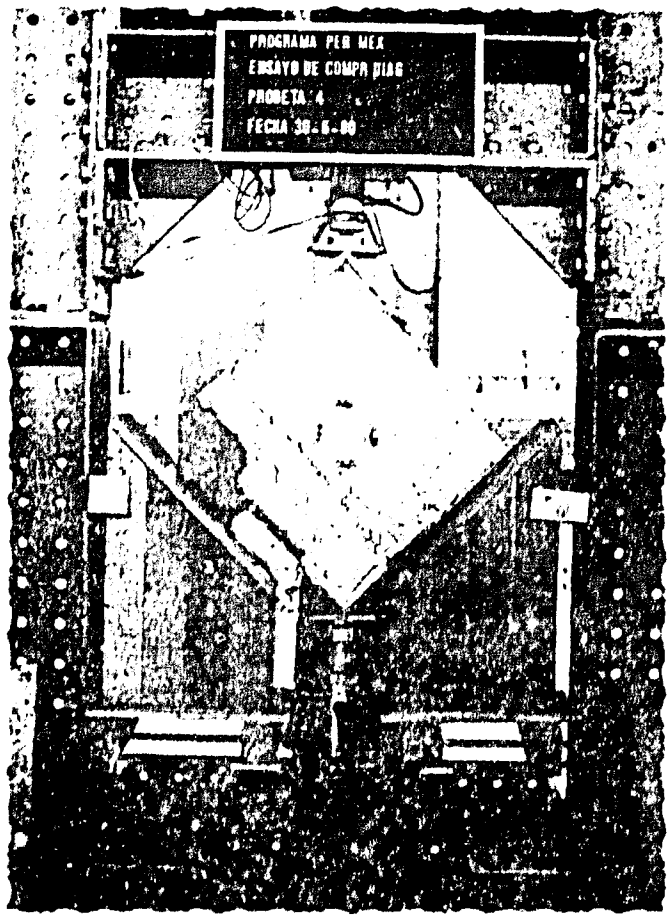

Fotografía N° 27

DISEÑO SISMICO DE CONSTRUCCIONES DE ADOBE Y BLOQUE ESTABILIZADO - Primera Parte: Propuesta de Normas de Diseño de Construcciones de Adobe y Bloque Estabilizado.

Por: Ricardo Yamashiro K*, Alejandro Sanchez O* y Roberto Morales M**

RESUMEN

En base a los mecanismos de falla de las construcciones de adobe*** observados en sismos reales y en el Laboratorio, se identifica los esfuerzos críticos. La resistencia de la albañilería y del refuerzo de caña, se determina mediante pruebas apropiadas y se establecen sus esfuerzos admisibles. Finalmente, con la información disponible se propone normas para el diseño de las construcciones de adobe.

SEISMIC DESIGN OF ADOBE AND STABILIZED BLOCK CONSTRUCTION - First Part: Proposed Code for Designing Adobe and Stabilized Block Construction.

By: Ricardo Yamashiro K*, Alejandro Sanchez O* y Roberto Morales M**

SUMMARY

On the basis of observed failure mechanism of adobe*** construction, during actual earthquakes and in the laboratory, critical stresses are identified. Masonry and cane strength are determined through appropiate tests, and their allowable design stresses are established. Finally, a design code for adobe construction is proposed on the basis of available information.

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*** En este trabajo se incluirá al bloque estabilizado en el término "adobe".

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I N T R O D U C C I O N

La gran actividad sísmica de nuestro territorio ha cobrado siempre sus mayores víctimas en las construcciones de adobe. Según Kuroiwa, Deza y Jaén (1)* en el terremoto del 31 de Mayo de 1970 "...Más del 90 por ciento de los edificios dañados eran de adobe y su colapso causó más de 40,000 muertes". Por otro lado, sin embargo, algunas construcciones de adobe resistieron sorprendentemente, los embates del sismo. "... En Coishco, a 40 kilómetros del epicentro y sobre terreno rocoso, el daño fué mínimo y muchas de las construcciones de adobe sobrevivieron y están habitadas".

Debe aceptarse, entonces, que existen ciertas condiciones bajo las cuales este tipo de construcción puede ofrecer un comportamiento "satisfactorio" ante sismos severos.

Lo que constituye un comportamiento "satisfactorio" ante sismos, está adecuadamente resumido en una de las filosofías en boga en la ingeniería antisísmica. Según Fintel (2), los objetivos implícitos en la mayoría de las normas de diseño antisísmico son que la estructura sea capaz de:

1. resistir sismos menores sin daños,
2. resistir sismos moderados con algunos daños estructurales leves y con daños no estructurales moderados,
3. resistir sismos catastróficos sin colapsar.

Por colapso se entiende (2) "... aquel estado que no permite que los ocupantes salgan del edificio debido a la falla de la estructura primaria".

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* La numeración entre paréntesis corresponde a las referencias.

En el presente trabajo se trata de sintetizar la información disponible sobre construcciones de adobe en forma de normas de diseño que permitan proyectar con este material, satisfaciendo los objetivos expuestos, en la mejor forma posible.

Se estudió, primeramente, el comportamiento sísmico de las construcciones de adobe con énfasis principal en la detección de los mecanismos de falla, lo que permitió identificar los tipos de esfuerzos que era necesario estudiar principalmente. Se estudió luego, experimentalmente, algunas de las propiedades mecánicas de la albañilería de adobe -especialmente su resistencia- bajo diferentes solicitaciones. A continuación, en base a estos estudios se estableció los esfuerzos admisibles para el diseño. Finalmente, usando información de diversas fuentes y cálculos adicionales que se publicarán en un futuro cercano se preparó una propuesta de normas para el diseño de estas construcciones.

COMPORTAMIENTO SISMICO DE CONSTRUCCIONES DE ADOBE

Las fallas en las construcciones de adobe pueden atribuirse, principalmente, a su poca resistencia en tracción y reducida adherencia entre el adobe y el mortero.* Los tipos principales de falla, que a menudo se presentan combinados, son los siguientes:

1. Falla por tracción en los encuentros de muros. En la figura 1 se ilustra este tipo de falla, que se debe principalmente a esfuerzos de tracción directa que se produce en uno de los muros, al dar arriostre lateral a otros muros del encuentro. Esta situación se agrava cuando a es-

* Estas características mejoran notablemente en construcciones de bloque estabilizado (4)

te efecto se superponen los esfuerzos de flexión.

2. Falla por flexión. En la figura 2, se ilustra algunas de las variantes de este tipo de falla que se debe a los esfuerzos de tracción por flexión al actuar el muro como una losa, apoyada en su base y en los elementos verticales que lo arriostran. La falla puede ocurrir en secciones horizontales, verticales u oblícuas.

3. Falla por corte. En la figura 3, se ilustra este tipo de falla, que se produce cuando el muro trabaja como muro de corte. Se debe, principalmente, a los esfuerzos tangenciales en las juntas horizontales.

En un trabajo experimental muy ingenioso, Corazao y Blondet (5) encontraron tipos de falla similares.

PROPIEDADES MECANICAS DE ALBAÑILERIA DE ADOBE Y BLOQUE ESTABILIZADO

Del estudio de los mecanismos de falla de las construcciones de adobe se determinó que las características mencánicas que más interesa conocer son:

1. la resistencia en tracción,
2. la resistencia en flexión,
3. la resistencia al corte.

Además, a pesar de que no se ha observado fallas por compresión, interesa conocer la resistencia de la albañilería en compresión, por ser esta una conveniente medida de la calidad estructural del material, siendo además, más fácil de determinar que las otras resistencias indicadas.

La resistencia de la albañilería de adobe se determinó mediante es-

pecímenes a escala natural y también mediante especímenes normalizados.

ESPECIMENES A ESCALA NATURAL.

Resistencia en tracción.- En un estudio experimental, Vera (6) encontró, como era de esperar, una bajísima resistencia en tracción, de la albañilería de adobe, apenas 0.036 Kg/cm^2, como se muestra en la figura 4. Para su aplicación al diseño de muros reforzados, se ensayó también algunos encuentros de muros reforzados con caña. Se encontró un dramático aumento en la resistencia del encuentro, hasta de 14.7 veces la resistencia del especimen sin reforzar.

Resistencia en flexión.- Moromi (7) estudió, experimentalmente, la resistencia en flexión en un plano horizontal de la albañilería de adobe con y sin refuerzo (Fig. 5). Nuevamente, la resistencia del muro sin reforzar resultó muy pequeña, mientras que con refuerzo se llegó hasta una resistencia 39 veces mayor cuando se usó mortero de barro con cemento, pero sólo 4 veces mayor cuando se usó mortero de barro simple.

Resistencia en corte.- Minchola (8), Guanilo (9) y Merino (10), estudiaron experimentalmente, la resistencia de muros de corte de albañilería de adobe con/sin refuerzo (Fig. 6). La resistencia del muro sin reforzar (especimen N° 1) fué de 0.123 Kg/cm^2 y la más alta resistencia obtenida fué 0.268 Kg/cm^2, correspondiente al especimen N° 6, reforzado en ambos bordes verticales y también horizontalmente cada tres hiladas. Es digno de notar que el muro sin refuerzo, con juntas de barro con cemento, resistió 0.236 Kg/cm^2, es decir, más que la mayoría de los muros reforzados y casi tanto como el más resistente. Debe destacarse, sin embargo,

que la capacidad de deformación de los muros reforzados fué significativamente mayor que la de los muros sin refuerzo.

ESPECIMENES NORMALIZADOS.

Generalidades. Los ensayos de modelos a escala normal(6)(7)(8) permiten determinar la resistencia a los diversos tipos de esfuerzos con cierto grado de confiabilidad. Por otro lado, sin embargo, son extremadamente morosos, requieren personal relativamente especializado y son, sobre todo, muy costosos. Estos inconvenientes se pueden subsanar usando especímenes y procedimientos de ensayo diseñados de modo de simplificar, lo más posible, el trabajo, con un sacrificio aceptable en la confiabilidad de los índices de resistencia que así se determinen.

A continuación se presenta los resultados de ensayos de albañilería de bloque estabilizado usando los especímenes de prueba propuestos por Meli y Reyes(11). Estos especímenes, que son fáciles de construir y ensayar, permiten obtener índices de resistencia de la mampostería en compresión, corte y tracción diagonal. Correlacionando estos índices con los resultados de ensayos de muros a escala natural, será posible en el futuro -cuando se disponga de un volumen suficiente de información- determinar con mayor exactitud las propiedades mecánicas necesarias para el diseño.

Especimen para el ensayo de compresión axial. Proporciona un índice de la resistencia de un muro a la acción de cargas verticales.

El tipo de especimen utilizado se muestra en la figura 7 (a). Consiste en una pila de bloques unidos por mortero. La relación altura-espesor de las pilas fué aproximadamente igual a 2. Con el fin de asegurar u

na aplicación uniforme de esfuerzos se procuró que las caras extremas de la pila fueran lisas, planas y paralelas. Esto se logró puliendo la cara inferior y enrasando la cara superior con una capa de yeso de aproximadamente 3 mm. de espesor. Los ensayos se efectuaron en un marco metálico, aplicando la carga mediante un gato hidráulico de 30,000 lbs. por incremento de 2000 lbs. Para cada incremento de carga se midió la deformación axial medianta un deformómetro de dial. Los ensayos se efectuaron a los 35 días de fabricadas las pilas.

Especímenes para el ensayo de corte directo. Proporcionan un índice de la resistencia de muros a cargas horizontales en su plano, cuando fallan en la junta de mortero que une los bloques. Se trata de una falla debida básicamente a esfuerzos tangenciales.

El tipo de especimen utilizado se muestra en la figura 7 (b). Consiste en una pila de tres bloques. El intermedio está cortado verticalmente por la mitad. Estos medios bloques están ligeramente separados, con su junta vertical sin mortero.

Al aplicar cargas en los medios bloques intermedios, se produce una falla por esfuerzos tangenciales en cualquiera de las dos mitades. Los ensayos se efectuan aplicando además cargas de confinamiento en los bloques extremos, simulando de esta manera el estado de esfuerzos en un punto de un muro de albañilería. Las cargas de confinamiento aplicadas fueron de 1,2 y 4 Kg/cm^2. Los ensayos se efectuaron a los 35 días de fabricadas las pilas.

Especímenes para el ensayo de compresión diagonal. Proporcionan un índice de la resistencia de un muro a cargas horizontales en su plano,

tanto para el caso en que la falla se deba a esfuerzos tangenciales en las juntas como para el caso en que esta se deba a esfuerzos de tracción inclinada en los bloques.

El tipo de especimen utilizado se muestra en la figura 7 (c). Consiste en una pila de tres bloques. El intermedio está formado por dos medios bloques. Las pruebas se efectuaron en una máquina Universal Tinius Olsen, de tal forma que la carga se aplicaba según la dirección de una de las diagonales a través de angulares colocados en dos aristas opuestas y asentados sobre una capa delgada de yeso. Los ensayos se efectuaron a los 35 días de fabricados los especímenes.

Resultados de los ensayos de compresión axial. En el cuadro N° 1 se presenta un resumen de los resultados de estos ensayos. Puede observarse lo siguiente:

1. Las resistencias en compresión f'_m, fueron iguales en los especímenes con mortero 1:10:1% y S - 2%. Con estos morteros la resistencia resultó 25% mayor que para los especímenes sin estabilizar (adobe).
2. La deformación correspondiente al esfuerzo máximo fué también mayor en los especímenes con suelo estabilizado.
3. El módulo de elasticidad fué también mayor en los especímenes con suelo estabilizado. El mayor valor se obtuvo con el mortero S - 2%.

Resultados de los ensayos de corte directo. En la figura 8 se observa que los resultados de estos ensayos responden satisfactoriamente a la expresión de Coulomb

$$v = \mu + f\,\sigma$$

donde: v = esfuerzo tangencial de falla, Kg/cm^2.

μ = resistencia por adherencia, Kg/cm^2.

f = coeficiente de fricción.

σ = esfuerzo de confinamiento, Kg/cm^2.

En estos mismos gráficos y también en el cuadro N° 2 se dan los valores de μ y de f para cada tipo de mortero, que fué la variable principal. Puede notarse lo siguiente:

1. Los especímenes con suelo estabilizado exhiben una resistencia por adherencia, μ, significativamente superior a los especímenes de adobe (sin estabilizar). En orden descendente de la resistencia por adherencia se tiene la siguiente clasificación de los especímenes ensayados:

   a. Con mortero 1:2:3:1/2 μ = 1.8 - 1.98 Kg/cm^2

   b. Con mortero 1:10:1% μ = 1.3 - 1.4 "

   c. Con mortero S - 2% μ = .75 - 0.90 "

   d. Con mortero simple μ = 0.55 "

2. Los especímenes con suelo estabilizado tienen un coeficiente de fricción, f, superior a los especímenes sin estabilizar, aunque la diferencia en este caso no es tan marcada como para la adherencia. En orden descendente de los valores del coeficiente de fricción, se tiene la siguiente clasificación de los especímenes:

   a. Con mortero 1:2:3:1/2 f = 0.98 - 1.06

   b. Con mortero S - 2% f = 0.78 - 0.80

   c. Con mortero 1:10:1% f = 0.60 - 0.63

   d. Con mortero simple f = 0.58

3. No se observa una diferencia sistemática, ni significativa, entre los resultados para especímenes fabricados con bloques grandes chicos.

Resultados de los ensayos de compresión diagonal. En el Cuadro N°3, se presenta un resumen del análisis de los resultados de los ensayos de compresión diagonal. Los esfuerzos de corte experimentales y los "teóricos" fueron determinados siguiendo los lineamientos del trabajo de Moli y Reyes. Se observa lo siguiente:

1. El esfuerzo de corte de rotura es significativamente mayor para los especímenes de suelo estabilizado, habiendo resultado una resistencia mucho mayor en los especímenes con mortero 1:10:1% que en los especímenes con mortero S - 2%.
2. La aplicación de las expresiones para las resistencias "teóricas" para fallas por tracción diagonal y por corte, indican que los especímenes debieron fallar por corte, lo que concuerda con lo observado.
3. Sin embargo, las resistencias "teóricas" calculadas con la expresión(3) resultan excesivamente altas en comparación con los valores experimentales.

Conclusiones. De los resultados obtenidos se puede extraer las siguientes conclusiones:

a. En general, la estabilización mejora las características mecánicas del suelo.

b. La expresión $v = \mu + f\sigma$ relaciona satisfactoriamente las diferentes variables.*

c. Pueden usarse especímenes con bloques pequeños (26.5 x 26.5) para obtener las propiedades mecánicas de la mampostería de bloques más grandes.

d. La expresión $v = \frac{0.8\ u}{1 - 0.9f\ h/l}$ para las pruebas de compresión diametral no es aplicable para los especímenes ensayados.**

PROPIEDADES MECANICAS DE LA CAÑA

La caña se comporta elásticamente casi hasta la rotura. Echazú(12) determinó, experimentalmente, un valor medio del módulo de elasticidad de 1.52×10^5 Kg/cm^2 con un coeficiente de variación de 6.2%, y un valor medio de la resistencia de 1350 Kg/cm^2 con un coeficiente de variación de 17.7 %.

Con la humedad se encontró una disminución de la resistencia del orden de 25 por ciento. En otros experimentos, que están siendo evaluados, se ha encontrado una disminución mayor.

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* Debe notarse, sin embargo, que para vlores pequeños del esfuerzo de confinamiento, los gráficos que se muestran en el trabajo de Meli y Rayes indican que esta expresión puede dar errores importantes.

** Aparentemente, debido a que los esfuerzos de confinamiento eran pequeños.

PROPUESTA DE NORMAS DE DISEÑO ESTRUCTURAL PARA CONSTRUCCIONES DE ADOBE Y BLOQUE ESTABILIZADO.

1. REQUISITOS GENERALES.

Estas normas forman parte de las Normas de Diseño Antisísmico y regirán en caso de discrepancia.

Las construcciones de adobe y bloque estabilizado serán diseñadas por un método racional, basado en los principios de la mecánica y la resistencia de materiales.

Las dimensiones y requisitos que se estipulan en los párrafos siguientes, tienen únicamente el carácter de mínimos y no eximen de manera alguna del estudio y cálculos correspondientes que serán los que deben definir las dimensiones y requisitos a usarse en el diseño, de acuerdo con la función real de los elementos y de la construcción.

Estas construcciones se limitarán a un sólo piso, con una altura máxima de tres metros entre pisos y cielo raso.

No se construirá con este material en suelos blandos, ni en suelos cuya capacidad de servicio sea inferior a 2 Kg/cm^2.

2. DEFINICIONES.

Altura libre de muro. Es la distancia vertical entre elementos de arriostre.

Muro arriostrado. Es un muro cuya estabilidad lateral está confiada a elementos de arriostre.

Extremo libre de un muro. Es el borde vertical no arriostrado.

Vigas collar. Son vigas de madera, de concreto o suelo estabilizado,

convenientemente reforzadas para dar arriostramiento a los muros de los cuales es una parte integrante. También se les llama viga solera.

3. ESTRUCTURA.

El conjunto estructural de las construcciones de adobe y bloque estabilizado estará compuesta de:

a. Cimentación.

b. Muros.

c. Elementos de arriostre.

d. Techo.

4. CIMENTACION.

La cimentación para los muros podrá ser de concreto, albañilería o suelo estabilizado. La cimentación debe transmitir la carga de los muros al terreno, de acuerdo a su esfuerzo permisible.

5. MUROS.

a. Los muros serán de bloque macizo. El espesor mínimo de estos muros, será la mayor de las siguientes dimensiones:

1/8 de su altura libre.

1/8 de la distancia entre los elementos de arriostre verticales.

b. La longitud entre el extremo libre de un muro y el elemento vertical de arriostre más próximo no excederá de 0.4 veces la altura libre del muro.

La sección de un muro correspondiente a un lado vertical no arriostrado de un vano de puerta o ventana será considerada como un extremo libre.

c. Los muros se diseñarán por el método de esfuerzos permisibles.

d. No se considerará ninguna resistencia a la tracción de la albañilería, en caso de tracción directa o tracción por flexión.

e. Las cargas de trabajo de la albañilería y del refuerzo estarán de acuerdo con lo establecido en el apéndice "A".

f. Como refuerzo podrá utilizarse cualquier material de propiedades razonablemente estables y que sea compatible con el material del muro.

g. El refuerzo de los muros podrá estar constituido por cañas huecas (carrizo) en tiras, tomándose las precauciones necesarias para evitar los efectos perjudiciales de los cambios volumétricos de la caña con la variación de su contenido de humedad.

h. Los anclajes y empalmes del refuerzo desarrollarán el íntegro de la resistencia a la tracción del mismo.

i. El mortero que rodee al refuerzo será de suelo estabilizado.

6. ELEMENTOS DE ARRIOSTRE.

Los pilares sin reforzar no se considerarán como elementos de arriostre.

Salvo que el muro se refuerce adecuadamente, deberá estar arriostrado por elementos verticales, como muros y/o columnas de arriostre y por elementos horizontales, tales como un techo rígido o vigas collar.

a. Los elementos de arriostre se diseñarán como apoyos del muro arriostrado considerado como losa, sujeto a fuerzas horizontales perpendiculares a él. Sus dimensiones, sección y armadura serán definidas por métodos racionales de cálculo.

b. La longitud de un muro de arriostre no será menor que tres cuartos de su altura, a menos que se coloque refuerzo vertical adecuadamente anclado a la cimentación.

c. Un muro se considerará arriostrado:

1. Cuando exista suficiente adherencia o anclaje entre los muros y sus elementos de arriostre que garantice una adecuada transferencia de esfuerzos.

2. Cuando los elementos de arriostre tengan una adecuada resistencia y estabilidad para transmitir las fuerzas actuantes a elementos estructurales adyacentes al suelo.

3. Cuando, empleándose los techos para su estabilidad lateral, se tomen precauciones para que las fuerzas laterales que actúan en estos techos sean transferidos adecuadamente al suelo.

7. TECHO.

a. Cuando el techo deba cumplir la función de transmitir fuerzas horizontales, se construirá de modo que tenga adecuada rigidez, permita un comportamiento integral con los muros y asegure la transmisión de las cargas de gravedad y/o horizontales.

b. Cuando el techo no contribuya a la distribución de fuerzas horizontales, las vigas collar se diseñarán para cumplir con esta función.

A P E N D I C E "A"

ESFUERZOS PERMISIBLES EN CONSTRUCCIONES DE ADOBE Y BLOQUE ESTABILIZADO

Para la determinación de los esfuerzos permisibles se tomará el promedio de no menos de tres especímenes.

Esfuerzo permisible del muro en compresión axial. Se tomará igual a 1/5 de la resistencia en compresión de pilas de bloques unidos por mortero. Las pilas tendrán una relación altura a espesor igual a 2. Para esfuerzos de contacto puede incrementarse el esfuerzo en 25 por ciento.

Esfuerzo permisible del muro en corte para acciones sísmicas o de viento. Se tomará igual a 1/5 de la resistencia por adherencia en pruebas de corte directo.

Esfuerzo permisible de la caña en tracción. El esfuerzo de tracción permisible de la caña se tomará igual a 1/4 de su resistencia en tracción.

Esfuerzos permisibles sin ensayos. A falta de mejor información se usarán los siguientes esfuerzos permisibles:

Compresión de contacto	2.0	Kg/cm^2
Compresión axial en muro	1.6	"
Corte horizontal en muro	0.07	"
Tracción en caña	250	"

* * * *

COMENTARIOS A LA PROPUESTA DE NORMAS DE DISEÑO ESTRUCTURAL PARA CONSTRUCCIONES DE ADOBE Y BLOQUE ESTABILIZADO

1. REQUISITOS GENERALES.

La albañilería de adobe, por su baja resistencia, requiere del mayor cuidado, tanto en su diseño como en su construcción. Por esto, su diseño debe basarse en los principios de la mecánica y la resistencia de materiales. No se descarta, sin embargo, que a partir de estudios de cierto rigor se llegue, en el futuro, a reglas prácticas que simplifiquen el diseño de este tipo de construcciones.

La limitación a un piso y a tres metros de altura en necesaria por el comportamiento extremadamente pobre de las construcciones que están fuera de estos límites.

No debe construirse con adobe en suelos blandos, ni en suelos cuya capacidad de servicio sea inferior a 2 Kg/cm^2. Con esta limitación se trata de evitar los efectos desfavorables de la amplificación sísmica y de los asentamientos desiguales, característicos en estos suelos.

3. MUROS.

a. y b. Estos requisitos se han determinado considerando la teoría de losas con apoyo simple en 4 y 3 bordes, respectivamente, no admitiendo tracciones perpendiculares a las hiladas para un coeficiente sísmico de 0.20.

f. El material que se utilice como refuerzo debe tener adecuada resistencia en tracción y adherirse a la albañilería para un comportamiento estructural integral. Estas propiedades, además, no de-

ben deteriorarse significativamente con el tiempo ni por la acción de agentes externos (humedad, calor, etc.).

i. Los beneficios de usar mortero estabilizado alrededor del refuerzo son muy grandes y su costo adicional es pequeño.

6. ELEMENTOS DE ARRIOSTRE.

El arriostramiento del borde superior del muro es fundamental y no debe omitirse.

a. Para el cálculo del refuerzo, cualquiera que sea el material, puede usarse una adaptación del método de esfuerzos admisibles para el diseño de elementos de concreto armado.

b. Mediante el refuerzo se consigue movilizar el peso de la cimentación para conseguir la estabilidad necesaria.

A P E N D I C E "A"

ESFUERZOS PERMISIBLES EN CONSTRUCCIONES DE ADOBE Y BLOQUE ESTABILIZADO

Esfuerzo permisible en compresión axial. Con el factor de reducción de 1/5 se pretende tomar en cuenta la variabilidad de las características de los materiales y de las cargas y las pequeñas excentricidades.

Esfuerzo permisible de corte. El esfuerzo de corte nominal se toma igual a la fuerza cortante dividida por el área de la sección horizontal del muro. Con el coeficiente de reducción 1/5 se pretende considerar el mayor esfuerzo actuante debido a la distribución no uniforme de los esfuerzos en un muro real y el incremento usual del esfuerzo admisible en

un tercio cuando se considera acción sísmica, reservándose un factor de seguridad neto de aproximadamente 3 contra la falla.

Esfuerzo admisible para la caña. La prueba se realiza con muestras de caña fresca secada al aire. El factor de reducción de 1/4 se aplica al esfuerzo de rotura, con la intención de tomar en cuenta la pérdida de resistencia de la caña por su envejecimiento y por los cambios en su contenido de humedad.

Esfuerzos permisibles sin ensayos. Teniendo en cuenta las normas para la determinación de esfuerzos permisibles con ensayos, los valores especificados para los esfuerzos admisibles sin ensayo implican los siguientes resultados de ensayos hipotéticos:

resistencia en compresión de albañilería	8.0	Kg/cm^2
resistencia al corte de albañilería	0.35	"
resistencia a la tracción de la caña	1000	"

De acuerdo a la información disponible, se estima que estos valores son suficientemente conservadores.

R E C O N O C I M I E N T O S

La información experimental utilizada en este trabajo se ha obtenido de proyectos de investigación realizados en la Universidad Nacional de Ingeniería, patrocinados por el Ministerio de Vivienda.

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* * * *

Cuadro N° 1. RESULTADOS DE LOS ENSAYOS DE COMPRESION AXIAL.

Tipo de Mortero	I : 10 - 1%	S - 2%	Simple
Resistencia, f'_m	12.8 Kg/cm^2	12.8 Kg/cm^2	10.3 Kg/cm^2
Deformación Unitaria en 1	12.3×10^{-3}	13.5×10^{-3}	9.7×10^{-3}
Módulo de Elasticidad	1788 Kg/cm^2	2140 Kg/cm^2	1600 Kg/cm^2

Los valores indicados representan el promedio de 3 a 5 especímenes.

Cuadro N° 2. VALORES DE LA ADHERENCIA, μ, Y COEFICIENTES DE FRICCION, f, DE ACUERDO A LOS RESULTADOS DE LOS ENSAYOS DE CORTE DIRECTO.

Mortero	1:10:1%		S - 2%		Simple		1:2:3: 1/2	
Bloque	Chico	Grande	Chico	Grande	Chico	Grande	Chico	Grande
Adherencia μ, Kg/cm^2.	1.40	1.30	.90	.75	.55	—	1.80	1.98
Coeficiente de fricción, f.	.60	.63	.78	.80	.58	—	1.06	.98

NOTAS.

1. Los valores de μ y f corresponden a la ecuación de falla

$$v = \mu + f\,\sigma$$

donde: v = esfuerzo tangencial de falla
σ = esfuerzo de confinamiento

2. Los valores de la tabla se obtuvieron ajustando líneas rectas a los puntos experimentales y sin considerar los valores para confinamiento nulo.

Cuadro N° 3. ANALISIS DE LOS RESULTADOS DE LOS ENSAYOS DE COMPRESION DIAGONAL.

Tipo de Mortero	u Kg/cm^2	f	f'_m Kg/cm^2	Esfuerzo de corte de rotura		
				Experimental (1)	Falla por tracción diagonal (2)	Falla por corte (3)
1:10:1% Bloque Chico	1.40	.60	12.8	1.01	3.56	2.44
1:10:15 Blo. Grande	1.30	.63	12.8*	1.15	3.56	2.65
S - 2%	.90	.78	12.8	.45	3.56	2.40
Simple	.55	.58	10.3	.30	3.19	.92

* Se ha tomado el mismo valor que para los bloques chicos.

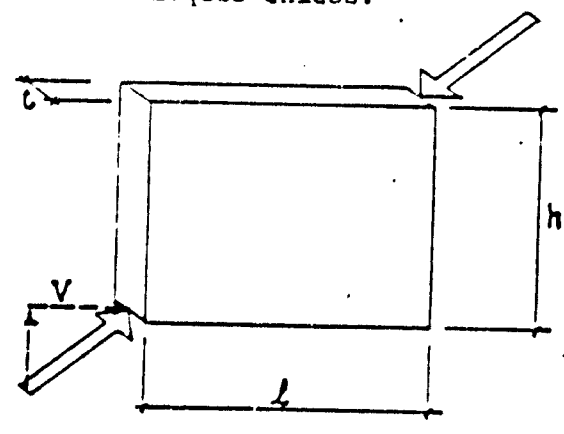
Del trabajo de Meli y Reyes:

(1) $v = V/\ell t$

(2) $v_{TD} = \sqrt{f'_m}$

(3) $v_c = \dfrac{0.8\,u}{1 - 0.9\,f\,h/\ell}$.

En estos ensayos $h/\ell = 1$



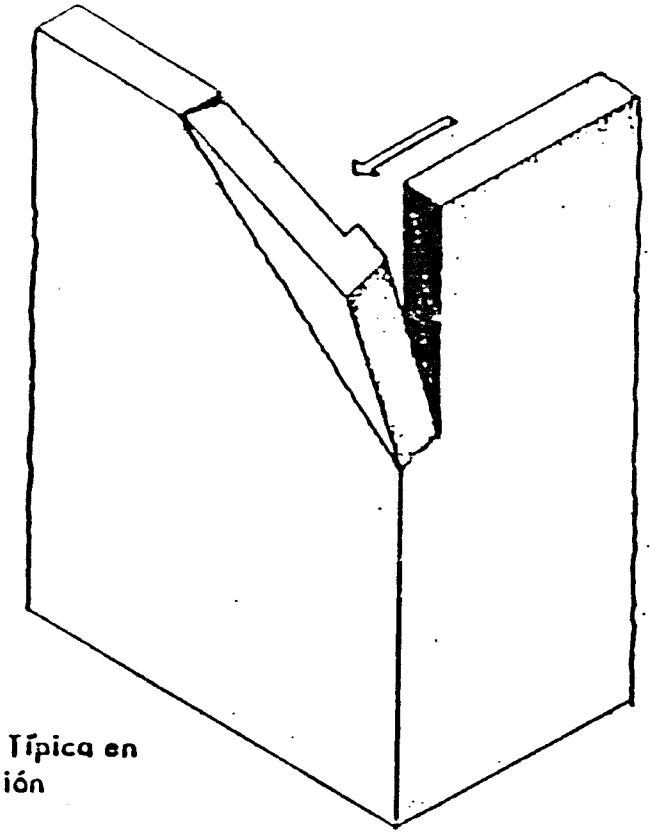


Fig. 1 Falla Típica en tracción

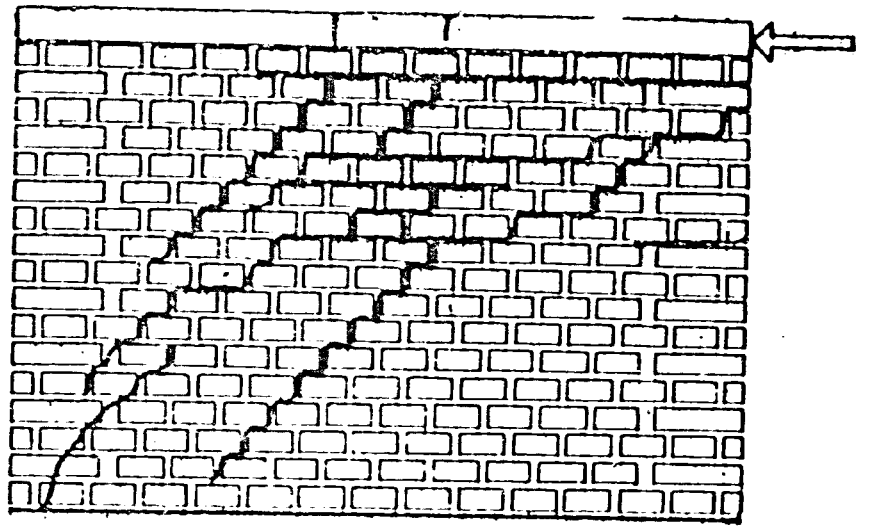
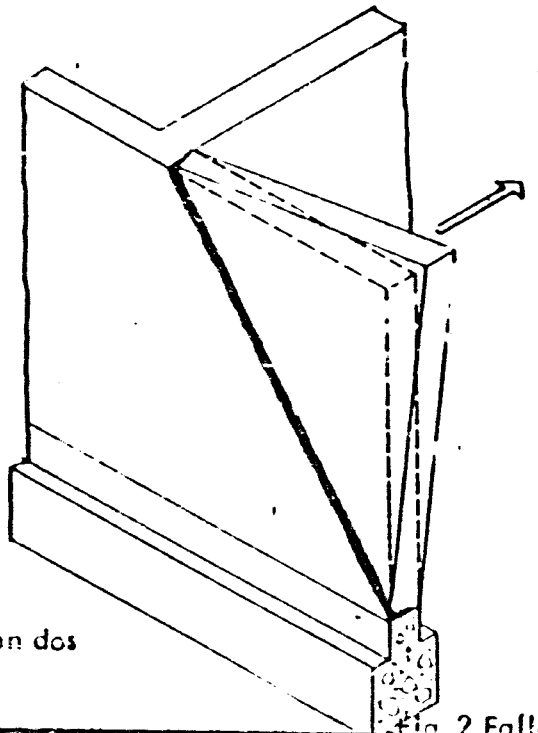
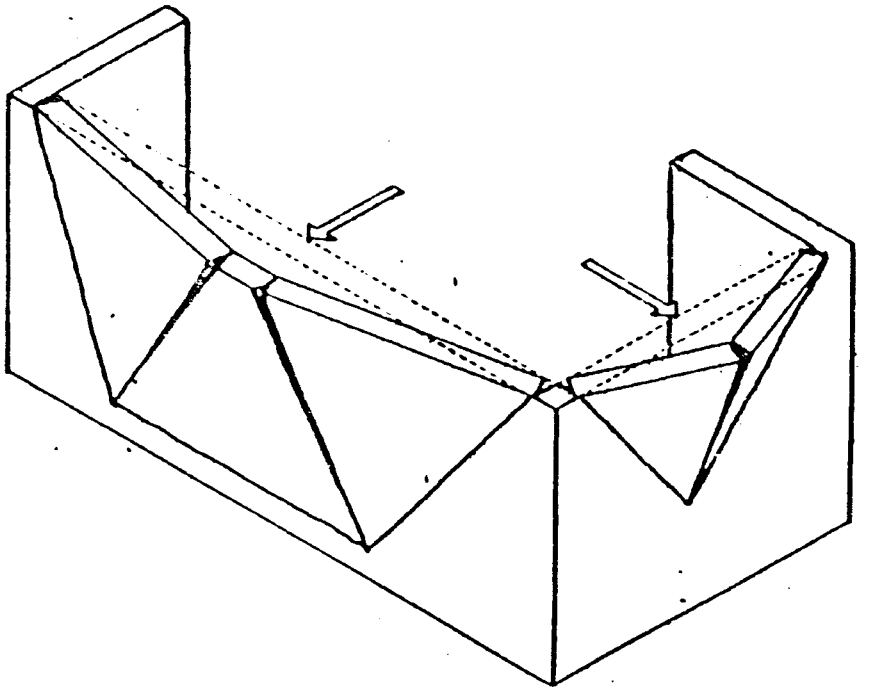


Fig. 3 Falla Típica por corte



a) Muro arriostrado en dos bordes



b) Muros arriostrados en tres bordes

Fig. 2 Fallas típicas por flexión

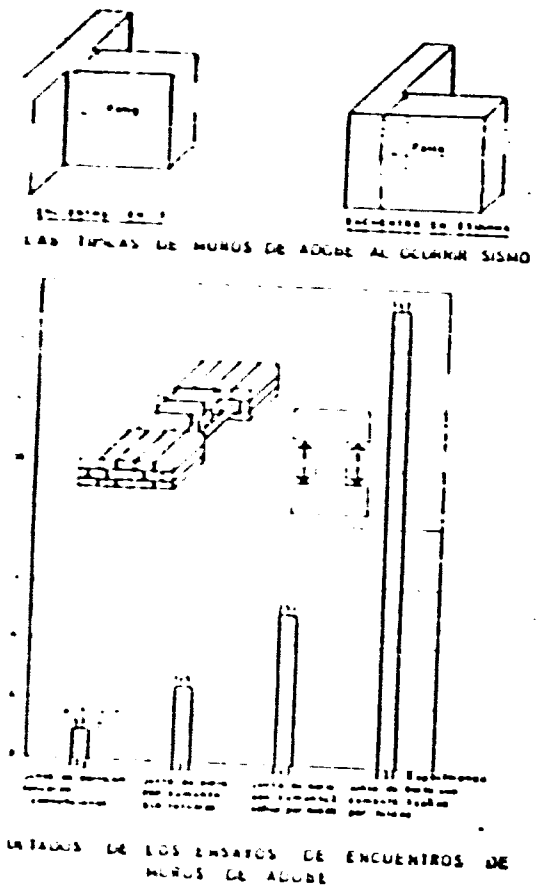


Fig. 4 Resistencia en tracción de muros

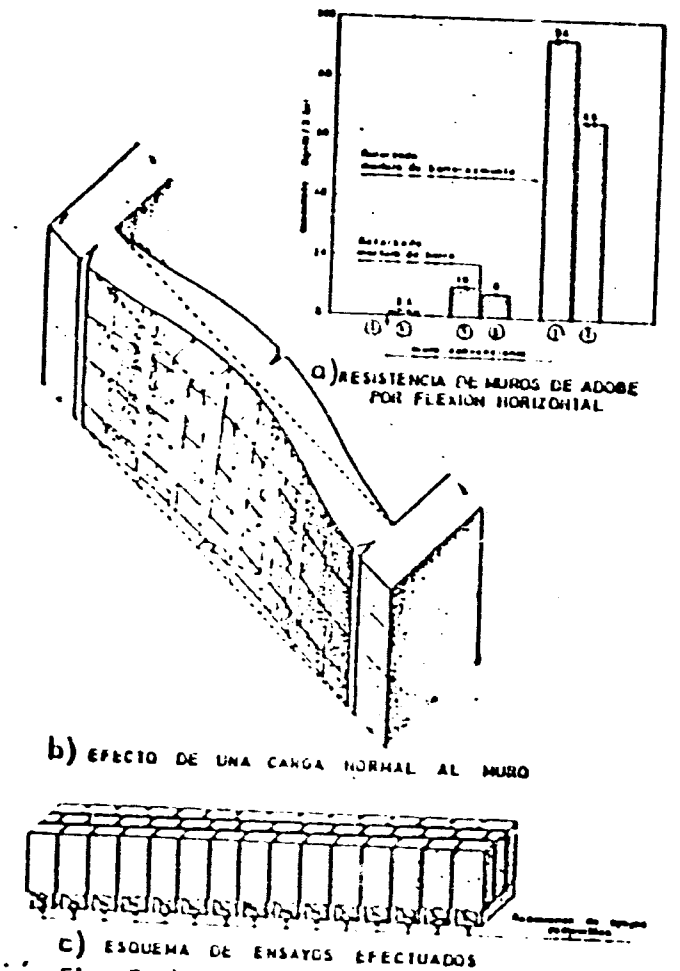


Fig. 5 Flexión horizontal en muros

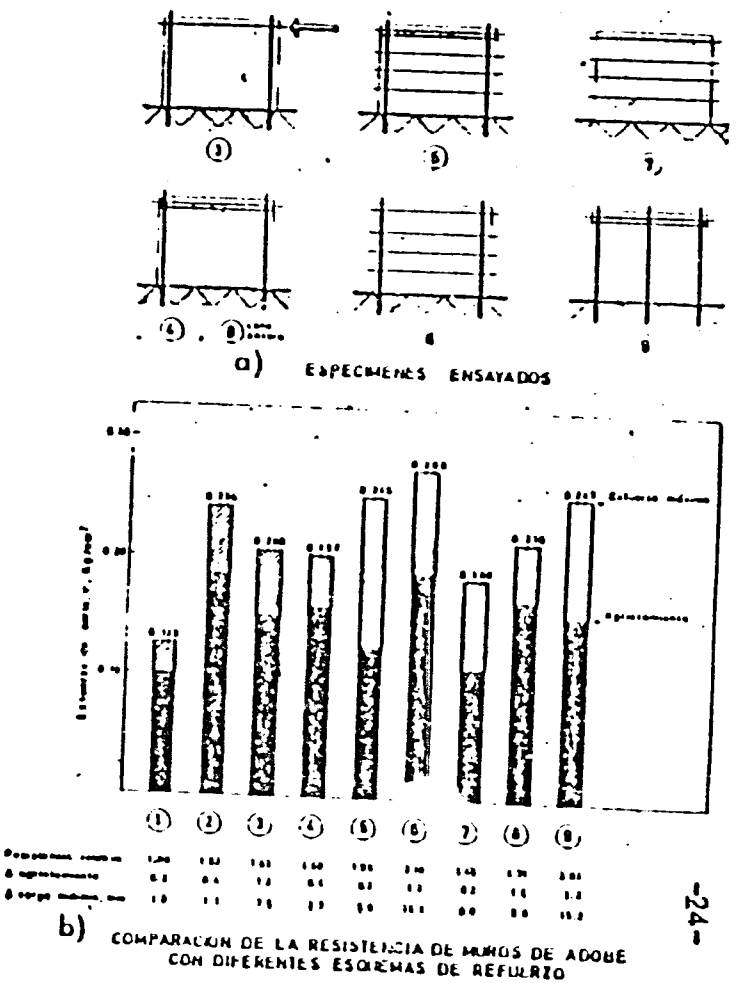


Fig. 6 Resistencia de muros de corte

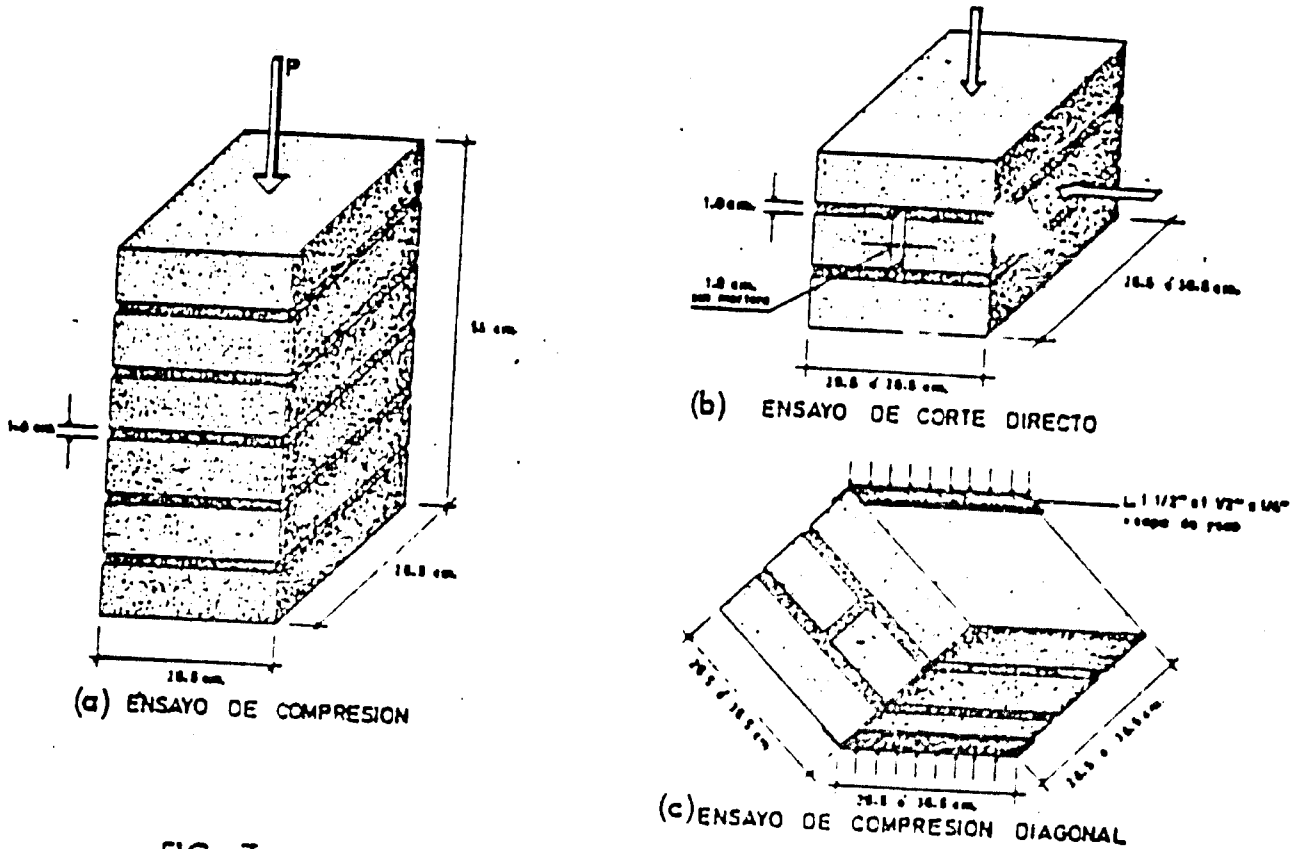
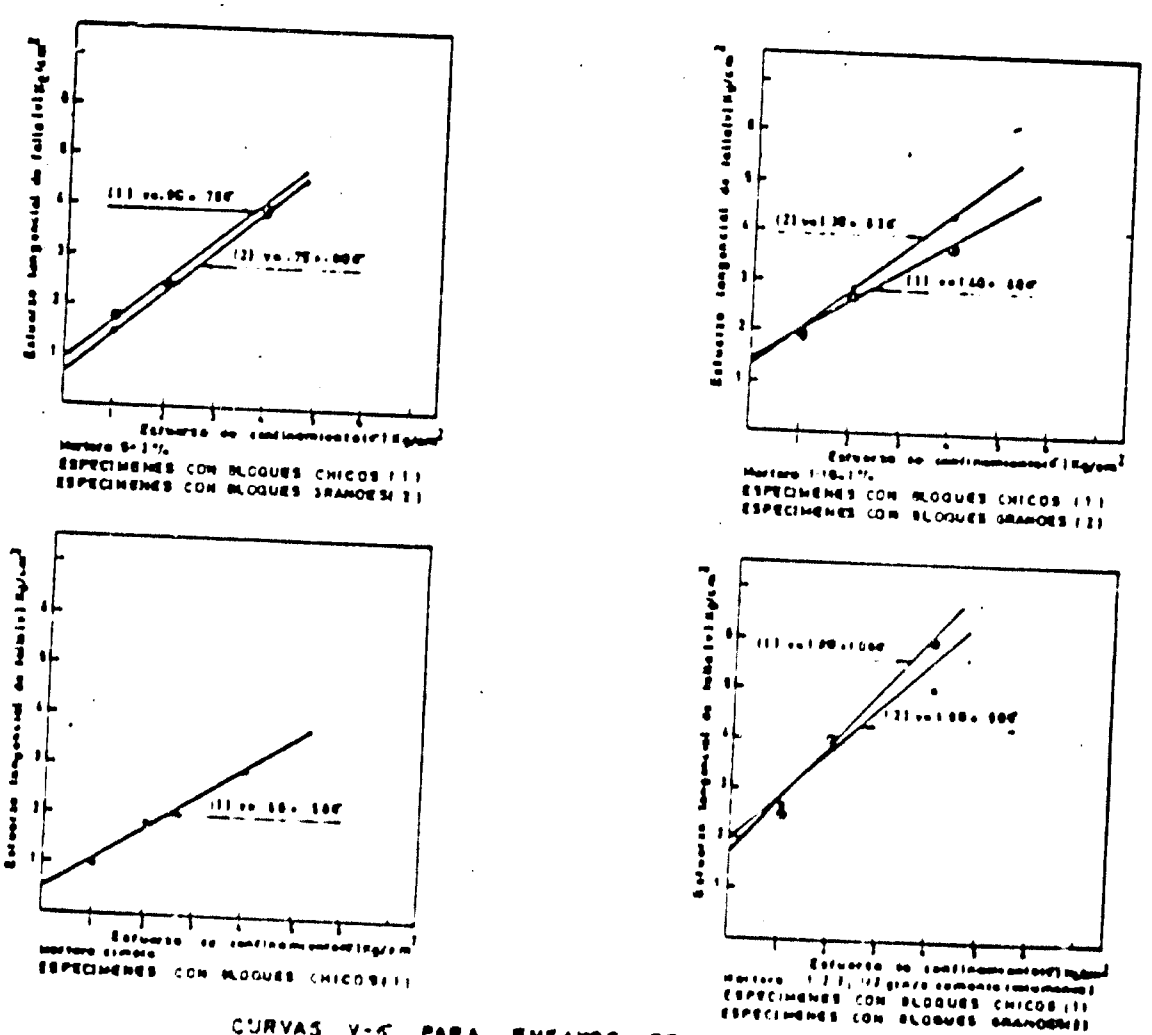


FIG. 7 · ESPECIMENES DE ENSAYO



CURVAS V-σ PARA ENSAYOS DE CORTE DIRECTO

FIG. 8 RESULTADO DE ENSAYO DE CORTE

A N E X O A

MATERIALES UTILIZADOS

Suelo. Se utilizó material extraído de terrenos de la Universidad Nacional de Ingeniería, designado en este estudio como M-2. Sus características básicas son las siguientes:

Granulometría:				
		Peso específico de sólidos:		2.65
arena	42 %	Límite líquido	:	25.5
limo	50 %	Límite plástico	:	17.5
arcilla	8 %	Límite de contracción	:	15
		Indice de plasticidad	:	8
		Clasificación S.U.C.S.	:	CL

Cemento y asfalto. Se usó cemento normal ASTM Tipo 1 y asfalto líquido RC-2.

Bloques. Se fabricaron con suelo M-2 con 1.5% de asfalto, de dimensiones 26.5 x 26.5 x 7.5 cm. y 36.5 x 36.5 x 7.5 cm.

Morteros. Se utilizó cuatro clases de mortero:

a. 1:10:1% (por peso). Una parte de cemento, 10 de suelo y 1% del peso del suelo en peso de asfalto.

b. S-2% (por peso). Suelo con 2% de su peso en peso de asfalto.

c. 1:2:3:1/2 (por volumen). Una parte de cemento, dos de suelo, tres de arena gruesa y 1/2 galón de asfalto por saco de cemento.

d. Simple. Mezcla no estabilizada de suelo y agua.

El suelo utilizado en estos morteros fué previamente tamizado por la malla N° 4.

DISEÑO SISMICO DE CONSTRUCCIONES DE ADOBE Y BLOQUE ESTABILIZADO*
SEGUNDA PARTE : UN PROCEDIMIENTO DE DISEÑO DE CONSTRUCCIONES DE ADOBE

POR : ROBERTO MORALES M.**ALEJANDRO SANCHEZ O.***Y RICARDO YAMASHIRO***

RESUMEN

Se plantea un procedimiento racional de diseño de estructuras de muros de corte y se aplica a una construcción de adobe para dos casos: techo rígido y techo flexible, utilizando los esfuerzos admisibles determinados según las normas propuestas en la primera parte de este estudio.

SEISMIC DESIGN OF ADOBE AND STABILIZED BLOCK CONSTRUCTION*
SECOND PART: A DESIGN PROCEDURE FOR ADOBE CONSTRUCTION

POR : ROBERTO MORALES M** ALEJANDRO SANCHEZ O.*** AND RICARDO YAMASHIRO***

SUMMARY

A rational procedure for designing shear wall structures is proposed and applied to an adobe construction for two cases: rigid and flexible roof. utilizing allowable stresses determined according to the code proposed in the first part of this study.

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* En este trabajo se incluirá al bloque estabilizado en el término "adobe"

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INTRODUCCION

Teniendo en cuenta que en los países del Area Andina un porcentaje alto de sus construcciones son de adobe, y encontrándose dichos países en una zona altamente sísmica se precisa de procedimientos de análisis y diseño antisísmicos para construcciones de este tipo.

En este trabajo, que es la segunda parte del estudio, se plantea un procedimiento racional de diseño de estructuras de muros de corte y se aplica a una construcción de adobe para dos casos: techo rígido y techo flexible, utilizando los esfuerzos admisibles determinados según las normas propuestas en la primera parte de este estudio.

A.- ANALISIS

A.1 CASO DE TECHO RIGIDO

Al considerar techo rígido, la fuerza sísmica se repartirá entre los muros de acuerdo a sus rigideces.
Las rigideces se han calculado con la teoría elástica para muros de corte, ignorando la rotación de la base. Se advierte sin embargo, que la rotación de la base tiene en general una influencia importante, sobre todo, si se trata de suelos compresibles.
Para el cálculo de la fuerza sísmica y su punto de aplicación se considera que la fuerza es proporcional a la masa y que el techo es infinitamente rígido.

A.1.1 Rigideces de Muros

La rigidez de cada elemento dentro de un muro específico se determinará con la expresión (1), ver Fig. 1 :

$$K_i = \frac{1}{3} \frac{\ell_i}{h_i} E\, t_i \qquad (1)$$

Debe notarse que la ecuación (1) toma en cuenta únicamente las deformaciones por fuerza cortante, por ser estas deformaciones las más significativas.
En la deducción de la expresión (1) se ha tomado un coeficiente de forma de 1.2 y un módulo de elasticidad por corte (G) igual a 0.4E.
Se asumirá que los desplazamientos relativos en cada nivel son iguales (Ver Fig. 2). Considerando las ecuaciones de equilibrio y compatibilidad de deformaciones se determinará el cortante que toma cada elemento.
Para determinar la rigidez de cada muro se igualará el desplazamiento total, en la coronación del muro, a la suma de los desplazamientos parciales correspondientes.

A.1.2 Centro de Rigideces

Se considerará que la fuerza cortante en cada dirección principal de la edificación es tomada únicamente por los muros paralelos a dicha dirección.

A.1.3 Centro de Masa

Se considerará que la mitad del peso de todos los muros y el peso total del techo están aplicados en la parte superior de la edificación.

A.1.4 Fuerza Cortante Sísmica

La fuerza cortante sísmica se puede determinar usando un método estático de fuerzas equivalentes o un método dinámico cualesquiera.

A.1.5 Cortante que toma cada Muro

Para encontrar el cortante que toma cada muro se considerará :

a) Cortante directo debido a la fuerza sísmica
b) Cortante debido al efecto de torsión
c) Cortante debido a la torsión accidental.

El momento de torsión accidental se tomará como :

$$M_{T_x} = 0.05\ H\ B_y$$

Donde H : Fuerza cortante

B_y : Dimensión de la edificación perpendicular a la dirección de la fuerza cortante H.

A.2 CASO DE TECHO FLEXIBLE

A.2.1 Cálculo del Cortante que toma cada Muro.- El cortante que toma cada muro es proporcional a su área de influencia.

A.3 FUERZAS CORTANTES DE DISEÑO

En general el diseño se considerará para la condición respectiva de techo rígido o techo flexible. En el caso de duda acerca de la rigidez del techo, de las dos condiciones expuestas se toma para cada muro el valor de cortante más desfavorable.

B.- DISEÑO

Sólo se tratará del diseño estructural de los muros, las otras partes de la construcción deberán diseñarse siguiendo las normas usuales que los rigen.

B.1 Diseño de los Muros

Los esfuerzos permisibles tanto del adobe como de la caña se determinarán de acuerdo a las normas propuestas en la primera parte de este trabajo. Es decir que los esfuerzos admisibles se determinarán mediante ensayos de Laboratorio o a falta de éstos se usarán los esfuerzos que especifiquen las normas.

Se considerarán las siguientes partes :

a) Como muro de corte :

Se verificará el esfuerzo cortante en sus elementos, y se diseñará por flexión y se determinará el refuerzo adicional de los vanos.

b) Flexión como losa (Fuerza sísmica perpendicular al muro) :

Se determinará la armadura en uno o dos direcciones de acuerdo al número de bordes arriostrados.

c) Transferencia de esfuerzos a los diferentes elementos : Diseño del refuerzo para tomar la tracción que se transfiere a un muro o solera de otro muro ó solera transversal.

d) Diseño de la viga collar (Solera).- La solera se puede considerar como una viga contínua apoyada en los muros o soleras transversales, sometida a una carga horizontal distribuída igual a la reacción del muro correspondiente. Se tomará en cuenta la fuerza de tracción indicada en el acápite (c).

C.- EJEMPLO DE APLICACION*

En el ejemplo se ilustra el cálculo de las rigideces de los muros, luego del centro de masa.

El peso total considerado, igual a la mitad del peso de los muros más el peso del techo, se supone aplicado en la parte superior de los muros.

Conocida la línea de acción de la fuerza resultante se puede calcular el momento de torsión. A continuación se distribuye la fuerza cortante entre los elementos de acuerdo a sus rigideces y se hace la corrección por torsión, resultando los valores que se muestran a continuación :

Muro	Corte Directo	Corrección Por Torsión	Corrección por Torsión Accid.	Corte Total (Ton.)
10-1	1.29	-0.11	± 0.10	1.29
13-2	0.91	0.00	0.00	0.91
16-5	0.92	0.10	± 0.09	1.11
1-5	1.77	-0.10	± 0.09	1.86
10-16	1.35	0.11	± 0.09	1.55

* En el apéndice se presenta los detalles del cálculo.

Considerando el caso de techo flexible, se obtiene :

Muro	Cortante (Ton.)
10-1	0.69
13-2	1.56
16-5	0.87
1-5	1.56
10-16	1.56

FUERZA CORTANTE DE DISEÑO.- En este ejemplo se supone que existe duda respecto a la rigidez del techo, por lo que se considerará el mayor de los cortantes obtenidos de las condiciones de techo rígido y techo flexible.

Muro	Cortante (Techo Rígido)	Cortante (Techo Flexible)	Cortante de Diseño (Ton.)
10-1	1.39	0.69	1.39
13-2	0.91	1.56	1.56
16-5	1.11	0.87	1.11
1-5	1.86	1.56	1.86
10-16	1.55	1.56	1.56

ESFUERZOS ADMISIBLES.- En este caso son los siguientes*:

Esfuerzo de Compresión : $f_m = 2.56\ Kg/cm^2$

Esfuerzo Cortante Permisible : $V = 0.18\ Kg/cm^2$

Esfuerzo de tracción permisible de la caña : $f_s = 300\ Kg/cm^2$

En el ejemplo se ha diseñado el muro 10-16. (Ver Fig. 5)

Los esfuerzos admisibles de las Normas adoptadas corresponden a esfuerzos promedios obtenidos dividiendo el corte actuante entre el área de la sección resistente del elemento. El máximo esfuerzo en el muro 10-16 es $0.09\ Kg/cm^2$ correspondiente al elemento (4). Este esfuerzo es muy inferior al admisible que es de $0.18\ Kg/cm^2$.

El momento flector en cada elemento se calculó suponiendo su punto de inflexión en la mitad de la altura. Por ejemplo para el elemento (3) :

$$M = \frac{Vh}{2} = \frac{410 \times 90}{2} = 18{,}450\ Kg\text{-}cm.$$

$$A_s = \frac{M}{f_s\ jd} = \frac{18{,}450}{300\ (.87)\ 141} = 0.50\ cm^2$$

Esta área de refuerzo se coloca cerca de cada borde del elemento.

En el diseño del muro como losa se ha tomado, en el ejemplo, una posición conservadora al asumir apoyos simples en los extremos. Sin embargo la cantidad de refuerzo es moderada igual a $1.38\ cm^2$ por metro de longitud, que como ilustración equivale a una caña de diámetro de 3/4" colocado a 76 cm (2 bloques). Esta caña es recomendable usarla partida.

En los ejemplos se ilustra el diseño de la viga collar para el muro 1-5. Conservadoramente se ha tomado sobre la viga so-

* Los esfuerzos de compresión y corte corresponden a una clase de albañilería de bloque estabilizado.

lera una carga correspondiente a la mitad de la carga del muro. Se ha hecho un "análisis exacto" de acuerdo a la teoría elástica de vigas contínuas, aunque se considera que sería suficiente con un cálculo aproximado. En el caso de la viga collar del muro 1-5, el momento negativo es de 272 Kg-m y los momentos positivos de 67 Kg-m y 190 Kg-m. Diseñando para los máximos momentos resultan una área de caña de 4.34 cm^2. Considerando una viga solera formada por las 4 hiladas superiores del muro debe colocarse 6 cañas de 1.45 cm^2 cada uno, 3 en cada cara.

La reacción interior de la viga collar 1-5 es tomada por la viga solera del muro 13-2. Esta reacción es de 776 Kg. y requiere de un área de caña de 1.30 cm^2 en cada cara. Sin embargo, como esta solera requiere en el centro del tramo un área de 6.86 cm^2, se usará esta última cantidad.

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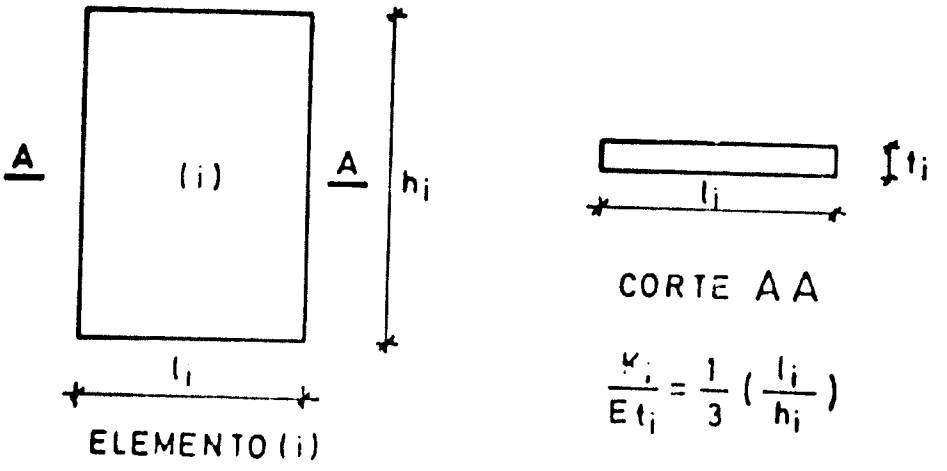


FIGURA (1)

RIGIDEZ DE UN ELEMENTO

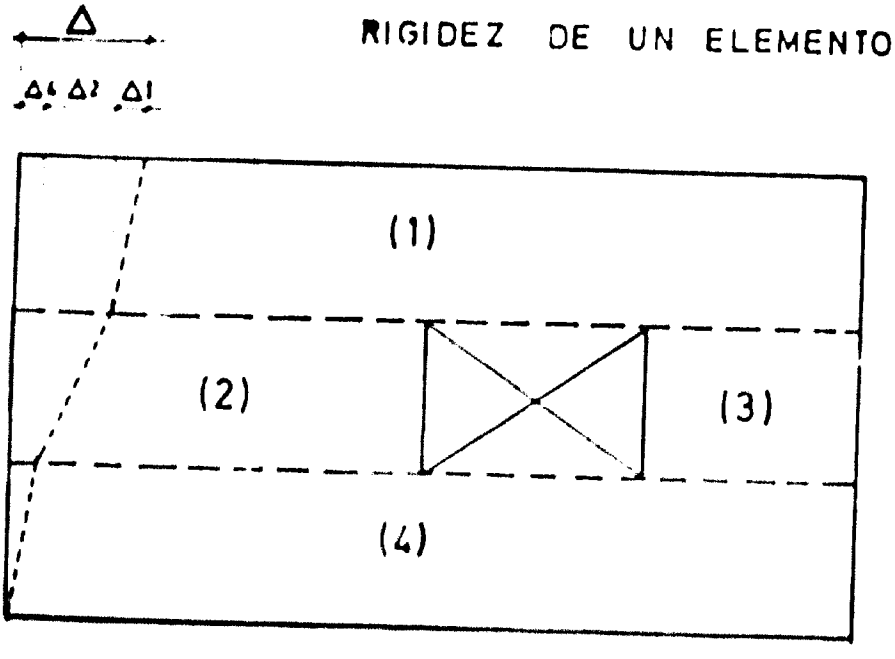
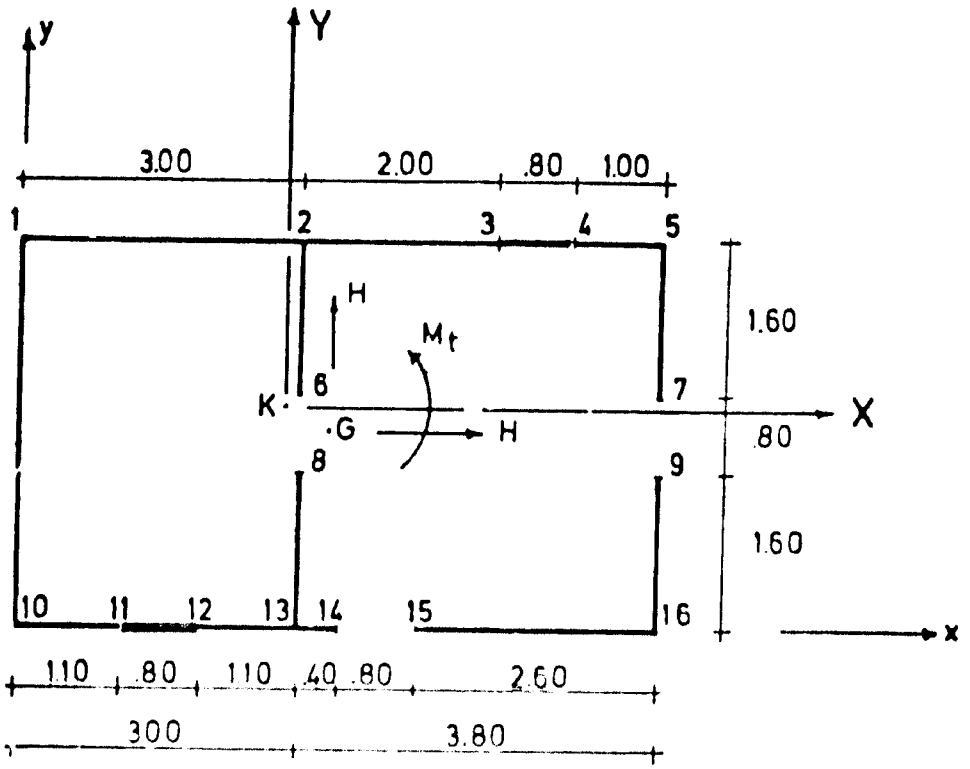


FIGURA (2)

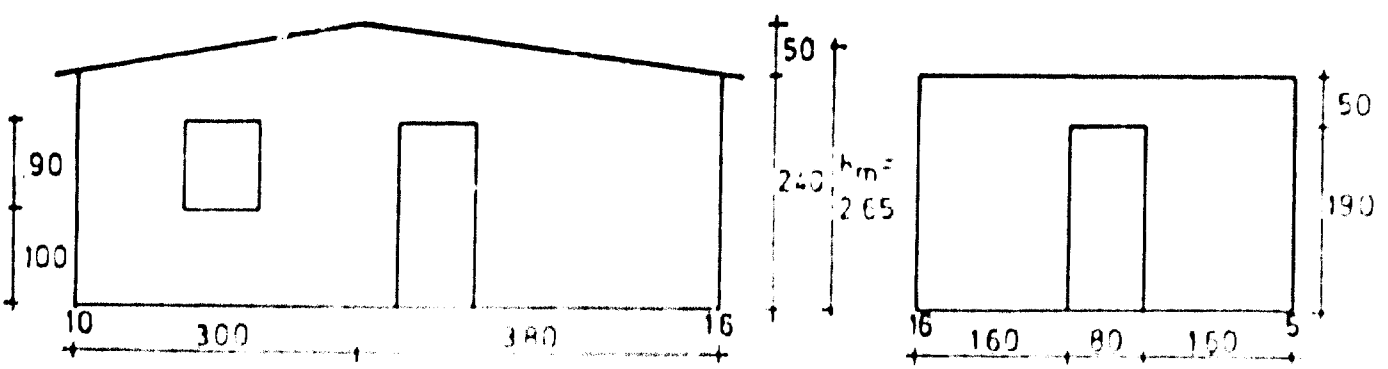
$\Delta = \Delta_1 \cdot \Delta_2 \cdot \Delta_4$

RIGIDEZ DE UN MURO CON ABERTURA



a) PLANTA
Esc. 1:75

centro de masa G(3.76, 2.04)
centro de rigidez K(2.88, 2.27)



b) ELEVACION 10-16
Esc. 1:75

c) ELEVACION 16-5
Esc. 1:75

Fig 3 CASA DE LOS EJEMPLOS ILUSTRATIVOS

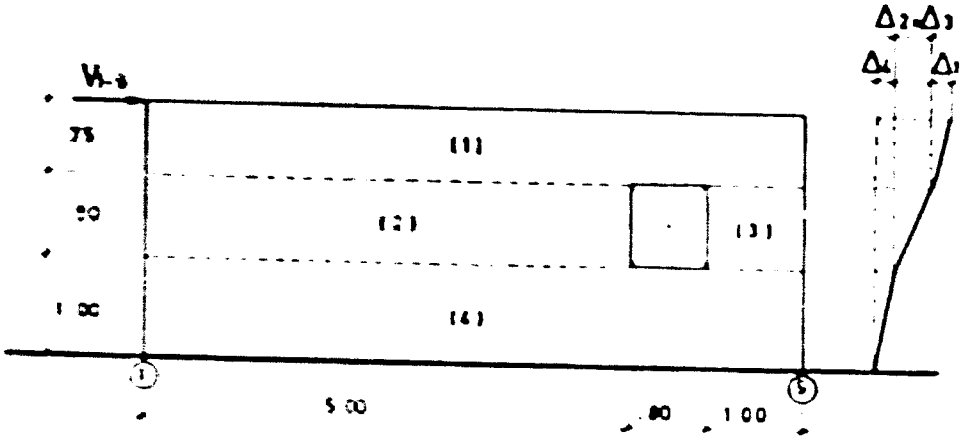


Fig 4 RIGIDEZ DE MURO 1-5

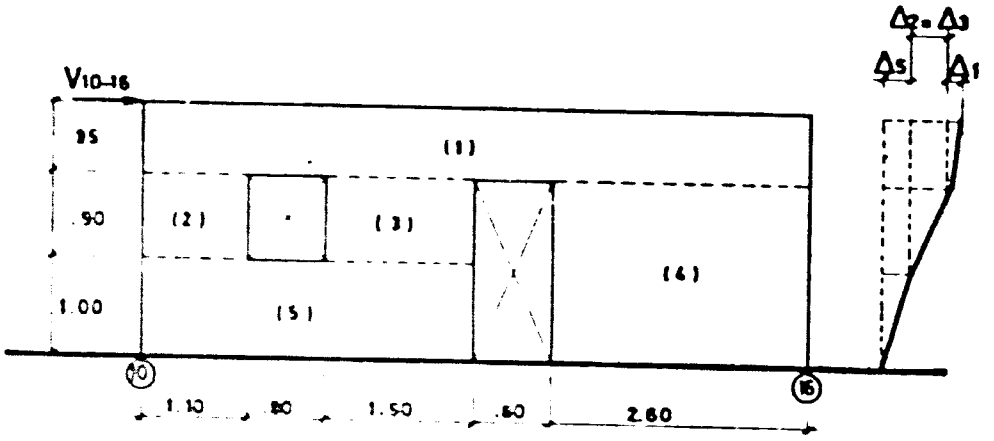


Fig. 5 RIGIDEZ DE MURO 10-16

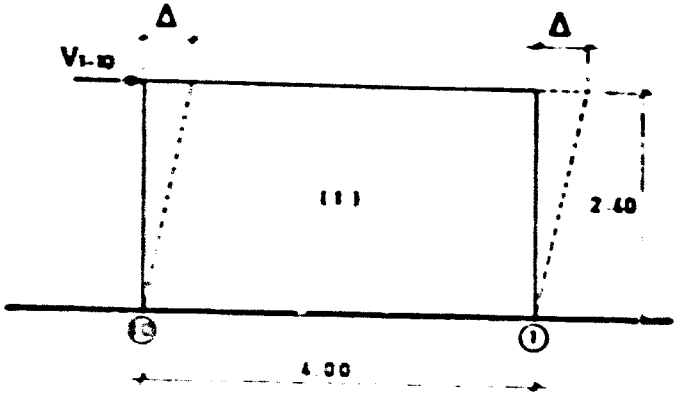


Fig. 6 RIGIDEZ DE MURO 10-1

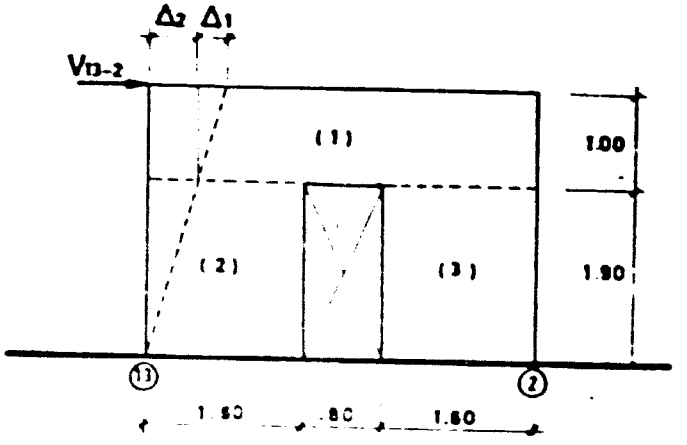


Fig 7 RIGIDEZ DE MURO 13-2

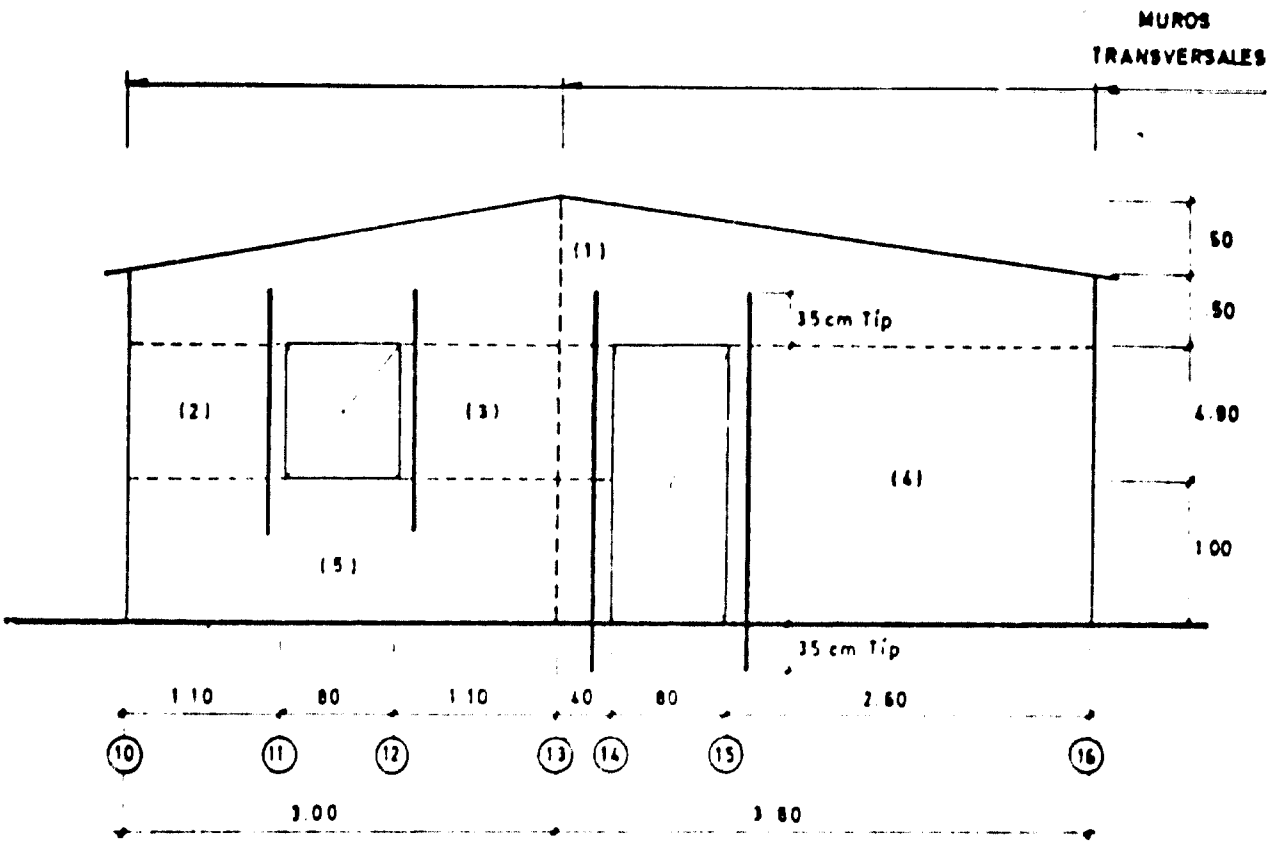
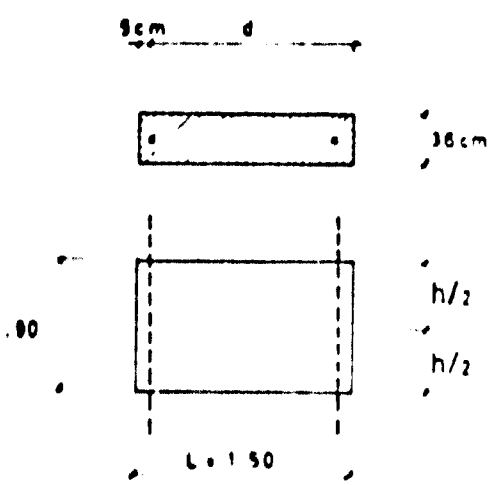
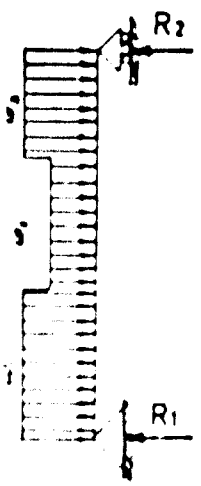


Fig 8 DISEÑO DE MURO 10-16





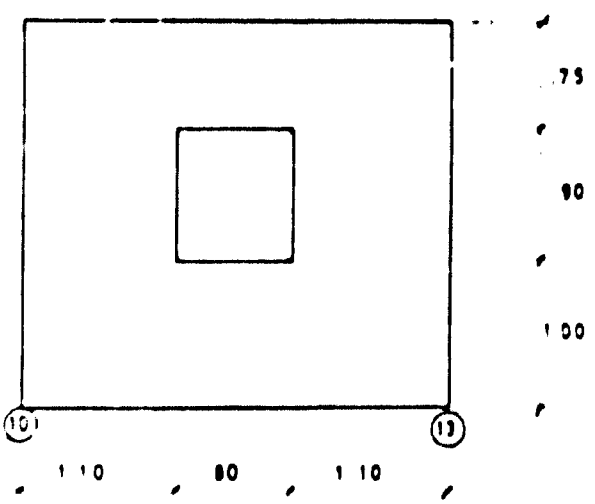


Fig.9 REFUERZO DE VANO Fig 10 DETERMINACION DE ARMADURA VERTICAL

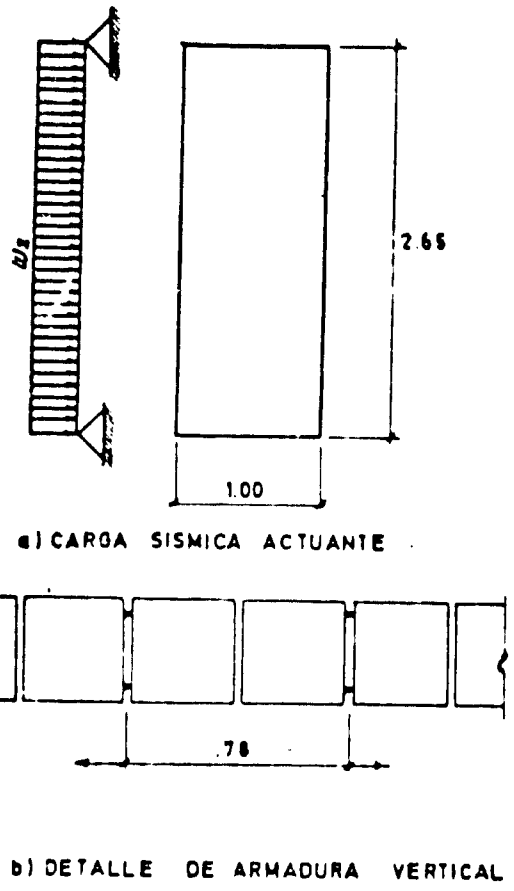


Fig. 11. ARMADURA VERTICAL

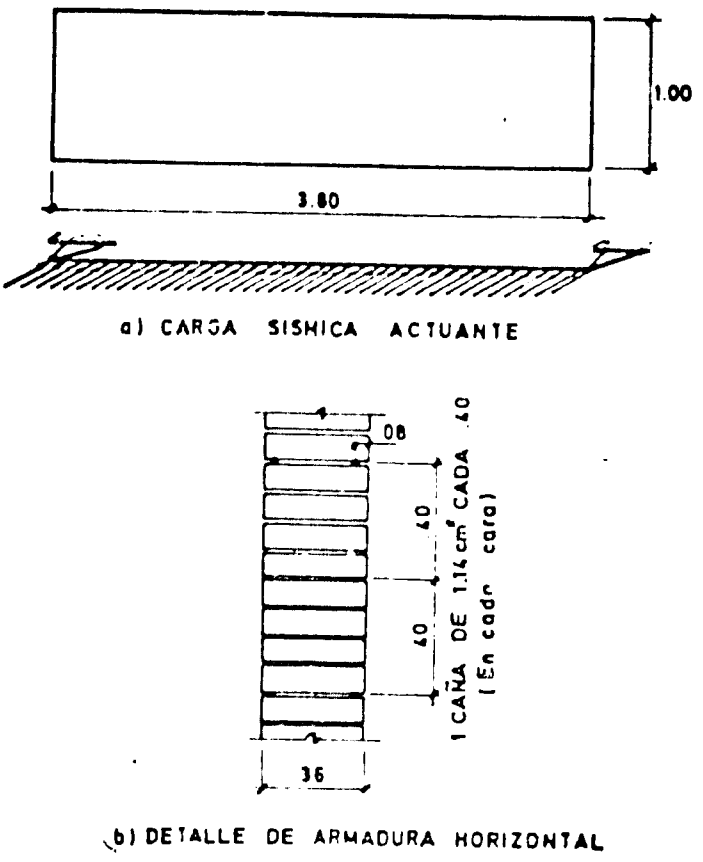


Fig. 12. ARMADURA HORIZONTAL

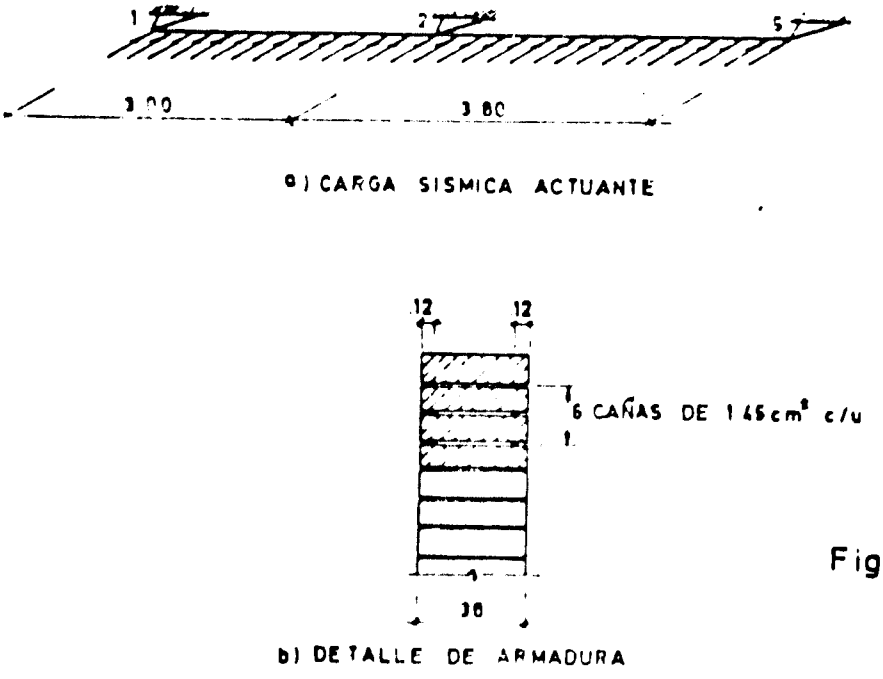


Fig. 13. VIGA SOLERA

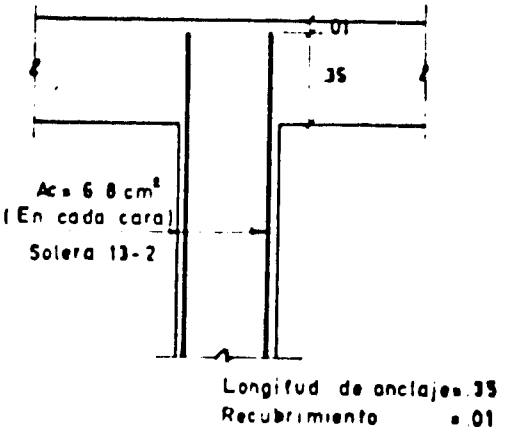
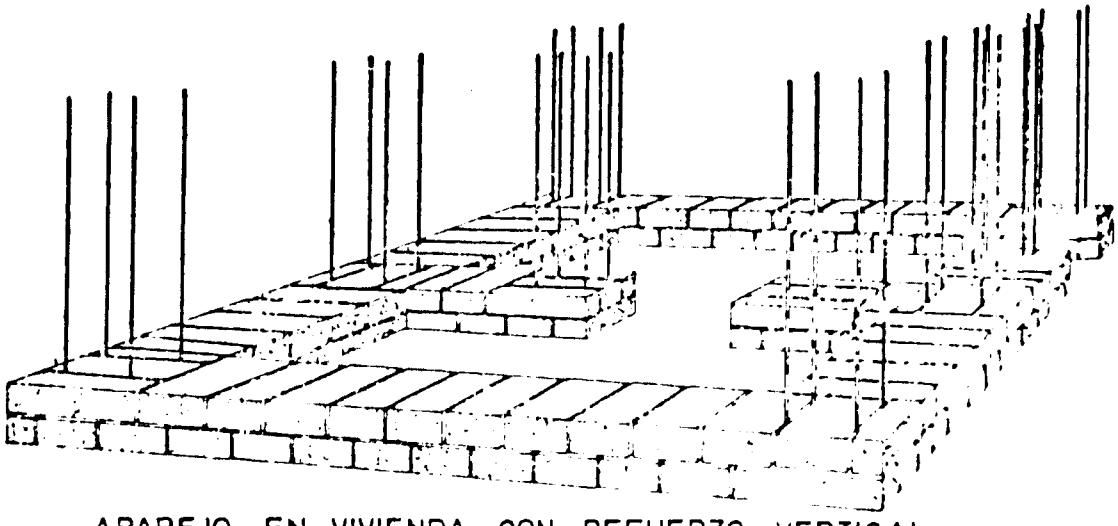


Fig. 14. VERIFICACION EN TRACCION DE VIGA SOLERA 13-2



APAREJO EN VIVIENDA CON REFUERZO VERTICAL

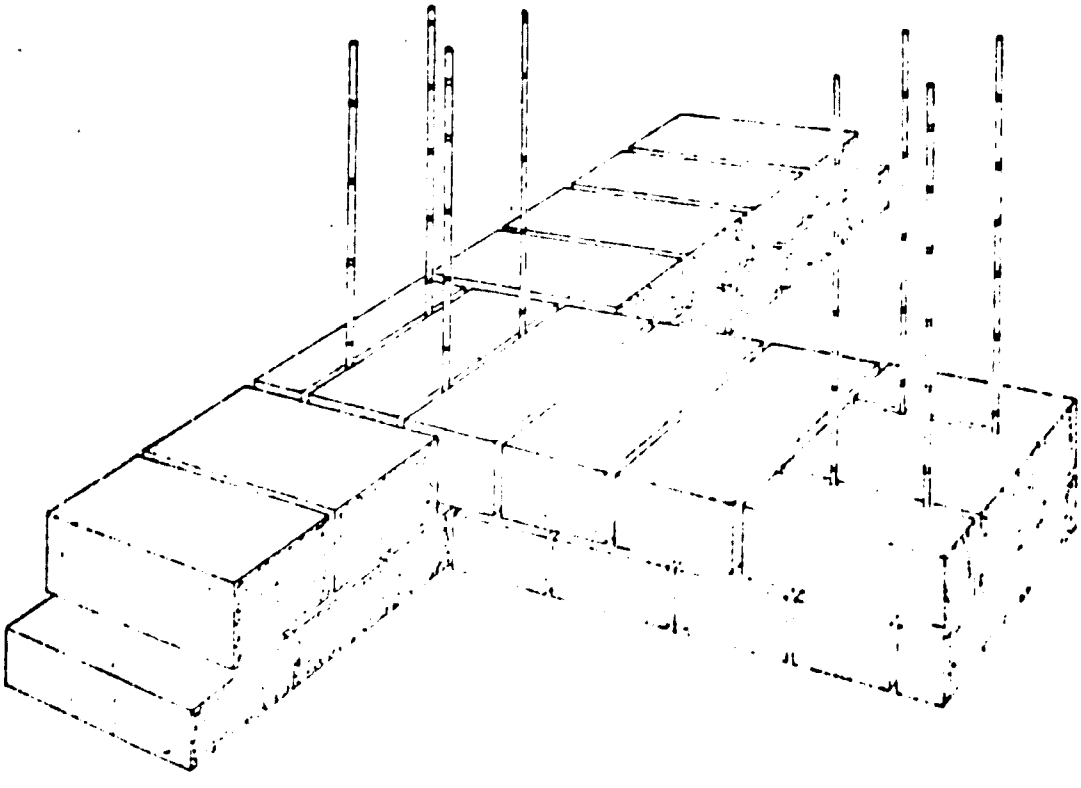


Fig 15 APAREJO EN ENCUENTRO DE MUROS

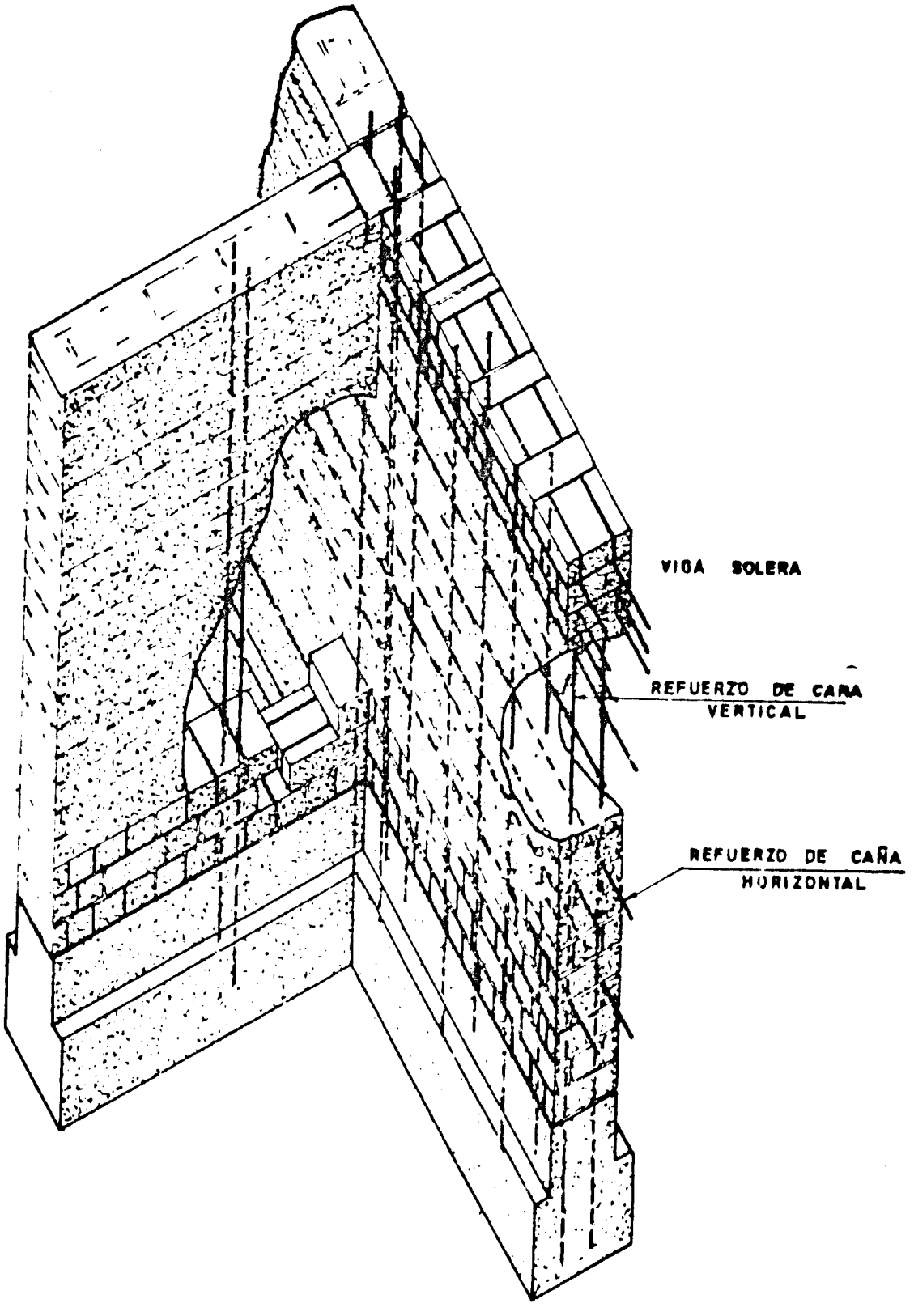
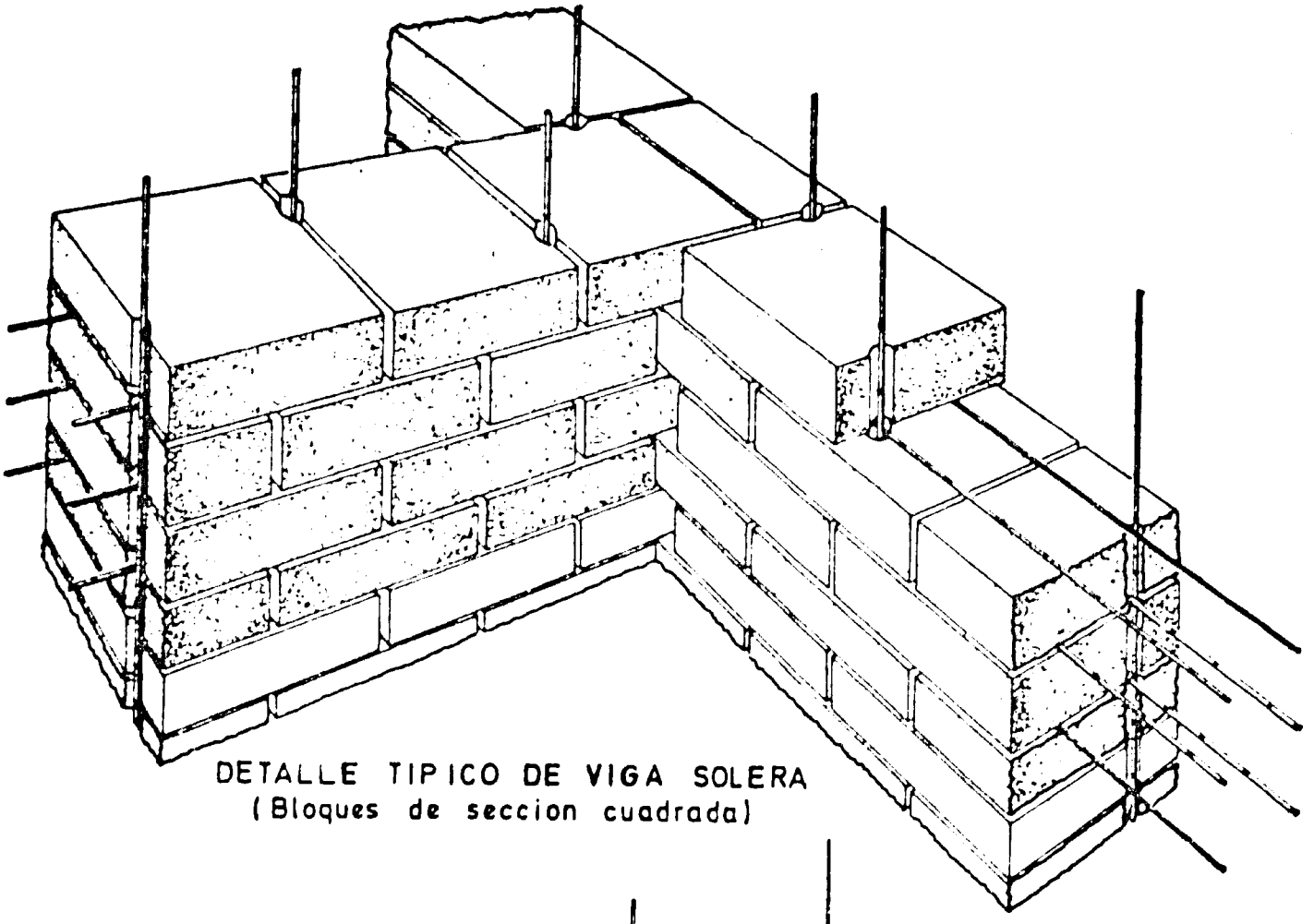
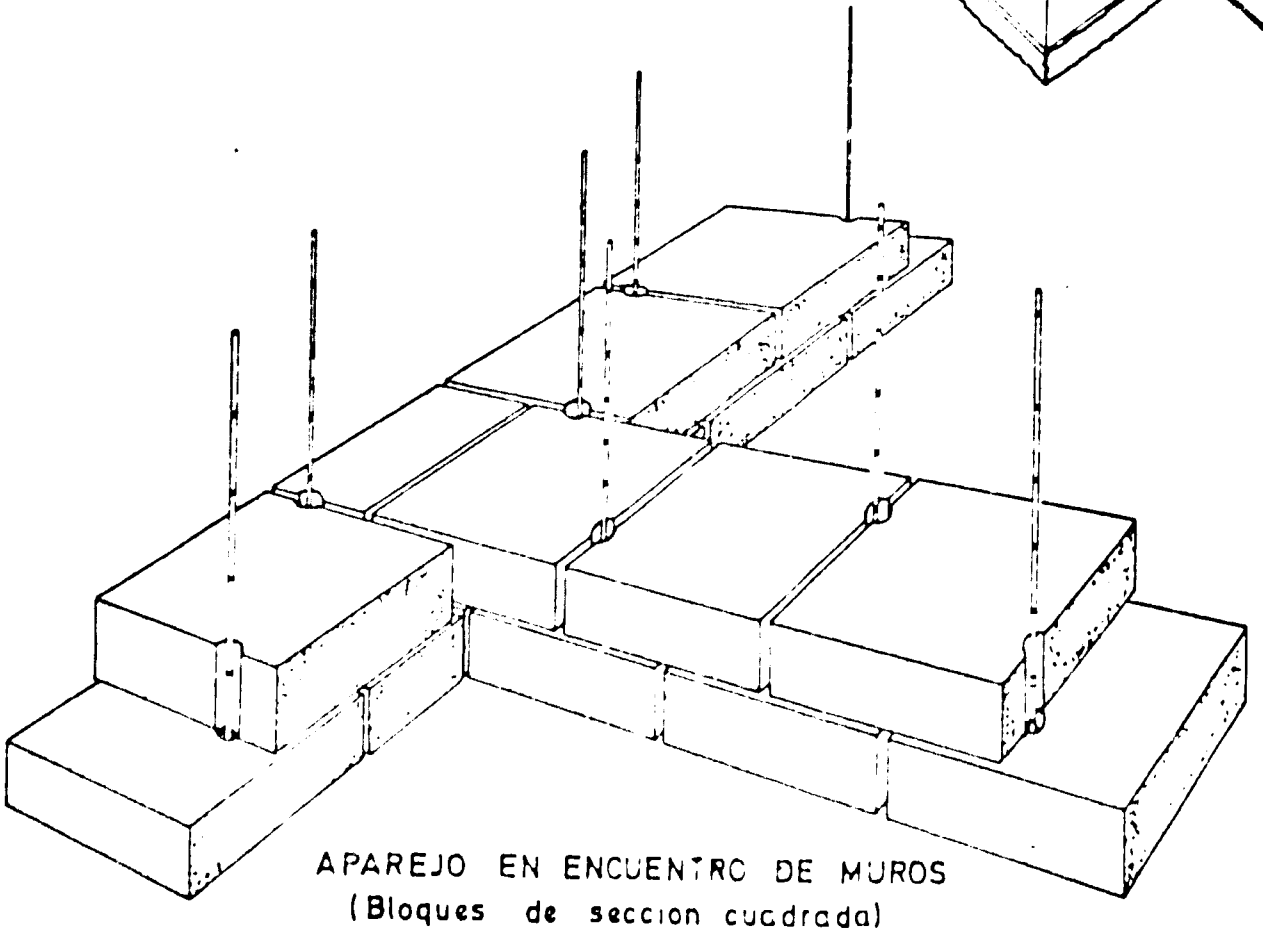


Fig 16 DETALLE DE INTERSECCION DE MUROS DE .36 mt.



DETALLE TIPICO DE VIGA SOLERA
(Bloques de seccion cuadrada)



APAREJO EN ENCUENTRO DE MUROS
(Bloques de seccion cuadrada)

Fig 17

ANEXO

EJEMPLO NUMERICO

En este ejemplo se hará el análisis y diseño de la construcción de adobe mostrada en la Fig. 1. En la determinación de las fuerzas sísmicas de diseño se ha adoptado un coeficiente sísmico de 0.16 para el análisis del conjunto, y de 0.20 para el análisis de los elementos.

1.- ANALISIS

1.1 CASO DE TECHO RIGIDO

1.1.1 DETERMINACION DE RIGIDECES DE MUROS

MURO 1-5 : (VER FIG. 4)

$$K_1 = \frac{1}{3}\left(\frac{6.80}{.75}\right)Et = 3.02\ Et \qquad K_3 = \frac{1}{3}\left(\frac{1.00}{0.90}\right)Et = 0.37Et$$

$$K_2 = \frac{1}{3}\left(\frac{5.00}{.90}\right)Et = 1.85\ Et \qquad K_4 = \frac{1}{3}\left(\frac{6.80}{1.00}\right)Et = 2.27Et$$

Ecuaciones de equilibrio y de compatibilidad :

$V_1 = V$	(1)	$V_1 = V$	
$V_2 + V_3 = V$	(2)	$V_4 = V$	
$V_4 = V$	(3)	$V_2 + V_3 = V$	(2')
$\Delta_2 = \Delta_3$	(4)	$\Delta_2 = \Delta_3$	(4')

En (4') : $\frac{V_2}{K_2} = \frac{V_3}{K_3}$ —— $V_2 = V_3 \frac{K_2}{K_3} = \frac{1.85}{0.37} V_3 = 5V_3 \qquad V_2 = 5V_3$ (5)

De las ecuaciones (2') y (5) : $V_2 = 0.833\ V$

$V_3 = 0.167\ V$

$V_1 = V$

$V_2 = 0.833\ V$ Cortante que toman los elementos

$V_3 = 0.167\ V$ del Muro 1-5.

$V_4 = V$

Rigidez del Muro : $\Delta = \Delta_1 + \Delta_2 + \Delta_4$

$$\frac{V}{K} = \frac{V_1}{K_1} + \frac{V_2}{K_2} + \frac{V_4}{K_4}$$

$$\frac{V}{K} = \left(\frac{V}{3.02} + \frac{0.833V}{1.85} + \frac{V}{2.27} \right) \frac{1}{Et}$$

$$\frac{1}{K} = \frac{1.222}{Et} \quad \therefore \quad K_{1-5} = 0.818\ Et$$

Muro 10-16 : (Ver Fig. 5)

$$K_1 = \frac{1}{3}\left(\frac{6.80}{.95}\right)Et = 2.386\ Et \qquad \Delta_1 = \frac{V}{K_1} = 0.419 \cdot \frac{V}{Et}$$

$$K_2 = \frac{1}{3}\left(\frac{1.10}{.90}\right)Et = 0.407\ Et \qquad \Delta_2 = \frac{V_2}{K_2} = 2.457 \cdot \frac{V_2}{Et}$$

$$K_3 = \frac{1}{3}\left(\frac{1.50}{.90}\right)Et = 0.555\ Et \qquad \Delta_3 = \frac{V_3}{K_3} = 1.802 \cdot \frac{V_3}{Et}$$

$$K_4 = \frac{1}{3}\left(\frac{2.60}{1.90}\right)Et = 0.456\ Et \qquad \Delta_4 = \frac{V_4}{K_4} = 2.193 \cdot \frac{V_4}{Et}$$

$$K_5 = \frac{1}{3}\left(\frac{1.90}{1.00}\right)Et = 0.633\ Et \qquad \Delta_5 = \frac{V_5}{K_5} = 1.580 \cdot \frac{V_5}{Et}$$

Ecs. de Compatibilidad : $\Delta_2 = \Delta_3$ (1)

$\Delta_5 + \Delta_3 = \Delta_4$ (2)

Ecs. de Equilibrio : $V_2 + V_3 = V_5$ (3)

$V_2 + V_3 + V_4 = V$ (4)

Resolviendo :

De Ec (1) $2.457\ V_2 = 1.802\ V_3$ $V_2 = 0.733\ V_3$

En Ec (4) $1.733\ V_3 = V_5$ $V_3 = 0.577\ V_5$

En Ec (2) $1.580\ V_5 + 1.040\ V_5 = 2.193\ V_4$

$V_4 = 1.195\ V_5$

En Ec (4) $.733\ (.577)V_5 + .577\ V_5 + 1.195\ V_5 = V$

$V_5 = .456\ V$

$V_4 = .544\ V$

$V_3 = .263\ V$

$V_2 = .193\ V$

$V_1 = V$

$$\Delta = \Delta_1 + \Delta_4 = .419\ \frac{V}{Et} + 1.193\ \frac{V}{Et} = 1.612\ \frac{V}{Et}$$

$$k_{10-16} = 0.620\ Et$$

Muro 10-1 : (Ver Fig. 6)

$$K_1 = \frac{1}{3}\left(\frac{4.00}{2.40}\right) = 0.555\ Et$$

$$k_{10-1} = .555\ Et$$

Muro 13-2 : (Ver Fig. 7)

$$K_1 = \frac{1}{3}\left(\frac{4.00}{1.00}\right)Et = 1.333\ Et \qquad \Delta_1 = \frac{V}{K_1} = .75\ \frac{V}{Et}$$

$$K_2 = \frac{1}{3}\left(\frac{1.60}{1.90}\right)Et = .281\ Et \qquad \Delta_2 = \frac{V_2}{K_2} = 3.559\ \frac{V_2}{Et}$$

$$K_3 = \frac{1}{3}\left(\frac{1.60}{1.90}\right)Et = .281\ Et \qquad \Delta_3 = \frac{V_3}{K_3} = 3.559\ \frac{V_3}{Et}$$

Ec. de Compatibilidad : $\Delta_2 = \Delta_3$ (1)

Ec. de Equilibrio : $V_2 + V_3 = V$ (2)

En (1) : $V_2 = V_3$

En (2) : $V_2 = V_3 = 0.5\ V$

$V_1 = V$

$$\Delta = \Delta_1 + \Delta_2 = (.75 + 1.780)\ \frac{V}{Et} = 2.530\ V/Et$$

$$k_{13-2} = .395\ Et$$

<u>Muro 16-5</u> :

$$k_{16-5} = k_{13-2} = .395\ Et$$

1.1.2 Ubicación del centro de masa con respecto al sistema xy (Ver Fig. 1)

CENTRO DE MASA DE ELEMENTOS VERTICALES		Pesos (T)	Coordenadas x	Coordenadas y	Momentos Estat. P_x	Momentos Estat. P_y
1-5	0.5(6.80 x 2.65 x .36 x 1.6)*	5.20	3.40	4.00	17.70	20.80
3-4	-0.5(.80 x .90 x .36 x 1.6)	-0.21	5.40	4.00	- 1.14	- .84
10-16	0.5(6.80 x 2.65 x .36 x 1.6)	5.20	3.40	0.00	17.70	0
11-12	-0.5(.80 x .90 x .36 x 1.6)	- .21	1.50	0.00	- .31	0
14-15	-0.5(.80 x 1.90 x .36 x 1.6)	- .44	3.80	0.00	- 1.67	0
10-1	0.5(4.00 x 2.40 x .36 x 1.6)	2.73	0.00	2.00	0	5.56
13-2	0.5(4.00 x 2.90 x .36 x 1.6)	3.35	3.00	2.00	10.05	6.70
8-6	-0.5(.80 x 1.90 x .36 x 1.6)	- .44	3.00	2.00	- 1.32	- .88
16-5	0.5(4.00 x 2.40 x .36 x 1.6)	2.78	6.80	2.00	19.00	5.56
9-7	-0.5(.80 x 1.90 x .36 x 1.6)	- .44	6.80	2.00	- 3.00	- .88
Techo	0.070 x 6.80 x 4.00 **	1.90	3.40	2.00	6.47	3.80
		19.47			63.49	39.82

$$\bar{x} = \frac{P_x}{P} = \frac{63.49}{19.47} = 3.26 \text{ m.}$$

$$\bar{y} = \frac{P_y}{P} = \frac{39.82}{19.47} = 2.04 \text{ m.}$$

* Para los muros el peso específico es de 1.6 Ton/m^3

** Para el techo el peso por unidad de superficie es 0.070 T/m^2

1.1.3 Determinación del centro de rigidez con respecto al sistema xy (Ver Fig. 1)

	Muro	k	x	y	kx	ky
Dirección y	10-1	.555	0	-	0	-
	13-2	.395	3.00	-	1.19	-
	16-5	.395	6.80	-	2.69	-
		1.345			3.88	
Dirección x	1-5	.818	-	4.00	-	3.27
	10-16	.620	-	0	-	0
		1.438				3.27

Coordenadas del centro de rigidez K :

$$x_K = \frac{Kx}{K} = \frac{3.88}{1.345} = 2.88$$

$$y_K = \frac{Ky}{K} = \frac{3.27}{1.438} = 2.27$$

$\therefore$ K(2.88, 2.27)

1.1.4 Fuerza Sísmica.-

H = c W = 0.16 x 19.47 Ton = 3.12 Ton.

1.1.5 Cálculo del cortante que toma cada muro

Momentos de torsión :

M_{t_x} = H ey = 3.12 Ton (0.23 m) = 0.72 ton.-m

M_{t_y} = H ex = 3.12 Ton (0.38 m) = 1.19 ton.-m

Momentos de torsión accidental :

M_{t_x} = 0.05 H By = 0.05 x 3.12 x 4 = **0.62 ton.-m**

M_{t_y} = 0.05 H Bx = 0.05 x 3.12 x 6.80 = **1.06 ton.-m**

Muros	$\frac{k}{\sum K}H$	d*	kd	kd^2	$\frac{kd}{\sum kd^2} M_T$	$\frac{kd}{\sum kd^2} M_{t_a}$	Vi (Ton)
10-1	1.29	-2.88	-1.60	4.61	-0.11	± 0.10	1.39
13-2	0.91	-0.12	0.05	0.01	0.00	0.0	0.91
16-5	0.92	3.92	1.55	6.08	0.10	± 0.09	1.11
1-5	1.77	-1.73	-1.42	2.46	-0.10	± 0.09	1.86
10-16	1.35	2.73	1.69	4.61	0.11	+ 0.09	1.55
				17.77			

* La distancia "d" se mide con respecto al centro de rigidez.

1.2 CASO DE TECHO FLEXIBLE

1.2.1 Cálculo del Cortante que toma cada Muro.

Muro	Area de Influencia	m^2	Vi (Ton.)
10-1	4 x 1.5	6.0	.69
13-2	3.40 x 4	13.60	1.56
16-5	1.90 x 4	7.60	0.87
		$\sum$ = 27.20	$\sum$ = 3.12 Conforme
1-5	6.80 x 2	13.60	1.56
10-16	6.80 x 2	13.60	1.56
			3.12 Conforme

1.3 FUERZAS CORTANTES DE DISEÑO

En general el diseño se considerará para la condición respectiva de techo rígido o techo flexible. En el caso de duda a cerca de la rigidez del techo de las dos condiciones expuestas se toma para cada muro el valor de cortante mas desfavorable. En este ejemplo se sigue el último criterio.

Muro	Cortante (Techo Rígido)	Cortante (Techo Flexible)	Cortante de Diseño (Ton)
10-1	1.39	0.69	1.39
13-2	0.91	1.56	1.56
16-5	1.11	0.87	1.11
1-5	1.86	1.56	1.86
10-16	1.55	1.56	1.56

2 DISEÑO

2.1 Resultado de los Ensayos Experimentales.- Para este ejemplar se reemplazarán los resultados experimentales obtenidos para los especímenes con mortero S-2 %. (Suelo + 2% de su peso en asfalto)

Resistencia a la Compresión Axial: $f'_m = 12.8\ Kg/cm^2$

Deformación Unitaria por Compresión Axial: 13.5×10^{-3}

Módulo de Elasticidad: $E = 2140\ Kg/cm^2$

Esfuerzo de Adherencia: $u = 0.90\ Kg/cm^2$

Coeficiente de fricción : $f = 0.7$

Resistencia a la tracción de la caña: $f'_s = 1200\ Kg/cm^2$

2.2 Esfuerzos Admisibles.- Según las normas propuestas en la primera parte de este trabajo, se tomarán:

a).- Esfuerzo de Compresión: $f_m = \frac{1}{5} f'_m = \frac{12.8}{5} = 2.56\ Kg/cm^2$

b).- Esfuerzo Cortante Permisible: $v = \frac{1}{5} u = \frac{0.90}{5} = 0.18\ Kg/cm^2$

c).- Esfuerzo de Tracción permisible de la Caña: $f_s = \frac{1}{4} f'_s = \frac{1200}{4} =$

$= 300\ Kg/cm^2$

2.3 Diseño de los Muros

2.3.1 Verificación del esfuerzo cortante en cada elemento de los muros (Muro 10-16) (Ver Fig. 8)
(Esfuerzo cortante permisible = 0.18 Kg/cm^2)

	V_i (Ton.)	Area (cm^2)	$v = \frac{V}{A}$ (Kg/cm^2)	Observaciones.
$V_1 = V$	= 1.56	680 x 36 = 24,480	0.06	Conforme
$V_2 = .193\ V$	= .30	110 x 36 = 3960	0.07	Idem.
$V_3 = .263\ V$	= .41	150 x 36 = 5400	0.08	Idem.
$V_4 = .544\ V$	= .85	260 x 36 = 9360	0.09	Idem.
$V_5 = .456\ V$	.71	340 x 36 = 12,240	0.06	Idem.

2.3.2 <u>Flexión en el plano del muro</u> : Refuerzo de los vanos

El momento flector debido al cortante es : $M = \frac{Vh}{2}$

<u>Elemento 3</u> : $M = \frac{410 \text{ Kg } (90 \text{ cm})}{2} = 18,450 \text{ Kg-cm}$

(Ver Figs.: 8 y 9) $A_s = \frac{M}{f_s \, jd} = \frac{18450}{300 \times 0.87 \times 141}$

$A_s = 0.50 \text{ cm}^2$ de caña

Elemento 2 : $M = \frac{300 \times 90}{2} = 13,500 \text{ Kg-cm.}$

(Ver Fig. 8) $A_s = \frac{13,500}{300 \ (.87) \ (101)} = 0.51 \text{ cm}^2$

Usar $A_s = 0.51 \text{ cm}^2$ de caña colocada en los bordes de ventana y puerta. Se dará una longitud mínima de anclaje de 35 cm, como se indica en el esquema respectivo.

2.3.3 <u>Determinación de la armadura vertical.</u> (Muro 10-13)

(Ver Fig. 10)

Carga sísmica normal $W = 0.20 \ W = 0.20 \ (1.6 \text{ T/m}^3 \times 0.36)$

$W = 0.116 \text{ T/m}^2$

$W_1 = .116 \times 3.00 = 0.348 \text{ T/m.}$

$W_2 = .116 \times 2.20 = 0.255 \text{ T/m.}$

Por Equilibrio : $R_1 = .423$ Ton.

$R_2 = .416$ Ton.

Momento máximo : $M_{máx}$ = 0.261 ton. (para x = 1.29 m.)

El área de caña será :

$$A_s = \frac{M_{máx}}{f_s jd} = \frac{26,100}{300\ (.87)\ 28} = 3.57\ cm^2$$

considerando espaciamiento de 0.76 m : $A_s = \frac{3.57}{2.20} \times 0.76$

$$A_s = 1.23\ cm^2 \quad \text{(en cada cara)}$$

Para simplificar los cálculos se puede tomar una franja típica vertical de un metro de ancho, considerándola como viga simplemente apoyada en la cimentación y en la viga solera, como se muestra en seguida :

<u>Muro 15-16</u> : (Ver Fig. 11)

Fuerza sísmica : 0.20 W

W = Peso de Muro : 1.00 x 2.65 x 36 x 1.6 = W = 1.53 Ton.

H = 0.20 x 1.53 = 0.306 Ton.

$$M_{máx} = \left(\frac{WL}{8}\right)L = \frac{.306}{8} \times 2.65 = 0.101\ ton.$$

El área de caña será :

$$A_s = \frac{10,100}{300\ (.87)\ 28} = 1.38\ cm^2/m.$$

Considerando espaciamiento de 0.76 :

$$A_{caña} = 0.76 \times 1.38 = 1.05\ cm^2 \quad \text{(En cada cara)}$$

2.3.4 <u>Determinación de la Armadura Horizontal</u> . (Ver Fig. 11)

Se ilustra a continuación el diseño del refuerzo cuando es horizontal. Para simplificar los cálculos se puede tomar una franja típica horizontal de un metro de altura, considerándola como viga simplemente apoyada en los muros transversales. El procedimiento se muestra en seguida :

Fuerza Sísmica = 0.20 W

$H = 0.20 \times 1.00 \times 3.80 \times .36 \times 1.6 = 0.44$ Ton.

$M_{máx} = \frac{.44}{8} \times 3.80 = 0.209$ ton.-m

El área de caña será :

$$A_s = \frac{20,900}{300\ (.87)\ 28} = 2.86\ cm^2/m$$

Colocando el refuerzo de caña cada 4 hiladas se tiene :

$A_{caña} = 0.40 \times 2.86 = 1.14\ cm^2$

2.3.5 <u>Diseño de la Viga Collar</u> : Muro 1-5 = Muro 10-16

(Ver Fig. 13)

Peso Techo : $70\ Kg/m^2 \times 2.00$ = 140 Kg/m.

1/2 Peso Muro : $1,600\ Kg \times .36\ m \times 1.00 \times \frac{2.65}{2}$ = 763 Kg/m.

W = 903 Kg/m.

$w = 0.20\ W = 181$ Kg/m.

$K_{21} = 0.333 \qquad 0.558$

$K_{23} = \frac{0.263}{0.596} \qquad \frac{0.442}{1.000}$

$$M_{Isost} = \frac{1}{8} \times 181 \times 3^2 = 203 \text{ Kg-m.}$$

$$M_{Isost} = \frac{1}{8} \times 181 \times 3.80^2 = 326 \text{ Kg-m}$$

Los momentos positivos en la mitad de los tramos serán :

$$+ M_{1-2} = 203 - \frac{272}{2} = 67 \text{ Kg-m.}$$

$$+ M_{2-5} = 190 \text{ Kg-m.}$$

Considerando el momento máximo :

$$A_s = \frac{27,200}{300\ (.87)\ (24)} = 4.34 \text{ cm}^2$$

Considerando como viga solera las 4 últimas hiladas del muro se tiene :

$$A_s = \frac{4.34}{3} = 1.45 \text{ cm}^2 \quad \text{(En cada hilada y en cada cara)}$$

<u>Diseño de la Viga Collar, (Solera)</u>, 13-2 :

Peso Techo : $70 \times \frac{6.80}{2} = 238$ Kg/m.

1/2 Peso Muro : $1600 \times .36 \times 1.00 \times \frac{2.90}{2}$ m = 835 "

1073 Kg/m.

$$H = 0.20\ W = 0.20\ (1073) = 215 \text{ Kg/m.}$$

$$M_{máx} = \frac{WL^2}{8} = 215 \times \frac{4^2}{8} = 430 \text{ Kg-m}$$

$$A_s = \frac{43,000}{300\ (.87)\ 24} = 6.86\ cm^2$$

Considerando como viga solera las últimas 5 hiladas del muro se tendrá :

$$A_s = \frac{6.86}{4} = 2.46\ cm^2$$ (En cada hilada y en cada cara)

2.3.6 Verificación de la tracción en una solera por efecto de las fuerzas sísmicas actuantes en las soleras transversales.

Para la solera 1-5 del acápite 2.3.5 encontramos la reacción máxima (Apoyo 2)

$R_{máx} = 776$ Kg.

Y el área de caña en la solera transversal 13-2 debida a esta tracción es :

$$A_s = \frac{776}{300} = 2.59\ cm^2 < 2(6.86\ cm^2)$$ OK.

THE WORK IN PROGRESS CONCERNING AS ISMIC EARTHEN HOUSING IN CHINA

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ABSTRACT

Earthen housing is the main kind construction of residential and public buildings in rural area of south and southwest China. In this paper, the damage to earthen buildings and lessons from recent China's strong earthquakes, the aseismic design requirements, the mechanical characteristics of earthen materials and elements, the testing work on earthen housing are described. It shows that the earthen buildings can be used in seismic region provided the buildings are consistant with the requirements of aseismic design code.

THE WORK IN PROGRESS CONCERNING ASEISMIC EARTHEN HOUSING IN CHINA

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ABSTRACT

Earthen housing is the main kind of construction for residential and public buildings in rural area of the south, the southwest and the northwest China. In this paper, the damage to earthen buildings and lessons from recent China's strong earthquakes, the aseismic design requirements, the mechanical characteristics of earthen materials, as well as the testing work on full scale earthen housing are described. It shows that the earthen buildings can be used in seismic region provided the buildings are consistant with the requirements of aseismic design code.

INTRODUCTION

Earthen housing is widely used for residential and public buildings in rural area of the south, the southwest and the northwest China. It has had thousand years historical record. Most of them are single story buildings. A few earthen buildings, up to four stories, have been constructed in some cities and towns. The earthen walls also used as cladding walls in some industrial factory buildings. The earthen cave dwellings are used in loessic region of the northwest China.

The Yunnan Tonghai Earthquake of January 5, 1970, was one of the remarkable seismic events experienced in rural area of China in recent decades. The main shock had its epicentre near Tonghai county town of Yunnan Province. It had a Richter magnitude of 7.7. The focal depth of this event was about 1 5km. The peak intensity was over grade X according to the Chinese Seismic Intensity Scale which is similar to the Modified Mercalli(MM) scale. The Isoseismal lines of the event are shown in FIG. 1 (1). The intensity in Osan county town was grade IX. There were many earthen buildings in Osan county. However, the buildings that existed there before the earthquake were not designed to resist the vertical and lateral loads produced by strong ground motion. Many earthen walls and buildings damaged or collapsed, but some of them still stood well. The authors inspected survived walls and buildings and get a lot of usefull ideas.

In this paper, the damage to earthen buildings and lessons from Tonghai earthquake, the aseismic design requirements, the mechanical characteristics of earthen materials, as well as the testing work on full scale earthen housing are described. It shows that the earthen buildings can be used in seismic region provided the buildings are consistant with the requirements of aseismic design code.

CLADDING WALLS

The advantages in earthquake resistance were found from survived earthen walls after Longhai earthquake. The following are some typical examples:

1. The warehouse of productive brigade NO.1 of Osan county town was a two stories timber frame building in Chinese type. In which, both adobe gable wall and longitudinal exterior adobe walls were built in the way tied by wooden ring beams which was not connected with the wooden columns. At the eaves level, the two purlins were purposely arranged so that they were capable to press the top of the adobe wall from both sides (FIG.4). The height of the gable wall attained to 6.5m. Although the gable wall was somewhat convex outward, it didn't collapse in the earthquake.

2. The office building of Osan county town was built as of Chinese type of three bay, two stories wooden frame building with adobe cladding walls. The two purlins were arranged on both sides of the front exterior wall at the eaves level for holding the top of the wall. The two ring beams were placed in the middle part of the walls. The surfaces of walls were plastered with mixture of mud and straw (FIG.). As the result of wooden columns which were placed on stone footings of 40cm high fell down in the earthquake, the building inclined. Although the wall tilted, it still stood.

3. The house belonging to productive brigade NO.2 of Osan county town was a two stories wooden frame building in Chinese type and with cladding adobe walls. The front wall, held by purlins at its top, was 45cm thick, 5m wide and 4.6m high. A log of 10cm in diameter was installed in the wall at the level of 3.5m high. The wall was plastered with mixture of mud and straw, and stood well after the earthquake.

4. The house owned by productive brigade NO.4 of Osan county town was constructed as of Chinese type of three bay, two stories timber frame building. The gable wall of the building was 40cm thick, 5.2m high, and plastered with mixture of mud and straw and finished

with white lime. A wooden rod of 13 x 10cm cross section was placed in the middle part of the gable wall and was tied with wooden column (FIG.4).

5. In a two stories timber frame office building, the wooden ring beam was placed underneath the windows of the second story. Although the gable wall of the building collapsed, the longitudinal exterior walls still stood.

6. The warehouse of productive brigade NO.2 of Osan county town was a Chinese type, single story timber frame building with adobe cladding walls. The eaves level was 2.45m high. The top of the surrounding walls had been held by purlins. The walls were plastered with mixture of mud and straw. There were two longitudinal tie rods to connect the columns, and through them the building was tied together to respond as a unit. The front exterior wall had two gates and three small windows. The dimension of each gate and window was about 220cm by 210cm and 110cm by 60cm respectively. The rear exterior longitudinal wall had only three small windows. After Tonghai earthquake, it was found that except there appeared spalling on the gable walls, all others sustained well.

7.It has been found that the meeting hall of productive brigade NO.1 of Osan county town was intact. This building was built as of two stories Chinese type timber frame, which had survived in the strong earthquake occured 57 years ago. The adobe cladding walls plastered with mixture of mud and straw were used for the first story, and being thin at its top but thicker at its lower part (FIG.5). The walls of the second story were made of board.

8. The house of a commune member of productive brigade NO.1 of Osan county town was a single story frame building with earthen flat roof and with infilled adobe walls (FIG.6). After the earthquake, this house including adobe walls was found still in good condition.

BEST AVAILABLE DOCUMENT

The another house, a three-bay Chinese type of wooden frame building, is located in Xiaojie village of Xiaojie commune. There were four frames in total. After earthquake, it was found that three of them inclined, while one infilled adobe wall as a gable sustained during the earthquake and had remained in proper position just since there was a infilled adobe wall in the frame. The house as a whole didn't collapse, because of the fact that the uninclining frame tied the other frames.

9. A rammed fencing wall of a height by 2m locating in Xiaojie village of Xiaojie commune had strengthened with bamboo reinforcement at corners of the wall. Minor cracking was taken place at corners during the earthquake, but the wall didn't collapse.

10. In a warehouse of Osan county town, a adobe fencing wall of 30cm thick, 2.4m high and 20m long had been plastered both sides by mud with straw, and finished by lime-white mixture, and had both side 10cm thick ribs of 4m spacing. This fencing wall still stood after earthquake except there occurred horizontal bent cracks at lower part of the wall.

From above examples, it follows that:

1. Following measures are recommended to be taken to prevent collapse of non-load-bearing adobe walls in seismic zones:

— Installing timber ring beam tied to the columns with wooden connecting rods.

— Utilizing purlins at the eaves level to hold the top of the adobe wall.

— Designing the wall with varied cross section, upper thin and lower thick.

— Adding ribs or buttresses to adobe walls.

— Plastering wall surfaces by mud with straw.

— Placing the reinforcing materials, such as bamboo strips, chaste twigs, or straw at the intersections of the adobe wall to tie them together.

— Decrease dimension of apertures (e.g. gates and windows).

2. The adobe wall infilled within a timber frame can increase the lateral earthquake resistant capacity of the frame and prevent collapse of the house.

3. The adobe walls can be used in earthquake-prone areas provided necessary aseismic measures are taken.

SINGLE STORY BUILDINGS

For the single story earthen housing, the walls generally are the rammed earthen walls or the walls laid with adobes. The thickness of the walls is 30cm to 50cm, and the height of eaves is about 3m. The purlins are directly supported on the earthen wall. The roof may be covered by mud, tiles or straw. This kind of building is schematically illustrated in FIG. 7.

The recent China's destructive earthquake had shown that the performance of earthen housing which is not specially designed by the aseismic design code can be summarized as below in the earthquake.

— In the area where seismic intensity is VII, the light damage was found. The small cracks were taken place on the intersections of the walls and the corners of the windows and doors only. The buildings are not need to repair and still could be used.

— In the area where seismic intensity is VIII, the damage was moderate or severe. Some exterior walls were tilted to outside. Some walls were cracked or collapsed.

—— In the area where seismic intensity is IX, most of the earthen buildings were severely damaged or collapsed.

The survived earthen buildings still can be found in the area where seismic intensity is grade VII to IX. The following are some typical examples:

1. The house of Osan Hotel was built as a single storey building with load-bearing adobe walls. The walls being supported by rubble footing with its top at level 30cm above the ground. The height of the eaves was about 2.5m, the thickness of walls 30cm, the width of the building in plan 4.5m and the length of each bay 3.3m. A timber ring beam was installed at the level above the window and four logs were inserted into two adjacent gable walls at the ceiling level. It was found after the earthquake that the wall cracked but both the walls and the roof didn't fall down. Those beside it, however, a multi-storey building of timber structure with triangular roof trusses and columns partially collapsed, and another multi-storey building with timber roof trusses, brick columns and adobe infill walls was severely damaged.

2. A dormitory house locating in Osan County town which was built as a single storey and single bay earthen house of 4m by 3.5m in plan and height of the eaves 2.5m, was found after the earthquake that there were cracks on the earthen walls, but the house didn't collapse. Beside this house, the partition walls of a single storey building of brick timber structure severely damaged with cracks as wide as 6cm.

3. A factory building was constructed with load-bearing earthen walls, 49 x 49cm load-bearing brick columns and triangular timber roof trusses. Dimensions of the building: 8m in span, 4m in each bay, 40m in total length, 3.5m as the height of the eaves, 20cm as the height of the stone footing above the ground, and 50cm as the thickness of earthen walls. The earthen walls were plastered with mud and straw. It was found after the earthquake that earthen walls slightly cracked and only the adobe walls underneath the wooden cantilever of eaves had spalled.

4. An office building near the above-mentioned factory was built in 1967 with 6.[illegible] in plan and [illegible] in each bay. This building was constructed with some load-bearing earthen walls 5[illegible] in thickness, longitudinal walls [illegible] in thickness, wooden roof trusses supported by brick columns, wooden purlins supported by the wooden block placed on earthen walls and with a lightened ceiling. Although it was found after the earthquake that some corner columns displaced slightly, while the earthen walls had small cracks and had spalling underneath the wooden cantilever of the eaves, this building is capable of to be used.

5. Eleven single storey buildings, each having [illegible]—12 bays and with 33 bays in total, were constructed of load-bearing earthen walls, timber triangular roof trusses and brick columns. The buildings were with 2.6m as the height of the eaves, [illegible]m as the bay and 7m as their width. Only two bays collapsed during the earthquake, while some of these buildings are still being employed at present.

6. The tobacco baking tube structure of a commune was so constructed that it was with 7.5m as the height of the eaves, 5.4x5.6m in plan and [illegible] as the thickness of the earthen walls, purlins at the eaves held the top of the earthen wall, within the wall there were two ring beams made of rectangular timber of 10 x 15cm and there was a timber at the height of 2.4m. Some logs for tobacco baking use which were horizontally inserted into the walls had been all cut off before the earthquake. This building was found almost in good condition after this earthquake, except that some adobes over the doors came down.

From the above six examples, it follows that the single story buildings with load-bearing earthen walls have a good performance in strong earthquake. It is recognized that those buildings survived just since they had the following advantages:

— Reliability of foundations.

— Adequate protective measures of the brick walls, such as higher stone footing, proper curing, cause and characteristics of the strain.

— Ring beam installed in the wall.

— Wall top held by purlins at the eaves level.

— Logs inserted into the two adjacent load-bearing gable walls tieing the walls together.

— Smaller aperture (e.g. door and window).

— More transversal walls.

— Good quality of the wall construction.

TWO-STORY BUILDINGS

There were few two-story buildings with load-bearing earthen walls in the 1970 Tonghai earthquake effected area, damages to four buildings of them were following(2):

1. The dormitory house of the Highway Station of Tonghai County was built in 1967. Where the seismic intensity was evaluated as a grade of VII. This building was built with its plan as 36x10.8m, the height of the first and the second story as 2.1m and 2.5m respectively, and the thickness of the walls as 30-40cm. At the level of the top of the windows of the first story, a reinforced brick ring beam has been installed and at the level underneath the windows of the second story, a timber ring beam has been installed. The purlins and timber blocks underneath them, and the roof has outstanding eaves at four sides. The house and rubble foundations with a depth of 70-100cm under the ground surface and and the footings with a height of 30cm. The building was slightly damaged after the earthquake, horizontal cracks occurred on the walls, the vertical cracks at the intersections of the exterior and the transverse walls of the second story was about 3mm and roof tiles slided somewhat downwards.

2. The Office Building of the People's Hospital of Tonghai County was built in 1967. Where the seismic intensity was evaluated as a grade of VII. This building was built with its plan as 3[illegible].5x11.[illegible], the height of the first and the second story as 3[illegible] and 2.[illegible] respectively, and the thickness of the walls as 40cm. The reinforced brick ring beam was installed at the top of windows of the exterior walls, and the roof had outstanding eaves at four sides. The foundations were made of rubble and buried 60cm under the ground surface, and the footing was built as 40cm high. It was found after the earthquake that the house was slightly damaged (e.g. small cracks on walls and sliding of roof tiles).

3. The Office Building of Epidemic Prevention Station of Tonghai County was constructed in 1968. Where the seismic intensity was evaluated as a grade of VII. This building was built with its plan as 25.9 x 11 m, the hight of the first and the second story as 3m and 2.[illegible]m respectively, and the thickness of the adobe walls as 40cm. Reinforced brick ring beams were installed above and underneath window aperture of both stories, and eaves at four sides of the roof was built with overhanging. The foundation was made of rubble buried 60cm under the ground surface and the footing was built as 45cm high. The house was damaged slightly in the earthquake, cracks occurred on the walls, the width of some cracks attained to 5cm.

4. The Building of Tax Office of Tonghai County was built in 1968 with its plan as 10.5 x 7m, the thickness of the walls as 40cm. The foundations on soft soil was made of rubble. The reinforced brick ring beams were installed above windows of the exterior walls of both stories. This building locating in the area of IX grade seismic intensity was collapsed during the earthquake.

The floor structures of the second floor of all above mentioned four buildings were built of timber. It was found that some aseismic measures, such as profitable construction site, harder subsoil, adequate foundation, higher footings, regular configuration in plan and in elevation, installing ring beams and installing tie logs both at the eaves level and underneath the

floor beams etc. had been considered and taken in the three buildings locating in the area of VII grade seismic intensity.

As what has been from above illustrations it is concluded that two stories buildings with load-bearing adobe walls might be permitted to be constructed in the areas of VII grade seismic intensity.

MECHANICAL PROPERTIES OF LIME-EARTH

Lime-earth is a mixture of slaked lime and earth. Slaked lime is produced by slaking quicklime in water two days before to be use. Green lime blocks, earthen blocks and miscellaneous materials should be silted out from the lime and earth. The volume ratio of lime to earth is usally in the range of 1:1 to 1:6, and the lime content approximately equals to 6-25%. According to experimental data, the mechanical properties of lime-earth can be summarized as below (3):

Compressive Strength

1. The compressive strength of lime-earth increases with the plastic index (PI).

2. The compressive strength of lime-earth increases with lime-earth ratio within a certain extent. The optimum lime-earth ratio is approximately 10 to 15 percent for the weight and is inversely proportional to the plastic index.

3. The compressive strength of lime-earth increases with its age. The compressive strength of the lime-earth less than one day old, is the same as that of pure earth. It will be increased over 250% when the lime-earth is 28 days old. Some testing reports show that the compressive strength of lime-earth is increased from 15kg/cm^2 at the age of 1 0 days to 55kg/cm^2 at the age of 10 years.

4. The compressive strength of lime-earth increases with its

density. For example, for the lime-earth with volume ratio of 3:7, the compressive strength can be raised [illegible] at the age of 30 days if remoulded once more.

5. The homogeneous degree for mixture of lime and earth has significant effect on the compressive strength. For some lime-earth, it still remained about 2kg/cm^2 at the age of 21 years due to non-homogeneity.

Shear Strength

1. The shear strength raises with increase of lime content, but there is a limit of lime content, beyound which, it will decrease somewhat. The optimum lime-earth volume ratio which gives the maximum shear strength is 1:3 or 1:4 when earth is made of sand clay and 1:2 when earth is made of sand with clay particles.

2. The shear strength increases with the plastic index. For example, for the lime-earth with volume ratio of 1:4, the shear strength is 1.44kg/cm^2 and 1.6kg/cm^2, if the plastic index is 7.9 and 14.9 respectively.

3. The shear strength increases with the age, but the internal fraction angle varies slightly.

4. Higher the density of the lime-earth, higher the shear strength.

Bending Strength

1. The bending strength of the lime-earth is about one third of the compressive strength. For the lime-earth made of clay, it is little higher than that made of sand.

2. The bending strength of the lime-earth is raises with increase of the age. The rate of increase is the same with that of the compressive strength.

Modulus of Deformation

For the lime-earth mixture with a volume ratio of 3:7 when earth is made of sand clay (dry unit weight 1.5gr/cm^3) or clay (dry unit weight 1.4gr/cm^3), the modulus of deformation of the mixture is 100-150kg/cm^2 after 7 days curing and 48 hours soaking and 320-400 kg/cm^2 after 28 days curing and 48 hours soaking.

FIELD TESTING OF FULL SCALE EARTHEN HOUSE

In autumn 1970, Institute of Engineering Mechanics (IEM) of Chinese Academy of Science conducted a field explosive earthquake simulating experiment of a full scale earthen house in Tonghai county, Yunnan province. FIG.9 shows the plan and the sectional drawing of the testing house.

The tested house had two rooms, the adobe walls were laid with local technique (the adobes were laid vertically) for one room, and with improved technique (the adobes were laid horizontally) for another. Vertical joints in the wall were filled with mud mortar. A layer of straw was placed in the walls every two courses.

The tested house had rubble foundations with 60cm below ground surface and a mud roof to simulate the tiles. The walls were plastered with mud and white-lime. The house had fundamental natural periods of 0.1 - 0.2 sec in different directions as actually measured.

The underground multi-hole explosion at a deepth of 5-7m was used as the vibration sources in the test. They conducted the test three times with total filling explosives 46.5kg, 228kg and 530kg for each time. The explosive sources had distances of 20 - 30m from the house.

First, the house was tested in single hole explosion, the induced maximum ground velocity was nearly of 7.6cm/sec, and the house was intact.

Second, the house was tested in four successive explosions of seven holes with explosive filling. The induced maximum ground velocity was about 20cm/sec. After explosion, the cracks with width of 1.5cm on the walls laid by local technique were found, but they couldn't find any apparent crack in the walls laid by improved technique, mud layers on the roof slided, and cracks occurred on the roof ridge.

Third, the house was tested in simultaneous explosion of three holes with explosive filling, the induced maximum ground velocity was about 75cm/sec. Most of the walls collapsed, and the roof fell down.

The above tests show that the earthen house had a certain capacity of earthquake resistance and the improved technique for laying adobe is better than the local one.

It should be noted that the ground motion excited by explosion was significantly different with that of natural earthquake, and it can be characterized as more content of high frequency waves, rapid decay of the amplitudes, higher amplitude of ground accelerations and the shorter duration. These remained problems shoud be study in detail in the furture.

LESSONS FROM EARTHQUAKES

According to the reports of recent Chinese destructive earthquakes, the damage to earthen buildings and aseismic constructive measures can be surmarized as following:

Subsoil

1. Where the subsoil is soft or the subsoil in the bearing layer associate with a soft and hard distribution, such as sections with abandaned and filled river bed and fracture belt of fault, hidden swamp, creek, gully and pit as well as partially cutting and filling subsoil, and where the distribution of the walls is severely unsymmetrical, the non-uniform settlement is easily taken

place, and can be led to cracks or collapse of the walls (FIG.10). Therefore, in order to prevent the nonuniform settlement, we have to pay more attention to the site selection and the arrangement of the walls.

Wall

2. Owing to the ravages of rain and wind, the thickness of the footing of a wall may be gradually decreased, and the wall is vulnerable to collapse in earthquake. Therefore, for safty, the wall should be plastered by mud with straw, and the house should be surrounded by sewage escape canal.

3. In earthquake, gables are very dangerous when they are made of adobe. For improving the aseismic capacity of a wall, the following measares can be used:

— Elongating purlins supported by a gable towards outside in certain length, i.e. using outstanding eaves (FIG.11).
— Putting bearing beams underneath the purlins. The beams are tied with rod and anchored with bolts. (FIG.12).
— Setting wall ties in a gable wall (FIG.13).

4. In earthen buildings with brick columns in corners and intersections of walls (FIG.14), during earthquake, the brick column can be separated with attached earthen wall, and led it to collapse. Therefore, this structural solution is not recommended.

5. For earthen wall with brick in exterior surface, the bricks are vulnerable to fall, and led to collapse of the wall in the earthquake. Therefore, in earthquake-prone area, the wall with brick in its exterior surface is not recommended.

6. Owing to lack of the ties in intersections of earthen walls, during the earthquake, the vertical cracks were taken place in intersections, and in some cases, the walls were collapsed due to tilt of them. Therefore, at intersections of walls, bamboo ribs, straw, wooden battens and chaste twigs should be placed for

strengthening (FIG.15). The wooden ring beams should be installed in the walls for better integrity.

7. The clay with little impurity should be selected for making an earthen wall. Mud should be mingle with wheat straw, sorghum stalks or rice straw to strengthen an adobe or an earthen wall.

8. Inserting 3-5 logs into two adjacent transverse lod-bearing walls at the ceiling level, the two walls will be tied together. These logs can be used as suport beams for the ceiling and attic (FIG.16).

9. The earthen walls, which were rammed layer by layer using mud with wheat straw, had good performance in 1966 Xingtai earthquake. This kind of wall have an advantage in prevent the ravages of rain and flood.

10. It is a good solution to hold the top of the wall by purlins at the eaves level.

11. A wall, which is very long and has no transverse walls connected with it, is vulneable to collapse in earthquake. In such case, the pilasters, buttresses or ribs may be added to the wall for increasing its stability (FIG.17).

12. For a house, in which the roof is the one with two sides and the purlins are directly supported by earthen gable walls, the upper triangler part of gables may collapsed during an earthquake. In such case, adding buttresses laid on longitudinal wall to triangular part of gables was recommended (FIG.18).

Eaves

13. The cantilever for eaves of a earthen house may be displaced and led to cracks or collapse of the wall. Elongating the rafter instead of the cantilever to make eaves can be avert this kind of damages (FIG.19).

Purlin

14. Vertical cracks may occur on the wall underneath the purlin due to stress concentration in the earthquake, if the purlin is placed directly on the top of the wall (FIG.20a). This damage can be avoided by inserting a bearing block under the purlin (FIG.20b).

15. If there is no mutual connection between purlins and no connection between the wall and purlins, some purlins could be drawn out from the wall, consequently, the wall would collapse and the roof would fall down. Therefore, the purlins should be connected among themselves and be connected with the wall (FIG.21).

Roof

16. An earthen house having a heavy mud roof is liable to collapse in the earthquake since the increased lateral force from the heavy roof. Such heavy mud roof, whose thickness may attained to 40cm, is usually formed in water-proof repairing by adding more mud to the roof from year to year. Therefore, the old mud should be taken off in repairing.

17. The best roof for an earthquake-prone area is the one with four inclined sides because it distributes its weight better and eliminates the neccessity to use gable walls(FIG.22).

ASEISMIC DESIGN REGULATIONS

Aseismic design requirements for buildings with lime-earthen load-bearing walls are specified in Section 7, Chapter 4 Aseismic constructive requirements, of the Aseismic Design Code for Industrial and Civil Buildings (TJ 11-78). The full text of this section reads as follows (4):

Section 7 Buildings With Lime-Earth Load Bearing Walls

Article 91

For buildings with lime-earth load bearing walls, the settlements

of walls should be as even as possible. Generally, transverse walls shall be installed in each bay and brick columns for open corridors should not be used. Staggered floors and abrupt change of the elevation of building should be avoided, and the number of stories must be the same in a building.

Note: The lime-earth wall generally indicates the rammed earth (mixed with lime) wall and the wall laid with lime-earth adobes.

Article 92

Where design intensity is 7, the height of the building shall not greater than 6m. The lime-earth load bearing wall is not recommended for design intensities of 8 and 9.

Article 93

Different materials for masonry walls should not be used for a building.
The compressive strength of lime-earth walls shall not be less than 15 kg/cm^2. The dry unit weight should not be less than 1.6 ton/m^3.
The adobes should be laid with lime mortar.

Article 94

The layers of interior and the exterior walls shall be rammed alternatively and adobes of walls shall be laid with racking.
At quoins of exterior walls and intersections of exterior and interior walls, reinforcing materials, such as bamboo ribs, wooden battens and chaste twigs, should be placed at every 30cm spacing along the height with both ends extending into the wall not less than 1m.
The minimum thickness of the wall is 25cm.

Article 95

A stepped buttress should be built on the top surface of inner longitudinal walls on both sides of the exterior and interior gables. The purlins should be supported by blockwood.

Article 96

The ring beams shall be placed on longitudinal exterior walls and all transverse walls at each floor. The depths of ring beams are:

For reinforced concrete ring beam	8-12cm
For reinforced brick masonry ring beam	4-5 courses
For wooden ring beam	6-10cm

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3. Yang, Hai, "Properties of Lime-Earth and its Aplication", Spread of Construction Scientific Knowledge, NO.3, (1980).

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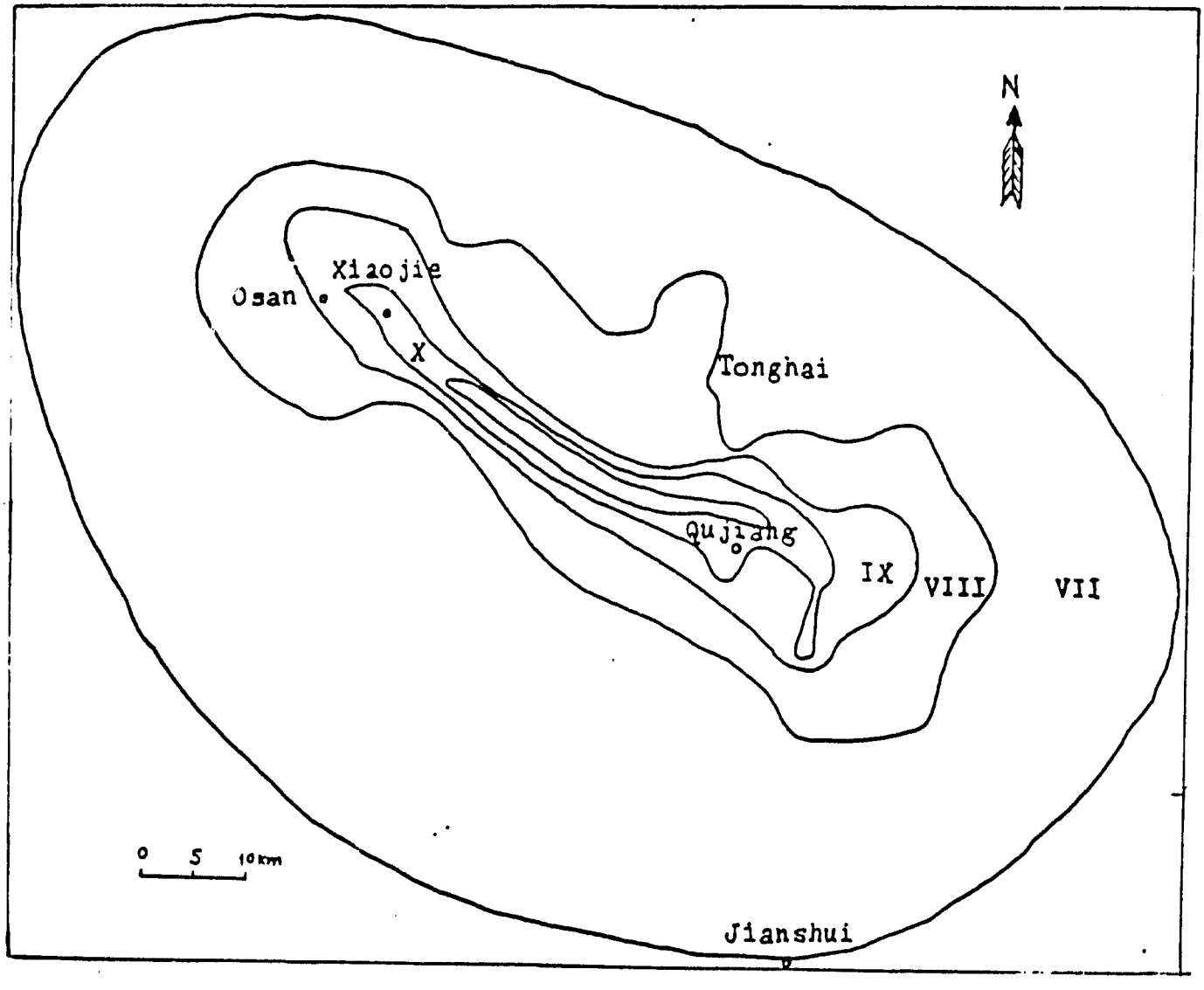
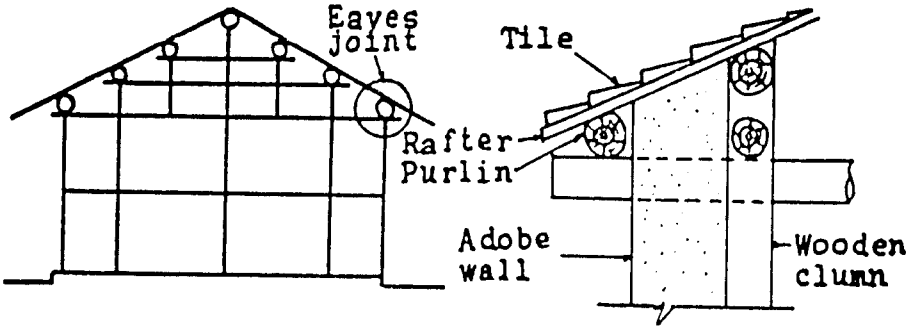


FIG.1 Intensity map of 1970 Tonghai Earthquake



Sectional elevation of wooden frame in Chinese type

Eaves joint

FIG.2 Utilizing two purlins to press the top of the adobe wall from both sides

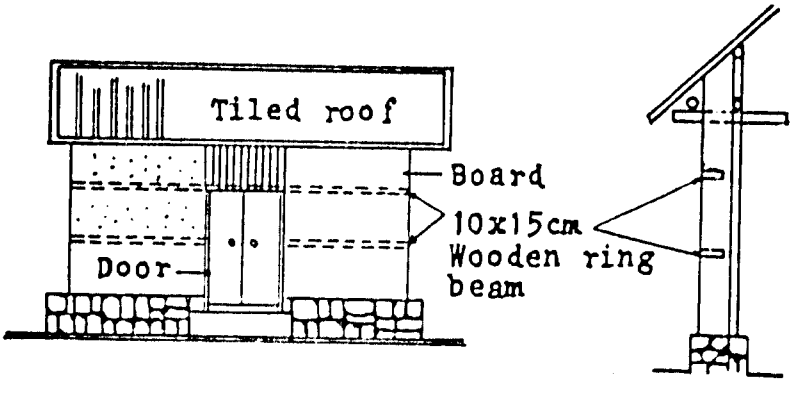


FIG.3 Earthen wall with ring beams

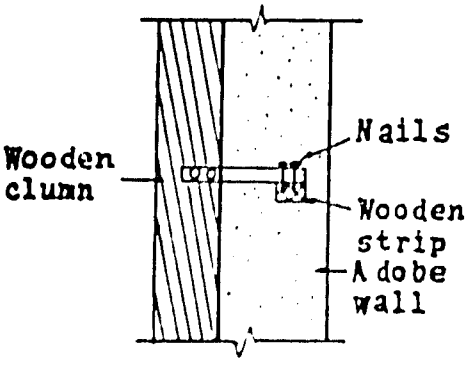


FIG.4 Wooden rod in the wall and its conection

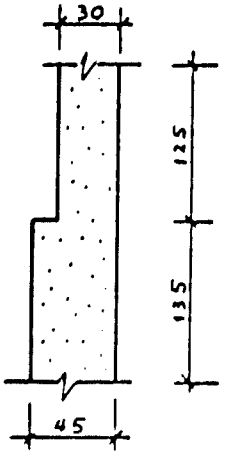


FIG.5 Earthen wall with varies cross section

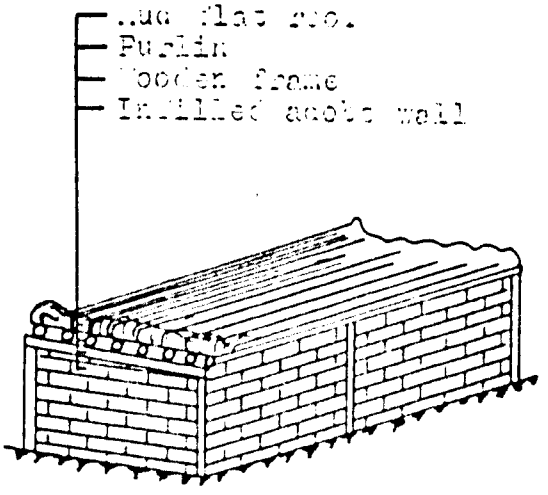


FIG.6 Single storey frame building with earthen flat roof and with infilled adobe walls

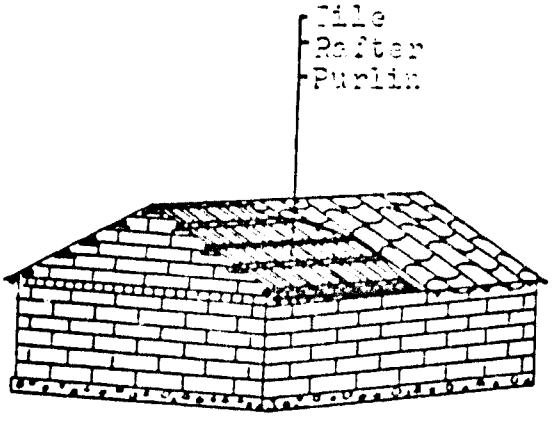


FIG.7 Single storey building with load-bearing earthen walls

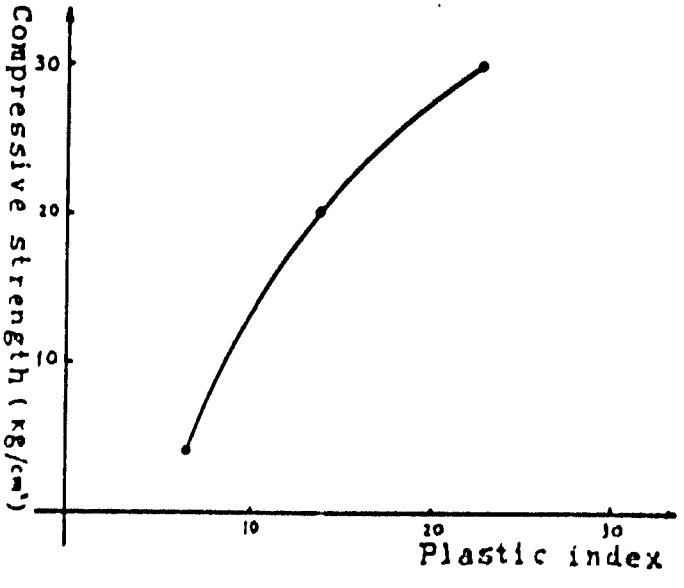


FIG.8 Compressive strength vs. plastic index

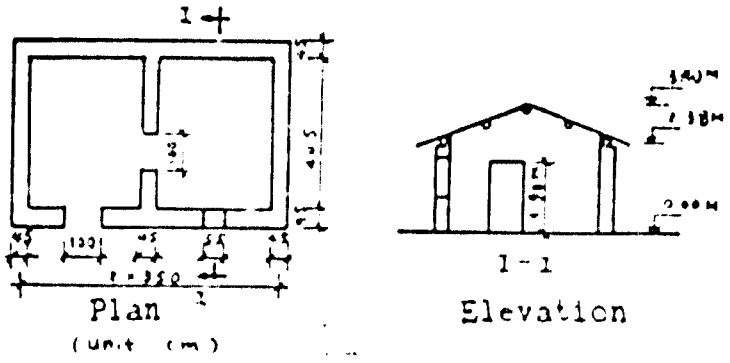
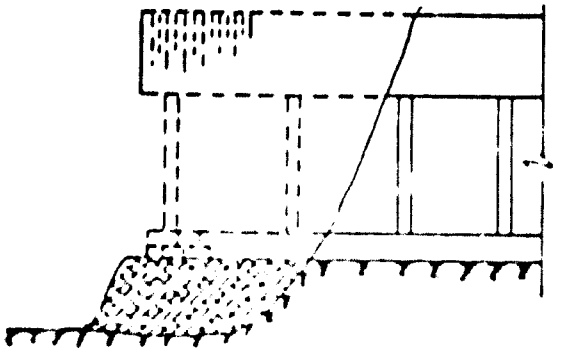
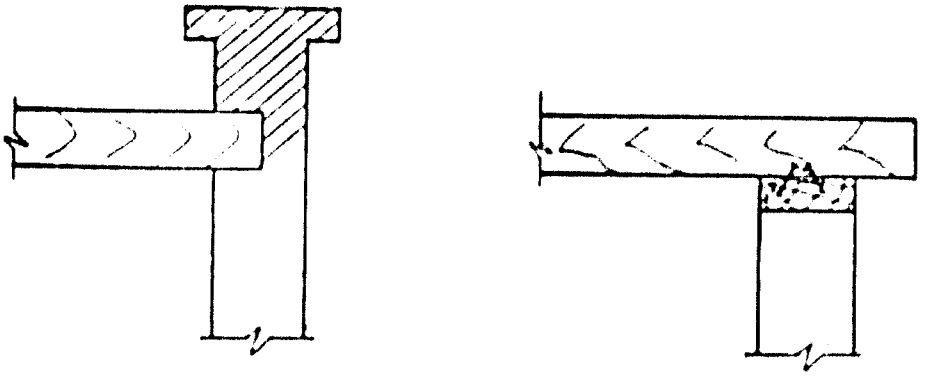


FIG.9 Full scale test house

FIG.10 Building built on partially cutting & filling subsoil, the part with dashed lines shows it may be collapsed in an earthquake



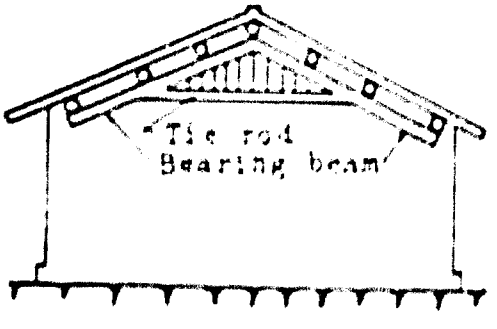


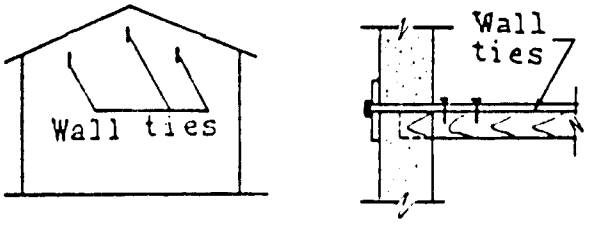
a. Without outstanding eaves, shaded part may be collapsed in an earthquake

b. Outstanding eaves by corrugating a portion outwards

FIG.11 Eaves

FIG.12 Bearing beams and tie rod within the gable wall





⇦ FIG.13 Wall ties

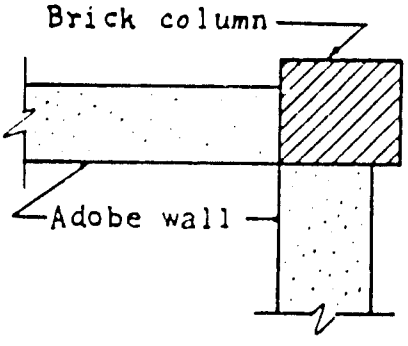


FIG.14 Earthen wall with brick column

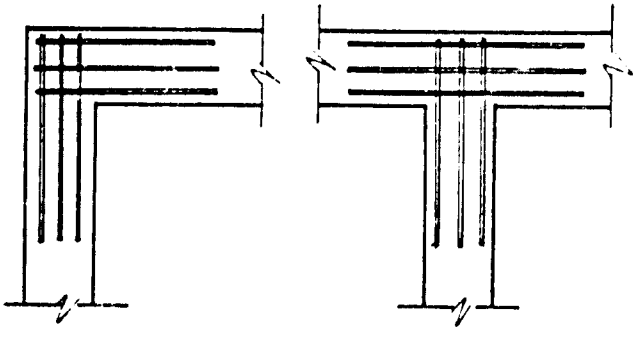


FIG.15 Reinforcing materials in the intersections of walls

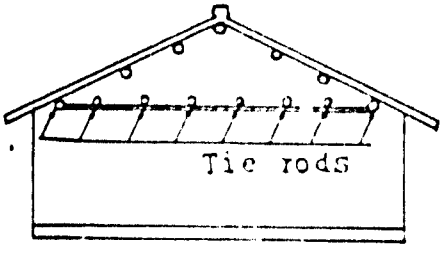


FIG. 1[illegible] [illegible] between [illegible]-bearing walls

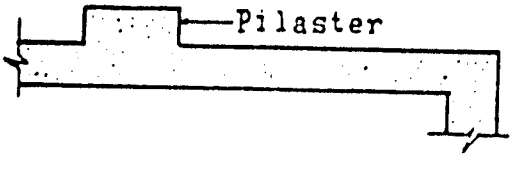


FIG.17 Pilaster

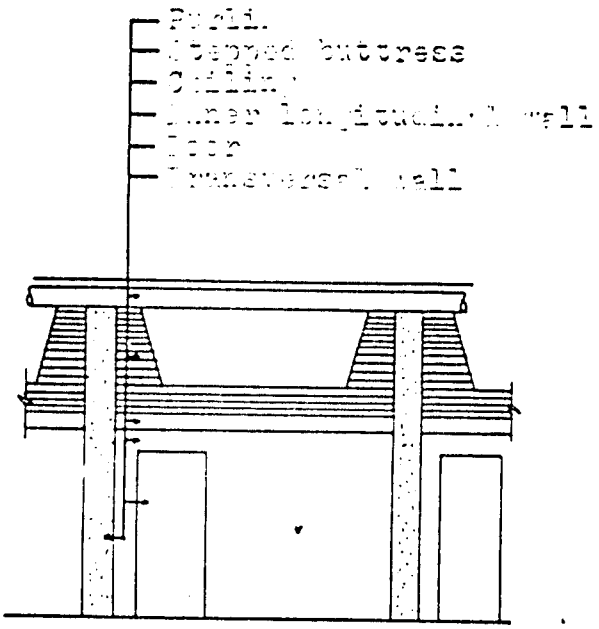


FIG.19 Stepped buttresses built on the top surface of inner longitudinal walls at both sides of the exterior and interior gable walls

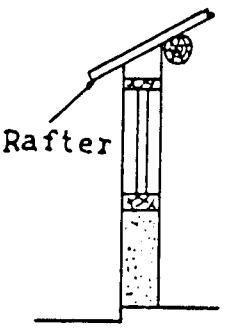


FIG.19 Cantilevering by elongating a rafter outwards

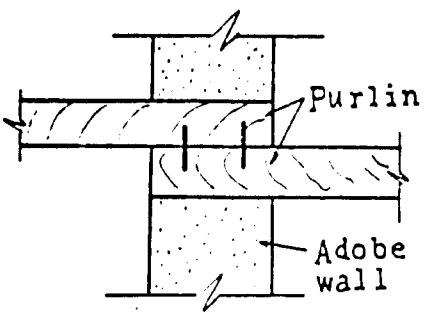
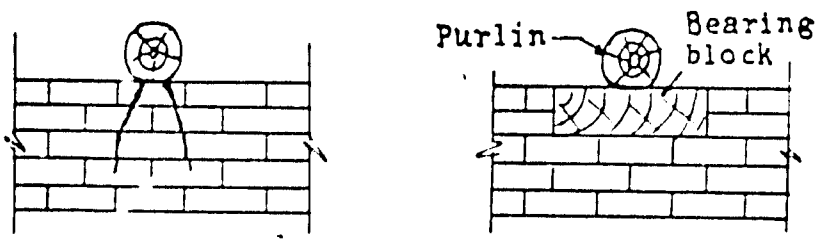


FIG.20 Connection of purlins on the wall



a. Without bearing block b. With bearing block

FIG.21 Purlins supported on walls

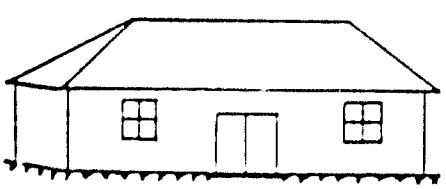


FIG.22 Building with four sides inclined roof

STATE-OF-THE ART PANEL REPORT

ON

EARTHQUAKE RESISTANT RURAL STRUCTURES

Dr. Özal Yüzügüllü, Author, Panel Secretary
Associate Professor of Civil Engineering, METU, Ankara, Turkey

FOREWORD

The rural structures pose a serious seismic risk problem in the seismic belts of the earth. It is unfortunate that this risk is increasing, rather than decreasing at most places on account of increasing population, poverty of the people, scarcity of wood, cement and steel, lack of understanding of earthquake resistance features etc. The magnitude of seismic risk to life could be imagined by the fact that number of dwelling units and other related small scale constructions may double itself in the next 20-25 years due to the explosion of population particularly in the developing countries. There is thus a great urgency that the know how of inexpensive earthquate resistance measures in such constructions should be propogated quickly and by simple illustrations, so that these techniques could find application at least in the new constructions.(1)

The state-of-the-art panel on the Earthquake Resistant Rural Structures of the 7th World Conference on Earthquake Engineering mainly aimed at collecting views and practices of selected countries where most of the earthquake damage is suffered by the rural structures. Following panel members have been appointed by the Organizing Committee and contributed to the panel :

1. Professor A.S. Arya
   University of Roorkee, Dept. of Earthquake Engineering
   Roorkee 247667, India

2. Professor D. Benedetti
   Technical University of Milan
   P.zza L. Da Vinci, 32-20133, Milano, Italy

3. Professor Sergey Bubnov
   University of Ljubljana
   Erjavceva 15, Ljubljana, Yugoslavia

4. Professor O. Hernandez
   National Autonomous University of Mexico
   Institute of Engineering
   Ciudad Universitaria, Mexico 20, D.F. Mexico

5. Professor J. V. Neumann
   Pontifica Universidad Catolica del Peru
   Pontifica, Peru

6. Professor Yang Yu-Cheng
   Chinese Academy of Sciences
   Institute of Engineering Mechanics
   Harbin, Peoples Republic of China

Each of the panel member conveyed their experience and ideas about the general practice and theoretical or experimental studies that they have carried out in their corresponding countries about the earthquake behaviour of rural structures. In the following state-of-the-art report all the above contributions have been classified and generalized by the panel secretary.

All of the panel members except Professor Yang Yu-Chang have attended to the conference individually.

INTRODUCTION

Most of the loss of life in the past earthquakes has occurred due to the collapse of structures in rural areas constructed in traditional materials like stone, brick, adobe and wood which are not engineered to be earthquake resistant. These "rural structures" may also be called "non-engineered structures" where the term non-engineered may only be vaguely defined as a structure whose analysis for lateral earthquake forces would defy reasonable mathematical solutions and the design will be based mostly on a set of specifications derived from observed behavior of such buildings during past earthquakes and trained engineering judgement. Such structures will include load bearing masonry wall buildings (brick, stone or adobe), stud wall brick-nogged constructions in wood, and composite constructions using combinations of load bearing walls and piers in masonry, reinforced concrete, steel or wooden posts and like. Reinforced concrete or steel frame buildings, tall buildings using various types of structural systems, major industrial buildings etc. are excluded from consideration.(1)

CLASSIFICATION OF RURAL HOUSES

There are various types of rural houses existing in different countries. Common building materials used are adobe, stone, brick, concrete block which are all heavy in weight and with low tensile and shearing resistance. Another category of materials is wood or bamboo which are highly flexible. Most of the time, these materials are used individually or in combination. Sometimes, concrete and steel reinforcements are also used. According to their structural systems, the rural houses can be classified as follows :

a) Adobe, stone, concrete block or brick masonry.
b) Wood block, timber or bamboo framed.

The masonry houses of item (a) usually have a heavy flat earth type of roof, concrete block or brick masonry houses sometimes have a reinforced concrete roof slab with tile or similar roof covering. Wood block or timber framed houses have a very rough timber trussed roof. The masonry houses built in rural areas are normally unreinforced, but may have lateral wooden laths at certain places. Timber framed houses usually have filler walls of adobe, stone, brick or some other material. Some of the timber framed houses may be plastered directly or they may be wood plated. The distribution of the type of the construction used in various regions of each country depends mainly upon the availability of the construction materials, economy and social trend and traditional technology of that region. For example in Yugoslavia, the majority of the rural houses are built of brick since in the larger part of the country there is clay of good quality which could be well formed and burnt, whereas in east and southeast Turkey stone masonry and adobe masonry constructions are in majority because of their low cost, availability of the materials and good insulation provided.

CHARACTERISTIC DAMAGES

Different types of rural houses have suffered different degrees of damage in the past earthquakes. The main factors contributing to the damage of the masonry houses have been their heavy weight, brittle behaviour of the masonry with low tensile and shearing strength, lack of adequate structural connections, poor quality of construction and deterioration of strength by time. The study of damage after an earthquake can clearly identify the weak and strong points of the design, the materials and construction techniques.

ADOBE MASONRY

Damage patterns of adobe houses are as follows : Pull apart of the longitudinal wall from the transverse wall; occurrence of vertical cracks; outward inclination of the wall. Damage is caused by the insufficient tension of the adobe. The adobe at the corners when pulled apart leaves the walls standing freely. The wall inclines outward due to its inertia force and due to horizontal push of the roof which collapses successively. If the portion of the beam or purlin supported on the wall is too short, it will fall down the ground due to excessive displacement of the wall, with the result of the collapse of the roof.

Usually fatality increases with such a collapse due to the debris and lack of air inside. Sometimes the wall may crush at the places where the purlins are supported and inclined or diagonal cracking may also occur.

Adobe houses are known to be the worst as far as their behavior under earthquakes are concerned and even some countries abondened its use but yet it finds application in most part of the Middle East Countries, South and Central America, and even in China. If built on sound foundation with a rational structural layout, good workmanship and maintenance, this type of building will not collapse even under an earthquake of intensity VII or less than VIII (Figs. 1 and 2).

STONE MASONRY

Usually mud mortar is used to combine the stones. If the stone used is not quarried but collected from fields or river beds they will be covered with moss and dirt and will have a round shape. The bond provided by mud mortar is very poor since as time passes the mud between the stone dries, shrinks and falls out, thus no bond remains between the stones. During an earthquake also no shearing strength is left except dry friction between stones.

Usually the thick wall is made out of two vertical planes, one inside, one inside. If stones to bind these two layers are not provided, the integrity is lost between these layers and inner and outer layers are split into two (Figs. 3 and 4).

Collapse of bearing walls may be due to failure of connections between wall and wall, wall and roof and walls and foundation. Thus lack of structural integrity is the greatest source of weakness.

Similar to adobe masonry houses the collapse of the flat earth roof is the cause of loss of life. The roof besides being very heavy, has also been poorly connected to the walls. Thus failure of the weak stone walls is followed by the falling down of the heavy roof (Figs. 5 and 6).

Another possible mode of failure occurs when the walls are somewhat stronger and the roof beams have longer supported lengths on the walls. In this case the roof beams slide down on one side while stay in place on the other side. This is less dangerous than the total collapse of the roof since it leaves space and time for people inside to escape.

Stone masonry houses behave worse than adobe masonry houses, both having the same type of thick flat earth roof. This may be partly due to stone being heavier than adobe and partly due to the non-homogeneous nature of the stone walls as compared to adobe walls. Stone masonry houses with mud mortar and flat earth type of roofs are completely destroyed at intensities of VII-VIII and heavily damaged at intensities V-VI.

BRICK OR CONCRETE BLOCK MASONRY

Analysis of various damage patterns shows that damage characteristics of "rigid" and "non-rigid" brick houses are different. For "rigid" brick houses, in which transverse interior walls are closely spaced and the lateral rigidity of the floor slab system is high enough, the following three damage categories may be identified :

a) Shear failure due to diagonal tension :

This kind of failure is frequent. First diagonal cracks occur on the walls, sliding discoloration, crushing of bricks, fall of debris and at last collapse of the walls follows. The collapsed walls usually fall around the building area and the floor slabs fall on top of each other (usually reinforced concrete slabs are used for more than one story houses). Some buildings totally collapse, whereas some of them have a collapsed upper story only.

b) Horizontal shear failure :

Cracking of horizontal joints, especially near the connection of the walls with the floor or roof slab isfollowed by horizontal sliding and dislocation of the wall.

c) Overturning failure :

This type of failure is often caused by the weak connections between exterior longitudinal walls and interior transverse walls. Exterior walls often pullapart from the interior walls. In some extreme cases exterior walls incline or even overturn due to loss of stability. Sometimes, exterior walls first collapse then the interior transverse walls, followed by the roof or floor slabs falling on top of them. As for the "non-rigid" brick houses; these are brick masonry houses with weak floor or roof slab (usually wooden floor Fig.7) and with relatively large spacing of the interior walls, thus the lateral rigidity of the floor slab system is poor. In this case the damage is characterized by the off-plane bending failure, occurence of horizontal cracks on the tension side of the wall and partial crushing on the compression side. In some extreme cases the walls incline and cause the house to overturn.

TIMBER-FRAME OR WOOD BLOCK

Earthquake resistance of the timber-framed or wood block houses are comparatively good among the other types of the rural houses discussed so far. In the timber-framed, filler walled type, the failure usually begins at the fill material inside the timber frame members and timber diagonal. (Fig. 6). The damage is conveyed to the frame members only after the filler walls are seriously damaged. The degree of damage on the wall depends on the wall materials (adobe, brick, rubble stones etc.), the workmanship and the stiffness of the frame as a whole. The deformation of the frame during an earthquake is larger than that of the wall, thus the wall is pulled apart from the frame

or pushed down by the frame. If the frame is rigid enough with small deformation and if at the same time the walls are strong enough to confine the deformation of the frame and to resist the inertia forces induced by its own weight, then the house does not suffer serious damage.

The following damages can be observed :

a) Cracks occur at the corners or at the wall-column connections, tiles may slide on the roof (slight damage).

b) Longitudinal and transverse walls are seriously damaged, top of the gable wall and the eave wall partially collapse (moderate damage) .

c) A large portion of the wall collapses, tenons full apart from the timber frame, frame is inclined (seriously damaged).

d) Roof falls down, upper part of the wood frame fractures or overturns, frame and wall collapses (collapsed).

Much difference in the damage to the timber framed houses can be found due to difference in the structure of the frame, filler wall materials, workmanship and the age of the house.

In a moderate earthquake (intensity VII-VIII) damage to the filler walls occur, in an earthquake of intensity IX, serious damage takes place the infill walls collapse but only in a few of the house total collapse of the structure as a whole takes place. Most of the collapsed houses are houses with a simple frame (very few diagonal bracings) or with a flat roof or with a timber truss poorly connected to the columns, or a timber frame with decayed members. (Fig. 8)

In case of wood-block or timber framed but wood-plated or plastered house the problem is only with the decay of wood by time, poor connections and inadequate bracing elements, since they don't contain any filler wall.

FACTORS AFFECTING THE DAMAGE

The structural action and the damage mechanisms of the rural houses discussed in the previous section bring out the critical and generalized as follows :

a) Defects in the structural configuration :

The geometry of the house in plan as well as in elevation has a significant effect on the distribution of the seismic forces. Unsymmetrical houses develop additional shearing forces due to twisting and warping. Failure commonly occurs at corners of openings at weakly built corners of the walls.

b) Weakness in the soil of the foundation :

Sometimes an inadequate foundation causes failure of a sound and strong superstructure. In many earthquakes, liquifaction of soil, occurance of sand pockets or settlement of soil lead to catastrophic failures of the buildings.

Very shallow foundations, deteriorate because of weathering, particularly when exposed to freezing and thawing in the regions of cold climate. Deterioration may also be caused by frequent flooding of foundations in tropical regions.

c) Weakness in walls :

Adobe, stone concrete block or brick masonry (unreinforced) are highly susceptible to damage because of their low tensile and shear resisting capacity. Due to door and window openings even further stress concentrations and reduction in strength occurs. A very critical source of weakness is the weak bonding material (usually mud mortar) between the masonry units.

Lack of structural integrity is the greatest source of weakness and may be responsible for severe damage or collapse. Failure of connections between wall and wall, wall and roof and walls and foundation may cause collapse of bearing walls.

d) Poor connection of roofs :

If the elements used in the roof or floors are not properly interconnected together and if the large seismic forces are not properly transferred to the supporting walls or frames through suitable connection between them, to roof and floors may be damaged severely or collapsed completely.

e) Poor construction quality :

In many instance the failure of rural houses in earthquakes have been attributed to poor quality of construction like weak materials, poor workmanship, e.g. inadequate skill in bonding units and improper and inadequate connections.

EARTHQUAKE RESISTANT DESIGN AND CONSTRUCTION OF RURAL HOUSES

The study of the performance of the rural houses in the past earthquakes clearly points out the structural action, damage mechanism and modes of failure and leads to the following general principles as to improve the design and construction techniques for earthquake resistance :

a) The site should be selected carefully. Stable slopes should be chosen to locate the house. The houses should not be built on very loose sands (due to liquifaction and settlement possibility during an earthquake) and on sensitive clays. Selection of construction sites is more feasible in the rural area than in urban area, such an advantage should be utilized.

b) Planning of the house should be done carefully. The house or its various parts should be kept symmetrical about both axes. A rectangular plan should be preferred without any projection. Blocks of different character should be separated from each other to keep symmetry and rectangularity.

c) An integral action of all the resisting elements should be provided by suitably connecting all the elements together, so that no seperation will take place during an earthquake.

d) Since adobe, brick, concrete block and stone are weak in tension and brittle in compression, their strength and ductility should be increased by providing some reinforcement at least at the critical sections in the form of steel bars or timber elements.

e) To increase the lateral resistance, diagonal bracing elements or walls to act as shear walls should be provided along both axes of the house.

f) The quality of construction should be improved and emphasized.

In the light of the above general principles, the following simple suggestions can be made to improve the earthquake resistance of the particular type of house:

ADOBE MASONRY HOUSES

a) To increase the ductility and strength of adobe, research work is continuing in various countries. Experiments show that 0.5% of dried grass added to mud of adobe (by weight) increases the strength by 50-100% . Also addition of a certain amount of cement or lime improves the strength of adobe.

b) To increase the integral action of the interior and exterior walls, reed straw, bamboo or wood planks should be placed at the corners and junctions of walls. A more reliable measure is to use steel bars or load wires which are anchored on a wood plate on the wall to tie the walls opposite to each other to avoid collapse. Such a measure is frequently used to repair the damaged buildings after an earthquake (Fig. 15).

c) Continuous timber lintels should be provided to prevent the top and bottom of the window openings.

d) The weight of the heavy earth roof should be reduced and its connection with the supporting walls should be done carefully. Enough projection of the roof beams or purlins (at least 50 cm) should be provided on top of the exterior walls.

e) Separately enclosed rooms should be preferred to a long barrack type, since small boxes are seismically stronger than a large single box. Therefore enough transverse walls should be provided in the layout of the house.

f) Simple shock absorbing measures can be adopted (such as a reed straw layer of about 5 cm. thick placed on the wall at a certain height of the wall may reduce the earthquake damage). (13)

STONE MASONRY HOUSES

Earthquake resistance of stone masonry houses may be improved by:

a) Increasing the shear strength of the stone walls. A better mortar than mud should be used for that purpose.

b) Quarry stone with corners should be preferred to rounded field or river bed stones.

c) In order to prevent splitting of the stone wall into two, the bond stones (or through stones) should be placed where needed.

d) The idems b, c, d and e for adobe houses are applicable here as well.

BRICK MASONRY HOUSES

Since brick or concrete block houses have also been widely used in the urban areas, their design and rules for construction have been included into the Earthquake Resistant Design Codes of most of the countires (Such as Yugoslavia, Peru, Turkey, China etc.). Their behavior is better than adobe or stone houses due to better quality and geometry of the material. The earthquake resistant rules stated for adobe and stone houses are also valid for brick or concrete block houses in addition or together with the code specifications.

TIMBER FRAMED HOUSES

a) Integrity and stiffness of the timber frame should be improved. Enough bracing members should be provided inside the timber frames.

b) Columns of the timber frame should be located near the inside face of the wall.

c) Steel plates and reinforcement should be used to tie the infill wall to the timber frame to provide integral action of the wall with the frame.

d) Light weight infill materials should be preferred.

e) Decay of structural wood members should be avoided. Columns should be placed on stone footings and should not be burried in soil. Beam-column connections should not be hidden inside the walls.

REPAIR, RESTORATION AND STRENGTHENING OF EXISTING RURAL HOUSES

In the repair, restoration and strengthening of existing rural houses the following stages should be distinguished :

a) Before an earthquake :

A survey should be carried out for the existing rural houses which are located in the seismic zones to determine the strengthening required.

b) Just after a damaging earthquake :

Damaged but standing houses should immediately be strengthened by temporary supports and emergency repairs to prevent their collapse during after shocks. By the same precautions less damaged houses should be brought back into use if necessary.

c) Long term repair after an earthquake :

Cost and feasibility studies should be carried out to decide on the demolishing or repairing a damaged house.

Architectural repair aims in bringing back the architectural shape of the house so that functioning of the house is resumed quickly.

The main purpose of restoration is to carry out structural repairs of the load carrying elements. It may require removal of some of the damaged elements so that the original strength is more or less restored.

If an existing house has original structural inadequancies (e.g. material may have degraded by time, alterations might have been carried out like providing new openings or adding new parts to destroy the symmetry etc.). They should be strengthened against earthquakes if it is not possible to replace it with an earthquake resistant one due to economic, social or historical reasons. The main items related to seismic strengthening are as follows :

a) Modification of the roofs :

Heavy flat earth roofs should be placed with lighter ones. Roof tiles are brittle and easily dislodged, where possible they should be replaced by corrugated iron or asbestos sheating. Roof truss frames should be braced by adding suitable bracing members in the vertical as well as in the horizontal planes. Anchors of roof trusses or roof beams (or purlins) should be improved and the roof thrust on walls should be eliminated (Fig. 9).

b) Substitution or strengthening of slabs :

A rigid slab inserted into existing walls plays an important role in the resisting mechanism of the house keeping the walls together.

If the slab is reinforced concrete a new reinforced concrete slab can be inserted by means of proper keys. The existing wooden slabs can be stiffened by placing a reinforced concrete thin slab on the old one or nailing planks perpendicularly to the existing ones. (Figs. 10,11).The slabs should also be properly connected to the walls by special detailing (Figs. 12, 13).

c) Adding new walls or strengthening the existing walls :

If the existing house is not symmetrical, it can be made symmetrical by adding new walls at proper places. For long barrack type houses transverse walls should be added to gain better box action and more rigidity in the transverse direction. In such modifications care should be paid to the connection details of the new walls with the old ones.

Existing walls whether they are cracked or uncracked can be strengthened by grouting a suitable cement mixture through special holes, by providing steel meshes on the two sides of the wall and connecting them through the wall and applying microconcrete on top of these meshes or by prestressing (place two steel rods on the two sides of the wall and stretch them by turnbuckles, thus shear strength of the walls increase and the connections with the orthogonal walls are improved) (Figs. 14,15).

As a variation and for economy of the technique of using wire mesh and microconcrete, the covering may be in the form of vertical splints between openings and horizontal bandages over spandrel walls at suitable number of points only (method is called "splints and bandages method") (Fig. 16).

OUTLINE OF THE CURRENT RESEARCH WORK ON THE SUBJECT

Most of the research work on rural houses are directed towards shear strength of masonry piers and panels (stone, hollow brick, adobe). Some static tests (cyclic) or shaking table tests have been carried out on small scale models of stone, adobe or brick houses or building fragments.

a) Tests on masonry piers :

Hayes, Obote and Clough (2) carried out cyclic in-plane shear tests on seventeen fixed-ended piers. Each test specimen was a full scale panel about 15 ft. square consisting of two piers and a top and bottom spandrel. The panels were constructed from 6 inch wide X 8 inch high X 16 inch long hollow concrete block units. The main

variables were; amount and distribution of reinforcement, rate of load application, vertical bearing stress and effect of partial grouting. The main conclusion of this paper was that much more research is required on the shear strength of masonry piers. It was also concluded that sufficient amount of horizontal bar reinforcement provides ductile behavior to the piers which mainly fail in shear, partial grouting produces an elasto-plastic force-deflection relationship prior to failure in shear mode and finally inclusion of 1/8 inch plates in the toes of the piers produces desirable ductile behavior before failing in flexural mode.

Sheppard, Terjelj and Turnsek (3) studied the flexural resistance of masonry walls to combined horizontal and vertical loads. The tests were specifically designed so that true flexural failures would occur. The results of the tests were generalized to provide a method for the calculation of the flexural resistance of unreinforced masonry walls, and a basis for the treatment of reinforced walls.

Benedetti and Casella (4) Tests were carried out on brick masonry panels to evaluate the shear strength. The tests were carried out by means of an experimental set-up which simulated the actual boundary conditions as close as possible. Post-cracking behavior of the panels, comparison of the nominal tensile strength derived by different criteria, possibility of the use of these values to define local strength values were the topics studied.

Steinmann, Anicic and Zamolo (5) carried out tests on wall specimens (approximately 1.0 m x 1,0 m) with or without reinforcement in the horizontal mortar joints, made by hollow brick blocks. The specimens were subjected to diagonal tension and also to cyclic and continuing monotonic load until failure. High strength mortar provided high static strength but brittle failure.

Turnsek, Terjelj, Sheppard and Tomazevic (6) carried out tests on stone-masonry walls, reproduced in the laboratory different from their natural environment. The walls were built of two outer layers of uncoursed stones, the middle of the wall being filled with rubble, poorly bound together with lime mortar.

The walls tested were repaired by the injection of cement grout into them and than retested. The test results showed that the basic strength of stone-masonry walls as they exist in ordinary houses is very low. However if the walls are repaired by cement grouting than the shearing resistance increased tremendously.

Vargas (7) studied the behavior of adobe piers. He carried out two series of tests. In the first series (overturning tests) it was possible to apply yield-line theory. The second series of tests demonstrated validity of the method also for the walls which are subjected to forces acting on plane normal to the wall.

b) Tests on small scale model houses and structural elements (Static and Shaking Table Tests) :

Vargas (8) carried out a research program to determine models of structural behavior practical rules and design procedures could be developed. Compression tests on adobe, splitting tests, flexure tests, axial compression tests on adobe piles with mortar joints, diagonal compression tests, shear tests on walls, flexure tests on walls, overturning tests on walls and module tests were carried out.

Meli, Hernandez and Padilla (9) Tests were carried out on a shaking table in order to evaluate the efficiency of three strengthening methods, which are : a reinforced concrete bond beam at the top of the walls, a welded mesh nailed to both faces of the walls and covered by mortar rendering, steel rods tied to both faces of the walls in their upper parts. Mechanical properties of adobe and structural behavior of adobe walls were also studied.

The test results showed that the siesmic intensity that can be withstood without major damage is increased at least twice by any of the strengthening methods studied, the most efficient being the welded mesh reinforcement. The emphasis is focused on adobe houses but most results are stated to be valid for unreinforced masonry in general.

Benedetti and Castellani (10) carried out tests on stone masonry buildings of scale 1/2, which intended to represent typical rural house without a rigid slab and without particular connections of orthogonal walls. The original and the repaired structures were loaded statically simulating earthquake effects. The load system represented one story plus roof above the model under test. Vertical loads were kept constant while horizontal loads repeated. The repairing technique proved to be efficient in restoring even increased the original strength of the structures.

Jabarov, Kozharinov and Lunyov (11) applied static and dynamic horizontal loads to a two-story fragment of a building with brick walls. At the first stage of the tests dynamic characteristics of the building and cracking, and ultimate strength of the building were studied. At the second stage, damaged brick masonry was strengthened by 2.5 cm thick reinforced mortar layers and tested under both static and dynamic loads. The test results showed that complete gain of initial strength and stiffness strengthened by this procedure was possible.

Gülkan, Mayes, Clough and Hendrickson (12) studied the seismic behavior of a simple masonry house subjected to simulated earthquake motions on a shaking table. The house was constructed such that similar masonry components were placed both parallel and transverse to the table motion. The test results indicated that the overall response is effected in a complex manner by the orientation of the timber truss, fixity of the in-plane walls and cracks developed in the walls. A nominal amount of reinforcement prevented the formation of cracks which could lead to failure.

Arya, Qamaruddin and Chandra (13) proposed a new system of brick buildings for improved behavior during earthquakes. In this system it is claimed that a clear joint between the superstructure and foundation masonry at plinth level would increase the earthquake resistance. Reinforced concrete bond beams are introduced just above and below the joint for integral action of respective components. Tests carried on shaking table on half size specimens and analytical seismic response calculations proved the reduction of effective acceleration acting on the superstructure masonry as compared with conventional buildings. Collapse is avoided and cracking damage is also seen to be much reduced.

Arya (14) carried out model studies of masonry buildings as related earthquake resistant design requirements. The items included were the strength tests on brick mortar composite, strength of shear walls with openings, lateral strength of small scale single room structures reinforced with steel bars in various ways, later a strength and free vibration tests on three storied single room buildings of one-third full-size, and shaking table tests to ultimate failure of half-size single room specimens reinforced in various ways. The last test were carried out on a specially made shock-type platform on an old railway wagon chassis. The test programs mentioned clearly brought out the critical sections of the walls requiring reinforcement in such buildings. With a little extra cost it seemed possible to prevent widening of cracks and also to prevent collapse.

Algabian (15) carried out a series of full-scale pseudostatic and dynamic tests of wood and steel deck diagrams. In addition a series of dynamic tests were performed on unreinforced masonry walls to study their behavior when subjected to out-of-plane excitation.

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PANEL DISCUSSIONS

The following panel members were present during the panel discussions : Prof. Arya, Prof. Bubnov, Prof. Benedetti, Prof. Hernandez and Prof. Neumann. Following are the general comments made by each panel member in summary in addition to their contributions to the general state-of-the art report :

Prof. Arya : Rural buildings account for the 95% of the loss of life during earthquakes. From the classification of the rural buildings it can be observed that all the good building materials are absent, besides construction quality is inferior, the buildings themselves are generally heavy in weight and the connections between the various elements are poor.

From the engineering point of view, since most of the rural buildings are one storied and generally very rigid, plastic no crack design is almost impossible. Also there is lack of communication between the engineers and the actual builders. The solution for the improvement of the seismic resistance of rural buildings should therefore be simple, along the traditional line and economical.

Prof. Bubnov : In Yugoslavia most of the rural houses are one or two story brick masonry structures. This type of construction may as well be found in the urban areas. Three types of seismicity should be considered : small, medium and strong. Measures should be taken according to these types. In general to increase the earthquake resistance of rural buildings the quality of the mortar should be improved, light roof covers should be used (many buildings collapsed due to that), tie-bands should be provided at various levels (could be reinforced concrete or steel). The corners are very sensitive, they must be reinforced and well constructed. In Yugoslavia reinforced concrete columns are placed at the corners; they do not carry vertical loads, they only provide good connection. Also for good earthquake resistance, the layout of the structure should be simple and a good foundation should be provided. A strong foundation is necessary not only for the earthquake loads but for carrying vertical loads as well.

In order to solve the problem, the following two aspects should be considered :

a - Economical aspects : This is the most difficult part of the problem since funds are limited.

b - Educational aspects : People should be educated. They must be taught what to do and how to do.

Some earthquake resistant solutions are not very expensive as compared to the usual construction. Additional reinforcement provided for earthquake resistance does not exceed 1% of the total cost. Tie bands are very effective, yet they are not expensive. Thus builders should be educated about all these effective measures.

Prof. Benedetti : Repair and Strengthening of Existing Stone Masonry Structures : (Demonstration Through Slides)

Some remarks : Most of the rural buildings in central Europe, especially in Italy are already existing structures. New ones are rather rare. Stone buildings may be 2 or 3 story high. Major damages may be due to : Separation of the two faces of stone walls, poor connection of slabs with walls and structural modifications (such as providing a new opening or adding a new wall etc.).

Due to economic reasons it is not possible to make these structures completely seismic resistant, but nevertheless their resistance can be improved through certain repair procedures and they can be used again.

Prof. Hernandez : Repair and Strengthening Adobe Houses (Demonstration through slides)

Some remarks : Many strengthening methods have been proposed but very few have been tested under actual conditions.

Model tests of rural adobe houses have been carried out in Mexico to see the effect of different kinds of strengthening procedures (9). Most effective strengthening procedure is found to be the use of wire mesh.

Prof. Neumann : Tests carried out at the Universidad Catolica del Peru (7, 8). (Demonstration through slides)

After oral presentation of each panel member, Prof. Arya made an announcement to inform about the new Monograph on Rural Structures which was prepared by Committee II of IAEE (1).

After that, discussion continued with the audiance. Mainly questions raised by the audiance pointed out the importance of education and the problem of lack of communication between engineers and builders and also between goverment authorities and the builders.

Prof. Arya had some comments about the improvement of communication; he suggested to prepare illustrative booklets (UNESCO is preparing a digest of 20-25 pages, to illustrate how and what is to be done) and even model houses for demonstration.

Prof. Bubnov commented on the level of the problem : The problem is not of University level but it is lower level. Supervision is important and different economic possibilities of each country should be taken into consideration.

FIG. 1 A WELL - BUILT ADOBE HOUSE
(Erzincan, Üzümlü town, Feb. 1978, Turkey)

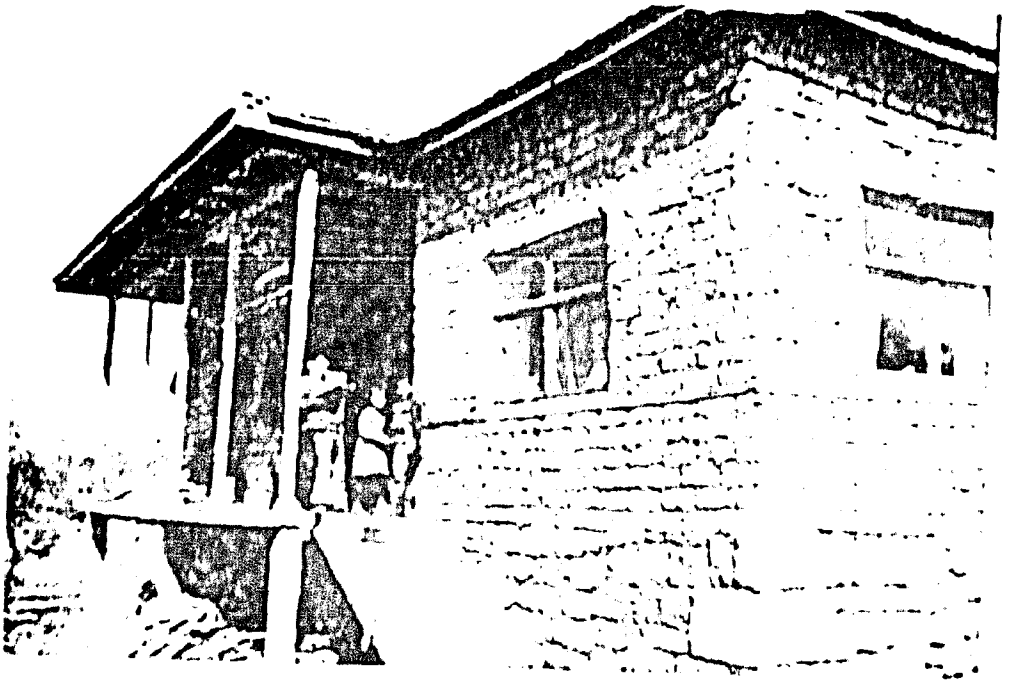

FIG. 2 A WELL - BUILT ADOBE HOUSE
(Erzincan, Uzumlu town, Feb. 1978, Turkey)

FIG. 3 INADEQUATE BOND BETWEEN TWO STONE LAYERS
(Sept. 6, 1975, Lice Earthquake, Turkey)

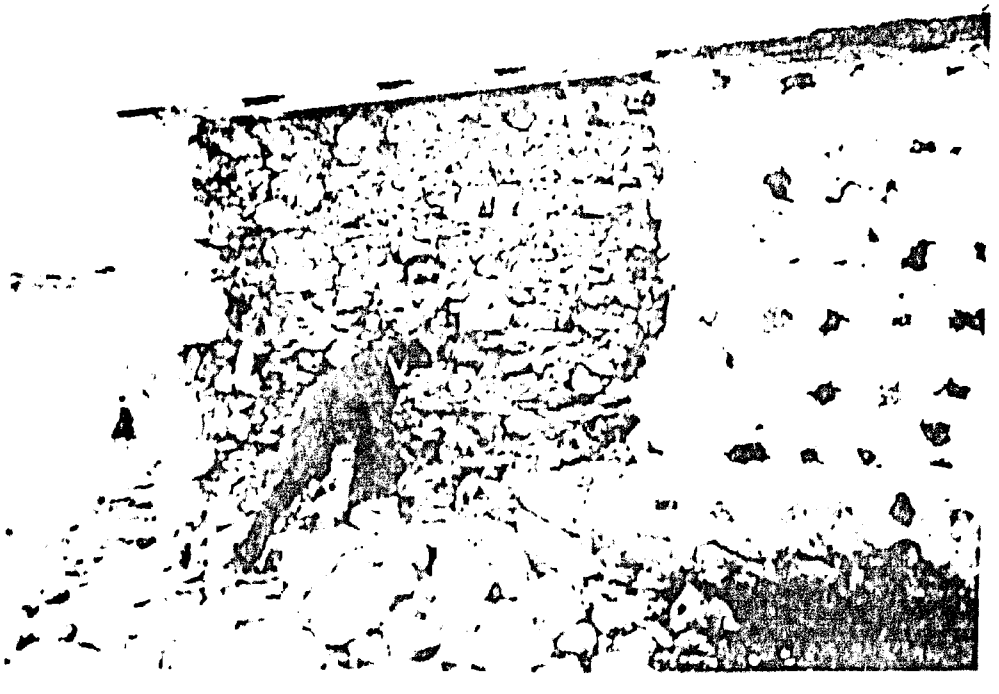

FIG. 4 INADEQUATE BOND BETWEEN TWO STONE LAYERS
(March 1976, Susuz Earthquake, Turkey)

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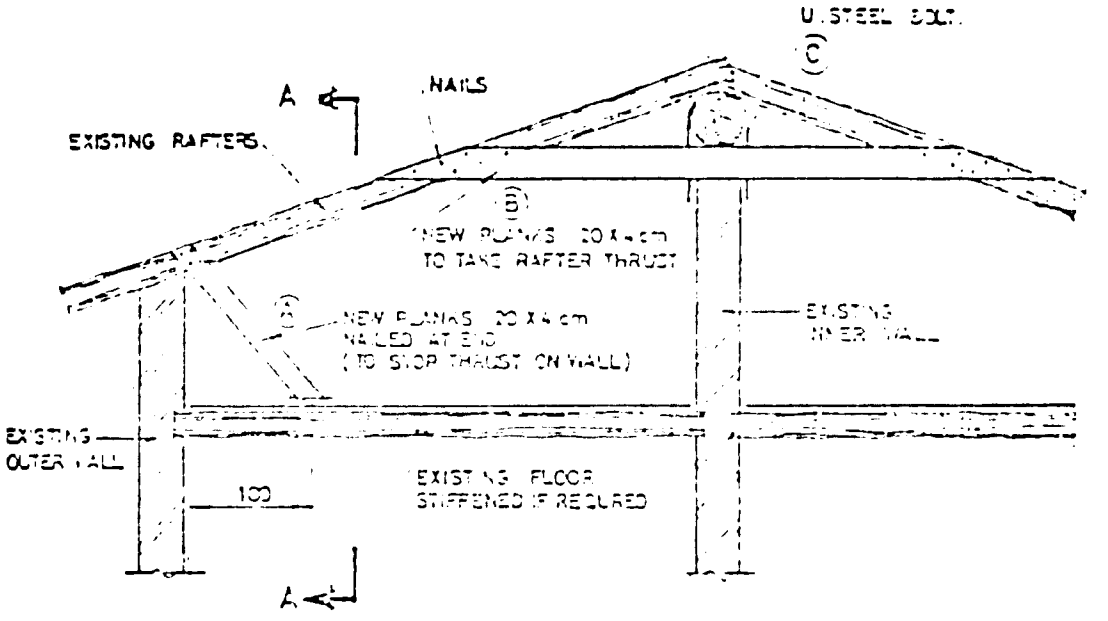

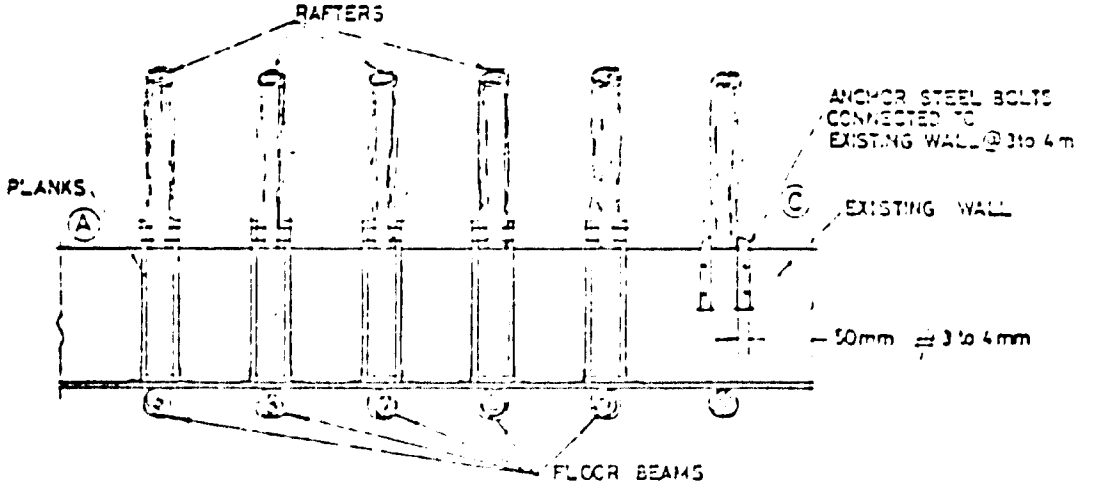

SECTION. A - A .

FIG. 9 ROOF MODIFICATION TO REDUCE THRUST OF WALLS (Ref. 1)

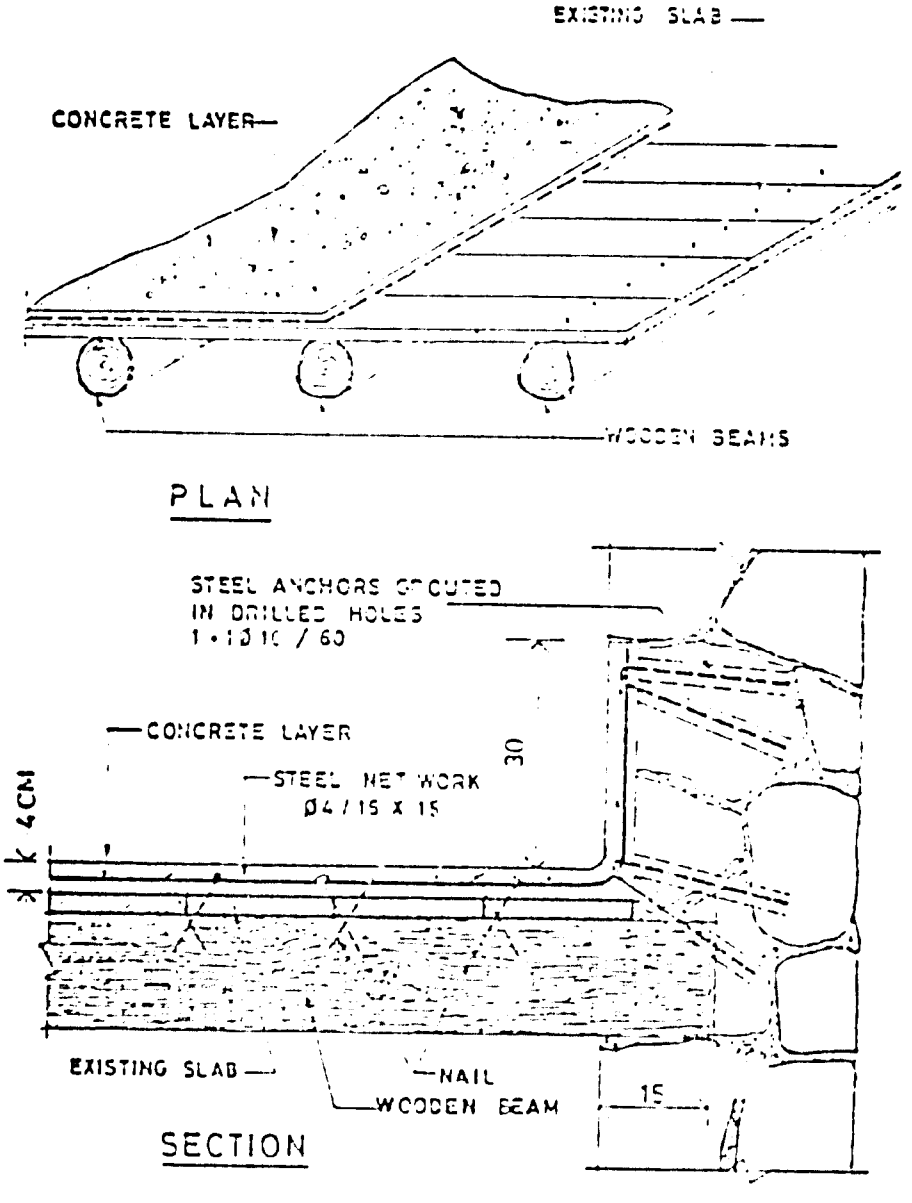

FIG. 10 STIFFENING WOODEN FLOOR BY REINFORCED CONCRETE SLAB AND CONNECTION TO WALL (Ref. 1)

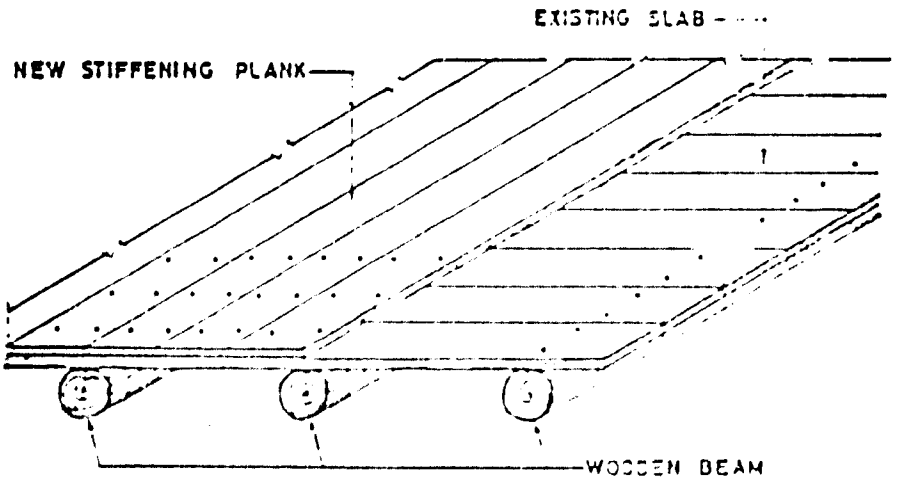

FIG. 11 STIFFENING OF WOODEN FLOOR BY WOODEN PLANKS (Ref. 1)

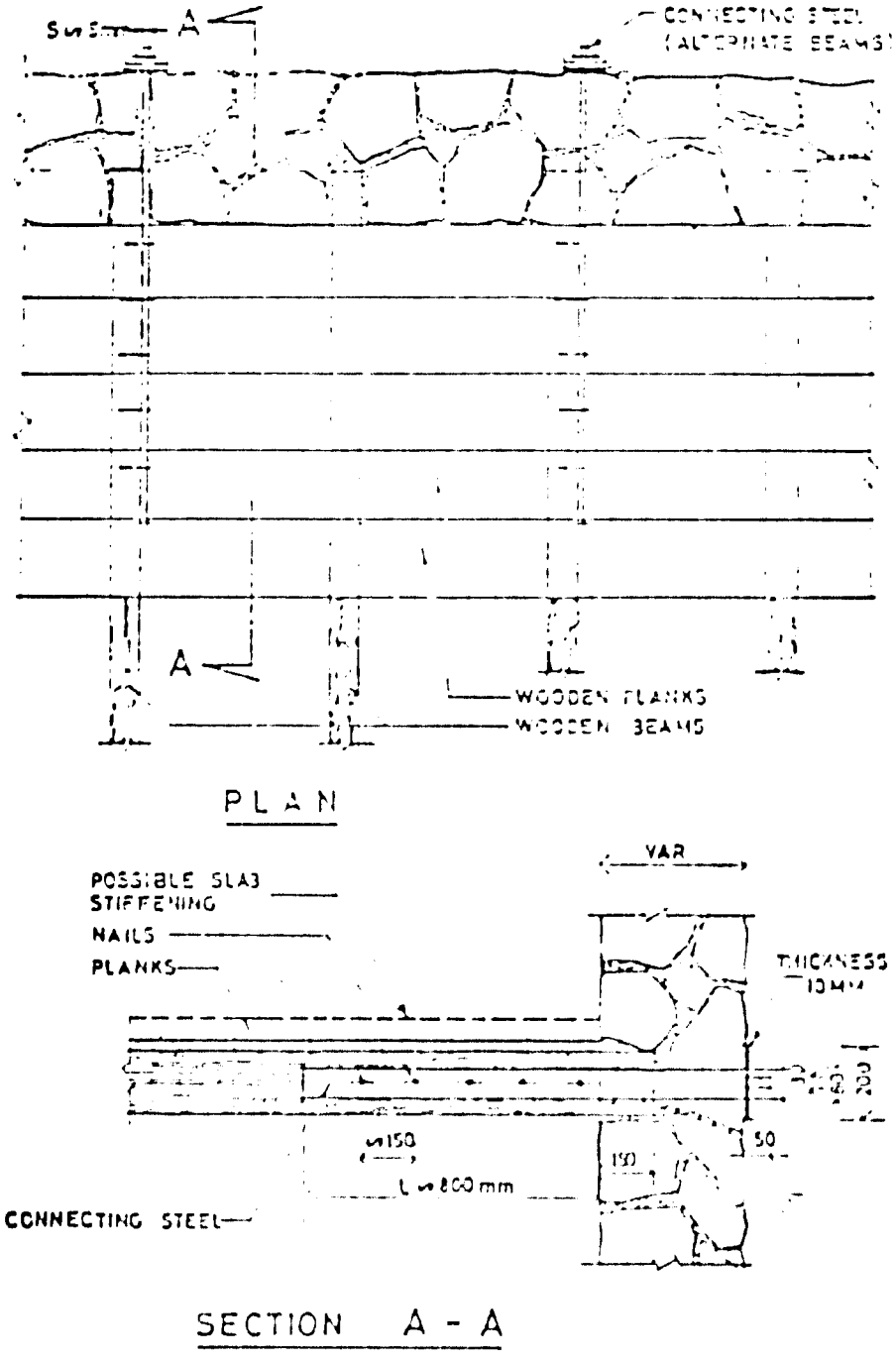

FIG. 12 CONNECTION OF FLOOR TO WALL (Ref. 1)

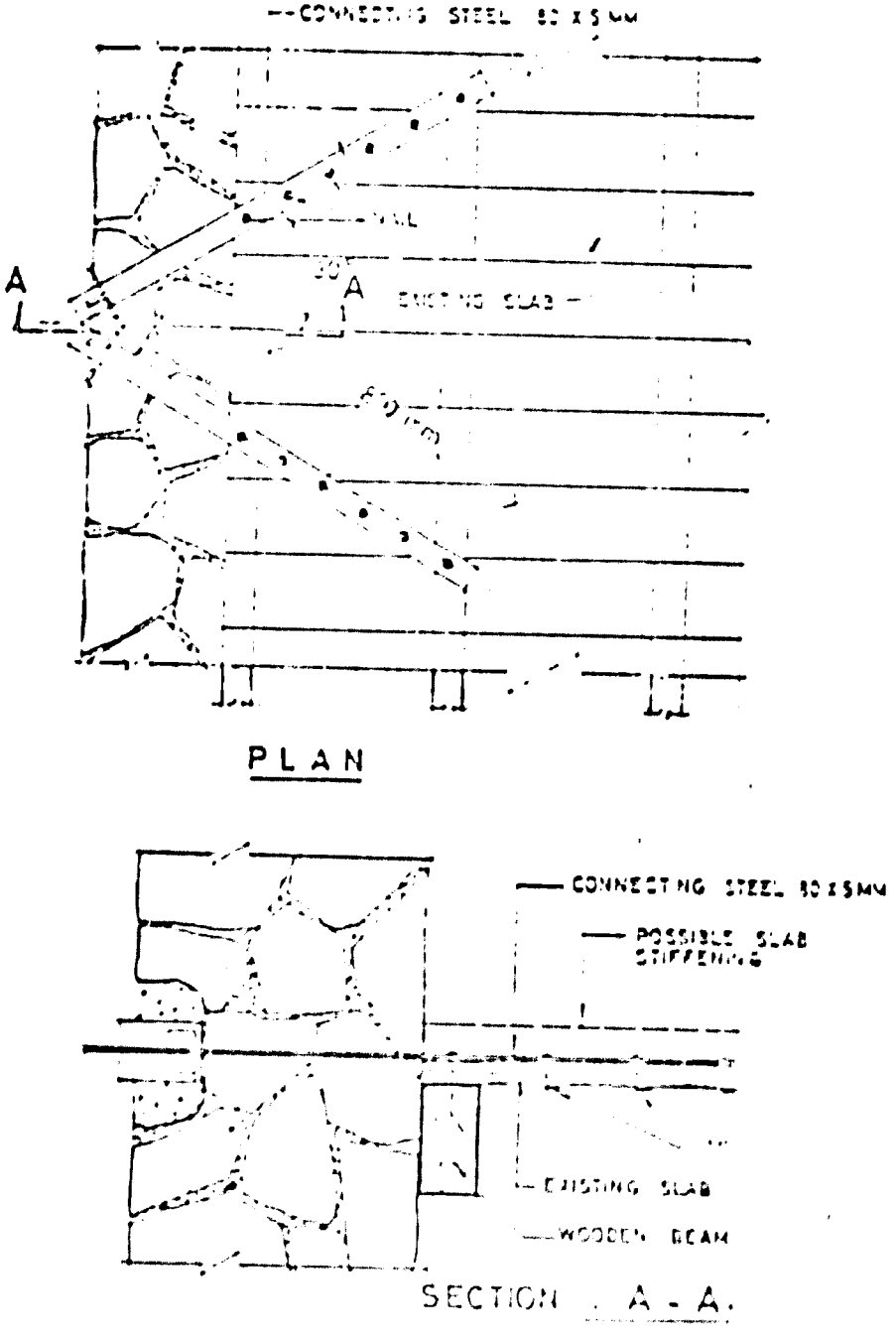

FIG. 13 CONNECTION OF FLOOR WITH WALL (Ref. 1)

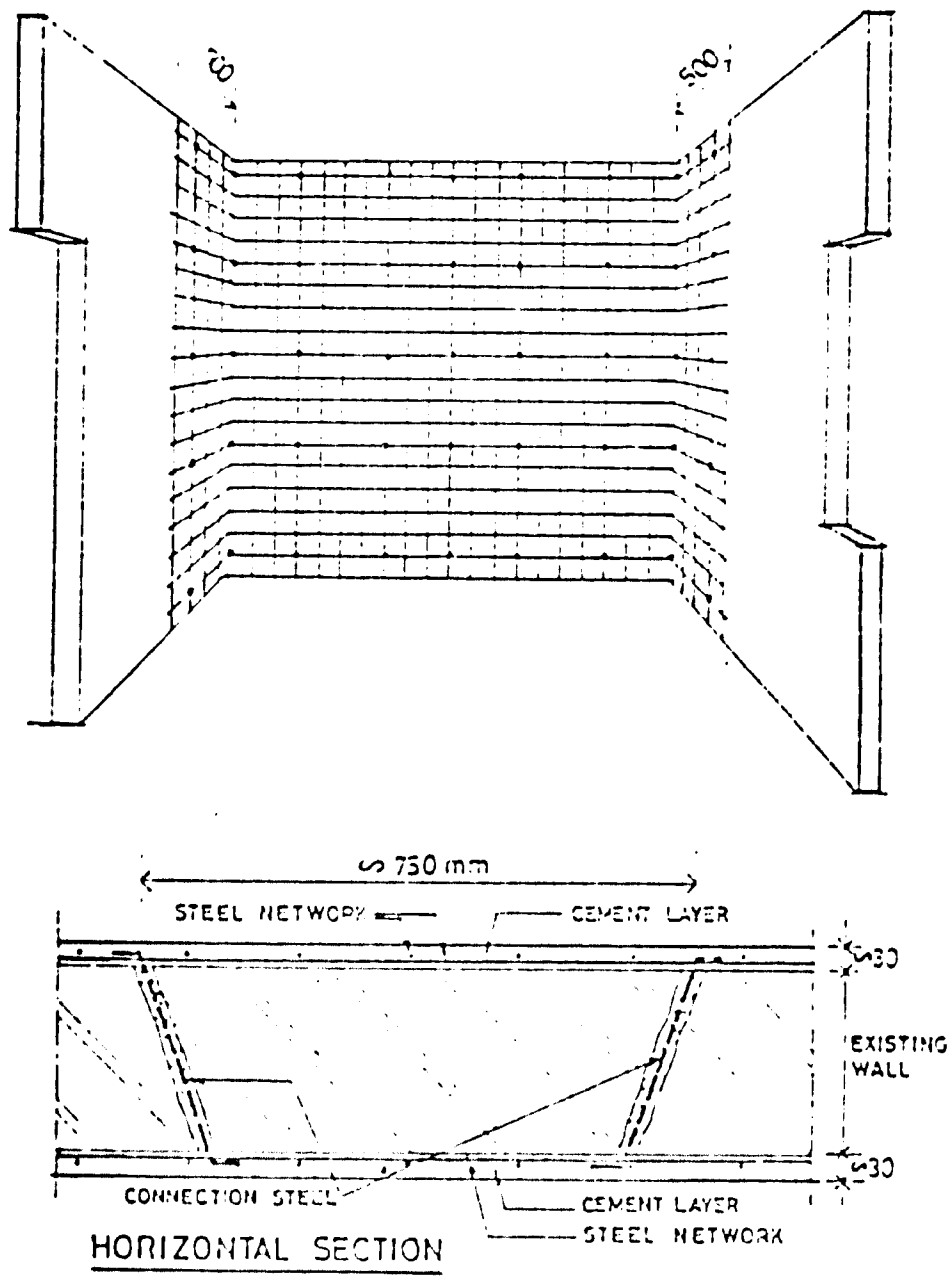

FIG. 14 VERTICAL REINFORCED CONCRETE COVERING PLATES (*Ref. 1*)

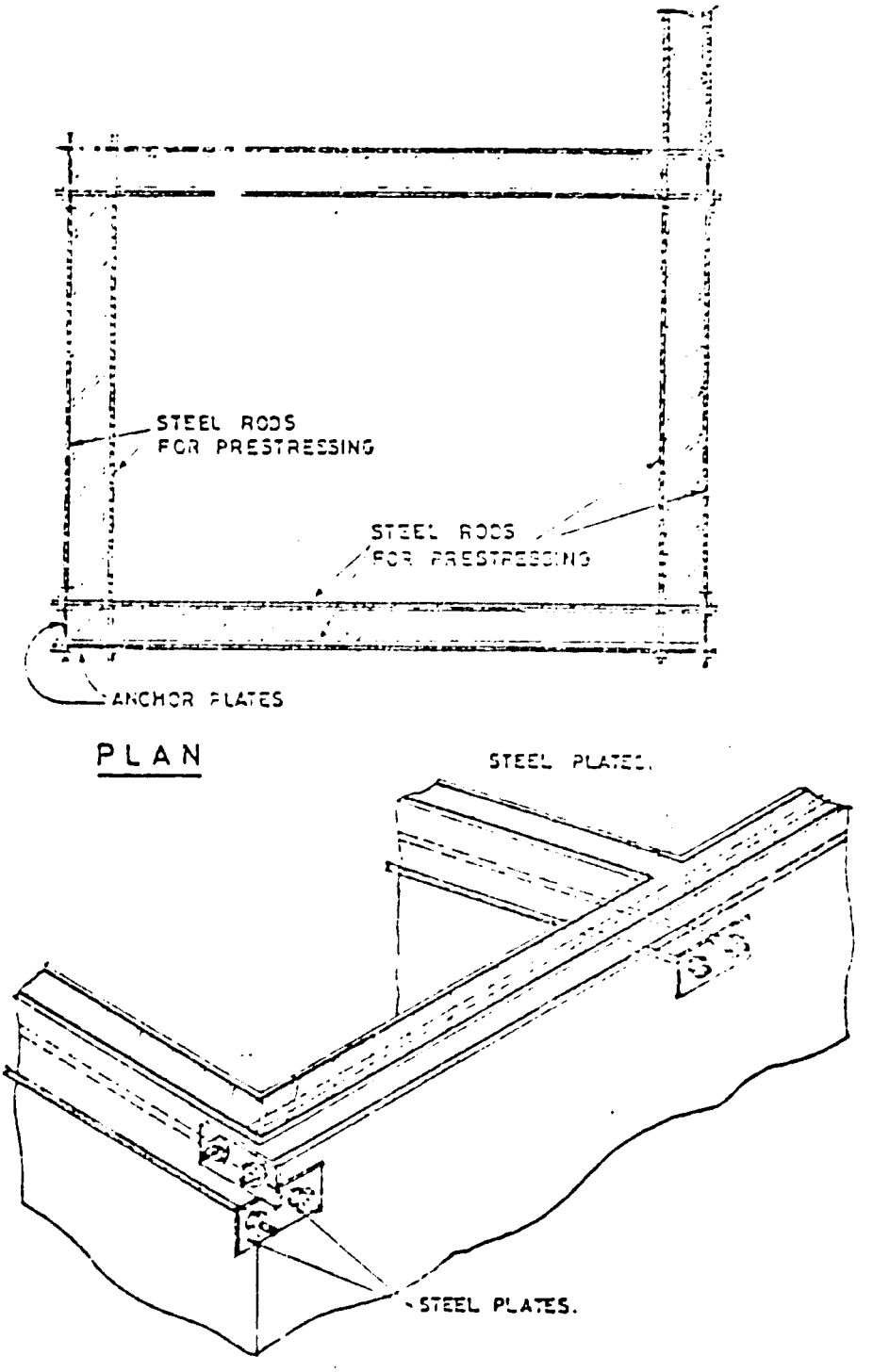

FIG. 15 STRENGTHENING OF WALLS BY PRESTRESSING (Ref. 1)

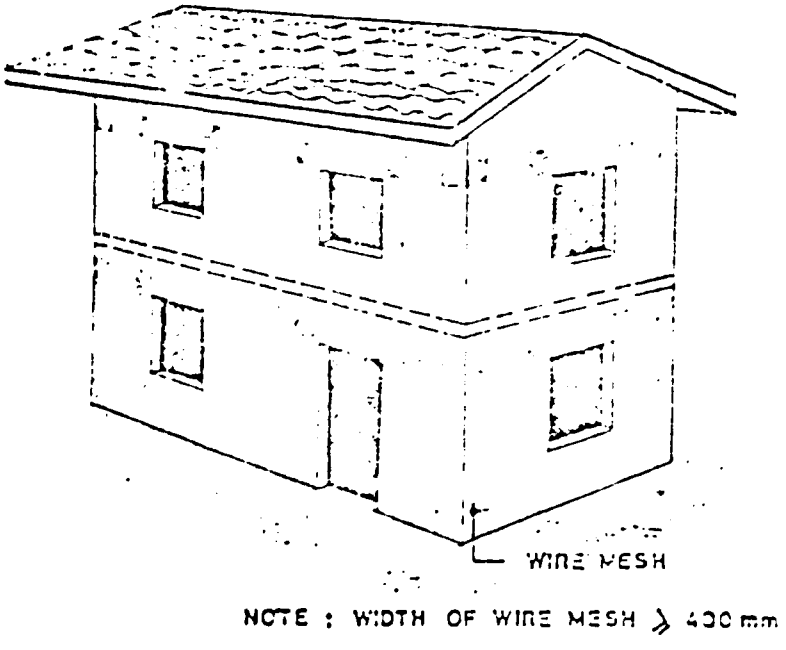

FIG. 16 SPLINT AND BANDAGE STRENGTHENING TECHNIQUE (Ref. 1)

INTERNATIONAL WORKSHOP

EARTHEN BUILDINGS IN SEISMIC AREAS

MATERIALS

The following individual made a keynote presentation:

Julio Vargas Neumann
Professor of Civil Engineering
National Catholic University
Lima, Peru

The following individuals acted as Session Chairmen:

Joseph Plecnik
Associate Professor
California State University

Rafael E. Torres
Professor, Departamento de Estructuras y Construccion
Universidad Nacional de Ingenieria
Lima, Peru

Frederick Krimgold
Program Director
National Science Foundation

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PERU ; LA RESTAURACION DE MONUMENTOS HISTORICOS CONSTRUIDOS CON ADOBE Y LAS TECNICAS UTILIZADAS.

Roberto Samanez Arguedo
Arquitecto Especialista en Restauración
Director Regional del Instituto Nacional
de Cultura del Perú.

ABSTRACT

Title of Paper: Perú: La Restauración de Monumentos Históricos construidos con adobe y las técnicas utilizadas.

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Abstract: En el Perú la geografía y el clima condicionaron la preferencia por la utilización de la tierra para las edificaciones. La presencia de una corriente marina de agua fría cambia el clima de la Costa y la hace árida y sin lluvias. Cinco mil años antes de Cristo el hombre se establece en los valles costeros en forma estable y utiliza la tierra para construir con adobes y tierra apisonada. Destacan las grandes edificaciones piramidales denominadas "huacas" que llegan a tener hasta 50 metros de altura o ciudades enteras como Chan-Chan que albergó a 100,000 personas. Cuando el Imperio de los Incas se extiende a través de un extenso territorio, adopta la técnica de usar adobes y con la conquista española producida en 1532 se continúa usando la tierra para construir murallas defensivas en torno a ciudades, iglesias y edificios para uso civil. La presencia contínua de terremotos por influencia del Cinturón Sísmico del Pacífico, obligó a interesantes soluciones estructurales en las construcciones.

En 1975 se inició en la zona de Cusco y Puno un importante Proyecto para restaurar monumentos arqueológicos y coloniales, entro de un Plan basado en el turismo cultural contando con asistencia de la UNESCO. Se desarrollaron técnicas adecuadas para restaurar científicamente las edificaciones de adobe, las que se describen en el trabajo del cual se ha hecho el presente resúmen.

F0005

EL MEDIO FISICO.

El área central andina en donde se ubica el actual territorio del Perú está definida por la presencia de la Cordillera de los Andes que origina un singular escenario geográfico con tres regiones naturales: La Costa, la Sierra y la Selva.

La Costa es una faja estrecha a lo largo del litoral del Océano Pacífico, con una extensión de 1,300 kilómetros, de los cuales el 70% está constituído por llanos estériles y arenosos, que se interrumpen para dar paso a 53 valles transversales, surcados por ríos que descienden de la parte occidental de la cordillera de los Andes. Una corriente marina de agua fría cambia el clima en toda la Costa, haciendo que se tenga un cielo cubierto y sin lluvias, contrariamente a lo que se podría esperar en esa latitud. La misma corriente genera abundante fauna ictiológica.

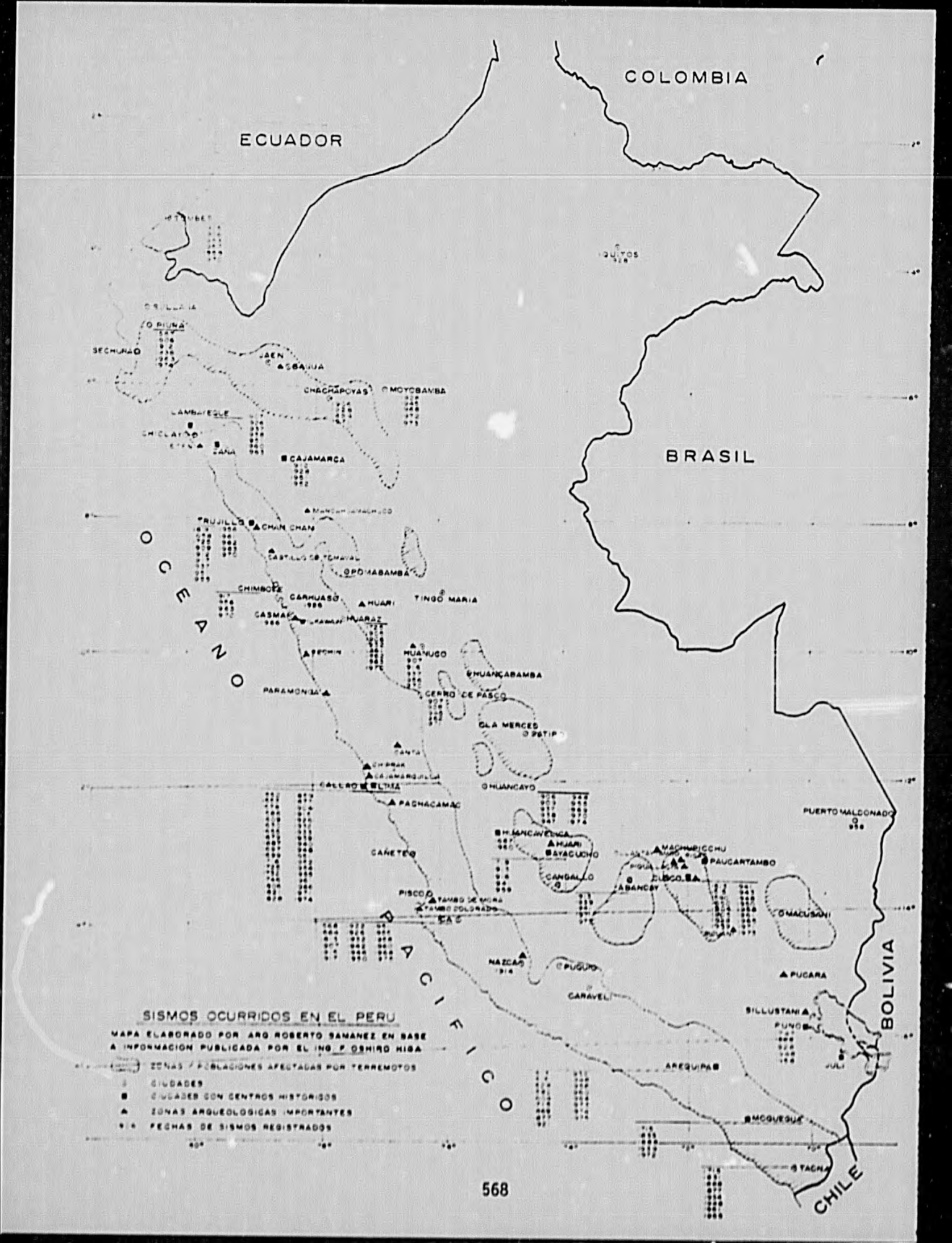
La Sierra corresponde a la parte medular y principal del sistema de los Andes, constituyendo una meseta de unos 4,000 metros de altitud surcada por hondos valles, testimonio de la notable erosión fluvial y pluvial que ha soportado esa zona geográfica. En ella se pueden distinguir las cuatro regiones de la cordillera, con cumbres que se elevan por encima de los cinco mil metros sobre el nivel del mar, las altiplanicies de páramos y punas, los valles y quebradas y las estribaciones de la cordillera que en su vertiente occidental descienden a la Costa y en la oriental hasta los llanos amazónicos. La Sierra presenta gran variedad de climas con lluvias periódicas que determinan abundantes recursos vegetales, bosques con gran cantidad de aves y plantas y una fauna alto andina de camélidos y cervidos, que favoreció los primitivos establecimientos humanos de cazadores y recolectores.

La región de la Selva situada al oriente de la cordillera de los Andes comprende la selva alta ubicada al final de las estribaciones con montañas menores cubiertas de bosques y la denominada selva baja, de grandes llanuras con vegetación exuberante, surcadas por grandes ríos y zonas anegadizas. Su clima es caluroso y húmedo con lluvias tropicales intensas. La población nativa es escasa y menor que en las otras dos regiones.

EL MEDIO GEOLOGICO Y LOS TERREMOTOS.

El área que ocupa el Perú forma parte del sector de influencia del Cinturon Sísmico del Pacífico registrando alta sismicidad, la costa recibe la presión de la placa de Nazca que se desplaza a razón de 5 cms. por año, generando una fuerza de compresión en la placa continental que ocasiona deformaciones, que al llegar a su límite de resistencia producen la mayor parte de los terremotos y por lo que los más fuertes tienen sus epicentros en el Océano Pacífico, llegando a magnitudes de 8.0 a 8.4 en la escala modificada de Mercalli, mientras que en el interior del territorio son menos frecuentes y llegan a magnitudes de 6.0 a 7.0 en la misma escala.

El litoral en el sector comprendido entre el Ecuador hasta Chile está flanqueado por hondos cauces marinos y la Cordillera de los Andes, constituyendo una placa tectónica donde se originan frecuentes sismos como los registrados en Ecuador: Latacunga (1698), Riobamba (1797), Quito (1859) y los que destruyeron Ambato e Ibarra en el siglo XIX, en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ECUADOR
BRASIL
BOLIVIA
CHILE
OCEANO PACIFICO
SECHURA
PIURA
JAEN
SOCAIUA
CHACHAPOYAS
MOYOBAMBA
LAMBAYEQUE
CHICLAYO
CAJAMARCA
TRUJILLO
CHAN CHAN
CHIMBOTE
CARHUAZ
HUARI
TINGO MARIA
CASMA
HUARAZ
HUANUCO
HUANCABAMBA
PARAMONGA
CERRO DE PASCO
LA MERCED
PETIP
CANTA
CHIRAK
CALLAO
LIMA
HUANCAYO
PACHACAMAC
PUERTO MALDONADO
HUANCAVELICA
HUARI
AYACUCHO
MACHUPICCHU
PAUCARTAMBO
CUSCO
CAÑETE
CANGALLO
ABANCAY
PISCO
TAMBO DE MORA
TAMBO COLORADO
ICA
MACUSANI
NAZCA
PUQUIO
PUCARA
CARAVELI
SILLUSTANI
PUNO
AREQUIPA
JULI
MOQUEGUA
TACNA
SISMOS OCURRIDOS EN EL PERU
MAPA ELABORADO POR ARQ ROBERTO SAMANEZ EN BASE A INFORMACION PUBLICADA POR EL ING F OSHIRO HIGA
ZONAS / POBLACIONES AFECTADAS POR TERREMOTOS
CIUDADES
CIUDADES CON CENTROS HISTORICOS
ZONAS ARQUEOLOGICAS IMPORTANTES
FECHAS DE SISMOS REGISTRADOS

CUADRO CRONOLOGICO DE LOS SISMOS FUERTES OCURRIDOS EN LAS CIUDADES CON CENTROS HISTORICOS MONUMENTALES DEL PERU

AÑO	DIA Y MES	CIUDAD								
		LIMA	CUSCO	AREQUIPA	HUANCAVELICA	MOQUEGUA	AYACUCHO	PUNO	TRUJILLO	CAJAMARCA
1552	2 - JULIO	●		●						
1573		●								
1578	17 - JUNIO	●								
1582	22 - ENERO	●		●						
1586	9 - JULIO	●								
1590			●							
1600	19 - FEBRERO			●						
1604	23 - NOVIEMBRE			●						
1609	19 - OCTUBRE	●								
1619	16 - FEBRERO								●	
1650	31 - MARZO	●	●							
1655	13 - NOVIEMBRE	●								
1658	14 - FEBRERO								●	
1687	20 - OCTUBRE	●			●					
1697	29 - SETIEMBRE	●								
1716	6 - FEBRERO	●								
1719	17 - JUNIO						●			
1725	6 - ENERO	●		●					●	
1732	2 - DICIEMBRE	●								
1746	28 - OCTUBRE	●								
1747								●		
1784	13 - MAYO			●						
1802	5 - OCTUBRE								●	
1806	7 - DICIEMBRE	●								
1821	10 - JULIO	●		●						
1828	30 - MARZO	●		●						
1831	8 - OCTUBRE			●						
1833	18 - SETIEMBRE			●						
1859		●								
1869	13 - AGOSTO			●		●		●		
1877	20 - SETIEMBRE	●								
1904	4 - MARZO	●								
1905	23 - ENERO		●							
1915	27 - DICIEMBRE	●		●						
1917	20 - MAYO								●	
1922	11 - OCTUBRE	●		●						
1926	11 - MARZO	●								
1928	14 - MAYO								●	
1933	5 - AGOSTO	●								
1937	21 - JUNIO								●	
1939	25 - ABRIL	●		●		●				
1940	24 - MAYO	●								
1950	21 - MAYO		●							
1951	23 - JUNIO						●		●	●
1952	3 - AGOSTO			●						●
1953	15 - FEBRERO	●								
1955	21 - JULIO			●			●		●	●
1956	16 - FEBRERO								●	
1957	14 - FEBRERO	●								
1958	1 - MARZO	●	●	●				●		
1959	24 - DICIEMBRE						●	●		
1960	9 - MARZO			●						
1964	28 - ENERO			●						
1965	30 - JULIO			●						
1966	17 - OCTUBRE	●								
1969	29 - AGOSTO								●	
1970	31 - MAYO								●	
1972	6 - SETIEMBRE					●				
1973	28 - JULIO			●						
1974	9 - NOVIEMBRE	●		●						
1974	27 - ABRIL			●						
1979	16 - FEBRERO			●						

FUENTES DE INFORMACION:

HISTORIA DE LOS SISMOS DEL PERU - ENRIQUE SILGADO FERRO
CITADO POR EL ING° FERNANDO OSHIRO HIGA
INVESTIGACION: ARQ° ROBERTO SAMANEZ

el Perú han sido muy frecuentes y numerosos como se puede constatar en la relación que se acompaña y en cuanto a Chile y Bolivia se pueden citar el maremoto que arrasó Concepción (1751) el terremoto de Chillan y Concepción (1939) el de Santiago (1960) y el de Chuquisaca en Bolivia en 1948.

Estas características han hecho que los terremotos sean fenómenos siempre presentes en la historia de los pueblos del Perú y debido a que una parte importante de las construcciones antiguas son de adobe, un material vulnerable al efecto de los sismos, se ha hecho necesario que las personas y organismos que se ocupan de la conservación del patrimonio cultural y monumental del país, se sumen a los investigadores que buscan desarrollar normas con consideraciones anti-sísmicas, de diseño y cálculo de las fuerzas laterales que permitan obtener un diseño sismorresistente para reforzar los edificios antiguos, aunque se está todavía en etapa inicial y se tienen pocos estudios y menos experiencias comprobadas.

LOS PRIMEROS POBLADORES.

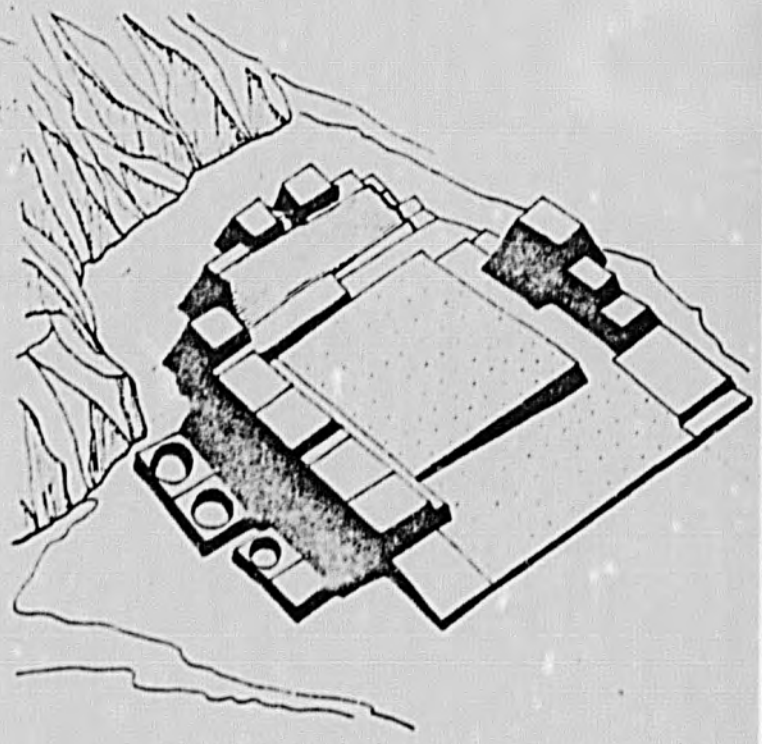
En el territorio descrito el hombre aparece en la remota prehistoria aprovechando las condiciones favorables que encontró para su establecimiento. Grupos humanos que se dedicaban a la caza y recolección con un nivel lítico de cazadores del pleistoceno, habitaron las zonas altas de los Andes (en torno a los 4,000 metros sobre el nivel del mar) en un período cuya antigüedad se estima en 12,000 años.

En la costa estos grupos de tradición cazadora se asentaron hacen alrededor de 9,500 años, adaptándose a la obtención de nuevos recursos del mar y formando aldeas incipientes, con una economía de carácter estacional que determinó desplazamientos entre los valles. Hacia el año 5,000 antes de Cristo la pesca reemplaza a la caza tal vez extinguida y los grupos humanos recolectores de plantas en las lomas más fértiles de las estribaciones andinas, empiezan a obtener la producción plantando y cosechando diversas especies silvestres. Al reemplazarse la dieta de recolección y caza por otra de base marina se produce un proceso de sedentarización, determinando también que el cultivo de plantas constituya la base de la economía. Entre los años 2,500 y 2,000 antes de Cristo se habían establecido en la costa numerosos pueblos que vivían de la riqueza del mar y de la agricultura incipiente.

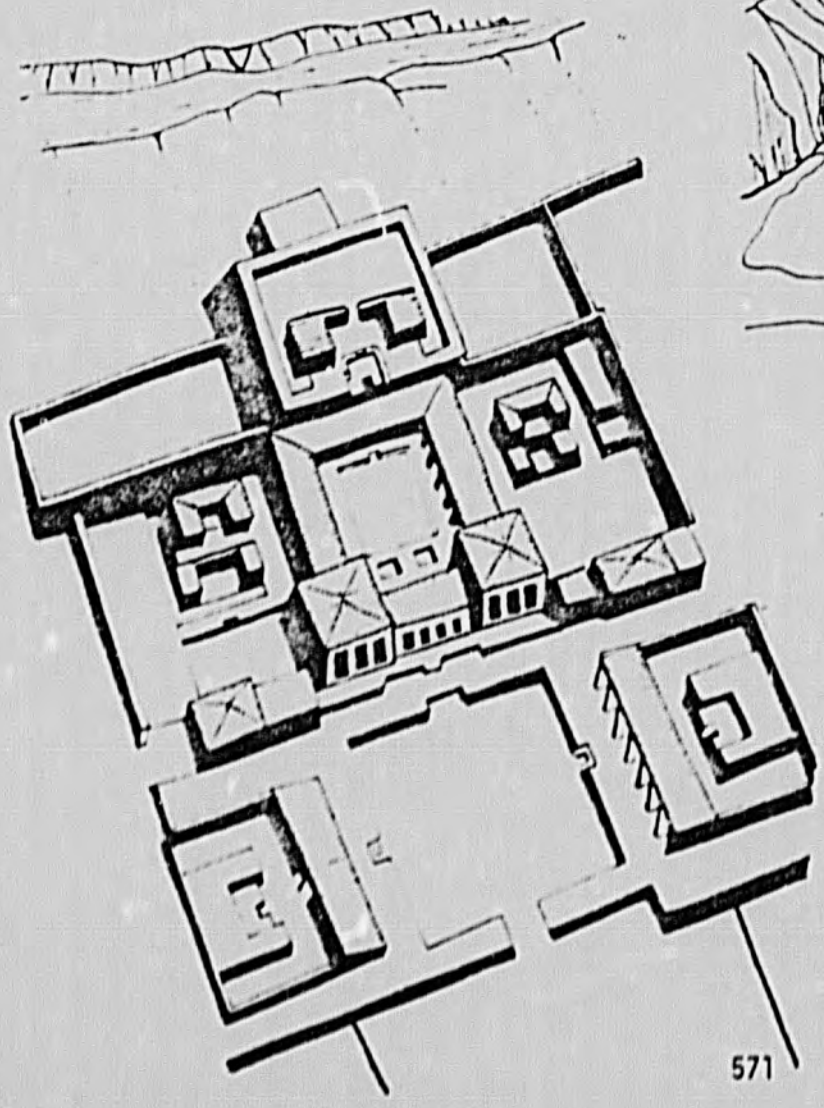
EL USO DE LA TIERRA COMO MATERIAL DE CONSTRUCCION.

Es en este período precerámico que se constituyen comunidades cada vez más organizadas en las que sus habitantes unían sus esfuerzos para construir canales de irrigación y estructuras públicas activas de índole ceremonial. Generalmente se construyen pequeñas plataformas escalonadas en las colinas y otras de forma piramidal. Las edificaciones se hacen inicialmente removiendo la tierra dura de la costa árida y se utilizan adobes y cañas, desarrollando luego la técnica de construir con tapia (tierra apisonada) y con adobes de diversos tipos. En la costa norte las habitaciones para vivienda eran semi enterradas construídas en fosas excavadas en la tierra, que se revestía con cantos rodados colectados en las playas. En otros sectores de la costa norte las viviendas se construían en plataformas a manera de terrazas que se formaban usando bloques de piedra para los muros

VIVIENDAS SEMISUBTERRANEAS DE LAS PRIMERAS COMUNIDADES SEDENTARIAS DE LA COSTA PERUANA (VALLE DE SUPE Y TABLADA DE LURIN)



ARQUITECTURA MONUMENTAL TEMPRANA CONSTRUIDA CON ADOBE Y TIERRA APISONADA - LOS GRANDES ESPACIOS CENTRALES ERAN UTILIZADOS PARA CULTIVOS (EL CARDAL-LURIN)



HUACA DE LOS REYES EN EL VALLE DE MOCHE, CONSTRUIDA EN TORNO A 1750 ANTES DE CRISTO

(DIBUJOS REPRODUCIDOS DE CARLOS WILLIAMS)

de contensión, sobre las que se ubicaban recintos semi-enterrados que se completaban con un material que tendría gran aceptación en la costa peruana, la "quincha" o estructura de caña revestida con barro.

Durante el período histórico denominado formativo inferior, entre los 2,000 a 1,250 años antes de Cristo, se construyeron complejas edificaciones utilizando adobes de forma cónica, cilíndrica, en forma de conos truncados y de paralelepípedos de diferentes tamaños.- Paralelamente se utiliza la tierra apisonada en moldes de madera con la técnica conocida como "tapia". La producción arquitectónica y la diversidad de concepciones en ese período nos hace ver que existían ya formas de organización social definidas, con jerarquía y capacidad de planificar y ejecutar, en las que el poder se sustentaba en el culto religioso.

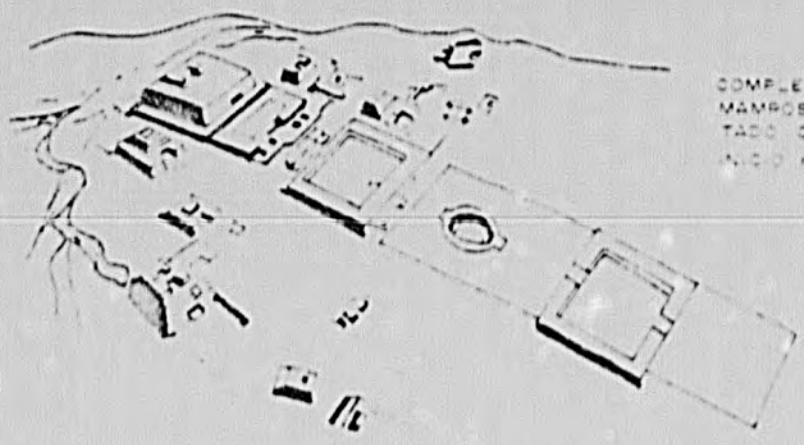
Los elementos formales básicos de la arquitectura entre los 2,000 y 500 años antes de Cristo, son las "plataformas" y los "montículos" vinculados a los "andenes" y los "patios rectangulares hundidos". Todas esas formas se combinan en una gran variedad de concepciones en las que destaca el "montículo piramidal" que es el origen de las pirámides escalonadas que se presentará hasta en las épocas tardías de la cultura Moche y aún en las concepciones de época Inca, constituyendo una estructura formal persistente que evoluciona haciéndose más compleja a medida que responde a exigencias funcionales mayores, determinadas por los fines religiosos y administrativos de sus constructores.

El uso de adobe o la tierra apisonada en esas edificaciones y las posteriores, aparece como una alternativa tecnológica que responde adecuadamente a las condiciones que la geografía y el clima de la costa árida y seca imponen a los hombres. La ausencia de lluvias hace que estos sean materiales duraderos.

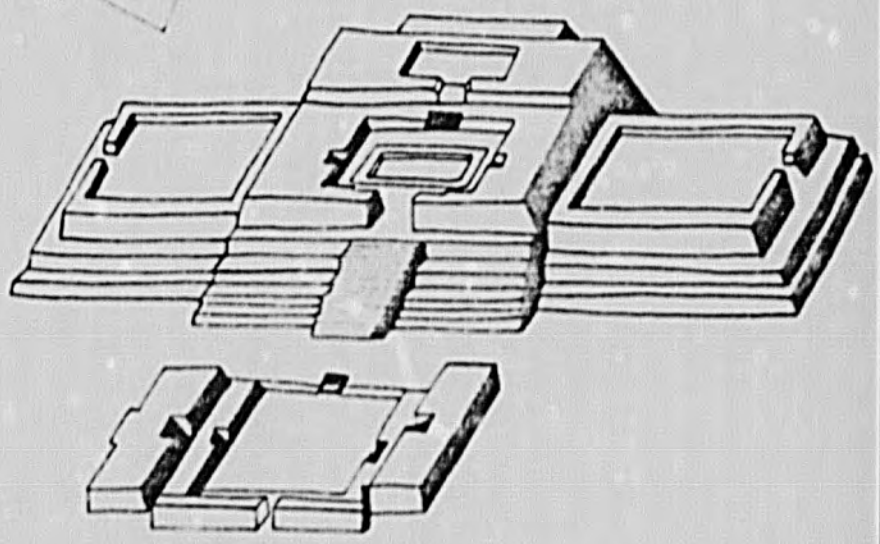
Alrededor del primer milenio antes de Cristo surgen culturas más evolucionadas como Chavín y quinientos años después se desarrollan culturas regionales en la Cordillera de los Andes, tales como Tiwanaku y Tucara y después estados militaristas como el Imperio Wari que se extendió por gran parte de la sierra y la costa. Sin embargo quienes conocieron mejor la técnica de construir con adobes de barro secados al sol, fueron los Mochicas cuya cultura floreció entre los 100 años antes de Cristo y 700 después. Ellos continuaron la tradición de construir pirámides hechas de plataformas superpuestas alcanzando hasta 50 metros de altura sobre el nivel del suelo, empleando millones de adobes.

Entre los años 1,200 a 1,450 después de Cristo surgió en el mismo territorio de los Mochicas la Ciudad de Chan-Chan, antiguamente conocida como Chimor, capital del reino Chimú, que fué la ciudad de adobe más grande de América, constituída por ocho ciudadelas y varias pirámides ceremoniales, templos, edificios públicos y viviendas, circundando a cada conjunto una muralla de adobes que llega a medir hasta 9 metros de altura y 3.50 metros de ancho en su base.

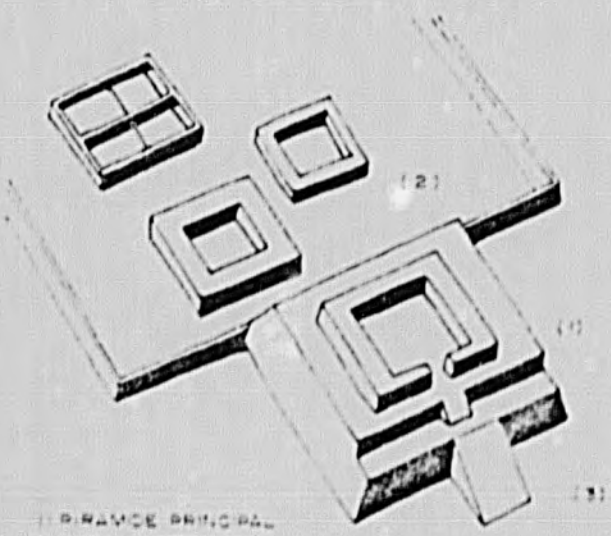
Las representaciones arquitectónicas en ceramios precolombinos permiten conocer las características arquitectónicas de las edificaciones que no se han conservado en su integridad a diferencia de los monumentos de grandes dimensiones. Esos testimonios y el estudio de los restos arqueológicos permiten deducir que la arquitectura precolombina de la



COMPLEJO TEMPRANO DE LAS ALDAS, CONSTRUIDO CON MAMPOSTERIA DE PIEDRA EN PRIMERA ETAPA Y COMPLETADO CON OTROS MATERIALES. LA CONSTRUCCION SE INICIO HACE 3.800 AÑOS

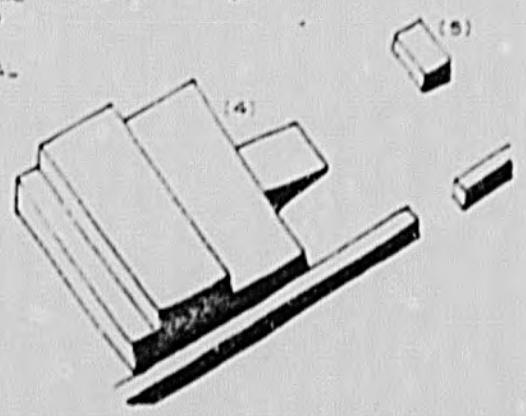


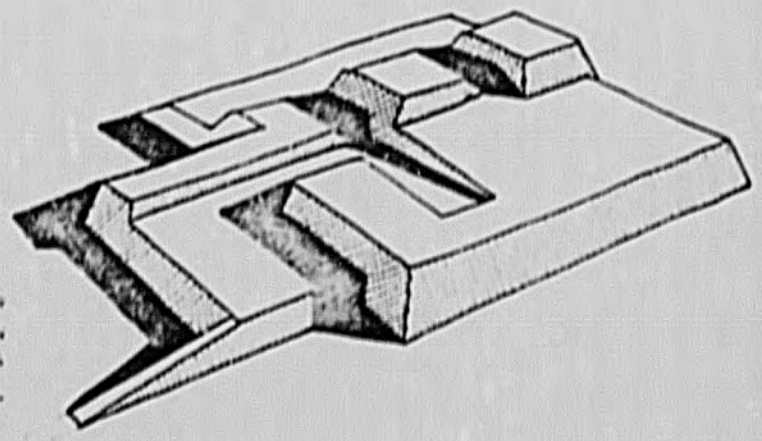
SITIO DE SARAGAY EN LIMA CON UNA PIRAMIDE ESCALONADA DE 17 Mts DE ALTO Y CON ALAS LATERALES ESCALONADAS TIENE FRISOS DE BARRO POLICROMADOS DE NOTABLE VALOR. ESTE COMPLEJO CHAVIN DE TIENE 3.000 AÑOS DE ANTIGUEDAD



COMPLEJO DE PACATNAMU CON LOS PRINCIPALES ELEMENTOS COMPOSITIVOS. LAS EDIFICACIONES TIENEN BASES DE PIEDRA Y ESTAN HECHAS CON ADOBES RECTANGULARES

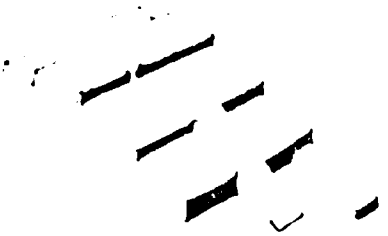
1) PIRAMIDE PRINCIPAL
2) PATIO POSTERIOR
3) PATIO ANTERIOR
4) PIRAMIDE LATERAL
5) ALTAR





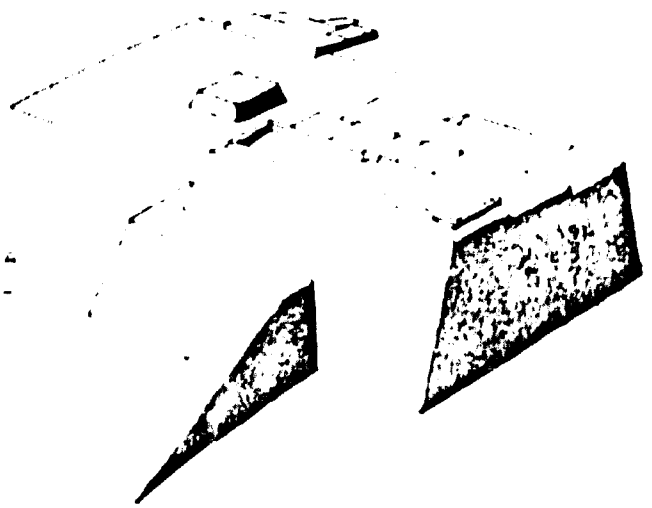
HUACA DE PAMPA GRANDE CONSTRUIDA ALREDEDOR DEL AÑO 600 ANTES DE CRISTO. RECONSTRUCCION HIPOTETICA DE LA PIRAMIDE PRINCIPAL, QUE ES LA TERCERA EN TAMAÑO EN EL CONTINENTE SUDAMERICANO

(DIBUJOS REPRODUCIDOS DE CARLOS WILLIAMS)

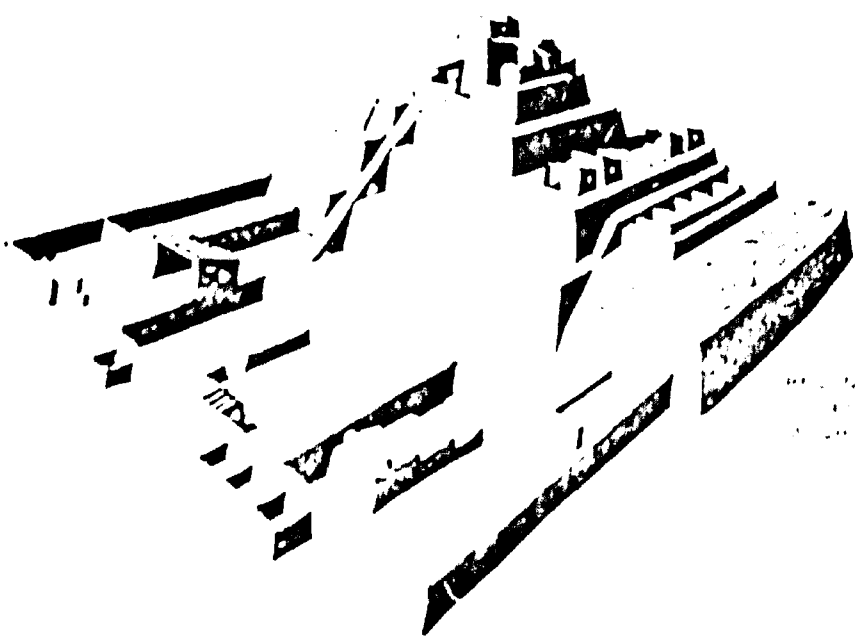


HUACA DE SAN MIGUEL EN EL VALLE DE ZAÑA
CULTURA MOCHICA

HUACA DE TEODORA EN EL VALLE DE ZAÑA
CULTURA MOCHICA

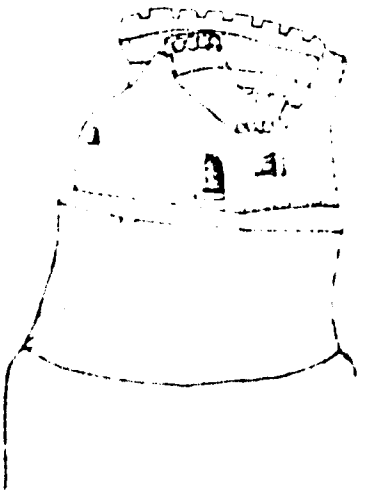


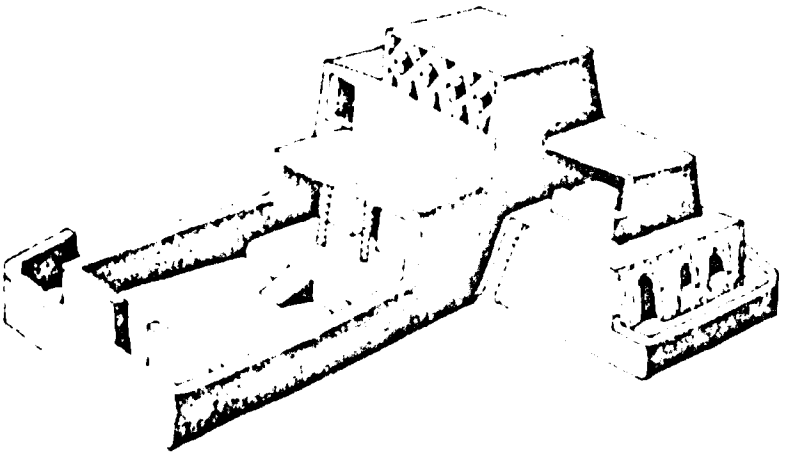
HUACA DE CHOTUNA EN LAMBAYEQUE A LA QUE SE ACCESE POR UNA RAMPA. CULTURA MOCHICA. DE AÑOS ANTES DE CRISTO HASTA 700 AÑOS DESPUES

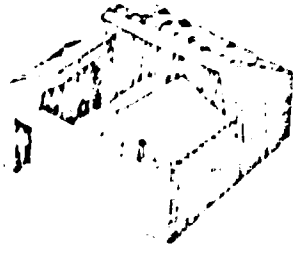


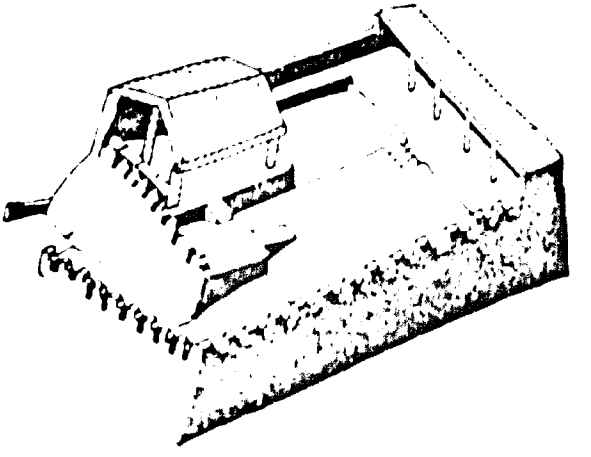
RECONSTRUCCION HIPOTETICA DE UNA [illegible] REGIONAL DE LA CULTURA [illegible]

DIBUJOS REPRODUCIDOS DE CARLOS WILLIAMS

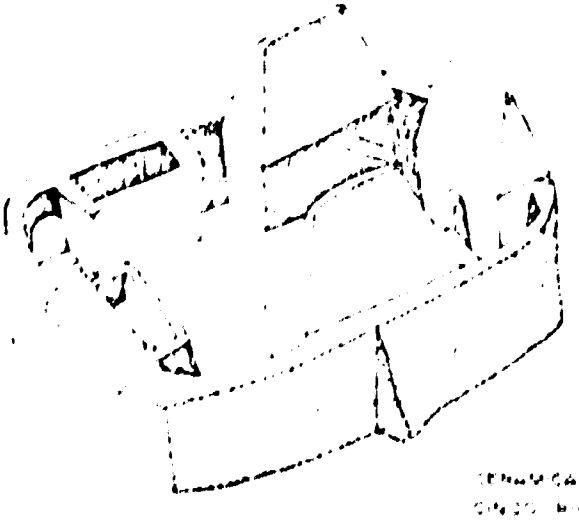








DIVERSOS TIPOS DE VIVIENDAS REPRESENTADAS EN LA CERAMICA [illegible]
[illegible] CASAS ESTRELLADAS CUBIERTAS CON [illegible]



CERAMICA REPRESENTANDO UNA CABAÑA HECHA CON
[illegible] PIEZAS SEPARADAS (DIBUJO DE RAMAREZ)

región andina central se caracteriza por la creación de extensos espacios exteriores rodeados de muros, terrazas, recintos, plazas y calles. No fué una arquitectura de grandes edificaciones techadas o de planimetría compleja en el interior, fué más bien caracterizada por recintos techados de dimensiones limitadas con una composición que destaca por el juego volumétrico obtenido, en la cual el adobe se prestó adecuadamente a esas necesidades expresivas.

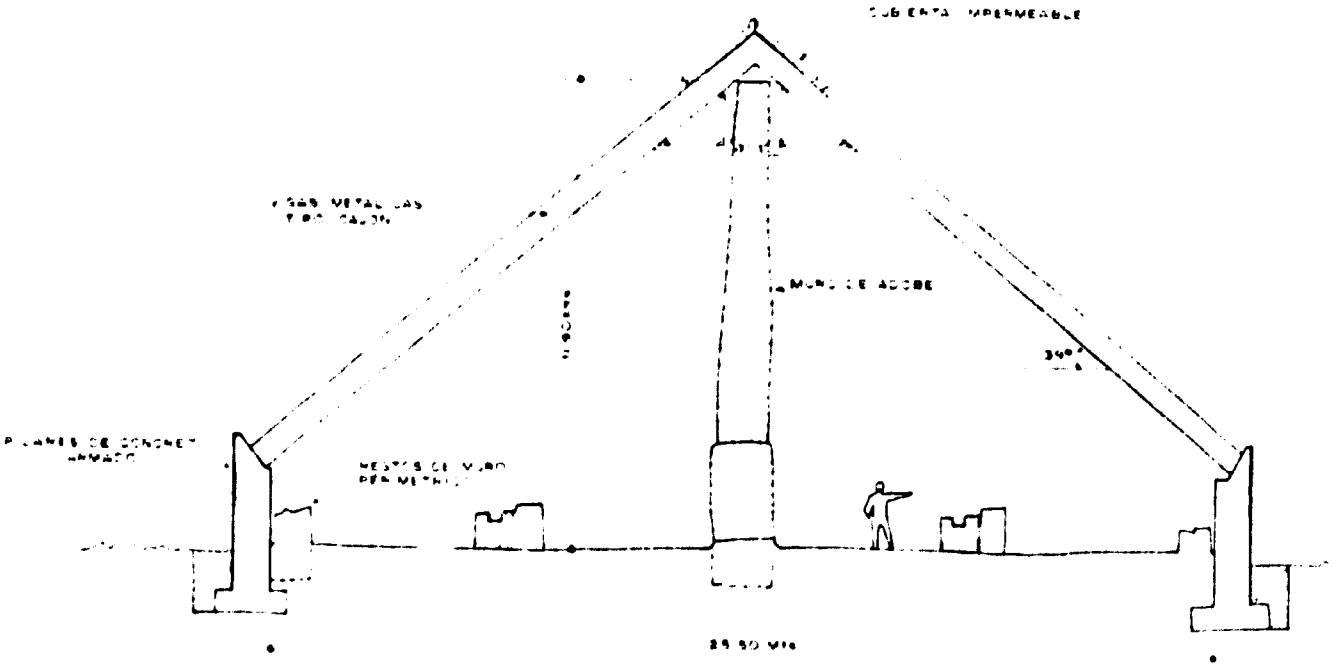
Al ocaso de las culturas Wari y Tiahuanacu hacia el final del período conocido como Horizonte medio, surge el Imperio Inca cuyo apogeo y expansión máxima se logra en el siglo XVI, décadas antes de la conquista española producida en 1533. Los incas adoptaron los conocimientos y la tecnología de los pueblos conquistados y el adobe continúo siendo un material de construcción de primera importancia y se utilizó para combinarlo en forma superpuesta a los muros de piedra, que por lo general tenían de dos a cuatro metros de altura y eran finamente labrados. Con los adobes se hacía un cerramiento y los hastiales triangulares sobre los que se apoyaba la estructura de madera del techo.

Uno de los ejemplos más importantes de esa arquitectura es el templo de Viracocha en Raqchi cerca de Sicuani, donde quedan los restos de un edificio cuyo espacio interior tenía un gran muro central de 12 metros de altura, de los cuales un promedio de 2.30 metros son de piedra de cantería y el resto de adobe con un espesor de muro de 1.05 metros.

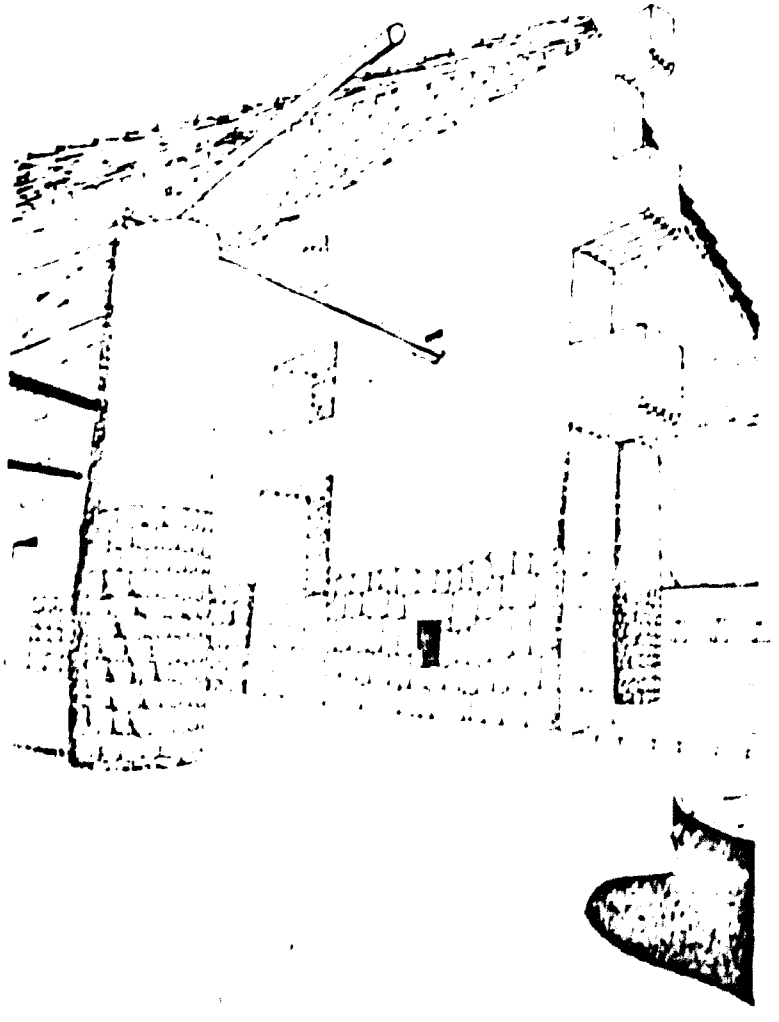
En la costa los incas siguiendo a sus predecesores utilizaron el adobe para la totalidad de las edificaciones, usando únicamente piedras rústicas para la cimentación. Los asentamientos de Cajamarquilla y Tambo Colorado son un buen ejemplo de ese período.

La tradición del adobe, la tierra apisonada y la construcción con tarquesh de caña y barro (quincha) de época precolombina fué continuada por los españoles después de la conquista del Perú producida en 1533, aunque se produjo un cambio fundamental en todos los aspectos culturales y tecnológicos al introducir los adelantos del mundo occidental. El adobe usado en las construcciones coloniales sufre algunas variaciones como el agregado de estiércol y el reemplazo de la paja entera colocada en forma de espiral por la paja cortada y mezclada con el barro. Como una reminiscencia incaica en la Costa se utilizaron adobes pequeños que tienen alrededor de 40 centímetros de longitud, mientras que en la zona de los Andes los adobes llegan a medir un metro de largo.

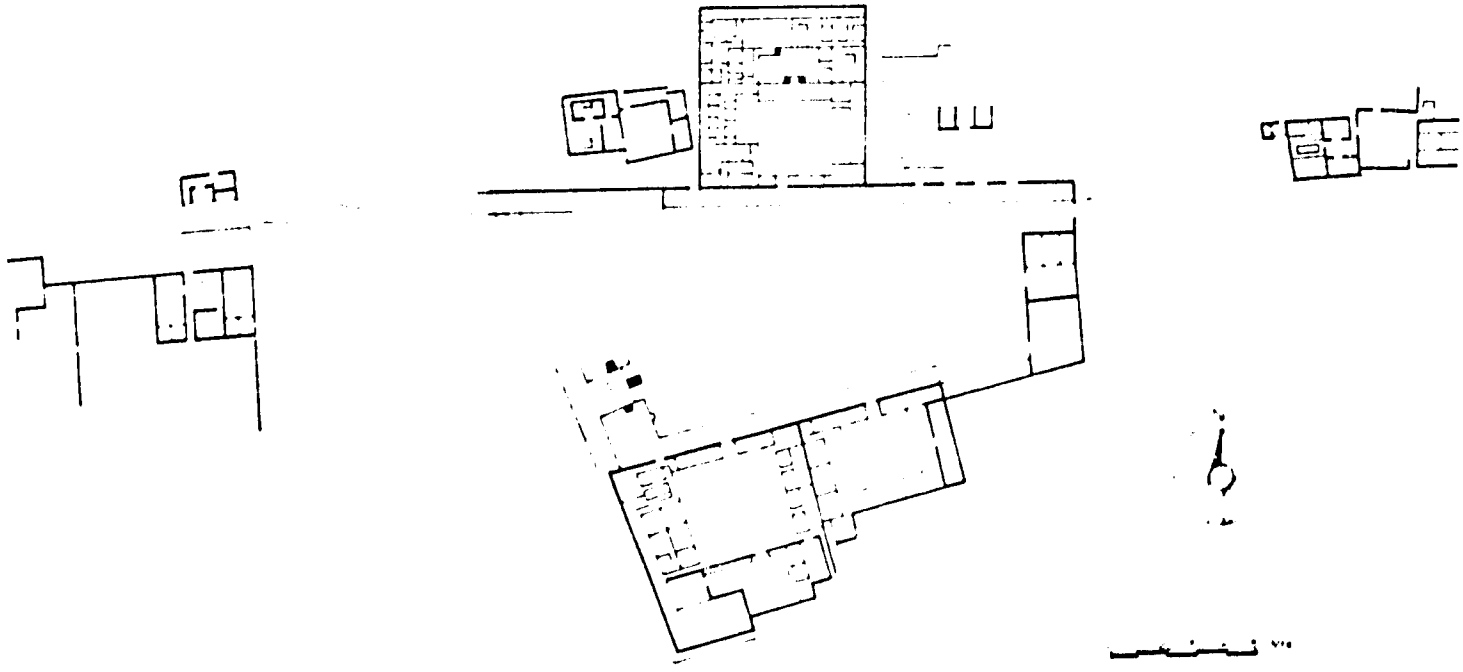
Una vez consolidada la conquista del Imperio de los Incas, hacia 1570 se construyen numerosas iglesias para catequizar a los naturales y en ellas se utiliza el adobe, material que en los siglos posteriores sería reemplazado por otros más resistentes a los sismos, en los edificios religiosos de mayor importancia. La arquitectura civil heredera de la tradición andina, en la que se acostumbraba construir casas distribuidas en torno a patios, con uno o dos niveles, emplea techos planos con armaduras de madera, caña y barro en la costa y estructuras inclinadas con tejas de arcilla en la zona de sierra y se utiliza el adobe en ambos casos. En Lima y Trujillo se utilizaron adobes para construir las murallas defensivas contra el ataque de los piratas.



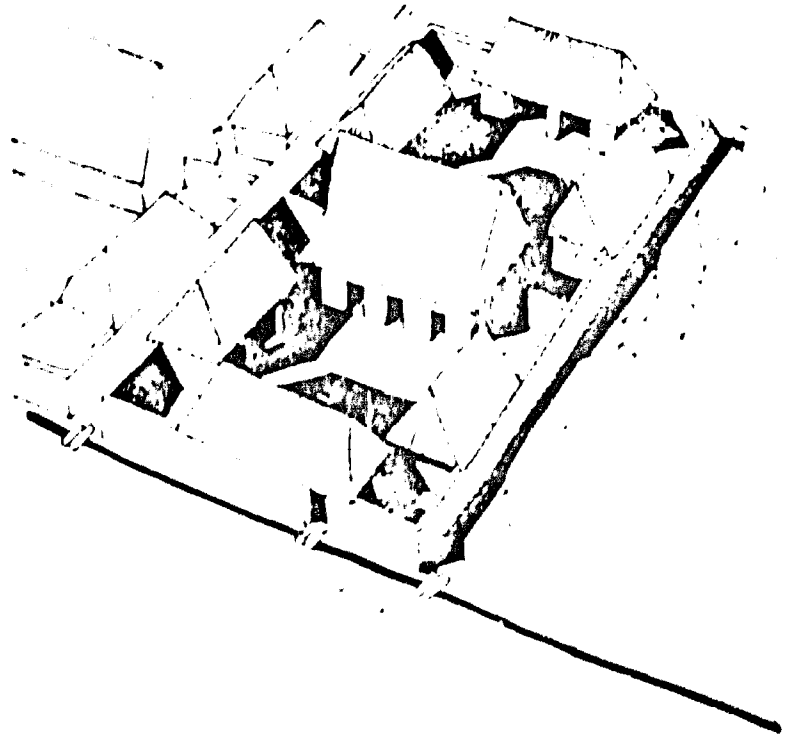
ESQUEMA DE LA INTERVENCION DE CONSOLIDACION ESTRUCTURAL DE LOS MUROS DE ADOBE (EN PROCESO DE EJECUCION)



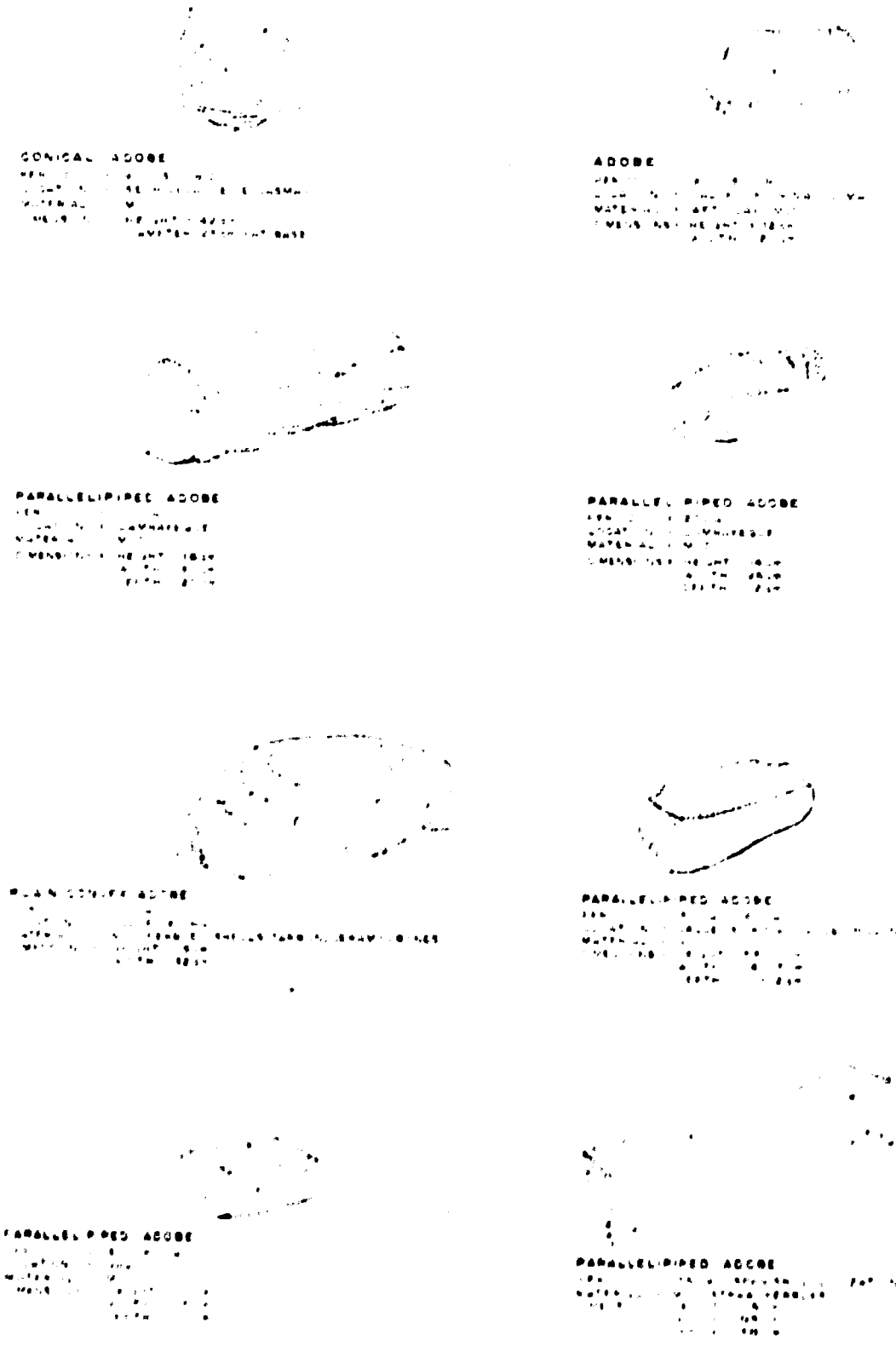
TEMPLO DE WIRACOCHA EN RAQCHI



PLANO DEL ASENTAMIENTO INCA DE TAMBO COLORADO EN EL VALLE DE PISCO, CONSTRUIDO CON ADOBES REVESTIDOS DE BARRO QUE A SU VEZ SE PINTARON DE ROJO Y AMARILLO (REDIBUJADO DE JASPAN N).



RECONSTRUCCIÓN HIPOTÉTICA DE UNA PARTE DE LA ARQUITECTURA DE ERIGA INCA CON NEVATES DE LOS MUROS Y LOS MASTILES TRABAJADOS DE SUPERFICIE LISA ADOBES QUE SE ASENTABAN SOBRE LOS MUROS DE PIEDRA (REDIBUJADO DE MILLAME).



DIFFERENT TYPES OF ADOBE - PERU

BEST AVAILABLE DOCUMENT

El adobe tradicional bien construído era bastante resistente y se hacía seleccionando la tierra adecuada con un componente de arcilla y arena, evitando materias orgánicas y sales. En el proceso de elaboración se observaba prácticas bastante estrictas como la de dejar transcurrir un día después de remojar el barro con la paja, preparar el terreno donde se efectuaría el vaciado de los adobes, con una capa de arena finay antes de sacarlo del molde de madera, se agregaba paja cortada superficialmente para evitar que se raje por el sol o los cambios de temperatura. Una vez terminada la fabricación, al cabo de cinco días se volteaba de costado y recién se volvía a cambiar de posición al cabo de quince días y el total de secado al sol era de treinta días.

Con adobes elaborados en estas mismas condiciones y observando un control estricto se ha logrado en Cusco una resistencia promedio a la compresión de 40 kg. por centímetro cuadrado. Durante la colonia la preocupación constante por los sismos hizo que se costumbre construir con muros muy anchos, cuyo espesor varía entre 1.30 a 1.50 metros (alrededor de 35 adobes por metro cuadrado) y se tenía la precaución de guardar una relación entre el espesor del muro y su altura, llegando a un máximo de altura equivalente a seis veces el ancho.

Este mismo temor a los fenómenos telúricos tan frecuentes o llevó en la costa a buscar una opción constructiva de mejor comportamiento con la utilización de la "quincha" a base de madera y caña recubierta con barro o cal y arena con barro, para construir grandes techos y bóvedas. En el período Virreinal que tuvo su esplendor en el siglo XVIII ese sistema constructivo estuvo en pleno auge gracias a la mayor flexibilidad para soportar los esfuerzos laterales de los sismos y la ausencia casi total de lluvias que hacían posible la utilización de estos materiales. Por lo general la quincha se combinó con el adobe y en las edificaciones de dos niveles el primero se hacía con adobes, superponiendo el material más liviano encima.

En la zona de los Andes, donde las condiciones de clima no permitían ese sistema y la sismicidad es menor, se utilizaron adobes para construir iglesias de grandes proporciones inclusive con torres de ese mismo material en base a muros de gran espesor y al arriostramiento de ellos con vigas y tirantes del sistema tradicional de techos de "par y nudillo".

En el período republicano estos sistemas continuaron siendo utilizados adaptándose a nuevas modas y estilos arquitectónicos que determinaron una nueva fisonomía de gusto neoclásico y eclectico. En las principales ciudades del país y aún en la capital el adobe se continuó usando en forma casi generalizada hasta la tercera década del presente siglo cuando se introducen otros sistemas constructivos y el adobe y la quincha se van relegando a las clases sociales menos pudientes.

LA PROBLEMATICA ACTUAL PERU - UNESCO.

A raíz de una petición de asistencia técnica formal dada por el Gobierno Peruano a la Organización de las Naciones Unidas para una eventual cooperación internacional que permitiera conservar y restaurar los monumentos de Cusco y Machu Picchu y el desarrollo turístico de la zona, la UNESCO realizó varias misiones entre 1965 y 1968 que posibilitaron evaluar las acciones para la valorización de los monumentos y sitios históricos en función del desarrollo turístico.

Como resultado de los informes y recomendaciones de la UNESCO el Gobierno Peruano creó la Comisión Especial COPESCO, para realizar estudios sobre restauración de monumentos-turismo, infraestructura vial y programas de asistencia económica para obtener el crédito de un organismo internacional.

Para el estudio de los monumentos se creó un programa especial de asistencia técnica de UNESCO y el Instituto Nacional de Cultura del Perú: el Proyecto PER 71/539. Simultáneamente el Plan COPESCO y los sectores especializados del Gobierno como el Ministerio de Transportes, el Ministerio de Vivienda y la Empresa Nacional de Turismo, llevaron a cabo los estudios previos para la petición de un crédito que fué formulado en 1972 al Banco Interamericano de Desarrollo, solicitando un préstamo destinado a financiar entre otros proyectos el acondicionamiento de la infraestructura de la región y la restauración y puesta en valor de monumentos.

Entre los objetivos del Proyecto destacaban los siguientes:

- Formular los criterios que deben normar la restauración y puesta en valor de los monumentos históricos, artísticos y sitios arqueológicos.

- Elaborar el inventario, catalogación y el levantamiento del estado actual de los monumentos precolombinos y virreinales existentes en el área, de acuerdo a las prioridades señaladas por el Plan COPESCO asesorado por la UNESCO.

- Ejecución de los proyectos de restauración, consolidación y puesta en valor de los monumentos existentes en el área escogida, señalando los presupuestos respectivos y la tecnología adecuada para restaurar los diferentes tipos de edificaciones existentes.

En base a la petición que el Gobierno Peruano formuló al Banco Interamericano de Desarrollo, se materializó un préstamo y la correspondiente contraparte nacional para el Plan COPESCO, iniciándose las obras de restauración en los monumentos y en otros rubros de la infraestructura en 1975. Mediante una enmienda en el Proyecto PER 71/539, la UNESCO prolongó la asistencia examinada a la supervisión técnica de las obras, lo que permitió seguir contando con expertos y consultores especializados, durante los trabajos directos de restauración de los monumentos a cargo de la Unidad Especial Ejecutora del Instituto Nacional de Cultura.

LA RESTAURACION DE MONUMENTOS DE ADOBE.

La problemática que plantea la restauración de monumentos tiene exigencias adicionales y si se quiere diferentes a la edificación con adobes para usos contemporaneos, por lo que no es muy factible aprovechar en forma directa todas las experiencias. Por poner solo el caso del adobe estabilizado con asfalto el 5% que alcanza una resistencia a la compresión que oscila entre los 40 y 50 kilogramos por centímetro cuadrado; su empleo en la restauración científica y bien estudiada, estaría limitado al completamiento de las partes faltantes que son factibles de ser reponentes. Los adobes originales de una estructura arquitectónica constituyen un testimonio y documento histórico que en principio deben conservarse en lo posible. Al reemplazar adobes que están deteriorados, necesariamente -

se debe buscar obtener un conjunto homogéneo, utilizando por lo tanto adobes nuevos pero no demasiados diferentes en sus características mecánicas y físicas, teniendo en cuenta además, que en climas variables el asfalto no se comporta satisfactoriamente.

Por estas razones se consideró importante aprovechar el rumbo de esas investigaciones para encaminar otras hacia el problema específico de la restauración de monumentos. Se partió de la premisa de que se tenía que trabajar con edificaciones existentes, sea cual fuera su calidad constructiva y que no se trataba de "construir" nuevas estructuras.

Con especial interés se consideró que el grado de afectación que pueden sufrir las edificaciones antiguas hechas de adobe, en caso de un sismo, dependían de la adherencia existente entre los adobes así como a la resistencia de los muros ante esfuerzos de tracción.

Las causas y efectos de los daños que ocasionan los terremotos se clasificaron en los siguientes casos:

- Cuando se presentan pandeos y fisuras verticales, se trata de una falla a la compresión. La resistencia del muro ante compresión vertical depende de las características mecánicas del adobe y del mortero (figura 1).

- Cuando se producen fisuras diagonales que en forma escalonada acompañan las juntas entre los adobes, se trata de una falla por esfuerzo cortante producida por las cargas laterales paralelas al plano del muro, que caracterizan a las ondas sísmicas. (figura 2).

- Cuando la acción de las ondas sísmicas es perpendicular al plano del muro, se producen cargas laterales que ocasionan grietas diagonales desde la parte superior del encuentro de dos muros perpendiculares. También se producen grietas verticales en la parte central de un muro trabado en sus extremos con otros muros. (figura 3).

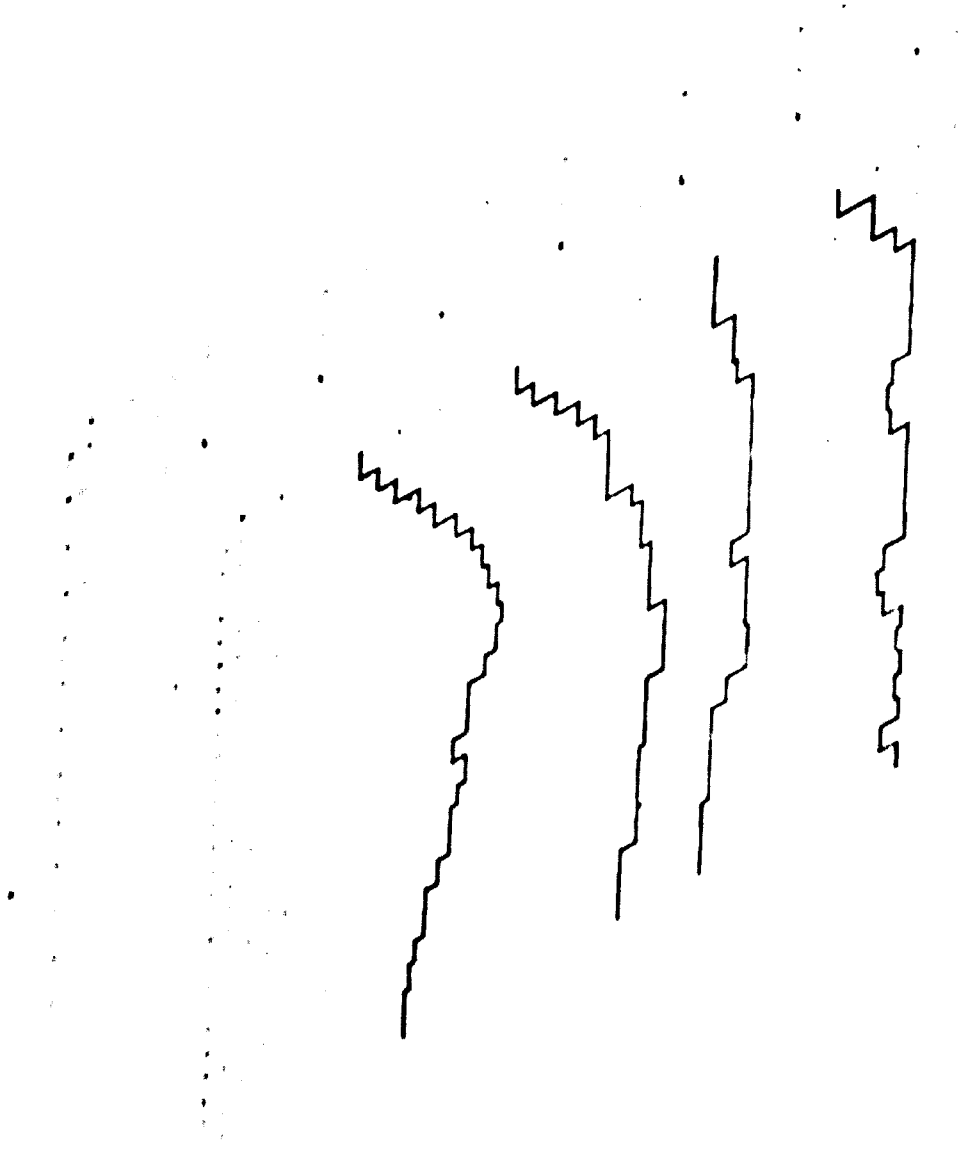
- En el encuentro de dos muros perpendiculares, las fuerzas laterales que ocasionan los sismos producen una falla por tracción, que se caracteriza por la separación de los muros, formando una grieta diagonal en la esquina superior del muro, indicando una falla por flexión ocasionada por los esfuerzos perpendiculares a uno de los muros y paralelos al otro (figura 4).

PRINCIPALES PROCEDIMIENTOS APLICADOS EN LA RESTAURACION.

Las intervenciones de restauración en los monumentos de adobe se hacen por lo general, respetando la secuencia que se indica a continuación, para evitar efectos secundarios en las estructuras:

- Apuntalamiento de muros, techos y control permanente de las deformaciones mientras dure el proceso de restauración.

- Calzadura de cimientos y sobrecimientos por las dos caras de los muros en forma alternada y logrando una trabazón total en los dos lados intervenidos. El trabajo se hace por tramos alternados no mayores de un metro evitando una excavación continua, que propi--



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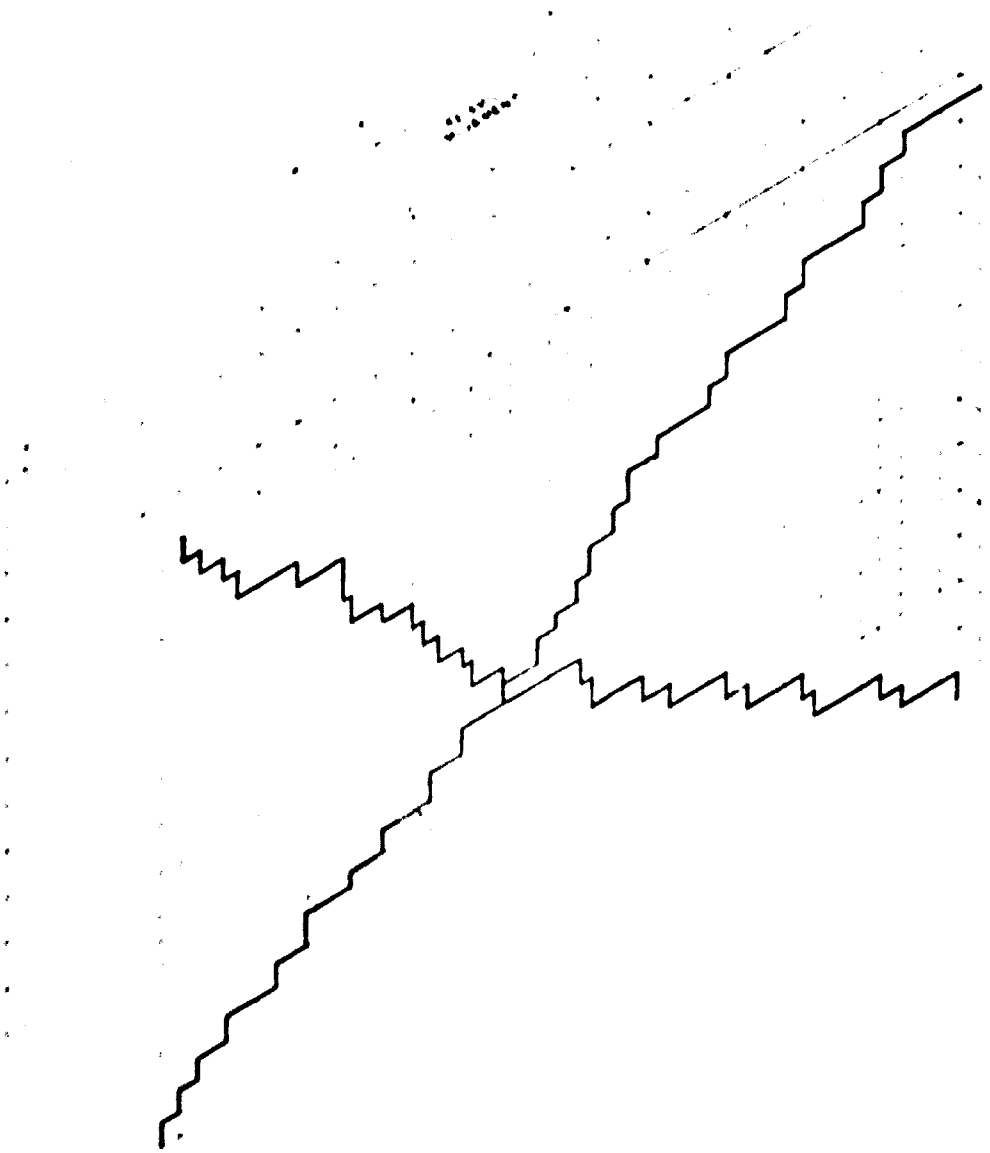


FIGURE 2

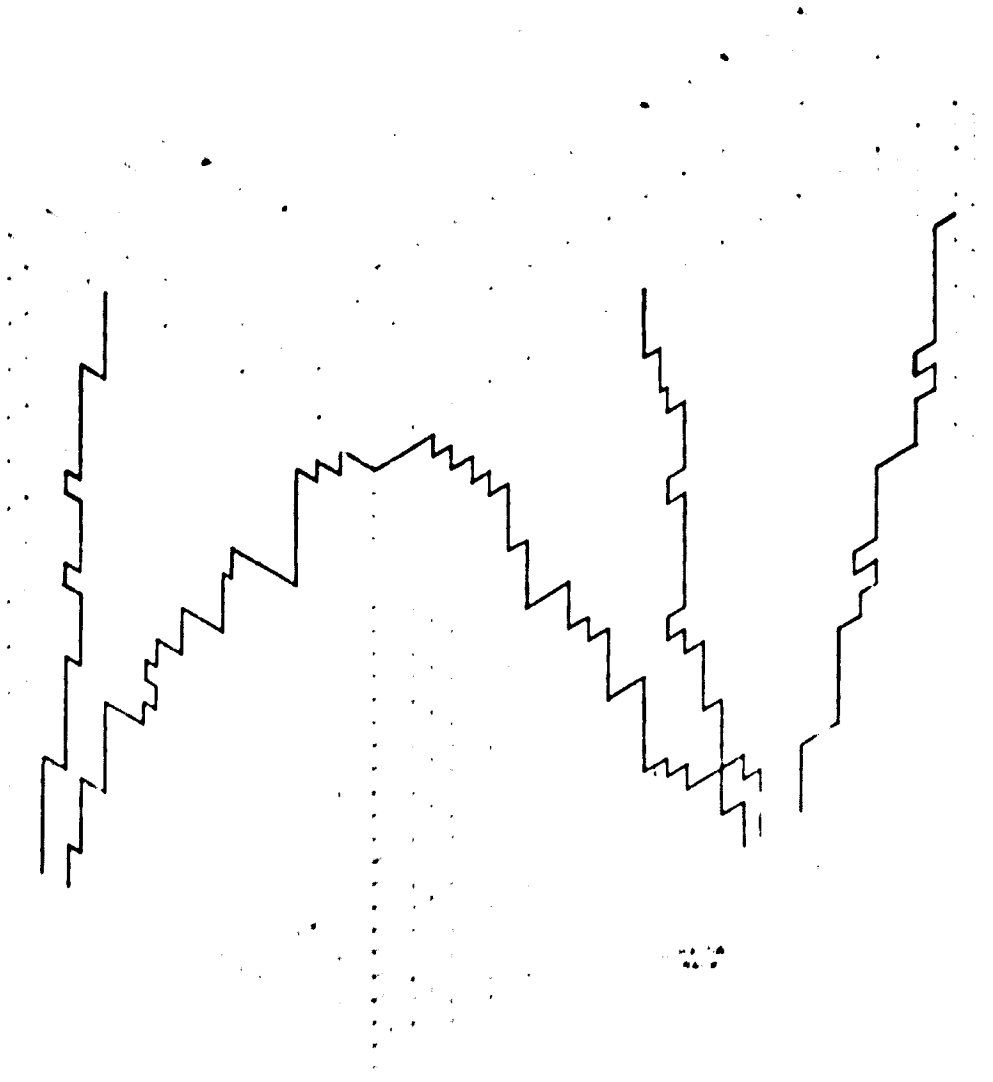


FIGURE 3

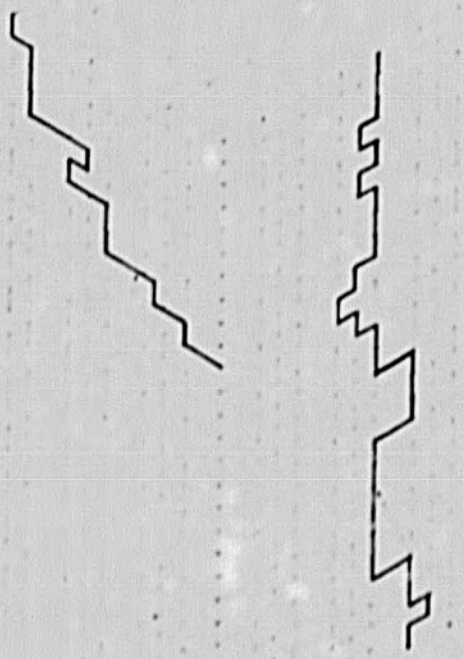


FIGURE 4

ciaría la inclinación del muro (figura 5).

- Calzaduras en muros de adobe, para reparar las fisuras y lesiones que presenten los muros. Debe procederse previamente a intervenir en la causa del daño, sea ésta debido a empujes transversales, a falta de arriostramiento o al asentamiento de la cimentación, por citar algunos casos. Se retiran los adobes lesionados colocando tacos de madera, reemplazándolos por otros nuevos, haciendo una especie de costura en el sector dañado. Se recomienda hacer como máximo dos hiladas diarias para evitar el aplastamiento del mortero (figura 6).

- Colocación de llaves de amarre, se utilizan debido a que el factor de seguridad en las primeras hiladas del encuentro de un muro con otro perpendicular es bastante bajo. Constan de elementos de tracción debidamente anclados. Analíticamente se iguala la fuerza actuante con la resultante, para determinar la longitud requerida por los tirantes de amarre.

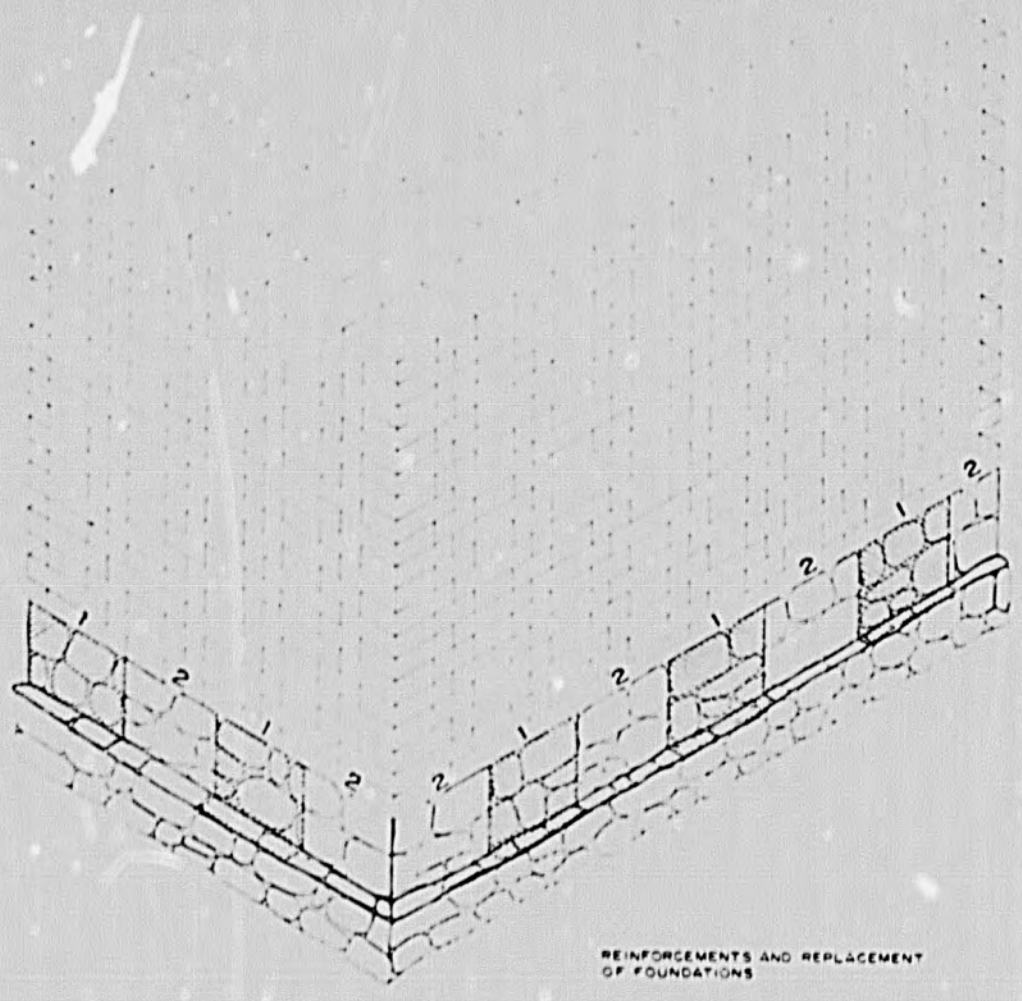
Por lo general las llaves deben llevar encima el peso de, por lo menos, dos metros de altura de muro de adobe y éstas se intercalan verticalmente cada 1.50 metros. En los muros perpendiculares se colocan dos piezas paralelas de madera aserrada a lo largo de los muros, cruzándose y trabándose a media madera, colocando luego los adobes hasta que las llaves queden perdidas en los muros.

En muros que no serán desmontados, la colocación de llaves se hace excavando las caras de los muros hasta dejar las piezas en el lugar previsto, rellenando luego los espacios entre los adobes y la madera, para que ésta quede comprimida.(Figura 7)

Existen llaves compuestas por un par de varillas de fierro de construcción anclada en sus extremos a tensores de madera. Los tensores metálicos se colocan cubiertos con pintura anticorrosiva y revestidos de un mortero de cemento y arena (figura 8).

Dinteles de refuerzo en los vanos, generalmente se usan dinteles compuestos por varias piezas de madera, redondas o rectangulares. Es característico de la construcción colonial en la zona de Cusco, que los dinteles tengan inclinación (derrame) y por lo general en la restauración se adopte el criterio de conservar esos dinteles originales, utilizando un sobre-dintel de refuerzo. Para éstos se supone que sobre él actúa una carga de tipo triangular y una sobre carga que puede ser el peso del techo. Analíticamente se calculan la longitud del nuevo dintel y el perfil mínimo que deberá tener, considerando los esfuerzos y las deflexiones.

- Intervenciones especiales para conservar fragmentos de muros, se dan cuando en un muro de adobe extremadamente deteriorado existen elementos arquitectónicos como nichos y ventanas, elementos decorativos como relieves o pintura mural. Se han llevado a cabo con éxito numerosas intervenciones con el objeto de rodear el fragmento que se desea conservar con adobes nuevos. Este fragmento puede llegar a medir varios metros cuadrados.(Figura 9)



REINFORCEMENTS AND REPLACEMENT OF FOUNDATIONS

FIGURE 5

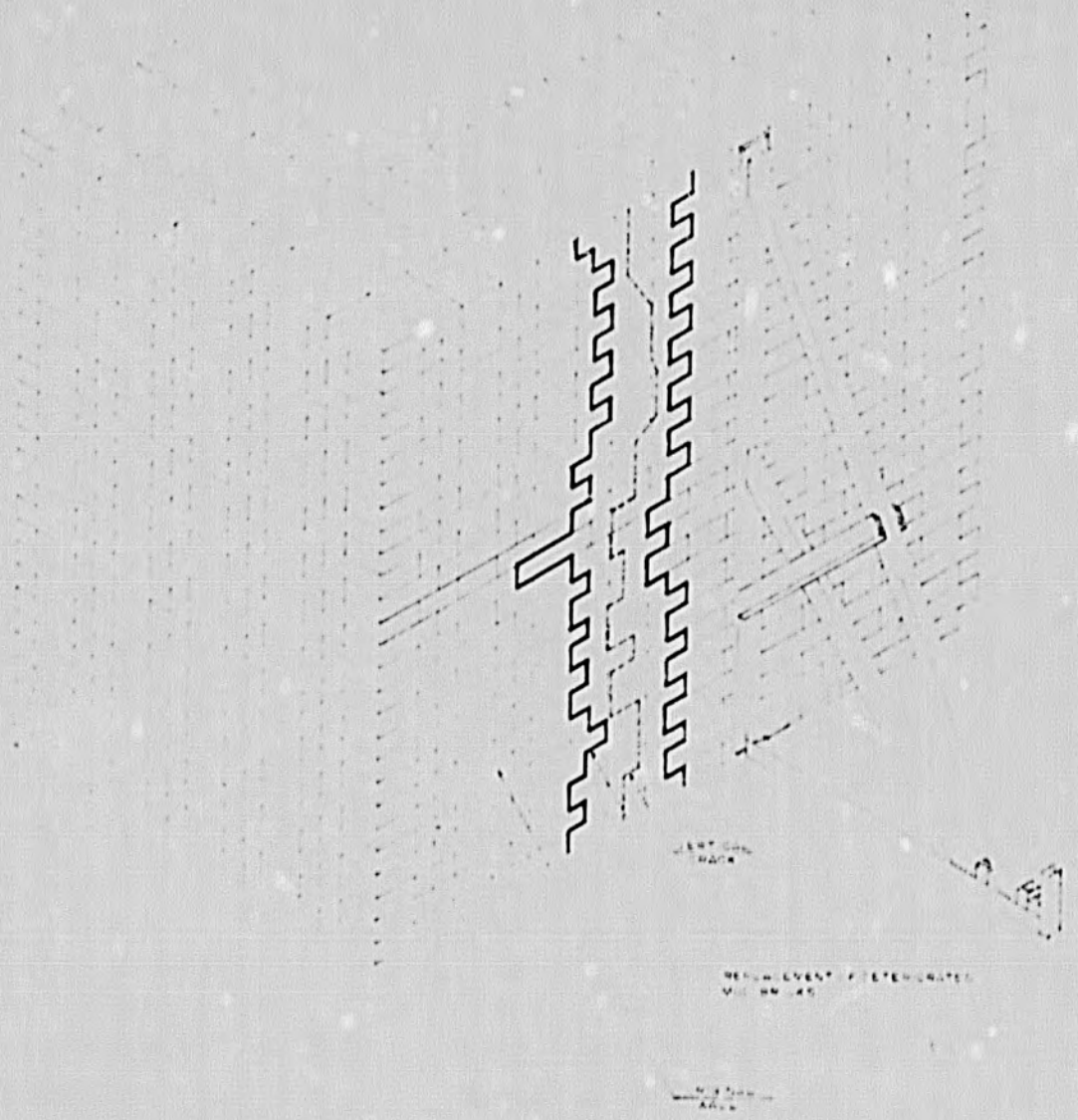


FIGURE 6

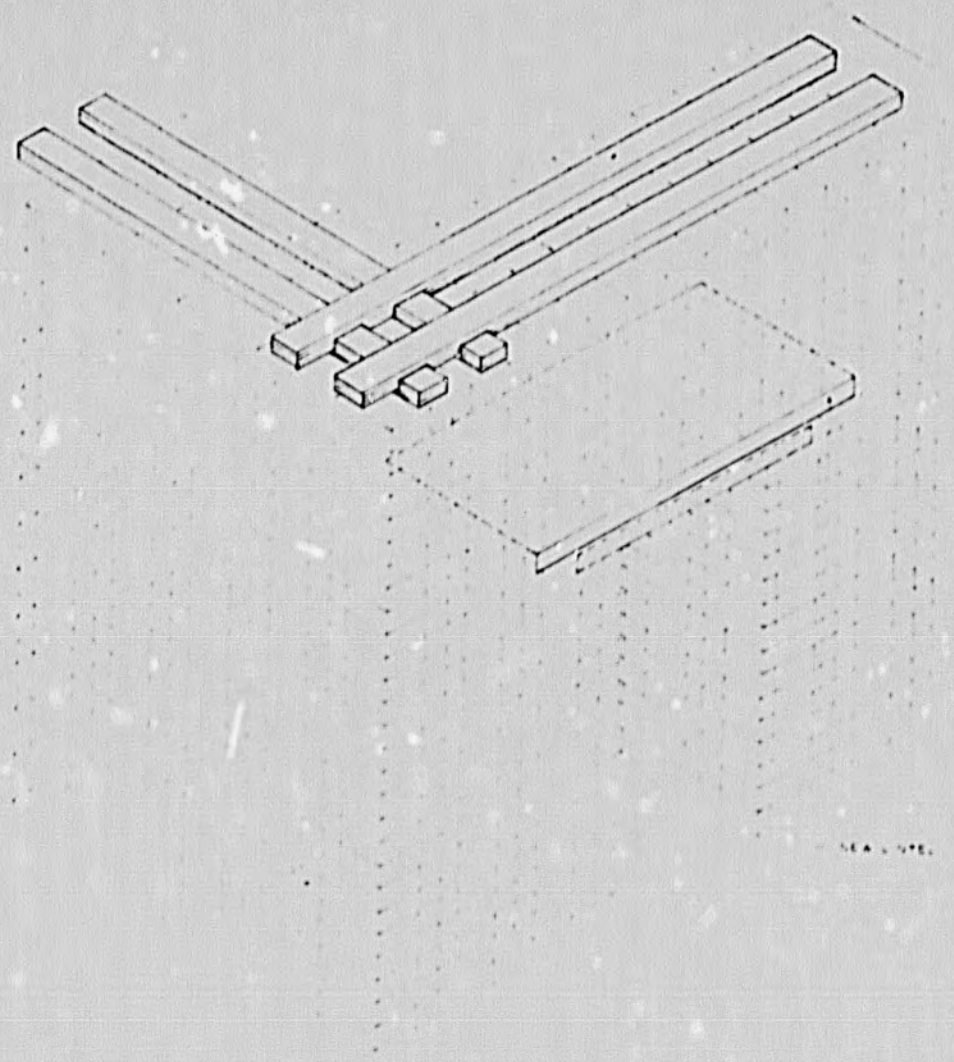


FIGURE 7

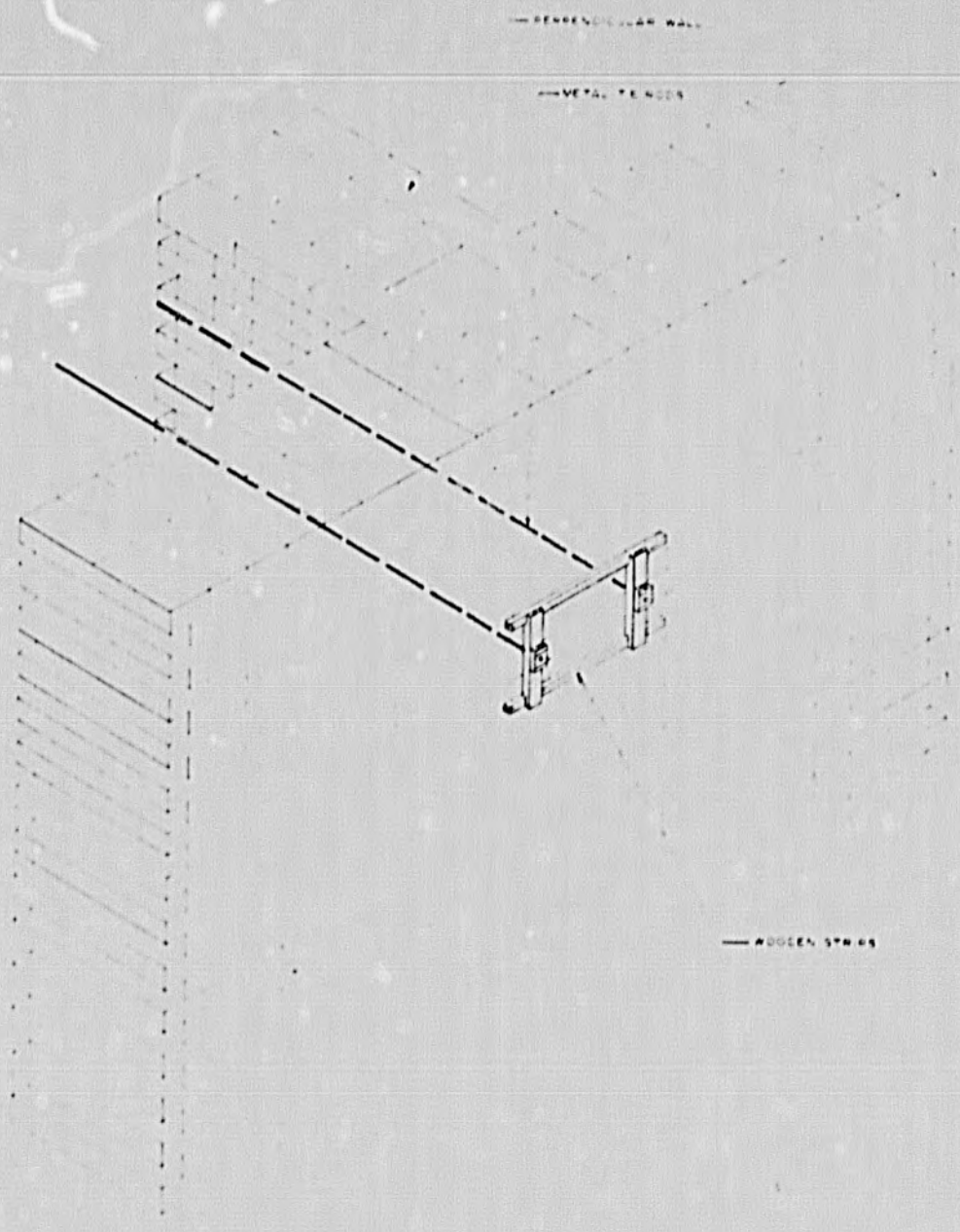


FIGURE 8

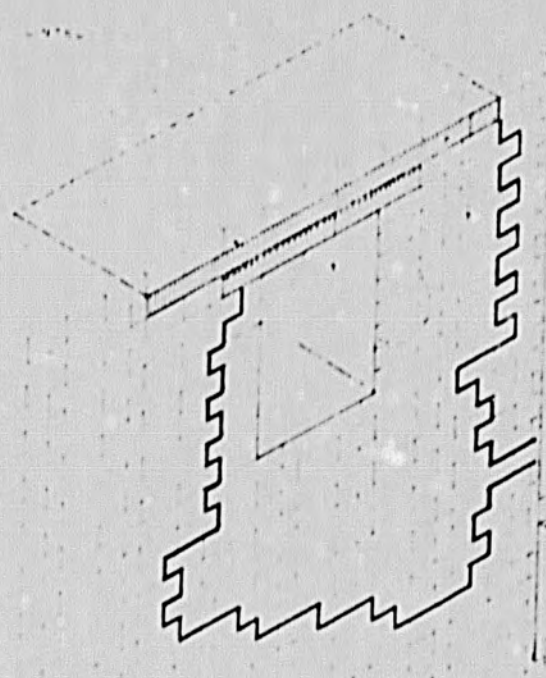


FIGURE 9

La operación se realiza luego de proteger la superficie de mayor valor con veladuras de papel de arroz y tela fina, retirando hilera por hilera los adobes de la parte inferior y laterales, llevando a cabo la calzadura en la forma indicada anteriormente. Al efectuar ese procedimiento es factible corregir deformaciones en el plomo del muro utilizando una gata hidráulica (figura 10).

EJEMPLOS DE ALGUNAS SOLUCIONES ESPECIALES ADOPTADAS EN LA RESTAURACION.

En las obras de restauración llevadas a cabo en Cusco se han empleado normalmente los sistemas y procedimientos señalados en las líneas anteriores. Se han presentado, sin embargo, muchos casos en que las condiciones de resistencia y estabilidad de los muros demandaban un análisis especial de la acción de cargas verticales debidas a peso propio y lasobre carga de la edificación, así como la acción de fuerzas laterales de inercia, debidas a posibles movimientos sísmicos.

1) Restauración del Colegio de San Bernardo.

La intervención más importante de lo que consideramos soluciones especiales se materializó en la Iglesia del Colegio de San Bernardo, edificada en 1619 sobre restos de los muros de casas pre-existentes, construídas entre 1539 y 1600. La iglesia de planta rectangular mide 5.25 metros por 31.80 metros, con muros de adobe cuyos espesores varían entre 1.00 a 1.35 metros. La altura de los muros es de 8 metros sobre un basamento de 4 metros de profundidad, construído de piedra.

El muro adyacente al exterior del Colegio no tenía contrafuertes intermedios que ayudasen a arriostrarlo y se necesitaba mayor estabilidad para resistir los esfuerzos laterales que podría causar un sismo.

Cabe destacar que durante la exploración arqueológica de la iglesia se descubrieron en el muro exterior vanos de nichos, puertas y ventanas de las casas pre- existentes, que se querían conservar como evidencia.

Para la restauración del muro se hicieron ensayos y se debatió largamente, llegando a considerar que la mejor alternativa era la de incorporar cuatro pares de columnas y una independiente (para respetar los vanos y la cripta) de concreto armado, empotradas en sus extremos inferiores en vigas de cimentación que descansan en zapatas. Cada viga de cimentación con las columnas en sus extremos forma una estructura en U.

Anteriores experiencias llevadas a cabo en diversos lugares, para reforzar el adobe con columnas, vigas y llaves de concreto armado, habían dado malos resultados debido al comportamiento diferente de los materiales, por lo que se requirió al consultor Estructural de UNESCO, Doctor Ricardo Yamashiro Kanimoto (4) que tuviera en cuenta las siguientes características para la estructura:

a) Que la estructura de concreto armado no trabaje en acción estática, ya que el muro se fractura solo para este caso.

b) Que la estructura de concreto armado actúe únicamente en caso de que el muro sea solicitado por esfuerzos laterales de tipo sísmico.

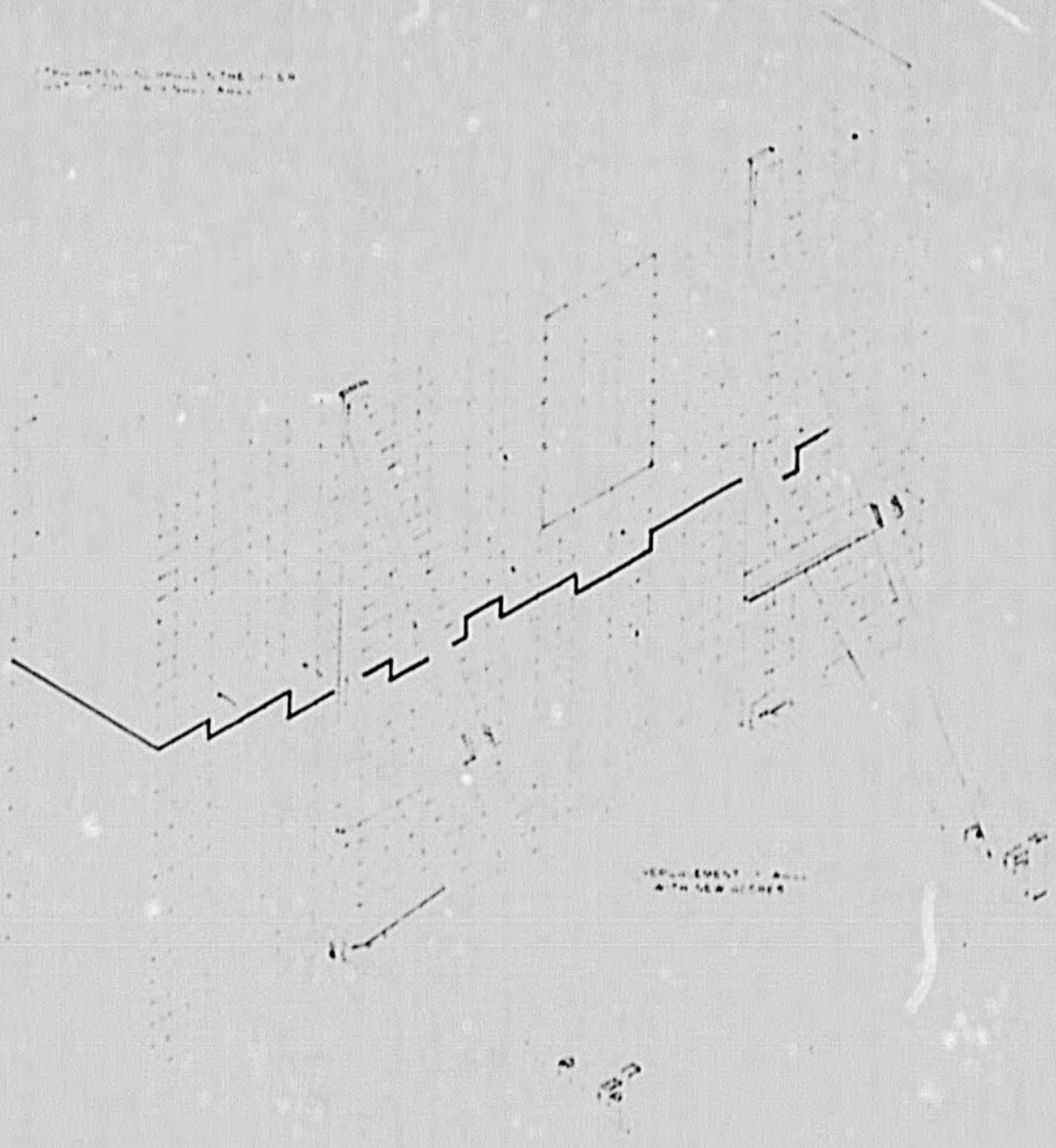
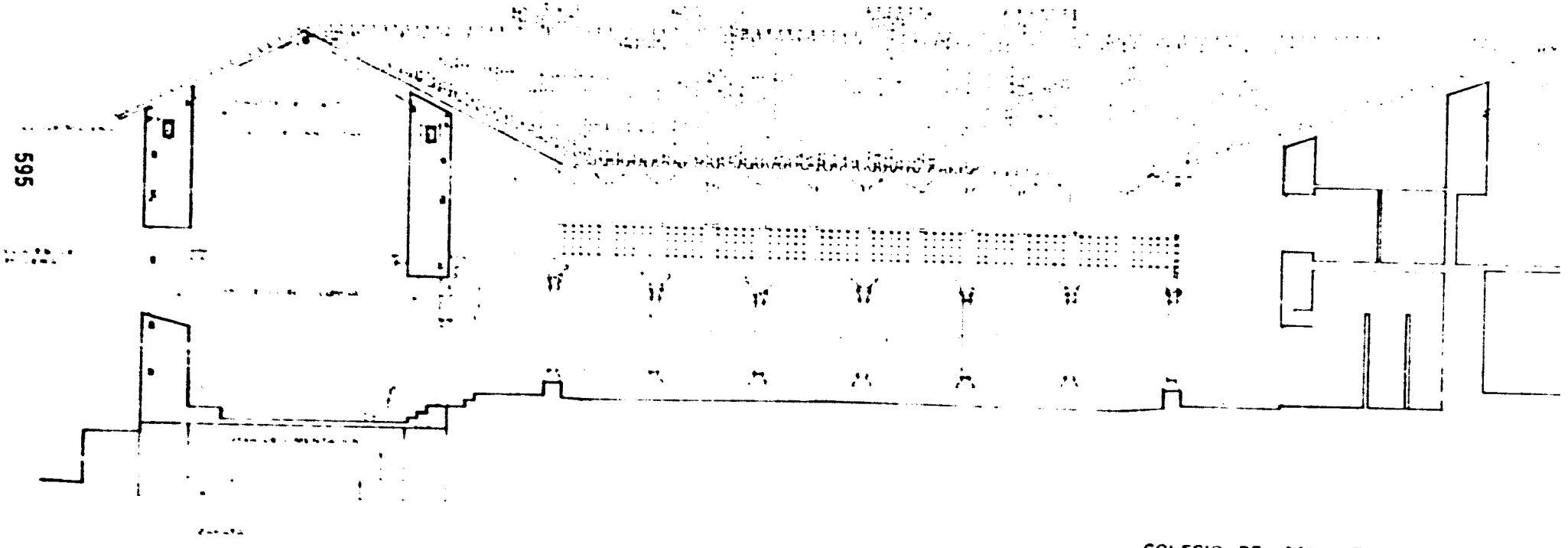


FIGURE 10



COLEGIO DE SAN BERNARDO

ESTRUCTURA ESPECIAL [illegible] UTILIZADA

Para evitar los aspectos desfavorables de la unión del adobe con el concreto, se tomaron las siguientes precauciones:

1.- Las columnas vaciadas en el seno del adobe tienen una forma rectangular hacia las caras del muro y achavada hacia los costados. Ese diseño especial hace que el concreto armado sujete la masa de adobe sin golpearla y sin producir concentración de esfuerzos.

2.- La experiencia muestra que el golpe del concreto armado contra la estructura del adobe se produce por existir ligeras separaciones entre ambos materiales. Los efectos del impacto han sido reducidos al mínimo mediante detalles constructivos que aseguran un contacto firme entre ambos materiales. De esa forma se garantizó también la transferencia de fuerzas horizontales en la superficie de contacto.

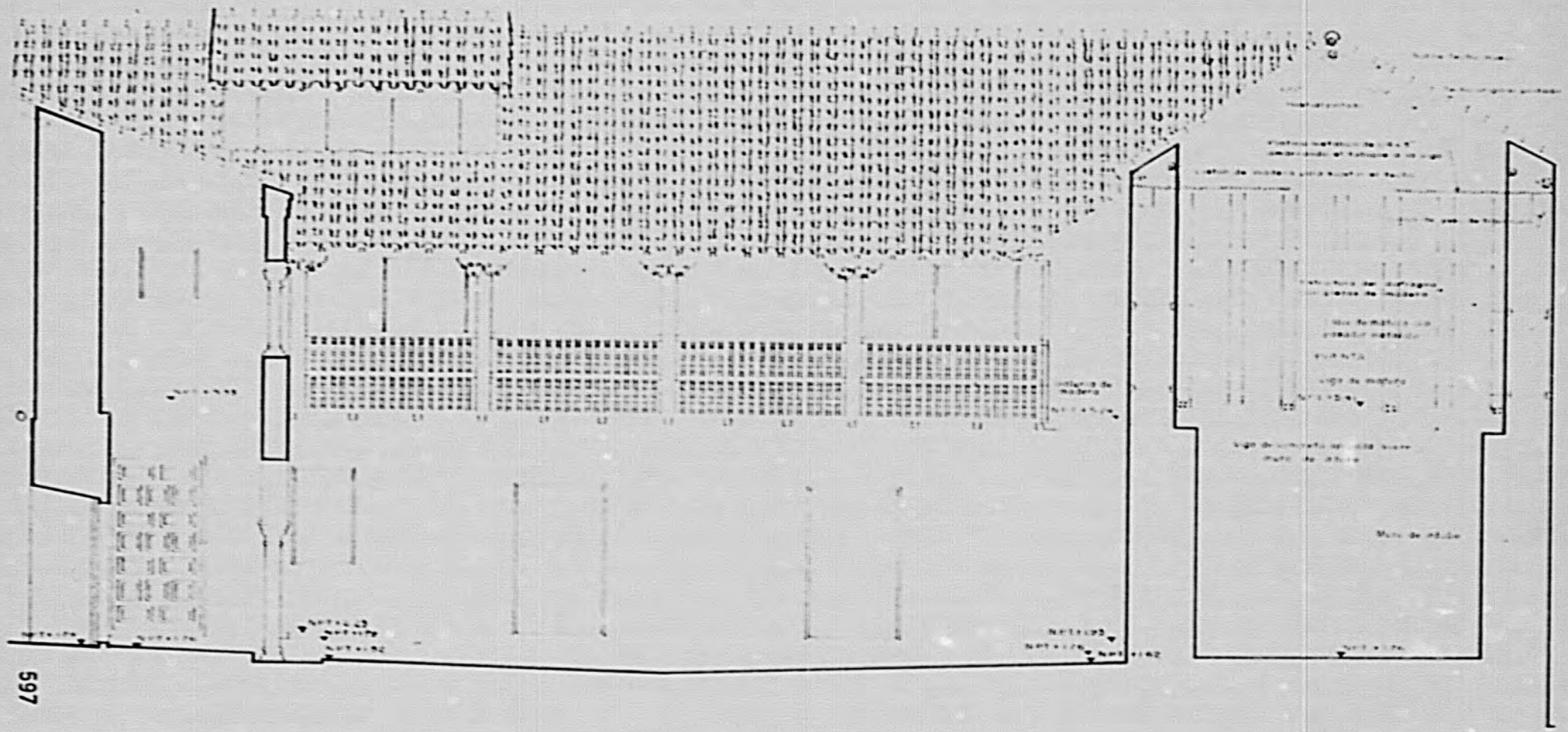
Entre los detalles constructivos cabe destacar que las columnas de 40 por 80 centímetros de sección, que tienen casi una forma de cruz, recibieron un revestimiento de yeso de una pulgada de espesor en las dos caras que están en contacto con las llaves de madera, fueron cubiertas con planchas de polietileno expandido de dos pulgadas de espesor. Las vigas de madera para arriostrar el muro de adobe se unieron a las columnas mediante cinco llaves de tres metros de largo repartidas en ambas caras del muro en toda su altura.

Un analisis sísmico del muro exterior de la iglesia de San Bernardo, tal como era originalmente, indicó un coeficiente sísmico de colapso de 0.053 equivalente a un sismo de grado VI en la escala de Mercalli modificada. La falla sería por exceso de presiones en el suelo, seguida del volteo del muro. En la solución adoptada se consideró un coeficiente sísmico de colapso como para un sismo de intensidad VIII en esa misma escala, al cual se aplicó el factor de carga para el diseño de rotura, con lo que se obtuvo un coeficiente sísmico de 0.[illegible].

2) Restauración de la Casa Clorinda Matto de Turner.
Se trata de uno de los mejores ejemplos de arquitectura civil cusqueña del siglo XVII restaurada para ser utilizada como sede del Banco Central Hipotecario del Perú. Se planteaba la necesidad de reforzar las estructuras portantes en los muros, entrepisos y techos, respetando la pintura mural que en gran cantidad cubre las paredes y parte interior de los techos de par y nudillo.

En uno de los lados de la planta alta se tenían ambientes muy largos y sin arriostramiento intermedio y por la existencia de pintura mural no se podían dividir las habitaciones con muros intermedios, como solución al problema. Se aprovechó la existencia de dos tabiques delgados armados con caña y barro (quincha) que remataban en un hastial pintado, para colocar en su lugar dos diafragmas de listones de madera, que se apoyaron en una viga de concreto armado unicada al nivel del entrepiso, a su vez apoyada sobre un muro de adobe existente.

Los diafragmas se unieron con dos vigas de concreto armado que corren perpendicular



CASA DE CLORINDA MATTO DE TURNER - BANCO CENTRAL HIPOTECARIO

ESTRUCTURA DE MADERA Y CONCRETO PARA ARRIOSTRAMIENTO DE MUROS

mente, a lo largo de la parte alta de la pared. Esas dos vigas tienen por objeto dar peso a la parte superior del muro que se necesitaba asegurar, facilitando la sujeción al diafragma y al otro muro paralelo.

La sección de esas vigas soleras se diseñó de manera tal que permite mayor adherencia al muro de adobe y mayor superficie de contacto lateral. Las vigas estan apoyadas sobre los muros de manera que no pueden dañar los adobes en caso de un sismo, aislándolas de los mismos mediante una ligera superficie de yeso.

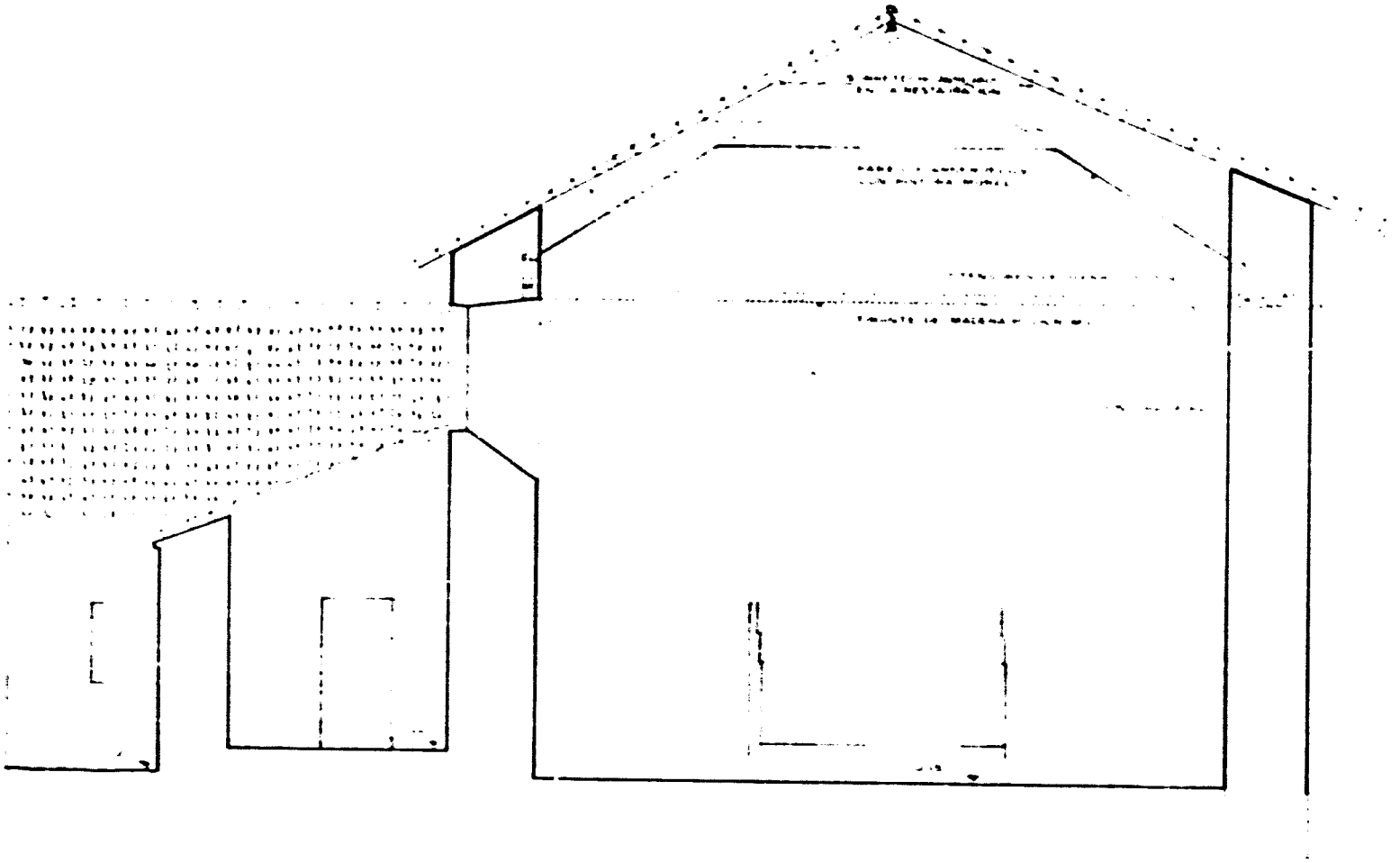
3) Hospital de los Betlemitas de la Almudena.
En este conjunto del siglo XVIII se han aplicado diversas soluciones especiales para restaurar los muros de adobe que estaban bastante afectados. Las más destacadas han sido las referidas a la calzadura y enderezamiento de un tramo del muro, correspondiente al segundo nivel del primer claustro. Se trataba de un segmento de muro con pintura mural que formaba parte de un tramo muy deteriorado y que había perdido suplomo original.

Después de proteger la pintura mural se enderezó el fragmento de muro usando palancas y tracción mecánica y luego de situarlo en posición definitiva, se procedió a trabar y completar el fragmento en mención con adobes nuevos, que se fueron colocando hasta restituir la altura original.

Otra solución que interesa destacar está referida a la crujía de fachada del monumento, que requería mayor estabilidad ante posibles esfuerzos laterales, teniendo en cuenta que las habitaciones del segundo nivel eran muy largas. La intervención consistió en colocar llaves en forma de "T" con dos vigas paralelas y cruzadas al nivel del piso del segundo nivel, a fin de arriostrar los muros perimétricos con los perpendiculares a ellos. Se agregó también un nuevo entrepiso con vigas de madera aserrada, por encima del antiguo de madera rolliza que se dejó en el lugar, porque constituía un elemento de valor por tener las vigas moldeadas con barro para dar la apariencia de un artesonado.

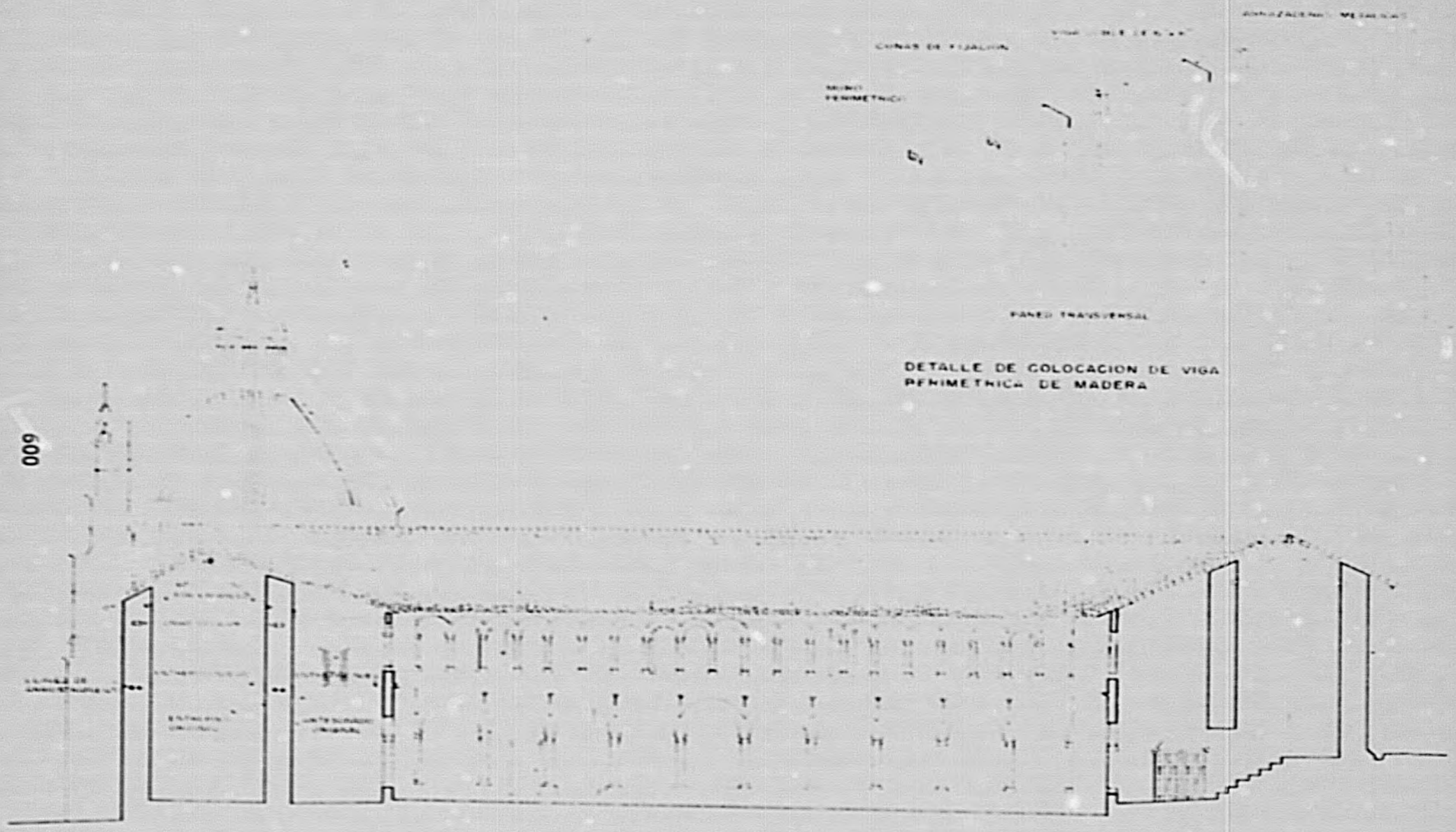
A nivel de la parte superior de los muros perimétricos se colocó una doble viga de madera de seis pulgadas de sección, formando un collar en toda la crujía. Esa doble viga constituída por piezas traslapadas aseguradas con abrazaderas de hierro y cuñas verticales de madera, que se introducen en el muro, recibe el peso de las hiladas de adobe que vienen encima y de los techos de par y nudillo, con lo que se logra una traba estructural que no permite que los muros tengan tendencia a inclinarse.

4) Iglesia de Canincunca.
En esta iglesia rural cercana a Cusco, los muros perimétricos de adobe tienen un espesor de 1.10 metros y una altura media de 6 metros, con una longitud de 21 metros, sin arriostramiento lateral. Uno de esos muros presentaba una inclinación hacia el exterior, posiblemente bastante antigua, porque existían contrafuertes para contrarrestar los empujes y encima de ellos se agregó un nuevo muro paralelo con la misma finalidad.



CONSOLIDACION ESTRUCTURAL DE LA IGLESIA DE CANINCUNCA

SOLUCION CONSIDERANDO FUERZAS LATERALES POR SISMO Y ESPESOR CONSTANTE



DETALLE DE COLOCACION DE VIGA PERIMETRICA DE MADERA

CONSOLIDACION ESTRUCTURAL DEL ANTIGUO HOSPITAL DE BETLEMITAS DE LA ALMUDENA

La restuaración estuvo encaminada a estabilizar en forma definitiva ese muro cubierto íntegramente de pintura mural en el interior, retirando el muro agregado. Se reforzó la cimentación con un mortero de cal, arena, y cemento y se repusieron los dos contrafuertes antiguos cuyas evidencias se hallaron al retirar el muro adosado. De acuerdo con el resultado del estudio estructural se agregaron dos contrafuertes nuevos.

Mediante una adecuada traba entre el muro y los cinco contrafuertes, se logró una efectiva acción de arriostramiento lateral de la pared inclinada y una correcta distribución de los esfuerzos de flexión para un posible efecto de las cargas laterales en caso de sismo.

Para proporcionar mayor resistencia a los encuentros del muro mencionado en el encuentro con la torre del campanario, también construída de adobe, se colocaron llaves de madera cada metro y medio de altura con dobles piezas de 3 por 6 pulgadas, que se cruzan en el encuentro de los muros. Fué necesario estudiar el diseño de un cobertecho para no tocar la cubierta antigua de teja y ladrillo íntegramente pintada al fresco. Para evitar que el empuje del techo original y del nuevo techo colocado encima produzcan empujes horizontales en los muros, se colocaron cuatro tensores metálicos disimulados por los tirantes antiguos de madera que atraviesan la nave de la iglesia.

Los ejemplos de intervenciones efectuadas y las fotografías y dibujos que las ilustran, intentan dar una idea del trabajo que se ha venido llevando a cabo en Cuzco durante los últimos años y que hasta el final de 1979 contó con la participación de la UNESCO.

DESCRIPCION DE LAS FOTOGRAFIAS QUE ACOMPAÑAN AL TEXTO.

Fotografía 1.- Altorrelieve de barro sobre muro de adobes hemisféricos en el sitio de Garagay, la figura esta policromada con colores blanco, amarillo, rojo y rosado.

Fotografía 2.- Conjunto de habitación rural pre-incaico en la costa, denominado Puruchuco. Los recintos de adobe y los muros de tapia fueron "reconstruídos" excesivamente en decadas pasadas.

Fotografía 3.- Cajamarquilla, extensa ciudad de época Tiahuanaco - Huari (entre 500 a 1,000 años después de Cristo), construída con adobe y tapia.

Fotografía 4.- Ruinas de Pachacamac en el valle de Lurin, sector de época Inca construído con adobe (también reconstruído en forma incorrecta).

Fotografías 5-A y 5-B.- Templo del Dios Wiracocha en Raqchi cerca de Cusco, muros de adobe de época Inca.

Fotografía 6.- Casa Oquendo en Lima y aspecto del conjunto de inmuebles coloniales vecinos. Construcciones mixtas de adobe, ladrillo y quincha.

Fotografía 7.- Casas de adobe de expresión popular en la zona de Moquegua en la costa-sur del Perú.

Fotografía 8-A y 8-B.- Colegio de San Bernardo en Cusco, en la primera fotografía se ven los restos de la iglesia afectada por el terremoto de 1950 y por el abandono posterior. En la segunda fotografía la iglesia después de la restauración utilizando un sistema estructural especial para fortalecer los muros de adobe, conservando todas las evidencias del colegio fundado en 1619 y las anteriores.

Fotografías 9-A y 9-B.- Casa de Clorinda Matto de Turner, ejemplo de arquitectura civil cusqueña del siglo XVII, restaurada para ser utilizada como sede de una entidad bancaria. La gran cantidad de pintura mural que se encontró obligó a soluciones especiales para restaurar los muros de adobe.
En las fotografías se puede comparar el estado de la casa antes y después de la restauración.

Fotografías 10-A y 10-B.- Antiguo Hospital de los Betlemitas de la Almudena en Cusco, construído en el siglo XVII. Se pueden apreciar dos aspectos del conjunto antes y después de la restauración concluída en 1980.

Fotografías 11-A y 11-B.- Iglesia de Caninguanca construída con adobes y cubierta de pintura mural en el interior. Recibió un tratamiento especial para estabilizar los muros en las fotos se ve la iglesia antes y después de la intervención.

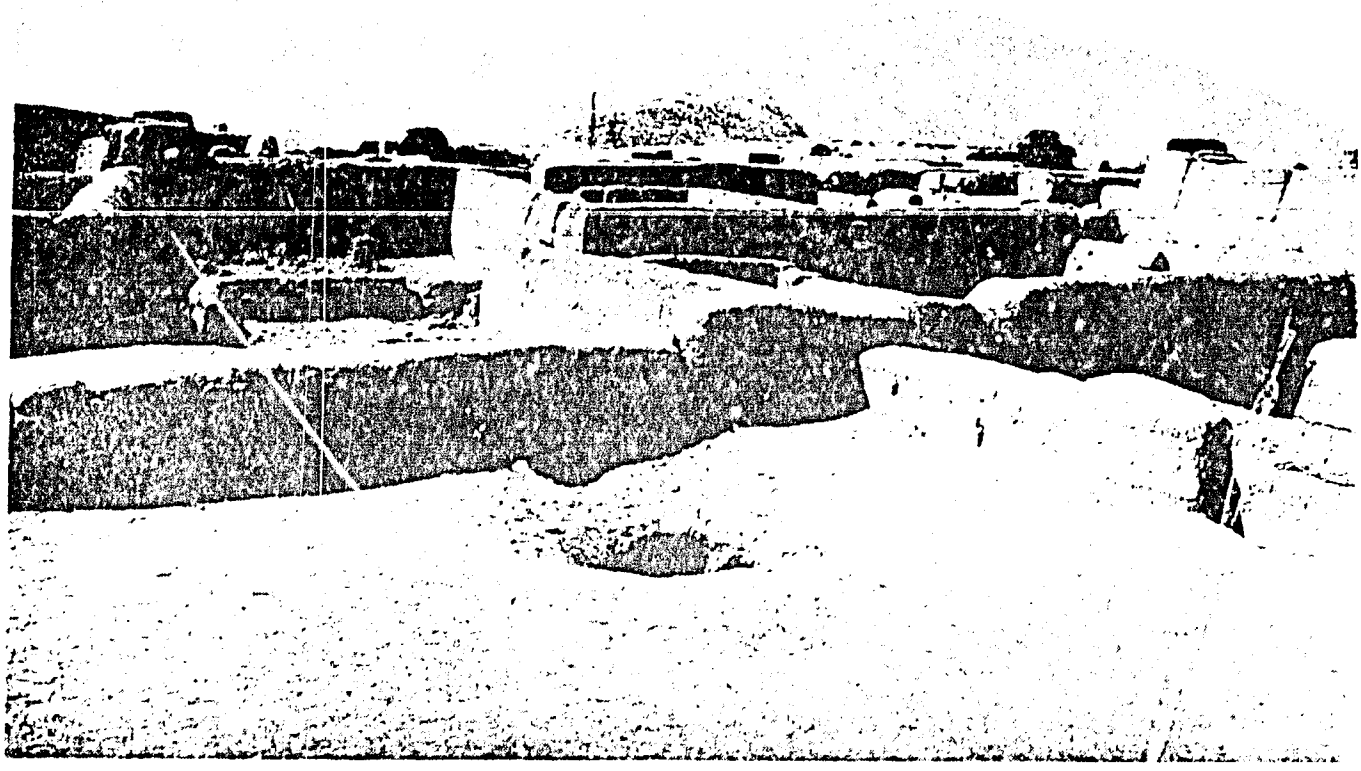
Fotografías 12-A y 12-B.- Casa del Almirante Francisco Alderete Maldonado construída a fines del siglo XVI con adobes sobre muros de época inca. Fué afectada por el terremoto de 1950 y por las equívocas intervenciones posteriores hasta que fué restaurada entre 1975 a 1979.
Las vistas muestran la fachada al inicio de las obras y después de su conclusión.

Fotografías 13-A y 13-B.- Iglesia de San Jerónimo, cerca de Cusco, construída en el último tercio del siglo XVI con adobes. La restauración concluyó en 1980.

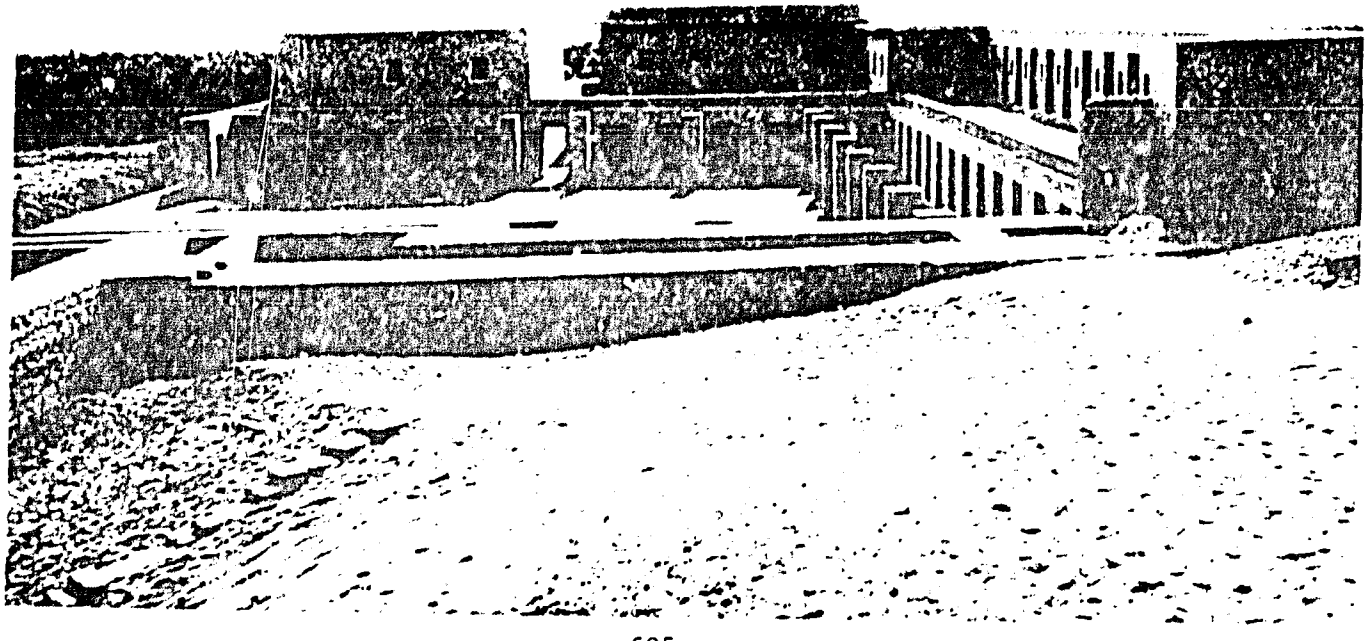
Fotografías 14-A y 14-B.- Casa del Marquez de Valleumbroso en Cusco en la que destaca la portada de transición Inca-Colonial. En la primera fotografía se aprecia la casa en 1974 luego de ser desvastada por un incendio. En la siguiente fotografía el estado actual de la casa en proceso de restauración.

FOTOGRAFIA 1

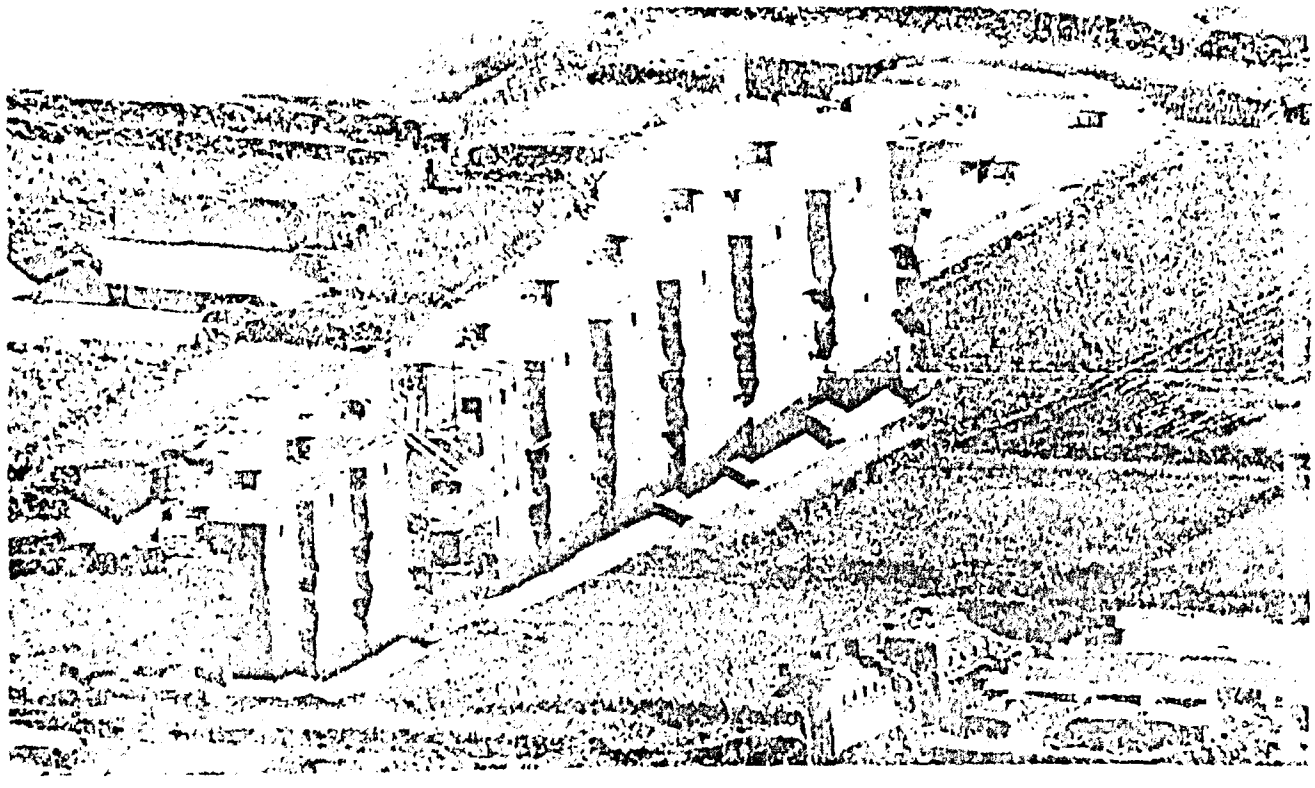
FOTOGRAFIA 2



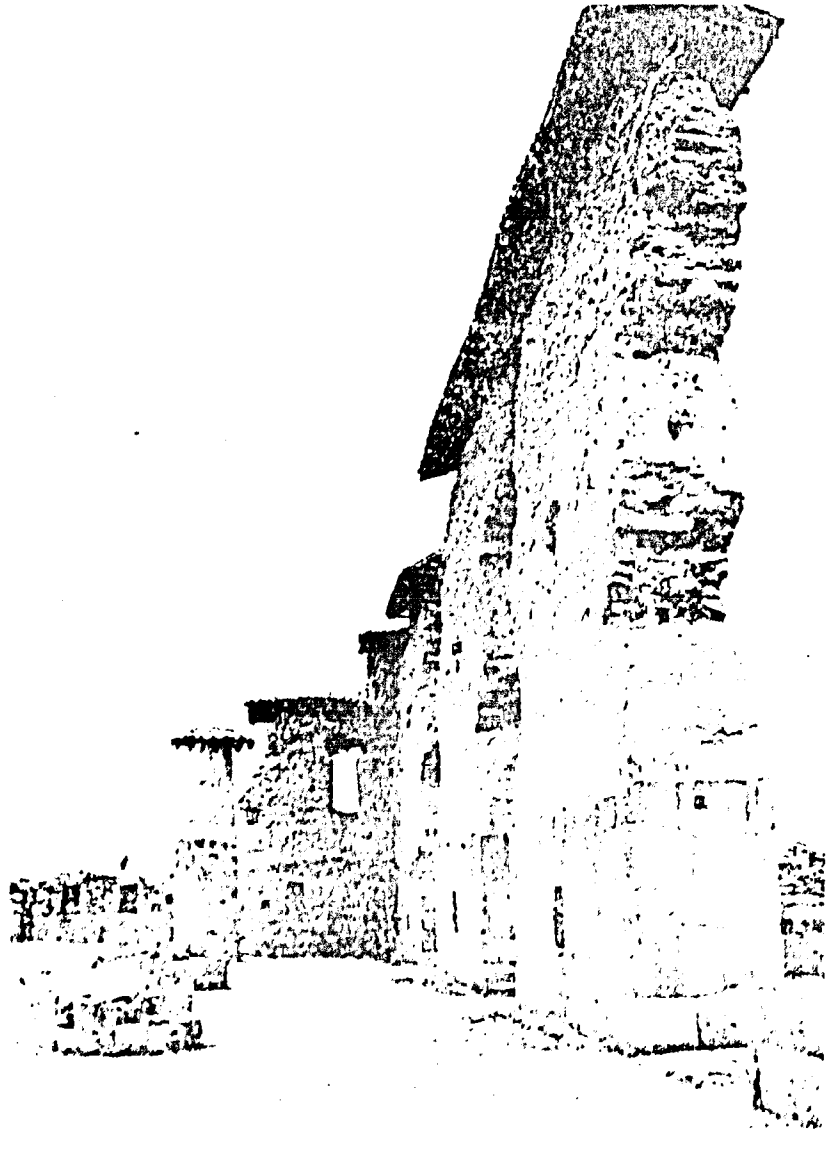
FOTOGRAFIA 3



FOTOGRAFIA 4

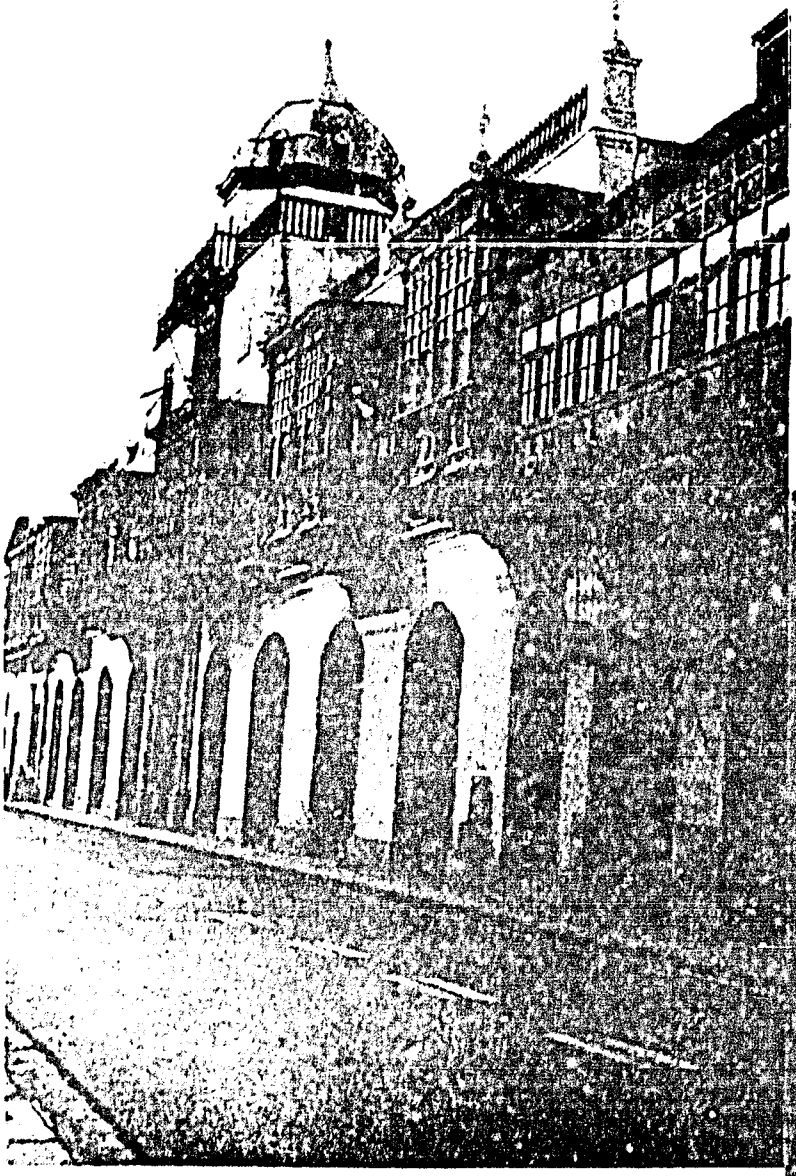


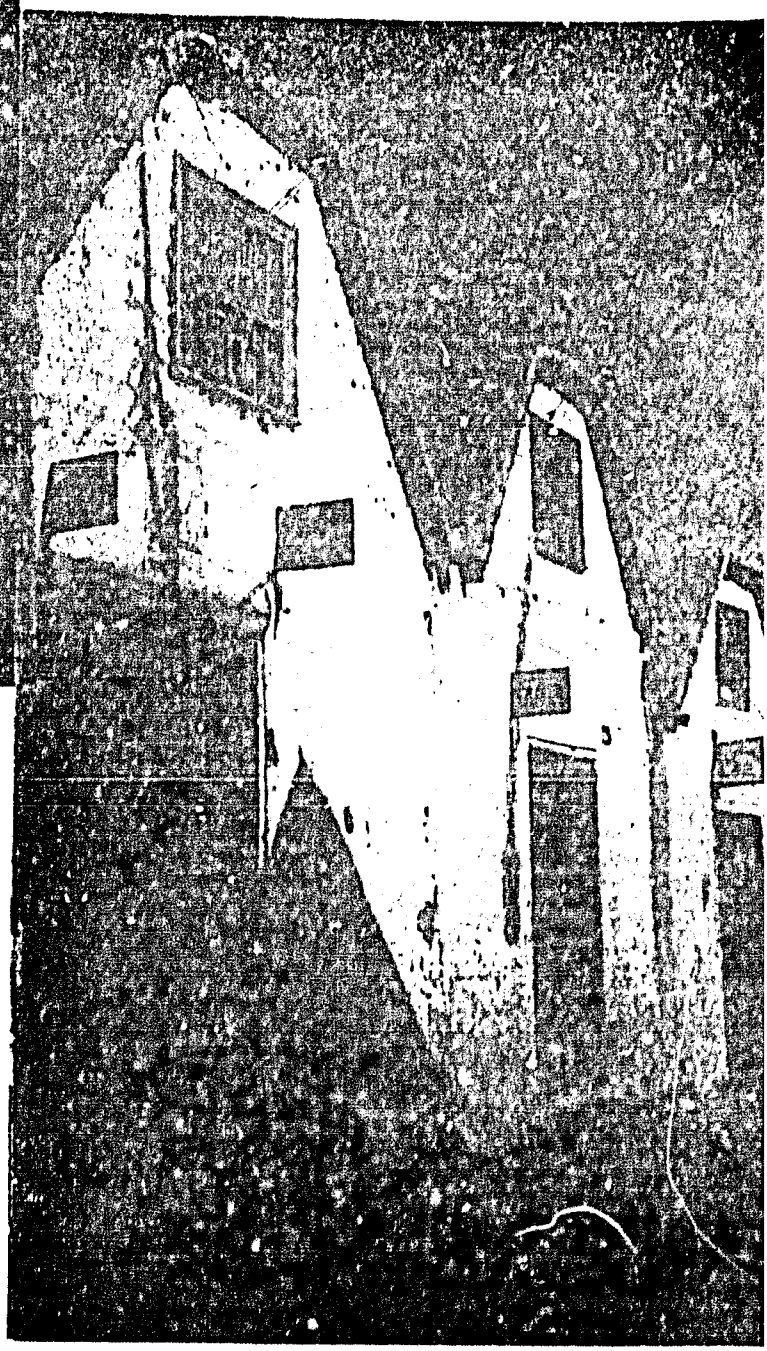
FOTOGRAFIA 5-A



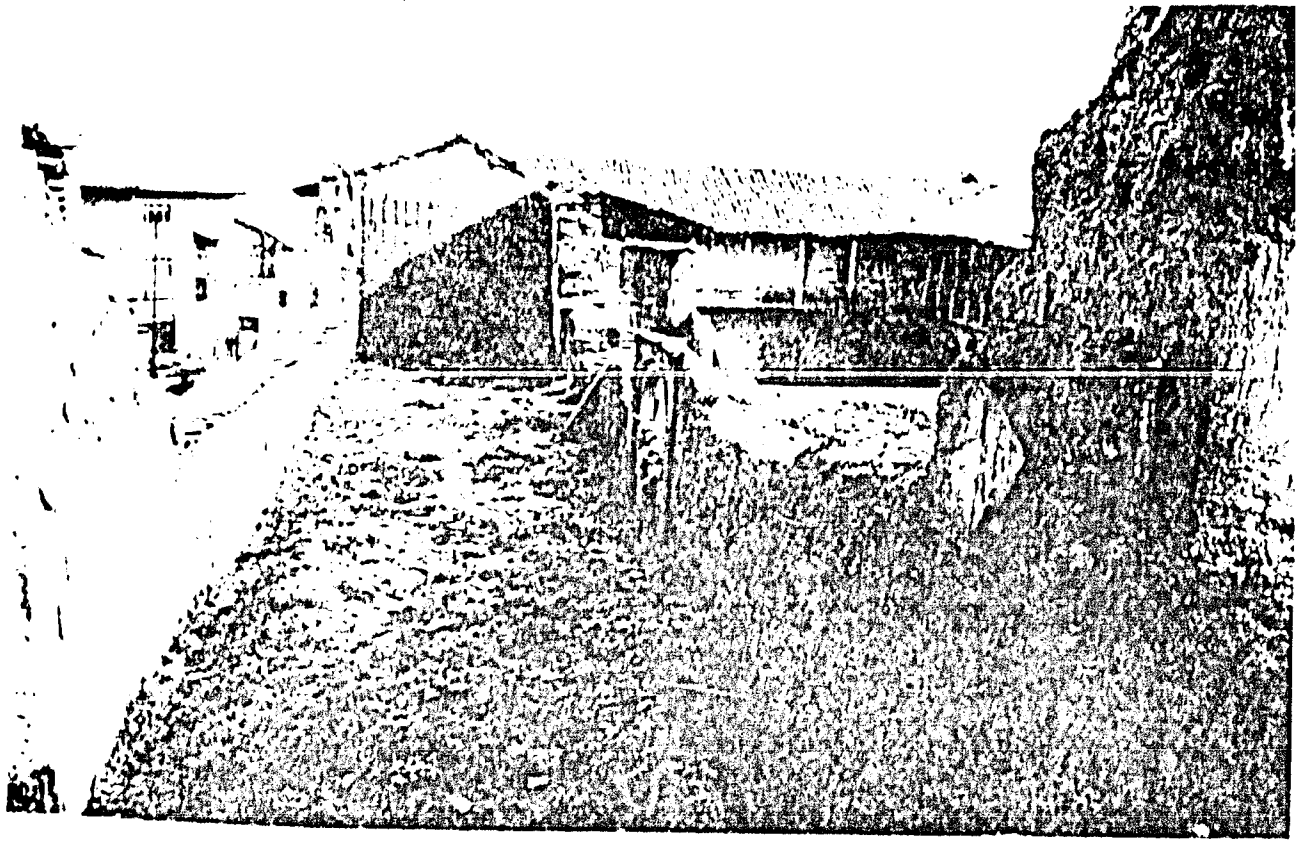
FOTOGRAFIA 5-B

FOTOGRAFIA 6

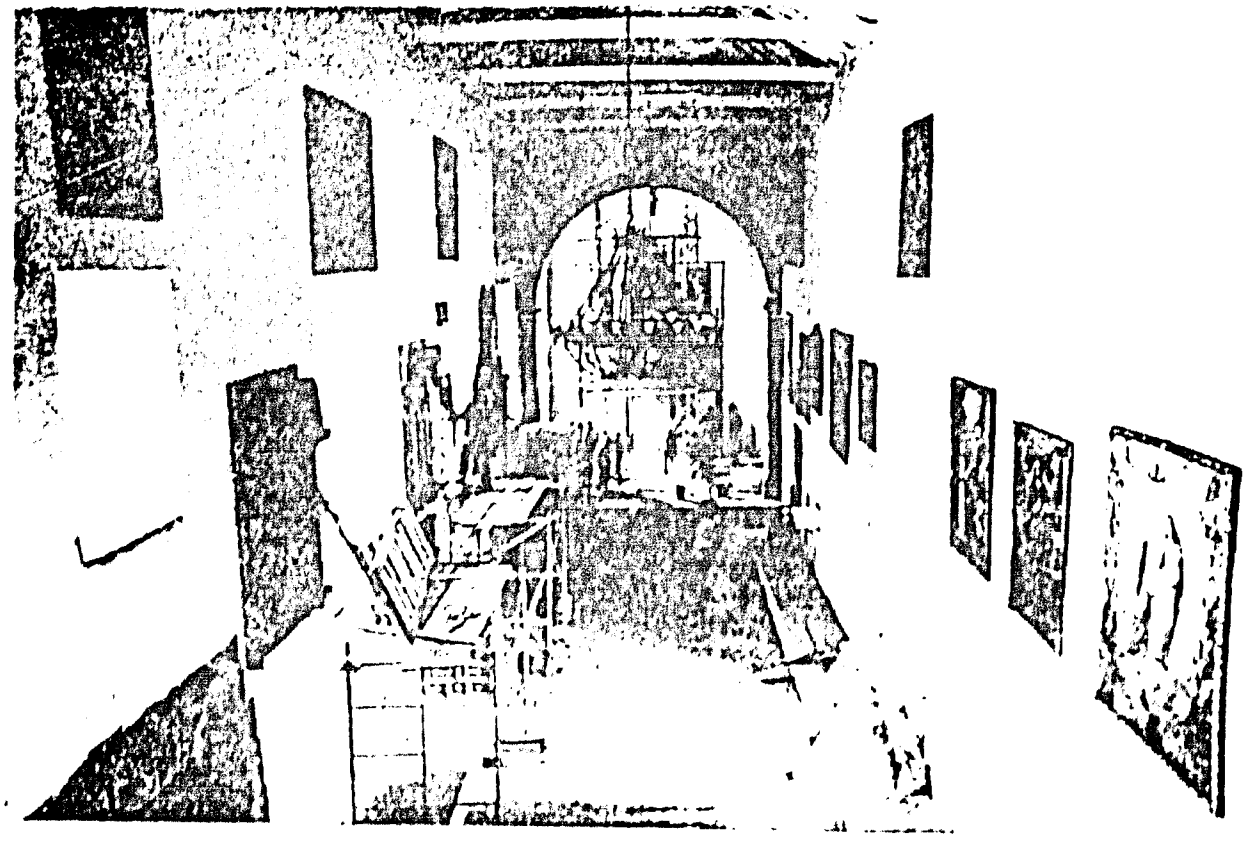




FOTOGRAFIA 7

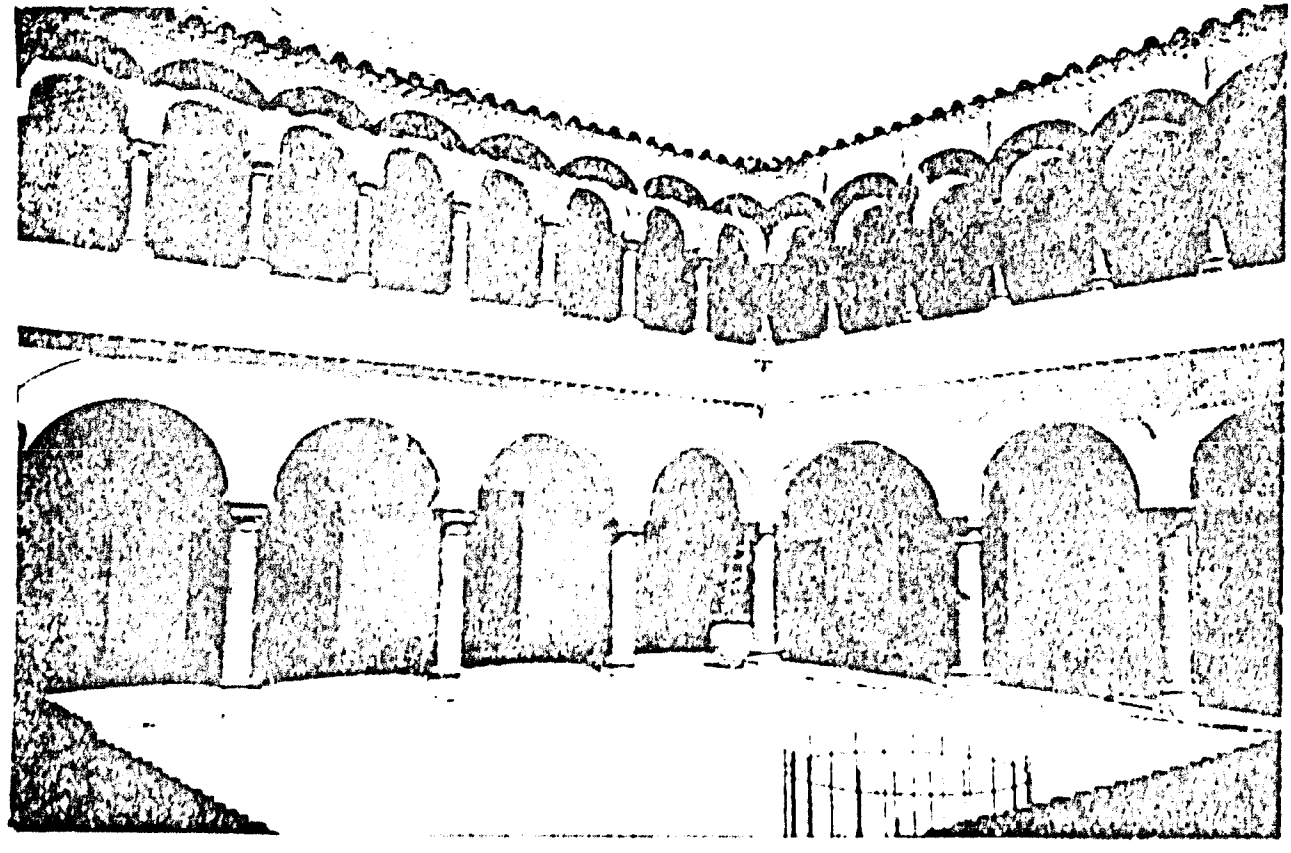


FOTOGRAFIA 8-A

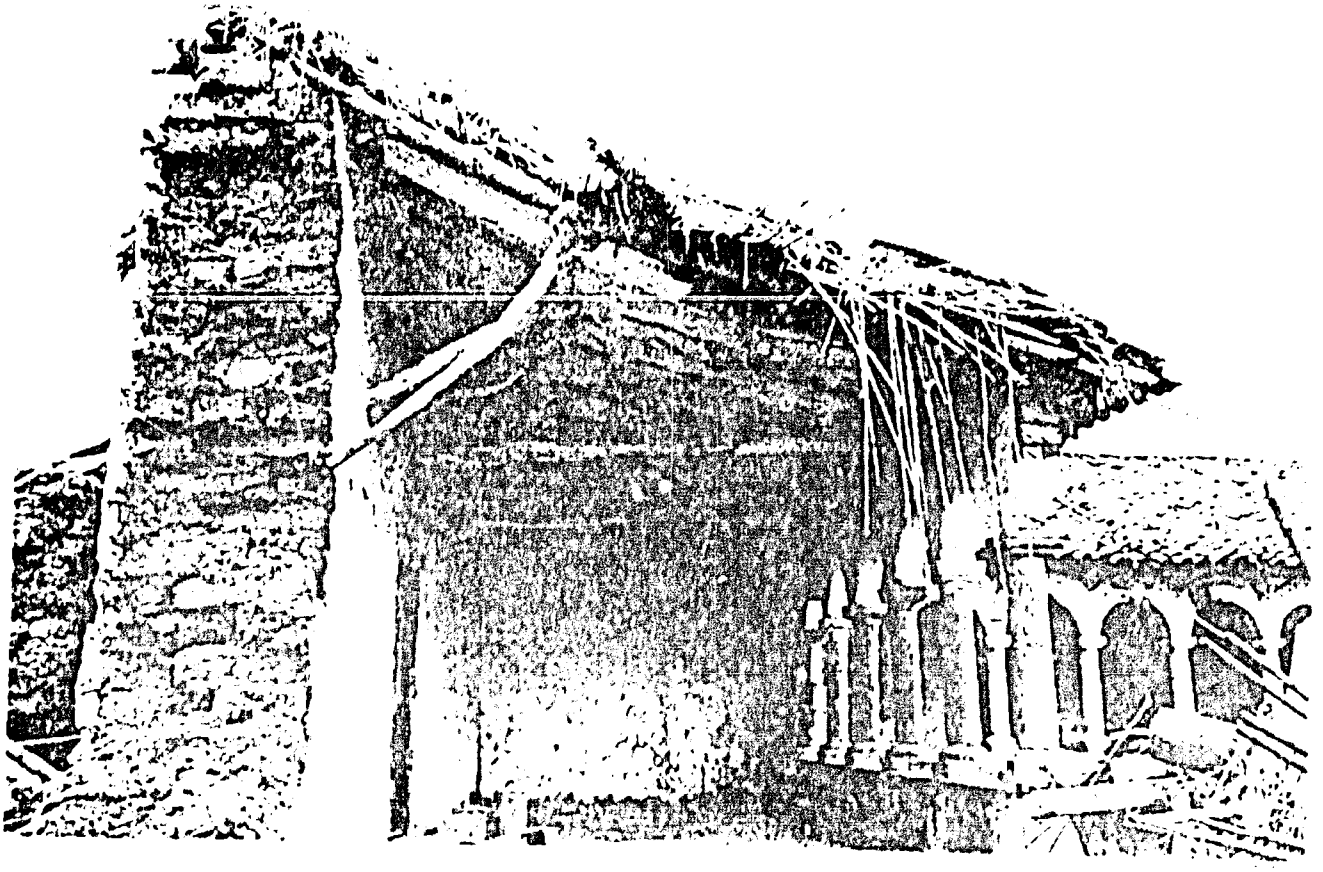


FOTOGRAFIA 8-B

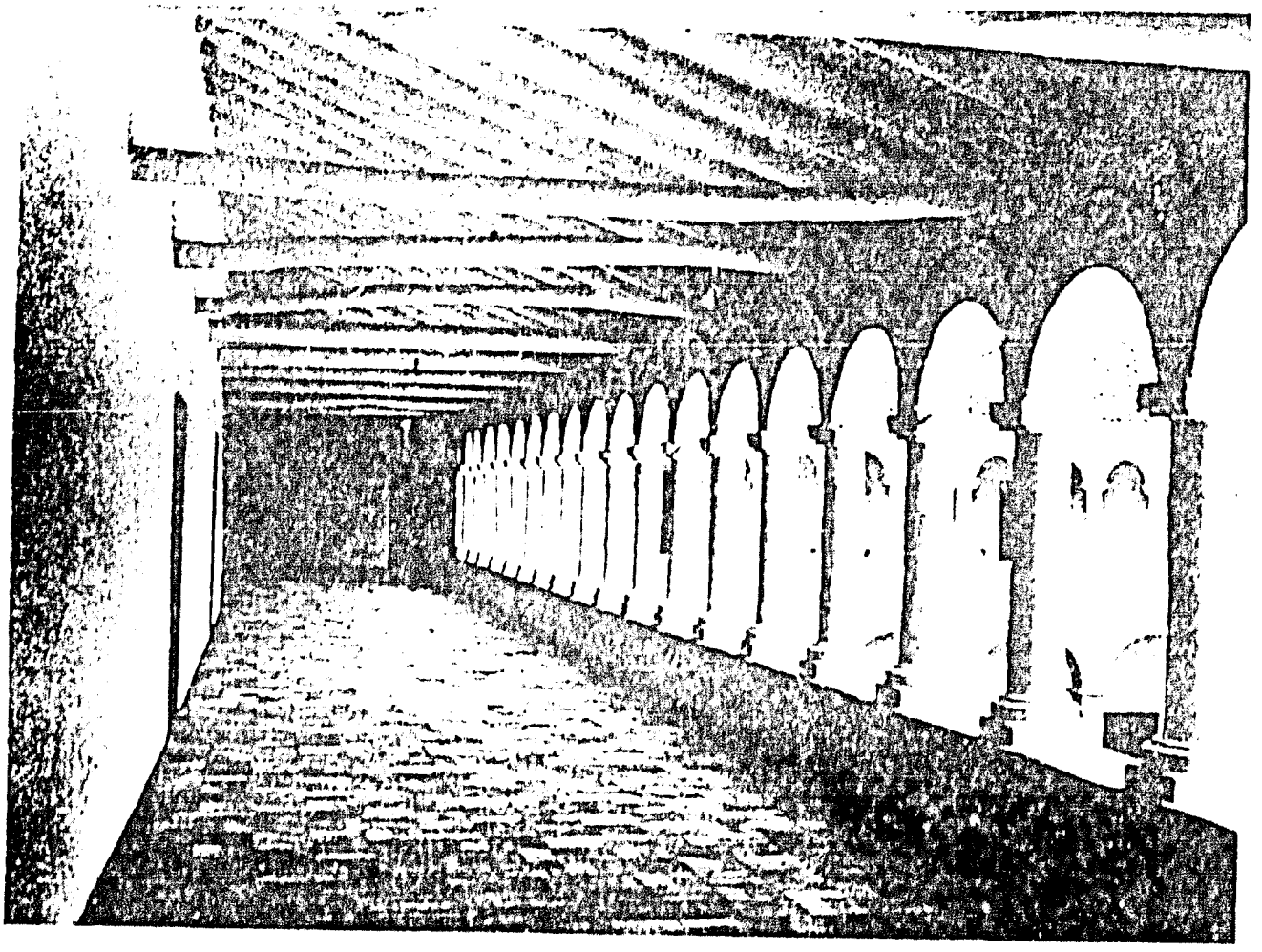
FOTOGRAFIA 9-A



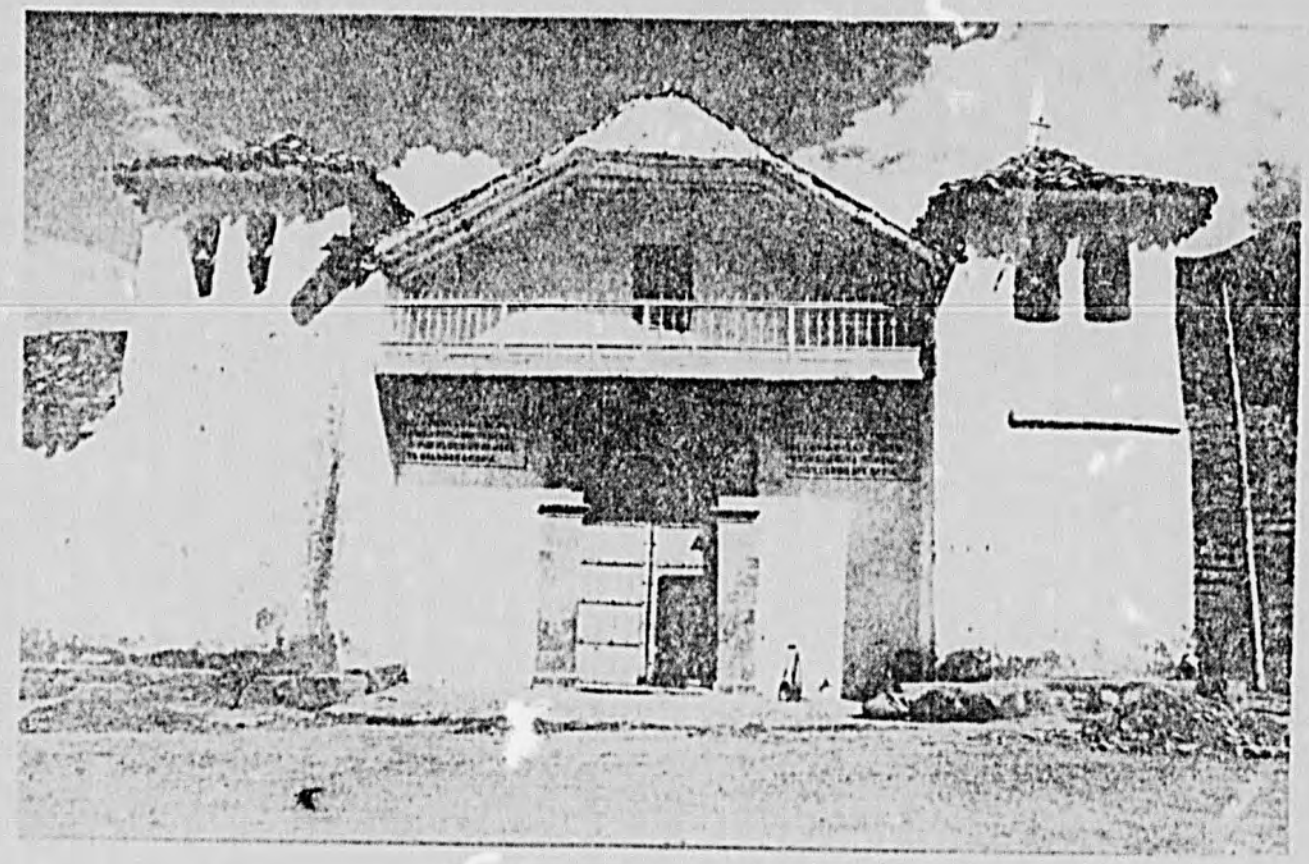
FOTOGRAFIA 9-B



FOTOGRAFIA 10-A

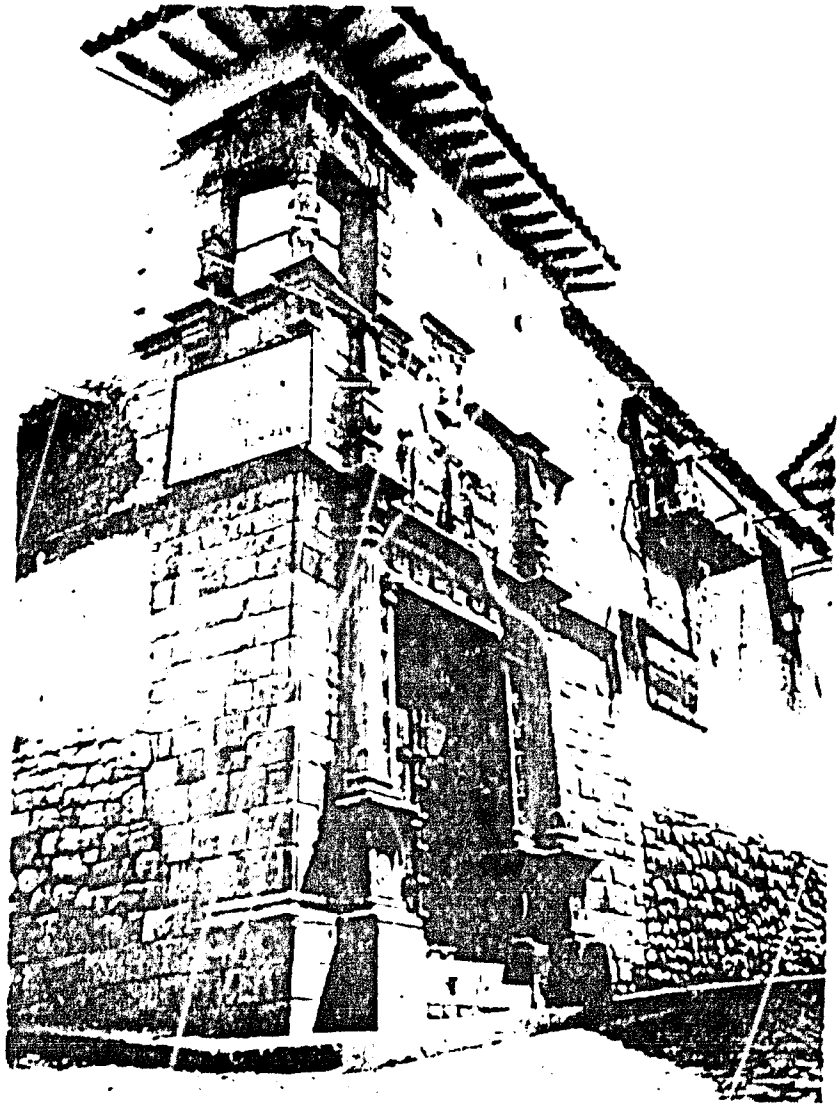


FOTOGRAFIA 10-B

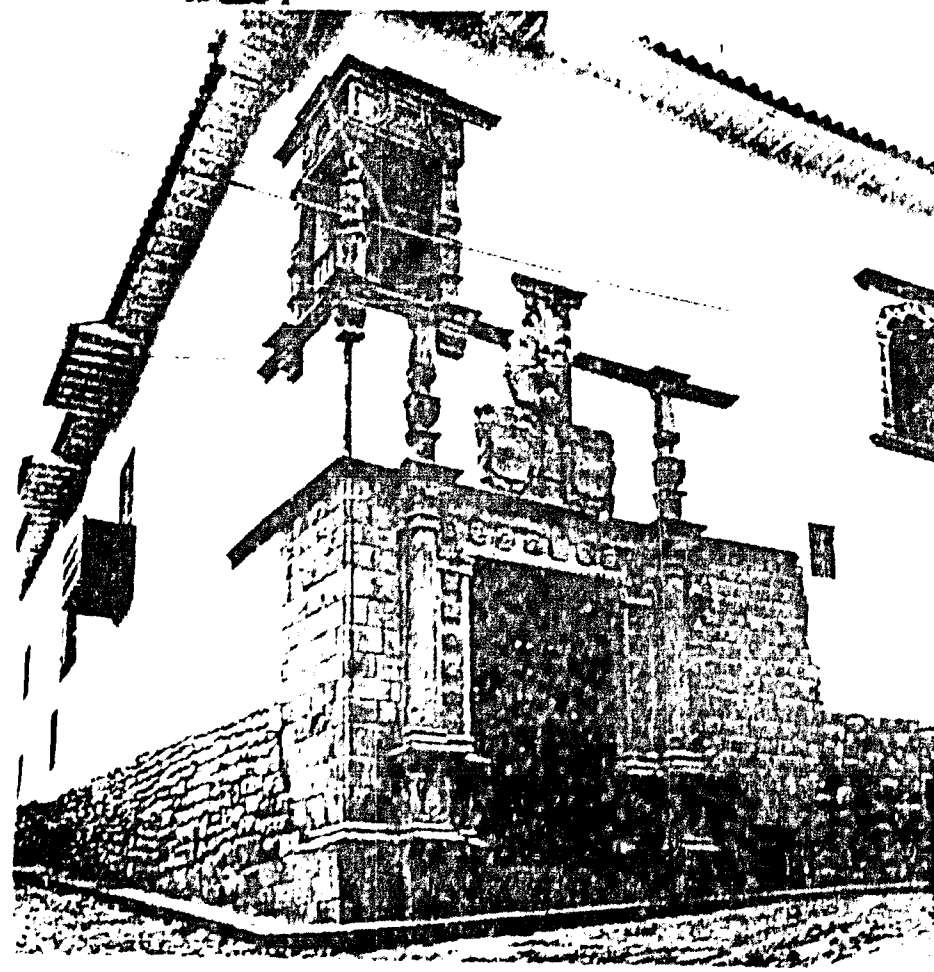


FOTOGRAFIA 11-A

FOTOGRAFIA 11-B

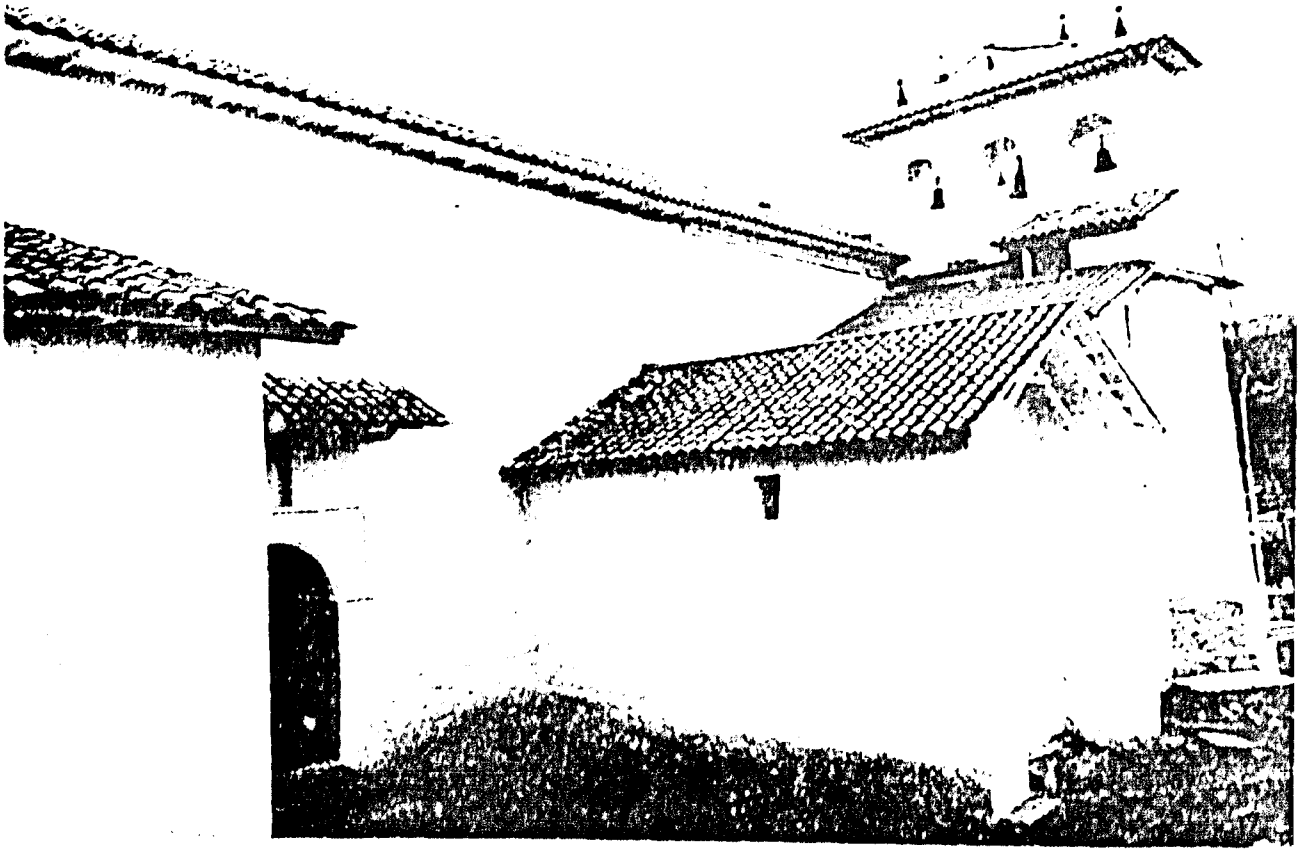


FOTOGRAFIA 12-A

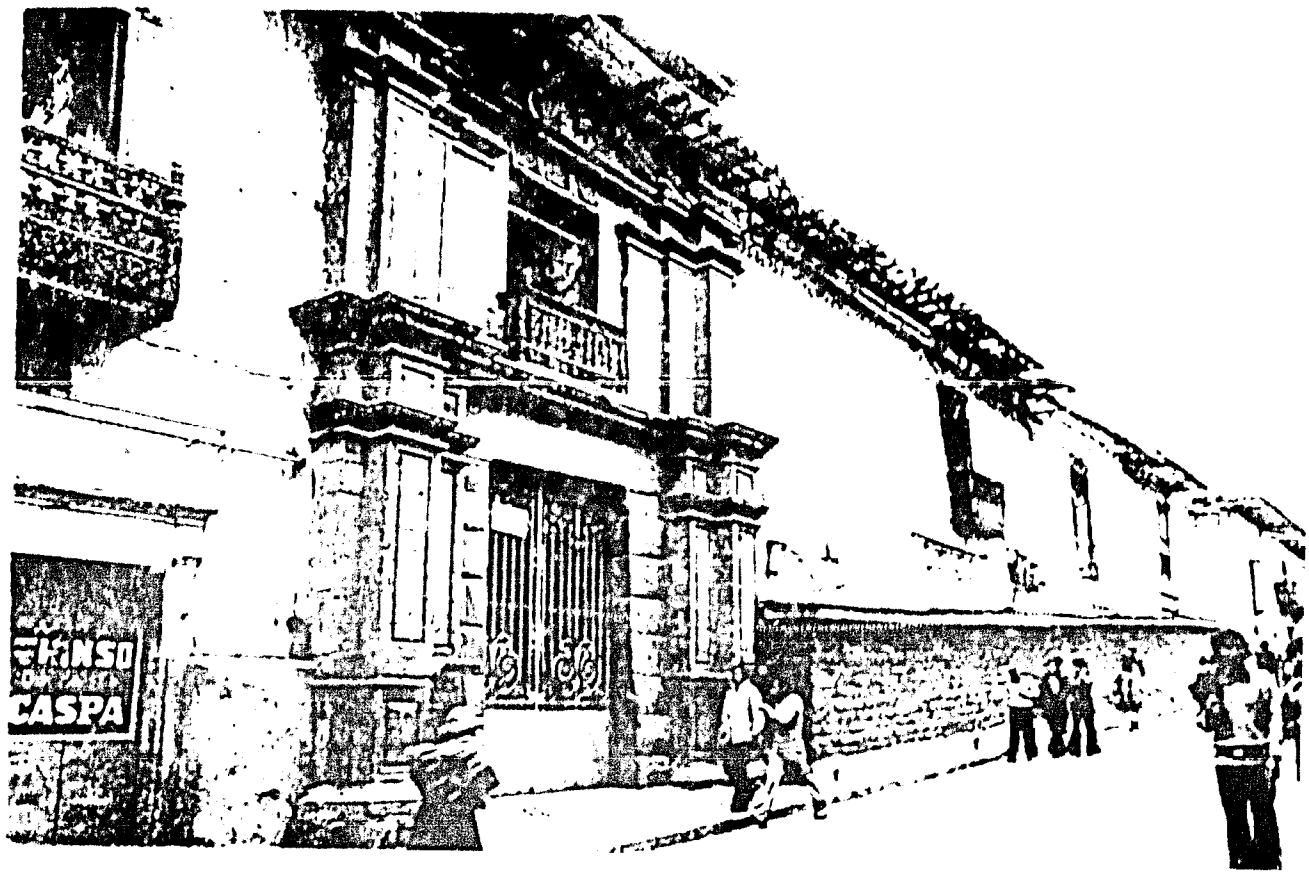


FOTOGRAFIA 12-B

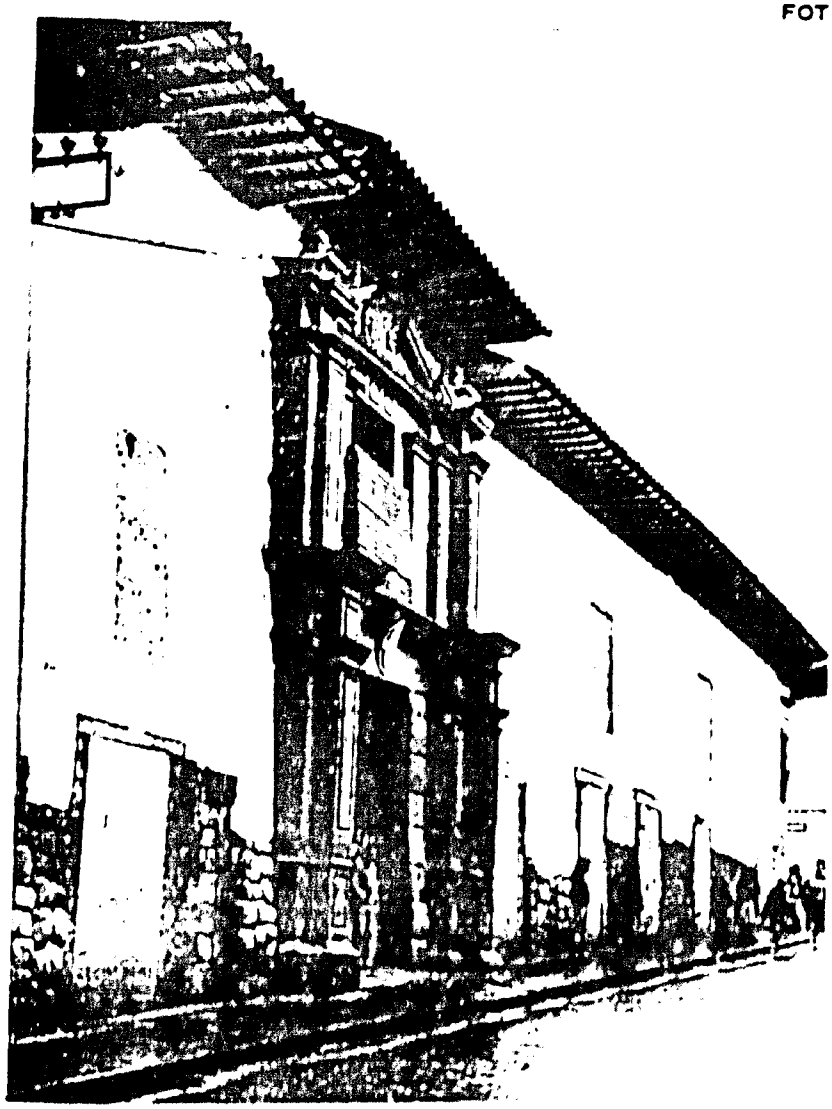
FOTOGRAFIA 13-A



FOTOGRAFIA 13-B



FOTOGRAFIA 14-A



FOTOGRAFIA 14-B

STABILIZED SOIL-CEMENT IN LOW COST CONSTRUCTION & ITS RESEARCH NEEDS

ALFRED BUSH - RESEARCH CONSULTANT

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10520

ABSTRACT:

Scientifically stabilizing soil with cementitious materials establishes its permanence for building. Reinforcing it with bamboo or small steel strands and mortar provides it with structural resistance to cataclismic hurricane or earthquake conditions. Training people to manufacture parts and build complete walls, floors, footings, sub-floors, columns and lintels, using reinforced and stabilized soil-cement block and rammed materials, through simple systems planning, results in a min -mobile industry for minimum cost structures development. My interest, through research, testing and demonstration is to prove out these theses.

Significance of the Problem

Housing has been built of soil in the form of adobe for centuries. These structures, though coated with stuccos of various kinds, have required extensive maintenance, and wash out due to heavy rainfall in those climates where this weather persists. Where earthquake conditions prevail, collapse and crumbling of the structures has killed innumerable occupants. Thus the study of this problem.

The stabilization of soils such as soil-cement has been studied in high technology countries and utilized to some extent (over 70,000 miles of highways in the U.S.) as sub-bases, secondary road slabs, shoulder for secondary runways, etc. With the low cost of materials and the high cost of labor in the past, more and more, sophisticated uses of mechanization has taken place, and the more labor intensive, or what were originally low cost systems were discarded. Large and extensive subsidies have been provided by the U.S. for the development of the cement and steel industries in highway construction to bolster the overwhelmingly extended use of the automobile.

In developing countries on the other hand, research has continued through the development of simple block making machines and the technology for labor intensive utilization. Methods for marrying concrete and soil-cement have been experimented with, as in Israel, (1), but never simplified sufficiently to the village level type of operation to be able to house the lowest income families. The least skilled population was helped on a one-to-one basis during emergencies, but not trained to utilize the skills developed for jobs, on a more permanent basis.

One great need is the provision of housing which will stand up over the years with practically no maintenance, yet at the same time withstand the ravages of the climate. By combining reinforcing, soil-cement construction and an easy-to- build roof cover system, such as one of ferro-cement or other, I believe this can be accomplished.

A second great need is the promotion of jobs and diverse appropriate industry at the village level in the rural areas. This will foster the stabilization and upgrading of the local population by creating mutual industries which can service their own communities, as well as the surrounding larger cities and towns.

Innovative Approach

The innovate approach herein suggested is for the pretesting a simple construction system in the laboratory to predetermine the ability of such

a low cost structure to survive rugged field conditions. In the lab, facilities are available to sufficiently simulate those conditions, but at the same time apply advanced techniques under controlled environment. This may not sound unusual in applying advanced techniques in developed countries, but in the application of basic technology for rural or less developed area or nation usage, it is rare that such linkage is established.

Since the author has published an article on low cost housing (2) which has circulated freely in many developing countries, so many responses have come in from around the world for information and assistance, that one could find a ready application for a field demonstration. It would be more practical for such a demonstration of self-help techniques to be tried in a rural U.S. community first, perhaps one such as the author previously participated in planning with a Georgia sharecropper, Appalachia or rural Puerto Rico community. Feedback, and the resultant improvements could be more immediate, and training techniques could be realistically worked out. Thus technology transfer would be greatly facilitated, and enhance the utilization of the benefits of the research.

The concept of producing a mobile mini-plant incorporating a cluster of small block making machines, is the key to maximizing the efficiency of this elementary tool. It entails a low investment in equipment, yet establishes quality control of the complete manufacturing process through the training of one man to become skilled in the operation of the mixing. This feeds the soil-cement at optimum proportions to all machines, and at the same time, through his supervision, assures control of the procedures in curing all block produced. This system was conceived as part of a presentation prepared for the U.N. Habitat Exposition held in Vancouver in 1976, discussed later in the section on 'Systems from Tools', which indicates the potential varieties of appropriate industries which could derive from the Cinva-Ram block making machine. Thus demonstrating the potential for creating new jobs appropriate to stabilizing the rural regions of any country.

Research Objectives

The desired research program would be hoped to demonstrate the following:

That soil can be used as a construction material for footings, foundations, sub-floors, walks, steps and other construction purposes as well as for walls and floors of houses and other buildings.

That reinforcement applied to soil-cement as well as concrete and soil-cement combined, can result in structurally sound, low cost and easy to construct parts of the building systems.

That optimum soil-cement mixes fed into a small hand operated block making machine can, with a minimum of 7 days curing, demonstrate quality control and the capacity of the block to carry loads equivalent to concrete block, and

equal-to or better water absorption characteristics than concrete block.

That ferro-cement panels for roofs, designed to meet required loads, can be properly fabricated, cured and assembled and anchored through simple techniques as part of the system.

That sub-assemblies of soil-cement, reinforcing steel, concrete and ferro-cement panels can be easily combined to make a completely structurally sound building to carry hurricane and earthquake intensity loads.

Stabilizing The Soil

To increase the stability of soils, they have been mixed with many types of bonding agents, varying from bituminous emulsions, salt solutions, organic liquids to lime and Portland cement. The results have been as varied as the type of mix. The most common materials used have been lime and Portland cement. Results with lime have been most erratic, since its manufacture in less developed countries has lacked any standards for production. The kilns for processing it have been set up near the local outcropping and whatever the purity of excavated material, whether containing 10% or 50% sand, is processed in the same manner, in hand fired kilns, with no quality control over the process. As a result, no assurance can be given that the batches will have any consistency.

In contrast, Portland cement (which has twice the strength of lime for the same mix) is the one of few quality controlled materials manufactured in most countries where lime bearing materials are native. Since the investment in manufacturing plant and process are high, and the techniques to produce are imported, the product generally meets basic international standards. Thus the mixes made with it usually are able to meet some commonly accepted norms.

Most research has been based on determining the optimum soil and using that for the mix, and if such is not available, then creating it by combining the necessary ingredients. Since all soils consist of varying size particals, ranging in different proportions of gravel, sand, silt, clay and colloids, and differing mineral characteristics, those soils with the best characteristics, have been chosen for use in large high investment public projects, where advanced technology standards are usually emulated.

In using the material for low cost housing, however, since the value of the material and the potential for using it at all is usually in its availability and close proximity to its end use, it is possible, by varying the cement content to obtain good results. The type of soil on hand must be considered, so that the proper % of cement to be added may be determined. In making block or ramming the soil in situ, it is possible to use any soil by first determining its characteristics.

Standard procedures usually require laboratory analysis, but up in the back hills none of this technology is available. So the author has invented a simple system that anyone able to read and count or note time on a watch may use to determine the proper proportions to use. The technique will be described shortly.

Variation in Mixes

The percent of cement required in a mix depends on the fineness of the particles in the soil. Since a clay of exceedingly fine particles ≤ 0.005 mm has a much larger effective surface than a coarser particle such as sand, it will take more cement mixed with a clayey soil to cover and bond all particles than a sandy soil, for that is the function of the cement- which creates the stability and resultant strength, wear resistance and water resistance to the soil-cement. Thus a good sandy loam may require only 5% cement for an optimum mix, and the quantity may range all the way to a 15% cement mix for a lateritic clay soil.

Percent By Weight Vs Volume

Most high technology producers use the cement measured by weight for accurate determinations, but, since the objective here is to use simple skills and still establish an effective use of quality control, and volume mixes have been determined, and are available from the laboratory research, the author has used the percent by volume mixes. This permits great simplification in not having to work with oven dry weights, but calling for mixes by references to the relative shovel fulls of cement to soil.

Optimum Density

Each soil and soil-cement mix has a density which varies with the percent of moisture in or added to the mix, and it is the mixing density which provides the best properties of the combination. This varies with each soil type as

well as each soil-cement mix, and would require a laboratory test to determine it, except that an exceedingly simple crush test so closely matches the results, that even children can and have performed it and produced excellent results. In this test it is not necessary to determine how much moisture must be in the soil to start with, or how much must be added. It is only required to lightly sprinkle enough moisture on the batch and mix it in to an even color throughout, grab a handful and squeeze it into a solid lump in the palm of the hand. The mix is too wet if it wets the hand. It must be just dry enough that when crushed with the thumb into the palm, it breaks into just two pieces. That is optimum moisture content for the mix. It is too dry if it crumbles.

Manufacturing The Block

Once the soil has been tested for optimum mix with the desired stabilizer, and sufficient material for its intended use has been determined, batches may be mixed for manufacturing the block. These may be most readily made in a portable block machine of low cost such as the Cinva-Ram (see Fig. 1). It weighs about 150 lbs. and has been manufactured in South America for use in many parts of the world for over 20 years. Two men can readily learn to operate it in a matter of minutes, and can produce 50-80 block in an hour. Operation of the press follows (Fig.2). Immediately after each block is made and ejected by the machine, it is placed on a plank so that when several have been aligned on the plank, it may be moved into a shady spot or under cover, where it is covered for at least one week, keeping it constantly wet for curing. This will assure a solid block of adequate strength and weather resistance. Soil cement is thus treated like concrete which the longer it is kept wet the more strength it gains. It is not to be treated like adobe and baked dry in the sun.

Similar techniques are used in casting soil-cement in situ. In this process the same mix is placed in the form or into a cut in the ground in the case of a grade beam, foundation, walk, sub-floor or steps. The material is applied in several layers, compacting each layer thoroughly with a weighted tamper. Moisture might have to be lightly sprinkled between layers to prevent premature drying out. The layers should be covered with wet burlap, straw or other material and kept continously wet thereafter, as for the block.

Varieties of Machines & Types of Inserts

Several forms of block machine have been on the market, but non more portable than the Cinva-Ram. Modifications and copies have been made of it, including

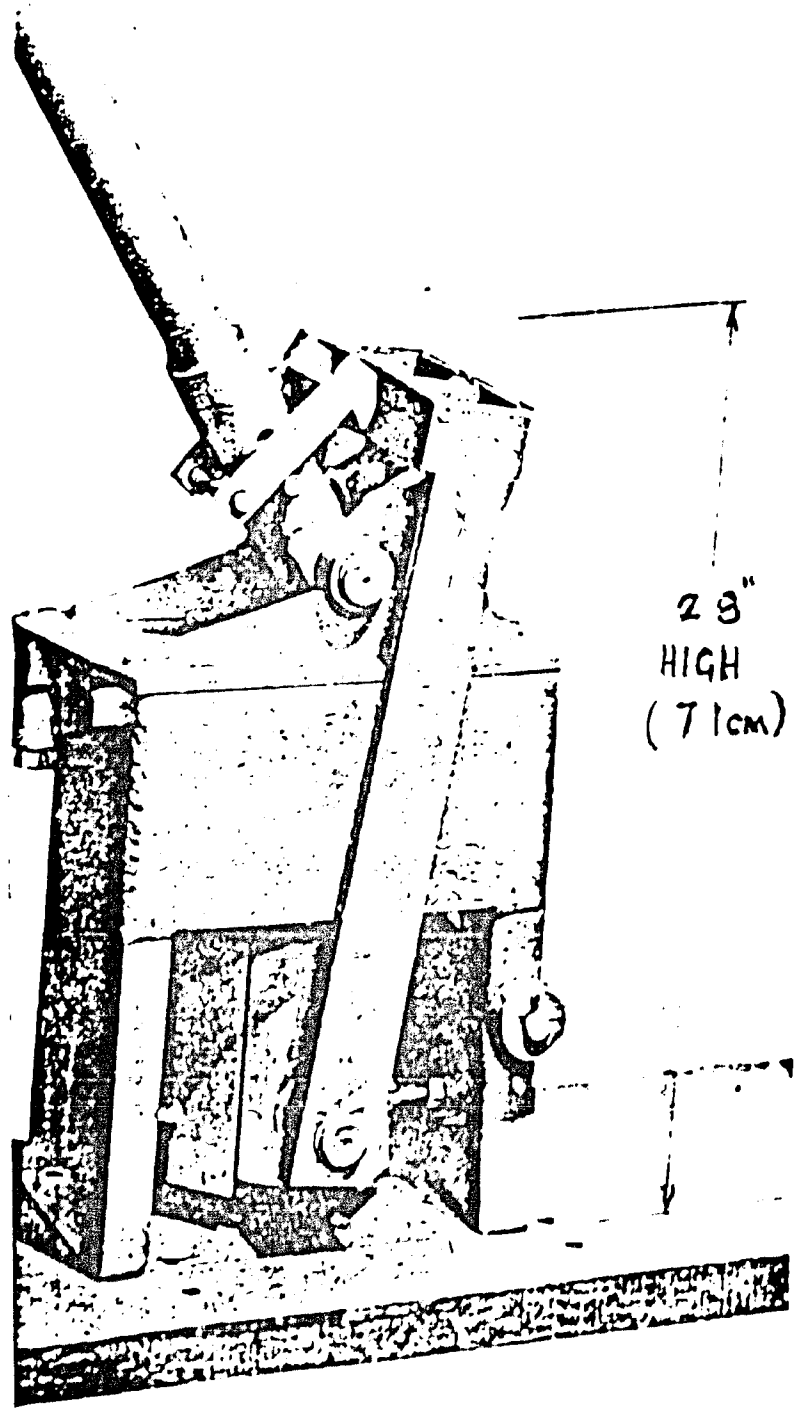


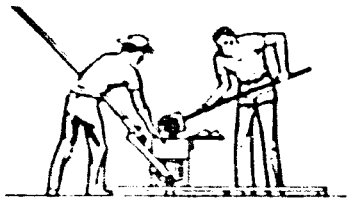
FIG. 1
Canva-Ram Machine

OPERATING THE PRESS

In order to make most compressed earth blocks and tiles, enough earth mix must be loaded into the mold box to require a *hard pull* on the handle. Make a few test blocks and tiles to determine the quantity of your earth mix which must be loaded into the press to give you this adequate hard pull.

There are three basic operations in making the compressed earth blocks or tiles:

1. Loading the mold box
2. Compressing the mix
3. Ejecting the finished product

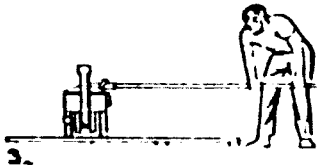


1.

2.

Detailed Movements

1. Place the handle in the rest position and open the mold box by swinging the cover horizontally until its stop is reached, then fill the mold box with the prepared earth.
2. Close the mold box, skimming off excess earth, and bring the handle to the vertical position, then release the latch.
3. Pull down the handle until it is parallel with the ground. This applies the necessary pressure to form the block. If the mold box is properly filled, this should require a *"hard pull"*.



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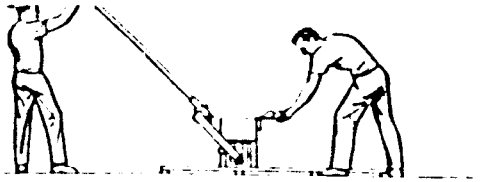
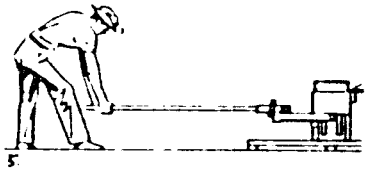


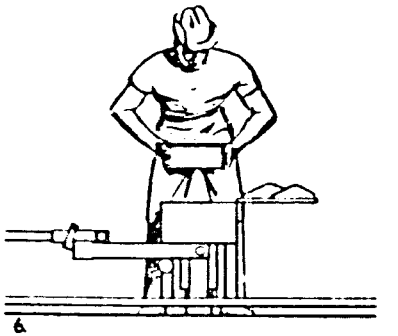
4.

4. Return the handle to the original rest position, swing cover back and open the mold box.
5. Pull down on the handle in the opposite direction until it is parallel with the ground. This ejects the block.



5.

6a *Removing blocks from the press.* Place hands flat at the ends of the block, being careful not to damage the corners or edges, and then gently lift the block from the mold box. Place on edge at the curing site.



6.

Fig. 2. Operating the Press

the Ceta-Ram. Since the Cinva-Ram consists of a rigid steel box with a yoke applying leverage from a long handle compressing the soil mix by way of a bottom stiffened plate raised towards a locked-on cover, it provides for the use of various inserts which can be either attached to the plate or inserted. These can be used to produce block to accommodate reinforcing, floor tile, grille block, lintel block, etc. (see Fig.3, 4, & 5)

The Ceta-Ram on the other hand has pipe fixed through the interior of the mold which provide for holes in the block to accommodate reinforcing. Because of this permanent insert, variations in the types of block cannot be provided for, so the flexibility in design application is limited.

The author has recently been working on a new modification of the machine to be operable by one man. One design was developed using this idea at Dartmouth College, but needs further study.

Reinforcing Techniques

In order to enable soil-cement block to become resistant to cataclismic hurricane and earthquake loads it must be reinforced using steel rod or bamboo. This can be accomplished by the use of the Ceta-Ram or an insert in the Cinva-Pam which provides for holes in the block (see Block Features Fig. 3). Then using a cement grout or concrete mortar tamped into the hole around an inserted rod, the reinforcing is enabled to transfer wind or shear loads better than a plain wall, and tie walls and all together. (See Fig. 4)

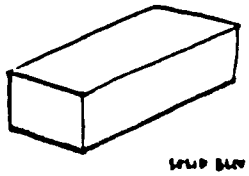
In the case of the lintel block, tie beams and lintels, they may be prefabricated as sub-assemblies or cast in place at the top of the wall to form continuity from wall section to section, or completely around the building. (See Fig. 5)

In the case of the use of soil-cement as footings or grade beams, it is anticipated that a light steel cage be suspended in the form and vertical rods be tied to it for the wall connections. The soil-cement is then tamped firmly around (as described above) the blocks with holes, and reinforcing anchored properly. Thus a monolithic structure is made which can withstand heavy loads and shock.

Simplified Block Usage

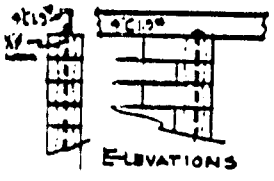
The building features developed by the author were created to eliminate skills in laying block walls. Lengths of wall are called for by the number of block,

BLOCK FEATURES

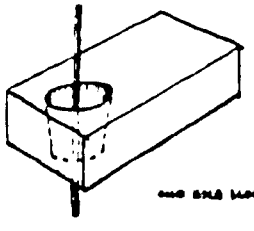


SOLID UNIFORM BLOCK

Coated with sodium silicate solution
Adequate compressive strength 400-1000 psi
Resistance to erosion

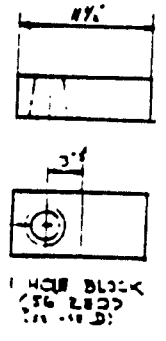


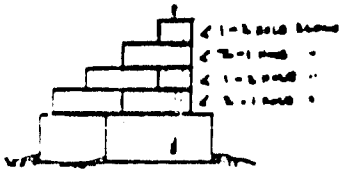
WALL AT ANCHOR



HOLLOW BLOCK

Provides continuity of reinforcing for anchorage of roof to footing





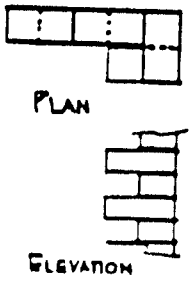
ELEVATION
EXHIBIT WALL
SHOWING ANCHORAGE

SIMPLICITY OF ERECTION

Full length blocks not cut

WRAP AROUND CORNERS

Provide stiffened
Walls self braced



TYPICAL WALL END RETURN

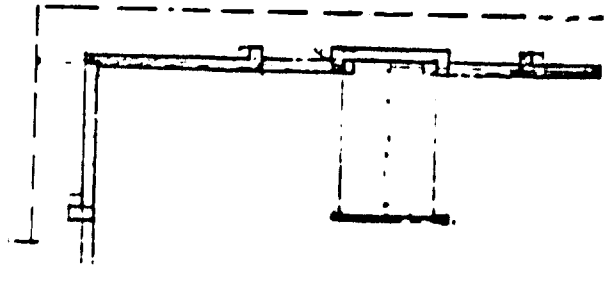
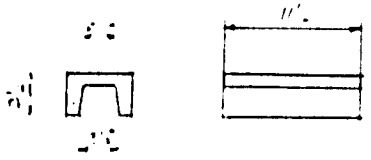
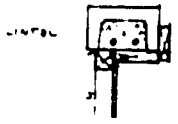


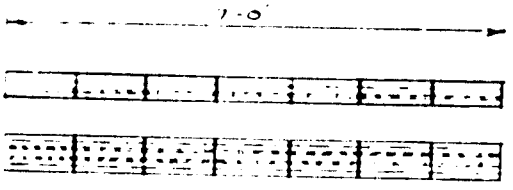
FIG. 3
Block Features



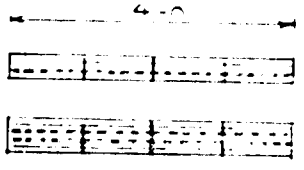
LINTEL BLOCK



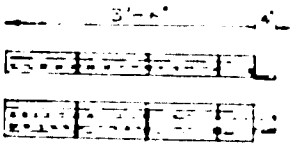
HEAD



7 FT LINTEL
OVER GRILLE
& ENTRY HSE



4 FT LINTEL

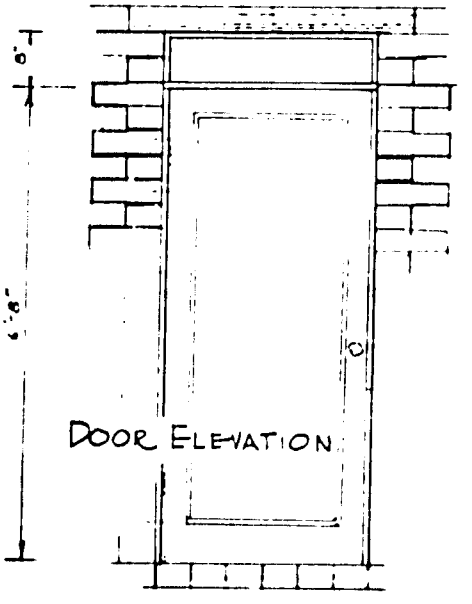


3'-6" LINTEL

LINTEL BLOCKS

Tied together with reinforcing rods and concrete fill

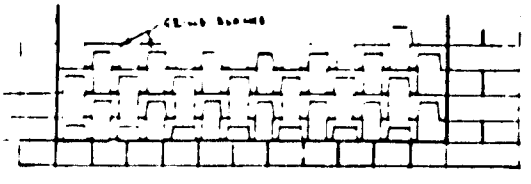
Span across doors and windows



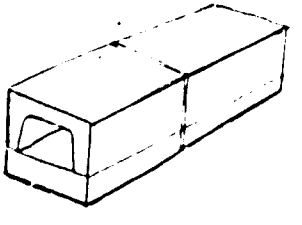
DOOR ELEVATION

and can be used as a

GRILLE BLOCK



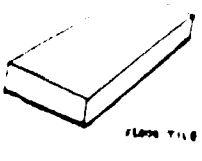
or field drains

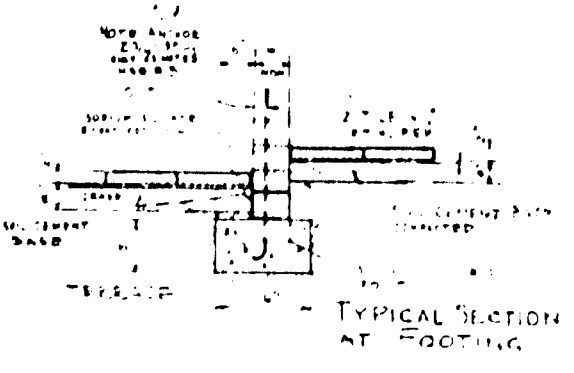


in conjunction with the

TILE BLOCK

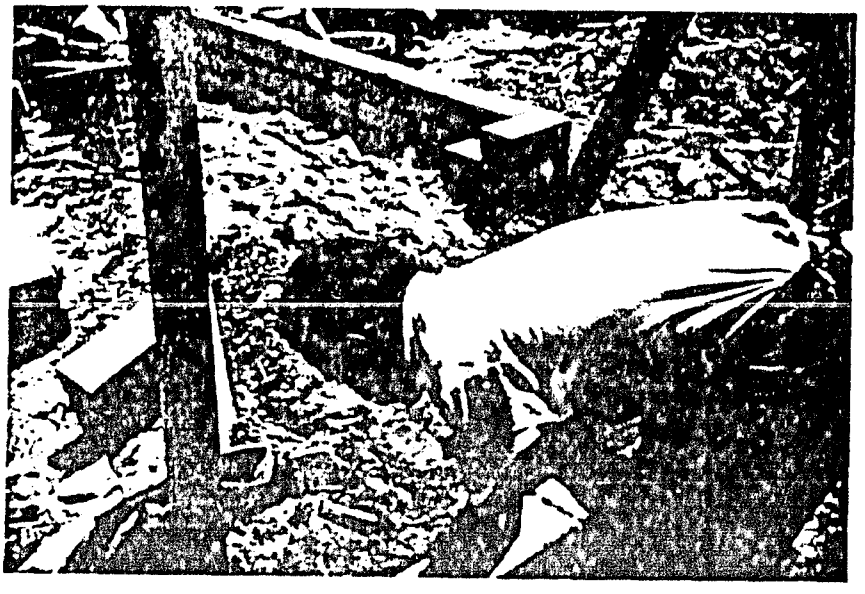
which is also used as the wearing surface of floors



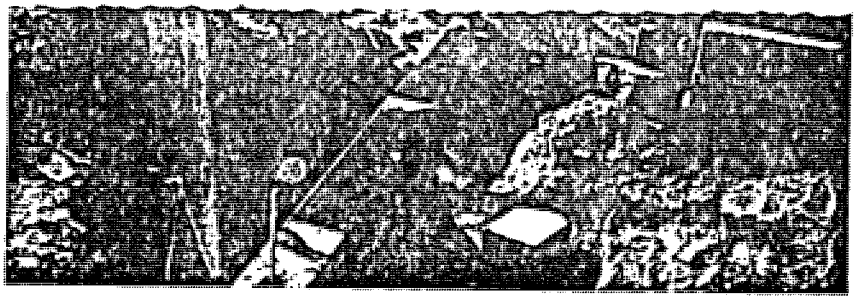


TYPICAL SECTION
AT FOOTING

FIG. 4
Block Features



WALL END RETURN



& ANCHOR

CASTING LINTELS

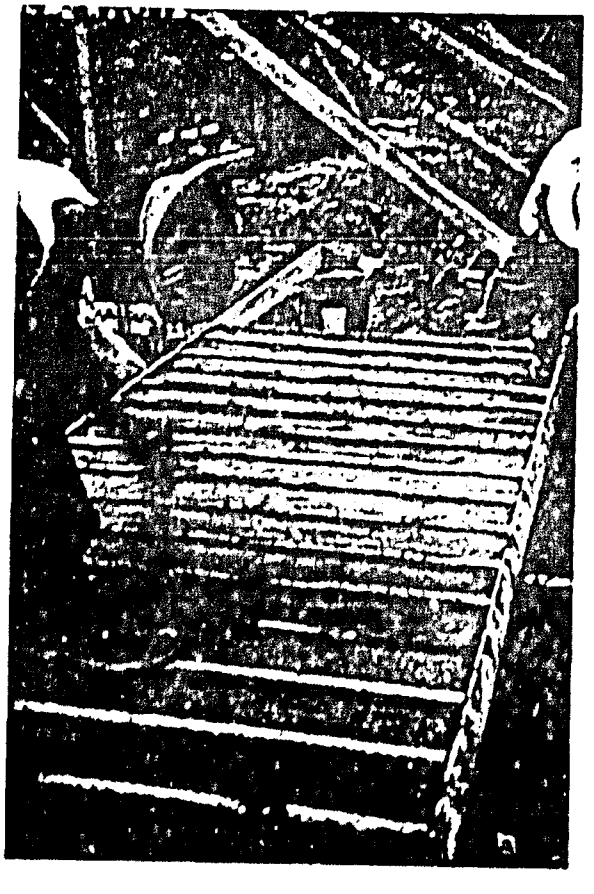


FIG. 5
Wall Return, Reinforcing
& Lintels

and are limited so each person can build his own section of wall without trying to match or keep up with his neighbors work. To eliminate skills in locating courses, leveling and alignment, guide posts or frames for windows and doors located and leveled in place, are guides, with pins or nails at course heights marked with guide string moved from pin to pin. These posts are previously placed by the one skilled man on the site - the carpenter with his helper. Thus self-help techniques are facilitated and costs for construction can be saved by the sweat equity supplied by the residents-to-be, who also participate in the manufacture of the block. These features were demonstrated by the author in 1960 at the World Housing & Planning Congress held that year in Puerto Rico.

Assembled Buildings With Varied Roofs

The houses demonstrated in Puerto Rico were of two types; a 2 bedroom unit of 665 sq. ft. and a minimum 2 room shelter of 215 sq. ft. (see Fig.6,7 &Fig. 8). Two 2 bedroom units, referred to as House #2 and House #3 were shown, having identical floor plans, but incorporating 2 different roofs. House #2 roof was formed with reinforced precast beams with projecting top steel. Specially cast concrete blocks spanned between and rested on notches in the beams, making a flush ceiling left exposed. This could have been plastered or painted. Over the top of the beams and block, concrete was poured, locking up the top steel and the block monolithically. After curing, a white vinyl paint applied on top, made for a highly reflective watertight finish.

House #3 on the other hand shows a small channel beam running the full length of the house over the longitudinal walls. This was anchored to reinforcing rod coming up through the walls in the manner shown on Fig. 5 and described previously. Across the top of these channels was attached a deep draw white enamelized aluminum roof, drilled and fastened with self tapping screws as recommended. These roof panels were long enough to span completely across the outside walls including generous overhangs. Despite the tropical sun, the under surface was merely warm to the touch after several hours of exposure to the sun. This was due to the fact that the underside, at the ends of the house, were left open as shown, and all corrugated fillers were omitted. (see interior view Fig. 7)

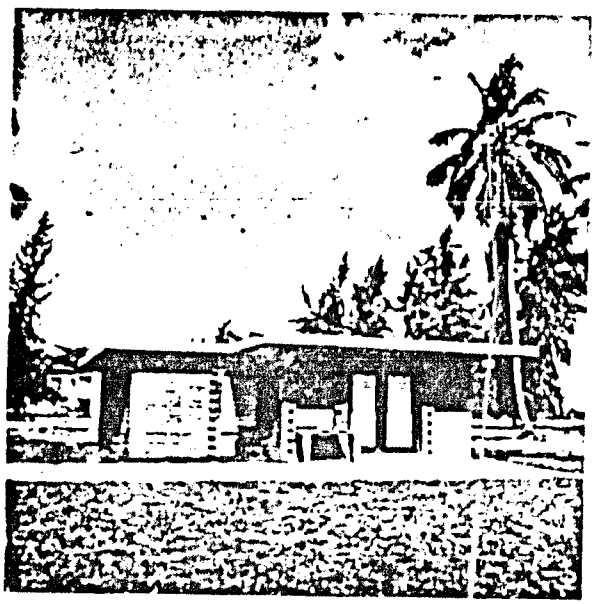
Finished floors were made of soil-cement tile cast with an insert in the Cinva-Ram machine. These were laid over a tamped in place soil-cement beds, and joints were grout poured.

Extruded aluminum jalousies were fastened directly into the block through their frames. The top sections were of the glass type turned on end to act as baffles and draw in the breeze.(see Fig. 7)

Simple surface wiring, connectors and sockets fastened into the block, completed the houses, along with basic sinks, toilet and shower stall.

These building units, based on Puerto Rico 1960 prices and a production of 200 houses, was estimated to cost $1,400 per unit, including all labor and materials

DEMONSTRATION HOUSE #2



Completed House

Entry Views

Entry Overhang
Side View

Note Grille

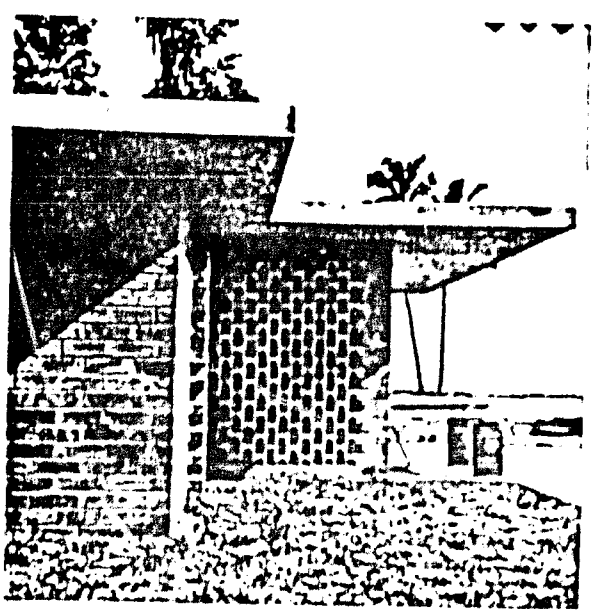
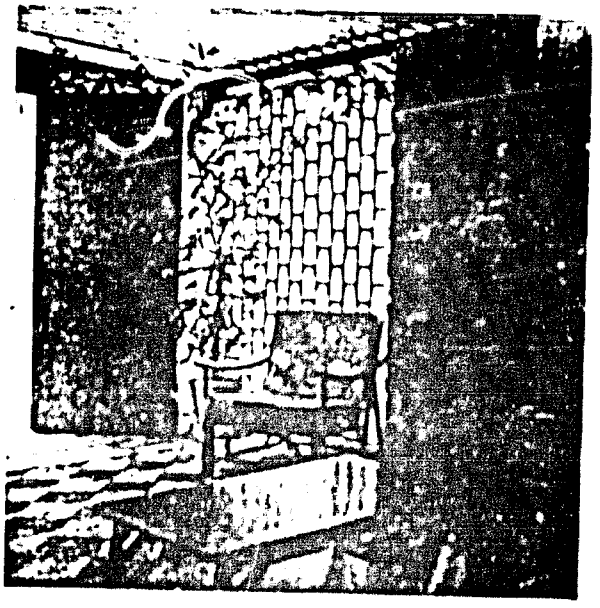
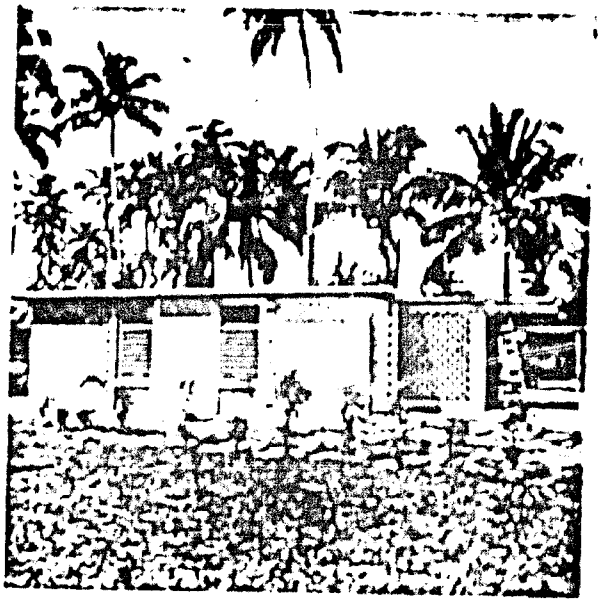


FIG. 6
House #2

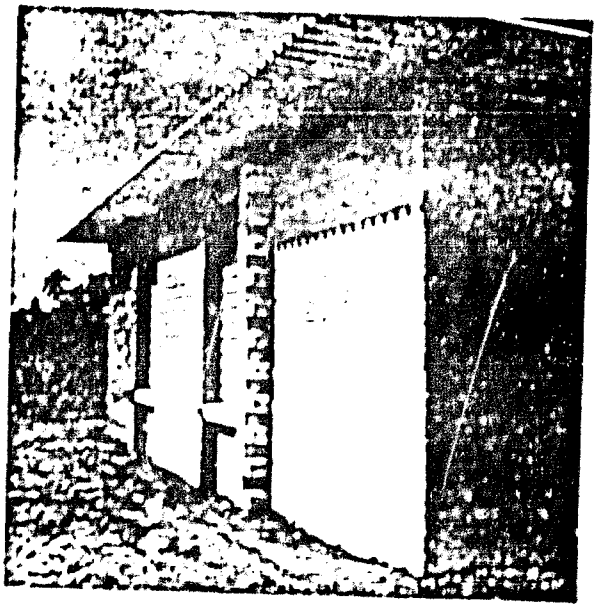
HOUSE #3



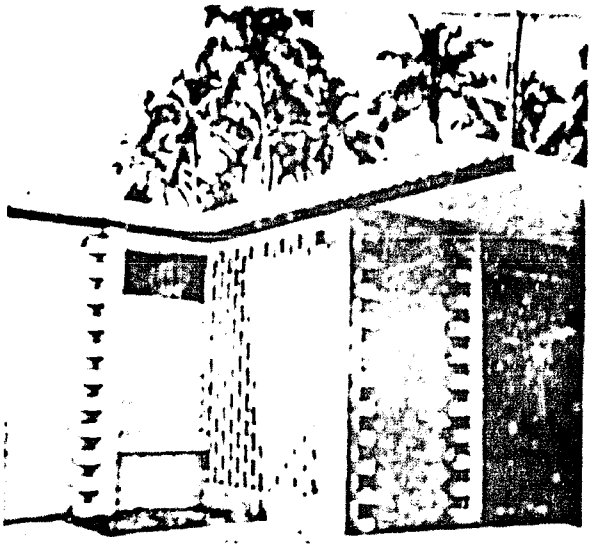
Interior View
Note Grille



Side View

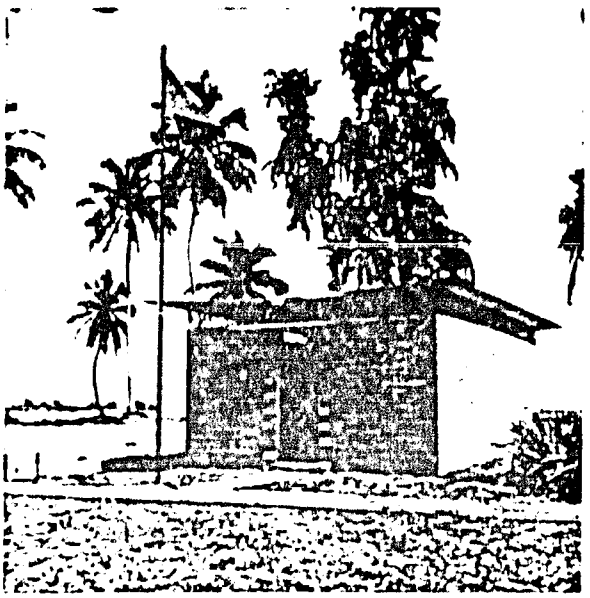


Side Overhang



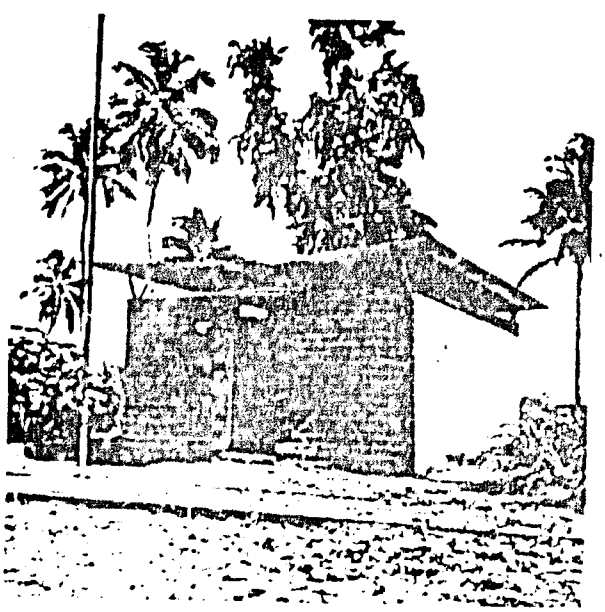
Entry Overhang

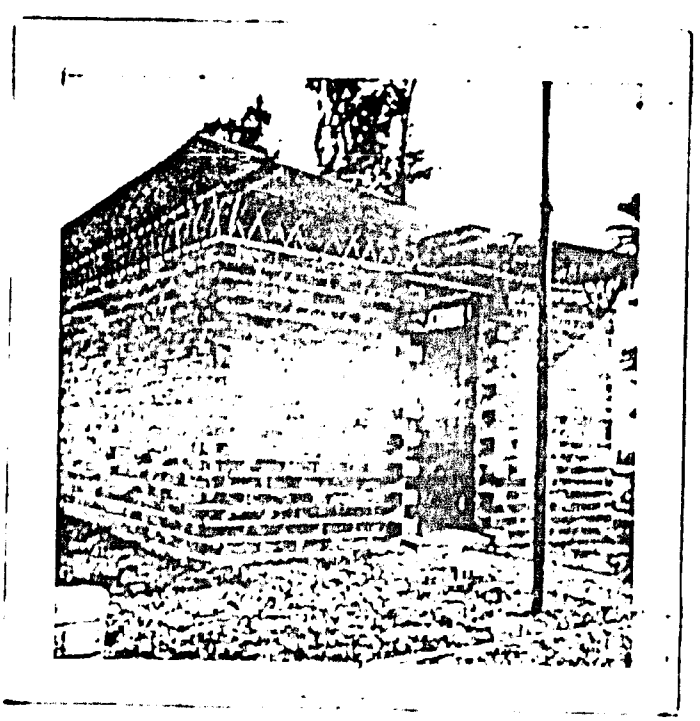
FIG. 7
House # 3



SHELTER #1

SAN JUAN, PUERTO RICO
1960 DEMONSTRATION





Note Split Bamboo
Grille

FIG. 8
Shelter #1

as well as equipment. Self-help input was not included, so savings could ensue. U.S. 1973 costs based on minimum wage was calculated at $3,800.

The Shelter

The Shelter Unit #1, (Fig. 8) made with the same block for walls and floor, included a butterfly white enameled minimum cost aluminum roof, fastened down to an aluminum angle frame with self tapping screws as in the other House #3. Since this unit was to satisfy the capabilities of a minimum income family in the most impoverished countries to pay, it was to cost no more than $100-$200. Thus the use of split bamboo grilles under the roof instead of windows. Two galvanized steel tanks were built into the back wall to collect water from the roof for use in a precast low cost sink and toilet. A septic tank was to be built out of the soil-cement block. (see Fig. 8A below)

The roof was of the lightest gage low cost aluminum, corrugated and textured, white enamelized to last for many years, and not need replacement every 5 years as is the galvanized iron roofing used in many parts of the world.

Other types of roofs are locally available in many countries and now may be considered as effective and low cost as the roofs described above. Asbestos cement roofings of the deep draw type are now available. These were considered for a more recent proposal for the government of Indonesia, for the larger housing units. They might be most economic, since they, as did the deep draw aluminum, span across the whole house without additional framing support.

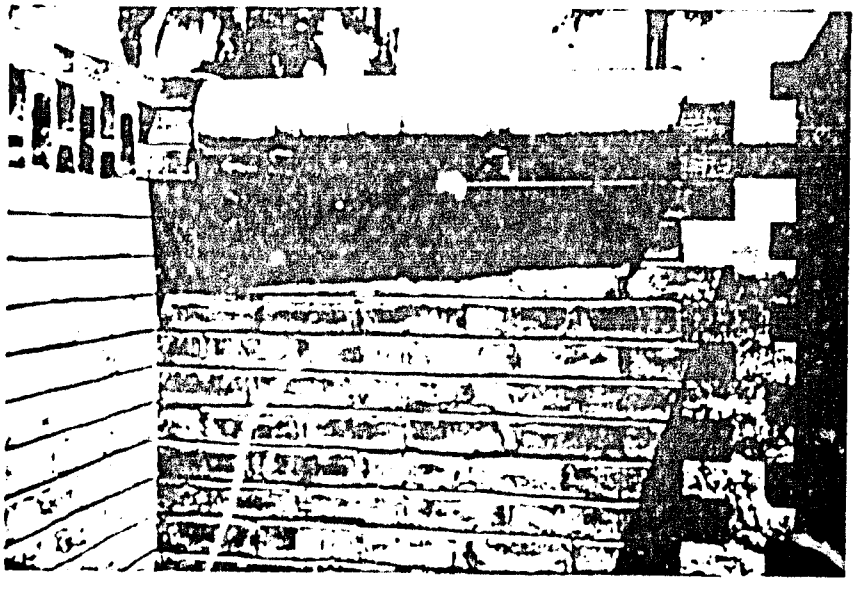


FIG. 8A
Shelter Water Tanks

Another type roof which has been proposed, and is further suggested herein, requiring further design, research and testing, is a small modular Hypar thin shell roof structure of 2 types of units (Fig.9A) as shown. These might be made of ferro-cement by unskilled self-help labor, similar in type to the units that the author designed for his own residence. They were Shotcreted using a dry gun process.

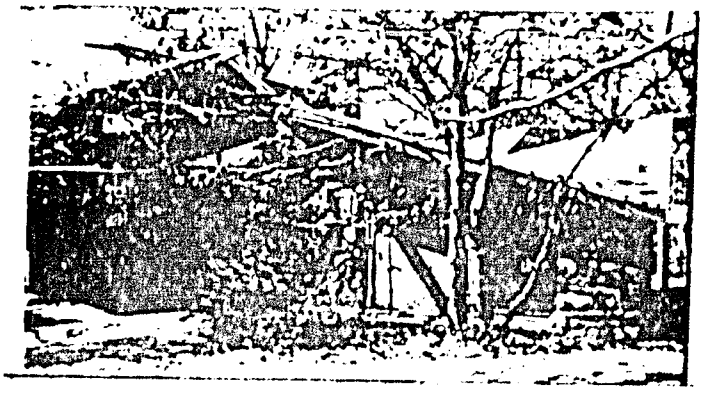


FIG. 9
Bush House Hypar Roofs

'Systems From Tools' - A Concept for Appropriate Technology Development

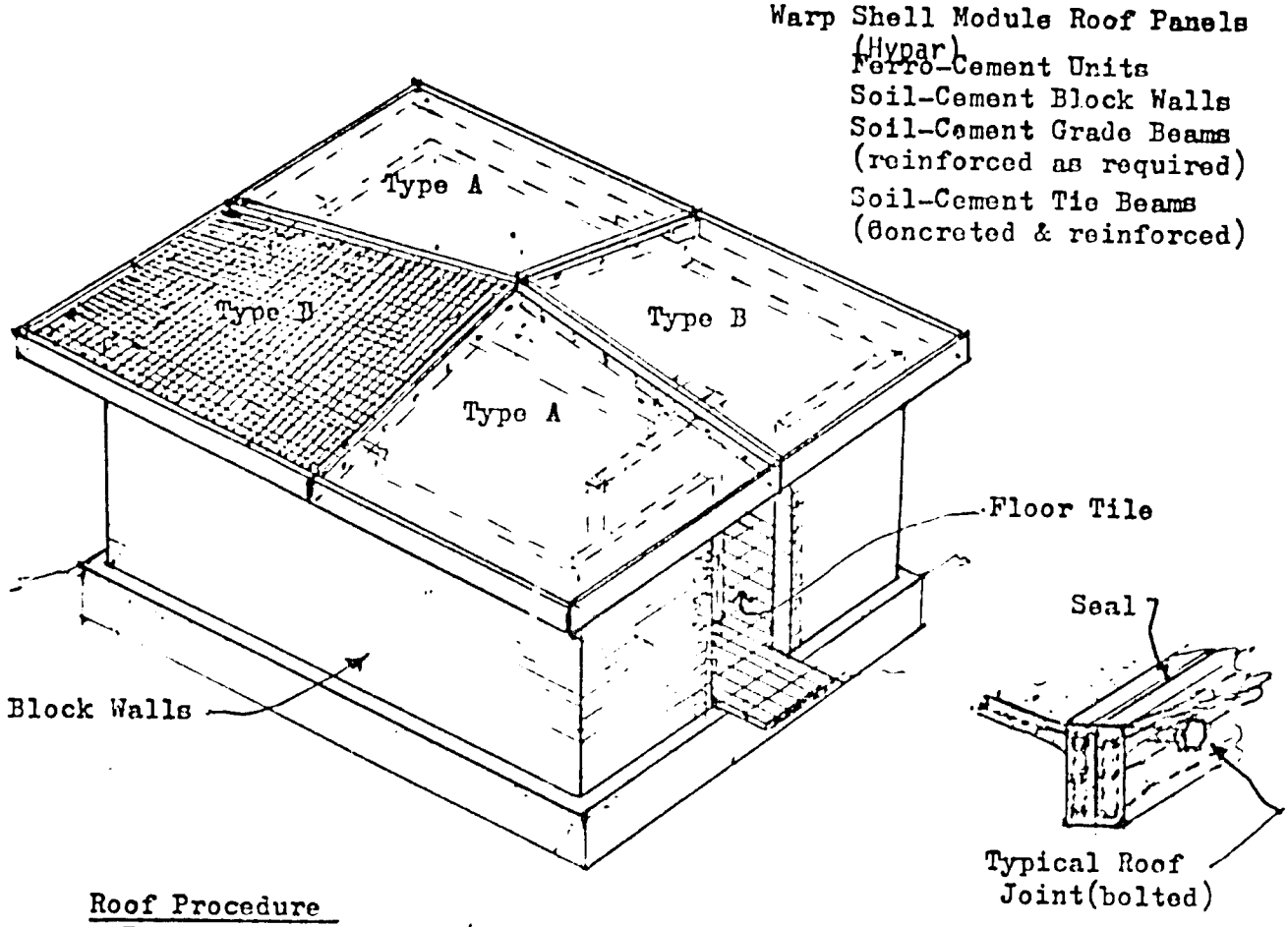
Many years use of the Cinva-Ram Machine suggested that a system of manufacture and creation of jobs was feasible through its local application to housing and community development. Each step in the process of adapting inserts and extending its use revealed the implication of another mini-industry which could feed into the end product of construction (see Fig.10).

Starting with the inserts, a small woodworking craft shop could manufacture the parts to go with each machine. The machines themselves could be sold to communities or small cooperative groups who could be trained to move out to a site and produce block for an individual need, or the machine could be leased by an entrepreneur who could include a short training program with the leasing charges to teach proper and efficient operation of the machines.

Another group might organize to use special block to manufacture sub-assemblies such as lintels and beams which they could sell to individual do-it-yourselfers or to contractors to use in construction.

A mini-manufacturing mobile center, organized by its workers themselves, including a demountable shelter for curing block, along with a cluster of 4 machines, a mixer, plank and covers, water tank and cement, could move to a building site for a cluster of houses for a more efficient production of block and parts. Twelve to sixteen men with this equipment could produce up to 5,000 block in one week; enough for building one complete 2 bedroom house. The soil would be taken from immediately beneath the top organic layer from each surrounding building site and moved to the center of production. Then the cured block would be moved back out to each site once the proper number of each type had been completed. Upon finishing the block for all the houses in the cluster, the equipment and demountable shed would be moved to the next cluster site and so on.

Sketch of Shelter - Proposed Study



Roof Procedure

Precast Frame Edge w/Cage & Mesh
Place on Roof Supports, Bolt &/or Grout Together, Connect to Wall Anchors &
Stucco w/Mortar on Top &/or Under Cover & Moist Cure(7 day minimum)

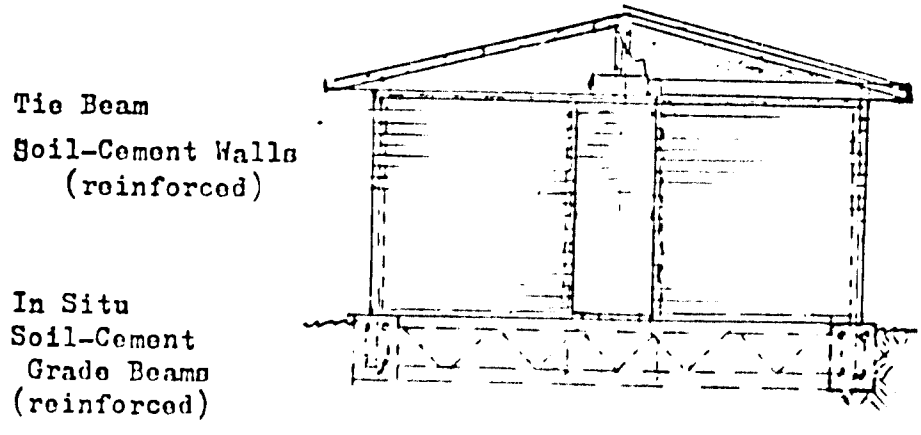


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FIG. 9A
Proposed Test Structure

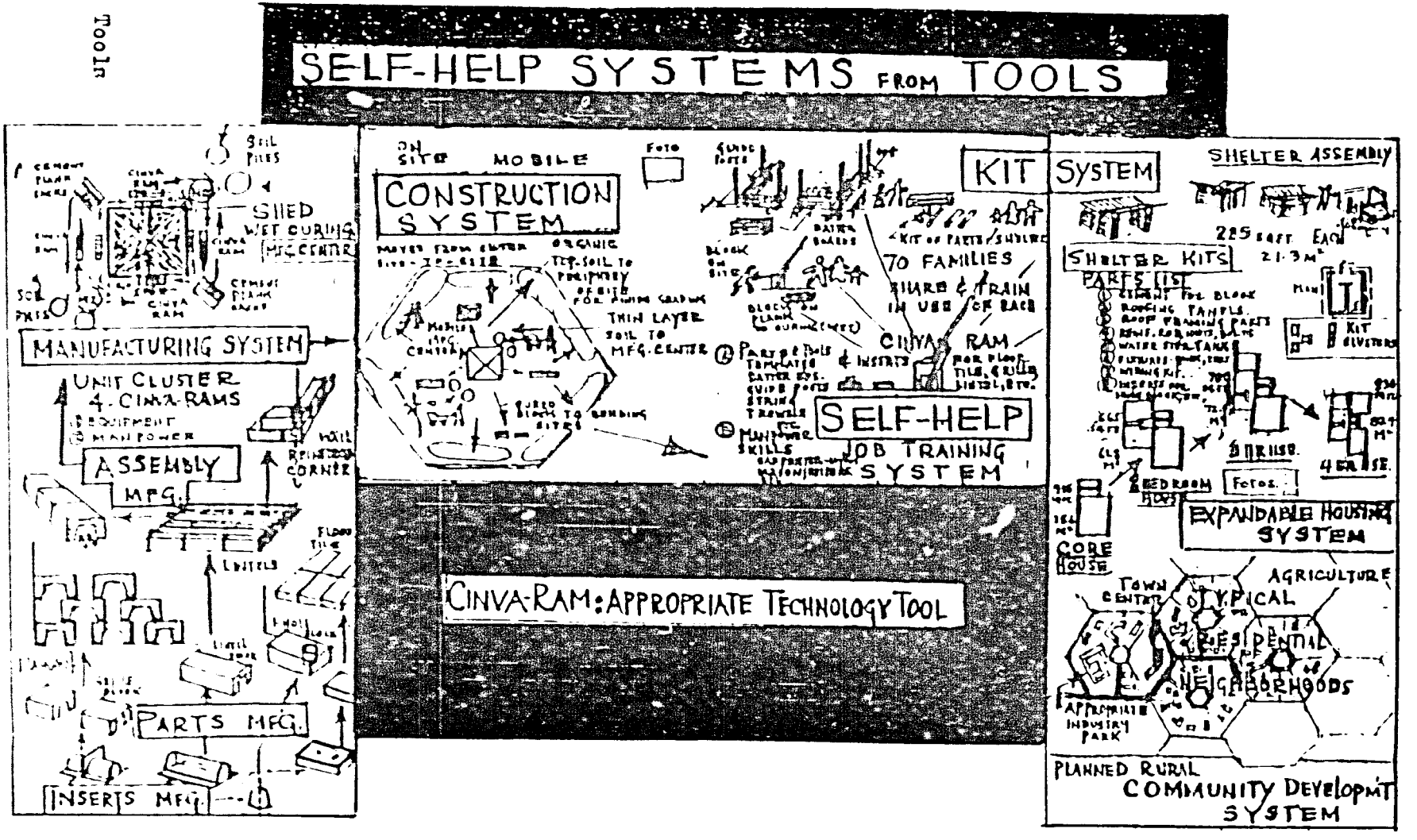

FIG. 10
Systems From Tools

Having studied the economics of low cost planning for low income cooperative communities around the U.S., the author has conceived the hex unit cluster site plan indicated at the lower right hand corner of the Fig.10). This provides minimum road and utility runs as well as an equitable distribution of land for each family, with the central site, temporarily used for manufacture of the block, to become a recreation play area for the children and youth living in the immediate cluster. This suggests another industry-the planning organization which can develop sites in the local or nearby communities. They would to acquire some of their more advanced skills and training through the secondary or college level institutions of the country. By training students with these potential developments in mind, there will be continuity in their development, so they can go right out to participate in their own community growth in a more orderly manner than being thrown into the market place looking for jobs for which they might not be trained.

Two other concepts are included in this system; one the Kit of Parts concept, the other the Expandable House Design concept. The Kit of Parts would be sold to a do-it-yourselfer or self-helper who would acquire all the pieces, equipment and training necessary to build himself the minimum unit shelter. He would have the use of a Cinva-Ram and necessary inserts for a period of time; so many bags of cement, depending on the soil analysis; reinforcing rod, anchors, framing for the roof and roof panels as required for the particular area, tanks for water storage, fittings, pipe and fixtures for sink and toilet connections and a minimum set of parts for surface wiring and electric outlets where electricity is available.

Absolute minimum kits could provide for roofing, framing parts, reinforcing rod and cement along with the Cinva-Ram machine for making a partial shelter; sufficient for making block walls to hold up the roof. The remaining walls might be installed using temporary materials such as slit bamboo mats. A sub-floor of soil-cement might serve until additional income was available to purchase more cement and a further use of the machine. Then floor tile and additional wall block might be made and tied in with the existing permanent structure.

An option for someone with a little more income might be the purchase of two or more kits. These could be combined and tied together with extended roof panels to make larger units (see Fig.11).

The other concept is concerned with the expansion of a house from a minimum core of some 415 sq. ft. forming a complete living core - a basic house. By the addition of 2 or up to 4 bedrooms, this house becomes up to 930 sq. ft. in size. (see Fig. 10)

Thus a great range in size and type of housing becomes available for meeting varied income needs, all buildable with local soil, and providing the potential for satisfying the additional need for jobs and development in areas even where seismic problems exist.

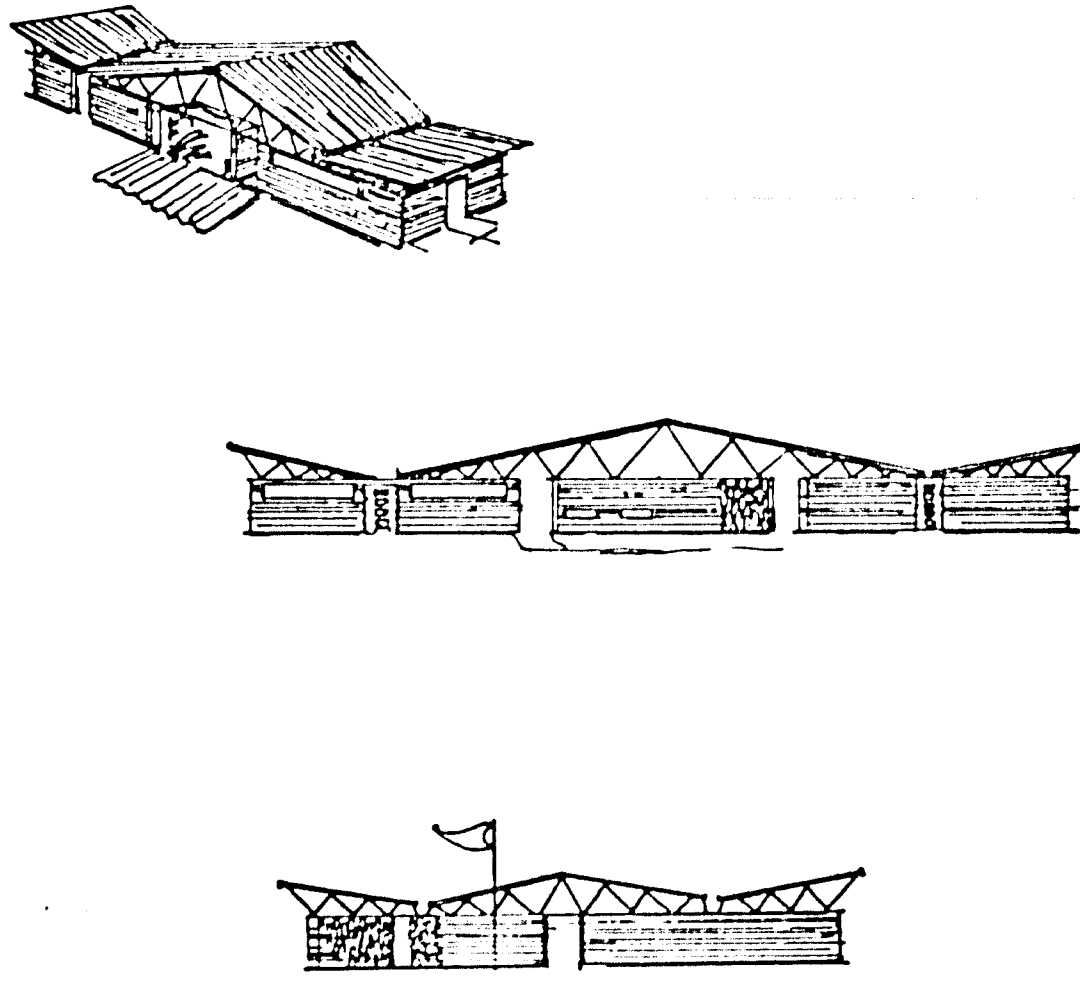

FIG. 11
Kit Expansions

Reasearch Needs

Soil-cement research has been conducted by the Portland Cement Association for many years. They published manuals for laboratory use (3) and field construction (4) on highways, irrigation canals and ditches, runway shoulders and sub-bases. Tables for mixes and test standards have been worked out for optimum mixes. More recently, they have published work on fatigue of soil-cement (5) and thickness design for pavements (6), but no study seems to have been carried out with reinforced soil-cement.

Testing has been performed by the National Bureau of Standards on 6" thick soil-cement block walls made from the Cinva-Ram or similar machine, comparing them favorably with brick and concrete block walls, but no analysis or comparisons seem to have been made with the block laid on its 4" side.

Cost comparisons determined by the author on 4" vs 6" soil-cement block walls indicated a savings of some 35%, since it only takes 2/3rds as many block to cover the same wall area as the 6" wall. So since 4" thick walls are adequate for load carrying capacity for low cost houses, great additional savings could be entailed in the thinner walls. This would be especially valuable at the poverty end of the scale, where permanent materials are looked on only as a dream, and housing is usually thrown together and maintained with any second hand materials available. Therefore, I would like to see comparative strength tests run on the block in the two directions. Ideas for mold inserts for use of reinforcing in the 4" wall have been studied.

Tests on the lintels have never been performed, so variations on the use of soil-cement vs concrete mortar for reinforcing embeddment could well be tested, as could even be embeddments with sand-sulphur. Therefore, a program for testing these would be of value.

In addition, it would be necessary to determine bond strengths and pullout resistance of reinforcing bars in these various materials and soil-cement mixes. To determine the best anchoring techniques, perhaps different types of anchor ends might be tested and experimented with, considering the skills required to make and assemble them, and the need to keep costs down.

For a permanent roof, a program for design, fabrication and testing of Hypar units should be organized, to determine the most economic amount of steel to use for the most effective roof slope. Joining techniques have to be worked out and evaluated, and tests run to determine the best joint method to use for the small test structure to follow.

Lastly there is a need to determine the ability to make and develop a simple reinforced grade beam of soil-cement to resist the serious effects of earthquake loading, when combined with the monolithically tied together walls, tiebeams and roof panels. This is recommended as an alternative to stone or rubble structures or concrete block building.

Finally, there is a need to assemble a composite of all these above parts into a small structure to test for earthquake loadings. It was this program that I had hoped to carry to fruition through NSF funding. It was estimated that the research and test program would run for some 12-16 months; that dynamic loads though desirable to test with, might be simulated with certain static loading. All in all a very exciting program to serve a very great need on an all too shrinking planet.

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LA PROBLEMATICA DE LA CONSERVACION DE EDIFICIOS HISTORICOS DE MAMPOSTERIA TECNICAS CONSTRUCTIVAS Y CODIGOS UTILIZADOS EN ANTIGUA GUATEMALA

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ABSTRACT

This paper points out the problems involved in the preservation of the Monumental Site of La Antigua Guatemala, which is located on a high seismic area. It also analizes the traditional materials and construction methods, the current damages caused by earthquakes in masonary historic building and the restauration technics that are being used by de National Council for the Preservation of La Antigua Guatemala.

ABSTRACT

El presente documento plantea los problemas que conlleva la conservación del Conjunto Monumental de Antigua Guatemala, situada en un área de alta sismicidad. Se analizan los materiales y técnicas constructivas tradicionales, las fallas más frecuentes causadas por los terremotos en edificios históricos de mampostería y los procedimientos de restauración que se están llevando a cabo por parte del Consejo Nacional para la Protección de la Antigua Guatemala.

I. Antigua Guatemala: su importancia histórica, arquitectónica y artística

Antigua Guatemala, fundada en 1543 en el Valle de Panchoy, fue conocida inicialmente como Santiago de los Caballeros de Guatemala. Fue la segunda capital de Centro América durante doscientos treinta años. En 1773, en el apogeo de su desarrollo, la ciudad de Antigua Guatemala fue destruída por un terremoto de gran magnitud. A raíz de esto, y por orden del Rey de España, la ciudad fue evacuada y se trasladó a otro valle, ubicado a 46 Km., en donde se fundó la Nueva Guatemala. Desde entonces se le conoce a la vieja ciudad como La Antigua Guatemala. (1)

El hecho de que la ciudad fuera abandonada ayudó a que, a pesar del tiempo transcurrido desde su abandono, esta conservara su fisonomía original con calles empedradas, amplias plazas y majestuosos edificios entre conventos, iglesias y palacios. Muchos de ellos se encuentran en ruinas a causa de periódicos movimientos sísmicos. Su valor histórico, cultural y artístico radica en que mantiene ciertas características muy especiales ya que es un ejemplo de una ciudad del siglo XVI con su trazo urbano típicamente renacentista; su arquitectura, predominantemente barroca, es un ejemplo de los siglos XVII, XVIII y XIX que constituye el testimonio de un pasado que parece haberse detenido en el transcurso del tiempo.

Sólo en el área del casco histórico de la ciudad existen más de 50 monumentos de primer orden entre iglesias, conventos y palacios. Su riqueza en lo referente a arquitectura doméstica, así como en cuanto a pintura e imaginería es incalculable, lo que la hace un centro cultural e histórico de mucha importancia.

En 1965 Antigua fue declarada por la Asamblea General del Instituto Panamericano de Geografía e Historia, Ciudad Monumento de América y desde 1979 forma parte del listado de Patrimonio Mundial de UNESCO.

En 1969 el Congreso de la República de Guatemala emitió una Ley Protec-

tora de Antigua, creando a su vez al Consejo Nacional para la Protección de la Antigua Guatemala (CNPAG), como entidad técnica encargada de velar por el rescate y conservación de la ciudad como centro histórico y artístico, declarándola área de conservación. Desde entonces un equipo, profesional y técnico, se dedica oficialmente a la delicada y enorme tarea de salvar Antigua para la posteridad.

2. Antigua: su problemática como Centro de Conservación en un área altamente sísmica

La conservación de la ciudad implica tareas bastante complejas, entre las que, por su importancia, podemos mencionar: mantener el estilo arquitectónico original de la ciudad, evitar su destrucción por la acción devastadora del hombre en nombre del "progreso", así como buscar fórmulas efectivas para hacer a los edificios históricos más resistentes a los terremotos. Estas son algunas de las preocupaciones del CNPAG.

La actividad sísmica constituyó, desde la fundación de Antigua, un desafío para los constructores. Por diferentes crónicas de la época se sabe que la ciudad ha sufrido, desde el año 1500 hasta nuestros días, aproximadamente 40 sismos de más de 5.5 grados en la escala de Richter, siendo 7 de ellos de magnitud 7.5 a 8.5 grados [2], lo que equivale aproximadamente a una intensidad, en la escala de Mercalli Modificada, de X y XI grados.

Guatemala, por su ubicación geográfica, ha sido afectada por el continuo movimiento de las placas tectónicas de América, del Caribe y del Coco, que ha dado por resultado la formación de cadenas volcánicas y de varios sistemas de fallas geológicas que atraviesan el país. Pariódicamente estas fallas se activan liberando energía, lo que da origen a movimientos telúricos. Así mismo, pero en menor proporción, la actividad volcánica, bastante frecuente en la zona, ha sido otro factor sísmico de carácter considerable. Temblores de escasa magnitud ocu-

rren con cierta frecuencia. En Guatemala, su número sobrepasa a los dos mil anualmente, y en cierta forma pueden afectar la durabilidad de los edificios históricos.

A finales del siglo XVII y durante el siglo XVIII tienen lugar varios terremotos de gran magnitud en la región, siendo los más destructores los de San Miguel en 1717, San Casimiro en 1751 y Santa Marta en 1773, que obligaron finalmente al traslado de la ciudad de Antigua hacia el Valle de la Ermita donde se fundó la Nueva Guatemala. Ya en el presente siglo, la Antigua se ha visto afectada por nuevos sismos de gran intensidad. En 1917 y en 1976, tienen lugar dos terremotos, de aproximadamente 8 grados Richter, que destruyeron nuevamente la Ciudad. Este último ha sido uno de los más intensos registrados, con una liberación de energía 32 veces mayor que el terremoto de Friuli, Italia, en 1977.(3)

Debido a que el interés por la conservación de Antigua es relativamente reciente (El CNPAG y la Ley Protectora tienen únicamente 10 años de haber sido creados y 6 de estar funcionando) los métodos de restauración y consolidación se han ido desarrollando paulatinamente, teniendo que adaptarse a la realidad del medio y a las posibilidades técnicas y financieras con que se cuenta. En los últimos 40 años, se han realizado diferentes tipos de intervenciones en los monumentos, muchas de ellas poco afortunadas. Estas van desde el uso de técnicas constructivas y materiales modernos hasta las de tipo tradicional.

Con ocasión del terremoto de 1976 se pudo hacer una evaluación de las mismas, habiéndose descartado varios sistemas y puestos a prueba otros.

Son varios los factores que influyen y deben tomarse en cuenta en la conservación de edificios históricos en áreas sísmicas. Al considerar este tipo de edificaciones, debe verse el fenómeno como algo dinámico, no en términos estáticos, ya que están involucrados, a la hora de un sismo; velocidades, aceleraciones, empujes laterales, masas,(3) así como otros factores que veremos más adelante. De la capacidad que tenga el edificio de absorver esa cantidad de energía li

berada, que se traduce en distintas fuerzas, dependerán los daños que el mismo sufra. En esto tiene que ver mucho el estado del edificio. La escala de Mercalli Modificada, basada en datos bastante subjetivos, le da mucha importancia a cuestiones como el mantenimiento del edificio, la calidad de la mano de obra y materiales usados, así como la calidad de reparaciones que se le hayan realizado anteriormente al edificio. Por lo tanto es necesario analisar los materiales y técnicas constructivas tradicionales utilizadas en el lugar

Antigua se ha convertido en los últimos años en un gigantesco laboratorio, a escala natural, donde se prueban constantemente nuevos materiales y técnicas, con el afán de conservar un legado cultural para las generaciones futuras de la humanidad.

3. Materiales tradicionales utilizados en la construcción y problemas más frecuentes

El análisis de los materiales que han sido utilizados tradicionalmente en Antigua en la construcción, es necesario para evaluar los procedimientos que pueden ayudar a preservar lo existente y evitar futuros daños en las edificaciones.

Podemos mencionar como los más utilizados en la época colonial los siguientes:

a. Piedra rústica y labrada. Usada en muros, dintales, jambas y bases de pilastras de madera. También se utilizó como piso en interiores y exteriores.
b. Ladrillo de barro cocido. Utilizado en muros, columnas, arcos, etc.
c. Mortero de arena amarilla, tierra o talpetate, cal y algunos otros aglutinantes como clara de huevo, miel y leche según crónicas de la época.
d. Adobe usado en levantado de muros y rellenos.

e. Tapiales, o secciones de muros, que se hacían formando un encofrado de madera que luego se rellenaba con lodo de talpetate, separándose los diferentes rellenos por rafas o soleras de ladrillo de barro cocido.

f. Bahareque. Se le llamó así a una estructura de cañas, amarradas con cintas de cuero, que luego se rellenaba con lodo o adobe de canto. Se utilizó para hacer tabiques divisorios especialmente en segundos niveles.

g. Baldoza de barro cocido. Fue utilizada para terrazas españolas, bóvedas, arcos, dinteles de puertas y ventanas. También se utilizó como piso.

h. Madera, utilizada principalmente en pilastras, dinteles, artesonados y terrazas españolas. También fue utilizada como estructura de tabiques de adobe.

i. Teja de barro cocido, utilizada para cubiertas.

La mayor parte de construcciones en Antigua fueron de mampostería, aunque en los muros se encuentran generalmente diversos materiales mezclados: piedra y ladrillo pegados con mortero de cal, bloques de tapial ó adobe, formando masas muy heterogéneas resistentes a la compresión, no así a la tensión.

Con el transcurso de los años, los muros han ido perdiendo consistencia. Esto se ha debido principalmente al proceso de deterioro de los morteros que, con el tiempo, tienden a perder sus cualidades aglutinantes, dando por resultado el desprendimiento de los distintos componentes. Este proceso se acelera cuando están sujetos a la erosión del agua y el aire, así como la destrucción causada por hongos, vegetales e incluso insectos, como sucede frecuentemente en los muros de adobe y tapial.

En la escala de Mercalli Modificada se menciona también la calidad de los morteros como un factor que debe tomarse en cuenta al evaluar un edificio histórico. Posiblemente este sea más importante incluso que la calidad de la mano de obra utilizada, pues como ya se mencionó, a través de los años pierde sus capacidades aglutinantes, creando zonas débiles en los muros, lo que fué reportado como una de las principales razones del colapso de muchos edificios históricos

durante el terremoto de Montenegro (Yugoeslavia) en 1979[3]. La reposición de los morteros y las inyecciones con material expansivo son soluciones adecuadas en muchos casos.

En lo que respecta a cubiertas y entrepisos de mampostería la situación es la misma. Aquí influyen también la humedad y el agrietamiento causado por terremotos anteriores o por sismos de poca intensidad. Las reparaciones hechas en épocas pasadas, por lo general de mala calidad, crean zonas débiles que fácilmente vuelven a fallar a la hora de un nuevo terremoto.

El problema en las cubiertas con estructura de madera, lo constituyen la humedad y los insectos, especialmente la polilla que la ataca fácilmente.

Por los materiales utilizados, los sistemas constructivos están basados en la gravedad. Las distintas cargas, son transmitidas por sucesivas compresiones hasta llegar al suelo, donde son absorvidas. Estáticamente no existe problema, pero como ya se indicó, la situación varía cuando se transmiten al edificio, a través de los cimientos, aceleraciones y empujes verticales y horizontales causados por las ondas sísmicas.

La arquitectura antigueña

Se ha mencionado cómo la actividad sísmica ha determinado desde sus inicios las características arquitectónicas de la Antigua Guatemala. Analisaremos ahora los tipos constructivos más representativos del lugar.

Por patrones de diseño, uso de materiales y sistemas constructivos utilizados, dividiremos la arquitectura antigueña en dos grupos:

4.1 Arquitectura doméstica

4.2 Arquitectura civil y religiosa

4.1 Arquitectura doméstica (casas de habitación)

Las casas de habitación desarrollaron un estilo típico, no sólo en -

cuanto a la distribución de los ambientes, sino también en cuanto a materiales y técnicas utilizadas en su construcción. Basados en el concepto de un patio central, alrededor del cual se desarrollan corredores que comunican con las habitaciones, este patrón se mantiene sin mayores variantes durante la época colonial. Es interesante el cambio que sufren las alturas de los muros, así como los espesores de los mismos, por las experiencias sísmicas que se tuvieron con el transcuros de los años.

Se ha dividido la arquitectura doméstica en tres períodos que reflejan los cambios más significativos ocurridos en las edificaciones, desde la época colonial, hasta nuestros días.

a. Construcciones del siglo XVII y principios del XVIII

Las casas son de un sólo nivel y tienen una altura de 5 ó más metros, siendo las paredes de un espesor aproximado de 0.60 m. Los techos son de madera cubierta con teja de barro y es típico el alero hacia el frente. Los materiales usados en los muros son la piedra y el ladrillo pegados con mortero de cal. El adobe y el bahareque fue utilizado sólo en construcciones de un estrato social y económico bajo, no así en las capas medias y altas.

b. Construcciones del siglo XVIII tardío y principios del XIX

Conforme se adquiere consciencia de la actividad sísmica del valle, las alturas de las casas tienden a reducirse y los espesores de muros aumentan. Un detalle típico de esta etapa es que el alero empieza a sustituirse por una moldura corrida, en donde remata el techo de teja. Los materiales más usados en los muros siguen siendo el ladrillo y la piedra pegados con mortero, así como el adobe en construcciones de baja categoría social. La tradición de la casa de un nivel se mantiene.

c. Construcciones del siglo XIX y XX

El descubrimiento del concreto armado y las influencias arquitectónicas

neoclásicas europeas, hacen desaparecer visualmente los techos inclinados, recubiertos con teja, al ponerse de moda un pretil que remata las fachadas en su parte alta. Se abandona casi por completo el uso de la piedra en la construcción de muros, sustituyéndose por el ladrillo y el concreto lo que reduce su espesor. Por economía, el adobe y el bahareque empiezan a cobrar importancia en las construcciones de niveles sociales medios e incluso altos. En muchos casos los gruesos muros se recortan, dejando sólo en la parte baja el espesor original, construyéndose el resto de bahareque, mucho más delgado y ligero, por lo que el muro da la impresión de tener pequeños contrafuertes.

En las cubiertas se empieza a sustituir la teja por lámina de zinc y, ya entrado el siglo XX, se ponen en boga las losas de concreto armado, que cambian radicalmente los patrones de diseño originales.

Los materiales y técnicas constructivas modernas, utilizados en este período, ofrecen soluciones estructurales adecuadas, pero por lo general van en detrimento del estilo arquitectónico de la ciudad, iniciándose además la construcción de casas de 2 ó más niveles. El concreto armado es utilizado en muros, losas e incluso en la hechura de arcos, bóvedas de cañón y cúpulas.

El terremoto de 1976 determinó en gran parte el uso que posteriormente se ha hecho de los materiales tradicionales de construcción. Miles de casas de adobe y otros materiales tradicionales, técnicamente mál construídas, se destruyeron durante el mismo. Esto hizo que se les considerara materiales no seguros para construir. Desde entonces su uso se ha reducido enormemente. En su lugar, el block de pómez y el ladrillo con refuerzos de concreto armado, ha cobrado gran auge, lo que se traduce en un tipo de construcción más seguro, pero mas costoso. En el caso de Antigua, deberá utilizarse de una manera que no afecte el estilo arquitectónico de la ciudad.

4.2 Arquitectura civil y religiosa

La arquitectura civil y religiosa que comprende palacios, colegios ma-

yores, iglesias, conventos y monasterios, también fue determinada por los terremotos. "Al menos en dos sentidos marcaron su arquitectura. Por un lado, como ha sido señalado casi unánimemente, los arquitectos fueron buscando soluciones que hicieran a las construcciones más resistentes a los terremotos: tuvieron poca altura, los muros se hicieron cada vez más gruesos, las torres cada vez más bajas. En general, la sensación que dan los volúmenes arquitectónicos es de pesadez. Por otro lado, es raro el edificio que constituye una unidad cronológica y arquitectónica. Los constantes terremotos obligaron a reconstruir y rehacer, pero algunas veces se aprovechaban partes que habían resistido; ello hace casi imposible o muy difícil determinar la exacta cronología de la arquitectura." (4) En este tipo de edificaciones es característico el uso de bóvedas, en techos y entrepisos, y de cúpulas de muy variado tipo.

En cuanto a los materiales, la mampostería fué el más utilizado. Los muros de piedra, ladrillo y mortero, eran generalmente revestidos de repello y estuco. En algunos casos, las fachadas de iglesias y palacios fueron recubiertas de piedra labrada.

En el levantado de muros se hizo frecuentemente uso del tapial. Este se hacía formando un encofrado de madera que luego era rellenado con lodo de talpetate. Una vez seco, la madera era retirada. Se formaban bloques de aproximadamente 0.80 y 1.80 y por el total del espesor del muro, que es variable. En otros casos los bloques tienen varios metros de largo siendo su altura no mayor de un metro. Antes de hacer un bloque de tapial sobre otro, se colocaban varias hiladas de ladrillo, a manera de refuerzo, formando una especie de solera. Como se comprenderá, este tipo de levantado de muros era rápido y económico, máxime si se toma en cuenta las enormes masas que conforman los muros. Este procedimiento fue muy utilizado en muros o bardas circundantes. En algunos casos alcanzan hasta 5 mts. de altura, hechos totalmente de bloques de tapial. Como es de suponerse, este tipo de muros sufrió muchos daños con los terremotos.

Al igual que sucedió con la arquitectura doméstica, los espesores de

muros en la mayor parte de edificaciones fue aumentando, conforme se tenían las constantes y desastrosas experiencias sísmicas. Este tipo de edificaciones, llegan a tener muros de más de 2.00 metros de espesor, lo que da origen a volúmenes muy interesantes. A la par de esto surgen grandes y masivos contrafuertes, de muy variadas formas, utilizados para reforzar los muros y hacerlos más resistentes a los terremotos. En muchos casos esta solución resultó adecuada, no así en otros en donde los contrafuertes funcionaron como arietes, dañando al edificio.

Tanto en la arquitectura civil como en la religiosa, encontramos edificaciones de dos niveles. Tal es el caso de los palacios de gobierno y la mayoría de conventos. El tipo de construcción es el tradicional, siendo los entrepisos y en muchos casos también los techos, bóvedas rebajadas hechas de baldoza de barro y mortero de cal, habiéndose utilizado también piedra pómez para reducir su peso.

Por lo general las fachadas de las iglesias, por su forma y dimensiones, son enormes masas que, a la hora de un sismo, trabajan independientemente del resto del edificio. Al tener distinta frecuencia de oscilación se separan, golpeando y provocando daños al resto del mismo. Este fenómeno se ha producido en edificios como el Palacio del Ayuntamiento y el Palacio de los Capitanes Generales, en donde las arquerías de las fachadas, se separaron del conjunto, abriéndose grietas a lo largo de las bóvedas que las unían.

En la mayor parte de los conventos con arquerías en el segundo nivel, cuyas bóvedas habían sido destruídas por anteriores sismos, sufrieron durante el terremoto de 1976 un colapso total ya que habían perdido los elementos que las conectaban con el resto del edificio.

Un elemento característico de la arquitectura antigueña son las chimeneas. Se encuentran tanto en edificios civiles y religiosos, así como en casas de habitación. Este elemento, generalmente de forma octogonal, sirve de cubierta del área de cocinado y funciona como una campana que ayuda a evacuar el humo de

la habitación. En su parte alta está rematado por una linternilla que tiene orificios por donde sale el humo. Su forma tan dinámica y estable, lo ha hecho un elemento muy resistente a los terremotos, conservándose muchas de ellas en buen estado.

Existen otros factores que afectan el comportamiento sísmico de los edificios históricos. Entre estos están su masa, su rigidez, su período de vibración, su capacidad de absorver energía, su resonancia, su estabilidad, su geometría estructural, la continuidad de su masa estructural y su resistencia.(3) Estos factores dependen en gran parte de la condición general de la estructura, del mantenimiento que se le ha dado al edificio y como ya se indicó antes, de la calidad de las reparaciones que se la hayan hecho en el pasado.

5. Comportamiento estructural de los edificios históricos

Los muros y construcciones en ruinas nos proporcionan lecturas de los distintos esfuerzos a que se vieron sometidas las estructuras a la hora de un terremoto. El comportamiento de los distintos edificios varía entre otras cosas, por el material que lo constituye, su forma y proporciones y el tipo de suelo en que se localiza el edificio.

No está por demás recordar que las edificaciones en Antigua fueron diseñadas para una zona altamente sísmica pero con materiales no aptos para soportar adecuadamente esfuerzos de tensión o flexión. En el estado actual de muchos edificios en ruinas, el desplome de bóvedas, arcadas y de elementos conectores, que hacían del edificio una unidad, ha dado por resultado que muchos elementos hayan quedado aislados del resto, lo que los hace menos resistentes a los movimientos sísmicos.

Se ha comprobado que la dirección de las ondas sísmicas tienen distintos efectos destructivos, según la posición del edificio.

La rigidez del mismo y el tipo de suelo sobre el cual se haya edificado, van a influir también en su comportamiento estructural. Los edificios históricos de mampostería son generalmente rígidos por lo que la unión de sus elementos es muy importante.

La frecuencia predominante de las ondas sísmicas y la frecuencia natural del edificio y del terreno sobre el que está situado son cuestiones que deben ser analisadas. El edificio podrá vibrar en una cierta frecuencia de acuerdo a su rigidez y forma y si ocurre una resonancia dinámica, los daños pueden ser más graves. Generalmente se considera que los edificios rígidos están más seguros si se encuentran situados en terrenos suaves de cierta profundidad. (3) También se ha observado que un edificio de mampostería puede resistir algunos temblores de gran intensidad, pero que las vibraciones de larga duración los afectan más.

En el caso de Antigua nos encontramos con un terreno de aluvión formado por sucesivas inundaciones en el valle. Su composición es arenisca y de piedras de mediano tamaño. Su nivel friático puede oscilar entre 4 y 6 metros de profundidad, por lo que existe cierto peligro de licuefacción durante un terremoto. Feilden recomienda un espectro sísmico para los sitios con edificios históricos ya que puede ayudar a predecir mejor el comportamiento de los edificios dependiendo de la conformación del suelo.

Analisaremos seguidamente algunas de las fallas y problemas que se presentan más frecuentemente en este tipo de edificaciones y en sus elementos componentes.

a. Fallas en muros

Por lo general encontramos dos fallas típicas en muros ocasionadas por esfuerzos de corte. Una es la falla a 45° en un sentido o formando una x. Estas aparecen generalmente en las partes más débiles del muro donde existen vanos de puertas y ventanas. Son causadas por las tensiones y compresiones producidas,

en el edificio, por las ondas sísmicas.

En vanos de ventanas y puertas encontramos los cortes a 45° por lo general en los vértices superiores y es común encontrar el dintel o la clave caída, fuera de su lugar.

En las esquinas, el empuje de los dos muros que las forman, frecuentemente ocasiona fallas de corte a 45°. Esto hace separarse a la esquina, como un bloque, hacia la parte exterior del edifico, causando un corrimiento de arriba a abajo y de dentro hacia afuera.

Otra falla muy común es el corte horizontal a lo largo de los muros. Por lo general este corte aparece en la parte baja del muro, debido a su oscilación y provoca muchas veces su falla por volteo. Se ha podido comprobar, que en muchos casos este tipo de falla está relacionado con la forma en que los muros eran construidos. El muro, hecho de piedra y mortero, era nivelado cada cierta altura con hiladas de ladrillo, sobre las cuales se continuaba luego el levantado de piedra. Es en las áreas de ladrillo, de por sí un material más frágil, donde aparece con frecuencia este tipo de grieta, ya que es allí donde pierde su continuidad el muro.

En esquinas y uniones entre muros, se presentan corrientemente fallas verticales, ocasionadas por la falta de anclajes adecuados entre una y otra. Cuando son sometidas a la acción de un sismo, las paredes tienden a trabajar cada cual en forma diferente y si no existe una liga adecuada, tienden a separarse verticalmente en su punto de unión.

De esa misma manera encontramos que muchas fachadas, principalmente en iglesias, trabajan independientemente del resto del cuerpo del edificio. Por lo general, la tendencia es a separarse y golpear el edificio como un ariete, ocasionando graves daños al mismo, teniendo la fachada mucha tendencia a fallar por volteo.

b. Fallas en columnas y arquerías

En las edificaciones en ruinas existentes en Antigua, es muy corriente encontrar columnas y arquerías que han quedado aisladas, debido al colapso de arcos, bóvedas o techos que servían de elmentos conectores con el resto del edificio. Al desaparecer estos elementos, no sólo la estructura pierde continuidad - sino que las columnas ya no soportan las cargas de compresión que dichos elementos les transmitían y para las que fueron diseñadas. Al verse afectadas por un sismo y vibrar, estas columnas tienden a fallar por corte horizontal y consecuentemente por volteo. Hay que tomar en cuenta las aceleraciones que se producen - en elementos tan masivos y esbeltos.

c. Fallas en arcos y bóvedas

En arcos y bóvedas encontramos fallas muy similares. Si consideramos que la bóveda de cañón es una sucesión de arcos, esto lo explica claramente. Por lo general las grietas aparecen 45° en los arranques, provocando en los arcos la caída de la clave y en las bóvedas frecuentemente el colapso de las mismas. Otra falla muy común en bóvedas, es una grieta que surge al centro de la misma y que luego la recorre longitudinalmente, provocando muchas veces su derrumbe. Estas fallas surgen generalmente como consecuencia del oscilamiento y separación de las paredes que las soportan.

d. Fallas en cúpulas, chimeneas y torres de campanarios.

Las cúpulas y las chimeneas, son elementos muy dinámicos que soportan bastante bien los esfuerzos de flexión y torsión a que son sometidos a la hora de un terremoto. Sin embargo, el hecho de estar colocados en la parte más alta de las edificaciones hace que sufran las aceleraciones más fuertes que el sismo ocasiona en el edificio, por lo que sufren algunos daños.

En las cúpulas encontramos fallas que las circulan horizontalmente en la parte superior del arranque así como otras perpendiculares al mismo. Muchas

veces el movimiento las desplaza varios centímetros de su base, lo que en algunos casos provoca el colapso.

En cuanto a las chimeneas, por lo general de base octogonal, los tipos de fallas más frecuentes son la vertical ó a 45°. La vertical generalmente aparece en los vértices de unión de los distintos planos que conforman la campana de la chimenea. Muchas veces su colapso se debe a la destrucción de los elementos, arcos o paredes que las soportan. Es muy corriente encontrar las linternillas, que rematan tanto chimeneas como cúpulas, falladas horizontalmente en su base y rotadas sobre su propio eje.

Los campanarios de las iglesias, a pesar de no haber desarrollado mayor altura en la Antigua, sufrieron muchos daños por su ubicación en la parte alta de los edificios. Por lo general, su período de oscilación es diferente al resto del edificio. Esto hizo que la mayoría de campanarios se destruyeran o resultaran seriamente dañados al ser afectados por un terremoto.

6. Códigos de construcción utilizados en Antigua

La mayoría de códigos de construcción se han desarrollado para edificaciones que incluyen materiales y sistemas constructivos capaces de absorver los empujes laterales, ocasionados por los sismos. El consenso de los expertos es que dichos códigos no se adaptan a los edificios históricos, por sus características especiales, que ya hemos analisado. Ahora bien, el hecho de que los edificios históricos no puedan llenar los requisitos de los códigos oficiales utilizados en la actualidad no es razón suficiente para condenarlos a desaparecer o no ser utilizados. Como ya se ha visto, existen diversos factores que, estudiados más a fondo, pueden dar respuestas a muchos de los problemas que se tienen actualmente en la conservación de los edificios históricos.

7. Procedimientos de restauración usados por el CNPAG

Los métodos de restauración utilizados en la Antigua, han variado en los últimos años, principalmente por las experiencias tenidas durante el terremoto de 1976. Esto originó que algunos procedimientos se descartaran y en su lugar se utilizaran otros en busca de nuevas soluciones a los problemas que se presentaron.

Nos hemos referido ampliamente a los factores que intervienen en los daños que los terremotos ocasionan a este tipo de edificios y a las fallas más comunes que aparecen luego de un sismo de cierta intensidad. Ahora nos referiremos brevemente a los criterios y métodos de restauración que el CNPAG está utilizando en la Antigua.

Basados en que los materiales tradicionales no soportan adecuadamente los esfuerzos laterales producidos por los sismos, se le está dando prioridad al refuerzo de los edificios, principalmente en el sentido horizontal.

Se utilizan anillos de concreto reforzado y cables de acero en forma de tensores para amarrar en la parte superior los distintos elementos del edificio. Estos anillos son luego unidos a la cimentación por medio de elementos verticales. Con esto se logra que el edificio se comporte como una unidad durante un sismo.

Como se comprenderá, este tipo de intervención es muy costosa, por lo que tomará muchos años reforzar la totalidad de edificios existentes en La Antigua. Actualmente está por terminarse un trabajo de este tipo en la iglesia de La Merced y se está iniciando uno similar en el Palacio del Ayuntamiento.

En cuanto a los muros, bóvedas y demás elementos de mampostería, el criterio de restauración ha sido utilizar los sistemas y materiales tradicionales con ciertas variantes. Entre estas está la utilización de morteros con cemento. En casos de grietas, se elimina el material suelto. Luego este se repo-

ne y se hacen inyecciones a presión de morteros con material expansivo, generalmente hecho de limadura de metal. De la misma manera los arcos y bóvedas que son intervenidos, se construyen como se hacía originalmente. Algunas bóvedas han sido reforzadas con una delgada fundición de concreto armado en la parte de arriba, para aumentar su resistencia. Las uniones entre elementos así como las esquinas, también suelen reforzarse, ya que se ha comprobado que son puntos críticos durante los terremotos.

Feilden recomienda que la resistencia del concreto armado utilizado en estos casos sea similar a la de la mampostería, por lo que deben utilizarse agregados más suaves y proporciones más pobres.(3)

Esto está basado en múltiples experiencias, en donde fueron utilizados como refuerzo, elementos mucho más resistentes que el resto de la construcción. En muchos casos, estos elementos fueron causantes de graves daños en el edificio, pues su comportamiento estructural fue muy diferente al del resto de la edificación.. Tal es el caso de las corbatas o grapas de concreto, cuyo uso en la reparación de grietas fue descontinuado.

En el caso de muros, columnas y arquerías que han quedado aisladas del resto del edificio y que tienen por lo tanto mucha tendencia a oscilar y fallar por volteo, se piensa usar una nueva modalidad, hasta ahora no utilizada en la Antigua. La solución consiste en estabilizar los elementos con cables de acero verticales que van sujetos en la parte de arriba a una plancha de acero y anclados al suelo con una fundición de concreto. Estos cables absorverían los esfuerzos de flexión que provocara el sismo. Otra solución a este problema es rehacer los elementos conectores perdidos, pero en muchos casos daría lugar a la reconstrucción casi total del edificio, lo que además de costoso va contra los criterios de restauración de la Carta de Venecia.

Mencionaremos por último y no por eso menos importante, la necesidad de investigar la cimentación de los edificios. En muchos casos su deterioro pro

voca asentamientos que pueden dañar gravemente el edificio. Desgraciadamente este tipo de trabajo también es muy costoso, por lo que no ha sido posible llevarlo a cabo en la Antigua hasta la fecha.

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INVESTIGACION DEL ADOBE EN EL PERU

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ABSTRACT

This document presents a brief description of the reasons and objectives for which Adobe is investigated in Peru, the principal programs realized, the institutes that have participated in the research. It indicates the benefits obtained and the tasks of technological research carried out.

Finally, it includes the perspectives of the research and general comments about the developed heretofore.

RESUMEN

Se presenta una breve descripción de las razones y objetivos por las que se investiga el Adobe en el Perú, los principales programas realizados, señala las instituciones que han participado en el proceso de investigación, los logros obtenidos y las tareas de difusión tecnológica efectuadas.

Finalmente incluye las perspectivas de investigación y comentarios globales sobre lo realizado hasta la fecha.

Introducción

La investigación sobre el Adobe en el Perú estuvo y está motivada fundamentalmente por la constatación objetiva de que un 60% de las viviendas construídas en el país, utilizan la tierra como material de construcción. Una fracción muy importante del porcentaje señalado está constituído por el adobe, razón por la cual el Ministerio de Vivienda y Construcción, a partir del año 1972, inició investigaciones sistemáticas sobre dicho material.

Los materiales de construcción que denominamos convencionales, es decir el ladrillo de arcilla cocida combinado con estructuras de concreto armado es usado aproximadamente por un 13% de las viviendas edificadas en el Perú. Aunque los conocimientos tecnológicos sobre esa modalidad de construcción están muy difundidos entre los técnicos peruanos, lo reducido de su uso se explica por el costo elevado de la tecnología convencional y lo reducido de los ingresos de la mayoría de la población peruana, muy en particular la asentada en los medios rurales.

Las construcciones con tierra en el Perú son edificadas generalmente mediante el sistema que denominamos Autoconstrucción y responde adecuadamente a las condiciones económicas de un elevado porcentaje de la población y también a sus patrones culturales, además de constituir construcciones cuyas características se adapten bien a los medios ecológicos en las cuales son utilizadas.

Las construcciones con adobe en el Perú datan de épocas muy antiguas, incluso pre-incaicas existiendo hasta ahora vestigios arqueológicos entre los que caben señalar particularmente las Ruinas de Chan Chan, Paramonga y Pachacamac. Con la llegada de los españoles al país continuaron con la edificación de adobe introduciendo las características propias de la cultura occidental existiendo sobre ello también muestras arquitectónicas que han soportado los rigores del tiempo y los movimientos sísmicos sin daños apreciables.

Por ello consideramos que el adobe es un material de construcción que ha sido usado eficazmente en el Perú, continúa usándose y lo será en el futuro durante muchos años, lo cual justifica plenamente todos los esfuerzos de investigaciones que se hagan para mejorar la tecnología de ese material.

Por lo tanto el objetivo fundamental de la Investigación del Adobe en el Perú es recuperar en lo posible los conocimientos que sobre la tecnología del adobe existen como acervo cultural de sus pobladores, sumando a éllo los conocimientos tecnológicos modernos para contar con una Tecnología Mejorada del Adobe que dote a la misma de adecuadas condiciones de habitabilidad y seguridad, sobre todo ante las solicitaciones sísmicas, tan frecuentes en el país.

Ello constituirá una contribución para la búsqueda de soluciones a la problemática habitacional del Perú.

La Investigación del Adobe

La investigación sobre el adobe se inició en Marzo de 1972 con el Programa COBE -Construcción con Adobe Estabilizado- . En este Proyecto participaron inicialmente el Ministerio de Vivienda y Construcción, el Banco de laVivienda del Perú, y la Universidad Nacional de Ingeniería, con el financiamiento y asesoramiento de la Agencia para el Desarrollo Internacional (AID).

Posteriormente en el año 1973 los profesores de la Pontificia Universidad Católica del Perú - (PUCP), Ing. Miguel Corazao e Ing. Marcial Blondet, obtuvieron el Premio SAYHUITE, que anualmente otorga el Banco Central Hipotecario del Perú, al mejor trabajo tecnológico realizado en el año. El trabajo de los profesores de la Universidad Católica consistió en propuestas para reforzar las viviendas construídas con adobe, empleando diversos tipos de refuerzos tales como maderas, cañas, alambres y otros. El indicado trabajo permitió iniciar una fecunda relación entre el Ministerio de Vivienda y la Pontificia Universidad Católica del Perú, para el análisis tecnológico de las construcciones con adobe común.

Programa COBE

El Programa COBE, desde su inicio, abordó el problema de la estabilización de suelos mediante el empleo del Asfalto RC-250 y emulsiones asfálticas, habiendo partido de información tecnológica procedente de los Estados Unidos en particular de la procedente del International - Institute of Housing Technology de la Universidad del Estado de California. Esta información técnica fue adaptada mediante diversos ensayos de investigación a las condiciones y modos - de producción del adobe que se utilizan normalmente en el Perú. Ello obligó a una profundización en el conocimiento de los modos de producción locales que permitieron a la larga, determinar los mejores procedimientos para la elaboración del adobe como unidad de albañilería y los requisitos para estabilizarlo con asfalto.

El Programa COBE incidió igualmente en aspectos vinculados a la utilización del adobe estabilizado en la albañilería abarcando los aspectos de reforzamiento de ésta, principalmente - ante las solicitaciones sísmicas. Ello condujo a una serie de conclusiones de carácter constructivo y estructural que constituyen una mejora notable a la forma de empleo de la albañilería de adobe.

Cabe destacar aquí la muy importante participación que tuvo el Ing. Ricardo Yamashiro, destacado Profesor del Departamento de Estructuras de la Universidad Nacional de Ingeniería , prematuramente fallecido, quien estableció las bases para un análisis racional de las estructuras de adobe, habiendo dejado valiosos documentos, colaboradores y alumnos suyos que - continuan su labor.

Otro rubro importante en este proceso de investigación ha sido el estudio de sistemas de techado que se adapten a la construcción con adobe, campo en el cual también se han obtenido avances importantes. Además el Programa COBE abarcó estudios vinculados a las cimentaciones más adecuadas a utilizarse según el tipo de terreno, diversas consideraciones relativas a la productividad y costos, consideraciones de tipo arquitectónico y otros aspectos técnicos complementarios.

Finalmente el Programa COBE abarcó aspectos relacionados a la divulgación de la tecnología obtenida, habiéndose logrado importantes avances metodológicos, para lo que se contó con el valioso apoyo de la Empresa INTERTEC de los Estados Unidos y de la Carnegie Mellon University y el Centro de Producción Audiovisual para la Capacitación (CEPAC).

Investigación del Adobe Común

A partir del trabajo anteriormente reseñado de la Pontificia Universidad Católica del Perú , la Oficina de Investigación y Normalización (OIN) del Ministerio de Vivienda y Construcción incrementó su apoyo a los trabajos de la Universidad Católica vinculados a la investigación sobre el adobe común, trasladando la información ya obtenida en el Programa COBE que podía ser aplicada al adobe común, y proporcionándole apoyo económico.

Se propició la ejecución de Tésis de Grado realizadas por egresados de la mencionada Universidad las que constituyeron importantes trabajos de investigación que contribuyeron a ampliar, fundamentalmente, los conocimientos relativos al comportamiento estructural de las edificaciones con adobe común.

La Universidad Católica hizo una importante publicación sobre sus avances denominada " Investigación sobre Vivienda Rural ", que aunada a las Tesis de Grado mencionadas y posteriores publicaciones efectuadas por el Departamento de Ingeniería de la Universidad Católica constituyen importantes fuentes de consulta para el diseño y construcción con el adobe común.

Relaciones Interinstitucionales

La investigación tecnológica que el Ministerio de Vivienda promueve o ejecuta, se realiza a través de la Oficina de Investigación y Normalización. Sin embargo, la OIN no asume exclusivamente la tarea de investigación, sino que por el contrario, procura la participación, de la manera más intensa posible, de otros organismos interesados en esa temática, a fin de

incrementar el número de investigadores, coordinar esfuerzos y evitar duplicidades.

Por ello nos parece importante señalar que la OIN, en lo que a investigación del adobe se refiere, ha compartido sus esfuerzos con diversas entidades nacionales tales como la Universidad Nacional de Ingeniería, la Pontificia Universidad Católica del Perú, el Instituto Geofísico del Perú, la Universidad Nacional Pedro Ruiz Gallo de Lambayeque, el Banco de la Vivienda del Perú, el Colegio de Ingenieros del Perú, el Instituto de Investigación Tecnológica Industrial y de Normas Técnicas (ITINTEC) y el Instituto de Investigación y Acción Para la Vivienda (INIAVI).

Entre los organismos internacionales, hemos recibido la colaboración y compartido información con entidades como la Agencia para el Desarrollo Internacional (AID), INTERTEC, Carnegie Mellon University, el Comité de Acción para la Vivienda Económica de Interés Social del Sistema Económico Latinoamericano (CAVEIS del SELA), Naciones Unidas y el Centro de Investigación y Aplicación - Tierra (CRATERRE).

Logros Obtenidos

Consideramos que el logro fundamental obtenido por los esfuerzos realizados por la Oficina de Investigación y Normalización y las entidades anteriormente mencionadas es contar con lo que denominamos Tecnología Mejorada del Adobe, término con el cual queremos abarcar la combinación y compatibilización de los conocimientos obtenidos tanto por el Programa COBE como por las investigaciones realizadas en el adobe común y diversos aportes recibidos de otras fuentes.

Dado que una descripción detallada de los logros obtenidos podría resultar demasiado extensa y que la información técnica que los mismos implican, se encuentra en diversas publicaciones, cuya relación bibliográfica presentamos como Anexo N° 1, informaremos sólo de manera general, los logros que consideramos más importantes :

El Adobe Como Unidad de Albañilería

En estos momentos tenemos la información suficiente como para preparar correctamente tanto adobes estabilizados como adobes comunes, contando con los procedimientos necesarios para la fabricación de los mismos, partiendo desde la selección de canteras, análisis de los suelos, tipos de gaveras a ser empleadas, tendales, procedimientos de secado, y almacenaje ,

hasta los métodos de ensayo para verificar las condiciones mecánicas de los bloques.

Procedimientos de Construcción

Contamos igualmente con el conocimiento técnico suficiente para construir albañilería de adobe de modo que la misma cuente con los refuerzos estructurales diseñados para cada caso particular y con el empleo de los morteros más adecuados.

Metodología de Análisis Estructural

Posiblemente es de los logros más importantes contar con una metodología de diseño estructural para el adobe, lo que permite dimensionar adecuadamente la albañilería, teniendo en cuenta las exigencias sismo-resistentes. Con anterioridad a las investigaciones realizadas sobre el adobe las edificaciones con este material se dimensionaban únicamente de acuerdo a las tradiciones existentes, lo que en épocas recientes produjo errores graves que se manifestaron con claridad, sobretodo, en el sismo del año 1970 acurrido en el Departamento de Ancash.

Diseño Arquitectónico

Se dispone también de una serie de recomendaciones técnicas de carácter arquitectónico, muy vinculadas a las necesidades de tipo estructural, que deben ser observadas para un correcto diseño de viviendas de adobe. Las recomendaciones arquitectónicas, se refieren principalmente a las dimensiones de puertas y ventanas así como a la ubicación de los vanos, encuentros de muros y otros.

Normas Técnicas

Los avances técnicos hasta ahora obtenidos han permitido elaborar normas técnicas, oficialmente aprobadas, para el adobe estabilizado, y en el Reglamento Nacional deConstrucciones existe un Capítulo dedicado expresamente a las Construcciones con Adobe, lo cual representa un importante paso para el buen uso de esta tecnología y el aprovechamiento de los conocimientos generados.

Tesis de Grado

Consideramos un logro igualmente muy importante, haber conseguido la realización de 20 Tesis de Grado por alumnos de diversas universidades sobre temas vinculados a la Tecnología del Adobe, lo cual permite relacionar mucho a la Universidad y a profesionales jóvenes con la tecnología del adobe, asegurando de alguna manera, que se continúen investigaciones posteriores y que los conocimientos actuales formen parte del Syllabus universitario (Anexo N° 2).

Difusión de la Tecnología del Adobe

Una etapa de trabajo considerada de primera importancia ha sido la difusión de los conocimientos obtenidos a los diversos sectores interesados, es decir, profesionales y académicos , técnicos especializados y usuarios.

Consideramos que la difusión de tecnología debe ser la etapa final de todo Proyecto de Investigación, puesto que si los conocimientos no se diseminan los esfuerzos realizados en investigación pueden devenir con facilidad obsoletos y las inversiones y esfuerzos no cumplirían sus objetivos.

En esta etapa de divulgación, que implica también tareas de capacitación, hemos contado con el aporte muy valioso de la AID, del INTERTEC, de la Carnegie Mellon University y del CEPAC, con cuya contribución se ha podido producir diversos materiales de divulgación básicamente como material escrito y como material audiovisual.

En la actualidad contamos con la Cartilla " El Adobe Estabilizado ", el Folleto " Mejores Viviendas de Adobe, el Folleto Techo Liviano de Caña y Barro, el Manual Técnico " Adobe Diseño y Construcción " así como con material gráfico de diverso tipo.

Se ha producido una película en 16 mm. denominada " El Adobe " y un Curso Audiovisual - denominado " Mejores Construcciones de Adobe ". Este último de notable aceptación que - nos ha permitido dictar cursos en diversas localidades de la Costa y la Sierra del Perú.

El material anteriormente indicado es empleado generalmente para dar instrucción a grupos, sean éstas comunidades, cooperativas o sociedades agrícolas de interés social, que muestran deseo de aplicar la tecnología del adobe mejorado en sus viviendas.

Para niveles de profesionales se han dictado Cursillos y Charlas en diversas localidades del país, y se ha llevado también esta información a Fórums de carácter internacional.

Una última manera de difundir los conocimientos, y que consideramos de singular importan - cia es la de efectuar construcciones de tipo experimental, tarea que hemos realizado, aún - limitadamente, pero que permanentemente tratamos de impulsar como una forma de glabali - zar los conocimientos existentes sobre la Tecnología el Adobe (Ver Anexo N° 3).

Perspectivas

Consideramos que en lo relativo al desarrollo de la Tecnología del Adobe, y en general a las construcciones con tierra habrá que hacer todavía muchos trabajos de investigación. Entre tales estudios señalaremos a continuación los siguientes :

- Variantes para la estabilización del adobe mediante el empleo de cal, cemento, compresión mecánica, y otras formas.

- Profundización de los estudios sobre morteros adecuados para la albañilería del adobe, principalmente mediante el uso de la cal cuyas características de adhesividad son ampliamente conocidas.

- Búsqueda de nuevas alternativas para el refuerzo de la albañilería de adobe.

- Profundización de los conocimientos sobre el comportamiento estructural de la albañilería de adobe, sobre todo en base a estudios de tipo dinámico.

- Estudio para la Reparación de Viviendas Antiguas de Adobe, analizando los requeri - mientos de refuerzo que pueden ser necesarios sobre eventos sísmicos.

- Estudio de las construcciones de adobe en dos pisos, cuya utilización está sumamente

difundida, sobre todo en la Sierra Peruana.

- Estudio de la albañilería construída con el Sistema de Tapial o Adobón, también muy difundida en varias localidades de la Sierra y Cabecera de Selva.

- Estudio de los muros realizados con el empleo de la Quincha, material este último compuesto por paneles de madera o caña recubiertos con barro.

- Incremento de los medios disponibles para la divulgación de la Tecnología relativa a la construcción con tierra en general.

- Realización de proyectos piloto con la finalidad de difundir el Uso del Adobe en la construcción de viviendas.

- Incremento de las Normas Técnicas relativas al Adobe así como la revisión permanente de las recomendaciones estipuladas en el Reglamento Nacional de Construcciones.

- Vincular la edificación con Adobe con el empleo de las Fuentes No Convencionales de Energía, principalmente la Solar, Eólica y Biogas.

Comentarios

Consideramos que la investigación sobre el Adobe realizada en el Perú ha generado un mayor interés de los profesionales en el conocimiento de las técnicas para el buen empleo de dicho material, el cual constituye, estimamos, un apreciable aporte a la problemática de la vivienda en el Perú, puesto que existen ya las condiciones mínimas necesarias para superar los defectos constructivos derivados del empirismo.

Creemos también que la Investigación del Adobe ha permitido contar con elementos técnicos que posibilitarán el mejoramiento de las condiciones de habitabilidad de las construcciones con adobe así como su seguridad.

De otro lado la realización de las investigaciones sobre Adobe ha mostrado la necesidad de mejorar los procedimientos administrativos para el desarrollo de Programas de Investigación, cuya dinámica es sensiblemente diferente a programas de otro tipo.

Ha sido también una muy importante y valiosa experiencia la vinculación interinstitucional lograda al desarrollar el programa de Investigación del Adobe, porque ello ha permitido compartir los esfuerzos de todos los interesados en la temática y proyectar las inquietudes generadas a otros campos de conocimiento de la tecnología lo que ha permitido impulsar en general la investigación en muchos aspectos de la vivienda y la construcción.

Lima, 14 de Abril de 1981.

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Tesis de Grado

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  Miriam Benites Albornoz

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  Cecilia Cano Moscoso.

Anexo N° 3

Construcciones Experimentales

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- Construcción de 1 Vivienda Experimental en la Planta Piloto de la OIN
- Construcción de 1 Aula y SS.HH. en el Centro de Educación Inicial de la Urbanización Micaela Bastidas.
- Construcción de 2 Aulas, SS.HH. y Vivienda Guardianía en el Centro de Educación Básica en Acomayo (Huánuco)
- Construcción de 1 Vivienda en Huánuco (2 ambientes) con fines didácticos.
- Construcción de la Segunda Aula (Aula N° 3) y SS.HH. del Centro de Educación Inicial N° 327 de la Urbanización Micaela Bastidas.
- Construcción del Local Comunal, Posta Sanitaria, Centro de Educación Básica y Vivienda para Profesores en la Localidad " El Papayo ", Piura.
- Construcción de 1 Aula - Cerro Grande - Ayaviri (Puno)
- Construcción de 1 Aula - Huaura
- Construcción Posta Médica - Palpa (Huaral)
- Construcción 1 Aula " La Candelaria " (Huaral)
- Construcción Almacén de Papas (Huancayo)
- 100 Casas en Cayaltí
- 20 Casas en Nepeña
- 1 Casa en Huaraz

REINFORCED POURED ADOBE AND ITS APPLICABILITY TO EARTHQUAKE RESISTANT CONSTRUCTION

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ABSTRACT

Results of rational analyses of reinforced poured adobe walls indicate that the structural concepts of this construction method are valid and satisfy the intent of the Uniform Building Code, even in high-seismic zones. Wall-forming techniques and shrinkage cracking represent major obstacles to the practical application of poured adobe. However, several solutions, including the use of plasticizers, bamboo rather than steel reinforcing, and fiber reinforcing, show promise for overcoming these obstacles in the future.

Introduction

Meli, et al. stated in a recent paper (1) that:

> "In developing countries the main cause of loss of human lives and of economical damage following strong earthquakes is the collapse of small houses built of unreinforced masonry, mainly with adobe or stones bonded with mud and mortar."

In the United States this has not been the case, primarily because of the wide-spread adoption of the Uniform Building Code (2) which imposes very restrictive requirements on the use of adobe masonry as a structural material. However, because of the ever-increasing economic pressure and scarcity of conventional materials such as wood and concrete, building materials such as adobe, which are readily abundant, are being re-evaluated. Many local county and city governments that originally adopted the UBC code as their own have since amended their requirements so that the restrictions on adobe construction have been liberalized. Such is not the case in California, where the seismic requirements are the most stringent in the United States.

However, adobe being as abundant and versatile as it is, it behooves us to devise new methods of incorporating it into structures without sacrificing seismic safety. One method of adobe construction which shows promise in the area of seismic resistance is the use of reinforced poured adobe walls in residential construction. The primary difference between poured adobe and adobe block construction is the use of the wet mix directly rather than molding the blocks and then mortaring them together in a wall. Reinforcement in the form of welded steel wire fabric or bamboo may be incorporated in a manner similar to the reinforcement in poured concrete construction (see Figure 1).

This paper presents a description of the reinforced poured adobe process and its applicability to seismic resistant construction. A rational structural basis for using reinforced poured adobe is presented along with a discussion of some of the problems related to its application and possible solutions to those problems.

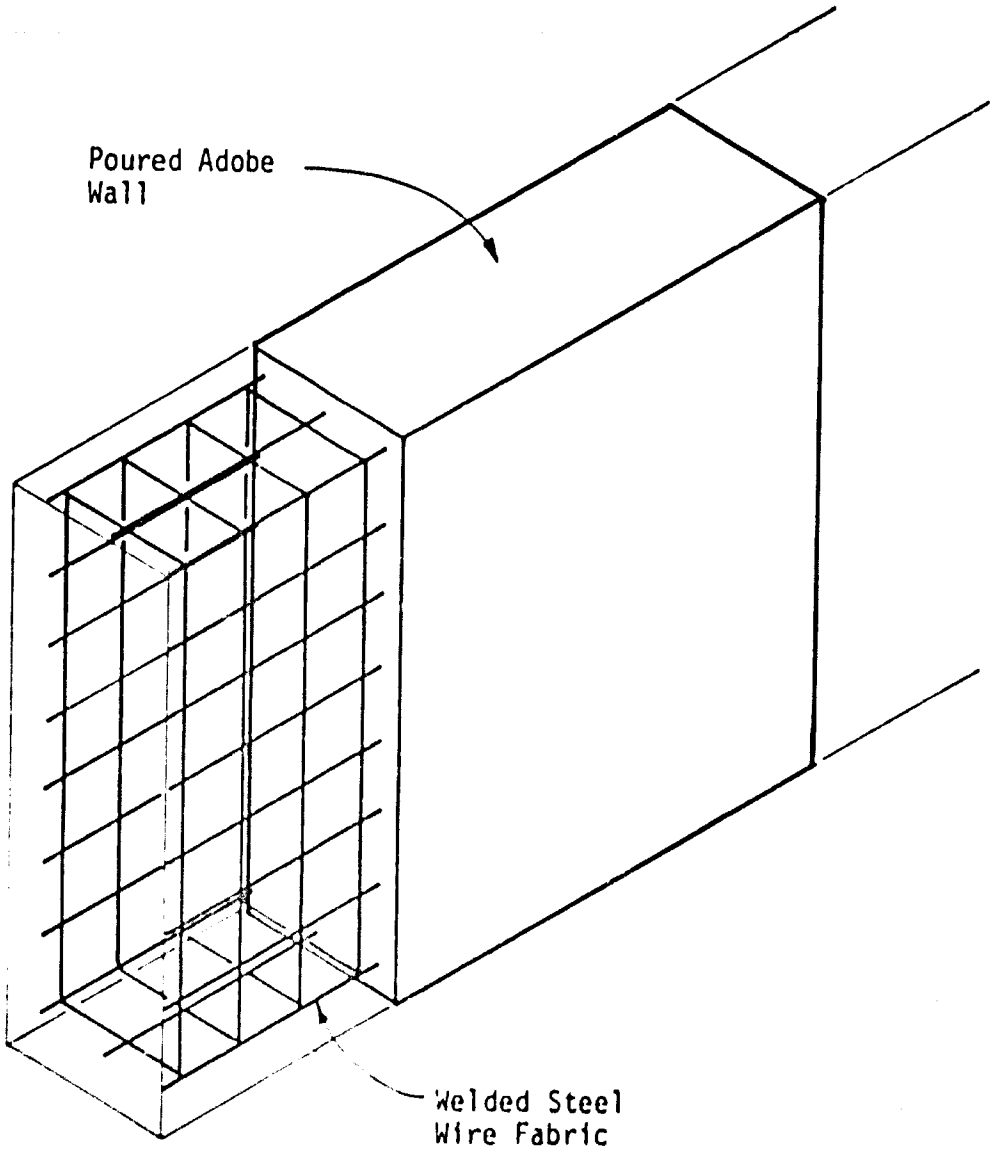

FIG. 1

Reinforced Poured Adobe Walls

Background

Little, if any, technical information on the earthquake resistance of reinforced poured adobe is found in the literature. Most information which is widely available concerns traditional adobe block construction (1, 3, 4, and 5) and is aimed at the less developed countries. For example, Razani (3 and 4) has developed seismic design criteria in Iran for low-rise, low-cost housing with brittle behavior. These criteria include minimum required design lateral loads and base-shear coefficients for ensuring against damage and collapse. In addition, Razani proposes that roof collapse, which he states is the main cause of death during earthquakes, can be prevented by means of a braced skeleton system within the unreinforced building.

Vargas-Neumann (5) presents minimum requirements for material strengths to be used in reinforced block adobe construction in Peru. The use of cane and wire as reinforcing is suggested, with vertical reinforcing being placed in concrete mortar between double adobe walls. This type of sandwich construction with steel reinforcing bars is typical of the adobe construction in California.

Meli, et al. (1), in considering existing adobe structures, present the results of dynamic shake table tests on three separate methods of strengthening adobe block constructed houses after they have been constructed without reinforcement. The three methods considered are:

- Concrete bond beam with corner spurs
- Tie rods at the tops of walls to hold the top of the walls together
- Wire mesh with cement rendering

In each of these methods the strength transverse to the plane of the wall was increased by varying degrees. However, because the wire mesh with cement rendering provides vertical as well as horizontal reinforcement, the increase was most dramatic for this method. The wire mesh is also advantageous, since it does not require removal of the roof for retrofitting.

Each of these references discusses the major concerns of adobe construction in seismic zones, namely the brittle behavior of the material, and the need of reinforcement to provide ductility and strength. The same concerns are valid for poured adobe. However, since this process is not widely recognized at the present, it appears necessary to first present a rational argument for its acceptance, followed in the future by experimental research and verification.

A Rational Basis for Using Reinforced Poured Adobe

The Uniform Building Code does not prescribe standards for reinforced poured adobe as a method of construction. However, Section 105 of the Code states:

> "Provisions of this code are not intended to prevent the use of any material or method of construction not specifically prescribed by this code, provided any alternate has been approved and its use authorized by the building official.
>
> "The building official may approve any such alternate, provided he finds that the proposed design is satisfactory and complies with the provisions of this code and that the material, method or work offered is, for the purpose intended, at least equivalent to that prescribed in this code in suitability, strength, effectiveness, fire resistance, durability, safety and sanitation."

Thus, in lieu of empirical evidence, a rational structrual analysis is believed to provide the building official with sufficient evidence to substantiate the suitability, strength, effectiveness and safety of reinforced poured adobe construction.

For a reinforced poured adobe wall to satisfy the provisions of the Code as a load bearing structural element, it must withstand the prescribed lateral and vertical loads. This means that, in addition to resisting in-plane shear forces and overturning moments, a wall must withstand out-of-plane forces and moments (see Figure 2). It is, in fact, these out-of-plane forces on the wall caused by inertia effects of the wall and roof which appear to be critical.

Assuming that in-plane forces and moments can be resisted by a combination of adobe compressive strength and steel tensile and shear strength, Section 2312(g) of the Code prescribes lateral forces normal to the wall to be:

$$F_p = ZIC_pW_p$$

where Z depends on the earthquake zone, I is the occupancy importance factor, C_p is a force factor dependent on the type of structural element, and W_p is the weight of the wall. For a single-story building with exterior bearing walls eight feet tall, 16 inches thick and located in seismic zone 4, the lateral load F_p is 44 lbs/ft^2.

The distribution of moments and shear forces caused by this lateral load depend not only on the unsupported length of the wall, but also on the edge conditions, namely whether the vertical and bottom edges are fixed or simply supported and whether the top edge is free or simply supported.

Diaphragm action of the roof is one of the most important considerations in the design of any type of adobe wall for transverse lateral loads caused by earthquakes. For example, if the roof is incapable of diaphragm action, which is usually the case in at least one direction of lateral load, the top of the wall must be considered an unsupported free edge and transverse lateral inertia loads due to the roof, as well as the wall itself, must be carried by the wall, rather than transferring these loads to the shear walls. Meli, et al. (1) discussed the

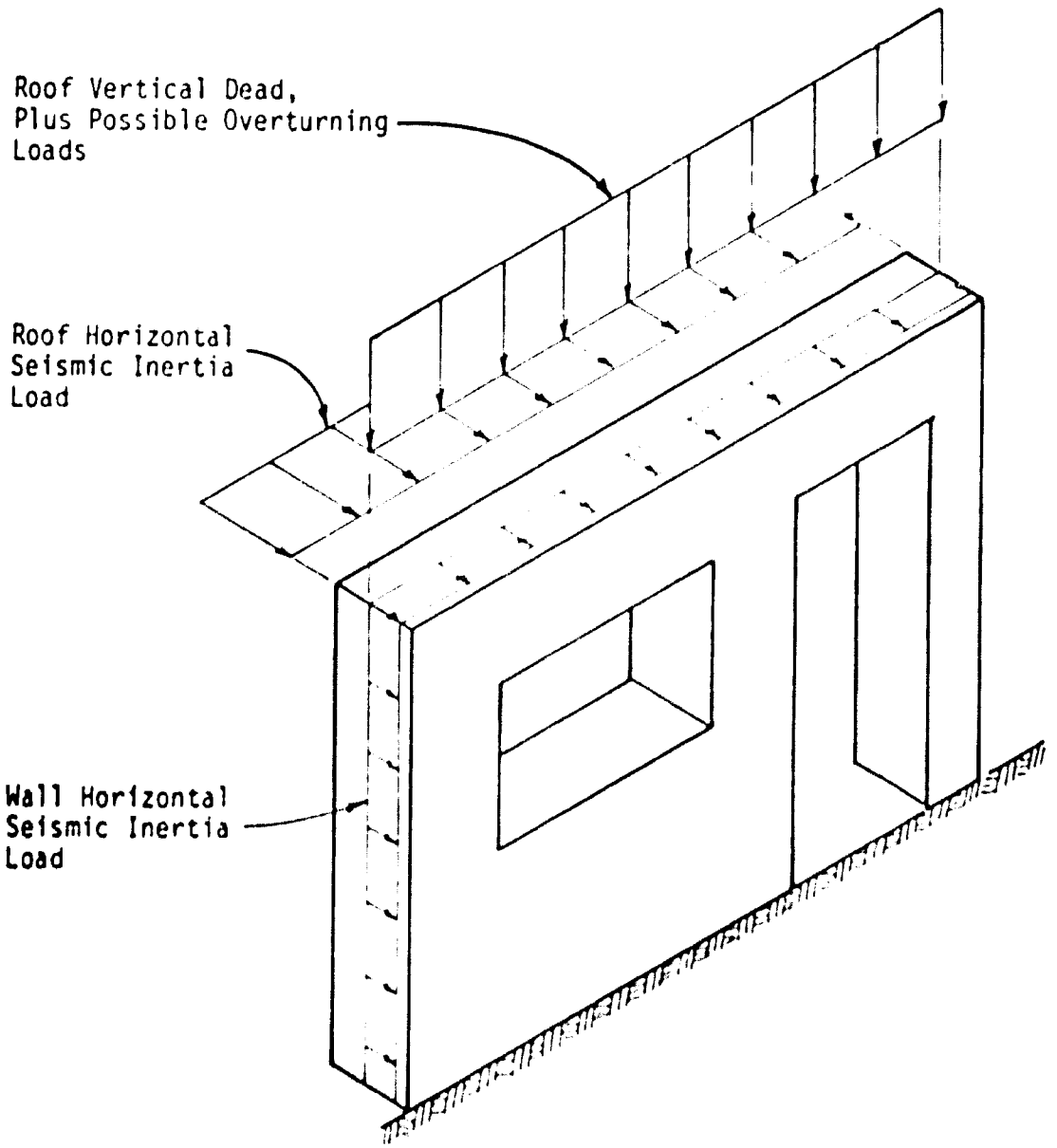

FIG. 2

Seismic Load Demand on Adobe Wall

dynamic behavior of this type of construction in unreinforced adobe structures, stating that:

> "The vibration of the longer walls normally to their plane induces bending moments that are maximum at their lateral ends and that produce vertical cracks that propagate downwards in such a way that the upper part of the wall starts vibrating as a cantilever; overturning moments in the base of the cracked length become critical as the crack length increases and finally the wall falls generally outwards producing the collapse of the roof."

If the wall is analyzed as a flat plate with a free edge at the top, the maximum unit bending moments are found to occur either at the top or bottom of the wall along the vertical centerline, or at the vertical edge of the wall at the top, depending on the assumed fixity of the vertical and bottom edge supports. For a wall 8 feet high and 16 feet long, the maximum unit bending moment is in the range of $15.4\ f_p$ to $19.3\ f_p$, where f_p is the lateral inertia load per square foot of wall. Considering a 16-inch thick wall, the unit bending moment from wall inertia alone can be as high as 850 lb-ft/ft.

Unit shear forces on the wall are also maximum under these construction limitations, with the largest shear occurring at the top of the vertical edge. Shear forces range from $12.6\ f_p$ to $15.8\ f_p$ for the 8 by 16 foot wall. For a 16-inch thick wall, the unit shear stress can be as high as 695 lbs/ft at these upper corners. Figure 3 shows the maximum unit moments and shears for different edge fixity conditions.

Assuming a wall edge fixity shown in Figure 3b, a 16-inch thick wall with a UBC lateral inertia force of 44 lbs/ft^2, and a roof load on the wall of 210 lbs/ft, producing a UBC lateral inertia load of 39 lbs/ft, the maximum unit bending moment at the base of the wall is 998 lb-ft/ft. The steel area required to resist this bending moment is based on the formula:

$$A_s = M/f_s jd$$

Assuming f_s = 20,000 psi and d = 14 inches, the required tension steel area for this moment is 0.0464 square inches per foot. This required steel area can be met by using 12½ gauge wire welded mesh with 2-inch spacing.

Even if steel reinforcing is capable of withstanding the bending stresses, the UBC allowable axial and bending compressive stresses on the adobe itself are quite restrictive. Axial compression at the bottom of the wall is equal to the roof load plus the weight of the wall, or 1,380 lbs/ft. Assuming that the working stress provisions of the UBC for masonry construction are valid for poured adobe, and if the compressive strenth, f_m', of the adobe is 300 psi,* the allowable bending compressive stress according to Table 24-H and Section 2303(d) of the Code is 65.8 psi, while the allowable axial compressive stress is

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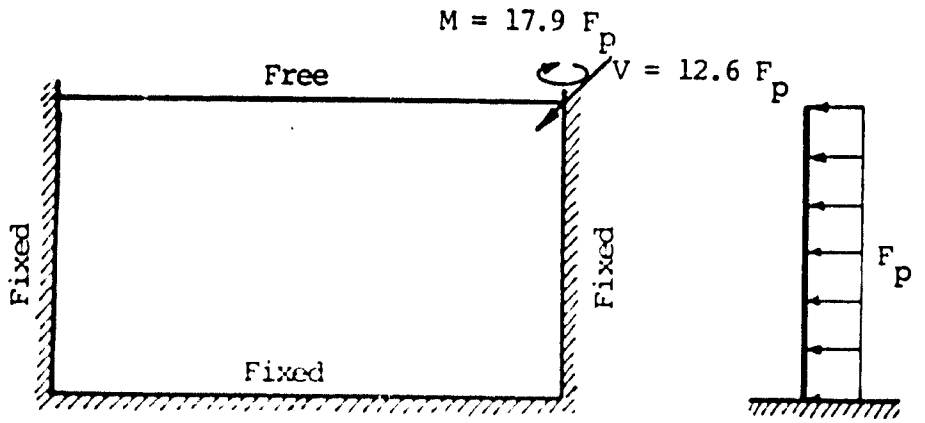
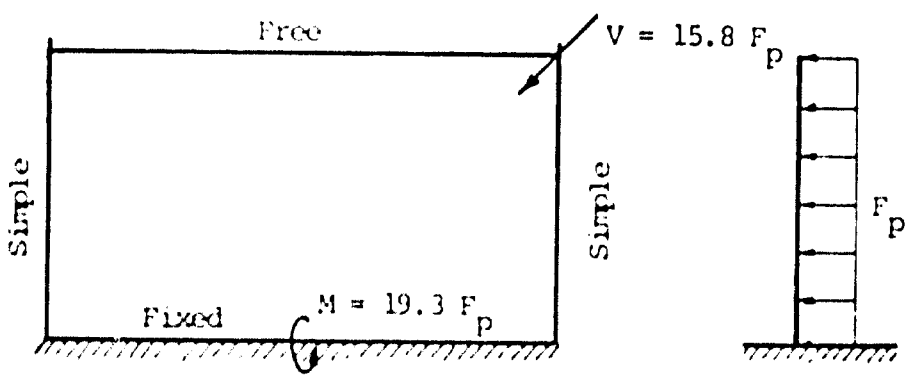
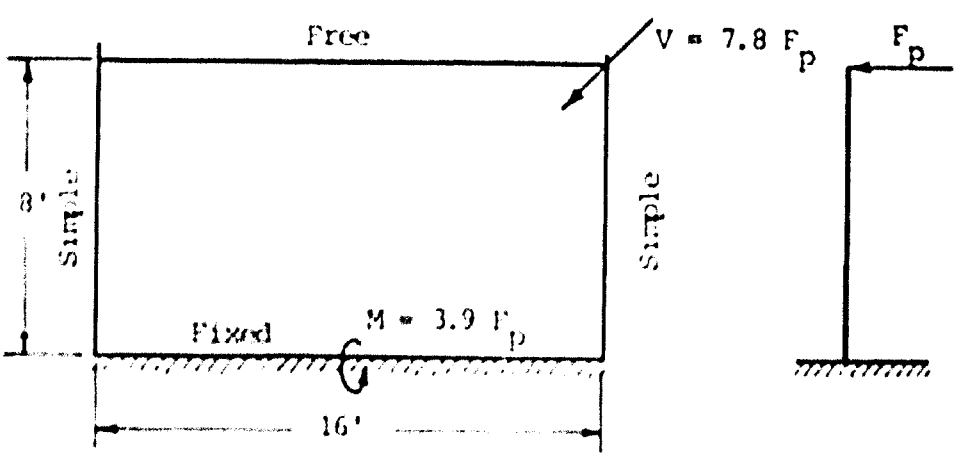
*Assuming a minimum compressive strength implies that a quality control program for mixing the adobe is followed, and sample specimens are periodically tested for strength.



a. Three Fixed, One Free Edge, Uniform Area Load (9)



b. Two Simple, One Fixed, One Free Edge, Uniform Area Load (9)



c. Two Simple, One Free, One Fixed Edge, Uniform Line Load (10)

FIG. 3

Maximum Unit Moments and Shears on Laterally Loaded Flat Plates

$1.33 \times 0.1\ f_m'R$, where R is a reduction factor based on the unsupported height to thickness ratio. For this example, the allowable compressive stress is 38.8 psi. The UBC required combined stress interaction equation is:

$$\frac{f_a}{F_a} + \frac{f_b}{F_b} \leq 1$$

where $f_b = 2M/bd^2jk$ and $f_a = P/A_g$. For this example, the interaction of axial and bending compressive stresses is 0.91, which indicates that a 16-inch thick wall is adequate for combined out-of-plane bending and vertical axial force.

The maximum shear stress at the top corner of the 16-inch thick wall is 6.0 psi, whereas the allowable out-of-plane shear stress on the wall from Table 24-H of the Code is $1.33 \times 1/2 \times 1.1 \times \sqrt{f_m'} = 12.8$ psi.

These computations are not intended to be exhaustive, but are meant only to illustrate the potential use of reinforced adobe poured in high seismic zones. The following two sections discuss the unique problems associated with using reinforced poured adobe and some possible solutions. Since so few poured adobe structures are known to exist, not all problems related to this technology can be foreseen at the present time, and solutions even to known problems are in need of research and evaluation.

Forming Poured Adobe Walls

Although there may be others, this author knows of three examples of poured adobe structures (6, 7, 8) in the United States, only one of which (7) has included welded wire fabric reinforcing. The key to this method of building according to Belshaw (6) is a simple light-weight form that is placed where needed on the walls, filled with adobe, and then moved to another location as soon as the adobe has begun to "set up." Where speed in curing is necessary, Belshaw recommends that soil cement be used.

Forms for poured adobe are lighter than those necessary for rammed earth. The form designed by Belshaw for unreinforced walls is shown in Figure 4. The form is a box joined at the back with continuous hinges. The hinges allow the sides to be spread apart when the form is removed.

Depending on the water content of the adobe, humidity of the air, wind, and size of the block, the form can be removed anywhere within four to twenty-four hours, although full curing takes weeks or months. However, it is strong enough to withstand the next step or even support another block on top.

A simple sequence of constructing the walls is shown in Figure 5. Adobe is poured and tamped. According to Belshaw, the adobe will have set up sufficiently to resist slumping when water does not ooze out when a firm imprint of a finger is made. The next step involves erecting simple plate forms which span between the already formed adobe blocks and filling with wet adobe as shown in Figure 6. Shrinkage in this forming process is reported by Belshaw to be negligible.

The process of manufacturing the adobe and pouring suggested by Belshaw requires the use of a backhoe to mix and carry the forms, although the adobe may be mixed in a cement mixer and carried in wheelbarrows up ramps to the forms.

A modification to the basic form designed by Belshaw is shown in Figure 7. This modified design allows for the inclusion of reinforcing welded wire fabric to be imbedded in the adobe, and also includes the use of expanded metal lath rather than wood as the basic siding of the form. The use of metal lath rather than plywood or boards enhances a more rapid and uniform "set up" time, since more surface area of wet adobe is exposed to air. If the size of the form is large, wire ties may be needed between the inner and outer lath of the form to ensure that the form does not bulge due to the hydrostatic pressure of the wet adobe.

In another example, Nelson (7) used forms to place a full wall height (up to 13 feet) of wet adobe at one time. A modular forming system was developed using expanded metal lath as the siding of the form. The wet adobe was placed using a concrete pumper. This method requires a wetter mix than is generally desirable to resist shrinkage cracking, although shrinkage cracking of the adobe did not appear to be a problem for Nelson.

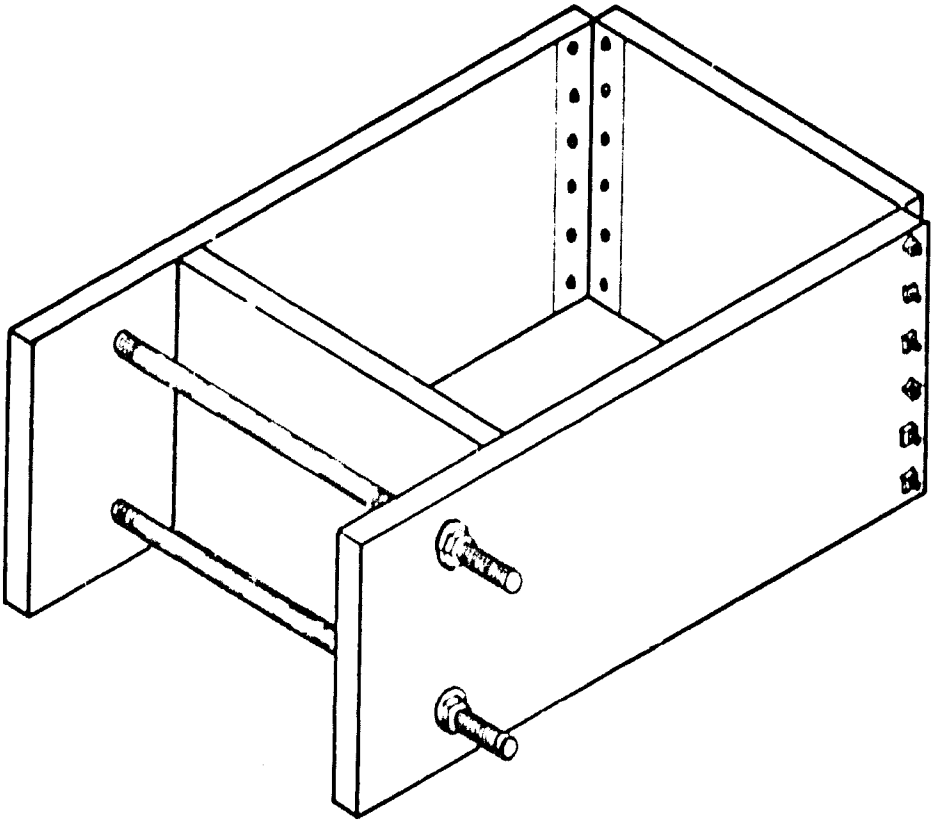


FIG. 4

Basic Form ng Block (6)

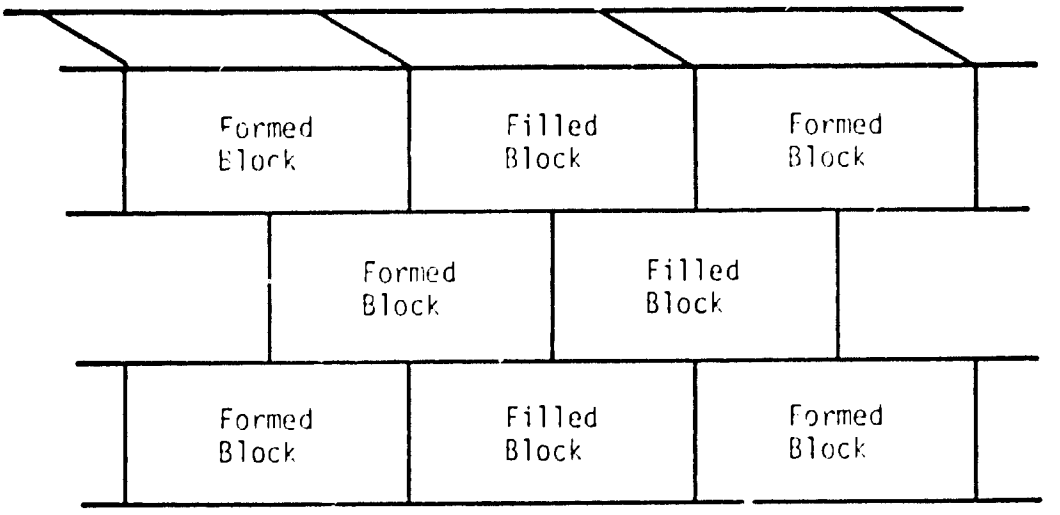


FIG. 5

Basic Sequence of Forming (6)

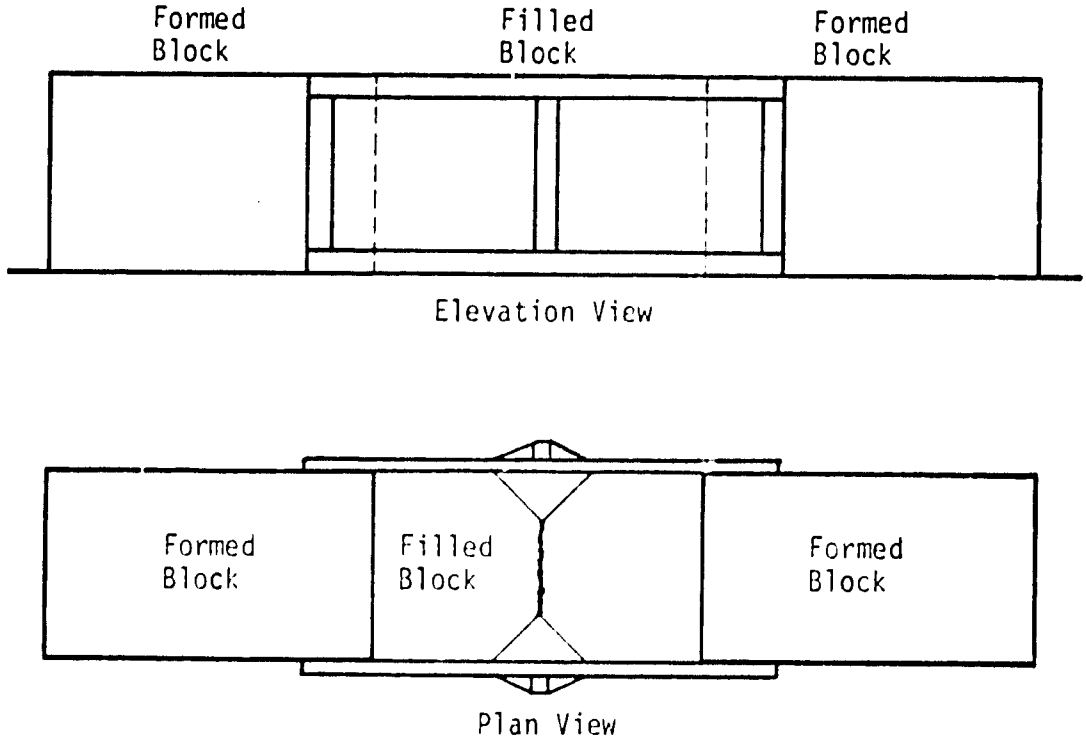


FIG. 6

Plate Forms for Filled Blocks (6)

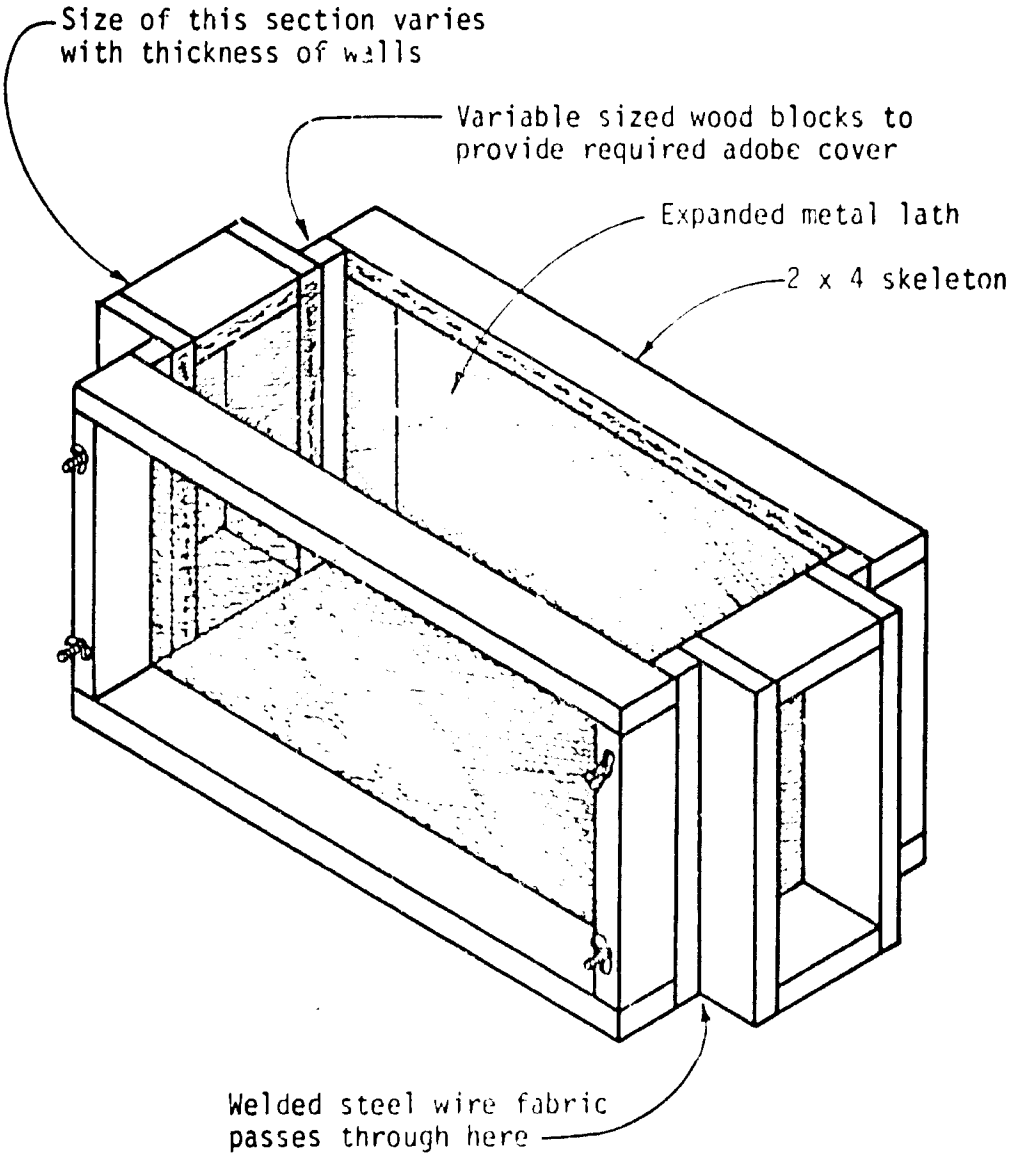


FIG. 7

Alternative Forming Block for
Reinforced Poured Adobe

Shrinkage Cracking

Shrinkage cracking appears to be another of the major problems to overcome in the application of poured adobe. This problem is amplified when steel reinforcing is embedded in the wet mix, since the adobe, when it drys, will tend to shrink away from the fixed position of the steel reinforcing. The following ideas are offered as potential mitigating schemes.

Superplasticizers

Schultz (11) has suggested the use of superplasticizers in adobe. Chemical additives to adobe, such as some of the lignin sulfonates, show potential as dispersants, binders, and emulsifiers. In the application to poured adobe the potential is greatest for reducing the required water content while maintaining the fluidity necessary to pour, thereby reducing shrinkage, shrinkage cracking, and drying time.

Fiber Reinforcing

The relatively high cost of man-made fibers as a reinforcing material has produced an interest in natural fibers as possible substitutes in construction. This is particularly true in developing nations where either the cost of reinforcement for seismic considerations represents a major portion of the total cost, or these man-made products are simply not available. A recent paper (12) in the American Concrete Journal describes the use of natural agave fibers, which exist in reasonably large quantities in many countries of the world, as possible reinforcement for Portland cement-based matrixes.

The logical extension of this technology to the issue at hand is the incorporation of natural fibers in the adobe mix as a reinforcement, providing ductility in a material normally characterized by brittle behavior.

The experimental program conducted by Castro and Naaman (12) included tests on individual fibers to determine strength, modulus of elasticity, and other physical properties, as well as flexural tests on fiber reinforced mortar specimens, to determine the influence of the volume fraction of the fibers. In a random sample of these agave fibers, the tensile strength ranged from about 40 to 70 x 10^3 psi, while the modulus of elasticity ranged from about 1.0 to 1.7 x 10^6 psi at 1.56 percent strain. These values compare quite favorably with man-made fibers.

Flexural tests were performed on mortar matrix specimens 12 inches long, 3 inches wide, and 1/2 inch thick. Fibers were cut to lengths of between 2 and 3 inches and mixed into the mortar in different volume fractions. Figure 8 shows average load-deflection curves of beam specimens reinforced with Maguey fibers for different volume fractions. It was generally observed that first cracking in flexure is not significantly influenced by the volume fraction of fibers. However, for a volume fraction greater than about 7 percent the load increases beyond first crack, providing the desired ductile behavior. Equivalent flexural stresses in the composite matrix with a 10 percent fiber volume fraction were

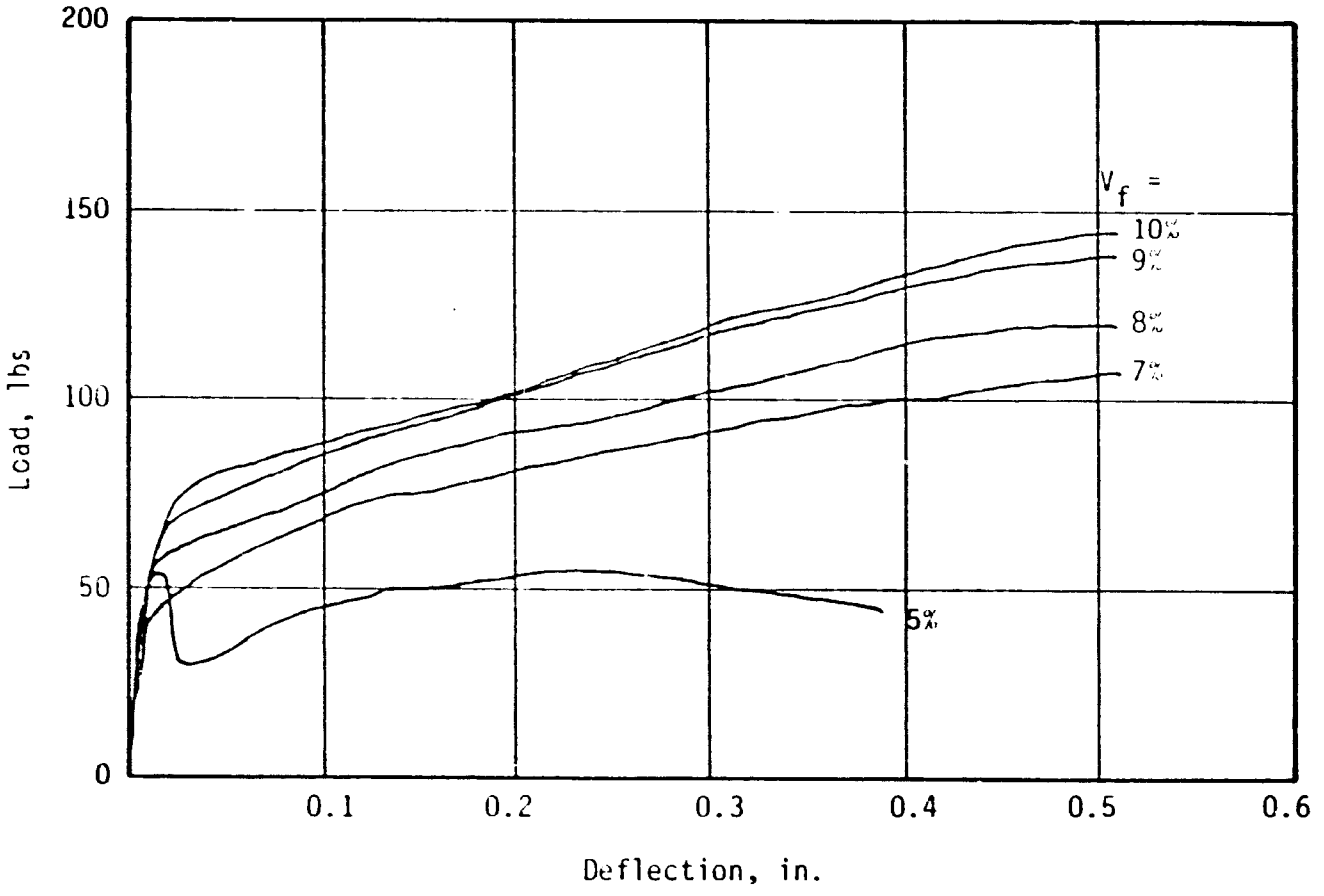


FIG. 8

Average Load-Deflection Curves of
Beams Reinforced with Maguey Fibers (12)

three times higher than the flexural strength of plain mortar specimens. It was also observed that with high fiber volume fractions the increased load capacity, after the first crack, was accompanied by multiple cracking in the specimens, showing a favorable distribution of stresses at ultimate load.

In the United States, man-made fibers such as polypropylene and polyester are readily available and relatively inexpensive, and, therefore, show promise in the poured adobe process. These fibers have ultimate strengths of between 50 and 80 x 10^3 psi and were primarily developed for use in the concrete industry to provide resistance to shrinkage cracking and to increase impact strength.

The addition of fibers to the adobe mix, in many respects, is analogous to the traditional addition of straw to help prevent cracking. However, the strength of the agave fibers and man-made fibers appear to be much greater than straw and can further provide resistance to brittle failure during earthquakes.

Bamboo Reinforcing

As a substitute for steel wire reinforcing, the use of bamboo shows potential for mitigating the shrinkage cracking of adobe associated with steel reinforcing. It was pointed out by Fang, et al. (13) that bamboo contains a large percentage of high strength fibers with ultimate strengths up to 25 x 10^3 psi.

The swelling and shrinking property of bamboo, which makes it undesirable for concrete construction, may in fact make it desirable for use in poured adobe construction. When dry bamboo absorbs water, swelling occurs. If the swelling pressure is large enough, it pushes the wet mix aside. At the end of the curing period for concrete the bamboo loses its water and shrinks at a greater rate than the concrete, leaving voids between the bamboo and concrete.

On the other hand, if wet bamboo is placed in poured adobe walls, both the adobe and the bamboo will shrink during the drying period for adobe. If the adobe mix is properly controlled, the shrinkage rates of the adobe and bamboo will be compatible, leaving no voids between adobe and bamboo.

Conclusions and Recommendations

The main conclusion of this paper is that the technique of using reinforced poured adobe as a structural load-bearing material can meet the intent of the UBC provisions for residential buildings in high seismic zones. The desired ductility and strength can be provided with the inclusion of welded steel wire fabric or other types of reinforcement in the walls. In lieu of experimental strength data, the existing technology for reinforced masonry appears to be adaptable to reinforced poured adobe.

Several areas of research needs are implied in this paper, the most pressing of which is the need for information on the static and dynamic behavior of poured adobe walls and structures subjected to vertical and lateral loads. Wall strengths must be tested both in-plane and out-of-plane. Many types of strength tests routinely performed on different masonry units will also prove to be appropriate for poured adobe. Shake table tests, similar to those performed by Meli, et al. (1) on unreinforced block adobe structures should be performed on scale reinforced poured adobe structures.

Finally, it is recommended that serious consideration be given to constructing and instrumenting one or more half-scale, half-strength poured adobe structures in an area of high seismicity, such as the Imperial Valley of California, where the occurrence rate of moderate-magnitude earthquakes is high enough to actually collect field data on the seismic behavior of these structures within a relatively short period of time.

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FOREWORD

The papers printed in these Proceedings of the International Workshop on Earthen Buildings in Seismic Areas represent the contributions of participants at the conference as well as other authors. Not all of the papers are original and have been presented, at least in part, at other forums. However, they were submitted for this publication, and we felt it of value to include them because they provided relevant background to the conference theme.

Assigning the papers to one of the five topics turned out to be somewhat difficult because of the overlap in the categories. We have attempted to use our best judgement in these decisions

Finally, in the interests of cost and time, it was not possible to reset the type nor to do more than a superficial job of editing the papers.

Gerald W. May
University of New Mexico

Frederick C. Cuny
Intertect

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EARTHEN BUILDINGS IN SEISMIC AREAS

SOCIAL, ECONOMIC AND CULTURAL ASPECTS

The following individual made a keynote presentation:

Ian R. Davis, Professor
Oxford Polytechnic University
Headington, Oxford, UK

The following individuals acted as Session Chairmen:

Paul Oliver
Oxford Polytechnic University
Headington, Oxford, UK

Ian R. Davis
Oxford Polytechnic University
Headington, Oxford, UK

Marco Tulio Gomez C.
Consejo Nacional para la Protección de la Antigua Guatemala
La Antigua Guatemala, Guatemala, CA

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EARTHQUAKE:
HISTORICAL CENTRES AND STONE BUILDINGS IN SOUTH ITALY

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Luciana Betocchi
Luigi Petrucci

Università degli Studi di Napoli,
Facoltà di Architettura, Istituto di Urbanistica.

ABSTRACT

- Objects of the research.
- Historical Town Morphology: Compact Towns
  Territorial Towns.
- Aggregation of Typological Units:
  Row Aggregation
  Aggregation around collective spaces
  Urban Block.
- Type of Housing.
- Building Features.
- Consequences of the Earthquake:
  Damages to the Urban Morphology
  Damages to the Buildings.
- Problems of Conservation:
  Conservation of the Urban Morphology
  Interventation of Repair.

Objects of the Research

After the recent earthquake of November 1980 in Southern Italy, the problem arises of how to deal with the traditional housing of a wide area including the regions of Campania and Basilicata.

The traditional buildings of the small towns in these regions have enough recurrent characteristics, so that the study of a sample area can give sufficient informations for the whole question.

We therefore refer to a research in a district of Irpinia (region of Campania) that we began before the earthquake and still in process. (•)

It is our opinion that the damages caused by an earthquake to the structures of a human settlement are of two different types: the first refers to the statical structures of buildings: the second, on a wider scale, refers to the modifications of the townscape owing to the destruction of entire quarters, to the subsequent enlarging of the streets, etc.

In the same way, the problems regard to repair and rehabilitation refer to not only to the first type of damages, but also to the second; especially when the morphology of the historical centres forms an heritage of particular historical and etnographical interest, as it is the case of Irpinia.

We will then expose the characteristics of the morphology of the traditional settlement and of the single buildings in this area, and afterwards the damages caused to the two types of structures and some types of implementation.

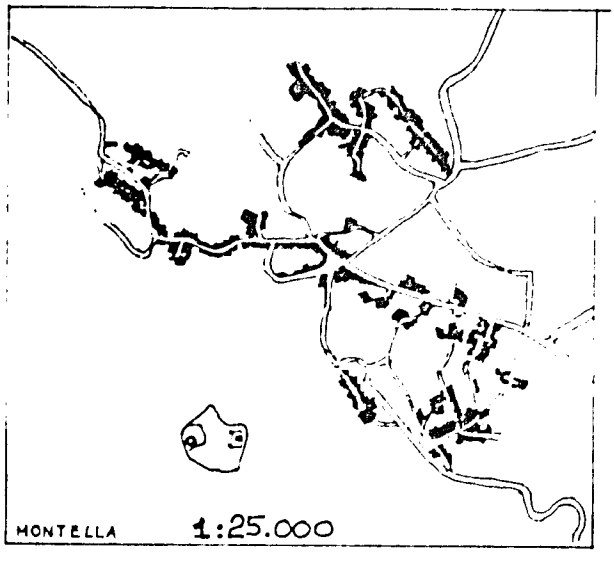
(•) The study we are referring to has been made by appointment of public agency, the FORMEZ Centro di Formazione e Studi per il Mezzogiorno. It regards the analysis of the urban morphology and the housing typology in an area including 12 small towns. At present, the research regards the damages caused by the earthquake, and will be edited by the FORMEZ.

That study has been made by the same autors of this paper.

Historical Town Morphology

Every settlement, in the area we are describing, although of small dimensions, has the characteristics of a small town: i.e. a complex and hierarchically organized morphology and a system of collective places and monuments.

We can subdivide them in two kind of settlement, we will call the "compact towns" and the "territorial towns".



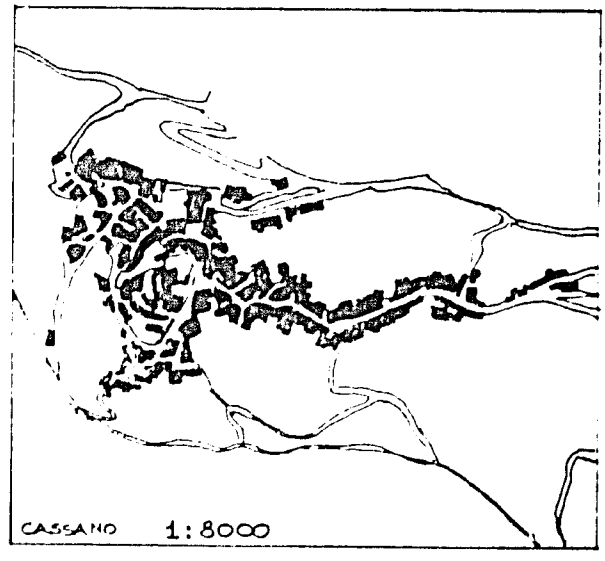


FIG. I

a) Compact Town b) Territorial Town

Compact Towns

Being in dominant position over the surrounding country, in naturally defended places or surrounded by walls, these centres, founded about 12th century, often have a castle on their top, near which the houses were built; the church, not apparent from the building texture, is placed in marginal position, near the walls. The "borghi", i.e. the new nuclei, grew along the main roads, out of the centre, forming a radial pattern. (Fig.1a)

Territorial Towns

The territorial towns consist of system of small scattered hamlets, connected by country roads. These so called "casali" however are not simple groups of houses, but have a clearly defined urban pattern, in which some monuments are placed.

These towns have different characteristics which dipend on the distance among the settlements, i.e. on the variations of the ratio between built areas and country. (Fig.Ib)

The historical evolution sometimes has caused the junction of the ancient nuclei by the new buildings.

The morphological system of compact and territorial towns is still of medieval type, while buildings are mostly built during the I8th century, i.e. after the great earthquakes happened at the end of I7th century.

Aggregation of Typological Units

The urban tissue of historical towns is sellom organized in a system of block, but more frequently it has complex forms of aggregation uf minimum units.

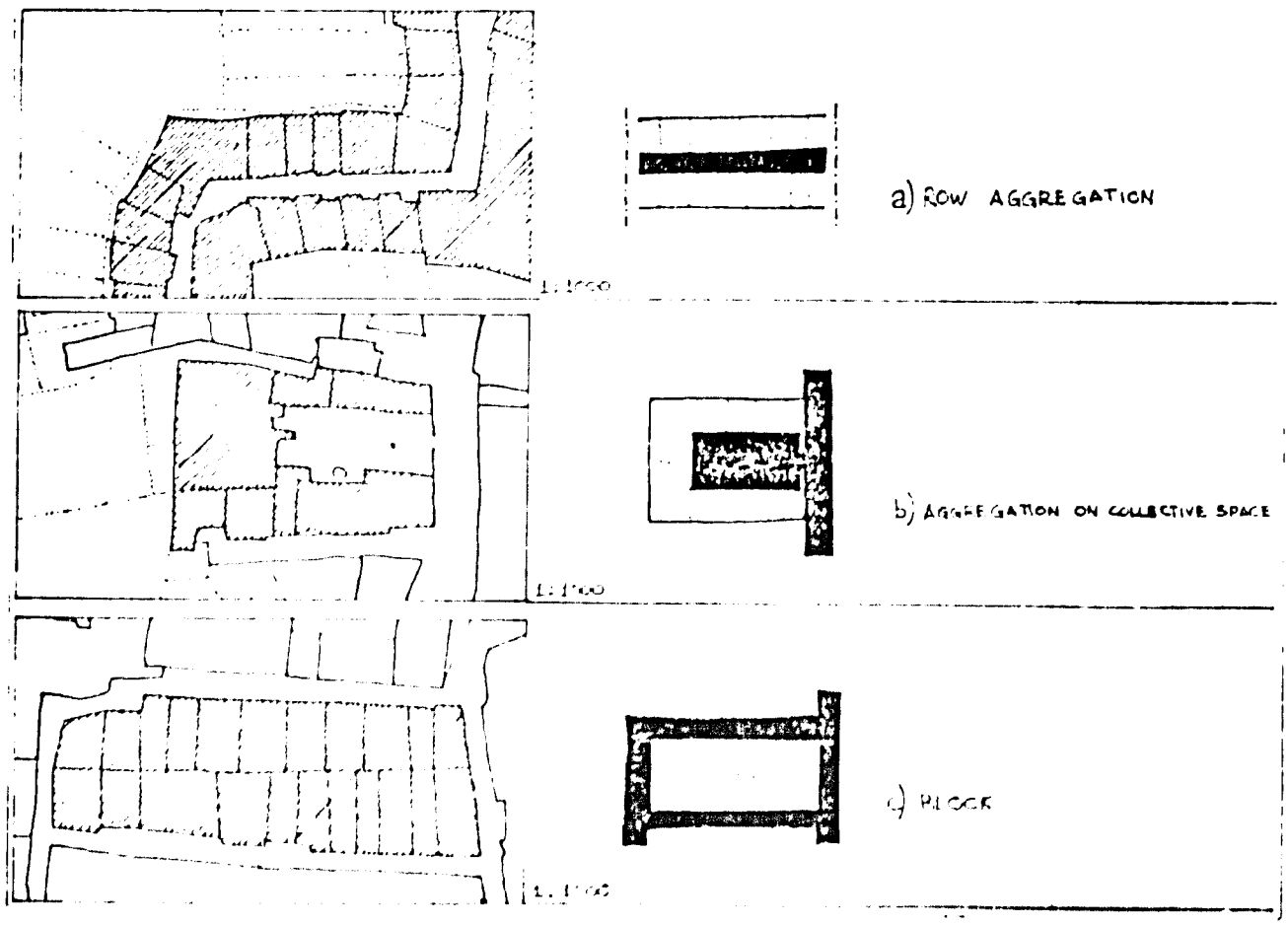


FIG. 3

Row Aggregations

Most frequently, the houses are ranged simmetrically in lines exclusively determined by the streets. (Fig.3a)

Aggregations around Collective Spaces

In other cases, houses are aggregated around dead-end streets: the street then is transformed into a route of distribution.

These aggregations around collective spaces are generally the mediation between public space of the town and tilled land.

The forms of the collective space are different (Fig.4 a,b,c): court, bent or rectilineal narrow street. The entrance in this space is through an archivolt.

Urban Blocks

Urban blocks are to be found only in towns whose foundation, generally in the Middle Ages, was planned. Thus the more urban character of the historic centre is revealed by the connection of houses only with public places and not with tilled land.

Sometimes the blocks have unbuilt places within them.

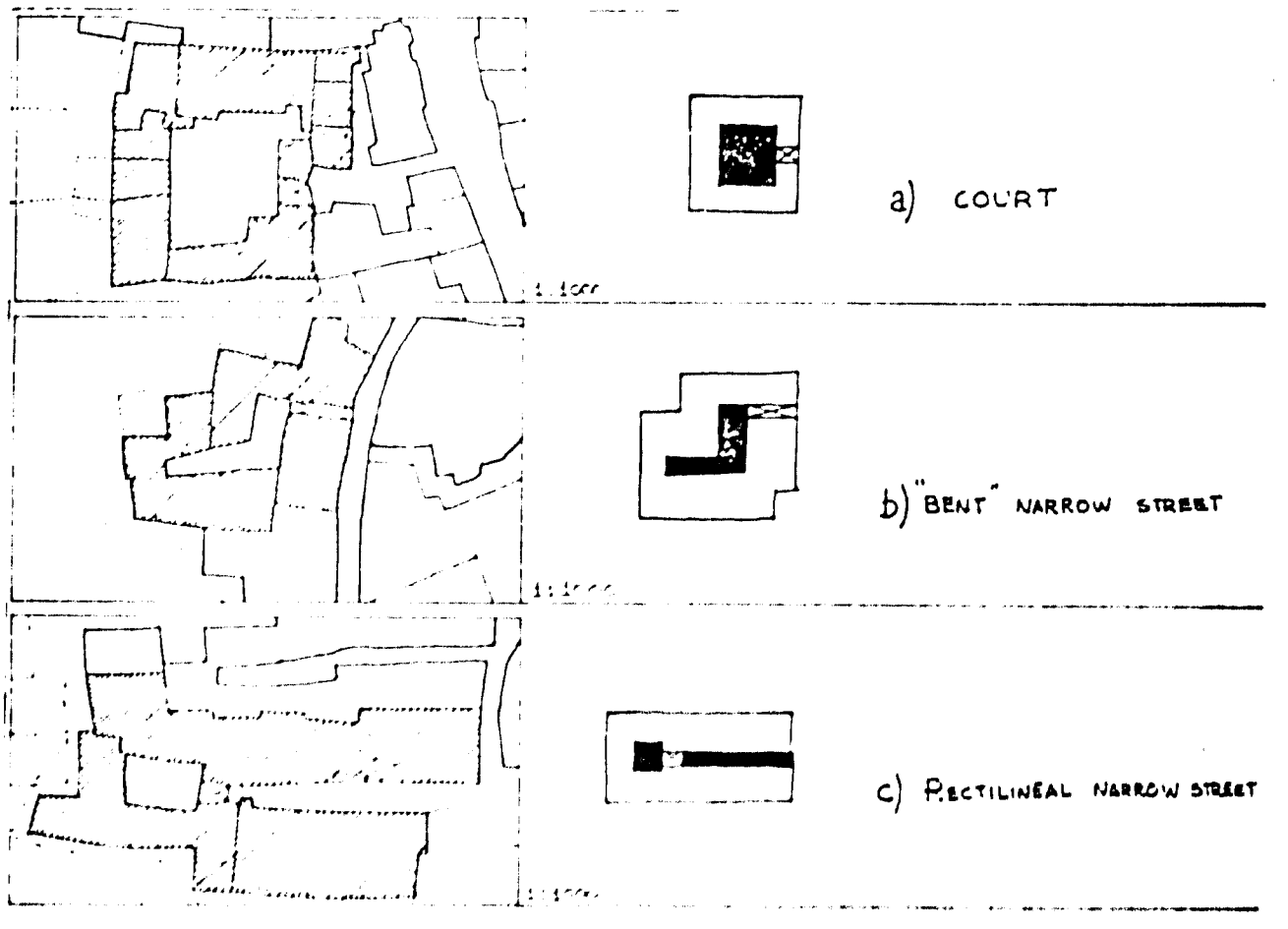


FIG. 1

Type of Housing

Poor residential buildings, generally row houses, are single family dwellings.

Minimum typological unit has small size: it is 4-5 metres (on facade) by 8-10, and consists of two floors.

The first one (popularly named "sottano") is used for tools or wooden storage, sometimes as stable.

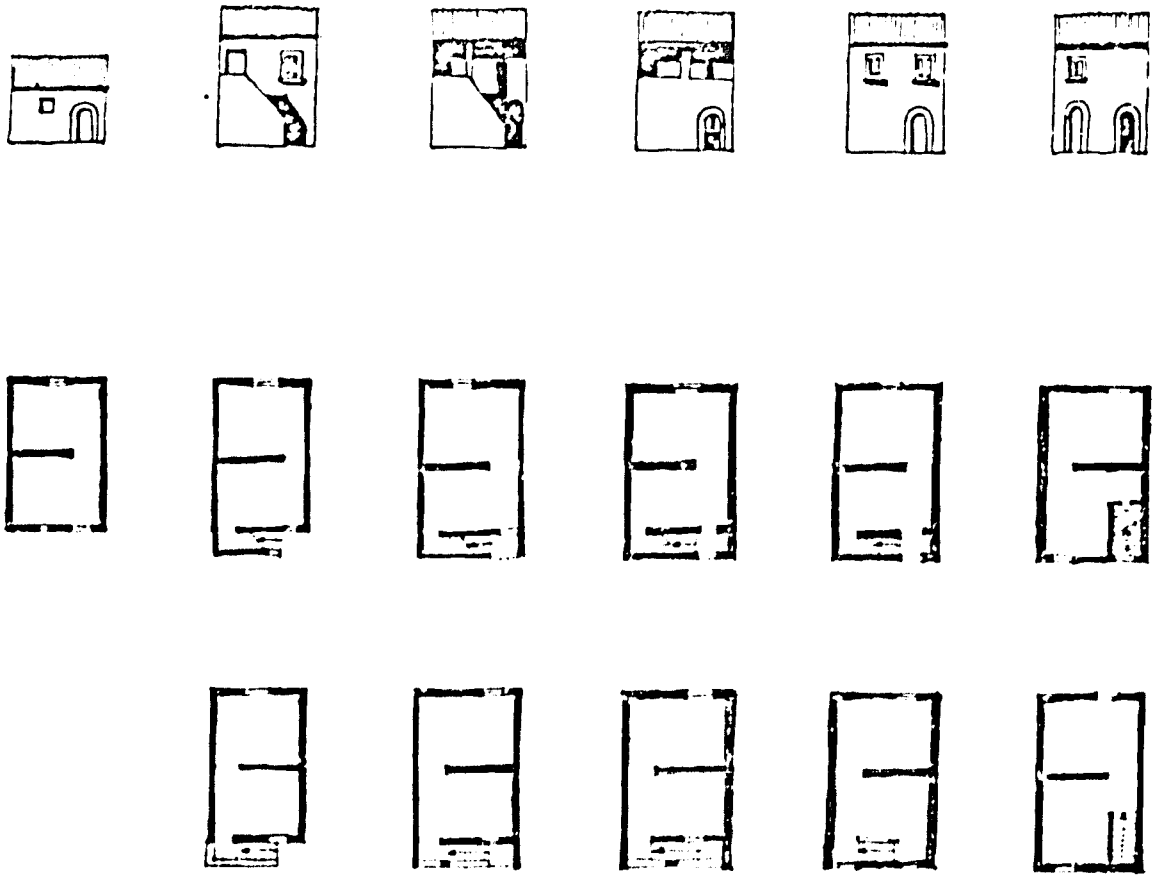


FIG. 5
Variations of minimum typological unit

The stairs are an important element in the construction (and design) of the front facade, to which they are parallel. Their stylistic variations form a fairly definite evolutive process.

In a first stage, the stairs, built with limestone, with parapet, are uncovered; in the following stage, owing to climatic conditions, the stairs are covered by the continuation of the slope of the roof, supported by a small wooden pillar.

Thus the stairs and their landing, with their cover, form a

"loggia", that acts as "atrium" (entrance) of the house.

Other variations aim the loggia's theme, hiding the stairs behind a wing-wall.

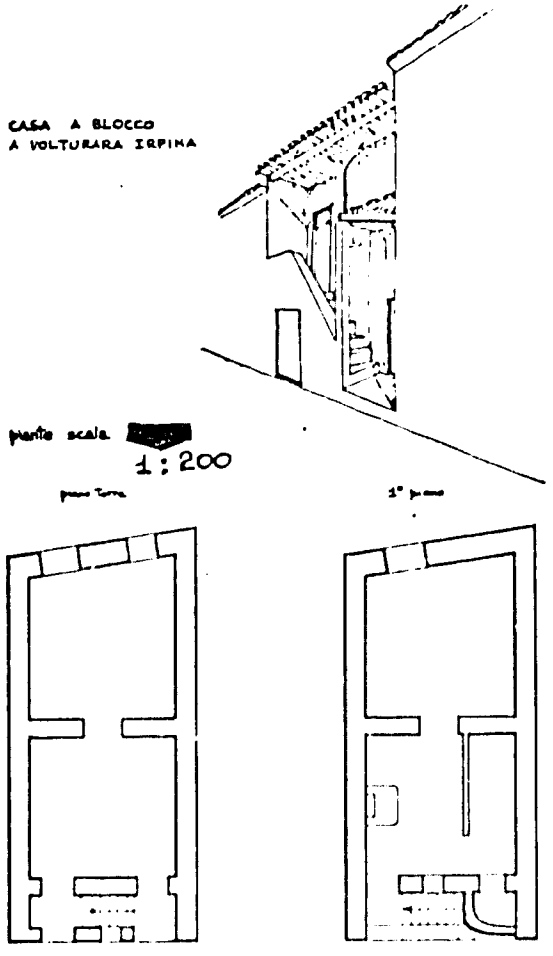


FIG. 6
Typical house

The interior organization of the house is very simple: the front door open into the kitchen, where are the fireplace and the oven, that is the centre of daily life: the only contiguous room is a bedroom.

The fireplace and the oven are immovable furniture: the first one has no mantle and it generally consists of a low stone-step with little chimney; the oven is, generally, jutting outside the house and, with its plastic form, concurs to define the facade.

Houses with internal stairs are very frequents too: the stairs are placed ortogonal to the facade, where there are two different entrances: the first one to the stairs and the other one to the ground floor room.

A variation of this minimum typological unit lies in some

centres that are on steep sloop. We call this type of house "slant-house", it uses natural ground: condition to obtain a floor below the street level. The houses in the lowest level have some rooms excavated in the rock.

Building Features

The houses are built with supporting walls. The walls are made by two facings of irregular blocks of limestone, in which orizontal rows of little stones or bricks constitute periodical levellings at a distance of about I metre. The little space between the two facings is filled with mortar and little stones. The wall is about cm.60 thick.

The corners are sometimes built with large stone blocks, but there isn't real toothing between the walls.

The portals on the facade are arch shaped, built with squared blocks of white limestone. The opening of the interior doors and of the windows have a wooden architrave on them.

The floors are built with wooden beams, at distance of about cm.90, which are placed parallel to the facade.

The saddle-roof is built with a wooden ridge-beam (so called "cérmene") between the two tops of the timpanums formed by the lateral walls. The other beams rest on the ridge beam and on the on the facade wall; over these, there are a planking and a bent tile covering. (Fig.5a)

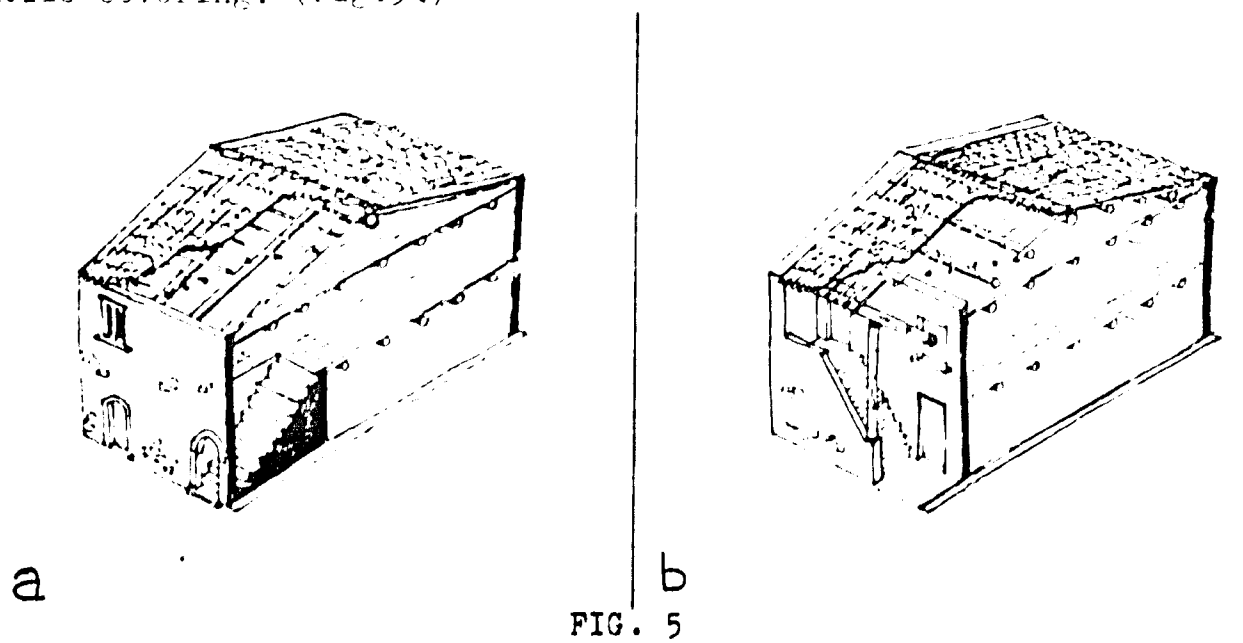


FIG. 5

There is another kind of roof construction, that is generally used in the houses with stairs-loggia. This kind of roof gave good results during the earthquake because it hasn't pushing effect. This roof is constructed with main beems that are parallel to the ridge beem, and therefore parallel to the facade. A thick set of wooden joists, over which the bent tiles are, rest on main beems.

Consequences of the Earthquake

Damages to the Morphology of the Centres

If we refer now to the destruction, and relating first to the wider scale of the urban tissue, we may observe that a different intensity of destruction is to be found in the different types of settlement we have described.

The damage intensity can be generally subdivided in three cases:

I) great quantity of destruction not only of the buildings but of all parts of the street pattern and even of the major features of the skyline;

2) destruction mainly concentrated in less extensive parts of the town, without the main stuctura of streets and sites being altered; in this case the streets layout within these parts may or may not have remained uninjured;

3) scattered damages at buildings.

First of all, we have to remark that, as far as these features are concerned, the demolitions and the openings of paths, to remove materials after the earthquake, have an important influence on the state of conservation, so that the effects of this phase have to be taken in account sometimes as much as those of the earthquake itself.

Next we can see, according to the classification of settlements, we have proposed, that the second type, the territorial towns, owing to the different geodynamic conditions of the single nuclei, has been affected by more differenciated damages, so that it is mostly to be placed in the second or third case we have shown.

The most serious cases of destruction have instead happened in the compact centres, and chiefly in the areas of steep slope.

Damages to the Buildings

Apart from the total collapses, we intend to mention only the

slighter types of damages, caused by the action of the earthquake, which are easily reparable.

Some collapses have happened at the top of the outer walls (sometimes the outer facing), owing to the presence of a pushing roof.

The inefficacious connection between orthogonal walls, with the addition of the push of roofs, has frequently caused cracks by detachment of transversal walls (localized in corners and intersections), and sometimes the partial collapse or, in extreme cases the total collapse of these transversal walls.

The action of earthquake is often added to a bad state of conservation: some buildings were already cracked, the walls were already weakened by the pulverization of the mortars and there were also floors and roofs unsettled.

We have already mentioned the main types of damages related to te features of building system, we wont now stress some other characteristics.

First of all, the presence of row houses has two tipical effects:

I) lateral walls without openings, and therefore more resistant;
2) the collapses are confined within the limits of the single allotments.

In the second place, the type of house with the stairs-log ia, or generally with stairs parallel to the facade, seems to be more resistant, because the roof beems are parallel to the facade (not pushing roof), and for the buttres effect that the stairs have on the facade.

Problems of Conservation

Conservation of the Urban Morphology

The morphology of the historical centres of Irpinia forms an heritage of particular historical interest, so every effort will be made to preserve those cultural worths; therefore we propose some types of intervention, and we relate them to the three cases of the damage intensity:
I) In this case, the problem is to re-plan some urban places, living in the collective memory, as squares, monuments etc.; a new urban plan may be planned to confirm the ancient skyline and the type of ancient urban tissue, starting from the collective places

and around the single elements of architecture or of urban tissue that are "survived";
2) the damages are concentrated in less extensive parts and the urban morphology has been less altered, it is possible to rehabilitate large pieces of urban tissue; the new interventation of rebuilding must solder these entirely defined pieces, so as not to modify the urban structure, and may respect and reconfirm the hierarchy of places and the streets layout, the building volumes, the housing typology (making the conditions of habitableness better), and every character of this architecture.
3) the problem is restricted to rebuilding of single houses.

Interventions of Repair

The interventions of repair must restore and make better the supporting structures: they must strengthen the walls, the floors, the roofs and the foundations, the connection between orthogonal walls.

We think that the strengthening of the walls (in this type of structures) may be better obtained by the application, on two faces, of electric-welded metallic nets, suitably united, covered with cemented plaster or with concrete with additives (Betoncino). This technique is easily applicable and give good results, but imposes the application of plasters on the walls, that is a stylistic violation to the traditional stone.

Horizontal connections and joints between orthogonal walls are realized by the insertion of iron bars and concrete injections in bored holes.

It is more difficult to employ tie-rods, with steel cables, because it is often difficult to work in impervious places.

The sloping beams may be connected each other by wooden or iron tiebeams: they must be anchored, by iron plates, to a stiffening wall corsion, that is constructed with reinforced concrete or with concrete and electric-welded metallic nets.

These repairs have not yet been experimented on the examined area, but in other sismic areas of Italy (Friuli or Umbria).

NON-CONVENTIONAL METHODS OF FINANCING HOUSING FOR LOW INCOME URBAN HOUSEHOLDS IN PERU

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ABSTRACT

Two methods are described: 1) Modification of conventional methods in an established institution - the home improvement loan program of the savings and loan system. 2) Establishment of a new method in a new institution - the Construction Materials Bank. The descriptions are set in the context of how these methods address the limitations of conventional financing. The same procedures could be applied to financing adobe dwellings.

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Preface

In Peru, adobe construction is used primarily by low income families to construct simple and inexpensive shelter. In the rural setting both the preparation of the adobes and the actual construction using additional local materials is done by self-help labor provided by family members and/or neighbors of the community. This is done to minimize the cost of shelter. In urban areas, however, the preparation of the adobes is often contracted or the adobes are purchased ready made from a local producer. Sometimes the construction labor is contracted as well. Thus, in the urban setting adobe shelter is a potential client for medium and long term financing. In order to adequately serve low income households such financing must be non-conventional in that it must consider the constraints and needs specific to these households.

Currently in Peru, there are two non-conventional financing programs for low-income housing. Although to date these programs have financed only dwelling units using standard (i.e., non-adobe) materials and employing standard construction methods, they are presented to this workshop since these methods could also be applied to the construction of adobe housing for low-income households.*

* It should be noted that throughout this paper the term "household" is generally used instead of "family". A "family" - either nuclear or extended - consists of individuals biologically related. In contrast a "household" merely consists of a group of individuals living under the same roof either related or not. This latter is a broader term which more accurately reflects the current living situation of urban low income groups in Peru.

I. Introduction

A. Statement of the Problem

In Peru, as in most of Latin America, urbanization has been on a large scale and rapid in process. Urban population growth averaged 5.9% per annum from 1961 to 1972 as compared to only .7% p.a. for rural population and 2.9% p.a. for the total population(1). Of Peru's total population of 17.8 million in 1980, 12 million or 67.4% is urban (over 2,000 people). Population in urban areas is projected to double by the year 2000, when it will represent 78.5% of total population(2).

The main factor causing this urban explosion has been the rural to urban migration which involves a movement primarily from the highlands to the more developed coastal areas, an increasing concentration in larger cities, and the overwhelming primacy of the capital city, Lima. Although more than half of Peru's total urban population is found in Lima, medium sized cities are now growing at a faster rate.

The shelter institutions have been unable to provide the resources for this population influx and growth. As a result, there has been an increase in inner city slums (tugurios) and the invasion of uninhabited land on the outskirts of the cities. The effects of the current economic recession and "galloping" inflation (approximately 60% in 1980)(3) have been felt most severely by the population of these areas, which includes the poorest groups on the income scale. The bottom 50% of income earners received only 11.4% of total incomes in December 1978-one of the most unequal income distributions in the world(4). As a result, these households cannot afford any conventional housing in the formal sector due to the high interest rates (currently 58.5% for loans over one year) and high construction costs (which presently increase faster than the general inflation rate).

In the squatter settlements or "pueblos jovenes" (young towns) families attempt to solve their shelter problems outside the conventional scheme through a slow process of incremental upgrading. Initially, the invaders put up reed-mat (esteras) huts, which they gradually transform over a long period of time to more permanent shelter. In fact, buying construction materials little by little when the household has a bit of extra income serves as a much better hedge against inflation than making savings deposits, the value of which is eroded by inflation. Unfortunately, due to the rapid increase in the cost of construction materials already mentioned, the time required to accumulate enough materials to complete an additional room, for example, may be several years since disposable real income buys progressively fewer materials.

B. Limitations of Conventional Financing

As indicated, in the current economic situation, conventional financing of housing is beyond the limited economic capacity of households with incomes below the median (estimated at $330 per month as of 3/81 for Lima).* As can be noted in Table 1, the monthly income required ($588) for financing merely a

* Housing Bank of Peru estimate for 3/81.

minimal habitable structure ($50m^2$) is nearly twice the median income.

In order to be successful non-conventional financing of low income housing must address not only economic constraints/needs, but also legal and procedural issues caused by the particular status and customs of the low income groups.

The divergence between criteria/terms of conventional financing and the constraints/needs of low income households are shown in Table 2. Particular aspects of the problem are shown in the left column and contrasted with the respective viewpoints of low income households in the right column.

TABLE 1

CONVENTIONAL FINANCING OF HOUSING
LIMA, PERU (3/81) (US$)

Type House	Cost per m^2(S)	Cost per m^2(S)	House Size = $50m^2$ Roofed Area			House Size = $65m^2$ Roofed Area		
			Total Cost/ Loan Amount	Monthly Payment	Monthly Income Required	Total Cost/ Loan Amount	Monthly Payment	Monthly Income Required
Habitable Structure	8.94*	96.25*	4,813	235	588	6,256	306	765
Minimal Finishing	11.02	118.75	5,938	290	726	7,720	378	944
Normal Finishing	13.35	143.75	7,190	352	879	9,345	457	1,143

Conventional Financing Terms (3/81):

1) Interest - 58.5% (56.5% + 2% commission)
2) Term - 10 years**
3) No down payment
4) Monthly payment cannot exceed 40% of monthly income

* S/.400=$1

** S&Ls used to lend for 20 year terms, in which case the monthly payments would be somewhat lower. However, currently the few mortgage loans that are made are rarely longer than 10 years since at 20 years the real value of recovered funds is much lower.

TABLE 2

LIMITATIONS OF CONVENTIONAL FINANCING OF HOUSING* AS RELATED TO LOW INCOME HOUSEHOLDS (PERU) (6)

A. High Eligibility Criteria	A. Constraints Inherent to Low Income Households
1. Income - an "adequate" income at a specified minimum - usually higher than the median**	1. Income below the median**
2. Saving - regular saving at a specified minimum rate and/or a a certain mimimum percentage of loan amount	2. Intermittent saving at a very low rate and often not deposited
3. Employment - regular	3. Intermittent employment
4. Collateral - in form of mortgage guarant	4. Lack of land title in many cases prevents mortgage - guarantee
5. Construction license - required	5. Lack of land title prevents obtention of construction license
B. Restrictive Loan Terms	B. Needs of Low Income Households
6. Purpose of loans - for completed dwellings	6. Loans for gradual improvement of dwelling
7. Loan size - minimum amount is large	7. Small loans
8. Interest - at market rate	8. Interest at below market rate targeted exclusively to these households
9. Monthly payment - equivalent to 40% of monthly income	9. Allocations of lower percentage (25-30%) of household income
10. Processing - complicated terms and conditions; lengthly procedures for application processing	10. Simple, easily understood terms and rapid processing of application

*As found at savings and loan associations and other institutions which finance housing.

**The income groups below the median are defined by USAID as the target group for Housing Guaranty financing. This is the group that receives only 11.4% of the income in Peru. Also see Section II.C.1.

This paper describes two financing programs currently operating in Peru which attempt to address and reduce this divergence so as to make financing more accessible to low income urban households.

II. Home Improvement Loan Program: MEVI

A. Purpose

The purpose of this program (Mejoramiento de Vivienda - MEVI) is to assist low income urban households finance improvements on their existing structures by making home improvement loans available, the amount of which is determined by their capacity to pay. This thereby reduces the time required to receive the benefits of such improvements. As noted above, improvements in pueblos jovenes are normally made through an incremental building process by the investment of savings in building materials (rather than saving deposits), but that process is slow and difficult due to the rapid rise in construction costs. This program provides credit to households which could probably not obtain it otherwise and allows the materials for a specific improvement or improvements to be purchased all at once, thereby avoiding future cost increases.

This program is basically an experiment to determine if the loan recipients have the capacity to amortize relatively small loans with an interest rate below the rate for conventional housing loans.* Another objective is to determine if these loans will actually improve the living conditions in accord with the needs and desires of the borrowers. Apparently these objectives are being met and the Housing Bank of Peru (Banco de la Vivienda del Peru - BVP) is planning to expand the program.

B. Participating Institutions

The BVP was authorized by the U.S. Agency for International Development (AID) to borrow $2.5 million under the Housing Guaranty Program (see description in Annex A). Of this amount $1.5 million was designated for home improvement loans to low income households. The BVP lends these funds to the six participating savings and loan associations (S&Ls) in various parts of the country, which in turn make the individual sub-loans.

C. Program Design and Implementation as Related to Conventional Limitations

The following describes the program design and implementation problems in relation to the limitations of conventional financing indicated in Table 2 and how this program has attempted to deal with these limitations. MEVI has required some significant policy changes by the participating S&Ls and the BVP in an attempt to reach low income households in the context of the current economic situation.

It should be kept in mind that some of these aspects are parameters established by AID and/or the BVP for the sub-loans (See Annex B) and others are specific to each S&L in accordance with their own policies, but within the broad

* The interest rate for this program is currently 27.5 points below the conventional interest rate.

AID/BVP project parameters.

1. Income

In an effort to assure that these loans reach the poorest households, AID has required that borrowers must have "family incomes" below the median for the respective urban zone (based on a congressional mandate) and that they must live in pueblos jovenes or similar areas. That is, a maximum, rather than a minimum income level has been established by AID and in turn by the BVP. This has caused a problem in some areas where households with median incomes or below had little, if any, debt capacity. In this sense, then, there is a minimum income since the amount of disposable income must be equal to or greater than the monthly payment. This problem was alleviated somewhat by increasing the maximum loan term from 3 to 7 years. Also, the estimated median income is adjusted upward every three months by a rise in the consumer price index. However, this conflict of the "floor pushing against the ceiling" is always a potential problem. This is discussed further in Section II.C.9.

2. Saving

In none of the participating S&Ls is regular saving or percentage of the loan amount on deposit a requirement to obtain a MEVI loan. However, in virtually all participating S&Ls it is required that the borrower has opened a savings account with a small deposit. As mentioned, currently savings, which pay a negative rate (50.5% - 60%* = -9.5%), are not as desirable an investment as the purchase of building materials. However, it is hoped that once the inflation rate and the savings deposit rate are more in line that these borrowers will become accustomed to regular saving. At this time, however, requiring regular forced savings on a percentage of the loan amount as a condition for loans would be a disservice to low income borrowers, although some may already make voluntary deposits for short periods.

3. Employment

One study determined that approximately 40% of low income earners have unstable or intermittent incomes (e.g., street vendors)(7). Of the 1980 labor force 47.9% were independent workers (presumably intermittent income) (8). Thus none of the S&Ls have required stable incomes for MEVI borrowers; only that the income be verified by the employer or, in the case of self-employment, that the borrower signs a sworn statement as to the type of occupation and his/her average monthly income.

4. Collateral

Since many pueblos jovenes residents in certain areas (such as Lima) have not received titles to their lots, a mortgage guarantee is not a feasible requirement. Consequently, for the MEVI Program the S&Ls have tried to develop a set

* Inflation rate 1980.

of acceptable alternative guarantees such as:

a. Employer's guarantee
b. Commercial establishment guarantee
c. Guarantee of solvent third person
d. Time Deposits for maximum of one year (at which time they would be replaced with another guarantee)
e. Salary deduction backed by up to 50% of the employee's indemnification fund.

In approximately 44% of the home improvement loans made to date, the participating S&Ls have accepted such non-mortgage guarantees as collateral.

Naturally, where the entitlement process is more advanced, the S&Ls prefer to have a mortgage guarantee when the borrower has title to his lot.

Some S&Ls have also accepted a global guarantee from housing cooperatives. This means that the total terrain of the cooperative is used to guarantee the loans of borrower members. Naturally, all cooperative members, both borrowers and non-borrowers, would have to approve this procedure in a general assembly to avoid potential future conflicts. This approach has the advantage that when a borrower becomes delinquent, other borrowers/members presumably would apply social pressure on him/her to pay so as to protect their own terrain against possible foreclosure.

Another S&L has used employer or commerical guarantees as transitory until land title is acquired, at which time the conversion is made to a mortgage guarantee.

Even though it does not serve as a guarantee, some S&Ls have required, in addition to the regular guarantee, that the borrower present documentation to prove he or she has a right to occupy the lot to assure that he or she will not be forced off the lot/relocated after the investment has been made in the construction.

5. Construction License

According to the law on construction licenses (building permits), all construction, including improvements such as finishing work, requires a construction license, which is issued by the local municipal government. Unfortunately, one of the requirements to obtain this license is that the applicant possess title to his land, an unrealistic condition for many pueblos jovenes residents. Also required are plans drawn by a professional engineer, an expensive proposition for low income households. In addition, the process is complicated and time consuming.

Consequently, for the MEVI Program some S&Ls have merely ignored this unrealistic (as relates to pueblos jovenes) law and not required the construction license of loan applicants. Others have required merely that the loan applicant show proof of having initiated the processing for the license when the applicant possesses a land title.

In the case of some housing cooperatives, where the house design as well as the improvements desired are basically the same for several members, it has been possible to obtain a single global construction license. One set of plans, the cost of which can be spread among members, and a global title are adequate to obtain such a license.

6. Purpose of Loans

Conventional loans are generally made only for completed units. However, MEVI resources are oriented exclusively towards gradually improving the existing unit. The program provides only partial solutions to the shelter needs of low income households, but it is in accord with the already existing incremental building approach described above. The possible uses for loans have been classified in eight categories of improvements. These are listed with the percentage of total improvements in each category.*

		Percentage of total home improvements as of 3/31/81.
a.	Installations - placement of electric, water and sewage systems in the home.	12.4
b.	Domestic connections - to the public service electric, water and sewage systems.	10.2
c.	Finishing - includes interior carpentry, plastering, floors, etc.	34.8
d.	Sanitary fixtures - such as placement or change of toilet, wash basin, shower, etc.	7.4
e.	Renovations - partial or complete change of deteriorated elements without a design modification in the structure.	1.9
f.	Conditioning - improvements that imply a structural design modification without expanding the roofed area.	2.1
g.	Expansion - of the structure to produce one or more additional rooms for bedrooms, bathrooms, kitchen, etc.	9.1
h.	Completion of structure - improvements such as columns, walls, beams, and roofs which complete the structure, including exterior carpentry.	22.1
		100.0

Most of the improvements have been for finishing work and for roofs to complete the structure.

7. Loan Size

Low income households do not have the debt capacity to amortize loans for completed dwellings. Consequently the program is designed to provide relatively small loans for "partial solutions".

* The total number of different improvements made is greater than the total number of loans since some borrowers made more than one type of improvement with the same loan.

The maximum loan amount established by AID and the BVP is the equivalent of $2,500. The minimum loan size was established by each S&L depending on what was administratively feasible to process. In actual practice, the smallest loans made have been $300-$500 (depending on the exchange rate). However, very few loans have been made in this range. Originally nearly all the S&Ls established maximum loan amounts less than the permitted maximum in an effort to make loans to the largest number of households possible with the limited funds available. However, this has become extremely difficult. During the year and a half of program implementation an increasing number of loans have been made closer to the maximum amount simply because the rise in material costs has meant that smaller loan amounts do not permit improvements that are beneficial and adequate. Currently (4/30/81), the average loan amount is approximately $1,900.

8. Interest

Even though the maximum interest rate which S&Ls are permitted to charge the borrowers for MEVI loans is 31% including 2% commission (some S&Ls are charging less), this is still 27.5 points below the rate (58.5%) for conventional mortgage loans. In addition, with an inflation rate of 60%, the borrower is actually paying a negative interest rate of 29%, which means that each monthly loan payment costs him successively 2.42% less in real terms. Nevertheless, within the context of economic recession and inflation such interest rates mean that this program cannot reach the "poorest of the poor" urban households. It can reach only those with incomes closer to the median (maximum qualifying income) which is periodically adjusted upward to accord with the rise in the consumer price index.

From the standpoint of the lender (the S&L) a negative interest rate means a decapitalization of the funds repaid by the borrowers. Consequently, the interest rate on this program should not be lowered. If anything it should be raised. If the rate were to be lowered this program would be even less commercially viable and would have to be subsidized further by the government.*

Unfortunately, due to the current interest rates, the demand for conventional financing of housing has virtually disappeared, which has meant that S&Ls must lend primarily for short term commercial purposes (not the purpose for which they were created) to maintain their existence during the current crisis.

The MEVI program is an attempt to allow the S&Ls to return to the financing of housing, but for small home improvement loans at less than the market interest rate. Funds are provided to the BVP at commerical U.S. rates, which are considerably lower than current local Peruvian rates for both savings and loans. The rate (17%) which the BVP lends to the S&Ls is 33.5 to 37 points less than what they must pay for savings deposits (50.5 to 54%), which is their main source of funds.

* The Government of Peru partially subsidizes this program by assuming the devaluation costs of repaying the AID HG loan in dollars at the current exchange rate (rather than at the rate originally received).

9. Monthly Payment

As mentioned, in some cases the loan terms were lengthened so as to provide lower monthly payments to borrowers. However, since loan amounts have increased in order to provide the same improvement, borrowers have nad to accept a higher payment or a lesser improvement.* Thus the benefits of increasing the loan term have eroded. Also, there is a sharply diminishing benefit by increasing the loan term beyond 5 years as can be seen in Figure 1.

Most of the S&Ls in the MEVI Program have allowed the monthly payment to be a maximum of 40% of household income (limit established by the BVP for conventional loans). This limit should probably be much less (20 - 25%) for low income households. The higher this maximum, the lower the qualifying income, but it appears that those with lower incomes have less percentage of income available to amortize a loan for housing. If we assume for the sake of illustration (see Table 3) that as a household's income decreases, their disposable income as a percentage also decreases, we can see that, theoretically, only those with the higher incomes (required when the ratio of payment to income is lower) can afford to make the payments without creating a deficit. Such a deficit means reducing other living expenses (e.g., food, health) or becoming delinquent.

In any case, it seems obvious that applying an arbitrary percentage to income to determine what a family can afford has certain inherent dangers, particularly at lower income levels. For example, if a household is assigned a monthly payment equivalent to 40% of their income, but they can only in fact afford 15%, the loan is really creating rather than alleviating hardships. Therefore, it seems like a case specific analysis of income less average monthly expenses should be done to more closely determine the individual disposable income.

One way some institutions have recently tried to reduce monthly loan payments initially is to establish a system of gradually increasing (periodic increments) payments to correspond to the expected increase in household income. This system basically defers payment of part of principal along with the interest that corresponds to this part to the middle or end of the loan term. Obviously, this has certain risks in that household income may not increase as expected. This system of graduated payments has not yet been applied to the MEVI Program.

* As an example, one year ago a loan of $1.500 may have provided a roof to cover 100m^2. Now to roof the same area may cost $2,400 (60% inflation). Assuming the loan term were the same this would mean a higher monthly payment (e.g., $103 per month for 3 years at 31% instead of $64). If the loan term were increased to 5 years, the monthly payment for the larger loan would be $79. If the borrower's income has gone up enough to cover this higher payment, he/she could still roof the same area. Otherwise the area to be roofed would have to be reduced so that the monthly payment would be equal to or less than his disposable income.

TABLE 3

ILLUSTRATIVE RELATION OF MONTHLY LOAN PAYMENT TO HOUSEHOLD INCOME

If monthly payment cannot exceed ___% of household income:	And the monthly payment is: ($)	Then the required household income is: ($)	Estimated disposable income available to make loan payment*		Excess/ (deficit)** after making loan payment ($)
			%Household Income	Amount ($)	
15%	120	800	40%	320	200
20	120	600	35	210	90
25	120	480	30	144	24
30	120	400	25	100	(20)
35	120	343	20	68	(52)
40	120	300 (median)	15	45	(75)

*These estimates are merely illustrative (not based on any specific study) to show how a family's disposable income decreases in relative terms (i.e., as a percentage of income) as well as in absolute terms in relation to total household income.

**Deficit means other living expenses (e.g., food, health) will have to be reduced to make payment or borrower will become delinquent.

Nevertheless, to date of the 456 loans (4/81) made in the MEVI program there have only been one or two delinquencies in repayments. This low rate of delinquency may be due to careful analysis of debt capacity or it may be that some borrowers have additional unreported income which allows adequate disposable income for making loan payments.

10. Processing

An objective of the participating S&Ls is the rapid processing and approval of loan applications to minimize the impact of material price increases. In addition, all have prepared simple and concise program descriptions to assist applicants in understanding the requirements and terms of the loans and to serve as a memory aid. The documentation required from the loan applicants has been reduced to the minimum.

Since the loan amount is relatively small and in nearly 44% of the cases the loans are without mortgage guarantee (which must be inscribed in the public register - a slow process at best) and often a construction license is not required, it has been possible to eliminate several steps from the normal application processing. Also, one S&L has established levels of approval authority, so that only the largest loans must go to the Credit Committee for approval. Loans of lesser amounts may be approved by the General Manager. In other S&Ls, the Credit Committee meets frequently (once a week), so that all qualified applications can be approved at this level without delay.

D. Other Aspects of Design & Implementation

1. Promotion

For program implementation all but two of the participating S&Ls have either hired or assigned personnel full time to the program. An important aspect of promotion/borrower orientation has been the personal contact between MEVI program personnel and the loan applicants, both in the office and in the field. In some S&Ls the technician/promoter visits the applicants in their homes in order to assist them to fill out the loan application and subsequently prepare the proposed project budget on which the loan amount is based. In one area the regional office of the Housing Ministry provided this service in coordination with the S&L.

The communities in which to promote and implement the program have generally been been selected on the basis of pre-established criteria and in one case on a study of communities as well. In virtually all cases the S&L has initiated its contact with borrowers through local community leaders. Their support is important to program success, specifically in regard to acceptance by potential borrowers. These leaders often assist in program promotion by, for example, arranging community meetings where the S&L can explain the program. One S&L invited community leaders to make comments/suggestions after reading the proposed program parameters. In this way the beneficiaries (i.e., their representatives) felt involved in the design process and that their needs were being taken into consideration. This resulted in still greater support during the promotion stage.

Working with communities and community leaders is more efficient and more positive than strictly advertising in local media and waiting for applicants to come to the S&L office. This "outreach" approach shows residents of these areas that the S&L really wishes to help them - an image contrary to that generally held of S&Ls by low income households. It also means that several applicants can be visited in their houses in a shorter period as opposed to dealing with applicants widely dispersed.

2. Construction

During the construction phase it is also obviously more efficient to visit several projects in the same area for inspections/technical assistance. One S&L has used an architecture student not only for these construction phase inspections, but also for promotion as well with very positive results. In addition, his student status means that his salary is much lower than a professional engineer or architect, which allows the S&L to provide this service to borrowers at no extra cost.

The following kinds of labor have been employed in the implementation of the home improvement projects:

a. Contracted - the contractor/foreman is in charge of the contracting of labor as well as the purchase of materials for which he provides receipts to the borrower.

b. Self-help - borrower and the members of his/her family provide the labor. Borrower buys materials himself with loan proceeds.

c. Mutual-help - borrower and his neighbors provide the labor. Borrower, in turn, assists his neighbors on their projects. Borrower buys materials.

d. Self-help, labor contracted - borrower contracts the labor which he directs himself. Borrower buys materials.

e. Mixed - contractor/foreman directs borrower, and his/her family members and/or neighbors in unskilled labor. Contractor provides skilled labor. Contractor or borrower buys materials.

Although there are no statistics, the author has gotten the distinct impression from talking to several borrowers that a significant percentage of borrowers prefer to contract all the labor because they do not have either the time and/or the skill to do the home improvements themselves. However, nearly all borrowers probably help with some unskilled labor (e.g., carrying materials, mixing cement, etc.)

3. Program Status

As of April 30, 1981, the six participating S&Ls had approved a total of 456 loans representing an approximate dollar value of $865,000 or 57.7% of the total $1.5 million assigned to the program. The average loan size was $1,896.

III. In-Kind Loans: Construction Materials Bank

A. Objective and Background

The Construction Materials Bank (CMB) was created by law in September 1980. Its objective is to contribute to the solution of the housing deficit in Peru by providing loans in the form of construction materials for the construction, expansion and/or improvement of basic core housing and the respective complementary services by means of self-help, mutual help or other labor systems.

In the strict sense, the CMB is not a bank in that it is not controlled by the normal banking regulatory agency. Also, it does not receive savings from the public. Its current resources ($3.7 million) consist of a capital transfer from the Government of Peru and a loan from the Housing Bank of Peru (BVP). A US$5 million loan has been projected using AID/HG funds channeled through the BVP and the S&L system in which the CMB will contribute technical processing of loan applications (i.e., these funds will not form part of the CMB resources).

The CMB's efforts are oriented towards the residents of marginal settlements - those who live in a pueblo joven, low income development, housing cooperative, or housing association.* To date, the CMB has made loans only in Lima, but it will soon be developing regional offices in other cities.

The basic concept of the CMB is to make loans in the form of building materials instead of in cash. The list of materials which can be loaned is limited since the objective is to construct only a basic dwelling with minimum services to keep total costs low and within the debt capacity of low income individuals.

The purpose of making the loans in specified materials is to assure that:

1) the loan proceeds are not diverted to other uses by the borrower.
2) the borrower receives the best quality materials.
3) the borrower receives the materials at the lowest market price available.

In addition, low income borrowers are not accustomed to dealing with conventional banks. They usually go directly to material suppliers with their savings to purchase materials for gradual upgrading of their dwelling.

Due to the volume of materials purchased, the CMB has been able to get wholesale or better prices (in some cases directly from the factories - bricks and cement). However, the borrowers do not receive the materials at these prices. Instead, the CMB has established agreements with selected suppliers to provide the materials to borrowers at the lowest current market price available. The difference between these two prices (about 17% of the wholesale price) serves as income to the CMB to help cover operating and financial costs as well as some coverage of the loss in value of its capital due to inflation. The latter is a serious problem since the CMB lends at only 15%. However, the CMB is not

* The latter three are more advanced stages of development of what originally was either a land invasion or a relocation of invaders.

stockpiling materials for speculative purposes. The prices are guaranteed by suppliers and factories for only about 10 days. After that period both the CMB and the borrowers are subject to price increases.

B. Program Design and Implementation as Related to Conventional Limitations

Again, the description of the program and the aspects/problems of implementation will be related to how this program deals with the limitations of conventional financing presented in Table 2. This will also provide a means of comparison with the home improvement loan program (MEVI) of the BVP and S&Ls. A description of the program for borrowers, highlighting the main points, is provided in Annex C.

One major distinction between the two programs is that the MEVI Program is one line of credit of various that each participating S&L has and it has modified a conventional structure and procedures already in place to try to reach low income households. On the other hand, the CMB is a new institution created exclusively to address the housing needs of low income households, which gives it a certain advantage over the MEVI Program.

1. Income

The CMB has also established a general maximum qualifying income. Rather than establishing the median income as a maximum, the CMB has set a multiple (5 times) of the official minimum wage (established by the government) as the maximum income (currently the equivalent of $372). This is automatically adjusted by increases in the minimum wage. This maximum will automatically be adjusted for each region since the minimum wage varies from region to region. It should be pointed out that this maximum is individual (applicant) income only rather than "family income" as in the MEVI Program. Conceivably, then, there could be additional household income which would not be considered in qualifying the applicant, but which would assist him in making his payment.

On the other hand, the CMB also has a minimum income requirement which is determined by loan size and the amount of the monthly payment. This is discussed further in Section III.B.9.

2. Saving

Since the CMB does not accept savings deposits from the public, regular saving is not a requirement of the loan. However, a down payment of 5%-20% is required (depending on the guarantee and loan size) which would indirectly require the borrower to save to accumulate this amount.

3. Employment

As in the MEVI Program, the borrower is not required by the CMB to have regular employment. All that is required is that a pay stub be presented as documentation or, in the case of self-employment, that the borrower present a sworn statement of average income and type of occupation. In actual practice, approximately 90% of the borrowers to date have regular employment. One need, perhaps, is an effort to reach more self-employed individuals, since as mentioned above, at least 40% of income earners have intermittent income and/or are self-employed.

4. Collateral

A mortgage guarantee is not required due to the fact many residents of marginal settlements do not have land title and that the cession of such to the CMB would necessitate an inscription of the title in the public register, frequently a very time consuming process.

There are three types of guarantees which the Construction Materials Bank will accept:

a. Guarantee of individual payments or of the full amount of the loan by a commerical establishment or the borrower's employer.
b. Salary deduction backed by retention of up to 50% of employee's indemnification funds.
c. Guarantee of individual payments by a third person.

Since the last does not require that the guarantor provide proof of solvency, it is really no guarantee at all. Consequently, loans with this type of guarantee are limited to 20% of the total value of the CMB's loan portfolio. Also, for these third party loans a 20% down-payment is required (and the maximum loan is less); 5% and 10% down-payments are required respectively for loans with the first and second types of guarantees.(Refer to Annex C.)

As in the MEVI program, the applicant must also present documentation to prove he has a right to occupy the lot (e.g , title or adjudication certificate) to prevent the possibility of his/her being relocated or otherwise forced off the lot.

5. Construction License

Since the CMB was created specifically to assist households in low income areas, it has been exonerated from requiring a construction license of borrowers in order to avoid the problems mentioned in Section II.C.5 (requirement of land title and plans). Nevertheless, borrowers sometimes have their own simple plans of the dwelling and/or of the project proposed, but these are not a requirement for obtaining the loan.

6. Purpose of Loans

Compared to the MEVI Program, the CMB provides somewhat greater flexibility in regard to loan purposes. In addition to providing materials for improvement, expansion or roofing an existing structure, the loans may also be used to initiate construction on a lot. (See Annex C for detailed description.) In theory the MEVI program generally provides loans only to individuals who already have something constructed, although, in practice, there have been a few exceptions (i.e., loans made to initiate construction).

On the other hand, the CMB is somewhat less flexible than MEVI in that it only provides loans in materials which must be picked up by the borrower from specified material suppliers and/or specified warehouses (in the case of bricks, cement and reinforcing rods). The borrower does not have the option of shopping for the best price himself (as in MEVI). The CMB does it for him. In addition, the borrower must provide his own transportation to pick up the materials and must provide his own labor.

Transportation may be no problem if the borrower has a friend or relative who can provide such at little or no cost. However, if he must contract the transportation this can be a significant additional cost. For example, transporting 3,000 bricks from the factory to a location in metropolitan Lima may cost as much as $50. The lack of funds to pay for transportation may be the reason why some borrowers are not picking up their materials in a timely fashion.

The CMB policy is that borrowers can contribute to lowering the cost of their own dwelling by the use of self-help or mutual help construction. Therefore, loans are not provided for construction labor. However, it appears that in many cases (as was the experience with the MEVI Program) the borrowers do not have either the time and/or the technical skill to build a dwelling unit themselves.* This means the labor must be contracted - a significant, additional cost for the borrower. For example, rather than working on the construction themselves in their limited free time (assuming regular employment), the borrowers prefer to contract the labor so the improvement and/or unit is completed more rapidly. In the case of not possessing adequate skill, the borrower must find a small contractor and obtain additional funds (possibly a loan from another source at a higher interest rate) - both of which may delay the project indefinitely.

An unfortunate situation occurs when the borrower has to assume these additional costs without having adequate disposable income to do so. In this case he may have to sacrifice expenditures on some essential items such as food. In such a case the loan has created rather than solved a problem.

Unfortunately, no statistically complete information is available yet on these questions. However, selected visits have revealed that these problems do exist in some cases. The CMB should seriously consider including transportation and labor costs in future loans.

7. Loan Size

Although the CMB has established a minimum loan amount of $250, (which is considerably smaller than the minimum for conventional financing - $1,500 to $2,500) the current average loan size is $1,013. The reason for this is that currently $250 buys very little (e.g., a single external wooden door costs $75).

The loan size is determined by the type of guarantee (as indicated in Annex C) with the maximum loan amount ($1,500) backed by a commercial or employer guarantee and requiring the smallest percentage of down payment.

8. Interest

The interest charge: (15%) for the CMB loans is 43.5 points below the current normal rate for mortgage loans. This subsidized rate was established to assure that the loans reach the lowest income households possible. More will be discussed about monthly payment and the relation to income in the next section.

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* Of 507 borrowers that have received materials (as of 4/30/81), 184 or 36.3% have elected to use contracted labor rather than self-help.

On the other hand, the decapitalization of resources due to inflation and a greater negative interest rate is potentially much more serious here than in MEVI. Fortunately, the unused funds have been invested in savings which earn from 50.5% to 54%. However, as these funds are drawn down and lent out for two and a half years at 15% their value rapidly erodes (at a rate of approximately 28%* per year). This means that in two years (if the current inflation rate continues) the value of the funds originally lent out will be 50% less in real terms than what it was at the time of disbursement. This means that the Government of Peru will have to replenish the capital of the CMB for it to continue its existence. Obviously what is needed in short order is an increase in the interest rate to a more positive rate of return.

9. Monthly Payment

The monthly payment on CMB loans cannot exceed 30% of the borrower's income. This is a more realistic limit than in the MEVI Program, but it is still arbitrary. Here again, a case specific analysis of debt capacity would be a greater assurance against potential future delinquency. Another obvious but not as accurate way to assure that the monthly payment is within the borrower's capacity to re-pay is to simply ask him what he can afford. This the CMB does at the time of calculating the amount of the loan.

If the interest rate on this program is to be raised, as will be done for loans made with AID funds, the loan term will obviously have to be lengthened to 5 to 7 years to keep the monthly payments as low as possible. A system of graduated payments should also be seriously considered here as well as in the MEVI Program. A potential problem, of course, is if the current program remains at 15% and the AID funds are lent at, for instance, 31%, borrowers will tend to choose the former of these two parallel CMB lines of credit. Either the rates of the two programs will have to be made more equivalent or a series of complementary benefits (e.g., program with higher interest rates will have lower initial payments) will have to be established.

Regarding delinquency, it is perhaps too soon to make an analysis since the recovery of the first loans only began about one month ago. In any case, to date there have been no delinquencies and some borrowers have even paid in advance.

10. Processing

From the outset of the CMB program, loan applications have been processed rapidly. The processing time of the one page application** is approximately two weeks and consists of the following principal steps:

1. The application is presented with required documentation by the potential borrower.

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* 15% Interest + 17% spread on materials - 60% Inflation = -28%.

** Other than the application, the only other documents required are the pay stub or sworn declaration of income, title or other proof of right to occupy the lot, guarantee, electoral card and directions how to reach the lot.

2. The legal advisor prepares an opinion on:
   a. Location of lot
   b. Guarantee
   c. Document which accredits right to occupy lot.
3. An inspector visits the lot to verify:
   a. Its existence
   b. Its location in pueblo joven or other qualified area
   c. Status and condition of permanent construction, if any.
4. The Technical Department prepares a short report.
5. The General Manager:
   a. Presents the application to the Credit Committee with recommendation to approve the loan, or
   b. Requests more information from the applicant, or
   c. Rejects the application for not meeting program requirements.
6. The Credit Committee approves or disapproves the application
7. The Technical Department prepares list of materials with the borrower and establishes the amount of the loan.
8. The Legal Department prepares the contract and verifies the guarantees.
9. The Administrative Department prepares the promissory notes and the material delivery order.
10. The borrower pays the down payment.
11. The borrower signs the contract and receives the material delivery order.
12. The borrower goes to the supplier and/or warehouse within 10 days to pick up his materials.

C. Other Aspects of Design and Implementation

1. Promotion

Initially, the Construction Materials Bank was publicized primarily through newspaper articles, which gave it extensive (if sometimes erroneous) coverage. At first the demand created was substantial, but then it began to drop off. This allowed the CMB time to establish the new policies and procedures and make adjustments as necessary.

Having now established these, the CMB has entered into a second phase of more aggressive promotion/publicity in a six month radio, television and newspaper campaign. This is beginning to show results in increased applications.

Another approach to promotion which could also show positive results as it did in MEVI, is to work through organized community groups (e.g., housing cooperatives, pro-housing organizations, etc.) Working through community leaders, talks could be given in different areas after work hours. This would allow the promotion to be tailored to the specific needs of each group; questions could be answered on the spot to avoid misunderstandings; and after the meeting those interested would receive applications and written information to study further. If several persons made applications in the same area, this would simplify the work of the inspectors both before and after the construction begins, since they could go to one area and visit several lots in a short time instead of spending a lot of time traveling between widely dispersed lots.

2. Construction

As mentioned, due to the fact borrowers receive only materials, they are strongly encouraged to build their homes themselves by self-help or mutual help. Even though there appear to be a significant number who contract the labor, all borrowers receive a certain amount of technical orientation. During the visit with the CMB engineer to prepare the list of needed shelter materials, borrowers are given a booklet on how to construct with bricks. During the periodic inspections of individual projects, the inspector sometimes gives the borrower informal suggestions about how the construction can be improved. Unfortunately, there is often no one present when these inspections are made, since they are done during normal working hours when the borrower is at his place of work. More formal on site technical orientation would be extremely useful in preventing problems like excessive mortar (up to 6-7cm on some projects) between bricks, which is not only wasteful, but which weakens the wall. For such orientation it would be necessary to have technical personnel (preferably engineers) visiting projects on a regular basis during the construction phase, in addition to the regular visits by inspectors.

To date the inspection system has been very successful. Some 15-20 engineering students perform this service at a very low cost. This system could be made more efficient, however, if each inspector were assigned a smaller area and could visit several projects in such a reduced area. As implied above, often the time spent on public transportation exceeds the time spend on inspections.

3. Program Status

As of 5/12/81, the number of loan applications received was 1,298. Of these, 917 were approved for an approximate total amount of $929,000 and an average loan amount of $1,013. Of the approved loans, 548 borrowers had received the "disbursement" of their material delivery orders.

IV. Conclusions

This paper has described two programs of non-conventional financing in Peru which are attempting to help low income households solve their housing problems in the midst of an economic crisis - high inflation and recession. It has been demonstrated that conventional financing of housing is basically non-functional in such a situation.

An attempt has been made to show that these programs are both similar and complementary. A future AID/HG loan will attempt to draw on the experience of both programs and coordinate the S&Ls and the CMB to form still another non-conventional approach.

It would appear that at least some of the principles, considerations, and problems presented here would be useful in designing a program to finance shelter housing for urban low income households.

Annex A

Description of the AID Housing Guaranty Program (9)

The Housing Guaranty Program was developed as part of the U.S. Foreign Assistance program in the early 1960s to respond to the enormous and rapidly mounting worldwide shortage of adequate shelter. This program is AID's principal instrument for helping developing nations address their shelter problems. Since its beginning, more than $1.4 billion in Housing Guaranty loans have been authorized for 150 projects in 39 nations and to three regional institutions.

This is a unique AID activity in which funds from the U.S. private sector provide long term financing for low income shelter and urban upgrading programs in developing countries.

The United States Government underwrites these transactions through the provision of a full faith and credit guaranty that will compensate U.S. lenders for losses. Maximum interest rates to lenders are established by AID and reflect the current cost of money in the U.S. mortgage market.

AID charges a fee for its guaranty to cover operating expenses and to provide a reserve against claim losses. As a result the program is virtually self-sufficient.

In its early years the program focused on introducing new building technologies and modern management practices to developing countries. In the mid 1960s the focus shifted to creating and strengthening housing finance institutions, particularly the savings and loan institutions in Latin America.

Another major change in emphasis occurred in 1973 when the Agency reformulated its shelter strategy. The new strategy, backed by legislative changes in 1975, called for Housing Guaranty resources to be used almost exclusively to finance shelter for lower income families. Since 1974, all Housing Guaranty projects authorized by AID have been designed for this income group.

In accordance with this mandate, various approaches to low cost shelter were initiated, including slum upgrading, basic or core housing, and the development of lots serviced with utilities to be later improved by the purchaser. Emphasis has been placed on the provision of basic services to provide a sanitary living environment and lay the groundwork for orderly, economical development as families are able to afford improvements and expansion. Typically, a family having an income below the median level in a developing country will be able to amortize a loan no greater than $1000-4000, depending on the country and location, and it is within this financial context, that the Office of Housing develops its programs.

In 1978, with the increasing recognition that shelter development and community development are interdependent, the authorizing legislation was amended to allow the financing of community facilities and services with Housing Guaranty loans. Such facilities could include, for example, schools, health clinics and community centers, job skill training centers, employment offices, markets, small industry centers, and post offices.

Less developed countries (LDCs) may request a Housing Guaranty project. Upon receiving a request, the Office of Housing, the USAID Mission or Embassy, and the requesting country jointly participate in project identification and begin the process leading to project authorization and implementation.

In the development stage of the project, the host country is encouraged to take a broader look at its shelter problems, particularly those of financing and low income households, and to develop new long range shelter policies based on sound cost recovery strategies. Important principles of the Housing Guaranty Program are: (1) maximizing a country's resource investment in shelter and (2) continuously recovering and re-allocating that investment to ensure a more equitable distribution of limited shelter resources.

In the past fiscal year, from October 1, 1979 to September 30, 1980, AID continued to focus its resources on the problems of lower income families.

The Housing Guaranty Program finances the following kinds of shelter solutions for families with below median incomes:

-- Slum and squatter settlement upgrading, including provision of potable water, sewage disposal systems, electricity, roads, and drainage to be complemented by home improvement loans to slum dwellers.

-- Sites and services, including preparation of vacant land for productive shelter use through lot division and installation of water lines, sewage disposal systems, roads, and drainage. This will be followed by self help home construction by low income buyers of the lots. This type of porgram may include training programs and building materials loans for self help builders and small scale contractors.

-- Core housing, involving basically a sites and services approach with the addition of a rudimentary housing shell (typically including a bathroom and a small multi-purpose living area) on each lot, designed to be improved and expanded by the owner. Building materials loans may be provided.

-- Low cost housing units for sale or rental.

Community facilities and services (schools, health clinics, markets, job skill training centers, etc.) in support of shelter projects are also financed by the Housing Guaranty Program.

Each project is designed to assist the participating institutions to define and clarify national housing policies, and to strengthen their capacity to plan, finance, implement, and service housing projects for the poor.

Twelve new Housing Guaranty loans totalling $174.5 million were authorized for guaranty by AID this year. U.S. lenders signed $45.6 million in long term loan agreements, with each loan guaranteed by the U.S. Government. For each loan, there is also a host country guaranty of repayment to the U.S. Government should the borrower default.

Additionally, the Office of Housing provided technical assistance and services in a broad range of shelter-related areas to many developing nations.

Annex B

HOME IMPROVEMENT (MEVI) LOAN PROGRAM (BVP/S&L SYSTEM)

GENERAL PARAMETERS FOR INDIVIDUAL SUB-LOANS*

1. Objective

The objective of the MEVI Program is to make supervised individual loans within the debt capacity of low income families for improvement of their existing shelters.

2. Requirements of Borrowers

A. Maximum family income - median family income for the respective urban zone.**

B. Must reside in "pueblos jovenes"*** or similar areas.

3. Purpose of Loans

The loans can be made for the following types of improvements:

A. Installations - placement of electric, water and sewage systems in the home.

B. Domestic connections - to the public service electric, water and sewage systems.

C. Finishing - includes interior carpentry, plastering, floors, etc.

D. Sanitary fixtures - such as placement or change of toilet, wash basin, shower, etc.

E. Renovations - partial or complete change of deteriorated elements without a design modification in the structure.

F. Conditioning - improvements that imply a structural design modification without expanding the roofed area.

G. Expansion - of the structure to produce one or more additional rooms for bedrooms, bathrooms, kitchen, etc.

H. Completion of structure - improvements such as columns, walls, beams, and roofs which complete the structure, including exterior carpentry.

4. Basic Terms of MEVI Loans

A. Maximum loan amount - equivalent of $2,500

B. Maximum loan term - 12 years

C. Maximum number of monthly payments - 144 (i.e., there is no grace period).

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* As established by AID and BVP. These are broad parameters within which each participating S&L has developed its own more detailed requirements, conditions and procedures.

** Median family income to be adjusted quarterly in accord with the rise in the consumer price index.

*** Marginal settlements.

D. Maximum monthly payment - 40% of monthly family income
E. Maximum costs of loan to borrower*

29% interest
2% commission
31% total annual cost

2.5% commission for processing loan application; paid once.

R. Down payment - none
G. Guarantee - mortgage on the property, employer's guarantee, or other guarantee acceptable to the S&L.
H. Insurance - borrower life insurance to cover the outstanding balance.

* Some S&Ls have charged less.

Annex C

CONSTRUCTION MATERIALS BANK

INFORMATION FOR BORROWERS (10)

1. Objective

The objective of the Construction Materials Bank (CMB) is to assist in the solution of the housing problem through the building and improvement of the Basic Core House, by means of support and service for the provision of construction materials.

In the first phase the CMB is oriented towards making loans to owners of lots located in:

a. Pueblos Jovenes that have land titles or are urbanized.
b. Cooperatives, Housing Associations and Low Income Developments which have an Approval Resolution of preliminary studies for urbanization projects.

2. Requirements of Borrowers

a. Maximum (individual) income: $375 per month
b. Possess a lot in: Pueblo Joven, Low Income Development Housing Cooperative, Housing Association or in a zone qualified by the CMB.
c. Maximum age: 75 years.

3. Documents Required

a. Loan application on the CMB form, signed by applicant.
b. Pay stub for dependent worker or sworn declaration for self-employed persons.
c. Property Document: (one of the following documents)
   - Provisional title (constancia) for a lot issued by the Regional Office of the Division of Non-Regulated Human Settlements, Fifth Region, Ministry of Housing and Construction, for the residents of Pueblos Jovenes, or purchase/sale documents issued by the corresponding authority.
   - Lot allocation document which is registered in the list of members, issued by the housing cooperative or housing association and for which the preliminary studies for urbanization projects have been approved.
   - Purchase/sale document for those living in low income developments.
d. Copy of the electoral card of the applicant and spouse; copy of the marriage certificate (if it exists)
e. Sketch of the location of the lot (information to assist inspectors in finding the lot).

4. Purpose of Loans

a. The CMB will make loans for:
- Construction of a basic core house ($50m^2$ of roofed area)
- Completion of construction already begun (up to $70m^2$ of roofed area).
- Expand a basic core house already constructed (up to $70m^2$ of roofed area).
- Improve an existing structure by providing the following materials: windows, doors, sanitary fixtures and materials for the installation of water, sewage and electricity.

Basic Terms of CMB Loans

Types of Credit	Maximum Loan Amount	Maximum Amortization Period	Maximum Number of Monthly Payments	Maximum Monthly Payment	Interest Rate	Down Payment	Guarantee
A	$1,500	33 months	30 (3 mo. grace period)	30% of individual income	15%	5%	Guarantee of individual paymts. or of total loan by commercial firm or employer
B.	$1,500	33 months	30 (3 mo. grace period)	30% of individual income	15%	10%	Salary Deduction
C	$1,125	32 months	30 (2 mo. grace period)	30% of individual income	16%	20%	Third person guarantee
D	$750	A, B or C	A, B or C	A, B or C	A, B or C	A, B or C	Additional loan for those who have paid off type A, B or C loan

Note: The minimum loan amount is $250.

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CLUSTER LAYOUTS: A BASIS FOR THE DESIGN OF (EARTHEN) STRUCTURES IN URBAN DWELLING ENVIRONMENTS

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ABSTRACT: The paper is focused on the task of physical planning in the context of developing countries, the low income majority and rapidly urbanizing areas. Specific aspects of the problem of land use and the provision of infrastructures are explored. The design of buildings must have a basis in the urban plan. A cluster design which groups individually owned lots around a shared common court is proposed as answering many of the problems. Cost, social, cultural and administrative advantages are outlined for the clusters. A model development is presented illustrating various densities in a flexible development.

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CONTEXT: LOW INCOME PEOPLE, DEVELOPING COUNTRIES, RAPID URBANIZATION

The paper is focused on the task of physical planning in the context of developing countries, the low income majority and rapidly urbanizing areas. The planner must be able to address the complex problems of rapid urbanization where the direct implications of the growth of poverty are not only that more and more dwellings, land and services are needed, but also, which is more critical, that these dwellings, land and services should be provided to a growing population that has less and less capacity to pay for them.

Although the paper does not directly discuss building design or use of materials in dwelling construction, it provides a planning framework for the consideration of construction systems or building types to be used in conjunction with the use of adobe structures in seismic regions.

Urbanization is occurring in developing countries at a rate far beyond that which the limited resources and abilities of cities can cope. These new populations, consisting primarily of unskilled, uneducated, and extremely poor people migrating from rural areas in search of employment, are in the midst of a fierce struggle for shelter and security. This struggle is creating an urban crisis all over the World. Until the cities are able to respond to the needs of thses new populations, spontaneous urbanization (squatter settlements) and general discontent will continue to intensify the struggle. Resources are limited, urban land is scarce, and the burden on the public sector (government) is becoming more unmanageable.

The urban immigrant in search of shelter has the two basic options of locating in a decaying (slum) area of the central city or squatting in illegal settlements on the perifery of the city. Governmental response to this situation has normally been the adoption of an attitude of benign neglect towards slums, squatter and other illegal settlements.

Programs for the legalization and rehabilitation of many existing squatter settlements have been undertaken with only marginal success. Improvement of infrastructure networks is costly because of inefficient layouts and only limited money is available.

Governmental programs have in some instances been initiated for the relocation of urban slum and squatter populations from valuable land/locations. Unfortunately most of these programs, having limited resources and being oreinted to the task of providing specific quantities of conventional or prefabricated dwelling units usually in the form of medium to high rise structures on government land, have been inappropriate and at the same time have not been able to reach down to the low income majority.

ALTERNATIVES

It is clear that the alternatives in "Housing" are to provide complete dwellings to a few beneficiaries, or to provide only basic utilities and services (infrastructures) to a much larger section of the population. If the latter course is taken, major efforts of the

government should be shifted from the provision of shelter to the provision of utilities and services. Regardless of the many other considerations, the latter course has the following in its favor: the construction of a shelter can be done within the limited resources of individuals because inexpensive materials can be utilized, no special skills are necessary and simple tools only are required, self-help or artisans or small contractors can be employed, and the shelter can always be reduced to a bare minimum.

While the construction of a shelter is a relatively simple operation, the provision of utilities to a community is not because it demands more than individual effort. It demands a collective effort both from the community and from the government in planning and mobilizing political, economic and technical resources. In short, the choice is clear; construction of utilities will always be a government task, but housing may be left to individuals.

PHYSICAL PLANNING INDICATORS

The task of the physical planner is complex; urban land is scarce, money is limited, and the time factor is very short. If the governments cannot provide planning guidelines for future growth quickly, the immigrants by necessity of shelter will continue to develop squatter areas without benefit of formal planning. This necessarily means that during the rehabilitation process when infrastructure is incorporated into these areas it becomes unnecessarily expensive for both the user and the public sector. In many cases it even precludes the availability of certain services to the areas. The lack of planning for the future growth and needs of a community only increases the burden of both the government and the user.

The public sector will substantially minimize its capital investment and continuing maintenance/operation costs and at the same time improve upon the potential amenity of developing urban areas by initially providing an efficient framework within which urbanization can occur. The criteria used for the evaluation of efficiency of physical layouts are:

LAND UTILIZATION DISTRIBUTION - Proportions of public, private and circulation areas within the layout. This determines maintenance, responsibility, user control, and functional efficiency. e.g. A high percentage of circulation means higher cost per person and therefore indicates an inefficient layout.

LAYOUT - Lot configuration, blocks and circulation. This determines the infrastructure network. e.g. Certain layouts result in complicated infrastructure networks requiring excessive lengths of networks and therefore higher cost per person.

DENSITY - Number of persons and dwelling units per hectare. This determines the intensity of use. e.g. Low density means a hgiher cost of development per person.

SITE ANALYSIS - Site attributes that define the economic and practical feasibility of development and site determinants that define the constraints of physical planning.

Use of the above criteria in the evaluation of urban dwelling environments will demonstrate that the design of buildings must have a basis in the urban plan.

In the discussion of physical planning in the context of developing countries, the low income majority and rapidly urbanizing areas, we are by definition, addressing ourselves to situations where population densities tend to be relatively high. High densities in general are viewed as being negative, but determining what specifically is inappropriately high is difficult. The lower the density, the larger is the land area required for a given population, which results in higher cost per person in land and infrastructure. At the opposite extreme, very high densities not only may put an excessive load on the infrastructures and services, but more serious, it could create negative and destructive social conditions. It is possible to determine a range of density limits compatible with adequate services and infrastructure. But very little can be done to determine similar indices to anticipate or forcast social and behavioral implications of population densities in a given physical environment.

However, there are many positive factors to higher densities: lower costs per person for land and the provision of infrastructures and services; advantages of better job opportunities, more viable transportation systems, higher access to social and commercial services in a high density area and potential social advantages for less alienation, loneliness.

Proper land utilization is extremely important in high density areas. The key to proper adequate land utilization is a coherent relationship among users, responsibility and physical controls. This coherence should unequivocally be reflected by the physical design or plan. Proper, adequate controls of the land should define the extent of a territory, facilitate its specific function, allow/encourage the users to assume their responsibility in terms of maintenance and operation. Neglect of these aspects is very common in the design of public housing everywhere. It takes the form of land waste, particularly in developments where walk-up apartments stand in open spaces of undefinable use. The most common consequences are misuse of the environment, destruction, vandalism, unsafety, crime, poor maintenance, garbage thrown everywhere. In low population densities of around 50 persons per hectare the proportion of land per person is large enough to avoid conflicts but when densities reach magnitudes of 200 persons per hectare or more as happens in any settlemnt with a low and very low income population the portion of land per person has shrunk so much that conflicts are inevitable if the proper physical conditions are not created.

The physical expression of densities and associated land utilization percentages required for a urban dwelling environment must be developed in the design of the layout. As stated earlier, the prime function of the public sector must be to provide an efficient framework within which urbanization can occur.

The scope of this paper being limited to the presentation of the general principals that must be considered in the physical planning process, the topic of site analysis will not be discussed.

The layout incorporates the two major functions of land utilization and circulation and related infrastructures. The layout should strive to minimize public costs in land, construction, maintenance and operation of streets and related services and to increase community initiative, responsibility and participation in the utilization of land. It is imparative that initial and continuing costs as well as control responsibilities to be born by the public sector be minimized.

In most cases the public sector has only very limited funds available for construction of infrastructures and where control of land/circulation is the responsibility of the public sector these areas will again in most cases in reality be without any control by the fact that there is just not enough money available to the public sector to provide this service.

An initial circulation network must be provided that allows for the possibility of both incremental as well as instant development of infrastructures and provides maximum amenity to the user.

In land subdivision, land utilization must be very specifically defined by use as:

PUBLIC LAND - The area for circulation of pedestrians and vehicles. It includes streets, pedestrian lanes, open spaces.

SEMI-PUBLIC LAND - The area of community utilization. It includes open spaces, playing fields, schools, etc.

SEMI-PRIVATE LAND - The area of shared utilization held in condominium by a group.

PRIVATE LAND - The area of residential, commercial, or small industries utilization. It includes lots and dwellings.

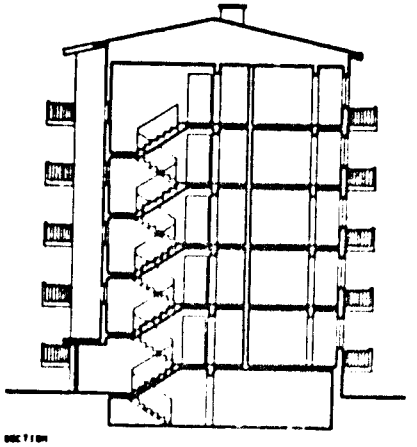
A comparison of typical existing situations will demonstrate the importance of proper land utilization and that in the context of the low income majority of urban dwellers in developing countries that the design of buildings must have a basis in the urban plan. The following examples are all located in Istanbul, Turkey.

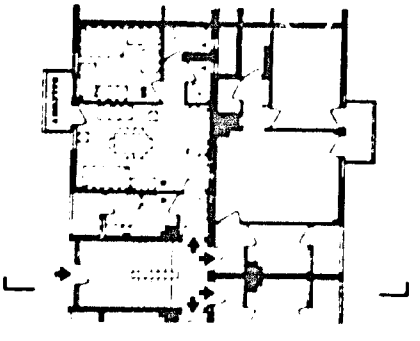
Osmaniye, typical of public housing projects all over the World, achieves high density by concentrating apartment units on a very small percentage of the land, in Osmaniye 9% of the total land area. This type of layout is efficient in the provision of infrastructures but excessive public space, besides being a costly problem of maintenance and responsibility of the government, does not recognize the urban users need for private/semi-private open area. The layout discourages future development. The public sector has made a large investment that benefits only a few.

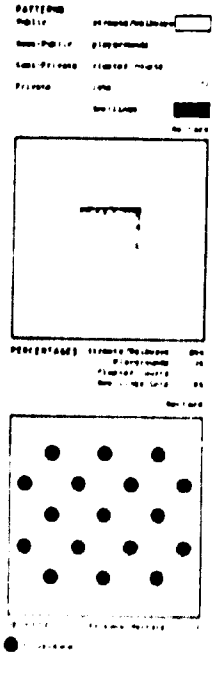
In contrast to the Osmaniye public housing project, the

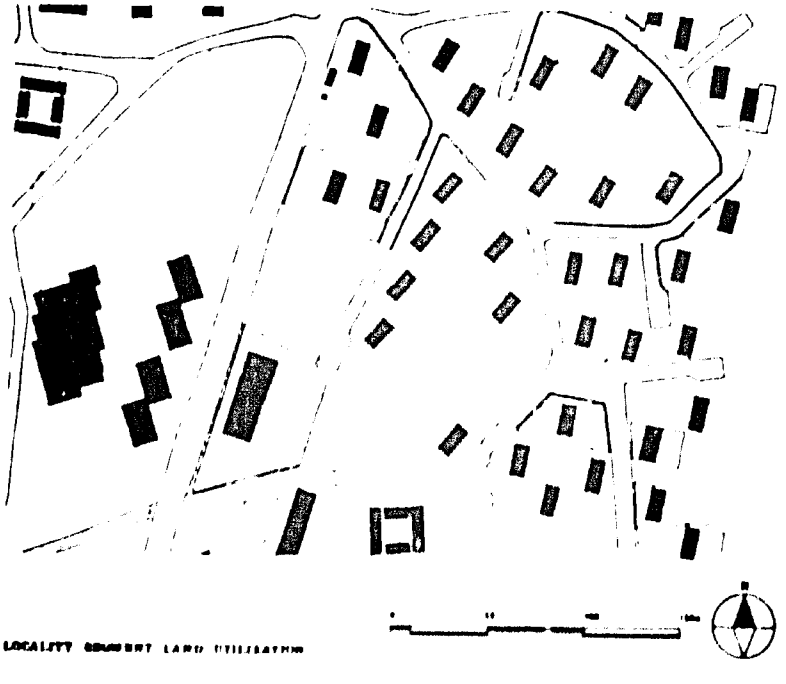
OSMANIYE - Public, Low Income, Block Apartments

DENSITY - 333 persons/hectare
PRIVATE AREA - 9% of total land area
DWELLING AREA - 45m^2 average
HEIGHT OF DWELLINGS - 5 stories



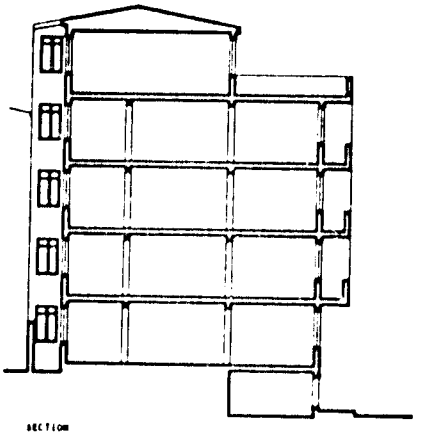


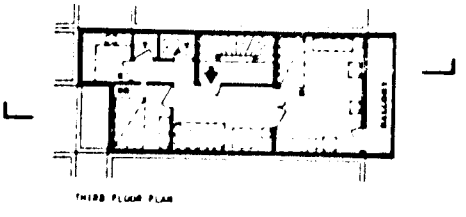


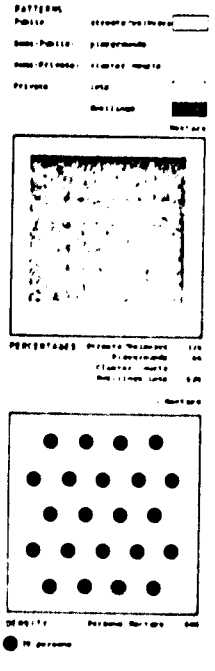


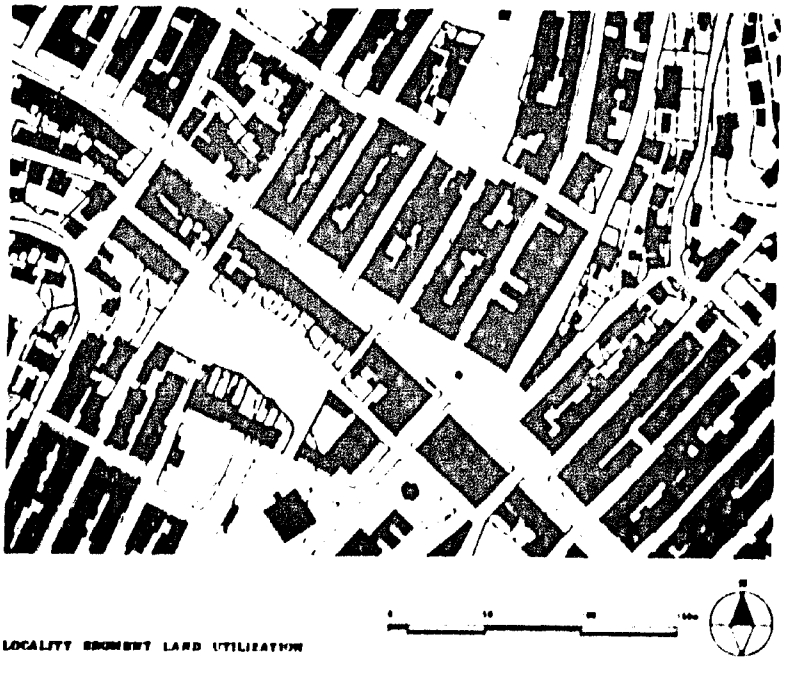
GULTEPE - Public/Popular, Low/Moderately Low Income, Row Apartments and Squatter Houses

DENSITY - 440 persons/hectare
PRIVATE AREA - 62% of total land area
DWELLING AREA - 55m^2 average
HEIGHT OF DWELLINGS - predominately 3 to 4 stories





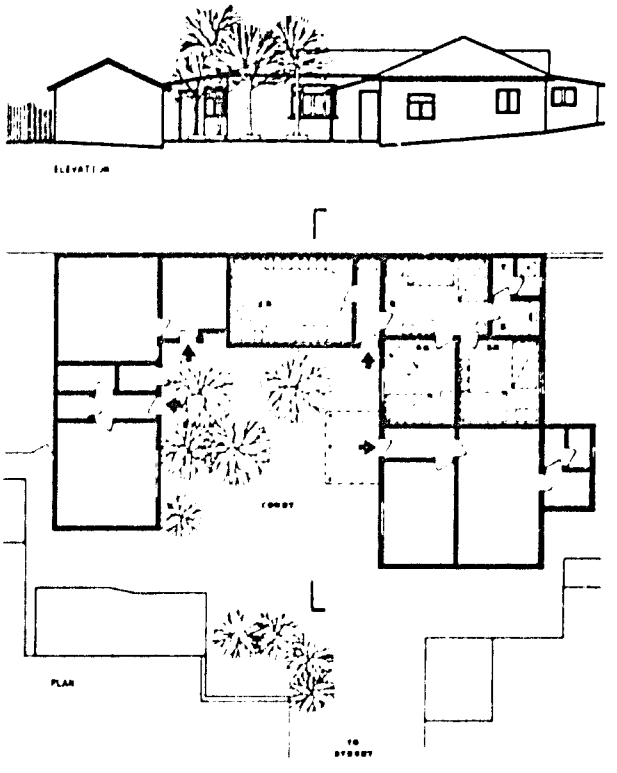


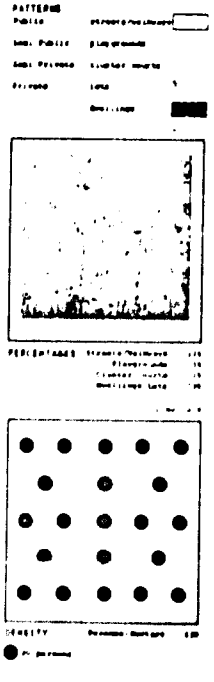


LOCALITY SEGMENT LAND UTILIZATION

ZEYTINBURNU - Popular, Low/Moderately Low INcome, Squatter Houses and Walk-up Apartments

DENSITY - 420 persons/hectare
PRIVATE AREA - 73% of total land area
DWELLING AREA - 60m^2 average
HEIGHT OF DWELLINGS - predominately 1 to 2 stories





LOCALITY SCHEMATIC LAND UTILISATION

Gultepe community demonstrates an example where the public sector parcelled land, in this case into 62.5m^2 parcels of land, for construction of one story dwellings to be built by self-help and/or use of artisans. The layout provides a large percentages of private land, in Gultepe 62% of the total land area, but the provision of infrastructure networks is excessively expensive in a gridiron pattern. Expensive utility lines are required in all of the streets. Service connections, one per lot, are impossible to concentrate to save costs. The small individually owned lots restrict future development. The row housing concept is valid where lot sizes are restricted in that the user will with time tend to incorporate any open space between detached dwellings into the dwelling itself. In the case here the lots are not deep enough to allow for sufficient open private/semi-private space adjacent to row apartments. The public sector investment being limited to the provision of basic infrastructure networks benfits many users. The user depending on his personal financial situation is able to build incrementally therefore the system reaches down to a lower sector of the population. Conventional construction techniques are appropriate here. The Gultepe community even though planned by the public sector does not provide sufficient land for community facilities commensurate with high density level of its population.

In a typical squatter settlement such as Zeytinburnu, land is essentially distributed among the private lot owners allowing a more manageable distribution of population as well as removing land from the responsibility/maintenance of the government. Social factors rather then physical forces determine layout. The squatters create their own "cluster" groupings and blocks. The blocks are large enough to allow lots of varied sizes and configurations to occur independently of the circulation network. A combination of row, semi-detached and detached one story dwellings predominate. Provision of infrastructure networks is expensive do to excessive lengths of circulation. Some savings are possible where one service connection can serve a whole cluster rather than just one lot.

HOUSING POLICIES

Much effort has been exerted in trying to deal with the problem of housing. Most of the results have been marginal at best. Unfortunately we are learning by past mistakes.

The design of urban dwelling environments in developing countries must be able to successfully work with the following realities:

1) Extremely high demand for shelter.
2) Very restricted public resources.
3) Low and very low income population sectors.
4) High population densities.
5) Need for flexibility for future development.

High densities must be encouraged. It is more appropriate to achieve these densities through dwellings of up to four stories maximum with a clear definition of land utilization and control. The high density policies avoid costly sprawl developments. The current codes require unreasonably large lots which have a costly effect,

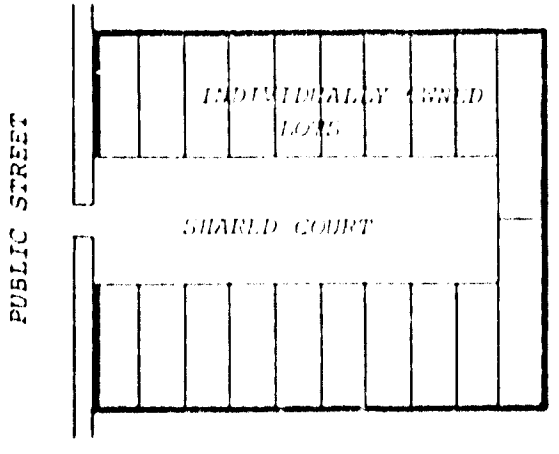
many urban areas are forced to unnecessarily extend beyond existing transportation, water, sewer and electrical networks. The developments force costly expansion to the relatively sparsely populated areas. The lower the density, the greater is the amount of land needed for a given population and the greater the cost per person for land, utilities, and services.

In developing countries, the provision of utilities and services and the control of land subdivision are the most important tasks of the hard pressed government. Efficient and economical provision of infrastructure is imperative. The design of the urban layout should provide flexibility in land uses. Blocks must permit the accommodation of different land uses; residential/commercial, light industries. There should be flexibility in residential densities and housing options ranging from the provision of lots, progressive development units, core houses to row and grouped walk-up apartments of low, medium and high densities.

Individual lots should be large enough to provide adequate space for the dwelling unit plus open private area. These lots should, by definition, always be rectangular in shape with frontage being the short dimension. This will maximize economies in the provision of all infrastructure networks. The row house concept should be encouraged. Small lots (100-200m^2) of rectangular shape offer a frontage normally ranging 5m to 9m. Even if codes require setbacks from abutting property, the lot area is restricted to the point where with time and in normal circumstance code enforcement being impractical, these areas will eventually be incorporated into existing or new construction.

CLUSTERS

The concept of clustering lots around a shared court, an old system used successfully in different parts of the World for centuries but with little large scale implementation, has proven successful as a means of coping with many of the problems in the design of urban dwelling environments. Clusters as defined here meet the specific requirements that the physical arrangement and land ownership is such that the group of individual lot owners/users has complete use, responsibility, and control. Schematically the physical design is that of a dead-end solution. Each lot would have individual title and the central area held in condominium. Another name of the cluster could be "horizontal condominium".



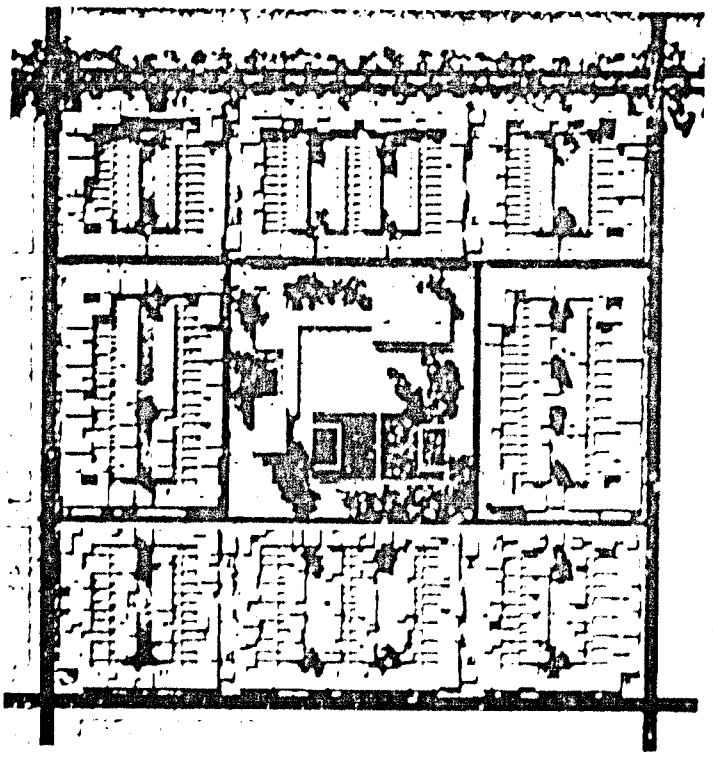
TYPICAL CLUSTER LAYOUT

COSTS - The use of the cluster layout can reduce infrastructure costs by as much as one half in comparison to standard gridiron layouts. If only a minimum level of infrastructure is to be provided initially to a settlement area the cluster layout, needing less actual network lengths of infrastructure, will provide the same level of service for less cost. In incremental development the cluster layout tends to be much more efficient and adaptable to future development. The cluster layout minimizes the amount of land required for public circulation therefore it reduces the countinuing maintenance/operation cost that must be born by the government.

SOCIAL - The cluster layout defines smaller community groups by creation of neighborhoods which encourage responsibility, a sense of belonging, collective effort in the use and control of the cluster as a whole.

ADMINISTRATIVE - The cluster allows simplified functions in title allocation, tax collecting, utility meter reading and billing, centralized refuse collection etc.

FLEXIBILITY - The cluster layout allows various lot sizes and dwelling types to be used without penalty of added infrastructure costs. Future land use can more easily be accommodated in the cluster layout. As often occurs in urban situations, changes for commercial uses which require larger properties are difficult because of the many diverse property sizes and owners.



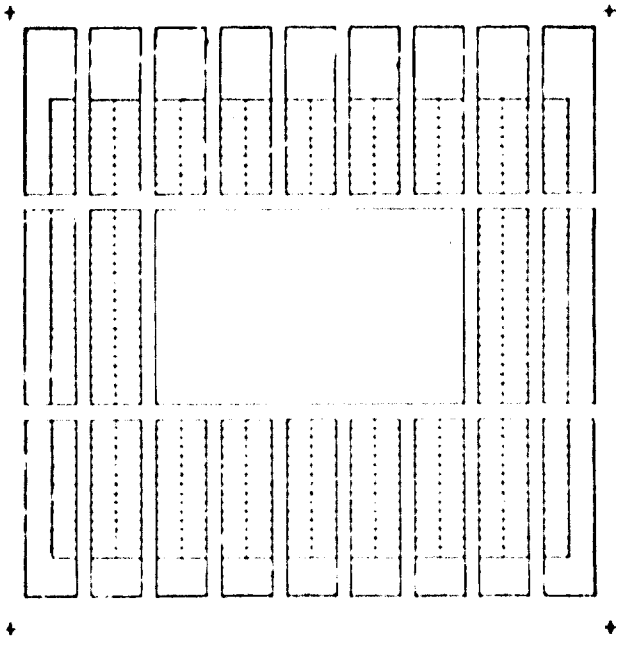
800 PERSONS/HECTARE
$12m^2$/person
Average number of floors: 2.4
Dwelling types: walk-up, row

600 PERSONS/HECTARE
$12m^2$/person
Average number of floors: 1.8
Dwelling types: walk-up, row

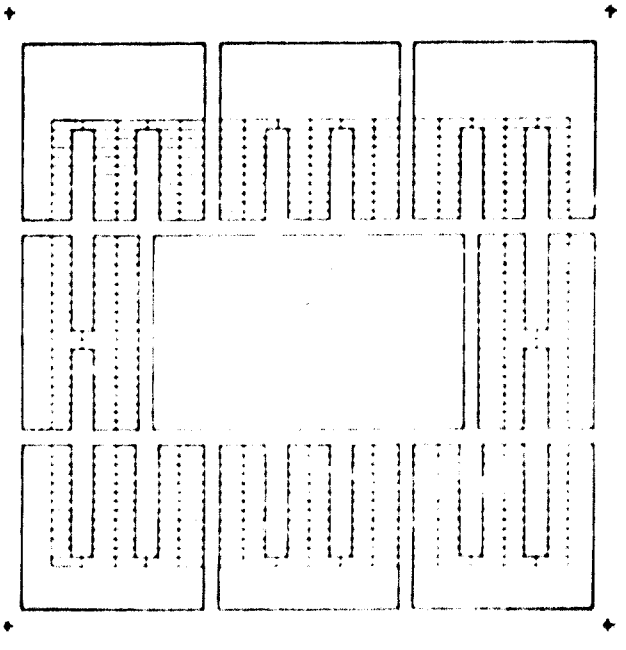
400 PERSONS/HECTARE
$12m^2$/person
Average number of floors: 1.2
Dwelling types: row, site & serv.

CLUSTER MODEL ILLUSTRATING VARIOUS DENSITIES

COMPARISON OF GRIDIRON AND CLUSTER LAYOUTS



GRIDIRON LAYOUT	
Lot area	100m^2
Private area (lots)	52%
Schools, community facilities	16%
Public area (streets)	31%
Street Length	4253m
Unit length	266m/Ha
Net density	600p/Ha



CLUSTER LAYOUT	
Lot area	100m^2
Private area (lots)	62%
Schools, community facilities	16%
Public area (streets)	21%
Street length	2400m
Unit length	150m/Ha
Net density	600p/Ha

From a physical standpoint (which can be translated into costs), there is an obvious advantage to the cluster layout: private land is 20% more, public land is 32% less, total length and unit length of circulation is 44% less.

From a social standpoint there is a potential for better social aspects despite the high net densities.

On a larger neighborhood/community scale, the cluster layout minimizes through traffic in residential areas. It focuses bus routes and defines and identifies more clearly streets with shopping potential as well as defining/identifying neighborhood centers.

Through variations in lot sizes and dwelling types, density variation can be achieved. Land utilization types are clearly defined and public land is minimized, leading to a better realization of responsibility, better maintenance and operation, and to a reduction of the economic burden on the public sector.

The cluster concept offers a more humanized hierarchy in the users daily life because the situation is physically created for a person to live in a more habitable environment in that he has the opportunity to participate in the creation and continual function of his own environment to a much greater degree (his environment is expanded to encompass the cluster as a whole) than in more conventional planning concepts where the users controllable environment starts at his front door.

CONCLUSION

In urban dwelling environments the creation of new or modified systems for the construction of (earthen) buildings must be based on an understanding of the importance of an efficient urban plan. Clusters are a physical planning device with obvious advantages to answering problems in developing countries of limited resources and overwhelming demand for services. In infrastructure the cluster can provide an efficient layout that minimizes public sector costs in implementation, maintenance, and operation of services. It also provides maximum amenity to the user. In land subdivision the cluster allows smaller social groupings and provides a sense of belonging and enhances social interaction. In housing the cluster allows dwellings and lots that can be easily expanded or modified to permit flexibility in their use, to absorb growth of the family needs and to minimize initial investment cost by the user and the public sector.

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3. Goethert, Reinhard; Butler, Mark and Nedret; and Tobian, Bulent. CLUSTER LAYOUTS IN HIGH DENSITY URBAN SITUATIONS, paper presented at the International Conference on Human Consequences of Crowding, sponsored by NATO and Middle East Technical University, 1977.

KEYNOTE PAPER SUBJECT AREA 4: PROGRAM IMPLEMENTATION

'THE PROOF OF THE PUDDING...'

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ABSTRACT

A 200 year old successful case study introduces a review of research work and aseismic adobe housing projects. Problems are identified including the gap between 'Thinkers and Doers', and cover the social/economic dimensions of improvement projects. Finally, nine priority themes are suggested which are concerned with bridging gaps between technology and social factors, privilege and poverty and the research and field context.

* In writing this paper the author has made use of material that is to be included in a different format in a research project being undertaken for the Office of the United Nations Disaster Relief Co-ordinator (UNDRO) on Shelter and Housing following Disasters. The author thanks UNDRO for agreeing to the early use of this material, and this publication does not imply that UNDRO, or any other body, share the views that have been expressed in this conference paper.

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Inventors, innovators and reformers are by nature an optimistic breed. They have to be, since their memories or filing cabinets are loaded with brilliant solutions that remain dormant, a part of the vast residue of unapplied knowledge. A good idea is one thing, but its application is another matter altogether. The gap between the two is so commonplace that most languages have sayings that enshrine the difference between theory and practice. There are for example a couple of English sayings that use the analogy of food - 'The proof of the pudding is in the eating'. Another describes the gap that exists between two processes of a single activity - 'There's many a slip betwixt (or between) cup and lip'.

Therefore the organisers of this workshop have been very wise to place a major emphasis with a substantial allocation of time devoted to the problems of implementation (Subject Area 4) as well as the all important social, economic and cultural aspects (Subject Area 1). If this workshop achieves nothing else (which is hardly likely) it will have established a new model for future consideration of aseismic design principles with this priority concern to bridge the divide between theory and practice - a division that we might well describe as a man-made 'fault-system'.

It is my task to briefly examine the gulf between the thinkers and the doers, as well as to review some of the work currently in progress, to suggest an approach to the problems that are presented and identify, or possibly reinforce (to use a particularly appropriate metaphor) the themes to be considered in this workshop.

As an introduction to these topics I want to pay tribute to an unsung hero of aseismic design. A Portuguese military architect, Manuel da Maia, advised the Marques de Pombal on the reconstruction of Lisbon after the 1755 earthquake. Da Maia may well be the first man to systematically analyse the changes needed in urban planning or building construction to resist earthquakes. He was also fortunate to see his reforms implemented in the rebuilt Lisbon.

These innovations have been identified in a recent excellent study by Stephen Tobriner (1). Da Maia, and his colleagues started off in a predictable manner with advice to Pombal that Lisbon be relocated. The negative response was equally predictable, and so they then suggested that all streets be widened in a newly designed city on the same site. The landowners said 'no' and therefore a compromise had to be reached. It was decided to redesign the worst affected area of the city centre known as the '<u>Baixa</u>' whilst keeping the existing plan for the remainder of the city. FIG 1.

The architects made two proposals for the design of new buildings in the city centre, neither of which was implemented for reasons of expediency. The first was to limit all buildings to two stories, and the second was to ensure that road widths were the same dimension as the height of adjacent buildings to ensure there were safe escape routes. Then turning to the buildings the architects proposed that their design be modified according to aseismic principles. They suggested a radically new construction system which substituted a timber framework, a form of cage called a '<u>gaiola</u>' for the pre-earthquake masonry system. This provided various forms of bracing to resist seismic ground motion, consisting of a form of stiffening at each corner, as well as cross bracing within the framework. Integral with this internal frame the engineers incorporated the external masonry cladding which was carefully mortared at its joints and attached to the internal timber cage. FIG 2

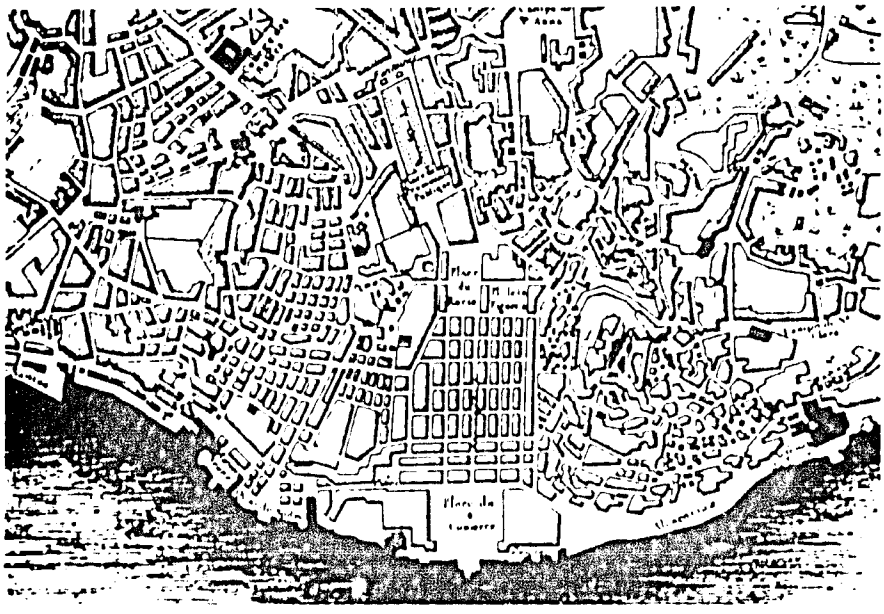


FIG 1. Map of Lisbon indicating extent of post-earthquake formal planning

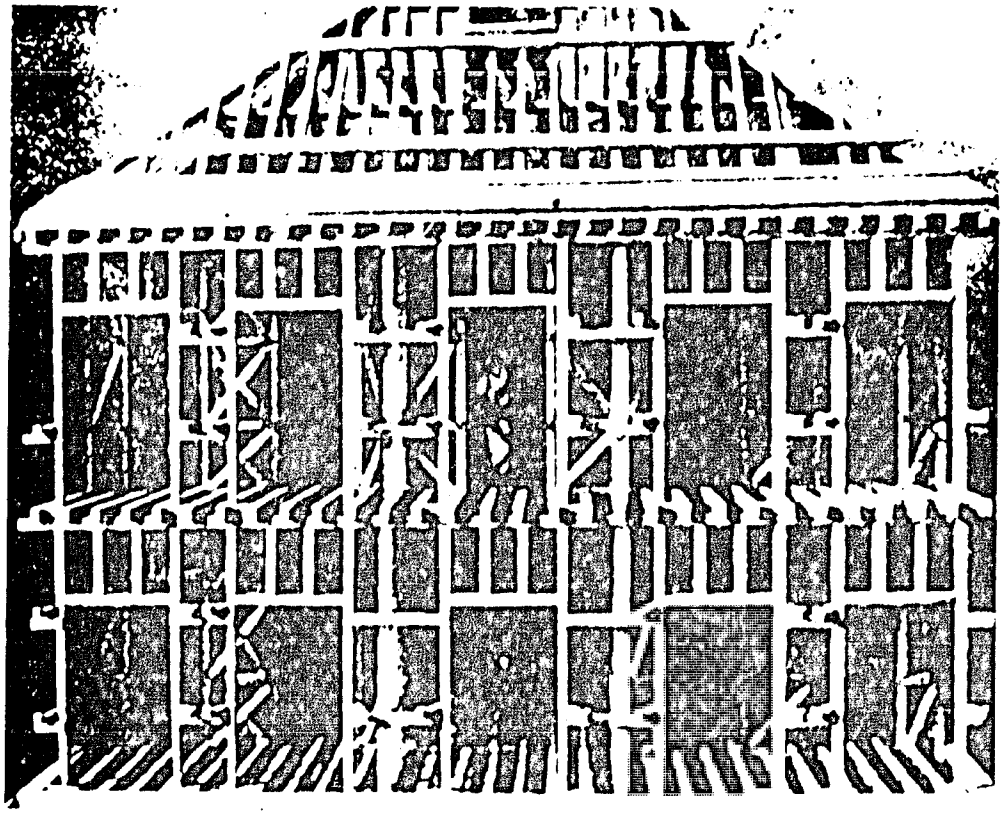


FIG 2. Model of 'Gaiola' indicating the aseismic timber frame prior to masonry infill

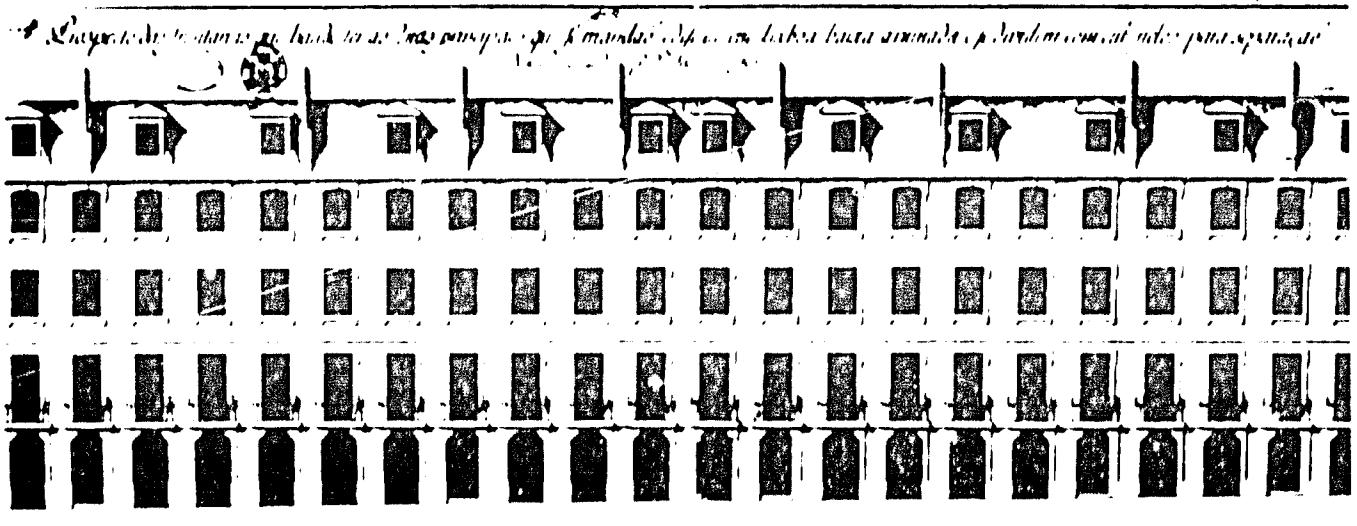


FIG 3. Elevation of reconstructed terraces indicating the fire breaks on the roof

A further mitigation device was the decision to incorporate masonry fire breaks as divisions between buildings. This was to prevent any recurrence of the fires that accompanied the 1755 earthquake. FIG 3.

No major earthquake has occurred in Lisbon since their disaster to test the overall effectiveness of the system, but the absence of any major fire is a tribute to the fire break system. Da Maia's form of construction was adopted as the normal way of building in Lisbon and persisted right up to the 1920s. There are a few pertinent lessons we can draw from this case study which are relevant to my theme. Firstly, the process of implementing aseismic design measures is by definition one of compromise; some battles may be won but others will be lost given the nature of vested interests and other priorities. Da Maia was sufficiently astute in political skills to recognise this reality in the way he presented his set of proposals.

Secondly, the modification proposal to improve the seismic resistance of traditional buildings was very subtle. The existing form of masonry building was preserved despite a totally different constructional system. Had the architects suggested a 'natural' expression of the timber cage (on the lines of an English half-timbered house) it would probably have been doomed to the dead storage drawer of an 18th century filing cabinet.

Thirdly, the implementation of the proposals was backed up by political power of Pombal. Without his absolute centralised authority it is doubtful if the reforms would have been carried out.

To summarise the lessons from a case study $2\frac{1}{4}$ centuries ago, we can see that the reasons why the modifications occurred were due to four factors: The fear of another earthquake (the city experienced no less than 500 aftershocks and 30 major tremors in the year after the earthquake); the centralised power of Pombal; the skills of the architects, and the subtlety of their proposals. And the entire process was one of compromise, the city was <u>not</u> moved, it was <u>not</u> totally redesigned and the existing architecture was <u>not</u> changed in appearance.

Of course there is a major question mark about the social implications of redesigning the street layout for the central area of the city, who gained and who lost in the process. The slender evidence suggests that the ruling property owning classes of Lisbon came out reasonably well and if anyone suffered it wasn't them. Thus a dilemma is posed. Are major planning reforms on aseismic, or any other grounds <u>ever</u> achieved without the most disadvantaged groups suffering the adverse consequences? In effect do ends justify means? Put another way, is the centralisation of power a prerequisite for major planning changes, and if so what likelihood is there within liberal democratic societies of such policies, however beneficial in the long term, being implemented?

This case study of Lisbon is instructive since it contains many of the ingredients of 'modification programmes' as we now come to know them. The two most basic elements were the linkage of knowledge about seismic factors with a sound understanding of building construction, and secondly the ability to implement the measures to reduce the risks, or put another way political determination.

The implementation of programmes to modify humble adobe buildings in seismic areas is a far cry from the proud avenidas of Lisbon, but as I hope to show later there are important points of similarity.

REVIEW OF WORK IN PROGRESS

1. Research Work

Keeping the theme of 'thinkers and doers', I want to review both some current research as well as certain implementation programmes. Then in specific instances the gap between the two has been happily bridged where research has lead to an implementation programme or has followed it as a form of evaluation.

One danger I can see in attempting this task is to confine my attention to projects that are strictly concerned with adobe in earthquake areas. This blinkered approach will ignor housing modification programmes concerned with other hazards such as designing against flooding or high winds. The dilemma is of course that in expanding into this sector this paper will be too long and lose its focus. Therefore, I want to identify some of the key literature under the following references for those anxious to pursue this study: (2,3,4) However, I am aware of the broad conclusions from some of these non adobe, non earthquake programmes and have taken these into account in my broad findings.

An additional aspect of this problem is that with knowledge being so compartmentalised, it is apparent that important lessons on attempts to change traditional patterns have a far longer history in certain disciplines than in the one under consideration. For example the field of nutrition has an extensive literature on attempts to improve the traditional diet of people suffering some form of nutritional deficiency. I understand that the broad results from these studies are sadly negative with strong evidence of failure of various attempts to introduce these changes. It is also apparent that this failure has occurred in both Third World countries as well as in industrialised societies. Numerous examples could be cited from developing countries, for example in the Phillipines the local families ground their rice so finely that the rice husks were destroyed. These contained Thiamin which is an essential vitamin source, without which people became vulnerable to the fatal disease of Beri-beri. Therefore in an attempt to rectify the deficiency, nutritionists attempted in vain to supplement Thiamin in pre-mixed grains. In Britain a well documented example was an attempt to persuade school children to increase their milk consumption. Despite intense advertising, no progress whatsoever was made. So any lesson from nutritionists must be that rapid results are unlikely to occur, despite the logic that lives may be saved by a change of habit.

I will start with a review of some of the research which is particularly relevant to the subject area of implementation. One section of this work is in the category of training programmes for builders concerned with the development of labour intensive traditional ways of building using local materials. Work in this area has been erratic and largely uncoordinated, and has of course been continually handicapped by the forces of 'modernization' of cultures, where pressures from both within and without have consistently undervalued local traditions including building skills. One of the main areas of work has been that attempted by the 'Development Workshops' who worked in the Middle East from 1973 up to the fall of the Shah of Iran. (5) They are now working in Angola. This team comprises three architects: Allan Cain; Farroukh Afshar and John Norton. This group have been committed to the

development of local skills and the improvement of traditional ways of building, and we will await with interest the results of their work in the very different context of Angola.

Immediate Technology Development Group (ITDG) have also taken some initiatives in this area with their studies of the Management and Organisation of Small Building Contractors. These studies have largely confined themselves to administration rather than providing guidance on training programmes. (6)

The World Bank have also examined the training issue and they commissioned a research project on the training of local contractors for labour intensive road building. This was undertaken for them by a British firm of Civil Engineers, Scott Wilson Kirkpatrick and Partners. (7)

In terms of research related to earthquake resistant housing, one project has been under consideration for some years in Turkey. The Council of Europe made a grant to the Turkish Government for a housing modification programme in seismic areas. This was handled by the Turkish Ministry of Village Affairs. One aspect of this project was an education programme with wall charts being produced for use in village community halls, teashops, etc. A further aspect was to build pilot 'modified houses' in various vulnerable locations to test them in the event of future earthquakes. However, I have not heard of recent progress of this project, and to my limited knowledge the pilot project has yet to be attempted.

Following a period of field study in Turkey I was approached by one of the advisers to this project and he had several proposals which were being considered for housing modification. One of these was to substitute a light metal roof for the very heavy earthen roof of the traditional Turkish unreinforced masonry or adobe house. In our comments on this proposal we made the point that such a proposal whilst being very logical on seismic grounds would have very significant cultural and economic consequences for families concerned. We pointed out that the flat roof of the traditional Turkish house fulfilled a very wide range of uses which included a protected area inaccessible to animals; a sleeping area for warm nights in summer; an area which was used for drying fruit and corn. In addition the traditional earthen roof was a very logical type of structure for families living at subsistence levels in that it virtually costs nothing if timber was available locally, and the way in which the roofs were constructed used every part of a tree including the branches and brushwood prior to putting on the heavy mud roof. I mention this detail because it seemed that any change to make the roof aseismic had to start with the concept of a flat roof rather than substitute it for another which would have so many adverse social consequences.

A further project, one in which I participated, was the Housing and Natural Hazards Project of the Royal Geographical Society's International Karakoram Project of 1980. A unique characteristic of this project was its multi-disciplinary nature comprising eight investigators from a variety of professions: Anthropology; Engineering; Planning; Architecture, Geology, Geography and Archaeology. (8)

The objectives of the proposal was to examine the vulnerability of settlements in the Northern Areas of Pakistan to natural hazards, to determine what forms of adaptation had occurred and whether the buildings could be modified to reduce the risks to the affected population. Four case studies were undertaken comprising study of diverse communities, their settlement and housing patterns as well as the risks they faced from five types of natural

hazard, and the local awareness of such risks. One of these case studies was of Pattan, an area that had been badly damaged in an earthquake in 1975. Prior to our departure the team examined the methodology of the only comparable project we could find. This was the Housing Improvement Programme undertaken by INTERTECT and Carnegie-Mellon University in Peru from 1977-79. This was a very important piece of research which was also a pilot project which I will describe later. (9) We took the list of nine topics used by INTERTECT in Peru (see column 1 of chart, FIG 4) and added two items which related to 'local awareness of risks' and 'conflicting priorities' (see column 2 of chart). One of the many conclusions from the project was that even our adapted approach of column 2 needed further change to include a detailed analysis of the local values and priorities (see column 3 of chart, FIG 4).

The overall findings of the expedition will be presented to the International Karakoram Conference in London in September 1981. However, a simple chart was developed which conveys some of the findings of the group (see Appendix 1). In addition, Dr Robin Spence, an engineer from the University of Cambridge, has presented a paper to this workshop on the vulnerability of local housing in the Karakorams to earthquakes. (10)

One of the major lessons from this project was the realisation of the very diverse contexts in which modification could be considered. There are two broad categories:

Existing Buildings - By this I am referring to the modification of existing buildings as a pre-disaster mitigation measure.

New Buildings - Here I am referring to two contexts which both require new construction, but which are totally different in nature, as I will explain. The first category of new building is the building of new structures within seismic zones. Therefore, the modification issue is the improvement of building skills or techniques. The second category is that of post-earthquake reconstruction. This relates to reconstruction work which I take to include the repair of buildings.

Studies of modification up to the present time have failed to recognise the subtle differences in these differing contexts. This is hardly surprising since the subject is still in its formative years. The main issue is that lessons learned in one situation (i.e. reconstruction) are not necessarily transferable to a pre-earthquake context or even to normal new building work. The following chart examines these different characteristics with an attempt to identify the constraints and opportunities in the different categories. (FIG 5)

Column 1. List used by INTERTECT in Peru (9.)	Column 2. List as developed by Karakoram Project Team Prior to departure	Column 3. Tentative results of Karakoram Project
1. Identify Areas of High Risk 2. Identify Areas with concentrations of Vulnerable Structures 3. Determine Housing Demand 4. Determine Receptivity of New Ideas 5. Conduct a Sociological Profile of Community 6. Select a Community/Site 7. Study Normal Building Process 8. Develop Training Aids 9. Conduct a Pilot Project	1. What is the normal lifestyle/economy/building process/housing condition? 2. What are the risks from natural hazards? 3. What is the awareness of these risks? (addition to INTERTECT list, column 1) 4. What are the conflicting priorities that may make housing modification improvement impossible? (addition to INTERTECT list, column 1) 5. What are the local resources to undertake housing improvements risk reduction/mitigation measures?	The evidence from our seven projects indicated that it is not possible to study the question in the way we had formulated the list (as left). In our view the analysis of vulnerability must be an intrinsic part of an examination of the total values and priorities of a given community. To isolate this topic of vulnerability produces a false perspective of local need and economic possibilities. (8.)

FIG 4. Questions to be answered as prerequisites to any housing modification program

CATEGORY			MODIFICATION PROCESS	CONSTRAINTS FOR MODIFICATION PROGRAMS	OPPORTUNITIES FOR MODIFICATION PROGRAMS
EXISTING BUILDINGS			Strengthen vulnerable existing houses by modification programs and by training programs	1. A lack of financial resources ; 2. A lack of urgency on the part of officials or building occupants; 3. The social upheaval of making any changes to existing houses; 4. The lack of any 'standard building', each building being a 'one-off' design problem requiring skills in appropriate modifications	1. Very limited for the houses of poor families, much greater for those with higher incomes; 2. A major problem is the vast proportion of vulnerable housing stock - too large for available resources; 3. Good opportunities for public buildings, especially those involving public assembly, i.e. schools, churches, mosques, etc.
NEW BUILDINGS	All new buildings in seismic zones		Modify existing skills, techniques and certain materials for construction, design and siting	1. Basic conservation of traditional societies to any change; 2. Additional costs of aseismic construction; 3. A lack of teachers to explain basic principles to local builders	1. Good, if there is the support of public authorities, if there are teachers available and institutions to implement projects
	Post earthquake reconstruction	New buildings	Modify existing skills, techniques and certain materials for construction, design and siting	1. The prevailing mentality of most reconstruction authorities and relief agencies that suggest that reconstruction should consist of (a) temporary 'stop-gap' housing; (b) a radical change of technology; (c) a contractor based activity that ignors local manpower and skills and the opportunity for training programmes	Very good for two reasons: 1. There is the visual aid of building failure, people are open to change; 2. There is an availability of cash as well as expertise from assisting groups
		Repairs to damaged buildings	Strengthen damaged houses with aseismic improvements incorporated into repair		

FIG 5. Opportunities and constraints for the modification of buildings

2. Implementation Programs

One of my reasons for attending this workshop is to find out about work in progress. Therefore, I find it impossible to fulfil this part of my assignment since I only know of a handful of modification programmes that have been implemented, and I am certain there must be others that have eluded my literature search. I am hopeful that much additional work has been attempted that resolves some of the dilemmas in the projects where I have some knowledge, and am looking forward to hearing of them from workshop delegates.

The first example I want to quote will be familiar to many delegates since it is probably the most comprehensive modification project to have been undertaken. My own part in this was minimal but it was interesting to have participated in some of the very early discussions that were held in Guatemala just a week after the 1976 earthquake when the project was being conceived. The project emerged from a combination of events and skills. The events were that OXFAM, a British development agency, had for some years been supporting World Neighbors in their work in rural areas. This had consisted of a variety of development projects, working for about ten years in close contact with local farmers through agricultural co-operatives. It was out of this context that the housing programme emerged. The skills were those of Fred Cuny of INTERTECT who was hired by OXFAM to advise them on their reconstruction programme. The Field Director of OXFAM was Reggie Norton, who had considerable previous experience of disasters, particularly in Nicaragua following the 1972 earthquake. The Project Director of World Neighbors was Mary MacKay who was another vital link in this project. Essentially the project differed from the programs of the other agencies in that it did not attempt to build lots of houses. Cuny and Norton saw little point in duplicating what people could well undertake themselves; they saw the role of an external agency as being strictly a support activity. Norton has recently described their priorities in these early stages of the project:

> "In disasters, as much as in other situations, an agency should be concerned with the development of self-reliance and the fulfilment of human potential among recipients and any programme should be consistent with this aim. It is essential, therefore, that from the beginning the people should participate fully in the decision-making process. They must have the major say in the sort of project that is pursued. The ability of the disaster victims to cope with their problems must be respected, and they must not be treated like children incapable of doing anything for themselves." (11)

The agencies recognised the well developed building skills of Indian house builders in the Guatemalan highlands and that it was therefore pointless to build large quantities of houses. What they (as an expatriate agency) could do was to provide key materials at prices which people could afford, and secondly, provide expertise to assist families in building safe houses. This was to give advice on both the safe siting of buildings and ways of making adobe houses resistant to a future earthquake. The OXFAM/World Neighbors project consisted of building model houses which incorporated safe constructional techniques in various towns and villages. These houses were then used for extension programs where classes were held to train people to build safe houses. (FIG 6)

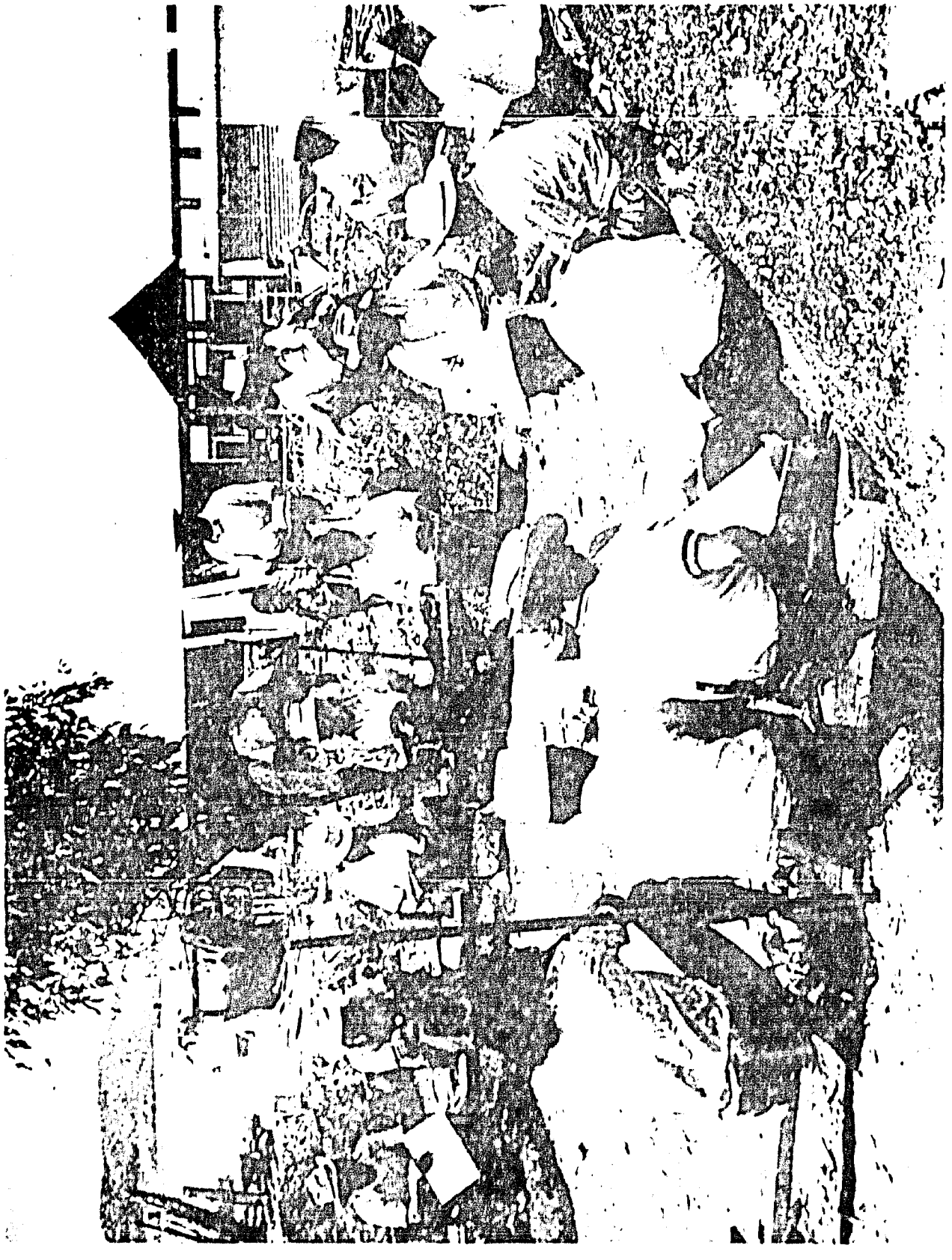


FIG 6. Training class in progress for Improved Construction Techniques in Guatemala. (The foundation trenches for the model house can be seen.)

The long term effects of this major innovation are still unknown; how far it has been successful in fulfilling its major objective which was of modifying people's traditional ways of construction has still to be established, but initial results are encouraging. One of the recent evaluations of the project has shown that some builders are using the system as part of their sales promotion, and that despite the departure of the agency the techniques persist. It is also apparent that many families are only now rebuilding their homes, five years after the earthquake. Their explanation for the delay is that they have been slowly buying the roofing sheets and developing their agriculture.

The success of this project appears to stem from the following:

(a) the fact that the survivors had a trust relationship with the various local co-operatives with whom OXFAM/World Neighbors were working (stemming from their pre-earthquake involvement with these communities);

(b) the modification of the traditional house was a significant change, but it attempted to retain as much as possible of the local building tradition , in effect it followed the good example of the Lisbon terraces described in my introductory case study. This is very important since many previous post-disaster housing programmes have attempted major technological advances with a different external expression, rather than a simple step forward; FIG 9

(c) the programme was able to capitalise on the all too obvious visual aid of past constructional failures;

(d) the programme was able to offer people corrugated iron roof sheeting which formed a very important emergency shelter protection in the immediate period following the earthquake and it then went on to form the roofing of the permanent house.

The experiences of Guatemala has been extensively documented by OXFAM, with independent evaluations of the housing programme. (12)

Two and a half years after the earthquake Mary MacKay described what OXFAM/World Neighbors had learned from the project. (13) She listed nine lessons and they remain as one of the most important statements relative to housing improvement programmes, therefore I will summarise them:

1. Reconstruction had been much slower than they had anticipated (a study of 20 villages showed that 15.2 of the population had rebuilt homes 2 years, 2 months, after the earthquake). She concludes that for a future post-disaster housing programme it should be based on a 3-5 year period.

2. The agency had to fully recognise that the success of this education programme could not be measured in numbers of houses built, despite some pressure to do this.

3. In areas where temporary houses had been built, there had been minimal interest in building permanent houses.

4. They found that the Guatemalan builders that they had trained had little inclination to motivate people to build safe houses. Therefore, leadership training was vital.

5. The use of timber frames in the houses required additional carpentry skills (the old houses principally required masonry skills).

6. More research is needed on educational aids to convey ideas to a rural population. (FIG 7)

7. More research is needed on unresolved technical issues (wood rot, termite attack).

8. The programme required the presence of a permanent architect or engineer to provide technical assistance.

9. The OXFAM/World Neighbors programme was concerned with adobe. However, many families had rising expectations during the reconstruction period with an appetite for concrete block buildings.

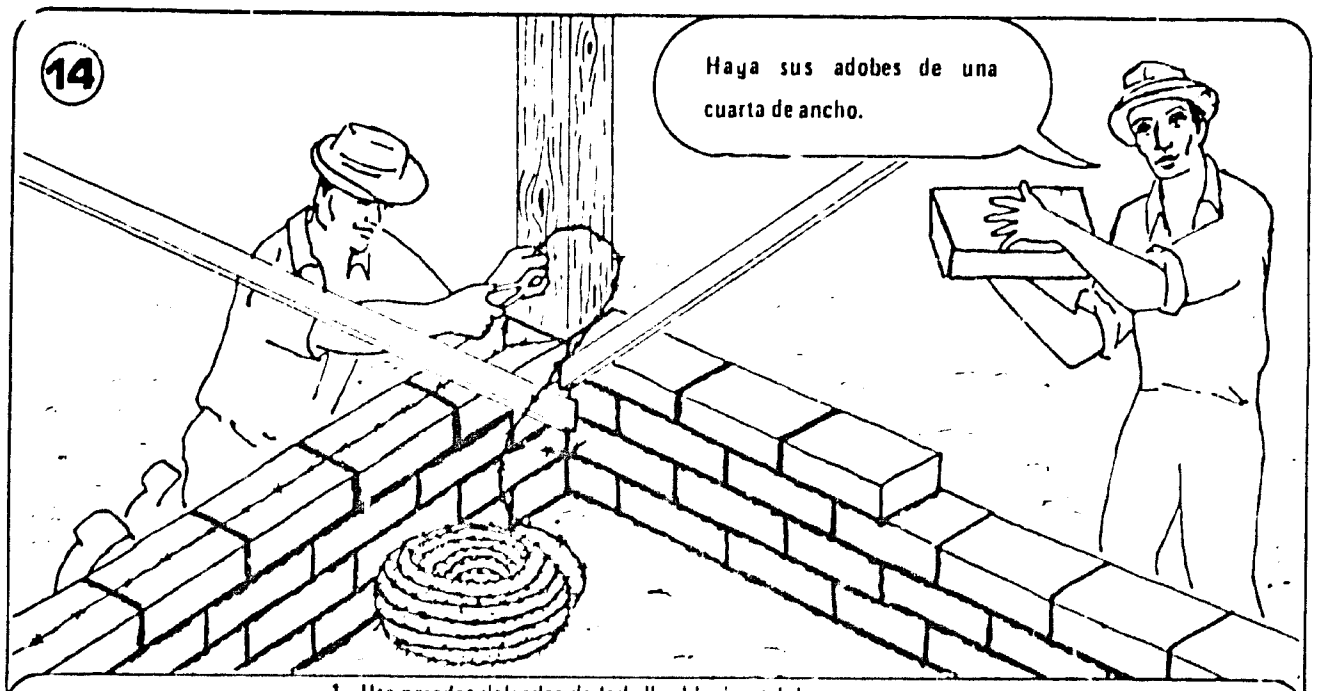
Five years after this programme was conceived we can stand back with the luxury of hindsight and reflect on an undoubted achievement, but also to raise four issues. Mary MacKay hints at one of these when she referred to the 'rising aspirations' of the local population. The question is whether the leaders of this project were right to place their committment and resources into the use of traditional materials. The reasons for this emphasis related to the logic of cost and cultural factors, but the rising aspirations may have indicated the need for a parallel programme to teach safe techniques in concrete block construction. Whether, in effect, there was more than a hint of social determinism by the agency in the decision to concentrate on adobe. (Advice was also given for walling made of bajareque, a form of wattle and daub construction.)

The other question relates to the construction technique that was adopted. Whether there is any future in the close mix of adobe blocks set immediately within a timber frame. The obvious problems are that of rot and termite attack.

Thirdly, it will be useful in future evaluations to find out whether the modified house has been fully accepted, since for all the similarities to existing houses there remain very radical changes. These are the lack of roof insulation with the CI roof and in lieu of heavier clay tiles. It will be very interesting to find out whether local families have found the reduction in roof heights a serious problem in lieu of the smoke problem where there is internal cooking, and what substitute places are now used to dry off their corn in lieu of hanging it from beams.

Finally, the slow reconstruction is very interesting since it suggests a very low priority for housing against other needs. Or, alternatively, is this due to some hesitation about the new mode of construction, and is slow reconstruction a characteristic also of other reconstruction not using this system?

Shortly after its role in the Guatemalan programme, INTERTECT became involved with Carnegie-Mellon University in a comprehensive program for housing modification in Peru. This was for a project organised by the Peruvian Civil Defence with funding support from USAID. This project is very



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2. Use poca mezcla para pegar los ladrillos, blocks o adobes.
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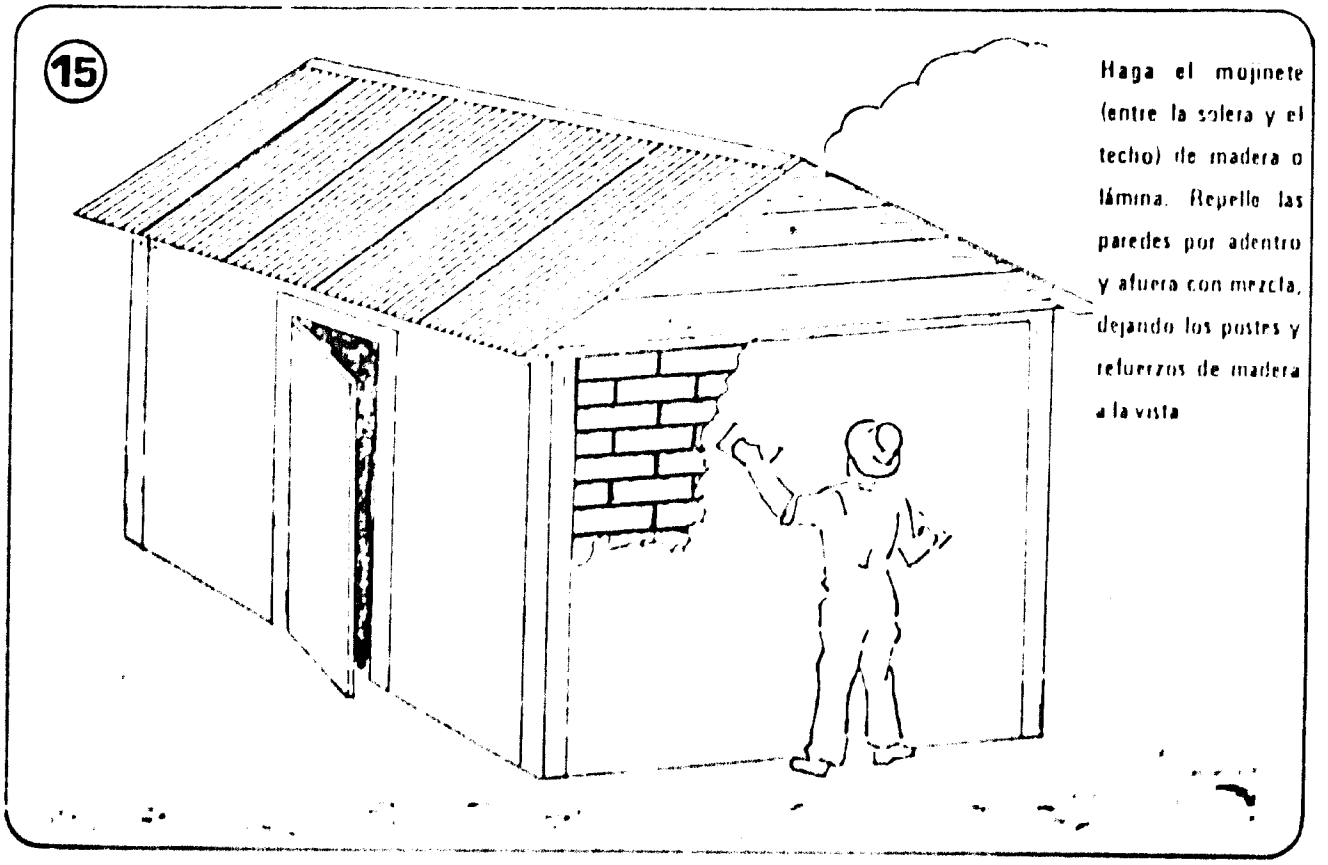

FIG 7. An excerpt from the Housing Education Booklet: 'How to Build a Safe House' (Como Hacer una Casa Segura)

important because it examined the overall risks to houses and settlements from various natural hazards and it sought to implement a pilot program to modify the most vulnerable houses, and in certain extreme instances relocate settlements. During the project Fred Cuny (who was a consultant to the project team from the Advanced Building Structures Program of Carnegie Mellon University, lead by Professor Volker Hartkopf) documented a work method or 'Scenario for a Housing Improvement Program' (14). This was largely based on the way the Peruvian project was structured. A further study has been produced which describes the findings of the project (15).

This project explored the implementation of a very interesting modification system where a bamboo frame was inserted into holes cast in the centre of adobe blocks called a 'Modern Adobe System' FIG 8.

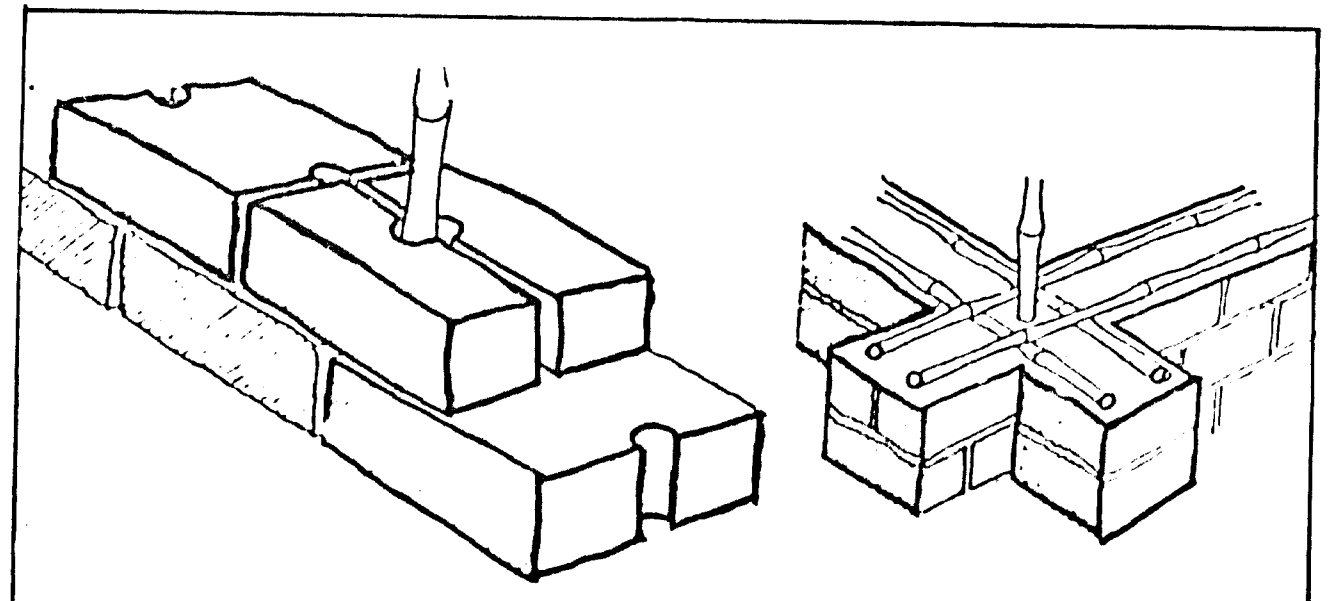

FIG 8. The adobe blocks with the central hole cast to enable the frame to be inserted. The second drawing indicates the attachment of the cane to a horizontal 'ring beam'.

This project in Peru represents part of important 'ongoing' work being undertaken in this sphere for many years. It is also apparent that the experience gained in both Peru and Mexico has not been disseminated widely, mainly as a result of language barriers.

DEFINING AN APPROACH TO CURRENT PROBLEMS

1. The Gap between Thinkers and Doers

In his seminal work on low-cost housing for the developing world, Charles Abrams wrote seventeen years ago:

> "In most places, housing does not get even the attention of a public works engineer, much less an architect. If, somehow, some houses do go up, they are most often neither flood- nor earthquake-proof; soil erosion undermines their foundations..." (16)

Abrams proceeded to catalogue a long list of defects which presumably would have been rectified if a professional was involved. With hindsight, it is apparent that this might not be the case; however the essential argument is still largely relevant.

In 1975 during the conference to mark the 10th Anniversary of the establishment of the Earthquake Engineering Research Institute in Skopje, Professor N N Ambraseys from Imperial College, London, looked round the conference room and asked for all the small builders and craftsmen amongst those of us in his audience to indicate their presence. The negative response prompted his observation that until they attended such meetings then we would see little progress, since much of what was being said in such conferences concerned with engineering seismology was a matter of preaching to the converted. A year later in 1976, Ambraseys concluded his chairman's remarks, at a Symposium on the Guatemalan earthquake, with the cryptic statement: 'Today's "Act of God" will probably be regarded as tomorrow's act of criminal negligence.' These two statements are of course linked. In any major earthquake, buildings collapse which have been built in total or partial ignorance of aseismic construction, whether it be basic structural design or general design principles of balanced design, and siting. Having just returned from a visit to the Campania earthquake site in Southern Italy, there is abundant evidence of the failure of builders to understand aseismic design (17). A further reminder of this reality came with the October 1980 El Asnam earthquake (18).

Neither of these two disasters is specifically relevant to our workshop since adobe was not the main building material in either context. But what is highly pertinent is the fact that despite our experience from numerous earthquakes, and the growth of our knowledge of aseismic design, the principles and practice are not being communicated to those who need this information.

All these issues are obvious, but what is not so clear is to see what steps can be made to bridge this yawning gap between knowledge and its application. I would suggest that a wide ranging strategy is necessary with roles being defined for all the various participants, including professionals; public officials; builders and house occupants. As far as architects are concerned, some have begun to show a belated but nevertheless genuine interest in vernacular traditions of building. However, the proof of such interest is rather like the pudding, and the eating. If architects are really committed to the development of vernacular building traditions then the acid test of this

concern is whether they will be sufficiently committed to assist this process, in what is likely to be an unremunerative, supportive role. Such a task requires that the creativity of an architect is focussed right down to resolving small scale details. Few architects have become famous from this type of work.

Similarly, there is the same gap or conflict within the engineering profession. In the same manner as architects and planners, they have concentrated their resources and energy on high investment buildings, and adobe and all forms of 'cheap' construction remain as 'cinderella' areas of concern. In his 1978 address to the Oxford Conference on Disasters and the Small Dwelling, Professor Reza Razani from Iran referred to only 5% of the engineering seismology literature being devoted to buildings consisting of adobe or unreinforced masonry construction. Yet he had calculated that 60% of all deaths from earthquakes in Iran had been caused by the collapse of such structures (19).

However, the very existance of this workshop is proof of the growing interest in this problem and this is in itself very encouraging. What is needed as a vital next step is for the subject of improving humble adobe structures to get into the curriculum of our various post-graduate schools of architecture and civil engineering. Such is the all pervasive influence of patterns within the US or industrialised Europe on the Third World (particularly in response to the influences exerted on students from these countries studying in western countries), that a change of outlook here could have rapid and far reaching consequences on attitudes in developing countries.

Aldo Norsa has presented a paper to this workshop where he comments on the enormous problem in Italy of seismic risk and the urgent measures needed to tackle the problem. He observes that 35% of the Italian population are at risk from earthquakes (57 million people) and that any attempt to prevent future disasters is concerned with no less than 40% of the country's entire housing stock. Norsa comments that this grave situation:

> 'will entail the need to train a new generation of planners, designers and builders who are expected to work in closer contact with communities and show a greater understanding of local traditions and of time-honoured techniques.' (20)

So the first approach to this problem must be an emphasis on training this new generation of designers. But perhaps even more important than this priority is the need to borrow one of the medical profession's best ideas, that of the creation of a new breed - the barefoot architect, or engineer. This occupation hardly exists at the moment, but it is probably the only really effective way to bridge the gap between appropriate knowledge and implementation. The qualities that such men or women will need are very demanding. I would suggest that they need four basic skills, and the first is probably the most important: to be able to relate to local people, certainly to possess leadership skills and to speak the same language as local builders; to be sensitive to local building traditions and construction practices; to have a working knowledge of seismic factors and seismic design principles; and finally to understand the social/political context in which they are working. Each barefoot architect must understand this broad developmental context so that he is sensitive to the need to promote self-reliance whenever possible without establishing a dependent relationship with those he helps.

Numerous problems exist on the possibility of this new occupation being formed. For example such questions as who will train them, how will they be paid, and what is their relationship to public officials? Could they be a method whereby aseismic codes are enforced?

Finally, will the engineering and architectural professions actively support the creation of barefoot designers? Or will they follow the example of many within the medical profession who regarded this innovation as a basic threat to their professional role and vigorously opposed it. This occurred despite the abundant evidence that they were too few for the task before them and that they were often overqualified for treating the vast majority of ailments. This is a pair of characteristics also applicable to this sphere.

2. The Relevance of Aseismic Building Codes

The fact that vast damage occurred in both Italy and El Asnam despite the existance in both contexts of aseismic building codes is a further reminder (if one was needed) that any implementation strategy, whilst including relevant codes backed up by laws, will not place reliance on them since their enforcement is so very rarely effective, or possibly even feasible for poorer countries. If authorities in earthquake prone countries had heeded Abram's warning on this issue a more realistic attitude might have developed:

> "Building codes are of course essential, particularly in congested areas subject to earthquakes... The tendency in a number of countries is to copy the complex codes of England, Germany or the United States, as well as their zoning and planning laws, though they are irrelevant and though the talents to enforce, construe, and adapt them may be completely lacking." (21)

Since this topic has an entire subject area devoted to it, there is no need for me to duplicate the work of others, I merely want to observe three points. Firstly, the need to devise relevant codes. So often adobe and other humble building systems have been excluded, and this is as meaningless as the refusal of public authorities in cities experiencing rapid urbanisation to recognise the existance of their vast squatter settlements. Secondly, for public authorities to use imagination in ways of ensuring that codes are followed, particularly by recognising that training programs in good safe building are a complimentary activity to code enforcement. Finally for all concerned to recognise the limitation of codes. They are not a panacea, rather just one of many strategies to reduce risk.

3. Classifying the Seismic Resistance of Structures

Scientific analysis requires an orderly structured approach to problem solving. This immediately poses a great problem relative to small dwellings, since it is difficult and often impossible to find regular patterns. For example, in the studies that were made in the Karakorams in Pakistan, our group spent much time in trying to establish what was a 'typical house'. We found a great variety of shapes, diverse siting conditions, mixtures of building materials, and continual varieties of condition, some being well maintained, others badly neglected. One classification category alone, 'unreinforced masonry' could consist of unbonded cut stones, bonded cut stones, unbonded riverbed round stones, dry stone walling, mortared walling, etc.

In a similar manner, when the focus is shifted to natural hazards again the variety is great relative to potential impact from a single hazard, let alone composite effects. These variables do not make analysis of hazard resistance impossible but they certainly indicate the need for a much better sampling method than has been adopted in the past.

4. Rising Expectations

I have already referred to this topic in considering the Guatemalan case study. Mary MacKay referred to the changing aspirations away from adobe towards concrete block houses. What stance should assisting groups take on this issue? One position is to advocate a 'small is beautiful' philosophy by advising a policy of traditional materials and skills at all costs. Against this there has been the 'party line of so many relief agencies - 'The traditional answer failed, so substitute a new one designed in New York and assembled from components from South Dakota'.

There are many difficulties here, which I have touched on elsewhere (22). My concern is that I believe the role of assisting groups is primarily one of response to locally expressed needs, as opposed to a socially deterministic attitude that determines peoples 'needs' for them, even if this is in the interests of the families in question. Naturally this raises the whole question of modification - who is asking for it, the occupants or some group totally remote from the economic level or value system of the society in question? The issue boils itself down to the old questions of who is helping whom, why are they doing it, with what presuppositions, on whose authority and to whom are they accountable for their actions?

5. Social Priorities and Implications

In the earlier discussion about the modification of the heavy Turkish flat roof to a lightweight pitched version, I raised the issue of the social cost of reducing earthquake risks. Paul Oliver has dwelt on this topic in his paper submitted to this workshop. (23) It would appear that officials and professionals who have been associated with modification programs have often played down the social impact of their proposals. These may not be as radical as the Turkish roof issue, but a glance through a guideline booklet such as Como Hacer una Casa Segura (How to build a safe house) (24) indicates a wide range of social/cultural implications. They include a change of walling system (keeping the adobe but inserting them into a timber frame), a totally new type of roof covering, a different 'balanced' shape of house from many irregular plan-forms, reduced ceiling height, different spaces between buildings, etc. In setting out this list I am not doubting the need to include any item; merely to observe that their cumulative effect is to propose a very different form of house from the one that failed to survive an earthquake. FIG 5 & FIG 9

The issue here is for all individuals involved in such projects to be aware of what they are doing and not to minimise the social impact of major changes with potential negative consequences. These could be a very slow reconstruction process, or rejection of the proposal by house owners.

On the subject of social priorities, the experiences of the Karakoram project indicated that given the scale of local poverty that any attempt to modify existing house construction or siting was not viable given other priorities of local families. There were far more pressing everyday needs such as better health facilities and agricultural needs. Our project therefore suggests that any investigation of risk reduction must take into account the total needs of a given community, and not presuppose that modification is desirable. (This is indicated on the chart on FIG 4 .) (25)

6. Objectives

Throughout these issues I have been questioning basic presuppositions that are frequently made, often without realising that they exist. Finally, I want to raise the question of what the aims are of housing modification. The first issue to clarify is whether it is to protect lives or property. Presumably the former is the aim and that damage is regarded as inevitable and repairable.

If our findings on FIG 5, and APPENDIX I are correct, then there is a major problem in protecting lives in existing buildings. The question is whether another strategy is possible in this instance, for example the idea of a safe 'core', or the 'four-poster' bed proposed by Reza Razana to protect people when they are asleep, and don't notice foreshocks with the opportunity they offer to run out of a house.

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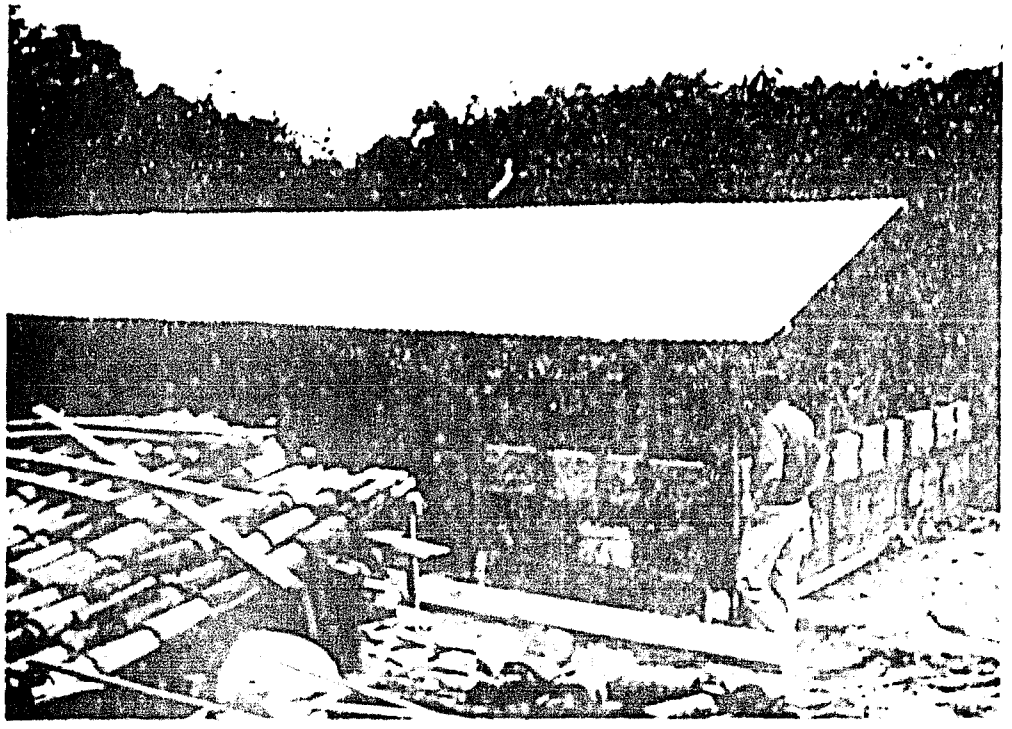

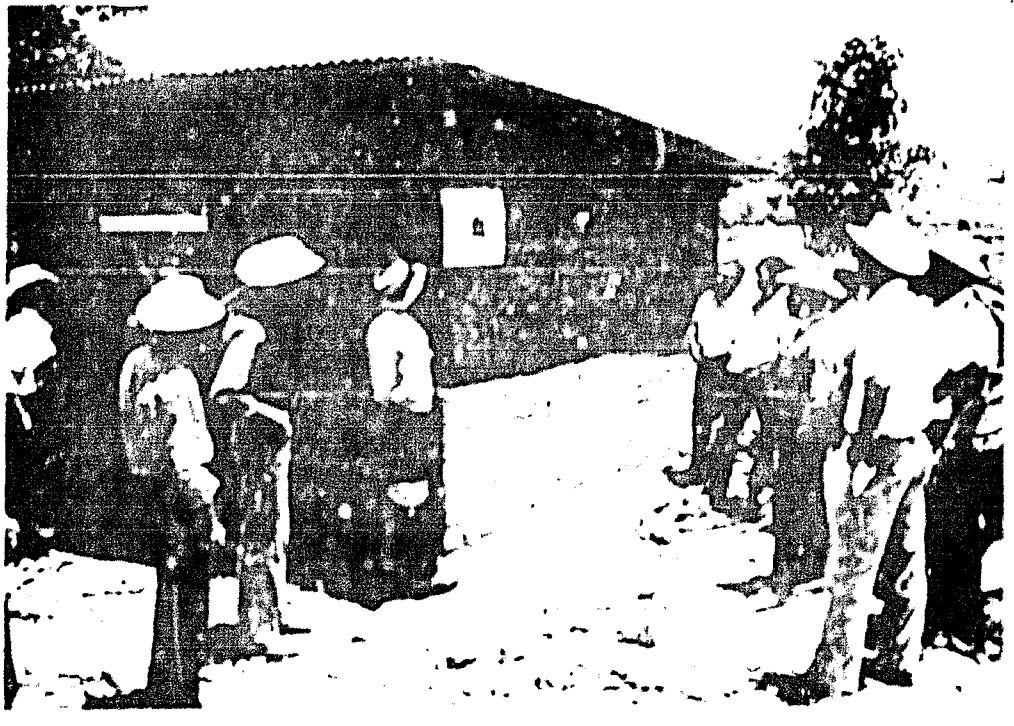

FIG 9. Model houses of the OXFAM/World Neighbors program. Note the insertion of adobe blocks within the sawn timber frame in the top photograph.

THEMES TO BE ADDRESSED

Emerging from these problem areas, I want to identify nine priority themes that this workshop subject area may choose to address. These are obviously a personal choice that suffer from my cursary experience of improvement projects, as well as personal prejudices and 'hobby horses'. However, despite such limitations, I hope that they will assist in framing our discussions.

Theme No 1

How to reconcile the technical criteria with social/political dimensions?

The following eight themes embrace technical (or technological) issues as well as social, philosophical, even ethical dimensions. This underlines the width of the subject and the problem I want to isolate is the narrow emphasis of those of us who work in this field. Much past study of this subject has suffered from the classic technical/social culture gap, and hopefully this workshop will recognise that a marriage is long overdue between different (but totally linked) subjects or disciplines, which are essentially facets of the same problem. The need is so obvious that it barely merits restatement that those working in a technical sphere need to recognise the wider social dimensions of implementation. Then conversely those with social concerns must grasp the complex technical issues which relate to engineering seismology, which are essential for a full understanding of this subject.

Undoubtedly, this theme takes us squarely back into the structure of academic education with the intrinsic weakness where a blinkered and often highly specialised study of subjects occurs with narrow parameters which merely reflect the bias of a given academic discipline rather than the totality of what actually occurs at the field level.

Theme No 2

What can be done to bridge the vast gulf between the policy and research level of concern and the field level?

Having identified the science/social gap, we now move on to an even greater gap (or perhaps gulf would be a more accurate description). This is the familiar 'poverty barrier' that separates those with knowledge, power and influence from the poor, who in our study live in adobe houses.

The gap relates to all assisting groups, and it constitutes a major reason for the minimal attention that has been devoted to our workshop theme heretofore. Attempts to close the gap take us into the realm of attitudes, relationships and structures. Starting with the latter, one answer to this problem is for assisting groups to focus their energy, skills and resources through the channel of local institutions (where such bodies exist). The advantage of these groups is that trust relationships are likely to exist with local families. Peter Berger and Richard John Neuhaus have written a perceptive analysis of the role of such bodies in their study To Empower People - The Role of Mediating Structures in Public Policy (26). They also identify another

factor which has contributed to the barrier – the issue of 'Professionalism' and the alienation it can bring to disadvantaged groups, rather than the service that they may well expect from such groups:

> 'Professional standards are of course important in some areas. But they must be viewed with robust scepticism when expertise claims jurisdiction, as it were, over the way people run their own lives. Again, ordinary people are the best experts on themselves... Lower income people are most effectively disfranchised by the successful establishment of expert monopolies.'

The issue of professionals retaining their power and authority is paralleled by the centralisation of control and finance by public authority as well as the centralisation of technology within the established building industry. John F C Turner has written about the consequences of the growth of 'ever-larger pyramid structures:

> 'Only the rich minority can be supplied in these centrally administered ways using centralizing technologies, and then only at the expense of an impoverished majority.' (27)

From the outset it is important to recognise that there will be no single panacea to resolve this gap, rather a wide strategy including new measures and attitudes. The devolution of power and finance to the local level is one prerequisite, another is the devolution of expertise. A new system is needed where the highest levels of technical knowledge need to reach some very humble levels. This suggests that the most positive way forward will be in the direction of developing (through training and resource allocations) the creation of the new breed of barefoot architects or engineers. Perhaps they will become the major 'gap-fillers' where relevant and appropriate expertise reaches its target alongside village builders and craftsmen. This leads on to my next theme, that of training.

Theme No 3

<u>How to facilitate training to occur for small builders and craftsmen?</u>

Authorities, agencies, professionals are normally 'product orientated' with a strong emphasis on a tangible result from their efforts. These physical solutions may be in the form of buildings completed or even in the passing of anti-seismic legislation. Therefore, the strategy of placing reliance on 'training' which was the strength of the OXFAM World Neighbors program in Guatemala, is extremely rare, in fact almost non-existant in agency thinking or housing programs.

So the way to 'enable' this to occur must be some refocussing on the part of the audiences I have noted at the head of this theme. It is probable that we now know far more about the nature of seismicity, or the performance of adobe structures in earthquakes, than in how best to train people at local levels. As I have already identified in this paper the literature on this theme is very thin, as a result of the pervasive pressure to convert building construction from a localised activity, into a centralised skill best left to major contractors with the ear of governmental housing banks and ministries.

What is needed, is for this workshop to come out unequivocally in favour of training as one of its primary recommendations for risk reduction with some positive steps having been taken as to who can finance, organise and equip the 'teachers of the teachers'. Allied to these questions there are the questions of what type of training aids must be developed and by whom. Major steps forward were made in Guatemala with the training aids developed by OXFAM/World Neighbors. These principles were then modified via INTERTECT's involvement for use in Andhra Pradesh, India (28), before being further adapted for use in Calcutta and Northern India by Jae Sen and his colleagues in UNNAYAN (29) for housing programs to resist cyclones and high winds.

All of these aids for housing facing diverse hazards need to be further studied to establish how far they were effective and what 'mixes' are necessary for their effective use, (i.e., on their own, with trainers, with expertise support and with training programs.)

In considering training programs and teaching aids for adobe structures, we nevertheless need to recognise that we may be watching a global movement towards 'modernized housing systems'. This introduces my fourth theme.

Theme No 4

Given the threat within some cultures to traditional building methods (such as adobe construction) from both within and without the societies in question, what attitude should authorities adopt to this demand for a change of building tradition?

Frequently societies have been observed in Central America, the Caribbean, the Middle East and India to reject their traditional buildings, along with many other traditions in favour of 'new' images that have been revealed by the media. As I have mentioned under the 'problems section' of this paper, this presents assisting groups with many dilemmas.

My hope is that this workshop will note this reality, and suggest that alongside our concern for the improvement of adobe structures we also see the need for a similar concern for the types of construction that are frequently replacing this form of construction. So often local families, after earthquakes, have switched their rebuilding to concrete block construction from adobe without recognising that it has little aseismic value unless built in a certain manner.

At a wider level, are we to remain neutral in this transition from adobe to concrete or whatever, or is the stance of assisting groups to either advocate adobe, or else to encourage rising aspirations for 'modern' construction? This issue may be one of the most problematic of all the workshop themes.

I now want to turn to a pair of technical themes:

Theme No 5

What are the outstanding technical issues that are still unsolved relative to the improvement in the seismic resistance of adobe structures?

It is essential that those attending this workshop from field contexts communicate the technical difficulties they face to those with the skills and resources to tackle these problems. The workshop will then hopefully identify these topics in some order of importance so that research groups can approach

specific practical questions. Going even further, field personnel need to advise on such matters as who they believe are the most effective bodies to make these studies, as well as suggesting the format for the advice that they need. For example, a housing extensionist does not have access to academic journals which are often the final resting place of important findings with potential field application.

Then relating these research findings to our theme, a strategy is also necessary for the implementation of new advances in aseismic adobe technology, and research groups need to discuss with field personnel appropriate ways to test their ideas.

One major technical/social issue is unresolved and it has accounted for the vast number of deaths and casualities in the Middle East and Central Asia - the heavy, flat earthen roof. This is my sixth theme.

Theme No 6

<u>What measures can be devised which are socially and economically viable to deal with the unsolved problems posed by the heavy flat roofs of adobe houses in Central Asia and the Middle East?</u>

I have already referred to the problem of modifying the flat Turkish earthen roof. In his report on the Iranian earthquake which destroyed Tabas-e-Golshan in 1978, Manuel Berberian made a very detailed damage survey (30). He described the context of Tabas where 95% of all houses were made from adobe, with flat or domed earthen roofs. Berberian described how the:

> 'High ratio of death to injuries emphasises that the traditional adobe houses of the region, with their weak walls and heavy earthen roofs, offer little resistance to shocks.'

He then went on to suggest that the houses needed to be redesigned to withstand future seismic forces. One proposal was for future construction to use a domed vault system with arched walls springing directly from the ground, rather than springing from supporting walls.

I hope that the workshop will identify the dry, arid zones of Central Asia and the Middle East with their severe climate and lack of timber for spanning purposes as a priority area requiring a solution to the heavy earthen roof problem. I also hope that any solution will not imply a major change in house construction or form so that people will continue to gain climatic protection from a fierce climate, and will still be able to sleep on their flat roofs on hot summer nights.

Manuel Berberian's hopes for a redesigned house for Tabas may have occurred for the post-earthquake reconstruction, but it is less likely to occur for <u>existing</u> vulnerable houses in Iran that have yet to experience an earthquake. For these families the picture is bleak, which is my seventh theme.

Theme No 7

<u>Given the difficulties in mounting improvement programs for existing buildings, what measures are appropriate for such families living at subsistence level?</u>

I have already touched on this issue in my review of problems associated

with objectives. The workshop may share my view that the modification of the existing housing of poor families is rarely a viable proposition due to economic and social constraints (see FIG 5). When this is the case, what are the alternative ways to protect the occupants of such homes? The only proposals that I have seen considered are that of the safe protected core which is built inside a house, particularly s a place for sleeping. If this existed the traditional main victims of earthquakes, small children, the elderly and sick may secure some protection. Another issue is whether advice can be given directly to the house occupants on simple and cheap measures that they can themselves adopt to make their houses safe.

If this type of cheap and grass roots solution is rejected, then what are the alternatives to an acceptance(given the scale of the existing housing stock) that casualities will continue to occur in vast numbers. If the preservation of life is the major aim of this workshop then this theme has a strong claim for priority attention.

The final pair of themes come right back to the issue of project implementation, what are the most effective policies, and how can we clarify their 'ends and means'.

Theme No 8

On the basis of past programmes of housing modification, is this workshop able to advise governments and voluntary agencies on effective implementation policies?

During the course of this workshop, various reports will be given on housing improvement programs. There is I believe a need to determine on the basis of our current knowledge which of these have been successful, and which have failed to meet their objectives. I hope that the workshop will identify the characteristics that have made up successful projects, whenever common denominators can be found. But in so doing it is also important that 'success' is defined, what makes it so, and what is a failure, and in whose terms?

Not only are we still unsure about how to modify adobe houses, these quite fundamental questions are still being debated.

Theme No 9

A consideration of the social and political presuppositions of modification programs. This theme will seek to define some prerequisites for successful improvement policies

I have referred in the discussion on problems that there is much confusion about 'ends' and 'means'. This theme requires an inventory of searching questions to be identified about objectives, patterns of authority and the development of accountable relationships between assisting groups and vulnerable families.

Frances Moore Lappe, Joseph Collins and David Kinley of the Institute for Food and Development Policy in San Francisco have written an important study in 1980 'Aid as Obstacle'. The book primarily concerns food aid, but is nevertheless relevant to our theme in many of their arguments. They list a set of 'Ten questions to ask about a Development Project' (31). These questions are all pertinent to any analysis of project objectives, but due to limitations of

space I would like to reinforce just four of their questions:

> 'Whose project is is? Is it the donor agency's or does it originate with the people involved?
>
> Does the project define the problem to be tackled as a technical or physical deficiency that can be overcome with the right technique or skill or does it address the underlying social, economic and political constraints that stand in the way of solving the physical or technical problem?
>
> Do new skills and information remain only with the leaders? Or does the project involve an ongoing educational process for all the participants?
>
> Does the project reinforce dependence on outside sources for material and skills or does it call forth local ingenuity, local labour and local materials, and can be maintained by local skills?'

Such questions are hardly new. the literature on development has persistently drawn attention to these matters. But there remains yet another gap between knowledge of what will or will not work in terms of an effective project and the application of these principles. One reason for the failure is pure ignorance, but at a deeper level it is currently not in the agencies interest to take note of these issues (unless it is a particularly altruistic body with minimal regard for its own needs). A project that is developed by (or with) the people to be ultimately housed will always take longer to instigate, it will become more open-ended and less tidy in any normal budgeting accounting system. It also may not deliver tangible objects very quickly that can be easily reproduced in agency magazines.

In the absence of any method of accountability between the agency and the recipients of their aid it is a great rarity for the questions quoted above to be taken note of. For example the final question on this list concerns evaluation:

> 'Is the evaluation a one-way process by which the donor judges the recipient's performance? Or is is a two-way dialogue in which the recipient also evaluates the donor and they together evaluate the project?'

To conclude this theme, can this workshop suggest any mechanism to improve the relationships between assisting groups and recipients so that a climate exists where the above process can take place?

CONCLUSION

These nine themes are a demanding agenda, and each delegate will doubtless have his own list of key topics which will expand the list into hundreds of themes. The themes we have been considering are so fundamental and far-reaching that it would be naive to expect solutions to emerge from this meeting. This could take a full decade of solid work given the early stage of our knowledge. However, rapid progress can be made when collective minds are concentrated, and our aim in the consideration of this subject area should be to establish dominant issues, rank them in order of importance, and explore their implications for the different levels of audience, ranging from agency field staff, active professionals, academics undertaking research and governmental policy makers.

But at the very centre of the issue of implementation there is another audience for our discussions. Rather like the missing small builders that didn't hear Professor Ambraseys, they are also missing from this meeting. The 'proof of the pudding is in the eating', and the ultimate test of our work is whether we produce ideas which are relevant, appropriate, understandable and acceptable to the small builders of Turkey, Iran, Peru and Guatemala. I hope that it will be accepted that this group are the main target of our collective concern.

A final note of warning. Whenever we recognise the 'early stage in our knowledge', the next paragraph of the report normally starts to develop a research agenda (often directed to the same group that defined the gaps in a self-serving posture). The assumption that answers to vital questions are a prerequisite for action must be resisted. In his excellent study of Urban Planning in Rich and Poor Countries, Hugh Stretton faces this issue:

> 'There is a pervasive dilemma which recurs in research, in planning and in politics. How much can you afford to know before you act? How much time can you afford to spend making sure that you will all act together? How far can people share power without destroying the power they share?'

Stretton then comes to the issue of knowledge being required before action:

> 'The less you know before you act the riskier the action is likely to be. But the more you insist on knowing the longer it may be before you act at all, and the staler a lot of the information may be before you act on it. It is never possible to know about the conditions and likely consequences of action... Most information has costs, so the more you spend on knowing, the less you may have left to spend on doing.' (32)

Clearly the need in the sector we are discussing in this conference is what Otto Koenigsberger has described as 'action planning' where swift decisions are made and implemented on the basis of available evidence. This policy requires 'feed-back' mechanisms from continual evaluation and monitoring of success or failure to enable projects to adapt in a responsive manner to emerging evidence. In effect, a need for research work and project implementation to proceed in parallel, each informing the other, but of course there is the proviso that the gap is closed between the two sectors to enable this to happen.

This paper began with a 250 year old case study of improved construction. I quoted this example since it is a source of encouragement to all those in this workshop with a concern to see things happen on the ground, not just within the pages of conference proceedings. As we have seen there are some massive obstacles preventing the effective implementation of aseismic modification programs. However, whenever a situation is fortunate enough to combine official 'will', local concern and involvement, appropriate skills and financial resources (all of which appeared to come together in Lisbon), we can be confident that good projects can occur, and at our next meeting we can review their effectiveness.

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THE REDUCTION OF RISKS FROM NATURAL HAZARDS IN THE KARAKORAM. APPENDIX 1.

NATURAL HAZARDS [illegible] in the Karakoram	FREQUENCY OF HAZARD OCCURRENCE	RANGE OF HAZARD	TYPES OF LOSS - POSSIBLE							SIZE OF REGION OF INFLUENCE	RELATIONSHIP OF REGION INFLUENCED TO EXISTING REGIONS OF STABILITY	THE NATURE OF THE VULNERABILITY OF REGIONS AND SETTLEMENTS TO SPECIFIC HAZARDS	RISKS OF RISK		REDUCTION OF RISK	
			Loss of life [illegible]	[illegible]	[illegible]	Loss of livelihood	Damage to [illegible]	Personal property	Injury				Possible Solution	Difficulties in implementing this solution	Feasible mitigation measures in this context	Difficulties in implementing these measures
Failure of water supply for both drinking and local irrigation	[illegible] every [illegible] in some areas	[illegible] months	[illegible]	[illegible]		[illegible]	[illegible]		Only in extreme situations	No evidence of deaths	No relationship	If failure is local, results in the eventual abandonment of settlements	Build more water channels Reduce the local population by relocation	Excessive cost and in some [illegible] leaves the supply is fully used. No other alternative.	Inject finance to improve water supply as a priority issue	Cost and lack of expertise
Erosion of [illegible] banks of water, wind and frost	Locally [illegible] [illegible] process	Local [illegible] [illegible] [illegible] action	[illegible]		Very rarely	[illegible]				No evidence of deaths	No relationship	Can result in the abandonment of settlements adjacent to cliff faces	Build protective river walls' channels	Excessive cost	Rural education for farmers to protect their own lands with simple measures; improve siting of all new buildings.	Lack of expertise
Flood [illegible] Slow flood Flash floods	[illegible] [illegible] [illegible]

THE EXTENT OF ADOBE USE IN THE UNITED STATES

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ABSTRACT

The extent of the use of adobe as a building material in the United States is examined in this paper. Since almost all of adobe use is limited to the Southwest, some estimates of its extent are made for the states of New Mexico, Arizona, Texas and California. It is estimated that there are over 17,000 adobe residences now in use in the United States, with over 1,500 new ones being built each year.

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Introduction

With increased interest in adobe as a construction material in the southwestern United States, where there is a relatively high potential for seismic activity, the need arises to assess the extent of adobe use. This requires an estimate of the number of adobe structures as well as the current state and future trends of the adobe construction business. While there is insufficient information to provide definitive answers to those questions, this report attempts to estimate the extent of use of sun-dried brick in the United States, both today and during the last century.

A survey of literature reveals a paucity of statistical information about production of adobe bricks, housing starts or total number of adobe structures. Although numerous details of housing types and facilities are included in the national census figures, the U. S. Bureau of Census does not classify buildings by wall type. Generally, even county or city building departments do not keep records of houses by construction type. Moreover, it is generally accepted that many adobe residences are constructed by individuals in rural areas. Thus, it is almost impossible to find comprehensive numerical data in published form.

For this reason, figures used in this report should be viewed as estimates rather than as hard figures. The statistics are derived from scant bits of information in the literature plus opinions of builders and producers, and includes extrapolation of this information. The figures should be regarded as a starting point for future research.

The report focuses on four southwestern states: New Mexico, Arizona, Texas and California. Although isolated use of adobe is widespread, and rammed earth was used fairly extensively in colonial times, its primary use is in the semi-arid Southwest, where climatic conditions and soil types are suited to adobe. Moreover, all four states have been influenced by Spanish colonization. Scarcity of wood not only discouraged construction with lumber, but also presented a problem in fueling kilns for firing brick. From various sources, it is estimated that 97 percent of existing adobe buildings in the United States lies in these four contiguous southwestern states.

A Short History of Adobe in North America

By the time the Spanish colonized the New World, sun-dried mud brick construction in the Americas could claim antiquity: Peruvian ruins dating to as early as 3000 B. C. revealed mastery of an earthen block construction in which bamboo molds were used to form the Andean mud and straw mixture, and the arid Mexican plateau invaded by Cortez in 1519 had seen the use of earthen bricks in the pyramids at Teotihuacan as well as in common housing.

In the last half of the 18th century, as Spanish settlers moved into northern Mexico and into what is now the United States, they encountered civilizations using two types of non-brick earthen construction: puddle and Pisé (rammed earth). Although thirteenth-century ruins along Navajo Creek in northern Arizona were made of bricks that were hand-formed in place in the wall, the indigenous people of the southwest United States were largely ignorant of sun-dried brick formation and construction. Under the influence of the Spanish, these North American Indians quickly adopted both the method and the Spanish term for the brick--adobe. By the nineteenth century, when English-speaking colonists moved into the southwestern desert region, adobe was synonymous with housing.

Mexican influence in the region diminished steadily following Santa Ana's ephemeral victory at the Alamo in 1836. The U. S. victory in the Mexican War (1846) and the 1853 Gadsden Purchase spelled the end of Spanish dominance in the region. The U. S. Army occupation of New Mexico in 1846 brought a movement to "Americanize" the Mexican villages in the territory. Rumors and nuggets of California gold (1849) precipitated a deluge of "gringo" settlers to the previously Spanish-speaking west coast.

This new influx of aggressive settlers brought not only new faces and new architecture, but also new means of transporting previously scarce building materials; the passing of the railroad through the Southwest in the 1880's provided the means to haul the favorite construction materials of the newcomers--rock, brick, and lumber. Brick kilns and sawmills sprang up. And as the frame house flourished, the time-proven adobe fell into disrepute. During the following century adobe construction in the U. S. was practiced mainly by a few rural people in the Southwest, most with Spanish surnames, who dried bricks in their backyards and built their own adobe homes. A few commercial producers sold to wealthy patrons enchanted with "territorial style" adobe haciendas. Only the very poor and the artistic types were reputed to be building with adobe.

Today, adobe is receiving renewed, although limited, interest. The increasing cost and growing scarcity of energy have forced builders to take a hard look at traditional energy-intensive construction materials.

The adobe, which features cheap and indigenous ingredients and a solar drying process, is becoming a viable alternative to wood and cement block. While the steady-state thermal resistivity of adobe is not as great as some high-technology materials, aficionados have always recognized its value in storing and stabilizing temperatures, the "thermal mass" effect. Earthen colors of adobe and its stuccoed exterior make it aesthetically pleasing with a desert backdrop as well as in an urban setting.

For these reasons, adobe production is seeing a modest rebound. For instance, Hans Sumpf, California's largest adobe producer, sold 280,000 units in 1958. From 1970 to 1980, however, Sumpf's sales have increased to around 1,125,000 sun-dried bricks per year. A long-time Albuquerque architect, author, and adobe builder, P. G. McHenry, states that, while fifteen years ago only three or four builders in Albuquerque constructed adobe houses, today, over twenty adobe builders ply their trade. This same pattern is evident in Santa Fe, Tucson, and other communities throughout the Southwest. Adobe, then, is regaining popularity as a building material in the United States. Time will tell whether it will again see wide-spread use in forming the portals and partitions of America's homes.

Methodology

A count of the total number of dwellings in each state is provided once every ten years by the U. S. Bureau of the Census, but the census does not classify houses according to wall type. The basic methodology used in this report was to estimate what percent of those dwellings listed by the census represented adobe houses. This percentage was then multiplied by the census figures to obtain the number of adobe houses.

Having established from the census the number of adobe dwellings at the beginning of each decade from 1850 to 1980, an estimation of the number of adobe dwellings built per year could be obtained. As an example, consider the statistics for Texas for the decade between 1850 and 1860. The number of adobe dwellings in 1850 is calculated as 19,590. The 1860 statistics on Table IV of this report show 55,240 adobe homes. 19,590 subtracted from 55,240 yields an increase of 35,650 adobe dwellings. Dividing this figure by ten years indicates approximately 3565 adobe houses per year were built during the decade. Since this procedure ignores the demolition of adobe homes during the ten-year period, the actual figure for houses constructed should be slightly higher. Of course, any variations within the 10 years could not be determined.

Of primary importance was the estimation of the percentage of adobe homes included in the total number of dwellings. As previously stated, statistical information on adobe structures is practically non-existent. The information leading to estimates of percentages falls into three main categories: 1) historical events and figures pertaining to Spanish influence in the region of interest, 2) production statistics from adobe makers, and 3) opinions of builders, producers, and adobe buffs. Additional information was found in Sanborn Fire Insurance maps. The assumption was also made that the percentages did not vary greatly or unpredictably from decade to decade. Using the census figures, estimates of percentages of adobe homes, and information on the number of adobe homes built per year results are calculated and presented in Tables I to V. In most cases, continuous data are not available, and trends are estimated and total numbers accumulated. Basic assumptions for each state are discussed below.

New Mexico

New Mexico is the acknowledged "adobe capitol" of the United States. Edward Smith, geologist for the Eight Northern Indian Pueblos Council states, "It is apparent that New Mexico is the leading manufacturer and user of adobe bricks in the U. S. with a total of 4,133,000 adobes produced by 47 active adobe makers this year (1980). Also, according to reports received by my office, this total production of adobes was sold by the end of November." Additionally, Smith estimates that again as many sun-dried bricks may be produced in "backyard" operations in the state. Albuquerque producer Richard Levine estimated that only 26,000 backyard adobes are made per year in New Mexico. Assuming a conservative estimate of 300,000 bricks produced in backyard operations in 1980, and the possibility of up to 100,000 imported adobes from Mexico would bring the total estimated use in New Mexico up to 4,533,000 adobes. A 1800-square foot house requires around 6,000 adobes, and it is assumed that 70% of the 4,533,000 bricks were used for house construction (as opposed to office buildings, walls, and other non-dwelling uses). The following calculation results in an approximation of the total number of adobe houses built in 1980 in New Mexico:

$$\frac{4,533,000 \text{ adobes}}{6,000 \text{ adobes/house}} \times .70 = 530 \text{ houses}$$

The New Mexico Business Current Economic Report of December 1980 lists 1305 building permits issued through October of 1980 in the City of Albuquerque. Using extrapolation to include the months of November and

December, and considering residential starts only, it can be assumed that around 1,400 house permits were issued in Albuquerque in 1980. The population ratio of Albuquerque to the total state population is 1:3.8 (from the 1980 census). If the number of housing starts per capita statewide is considered to be about the same as in Albuquerque, then the State of New Mexico saw approximately 5,320 housing starts during 1980. Dividing the number of adobe homes (530) by the number of total housing starts (5320) yields 10 percent adobe construction for the year statewide.

Albuquerque city building inspector Ed Ordonez estimates that 100 permits for adobe homes were issued per year in Albuquerque during the last 10 years. For Albuquerque, then, this estimate yields 7.1 percent adobe homes for 1980. Of interest here is the indication that adobe is utilized more extensively in rural areas than in the urban, as the state use was 10%, but Albuquerque's use of adobe was found to be only 7%. This is not an unreasonable conclusion, since the state is largely rural.

This unexpectedly high percentage of adobe use is not typical of years previous to 1980. The number of housing starts in New Mexico in 1979, for instance, was more than double that of 1980. Using the same estimate of adobe starts (100/year), results in an average of only 3 percent adobe construction, which probably is more typical of the 1970-80 decade. This report postulates the following explanation for the discrepancy: while the housing industry in general fluctuates greatly from year-to-year, the adobe business remains fairly constant. For instance, production figures from the Hans Sumpf Company of California for the last ten years reveal a mean adobe production of 1,177,677 adobes with a standard deviation of only 166,000 bricks. Sales varied slightly more, but were, in general, steady over the ten year period. From an economics viewpoint, the backyard producer who builds his own home out of adobe and makes a few thousand additional bricks to sell is more apt to engage in these activities during a slow economic period, thus damping out fluctuations. If the above postulate holds true, then the short-term percentage of adobe homes built per year is more a function of the overall housing market than of any change in the use of adobe, which varies only gradually. If conventional housing construction is down (such as in 1980), then the percentage of houses built of adobe appears high. If conventional construction is booming, then the adobe percentage is less.

Less information was available from the previous 130 years. A USDA publication, Farmers' Bulletin #1720, issued in January of 1934 states, "Eighty percent of all structures in Las Cruces, New Mexico are adobe." A reading of the 1919 Sanborn Fire map of Albuquerque reveals 776 adobe dwellings and 175 other adobe structures. The 1920 census lists 3,280 dwellings in Albuquerque. However, the Sanborn map illustrated only about 90% of the city. This report estimates that the total number of adobe houses was closer to 900.

Historical implications on New Mexico adobe use have been mentioned earlier in this report. Weighing these considerations, it was concluded that in 1850, 97% of the dwellings in what is now New Mexico were made of adobe. Subsequent intrusion by white settlers coincides with the demise

of adobe in the state.

Arizona

Second in importance in the use of adobe is the state of Arizona. A comparison of the 1850 data from both Arizona and New Mexico shows identical percentages of total dwellings which were adobe--97%. However, significant differences between the population growths in the two states led to consequential differences in the use of adobe. The 1870 census shows only 9,658 inhabitants in Arizona. (This figure may ignore the Indian populace.) By 1890 the population had swelled to 88,243. During the previous decade, the railroad had arrived in Arizona. The growth in population consisted mainly of an influx of U. S. settlers bringing their distinctive architecture and building materials. The use of adobe dwindled much faster in Arizona than in New Mexico, where the larger indigenous population (in New Mexico) preserved the traditional ways much longer.

Tucson architect/engineer and adobe expert E. D. Herreras states that in Tucson, approximately 1,000 adobe homes were occupied in 1980. The 1980 census lists Tucson with 138,211 total dwellings. This calculates to 0.7 percent adobe homes. The percentage is undoubtedly higher in rural areas where Spanish influence is stronger, but lower in the great population center of Phoenix. In 1970, half the population of the state lived in Phoenix, and few of the new houses built to accommodate this populace were built of adobe.

Texas

No statistics concerning adobe structures were obtained for analysis in this report. Instead, a comparison was made between Texas and its western neighbors, New Mexico and Arizona, in a historical context. The 1850 census lists 27,988 dwellings housing "white and free colored" residents. A population count of 212,592 inhabitants was also cited. It can be inferred that a sizable anglo populace lived in the area at that time and that many lived in non-adobe dwellings. Thus, the percentage of adobe

houses in 1850 was estimated to be 70%, rather than the 97% in New Mexico and Arizona. After the turn of the century, Texas saw an average gain of population of over one million each ten years. Table IV reflects this growth and its effect on the number of adobe homes. The number of adobe homes actually decreased from 120,725 in 1890 to 30,635 in 1970.

California

Historical implications again directly affected the estimated percentage of adobe homes in 1850 in this state. While Mexican influence had earlier been strong in the southern half of the state, by 1850 it was fast decaying. Non-Spanish settlers were well-established by this time in the central and northern parts of California. A wetter climate and bountiful timber led to the use of wood as a primary building material in the north. The California Gold Rush in 1849 brought a deluge of non-Spanish prospectors and settlers. Between 1850 and 1860 the population of the state quadrupled.

Production figures were obtained from the Hans Sumpf Company, California's largest adobe producer. For the years 1970 through 1980, Sumpf has sold an average of 1,250,000 sun-dried bricks per year. Of these bricks, approximately two-fifths are used for structural purposes. Using the same analysis as was used with production figures from the State of New Mexico and considering backyard production and Mexican adobe imports, California had the production capacity of 150 to 200 adobe homes per year during the last decade. This represented 0.09 percent of the houses built in the state.

All Other States

The U. S. Department of Agriculture's Farmers' Bulletin #1720, issued in January of 1934 includes a map picturing the geographical use of earthen wall construction in the U. S. Besides the four states specified in this report, the map included the southeast quarter of Oregon, the southern one-eighth of Utah, the southern tip of Nevada and an enclave in

the center of that state, scattered areas in southern Idaho, and the western third of Kansas. The map encompassed not only adobe but sod houses and any other type of earthern wall construction. This report accounted for adobe use in these states by estimating that all but 3 percent of the adobe use in the United States is found in the four states of New Mexico, Arizona, Texas, and California.

Finally, Table VI shows a summary of estimates of total adobe dwellings in the United States, plus the number of adobe houses being built each year.

Conclusions

An estimated 176,000 adobe homes stand in the United States today, sheltering half a million Americans. Ninety-seven percent of these dwellings are found in the states of New Mexico, Arizona, Texas, and California, with the other three percent scattered among the states of Oregon, Idaho, Utah, Nevada, and Colorado. 1560 new adobe homes are being built each year. The State of New Mexico is the largest producer and user of adobes, and contains within its borders a third of the adobe dwellings in the United States. Ten percent of the homes built in 1980 in New Mexico were made of adobe (although 3 percent is a more reasonable longer term average). The percentages in Arizona, Texas, and California were 1%, 0.1%, and 0.09%, respectively.

The use of adobe has decreased steadily since the end of Spanish domination in what is now the southwest United States. Although the total number of adobe dwellings has increased in the last twenty years from 154,000 units in 1960 to 176,000 units in 1980, the percentage of adobe homes over the total number of homes has continually decreased. Only in the State of New Mexico has the percentage of adobe homes being built per year increased. By 1970, the percentage of adobe homes being built compared to conventional houses had dropped to two percent per year in New Mexico. In the following ten-year period, however, the percentage increased slightly to three percent.

It would be improper to view these figures as anything more precise than a first estimate. The difficulty in providing this sort of data lies in the fact that the statistics are cumulative. Assumptions are generally made on the conservative side, but much more analysis would need to be done, including a careful census, before more confidence could be assigned.

The fact does emerge that substantial numbers of homes in the United States are being built of adobe. The trends, certainly in New Mexico and Arizona, are toward steady or even increasing absolute numbers each year, although the percentages vary. Solar thermal applications, now being researched or experimented with by individuals, promises to make the use of adobe with passive solar heating more and more popular. The prognosis for the use of adobe is positive.

Thus, it is important to note that the areas of greatest use of adobe also are areas of seismic risk. A significant portion of the states of California, Arizona, and New Mexico lies in zones designated as seismic risks by the U. S. Department of Agriculture's Farmers' Home Administration and by the Uniform Building Code. Seismic zones 2, 3, and 4 are considered unsafe without specially engineered construction. While Texas contains only zero and one zones, New Mexico's large population concentrations lie in a #2 zone. Half of Arizona is rated #2, and southern California is divided between zones #3 and #4. In this light, the increase in total number of adobe houses and in the number of people housed within gains immediate significance. From visual inspection of the FAHA map, one would estimate that at least 50% of the adobe homes in the United States lie within zones of seismic risk. This represents a quarter of a million citizens housed in buildings which are vulnerable to seismic activity.

It is of paramount importance, then, that consideration be given to retro-fitting those dwellings already constructed to protect the inhabitants, and to devise technology for future construction of safe adobe homes. Since many adobe home owners and builders are among the less wealthy portion of the nation, these retro-fitting and new construction techniques must be economical in cost and practical in nature. Such technology would be of use not only in the United States but to the half of the world's population housed in adobe structures.

ALBUQUERQUE

	Population	Total number of dwellings	Adobe % of total	Number of adobe dwellings	Number of adobe dwellings built per year during decade	Percentage of homes built per year which were adobe
1890	3,785	820[1]	56	460		
1900	6,238	1,435[1]	45	650	20	30
1910	11,020	2,555[1]	37	950	30	27
1920	15,157	3,280[1]	27	900[2]	—[3]	—
1930	26,570	5,810[1]	18	1,050	10	6
1940	35,449	8,147	14	1,150	10	4
1950	96,815	30,652	6	1,850	70	3
1960	201,189	60,930	3	1,830	0	—
1970	315,774	98,638	3	2,950	110	3
1980	323,837	132,267	3	3,950	100	3

TABLE I. Albuquerque Statistics

[1] Extrapolation from state ratio of houses to population.
[2] 1919 Sanborn map estimate.
[3] Blanks denote net reduction

NEW MEXICO

	Population	Total number of dwellings	Adobe % of total	Number of adobe dwellings	Number of adobe dwellings built per year during decade	Percentage of homes built per year which were adobe
1850	61,546	13,453[1]	97	13,050		
1860	93,516	21,000[2]	95	19,950	690	91
1870	91,874	21,052	94	19,800	—[3]	—
1880	119,565	26,311	89	23,400	360	70
1890	160,282	34,671	85	29,500	600	72
1900	195,310	44,903	80	35,900	650	63
1910	327,301	75,888	71	53,900	1800	58
1920	360,350	78,024	63	49,000	—	—
1930	423,317	92,530	50	46,300	—	—
1940	531,818	145,642	34	48,900	270	5
1950	681,187	199,706	26	51,100	—	—
1960	951,023	281,976	19	52,500	210	4
1970	1,019,060	325,762	16	53,600	170	2
1980	1,299,968	503,675	12	59,000	620	3

TABLE II. N. M. Statistics

"Population" and "Total dwellings" figures without subscripts are taken from the U. S. Bureau of Census

[1]
[2]Dwellings occupied by "white and free colored" populace - U. S. Bureau of Census.
[1]Estimated from 1870 census.
[3]Blanks denote net reductions.

ARIZONA

	Population	Total number of dwellings	Adobe % of total	Number of adobe dwellings	Number of adobe dwellings built per year during decade	Percentage of homes built per year which were adobe
1850	No census		97			
1860	No census		97		—	—
1870	9,658	2,822	97	2,700	—	—
1880[1]	40,440	9,033	78	7,100	440	70
1890	88,243	13,338	69	9,200	210	50
1900	122,931	28,763	54	15,400	610	40
1910	204,354	45,386	45	20,400	500	30
1920	334,162	73,673	35	26,100	570	20
1930	435,573	98,633	29	28,500	250	10
1940	499,261	147,079	21	30,900	240	5
1950	749,587	240,750	14	34,700	370	4
1960	1,302,161	415,834	10	40,000	520	3
1970	1,770,900	584,171	7	43,300	340	2
1980	2,717,866	1,110,360	4	48,600	530	1

TABLE III.

[1] Railroad arrived in Arizona in 1880's bringing anglos and new building materials.
[2] Tucson architect/engineer, E. O. Herreras said Tucson has approximately 1,000 adobe homes in 1980. 1980 census figures list 138,211 dwellings in Tucson.

TEXAS

	Population	Total number of dwellings	Adobe % of total	Number of adobe dwellings	Number of adobe dwellings built per year during decade	Percentage of homes built per year which were adobe
1850[4]	212,592	27,988[1,2]	70	19,600		
1860	604,215	92,065[3]	60	55,200	3,560	56
1870	818,579	141,685	50	70,800	1,560	31
1880	1,549,749	287,562	40	115,000	4,420	30
1890	2,375,527	402,422	30	120,700	570	5
1900	3,048,710	575,734	20	115,100		
1910	3,396,542	779,177	10	77,900		
1920	4,663,228	946,629	7	66,300		
1930	5,824,715	1,281,876	4	51,300		
1940	6,414,824	1,864,884	2.5	46,600		
1950	7,711,194	2,393,838	1.5	35,900		
1960	9,579,677	3,153,127	1.0	31,530		
1970	11,196,730	3,829,502	0.8	30,600		
1980	14,228,383	5,534,490	0.6	33,200	257	0.1

TABLE IV.

1
2 "White and free colored" populace according to Census Bureau
3 U. S. victory in Mexican War in 1946 brought large influx of Anglos.
4 Census data not available. 1850 and 1870 dwellings per capita used for extrapolation.
Alamo battle in 1836.

CALIFORNIA

	Population	Total number of dwellings	Adobe % of total	Number of adobe dwellings	Number of adobe dwellings built per year during decade	Percentage of homes built per year which were adobe
1850[4]	92,597[1]	23,742[2]	50	11,900		
1860	379,994	95,000[3]	42	39,900	2,800	39
1870	560,247	126,307	34	42,900	300	10
1880	864,694	161,016	26	41,900	—	—
1890	1,213,398	235,925	18	42,500	60	0.8
1900	1,485,053	313,217	14	43,900	140	2
1910	2,377,549	513,481	8	41,100	—	—
1920	3,426,861	778,861	4	31,200	—	—
1930	5,677,251	1,403,131	2	28,100	—	—
1940	6,907,387	2,340,373	1	23,400	—	—
1950	10,586,223	3,590,660	0.7	24,200	70	0.06
1960	15,717,204	5,465,870	0.5	25,300	110	0.06
1970	19,953,134	6,996,990	0.4	26,700	140	0.09
1980	23,668,562	9,253,290	0.3	28,700	200	0.09

TABLE V.

1
2 Census "incomplete" according to U. S. Census Bureau.
3 "White and free colored" populace according to Census Bureau.
4 Extrapolation from 1850 and 1870 dwellings per capita.
Gold rush in 1849.

1980 ESTIMATED ADOBE STATISTICS

	Total number of adobe dwellings	Percentage of homes built in 1980 which were adobe	Number of adobe homes built in 1980
New Mexico	58,930	3	530[2]
Arizona	48,600	1	525
Texas	33,205	0.1	260
California	28,690	0.3	200
All Other States[1]	6,500		50
Total	175,925		1565

TABLE VI. 1980 Estimated Adobe Statistics

[1] Oregon, Idaho, Utah, Nevada, Colorado.
[2] See calculation in the "New Mexico" section of this report.

EARTHEN BUILDINGS IN SEISMIC AREAS

Thoughts on the Occasion of the Albuquerque Workshop
May 24-28, 1981

Otto H. Koenigsberger

THE LOW INVESTMENT/HIGH MAINTENANCE (LI/HM) SYSTEM

1 The problems of earthen buildings are as much social and economical as they are technical.

2 The use of earth as a building material was invented by peasants and perfected for the needs of peasant societies.

3 It forms an integral part of rural economies and is designed to fit the life style of peasant communities.

4 Its main characteristics are minimal initial investments of cash and maximal subsequent investment of labour and time in maintenance.

5 In traditional peasant societies, every farmer is also a house builder. He learns the necessary skills in childhood while helping friends and relatives to build their houses. His tasks as an adult farmer leaves him time to apply these skills to the maintenance of his own house. Agricultural work is heavy, but not evenly distributed throughout the year. Many peasant societies have definite periods each year when everybody is busy house-building or house-repairing.

6 Rural communities are usually small. Homesteads, hamlets and villages are scattered and sufficiently separated from each other to permit the gathering of suitable material for earth building and home repairs without causing ecological damage and often even without the need to fill in borrow pits.

7 In traditional peasant societies and peasant economies, earth building in its various forms is still the best solution of the shelter problem. It forms part of a functioning social, economic and technical system that could not be improved by changing one of its elements alone.

8 As it is, it is also part of a social language through which rural communities express their aspirations and identities. As Paul Oliver's studies of vernacular architecture in Asian, African and Latin American settlements have shown, this language can be of great sculptoral beauty.

THE HIGH INVESTMENT/LOW MAINTENANCE (HI/LM) SYSTEM

9 None of the advantages of earthen buildings exist in towns and cities. Bulk materials for construction are not free as earth is in the neighbourhood of villages. You cannot make a borrow pit in your own - usually small and always valuable - building plot and leave it to nature to fill it in gradually over the years. Earth has to be brought in from far outside the city. Loading, unloading and transport have to be paid for. Far from being free, earth can become an expensive commodity.

10 City jobs go on throughout the year. The urban worker, the trader or service employee cannot count on slack periods which he could use to be an amateur house builder or repairer. Building in the city is a job for specialists who want to be paid for their services. Despite various forms of self-help, urban house building forms part of the urban monetary economy. Most investors prefer to minimise maintenance costs through the use of more expensive but durable wall materials.

11 The tendency for urban house builders and buyers to prefer the High Investment/ Low Maintenance System is reinforced by the attitude of housing finance institutions. Mortgage banks, building societies or savings and loan associations do not accept an earthen wall house a collateral for a loan. Public health inspectors dislike it and the building regulations and by-laws of many cities prohibit it.

12 To sum up, the earth building system that fits rural living so perfectly, does not suit urban conditions and is therefore rare, even in small towns. There are however a few exceptions. They are worth mentioning because they illustrate rather than refute the foregoing observations:

The first is the city of CUTTACK, the former capital of the State of Orissa, in India. "Cuttack" means army camp. The city grew out of a temporary military settlement and, presumably, was not intended for permanent occupations. All walls were made of earth that was dug out of large pits, one by the side of each house. These pits filled with stagnant water and became breeding places for the vectors of malaria and elephantiasis, a cheap solution, but so unhealthy that, in the end, the Government of Orissa decided that Cuttack was unfit to remain the State capital and built a new city at nearby Bhubaneshwar.

The second example is a happier story. It is that of KANO in Northern Nigeria. Kano too is entirely built in earth and a classical example of the beauty that can be achieved with this material. The city appears to have been built almost in one go. A powerful central authority saw to it that all borrow pits were dug on the perimeter of the tightly built-up area and combined to form a deep moat outside the fortifications. In the vicinity of the city gates, this moat was widened to form large stepped cisterns which collect the scarce rainwater of the city's surroundings. The Kano houses are built of earth. They are rendered with a mixture of clay, horse manure, the powdered pods of the locust bean tree and the residue from indigo dyeing which produces an attractive purple-grey colour* They have been well maintained for more than a hundred years, presumably in the context of the Emir of Kano's strict feudal rule.

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*For details see Daldy, A.F., Temporary Buildings in Northern Nigeria, Public Works Department Nigeria, Technical Paper No.10, Lagos 1945.

THE PENUMBRIAL ZONE

13 Every fast growing Third World city is surrounded by a penumbrial zone that is neither town nor village. It consists partly of villages that have been engulfed by the fast growing cities (e.g. the Kampongs of Jakarta) and partly by the huts and shanties of newcomers who have found no room within the city. Their household economies and styles of living are often mixed. One member of the family may cycle daily into the city where he holds an urban job, while others continue with their accustomed rural occupations such as dairy or chicken farming and market

gardening. Until the density of such settlements has reached urban levels, earth building is often feasible and forms an important stage of the "instalment building" system, which is the most frequent method for a newcomer to build up his family home**

14 As the inhabitants become more and more urbanised they have less and less time for the maintenance of their earthen houses. It should be possible therefore to interest them in methods of making earthen walls more durable through stabilization or semi-waterproof rendering. The penumbrial zone around a big city could therefore become a suitable ground for the transfer and development of new technologies.

**The term "instalment building" was coined by the late Charles Abrams for the ubiquitous method of poor men's house building which starts with one or two rooms and adds to them as the owners fortunes improve. The first instalment has frequently earthen walls which are later replaced by more durable materials.

EARTHEN BUILDINGS IN SEISMIC AREAS

15 It follows from the foregoing that the earthquake resistance of earthen buildings is a rural or suburban problem. Examples of urban multi-storeyed buildings of dry stone in earth mortar exist in the cities of the Magreb, of Yemen and a few other arid regions, but they are structurally so different that they cannot be called "earthen buildings" and require a separate study.

16 It seems unlikely that many grown-up persons are killed during earthquakes by the debris of collapsing earth walls, particularly if such walls are no more than seven or eight feet high, as is customary in village housing. But it is certain that many are injured or killed by the collapse of the roofs and ceilings that are supported by such walls.

17 It is the construction of roofs and ceilings that needs urgent attention in seismic areas, not the material of the walls. Two lines of approach seem promising: - The one is the construction of independently supported roofs that will stay in position when the walls collapse. The British Karakoram Expedition has studied examples of such solutions in the Pattan Valley of North-Western Pakistan. These could well form the starting point for a programme of research into constructions of this kind for different climates and different locally available materials. The other is the production of rigid light weight roofs that stay in position even if the supporting walls are partly distroyed or cause little harm if they slide to the ground. This second approach might have to go beyond the investigation of conventional methods and include new light weight compounds and ways and means of making them universally and cheaply available.

18 Rural communities have no difficulty in re-building or repairing earth walls that have been damaged by earthquakes. Attempts to strengthen such walls through stabilization would tend to slow down or delay the rebuilding. Moreover, such attempts might well increase rather than decrease the danger to life and limb of the inhabitants. Ordinary earth walls tend to crumble on impact. Stabilized walls may break up in larger pieces that could do greater damage.

19 What seems needed at this stage is therefore a major effort to find and develop a cheap lightweight roof for seismic areas that is accessible, or can be made accessible even to the poorest of the poor or else design additional roof supports that can be built into existing houses.

London, May 1981 **Otto H. Koenigsberger**

SOCIAL AND ECONOMIC CONSTRAINTS TO MODIFICATION AND OBSTACLES TO TECHNOLOGY TRANSFER FOR MAKING MUD HOUSES RESISTANT TO SEISMIC FORCES

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ABSTRACT:

Great significance is attached to improvement of mud houses in developing countries particularly in areas which are subjected to earthquakes. In India over 72 per cent of the dwellings employ mud as principal building material and two-third of the country lies in seismic zone of moderate to severe intensity. Construction techniques for imparting greater earthquake resistance to mud houses and buildings have been briefly described. Social and economic constraints to improvements of mud houses and obstacles to transfer of technology have been indicated. Appropriate technology being propagated by N.B.O. is briefly described.

SOCIAL AND ECONOMIC CONSTRAINTS TO MODIFICATION AND OBSTACLES TO TECHNOLOGY TRANSFER FOR MAKING MUD HOUSES RESISTANT TO SEISMIC FORCES.

An abode to live in ought to fulfill the basic requirements of living particularly that of structural safety and protection from natural disasters like earthquakes. As such the proverbial 'mud-hut' which abounds in developing countries symbolising simple way of life, needs to be upgraded by application of science and technology to serve the modern requirements of living as well as to resist earthquake forces to the extent possible.

MASSIVE POPULATION AFFECTED

It has been estimated that in India, as per 1971 Census there was a total housing stock of 93.0 million dwelling units in the rural areas. Out of this 72.2 per cent of the dwelling units i.e., 67.1 million, employ mud as the principal building material, particularly for walling in one form or the other Taking an average of 5 6 persons per dwelling unit, the total population in India living in mud houses amount to 376 million. It is evident that to meet the modern requirements of living, the mud houses needs to be upgraded with a view to improving its performance, particularly from the point of view of durability and resistance to earthquakes.

Considering the fact that a large majority of population in India, as in other developing countries, lives in mud houses. there is great need to undertake intensive research and development work to evolve appropriate technology for improving mud houses including its earthquake resistance. However, uptill now not much attention has been given to this problem and mud houses continue to be vulnerable to various hazards, including destructive effects of earthquakes thereby endangering the lives of millions of people.

The gravity of the problem is not realised until a major earthquake is struck, when people think seriously about this problem and lament. Great importance should, therefore, be attached to creating social awareness of the problem and for taking preventive measures to avoid loss of life and property. In this work great significance is to be given to improvement of the technology of mud houses in order that they resist earthquake forces adequately.

It is equally important to draw up a programme of preparedness to meet the eventualities so that soon after the earthquake is struck, re-construction programme could be undertaken with utmost urgency and speed. In fact the reconstruction programmes provide an opportunity to take advantage of improved technology of construction of mud houses and buildings to resist earthquake forces adequately. It is often seen that such opportunities are not fully utilized as due to exigencies of situation, reconstruction programmes cannot be delayed and traditional techniques, that are deficient in many respects from earthquake resistant point of view, are per force adopted. Such a situation should be avoided by advance planning.

MUD HOUSE TYPES

Several types and modes of construction have been adopted in different parts of India for building low cost houses and buildings using mud as a principal building material. Several local variations are noticeable in the construction techniques depending upon the type of dwelling including the size of rooms and openings, the characteristics of soil, the geographical requirements such as extent of erosion from rainfall, subsceptability to flooding, vulnerability to cyclones and earthquakes. etc

Basically, the use of soil is made for construction of walls which are either non-load bearing or load bearing. Often the foundations, plinth and superstructures are made of the local soil. The roofing may also consist of mud construction or other types of traditional roofing such as use of grass, thatch, palmyrah leaves, clay roofing tiles, etc.

SEISMIC RESISTANCE

In India almost two-thirds of the country lies in seismic zone of moderate to severe intensity. In the past, several catastrophic earthquakes have struck causing large scale damage and destruction to houses and loss of many lives. The human habitations both in urban and rural areas, are becoming very dense and congested due to fast rate of increase in population, which is of the order of 2.5 per cent per annum. It is, therefore, becoming increasingly important to ensure that in the event of earthquake damage and destruction to houses should be minimised to the extent possible. Obviously the mud houses which are in existence in large numbers, particularly in the earthquake zones, need to be strengthened to resist earthquake forces adequately and in the construction of new houses using mud, due attention should be given to improve its resistance to earthquake forces.

DESIGN AND CONSTRUCTION OF MUD WALLS

In olden days some traditional types of construction technologies had been developed by adoption of which earthquake resistance houses using soil as a building material could be made more resistant to earthquake forces.

For example, in the State of Jammu & Kashmir in India, which lies in earthquake zone V (severe intensity) in the construction of mud houses the traditional method of 'Dhaji Diwari' technique is adopted to minimise the destruction during earthquakes. The method of construction comprises of making in-built timber frame construction with diagonal braces in the body of the mud walls, which imparts greater rigidity to the structure.

In Assam, which also lies in earthquake Zone V (severe intensity) the system of 'Ikra' walling is adopted, which resists earthquake forces admirably. This structure is light comprising of timber frame construction with in-fill panels of reed or split bamboos having mud plaster on either side.

In other areas in earthquake Zone IV (moderate intensity), twigs and branches of trees are incorporated in the mud wall by way of reinforcement to offer greater resistance to earthquake.

Instead of using lumps of mud for construction of walls, use of sundried bricks is made for masonry work or rammed earth construction is adopted which provides better performance in the event of earthquake.

In addition to the above, some traditional design and construction practices pertaining to height thickness and length of walls, distribution of roof load on walls, placement of openings for doors and windows in walls, etc. are in vogue which are based on considerations for imparting greater resistance to earthquake forces.

In olden days use of sun dried bricks was also made for construction of domes and vaults, taking advantage of arch action for resisting horizontal forces which are a major cause of destruction during earthquakes.

It is necessary to scientifically analyse these construction practices in terms of their behaviour during earthquakes to identify and also evolve rational design and construction practices that are economical for wider adoption.

ROOF STRUCTURE AND COVERING MATERIAL

The structural behaviour of the roof over-the-head, including the covering material and the supporting structures for the roof have great significance in the design and construction of earthquake resistant houses and buildings.

Thatch roof is most commonly adopted in India and light structure for supporting roof structure transfers the roof load to the mud walls in a manner that in the event of earthquake least damage and destruction is caused to the mud walls and by preventing their collapse, injury to the inhabitants is avoided to the extent possible.

Light roof coverings of shingle or wood veneers having light structure of timber for supporting the roof are constructed in areas prone to earthquake of moderate to severe intensity.

Sloping roofs are made of clay tile coverings or stone slates are more vulnerable to earthquake forces as the tiles and slates are easily dislodged.

The use of roofing sheets such as galvanised iron sheets and asbestos sheets over proper supporting structure offer better resistance to earthquake forces as the sheets are light and in the event of earthquake they may be dislodged but they do not fall down immediately.

However, flat roof construction using mud as a roofing material is also adopted in earthquake regions. The roof is generally constructed with timber rafters spaced at short intervals on which wood flats are placed to cover the gap, over which a layer of mud is spread to form the roof covering. This type of roofing also offers better performance during earthquakes as it prevents the collapse of the entire roof and only portions of it are damaged.

RESEARCH ON MUD HOUSES

Mud houses are built by people themselves through self-help. Mud or soil that is locally available is the principal material for construction particularly for walling. Thatch, jungle wood and bamboo are often procured by the people from nearby forests at very little costs. As such low cost mud houses can be said to be in a way "no cost" houses. However, such houses require frequent repairs as mud walls are damaged due to heavy rains and thatch is required to be replaced due to decay and is vulnerable to fire. As a result of research and development work undertaken in India, simple and inexpensive techniques for protecting mud walls and extending the service life of thatch and minimising fire hazard are being widely propagated by National Buildings Organisation, New Delhi, India which is also functioning as United Nations Regional Housing Centre for ESCAP.

SOCIAL AND ECONOMIC CONSTRAINTS TO MODIFICATION

In any large scale programme of improvement of houses particularly to improve their earthquake resistance of mud houses, which are existing or are being put up in large numbers it is important to identify social and economic constraints which come in the way of modifications evolved as a result of research and development of science and technology. Figure 1 presents important social and economic constraints. The social constraints include:

(a) Lack of Awareness: A vast majority of population, particularly in the low income groups, is oblivious of the potential hazards to houses and buildings in the event of earthquakes. It is necessary to bring home to them the implications of earthquake disasters and the difficulties and costs involved in undertaking large scale re-construction work. Information about past case histories of incidence of earthquake damages can be an eye opener in creating in them an awareness for effecting improvements to their existing houses and for building more earthquake resistant houses.

(b) Attitudinal Change: The mass of population is largely tradition bound and offers resistance to change due to several inhibiting factors. Through dissemination of information, personal contacts and community action, attitudinal changes have to be brought about so that the people become responsive to modifications required to make buildings and houses more resistance to earthquake forces.

(c) Illiteracy: Large population in developing countries is not literate. As such they are unable to appreciate scientific and

technological developments and the advantages accuring thereof. Their backwardness can be substantially eliminated through a programme of literacy. Emphasis would have to be laid on non-formal methods of education and greater importance would have to be given to audio-visual media in imparting education and presenting information regarding prevention of damage and destruction to earthen houses and buildings most commonly built by them.

(d) Lack of Motivation: Unless the people particularly in the low income groups, see for themselves benefits accuring from proposed modifications to the existing houses or in the construction of new houses to improve their performance in the event of earthquake they do not come forward to adopt improvements. It is therefore necessary to motivate them so that they themselves are willing to adopt improvements and this calls for a programme of motivation through several means.

(e) Lack of Community Action: It is often seen that individuals may not come forward to accept modifications to safety of houses in the event of earthquake. However, community action can be taken advantage of to bring about desired improvements. For this the local community organisations would have to be activised and the local leadership appropriately oriented. This will greatly promote the programme of housing improvement through mutual help and cooperation.

The important economic constraints to modifcation include:

i) Acute poverty: In most developing countries a vast majority of the population lives below povery line and their consumption level is below subsistence level. They have per force to stay in improvised shelters made practically at no cost using locally available materials. Poverty is the predominant inhibiting factor which makes them averse to any modifications to improve their houses.

ii) Poor occupational base: There are several factors which contribute to poverty and important among them is the poor occupational base on account of which the poor have no option to increase their level of income, without which it is difficult to undertake any effective programme for improvement of existing houses to withstand earthquake forces.

iii) Lack of Credit Worthiness: As poor people and those in the low income groups have hardly any assets or very low assets in the form of land and houses, they are not in a position to borrow any money from credit institutions like Banks, Cooperatives etc. for improving the earthquake resistance of their houses. Unless they are able to procure some finances at low interest rates, they will not be able to adopt appropriate modifications.

iv) Non-availability of Materials: Often improved construction techniques involve use of specific types of materials, products and

techniques. Non-availability of such resources as well as appropriate skills prevents adoption of modifications. Even though these may be available obviously, some extra cost may be involved in their adoption which the poor people are not in a position to afford.

Although research and development work to some extent has been undertaken to tackle technological problems of improving the resistance of mud houses to earthquakes, not much research and investigations have been undertaken. To eliminate or reduce the impact of the social and economic constraints to modifications as mentioned above, there is great need to undertake studies in order to investigate and establish the relevance of technology in terms of social and economic change.

OBSTACLES TO TRANSFER OF TECHNOLOGY

The vast majority of population who live in mud houses are tradition bound. They have been adopting age old techniques for building their houses using the local soil. In order to improve the durability and performance of mud houses, particularly their resistance to seismic forces, some innovative techniques of design and construction of houses have been evolved which have been briefly mentioned above. The work involved in transfer of technology is faced with many obstacles arising mainly out of -

(a) the extensive area to be covered as human settlements are scattered far and wide and many villages are in remote areas;

(b) the villages to be reached are colossal in number as in India where there are more than 7,000,000 villages;

(c) a wide variety of climatic and topographical conditions are to be encountered which have far reaching impact on the type of houses and materials used for construction;

(d) lack of awareness and non-availability of required technical know-how and skills as regards improvement of seismic resistance of mud houses;

(e) absence of financial and institutional support to promote improvements in mud houses etc.

To surmount the obstacles a comprehensive programme for transfer of technology therefore needs to be evolved to bring about improvements in mud houses. The ingredients of the programme and their interaction are illustrated in Figure 2 and briefly described hereunder.

i) Providing Incentives: Motivate the rural people in improving their mud houses for which greater awareness regarding the draw backs of dilapidated mud houses and structural deficiencies of such constructions and possible damage to these in the event of heavy rainfall, earthquakes etc. should be brought to their notice.

ii) Provision of Financial Assistance: Financial assistance to the villagers for improving their houses could be in the form of subsidy or loan on easy terms. Instead of this required building materials could also be supplied to them if possible free of cost or at low cost.

iii) Technical Guidance: Technical guidance in adopting improved mud construction techniques by dissemination of information, demonstrations, exhibitions etc.

iv) Demonstration Projects: Demonstration rural housing projects should be taken up to create an impact of improved mud construction techniques so that the villagers can appreciate the proposed improvements.

v) On-the-job Training: On-the-job training should be imparted to unskilled and skilled villagers in the techniques of improved mud construction.

vi) Organising Communication: A proper system of communication between research and development organisations and the village community should be established to bring to them the potencialities of new construction techniques for improving mud houses.

vii) Institutional Support: Institutional arrangements should be made to organise, support and propagate improvements in mud construction and for channelising necessary financial and technical assistance.

viii) Undertaking Research and Development: Research and development work should be undertaken in tackling local problems that are involved in effecting improvements in mud construction in different regions.

APPROPRIATE TECHNOLOGY OF IMPROVED MUD HOUSE:

The National Buildings Organisation, New Delhi which is also U.N. Regional Housing Centre of ESCAP has evolved a typical design of an improved low cost mud house as shown in Figure 3 and which provides a plinth area of 20 sq.m. having one room, a separate kitchen and a platform. A built-in latrine and a bathing place is also provided. The house is intended for the landless rural families whose number is estimated to be 17.6 million in India. Each of these families are being allotted

100 sq. yd. plot of land free of cost for putting up a modest house largely through self-help making improved use of local materials like mud.

The walls of the house are to be constructed with sun-dried bricks produced from the local soil which improves its structural performance including earthquake resistance. Also waterproof mud plaster is to be applied on the walls to protect the mud walls. It is prepared by mixing upto 5 per cent bitumen emulsion with ordinary mud plaster with straw and cow dung. To prepare bitumen emulsion 80 per cent of 80/100 grade bitumen is mixed with 20 per cent keroscene oil and creosote oil and heated upto 100° C. One per cent wax is also mixed with kerosene oil.

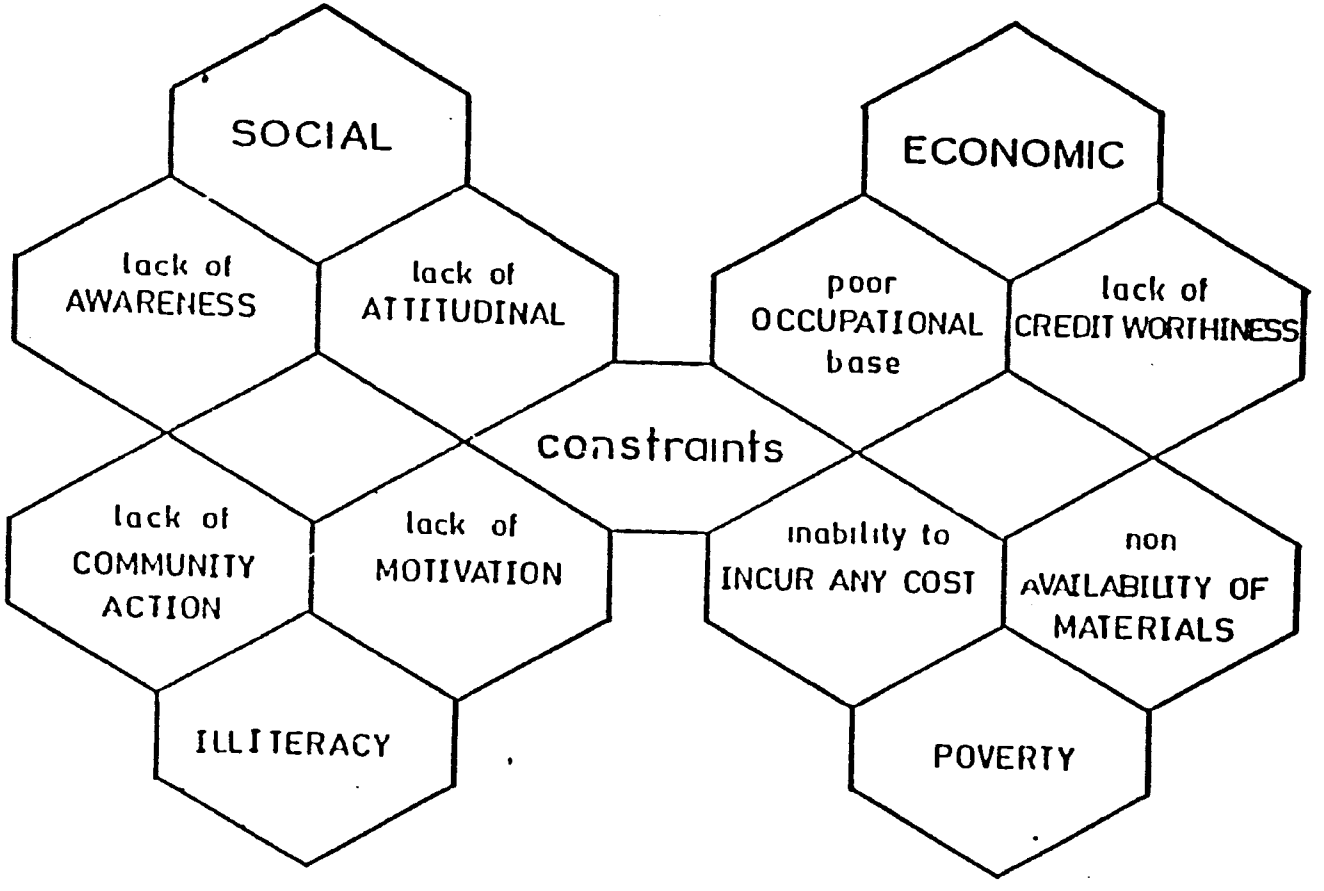
The roof is made of thatch over supporting bamboo or timber structure. For reducing fire hazard the top and bottoms surface of the thatch are plastered with bitumen stabilised mud and a solution of bitumen is prepared by adding one per cent of hot melted bitumen into 2 per cent of kerosene oil and stirred. One coat of this emulsion is applied by brush on the top surface of the well-dried and plastered thatch. The treatment is allowed to dry for three to four hours and then the second coat of this emulsion is applied.

Other methods for imparting greater earthquake resistance to mud houses have also been suggested. These include bamboo reinforced mud construction, use of stabilised soil blocks for construction of walls, construction of walls with bamboo frame and mud-in-fill panels etc.

DEMONSTRATION HOUSING PROJECTS:

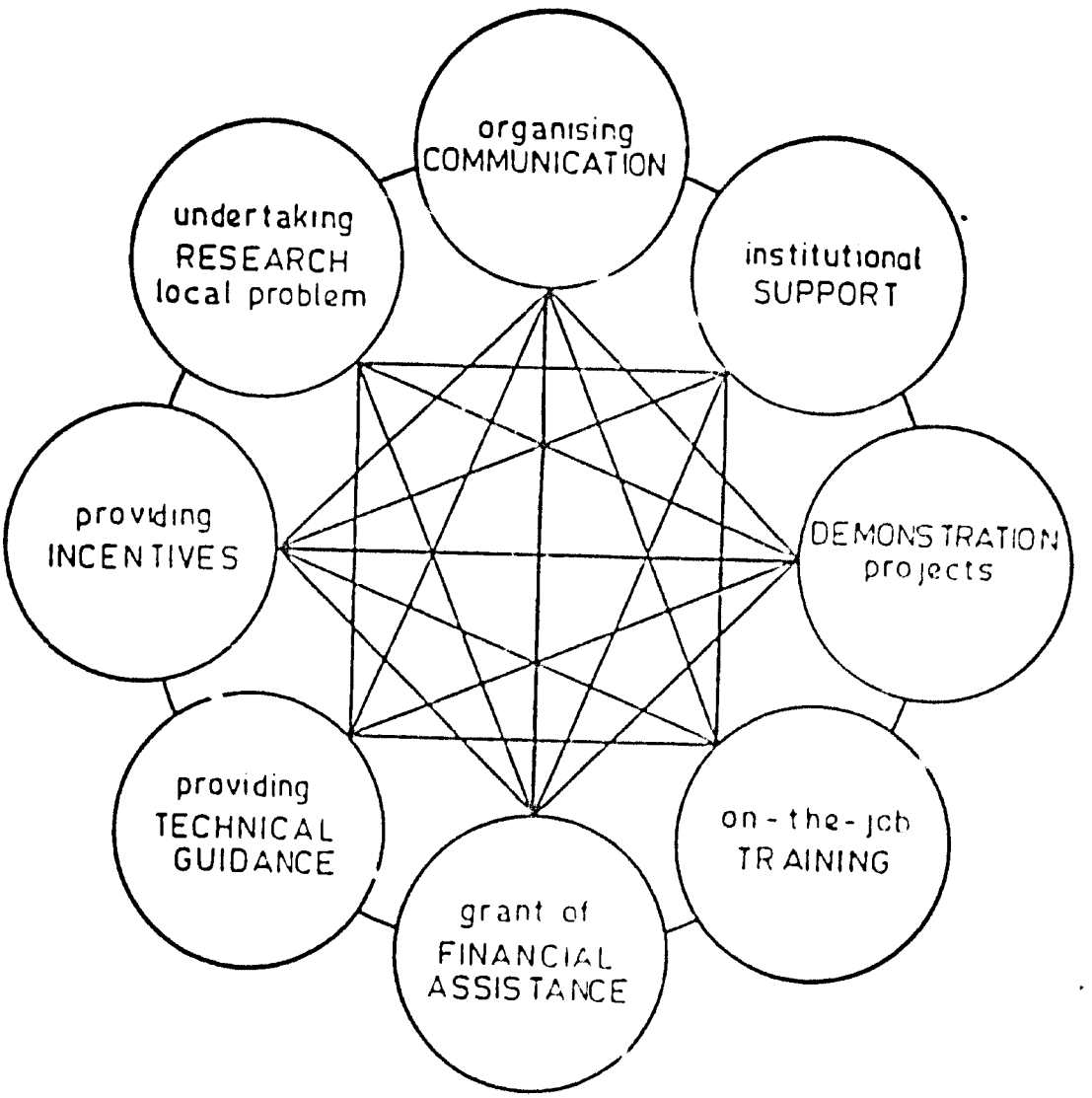
Several measures have been adopted for transfer of technology particularly in the rural areas by the National Buildings Organisation and its Nine Regional Rural Housing Wings which are engaged in promoting improvement in design and construction of rural houses. Clusters of 20 demonstration low cost houses have been put up so far in 36 villages in different regions in the country having varying climatic conditions with a view to motivating the rural people in adopting appropriate technology largely for building more durable and earthquake resistant low cost houses based on improved use of local materials such as mud, bamboo, timber, thatch, etc. and self-help building methods.

The basic principles of design and construction of earthquake resistant houses and buildings have been widely propagated through a movie film 'When the Earth Trembles' and 'For You a Cheap House', the production of which was sponsored by N.B.O. A number of T.V. and radio programmes, desmonstration and exhibitions have been put up to widely propagate appropriate techniques of construction of mud houses which may offer greater resistance to seismic forces.



SOCIAL & ECONOMIC CONSTRAINTS

FIG. 1



TRANSFER OF TECHNOLOGY

FIG. 2.

IMPROVED MUD HOUSE FOR THE RURAL POOR.

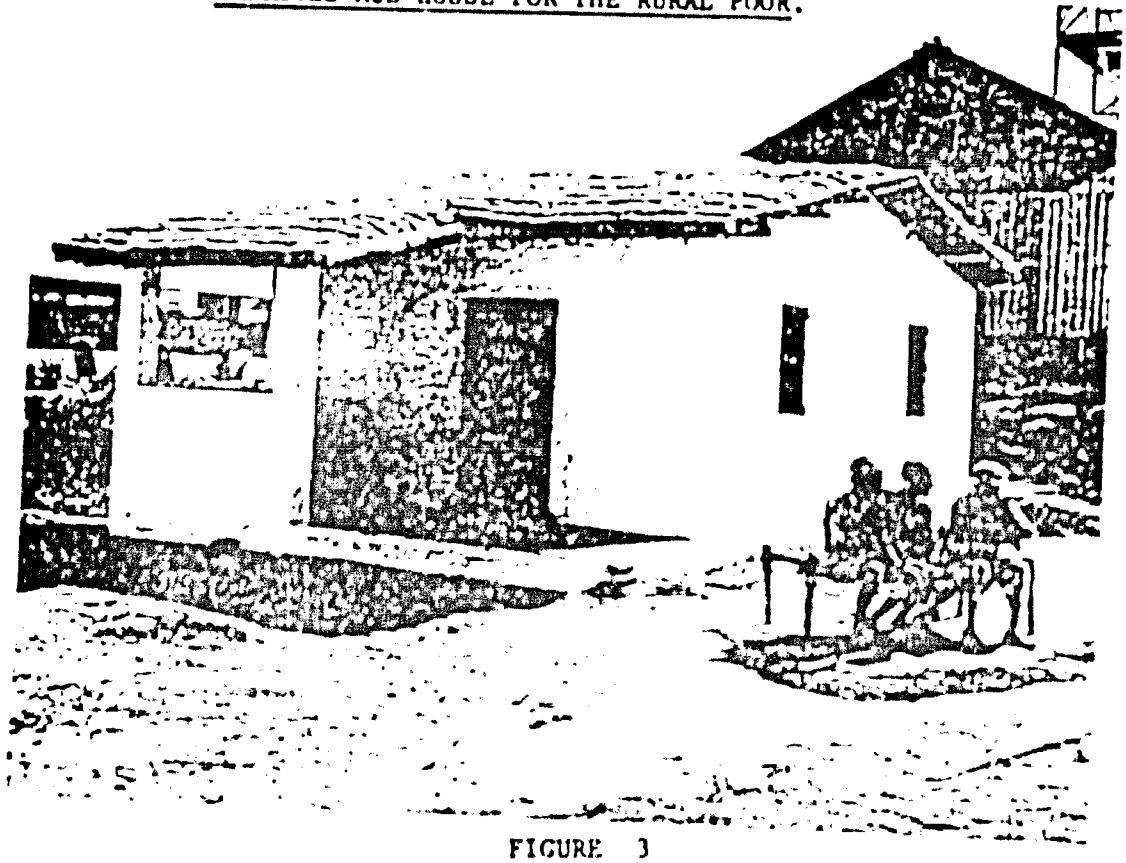
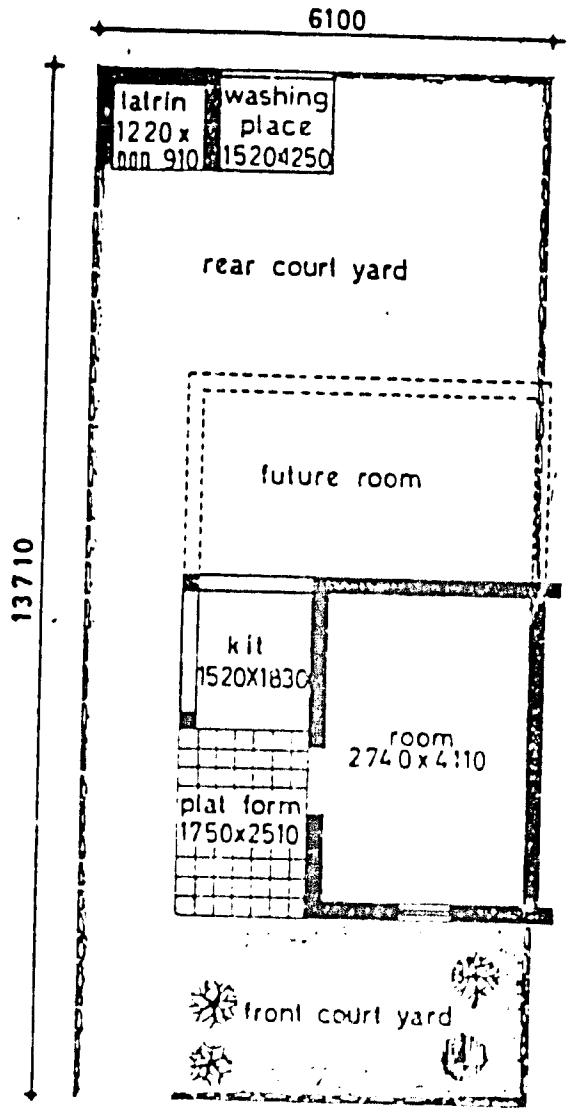


FIGURE 3

FIGURE 3-A



	Thatch Roof	Tile Roof
Plinth Area	20m²	20 m²
Cost	1500/-	Rs. 2000/-

IMPROVED MUD HOUSE FOR THE RURAL POOR.

THE CULTURAL CONTEXT OF THE USE OF ADOBE AND OTHER EARTHEN BUILDINGS

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ABSTRACT

The general context is established in terms of the characteristics of earth and the determinants of the choice of materials and forms for earth buildings.

Examples of traditional uses illustrate appropriate forms and techniques, evolved in relatively static cultures.

Finally, the introduction of new forms and techniques is discussed in relation to their acceptability in a changing cultural context.

INTRODUCTION

The context in which adobe and other forms of sun-dried earth is traditionally used in buildings, is presented in this paper with particular reference to two countries - Ghana in West Africa and Pakistan in the South Asian Sub-continent.

The general context is established in terms of the physical characteristics of earth and the social, economic and material factors which influence the choice of this material and the forms in which it is used for building. These are illustrated by examples of traditional uses, mainly in a rural context, in Ghana and Pakistan. A few examples from both countries, of the introduction of new forms and techniques, are included to raise some of the issues related to the context of cultural change. But the questions of 'acceptability' are not analysed here in any detail as they belong more to the discussion on problems of programme implementation and future directions in the use of adobe in building.

GENERAL CONTEXT

The chief advantage of earth as a building material is its low cost. Indeed wherever it is available it usually costs nothing more than the labour required for its preparation and placement. A second advantage is the low level of skill & technology required for its use in construction. Earth construction often requires no more tools than a spade and a bucket. Similarly the cost of repair and maintenance of earth structures is nominal and does not usually require the employment of specialist skills. However, it permeability to water makes it an impermanent material in wet climates. Furthermore, its permeability to pests and its structural weakness impose certain limitations upon its use in building.

As will be evident from these characteristics, the choice of earth as a building material will normally be determined essentially by its availability and considerations of costs, compared with other alternatives, and of available technology and skills. After air and water, earth is of course the most abundant of materials, and wherever it is available at site it is practically free. But in many situations, for instance along sandy coastal and rocky or wooded mountainous areas, or indeed in built-up urban centres, it may be either not available or may be available at some distance from the site. In such situations timber or other available vegetation (bamboo grasses, reeds, palm fronds etc.) or stone, or even throw-away industrial products like packing material, (plywood, plastics, boards & sheets) and abondoned or unused existing buildings, may provide a more attractive source of building material.

In any case where it is available, it will normally be used for building if cost represents an important constraint, or where considerations of cost out-weigh the disadvantages of water and pest penetration and impermenance.

An important determinant in the choice of earth is also the level of skills and available technology, especially in situations where cost constraints are critical. Labour, skills and technology which the builder himself does not possess have to be paid for in cash or kind. In subsistance economies, or in societies where labour and goods are exchange by barter, traditional skills and labour can usually be acquired without any cash outlay. But industrial products or skills on the other hand often become inaccessable not only for lack of effective communications and distribution or marketing but also because they must be bought with cash.

Another factor determining the choice of earth is time. That is, the expected or desired life of a building. The life of earth buildings, especially under wet conditions, is relatively short. However not every building needs to be designed for a long life. Conditions of high mobility (as in the case of semi-nomads, rural & urban migrant labour), or insecure proprietorship of land often require a temporary structure which can be put up with little or no money and can thus be abondoned if necessary without much loss of invested capital. Alternatively buildings which could be conveniently modified in time - added to or changed - also have a distinct advantage in many circumstances.

In dry climates of course earth structures are known to have lives of a hundred years or more. Under these circumstances even buildings normally associated with long lives such as forts, mosques, palaces etc., may be made of earth. Besides, the thermal properties of earth (high thermal capacity) can be a valuable assets in extreme climates, particularly in hot-dry desert climates, where it is often used in massively proportioned structures which provide evenly comfortable interior environments in climates with high diurnal ranges of temperature. In warm-humid climates however with low diurnal ranges, structures with low thermal capacity are more desirable. In these climates lighter materials such as bamboo, reeds, etc., or composites such as earth plaster on timber lath & frames, are preferred over massive earth.

The forms of earth buildings are naturally determined to a large extent by physical factors such as the properties of available materials, and the requirements of each climate. But equally decisive is the level of social evolution or development and social structure. This last determines both the availability of resources (monetary, technical and intellectual) available to a community and the functional types of buildings required by it. Modes of production, social and property relationships, political structure and ideology are strong cultural factors which make up the context for earth buildings.

A thoroughly industrialized society, employing capitalist modes of production in industry and agriculture generates both the surplus value and the need for an expanding consumer market. This environment is not compatible with a subsistance economy and with social activities which place no demand on the products of its industries.

Such societies can not only afford better than simple mud houses, they can not afford 'no-cost' buildings. Besides, even on purely technical grounds, traditional earth technology can seldom provide the performance required of most functional categories of buildings in an industrialize society.

Adobe or earth, as it is traditionally used in buildings, has little relevance in this context of thoroughly industrialized consumer societies, except as the playthings of rich accentrics or as a potential area of expansion of the consumer market.

Self-help, no-cost building, with freely available materials and techniques, requiring no imported skills, are indeed only relevant in the context of under-development or uneven development. It is normally only situations of uniform distribution of poverty or of unequal distribution of wealth which provide the cultural contexts for earth buildings. Even within such situations, in drier climates earth becomes more universally used by all sections of a community and as a primary material for all types of uses, and in all climates it is more frequently used in a rural rather than an urban context.

In a rural context the annual cycle of activities related to agriculture includes periods of relative unemployment in which labour can be utilized for the construction or repair of buildings. This coupled with a near subsistance economy in which cash is scarce, free availability of earth and often insecure or temporary tenure in many rural societies makes for conditions in which the use of earth for buildings becomes more general.

In the market economy of urban societies, however, any period of unemployment is catastrophic and must be utilised in search of employment. In addition, urbanisation, by its very nature, usually closes up the sources of freely available soil, except at the fringes of urban development. Nevertheless, inspite of the unfavourable context, earth buildings in urban areas are not uncommon, particularly in very dry climates or as a reflection of extreme poverty and insecurity.

The examples which follow show the variety of forms and techniques evolved for building in two countries: Ghana and Pakistan. These examples show that where the determinants remain constant for long periods or change very slowly, appropriate forms and techniques are evolved within the context of an indiginous culture. When the determinants are modified, by the introduction of new resources, materials, skills, techniques, or design concepts and cultural values etc., the indiginous builder and craftsman often responds in ways which are different from those of a 'professional designer'.

GHANA

Under favourable conditions of dry climate, availability of materials, and constant maintenance, and with appropriate design, earth buildings can serve a variety of uses including multi-storied structures with reasonably long lives. The Mission School in Novrongo (Fig.1) in the Upper Region of Ghana is a good example of intelligent design in sun-dried earth brick. This double storied structure, with massive walls and arched openings, has survived several decades in the dry Savana climate aided by regular maintenance

Traditional earth buildings include a variety of architectonic devices which are employed to reflect social significance and function. Extra height and minerates are easily recognisable forms in the landscape or townscape, which help identify an important community building such as a mosque. (Fig.2)

Functional elements are also exploited as an integral part of the design. Thus buttresses provide necessary strength to the tall structure and permanent scaffolding facilitates regular maintenance of mud plastered surfaces. They also become the distinctive features of mosque architecture in West Africa.

In a chiefs compound (Fig.3) a distinctive architectural treatment - decorative parapets, flat roof and whitewash - gives prominence to the central apartments of the chief, while simpler round houses provide iden-

FIG. 1
Mission School, Navrongo

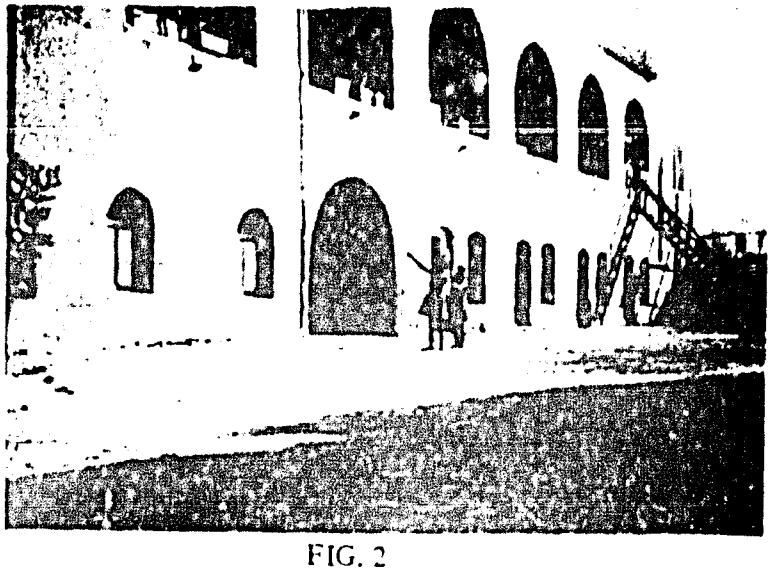


FIG. 2
Mosque, Ghana

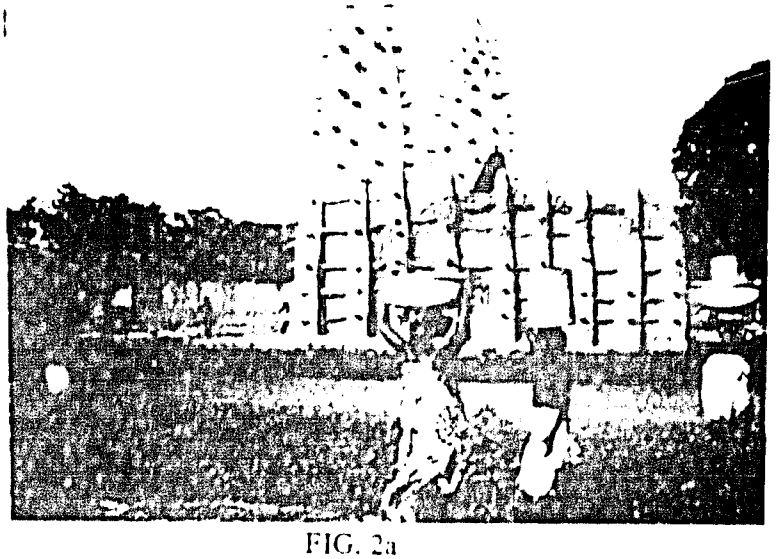
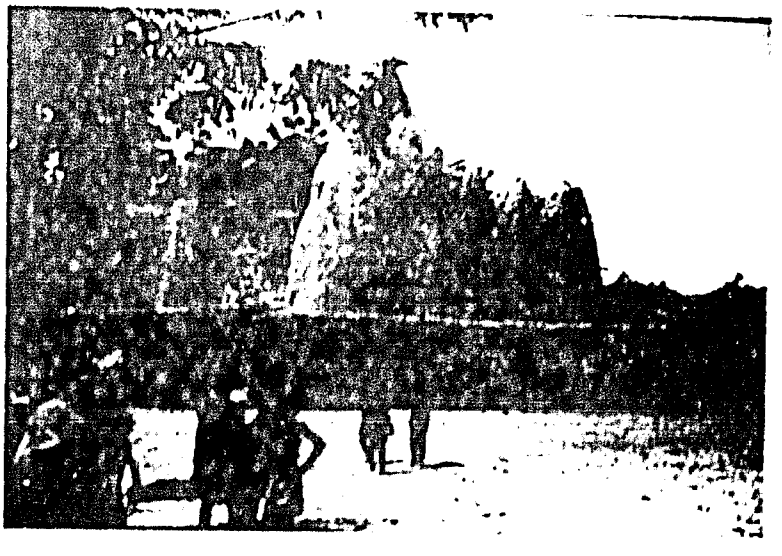


FIG. 2a
Mosque, Walewale



tical accommodation for each of his four wives.

In another case, the Yiwasi Chief's Compound, the traditional round house form provides an intricate but elegant complex of living quarters, grain stores and courtyards (Fig.4). The basic unit of this cellular structure is the bin-shaped round house with mud-pise walls and a conical thatch roof. Two or three such cells make up a typical family compound. In the extended structure of a chiefs household a number of family units are combined into a series of distinct courtyards. Access to each courtyard is by climbing with the help of a ladder, over the screen walls.

The pottery-smooth red finish is achieved with a traditional formula for mud plaster which includes juices from the Boabab tree.

Door openings with low headroom are shaped like large keyholes to admit a slightly crouched adult. Old enamelled basins provide convenient collars to thatched roofs.(Fig.5)

Massive high walls, layered or coursed mud pise construction, buttresses, mud plaster with finger-patterned decorations(Fig. 6) reflect appropriate traditional building techniques evolved within a specific cultural context where earth is the principal building material

In a wetter climate earth is used as a secondary material with timber providing the primary structure. Flat roofs are replaced by pitched roofs, the load of the roof structure is

FIG. 3
Chiefs Compound, Ghana

FIG. 4
Chiefs Compound, Yiwasi

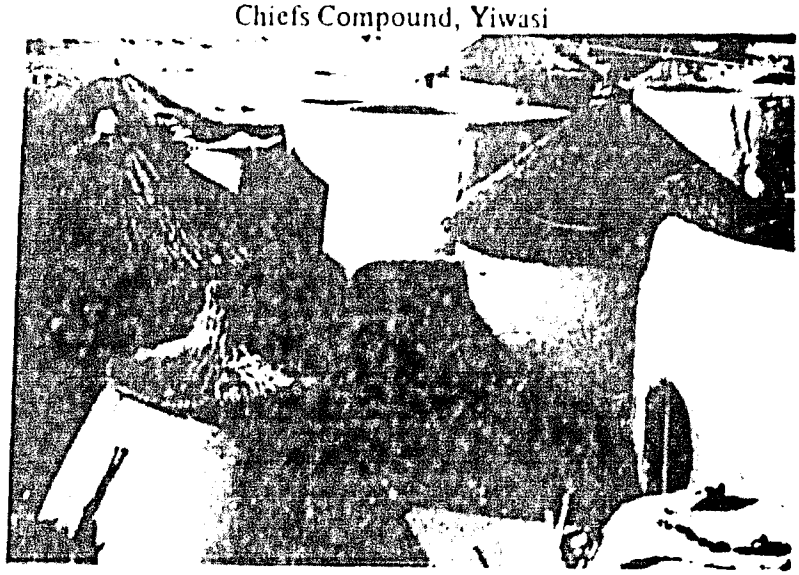
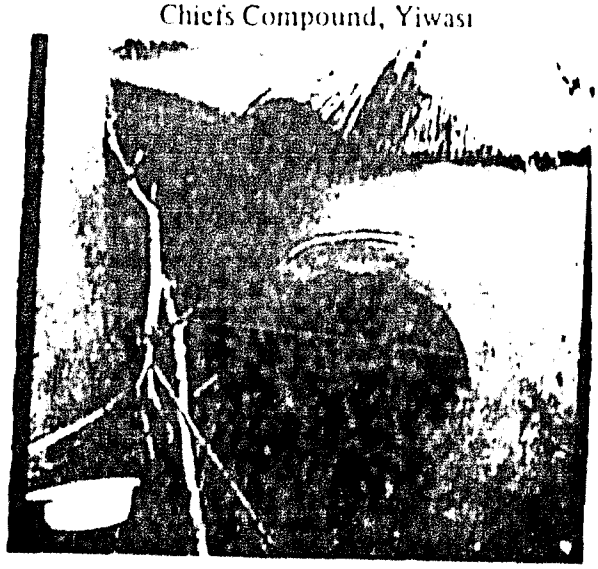


FIG. 5
Chiefs Compound, Yiwasi



carried by timber posts and the screen walls can be made lighter by techniques such as mud plaster on a timber lath(Fig.7).

In an area of 'slash-and-burn' subsistance agriculture the grain store plays a central role in the family house.

The design of these elements is determined by their location within the building. They may be attached to the building for convenient filling from the roof (Fig.8); or constructed as free-standing structures(Fig.9). In each case protection from damp and vermin remains the principal design constraint.

In a typical Dagati or Lobi house the grain store is placed on a timber raft which isolates the earthen bin from rising damp. A large flat roof provides both protection from rain and a platform for access to the top for filling.

In other areas the grain store may be constructed as a free-standing structure consisting of a timber trestle on which is placed the earthen bin, and a large, conical thatched roof carried on a ring of timber posts.

As much as the form of individual buildings, the cultural context determines the form of an entire village. Considerations of security may lead to a settlement pattern in which the whole village becomes a single compact structure and public circulation is at roof level, with access by ladders down to the courtyards of each house(Fig.10).

Furthermore, flat roofs are generally an important useable space in a warm climate

FIG. 6
Mud Walls, Bole

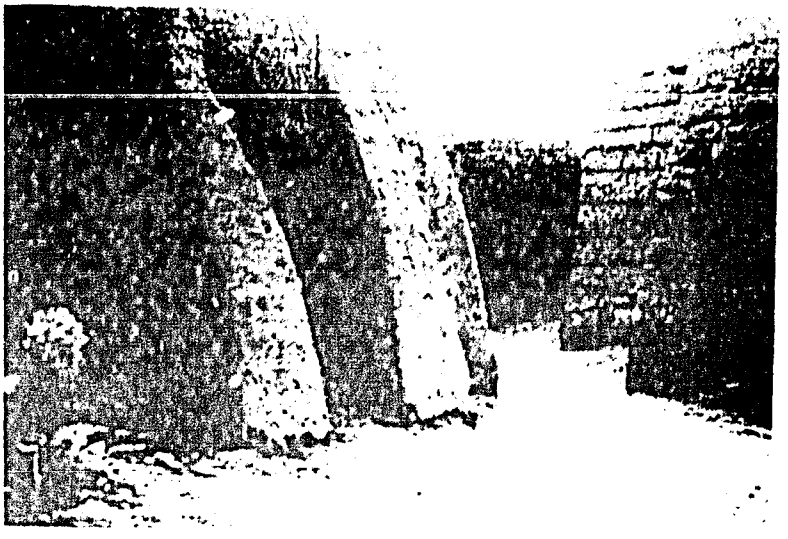


FIG. 7
Fetish Priests House, Carpenter

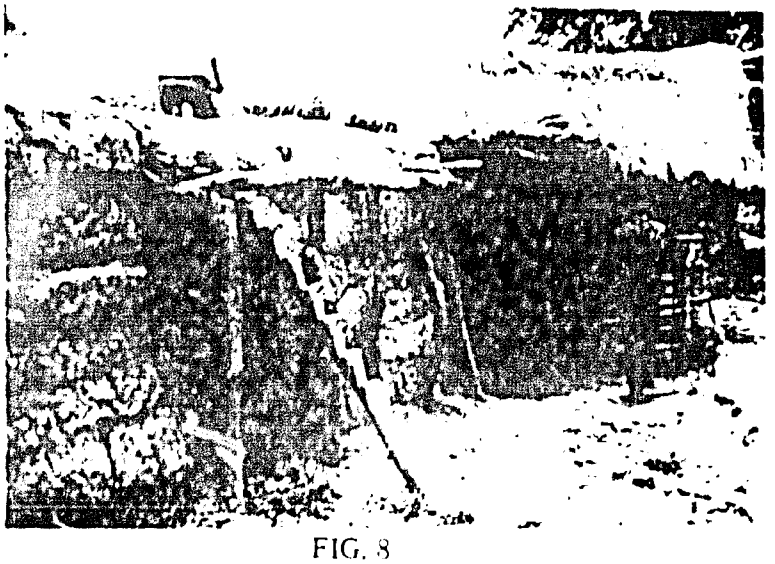
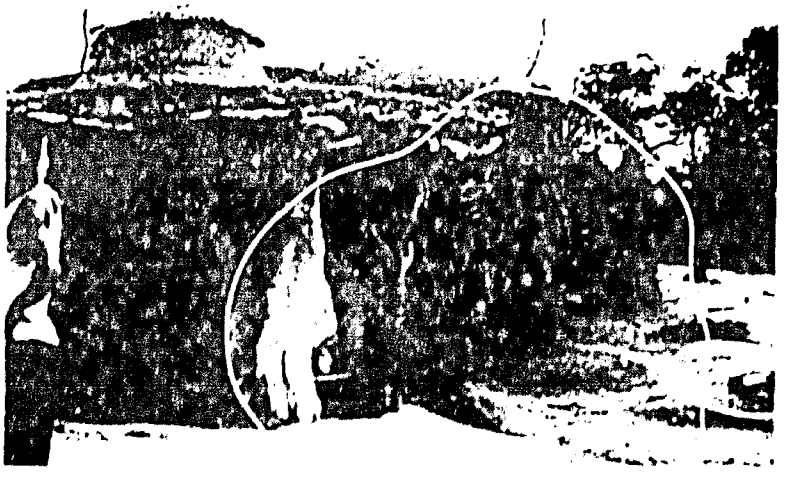


FIG. 8
Grain Store, Dagati & Lobi Houses



As can be expected such a settlement pattern is accompanied by appropriate design details for elements such as steps, handrails, and surface water disposal.(Fig. 11) The courtyards in these villages have an ingenious soakpit in the centre, filled with potsherds and finished with a neat outlet at floor level made from the neck of a broken earthen pot.

Permeability to water is perhaps the single most common cause of erosion and damage to earth structures.

Periodic maintenance thus becomes an important aspect in the culture of societies in which earth building is traditional. A variety of protective mud plastering techniques are employed, and often this is applied by women.(Fig.12)

The seasonal maintenance can become a social event with the pooling together of skills and labour, frequentely resulting in highly decorative results.

Mural decoration may take the form of indented patterns made by fingers in wet plaster or of areas of coloured plaster.(Fig.13)

The indented finger-pattern is believed to improve resistance to erosion by rainwater as it flows down the face of the wall. But they are probably used as much for their decorative effect as for other functional reasons.

The patterns, symbols, motifs and design schemes of mural decoration specific to each culture must be seen in the context of the ideology, symbolism and value systems specific to that culture.

FIG. 9
Grain Store, Wagawaga

FIG. 10
Roofs, Seripe

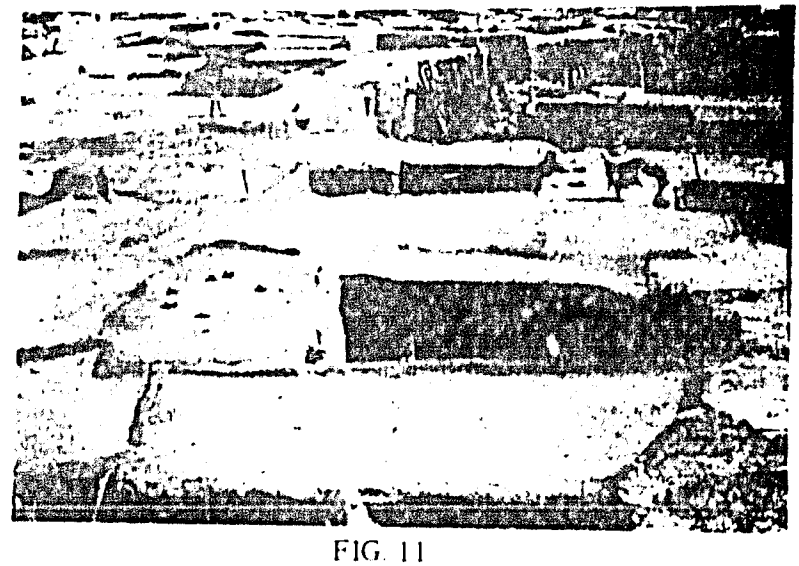


FIG. 11
Roofs Access and Rainwater Spout, Bole

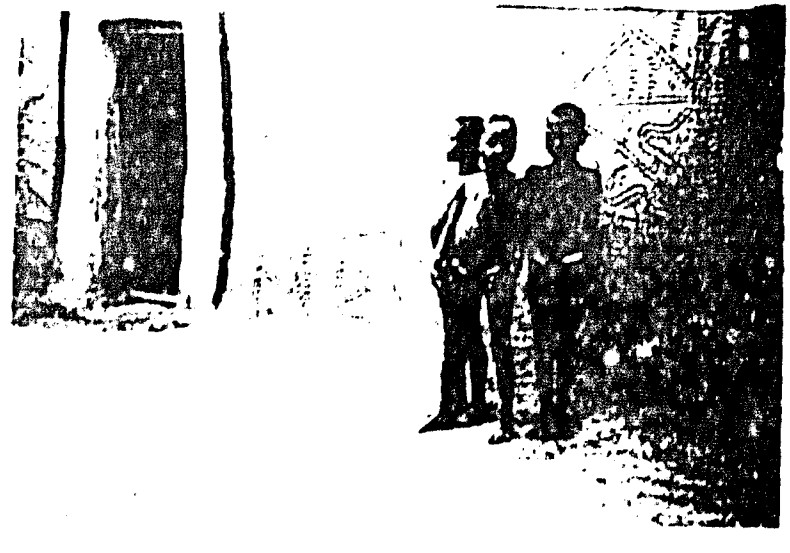


FIG. 12
Mud Plastering Sakpa

Photo not available

FIG. 13
Wall, Chief's House, Seripe

Photo not available

FIG. 14
Mural Patterns, Tongo

Photo not available

FIG. 15
Courtyard, Teselima

FIG. 16
Mural Patterns, Paga

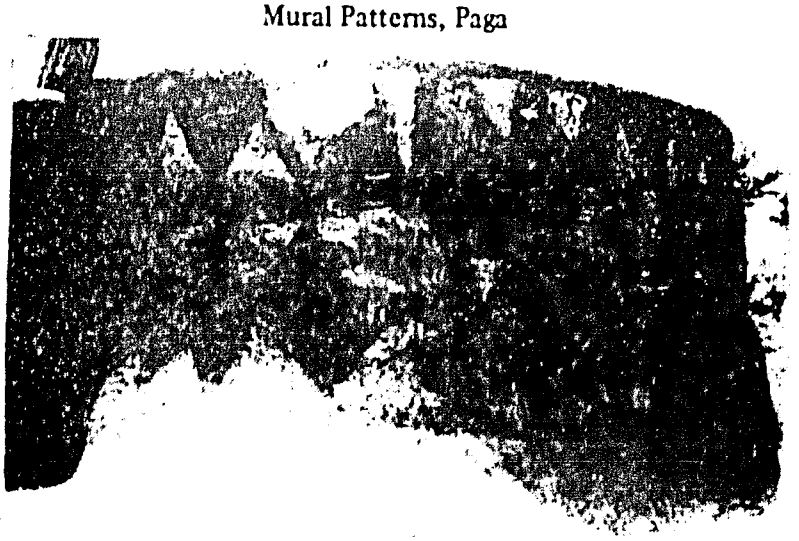


FIG. 17
Mural Zuarungu

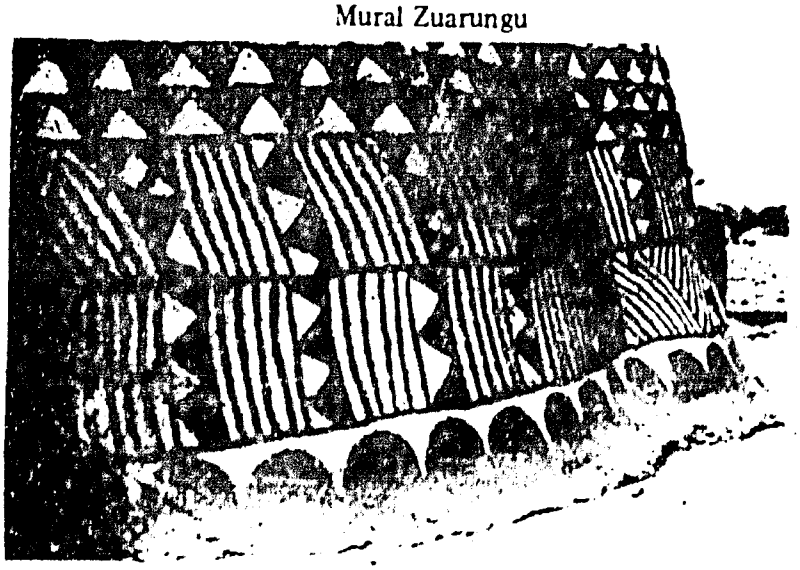


FIG. 18
Mural Reliefs

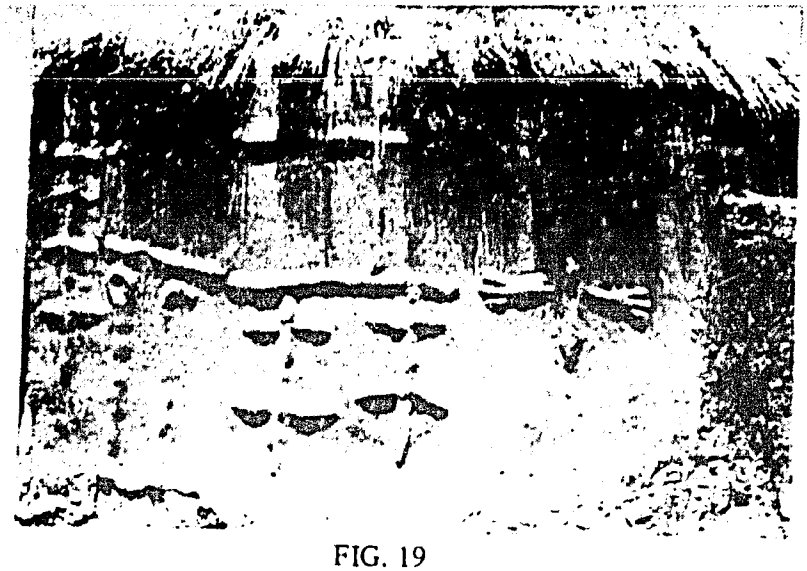


FIG. 19
Plastered Wall, Sakpa

FIG. 20
Play Picture, Kamen Kwesi

Fetishes, human and animal figures, gestures, abstract geometric motifs, and colour etc., make up a complex communication system or vocabulary of symbols. These are an important element in the design of woven and printed textiles, goldweights and murals.

A fuller interpretation or analysis of how such values, concepts, symbols etc., are acquired and become part of a collective memory, through rituals and even children's games(Fig.20), and the process of assimilation of new ideas and images(Fig.21) etc., would be a subject deserving of attention. But of more immediate relevance to this workshop is the cultural context for buildings and the evolution of appropriate structural and constructional forms and techniques, and the impact of technological change and design innovations introduced into the context of cultures which are alien to those of the technologists and designers.

Building traditions evolved over long periods of time in relatively static cultural contexts, evolve an architectural idiom which is closely integrated and in harmony with its environment(Fig.22).

All too often, however, development and change is accompanied by dramatic upheavals in which the fabric of traditional societies is uprooted and replaced by unfamiliar patterns of buildings, of living and of relating (Fig.23) Projects and programmes involving technological and design innovations often fail to achieve the results intended or ever get beyond the pilot project(Fig.24) Well intentioned efforts to introduce designs or techniques to

FIG. 20a
Play Picture, Kamen Kwesi

FIG. 21
Wall Painting, Samanaku

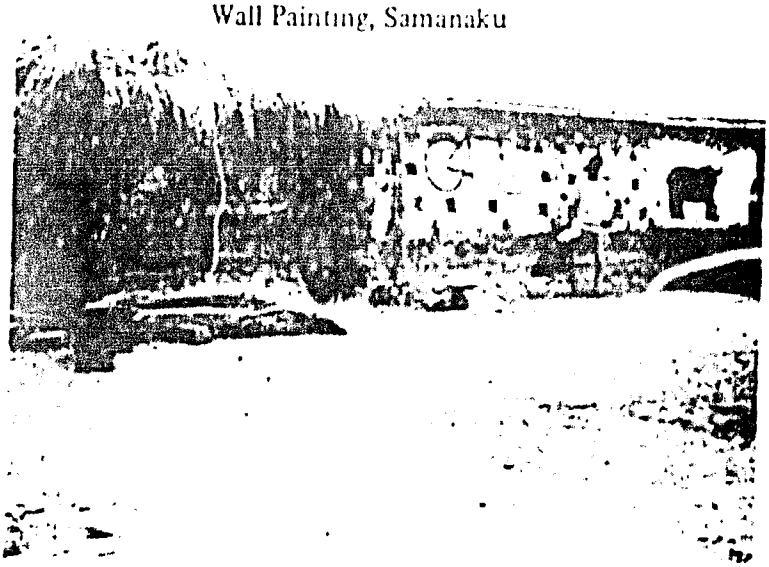


FIG. 22
Village

improve the potential of traditional materials, or to re-introduce traditional forms of building with local materials, have often been re ected by while improbable scautions borrowed from urbanised/industrialised cultures have been accepted by societies in transition. However, these and other problems of programme implementation and of 'acceptability' will no doubt be discussed by others in this workshop.

FIG. 23
V.R.A. Resettlement, Akosombo

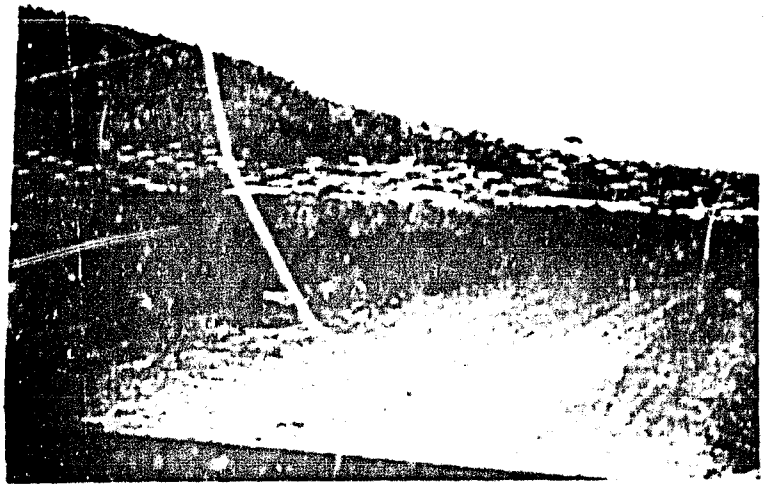


FIG. 24
Faculty of Architecture Project, Nangodi

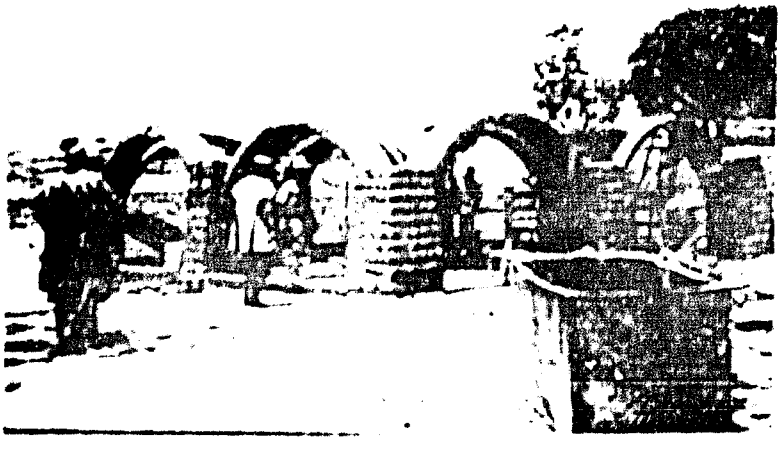
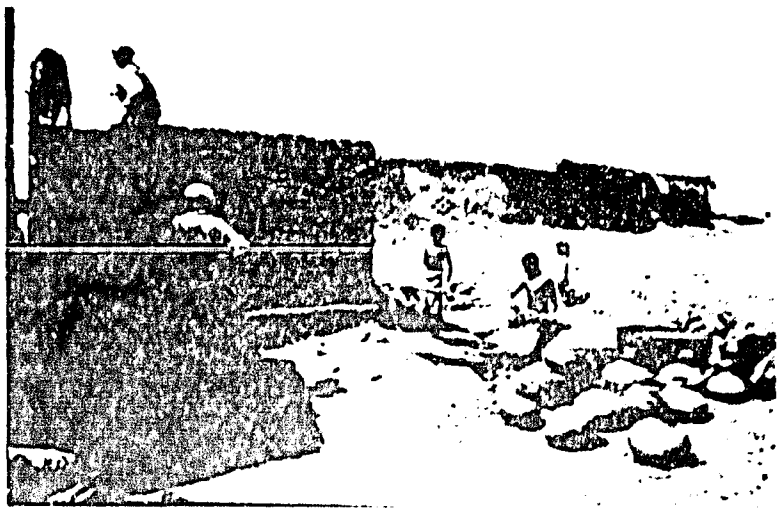


FIG. 25
Mud Brick Building Site, Dingarh



Longer durability in the hot dry desert climates makes earth the preferred material for all types of buildings ranging from simple peasent houses to forts and palaces.

For the ordinary rural dwelling the techniques are simple, and traditional house building is an activity in which the entire family and their neighbours can join in(Fig.25). Ocassionally a mason or craftsman from the town may bring in new concepts which can quickly become the symbols of "modernity" and higher status.

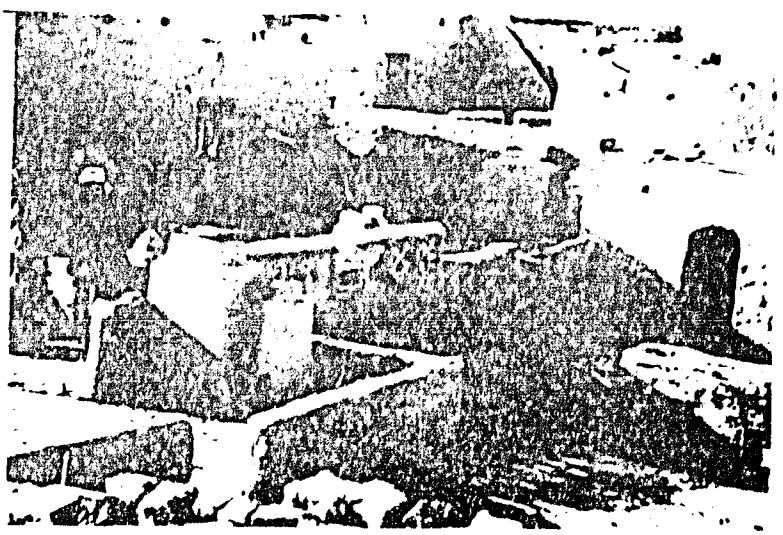
Familiar building techniques and the plasticity of the material results in forms which can be organically moulded to the changing rythm and cycle of rural life.(Fig.26)

Inspite of the existance of a well developed tradition of adobe building or the ruined fort of Phulra, in the desert of Cholistan is used as a ready quarry for burnt brick tiles, or timber beams and doors etc.

Traditional forms and structural systems are evolved in conformity with the nature of the materials and the dictates of the climate.

Chanan Pir, named after the saint whose annual feast is celebrated by a festival stretching to seven consecutive thursdays, is one of the few permanent settlements in the Cholistan desert.

FIG. 26
Ad ,be Houses, Phulra



The domestic architecture of the more permanent structures indicates a long tradition of adobe building.

Sun-dried bricks have long been used in arid climates for such monumental structures as forts. In the desert tract of Bahawalpur a chain of over two dozen forts, mostly of the 18th century, formed a 300 mile or line of defence.

Most of these forts are situated along the ancient bed of the Hakra river. These are all built of burnt bricks enclosing a mud or mud-brick core. However, some, situated deeper in the desert are entirely of sun-dried bricks.

Erosion by water, from flash floods, rain or rising damp, remains the most serious cause of damage to earth structures even when protected by a veneer of burnt brick.

Damage by flash floods is of course limited to the base. As the water washes out the mud-mortar the bricks come loose and fall away. Rainwater penetrating from the top creates a myriad crevices as it seeps through the mud-brick core. When the bond between the veneer and core is dissolved whole sections of walls have been known to slide down to the base.

Added to the ravishes of nature is the immeasurable damage caused by the hand of man himself. Thus some of the most impressive examples of military architecture in Pakistan are today rapidly crumbling and decaying due to inadequate maintenance and repair.

FIG. 27
House, Chanan Pir

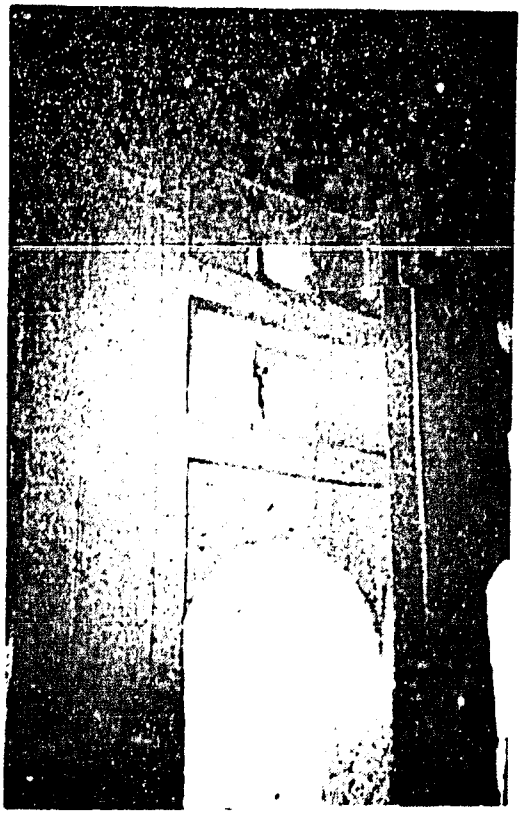


FIG. 28
Mud Fort, Nawankot

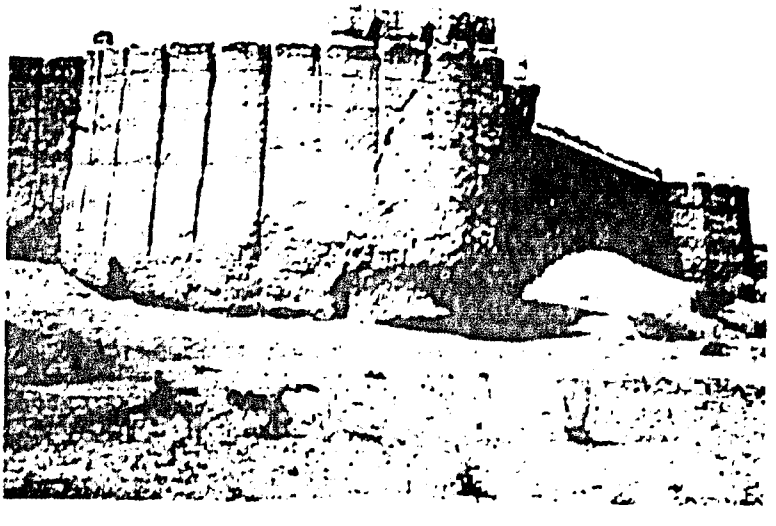


FIG. 29
Fort, Mirgarh

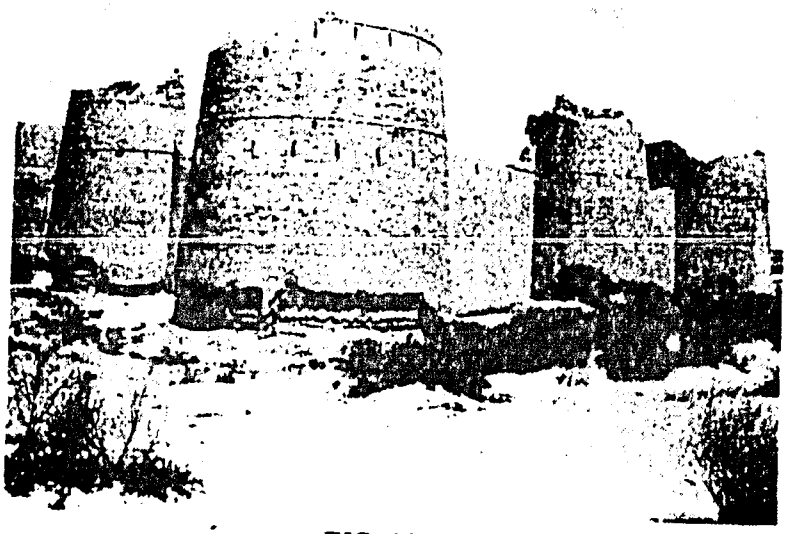
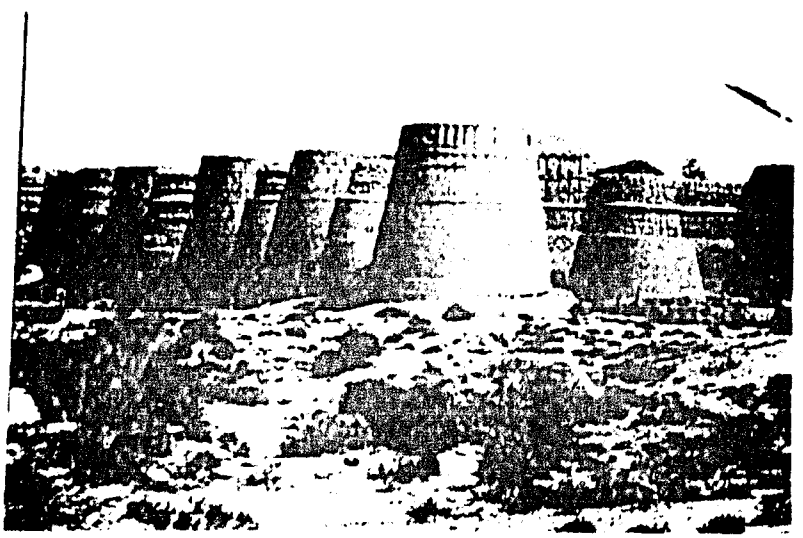


FIG. 30
Fort, Derawar



The largest and still most imposing of the Forts of Cholistan is Derawar. Once the stronghold of the Nawabs of Bahawalpur, its rolling battlements rise out of the desert like giant waves, or a mountain range.

The numerous palaces and pavillions inside were levelled by the Nawab himself to make room for parade grounds in preparation for the expected Japanese thrust in World War II. That was when the Nawab was a Nawab. Today his State, his privellages, his army are gone. And with them the camp-followers. The once populous city outside the walls of Derawar lies deserted. Soon the fort too will sink back into its native earth.

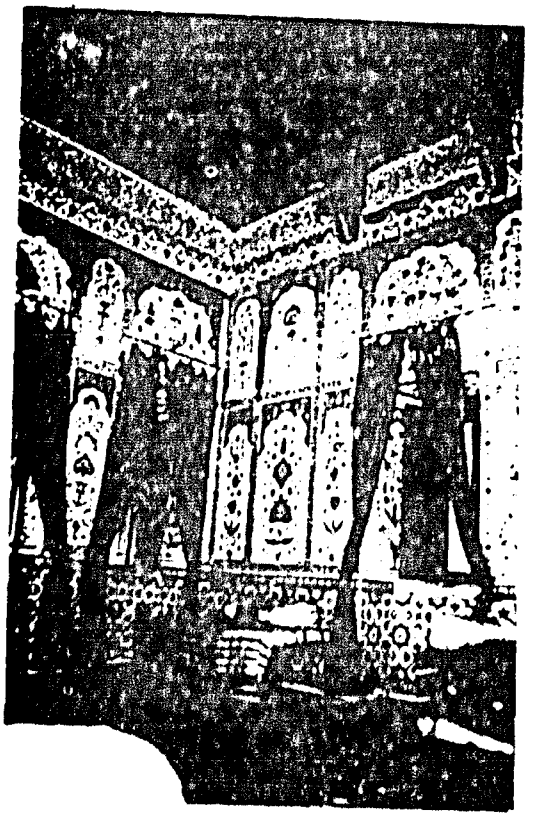
While earth building for the poor, in both the rural and urban context, survives as a continuing tradition, examples of earth building in the service of the state and the wealthier classes are becoming increasingly rare.

Amongst the few that remain are some of the buildings still in the custody of the family of the Nawabs of Bahawalpur. The lake Pavillion in Derawar (Fig.32) must be amongst the last of the royal structures built in the traditional style. It combines a simple exterior or structure of wood, burnt brick and adobe with a lavishly decorated interior.

As social and property relations changed, the rich became the first to discard traditional building practices in favour of modern techniques and materials. Many an exquisite palace or pavillion, which used mud as a primary or secondary material,

FIG. 31
Fort, Derawar

FIG. 32
Lake Pavillion, Derawar



today lies neglected and threatened with extinction.

The Ladies Pavillion in the old garden at Dera Nawab Sahib (Fig.33) is perhaps one of the most elegant specimens of this genre of architecture. This three storied pavillion has a timber framed structure with burnt brick and adobe infill walls, finished in fair-faced decorative brickwork or a fine mud plaster with frescoe decorations.(Fig.34)

The upper floors are provided with airy balconies overlooking the garden and the central hall. But the ladies of the harem were well protected from public view behind timber jalousies.

Among the traces of other royal residences that do still remain like ghosts and skeletons of once impressive edifices, is the Royal Tower at Phulra. The remains of this lofty seven storied tower testify to the degree of refinement and sophistication that was achieved in the details of the interior mud plaster, and fine brickwork laid in mud mortar.

Each of these forts show evidence of some mud brick residential quarters within them. But most appear to have been of a more utilitarian nature and were presumably not faced with fired bricks.

Earthen buildings in an urban context (Fig.36) are not uncommon, particularly in very dry climates. But it is in the rural context that earth building usually comes into its own, reflecting in the diversity of its forms the variety of social, economic and physical conditions peculiar to each environment.

FIG. 33
Ladies Pavillion, Dera Nawab Sahib

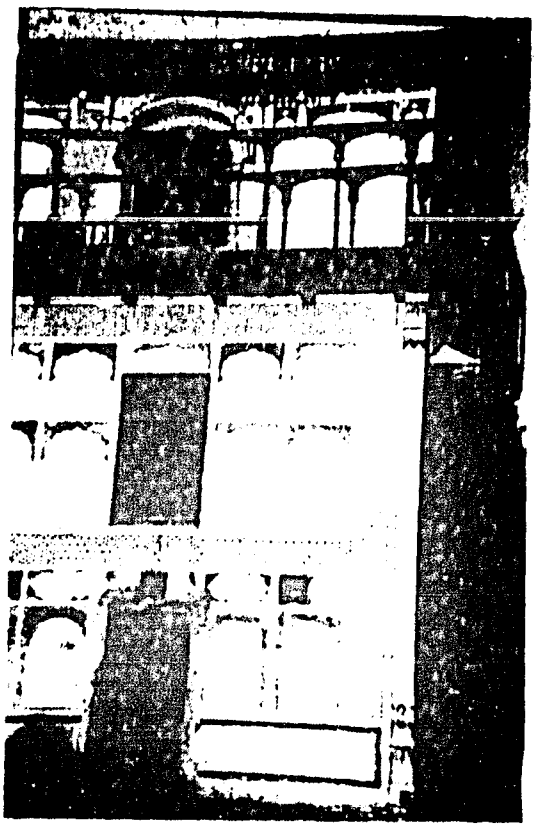
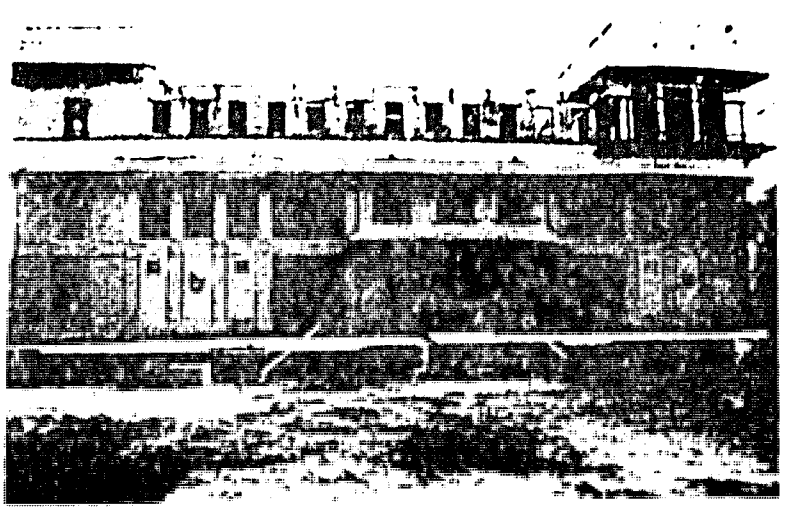


FIG. 34
Ladies Pavillion, Dera Nawab Sahib



The Baluchistan plateau is extremely dry. Not surprisingly large sectors even of the major cities of this province are of adobe construction. The high windowless external walls of massive earth, the flat roofs and chimneys a" bear witness to the extreme climate and social values of this highland culture.

A very different form of earthen buildings are the "cave" dwellings carved out of the compact loess soil on the Pothowar plateau (Fig.37) and in the North West Frontier Province. While being a picturesque reminder of human ingenuity and adaptability, these dwellings are often also indicators of extreme poverty. They are normally used by the poorest families in the Campbelpur District of the Punjab or by outlaws and fugitives in the tribal area of the North West Frontier Province

Strong clan affiliations, jealously guarded privacy and blood feuds in tribal societies produce their own unique architecture of clan compounds with up to 20 families within their high walls, and all the acrutements of tribal warfare - watch-towers, shooting galleries and loop-holes.(Figs.38, 39). Each household within the fortified compound has its own courtyard with rooms and lean-to verandas around it, and includes a bathroom and kitchen.

The clan compounds of the Khyber Agency are among the most striking. Constructed of mud pise these walls have no copings but each floor and roof is marked by a projecting cornice or moulding. In one

FIG. 35
Royal Tower, Phulra Fort

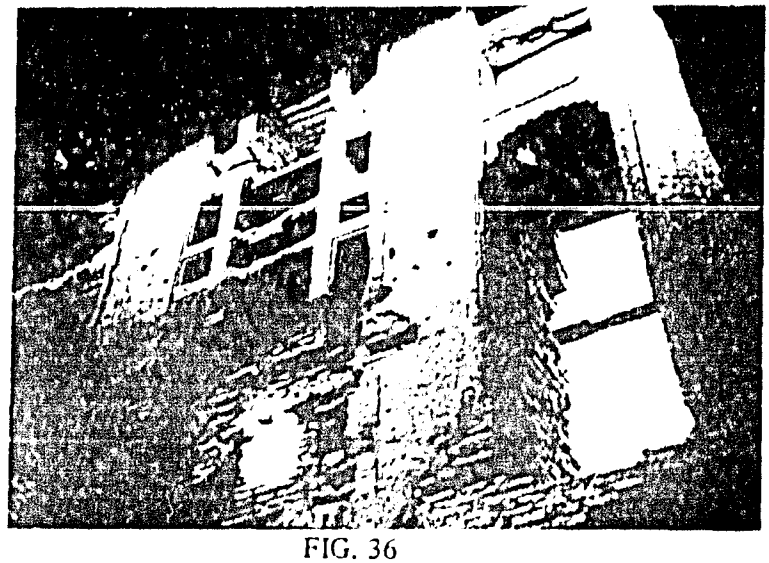


FIG. 36
Mastung, Baluchistan

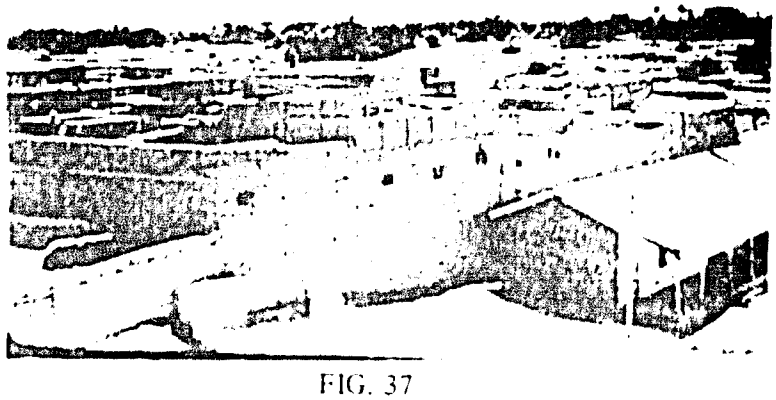
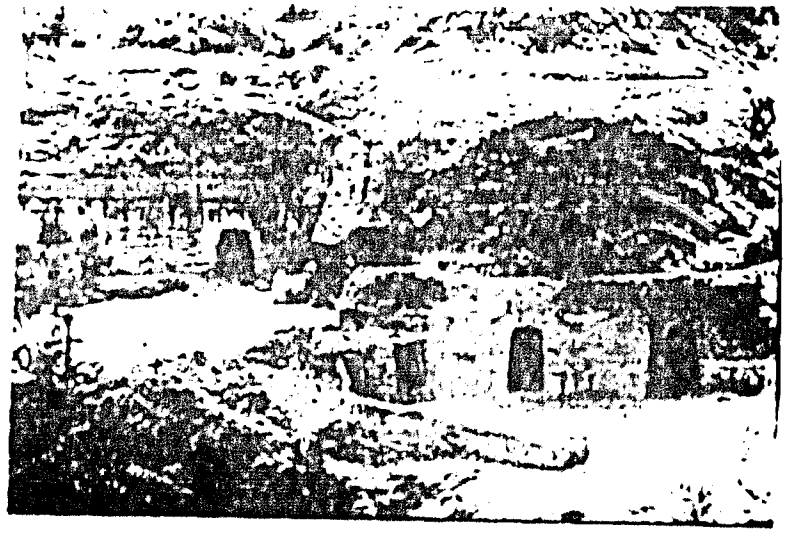


FIG. 37
Cave Dwellings, Jallo



corner of the compound, usually flanking the entrance, a tower rises one or two stories above the roof.

The parapets are sometimes castellated, adding to the fortified appearance. The walls and tower slope inwards, tapering towards the top.

In other neighbouring valleys, where stone is readily available it becomes the preferred primary structural material, sometimes bonded with mud morter.(Fig. 40).

Dara Adam Khel is a unique example of an entire valley which has preserved a local style of architecture with amazing purity.

Less forbidding in appearance and more intimate in scale, the warmer texture of unhewn stone in these villages is further softened by the bushy but neat copings which top each wall and parapet and mark each floor and roof.

Topology strongly influences building forms On a sloping site the lower roofs provide terraces for the houses above.(Fig.41).

Used much like the courtyards in the plains, it is not unusual at harvest time, to see a pair of diminutive hill oxen threshing corn in endless circles on these sturdy terraces.

To the north-east of Peshawar, in the catchment areas of the Swat, Indus and Jhelum rivers,

FIG. 38
Clan Compounds, Dera Adam Khel

FIG. 39
Clan Compound, Bara

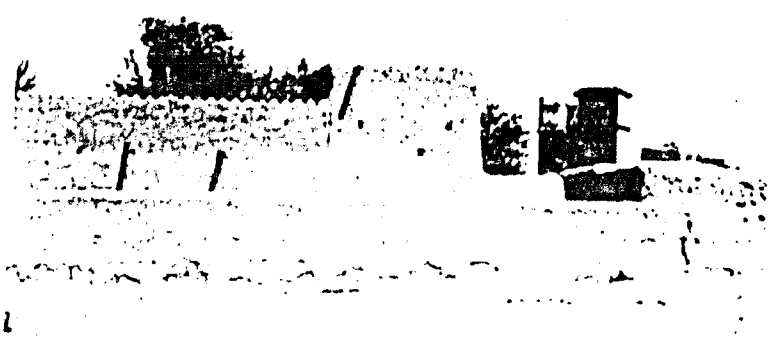


FIG. 40
Village Tandival, Bashkhel

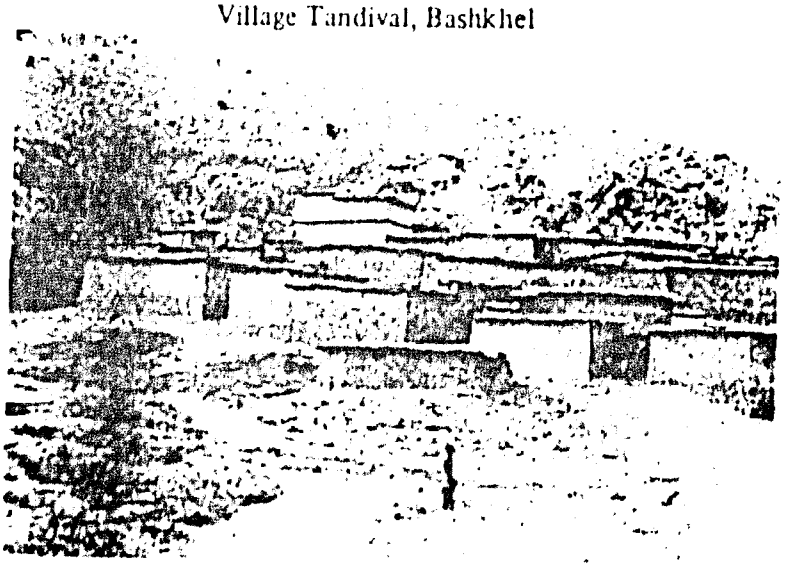


FIG. 41
Village Near Madyan, Swat

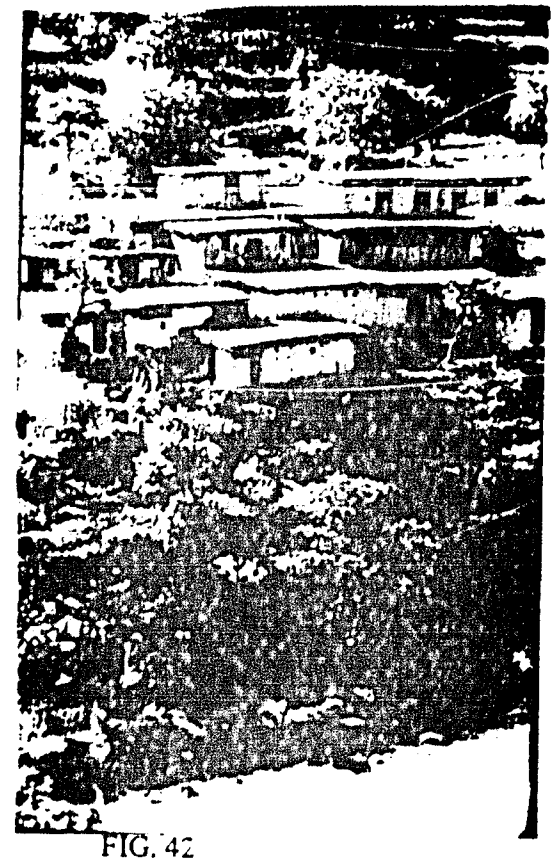


FIG. 42
House Near Kalam

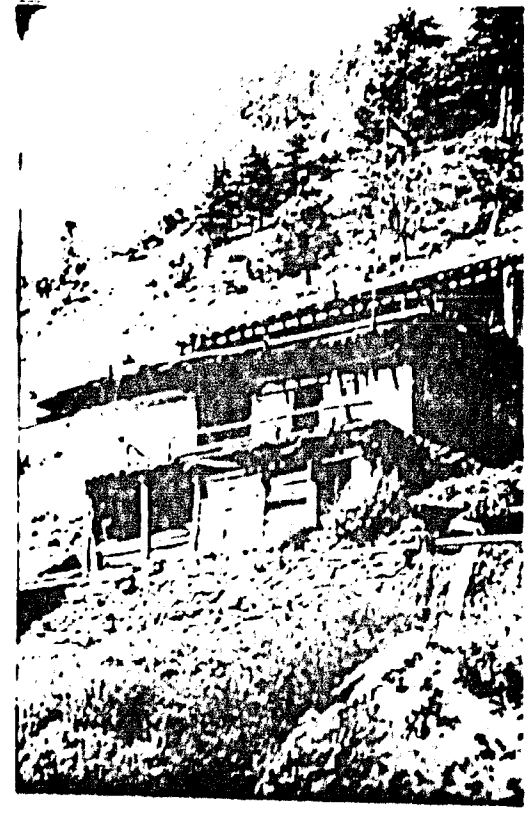


FIG. 43
Mosque, Kalam

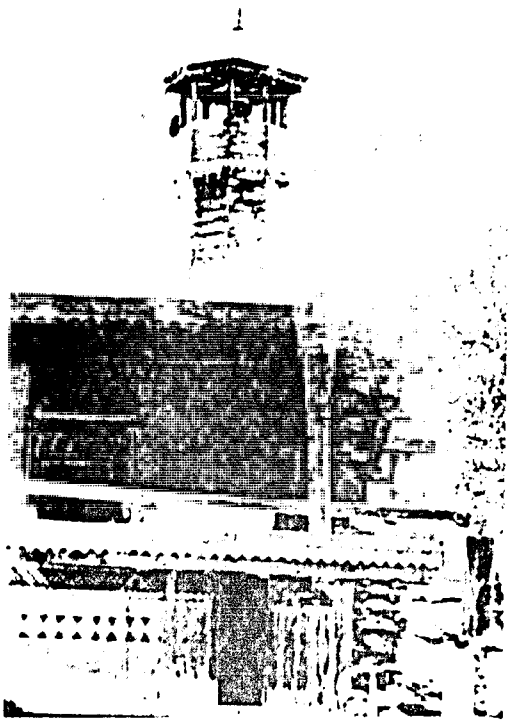
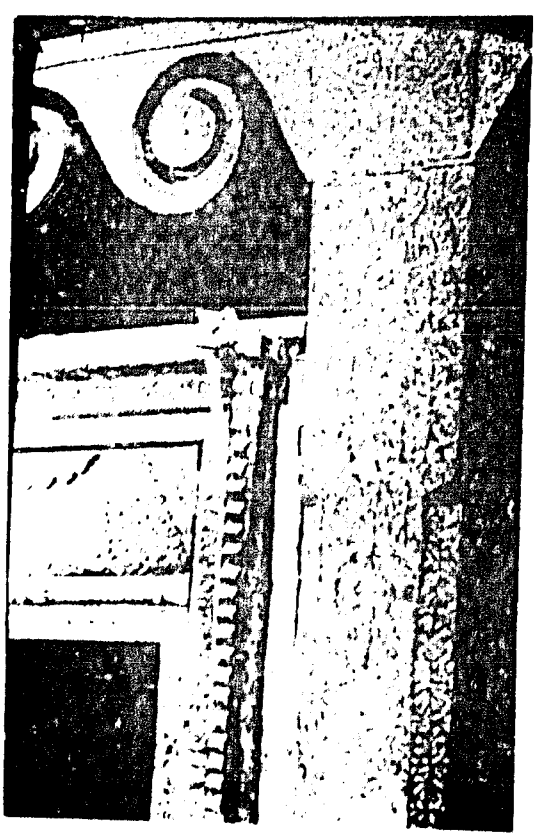


FIG. 43a
Mosque, Kalam



the slopes are covered with dense pine forests. Timber naturally forms an essential part of the building traditions of these valleys.

Decorative timber carving artistry in the handling of structural elements and attention to sophisticated compositions and careful proportioning of every detail, such refinements are usually reserved for the exquisite mosques of this region.(Fig.43)

The domestic architecture is much simpler and more functional. The external walls are usually thick, rough masonary, often reinforced by crudely hewn timber sections, or given a coat of mud plaster. The roofs are invariably flat and made up of a heavy layer of compacted earth on timber boards and joists.

The ancient technique of brick domes is known but reserved for mosques or tombs, and seldom used for ordinary dwellings. (Figs.44,45).

Even fairly isolated communities are not immune to new ideas. Deep inside the Cholistan desert the traditional Gopa, round house plan with conical thatched roof, is giving way to the rectangular plan form imported from the adjacent 'developed' areas of the Punjab. A similar process of transformation can be seen in the roof construction (Fig.46): from conical thatch to double pitched thatch and to flat roofs employing sawn timber or steel beams imported from the town.(Figs.47,48). These trans-

FIG. 44
Mosque, Dingarh

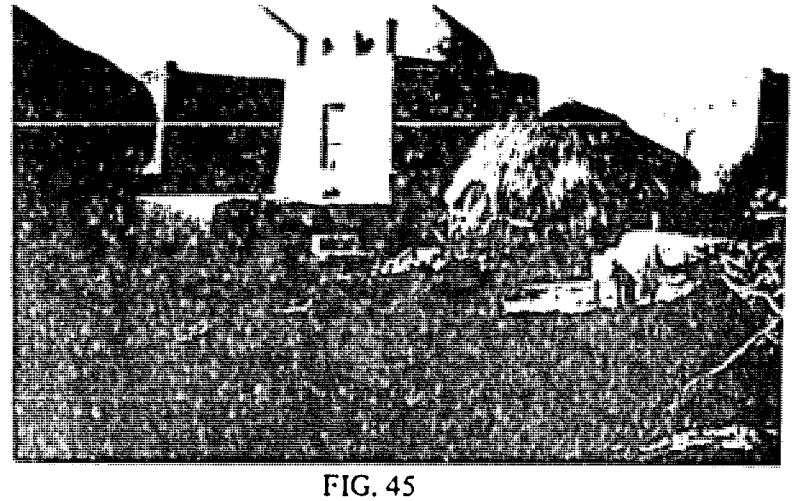


FIG. 45
Tomb, Baluchistan

FIG. 46
Dingarh, Cholistan

formations take place "spontaneously" through the agency of travelling master craftsmen (mistrees).

The population of the desert region of Bahawalpur is nomadic moving with their herds of camels, sheep, goats and cows, from one water hole, "Toba", to the next. When these dry up they move to the semi-permanent settlements around the wells, or in extreme drought to the permanent settlements at the edge of the desert.

At the "tobas" living is in the open, requiring no permanent structures.

Occasionally a toba, and more often some wells have a "Gopa" shelter or two. The traditional gopa has a low circular mud wall with a gap for the entrance, and a domical thatched roof. The group of gopas at Nawankot, include a "siamese twin" gopa roof on a rectangular room, representing a stage of evolution towards the flat roofed rectangular form.

The gradual assimilation and adoption of new ideas and techniques by indiginous builders and craftsmen is one of the ways in which traditional forms of rural architecture are being transformed. Another phenomenon is the introduction of designs, building methods and materialswhich are developed "at a distance" Figs.49,50,51). One of the most bizarre illustration of this phenomenon are the buildings constructed by the Sheikh of Abu-Dhabi in the desert near Rahimyarkhan. These [illegible] rude neat rows

FIG. 47
Gopa House, Nawankot

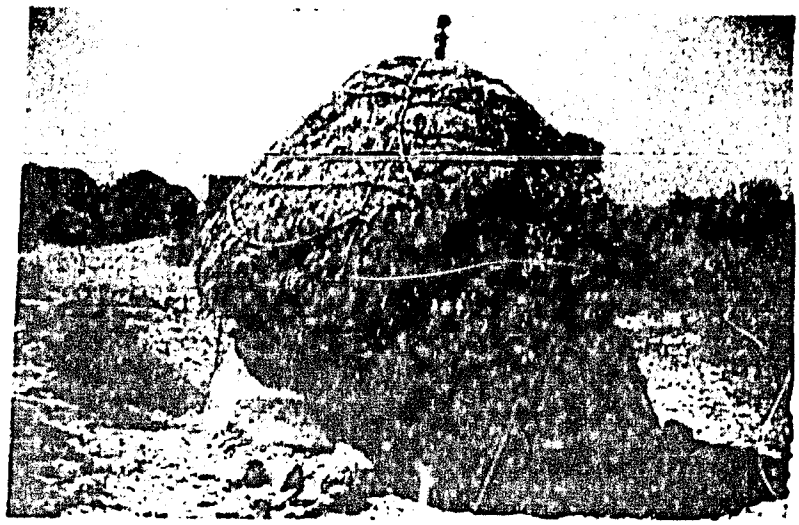


FIG. 48
Gopa Houses, Nawankot

FIG. 49
Abu Dhabi Quarters, Bhai Khan Wala Toba

of brick and concrete barracks with the inevitable "modern" mosque, located at staging points along the hunting routes.

What will be the impact of wholesale transplants of 'modern' architecture in the cultural context of under-development remains to be seen. Will traditional societies "buy" improved methods of mud building or will they be sooner "sold" on the symbols of modernity represented by reinforced concrete and steel. Are "we" any more justified in insisting on the glories of mud in the context of poverty than "they" are in aspiring to the trappings and frills associated with a context of wealth.

FIG. 50
Mosque, Bhai Khan Wala Toba

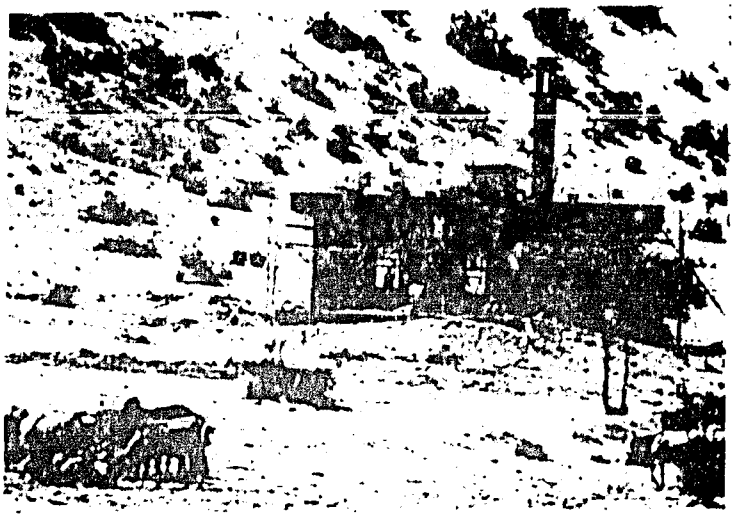
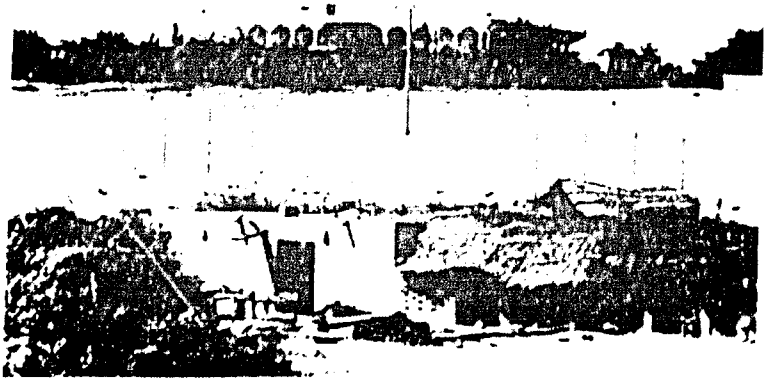


FIG. 51
Abu Dhabi Palace, Rahimyar Khan



SOCIAL AND CULTURAL ASPECTS OF AN EARTHQUAKE RESISTANT ADOBE HOUSING PROGRAM

DAVID OAKLEY

VICE PRESIDENT PADCO INC WASHINGTON DC

ABSTRACT: Failure to consider social and cultural aspects of reconstruction housing can create obstacles to the introduction of earthquake resistant adobe. The interweave of three themes is explored: that of built fabric, that of activity and environment and that of society and culture. Changes in the forms of dwellings may be more than some communities can absorb after disaster. Program and design preparedness makes acceptance easier for helpers and the helped.

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A ORIENTATION

This paper focuses on the social and residential needs of earthquake victims over the long term. These will structure the physical design of earthquake resistant adobe housing to the same degree as the aftermath of the disaster itself.

A disaster is an interruption in the normal pattern of habitat that defines a location, a community and its dwellings. Recovery and reconstruction will inevitably contain elements of upgrading and in part be new. But continuity is also important to the sense of community identification that families in new dwellings and perhaps on new sites desire so badly. If continuity is to be offered, then those who assist in reconstruction programs need an awareness of what has constituted the traditional habitat. The design attitude is preferably that of 'designing with' rather than 'designing for'.

B ISSUES IN ADOBE RECONSTRUCTION PROGRAMS

1. Influences in Habitat and Building Form.

It is useful to relate design criteria to three themes, all of which contribute to building form:

(A) Building fabric. Building materials, building structure and stability in the face of the earthquake hazard.

(B) Activity and environment. Geography and place, climate, tenure activity i.e. domestic life in and around the dwelling and in community, services and utilities, water sanitation, cooking and lighting.

(C) Society and culture. Psychology, including attitudes to the earthquake risk, family roles, social order and community life, beliefs, signs and symbols.

There is a tendency in long-established, slow developing societies for these themes to form an interweave. House form and settlement patterns become expressive of a cultural unity and a whole way of life. The building process and its customary ways form an integral part of this pattern.

2. Changes in the Pattern of Built Habitat

The foregoing is of direct relevance to earthquake resistant adobe project preparation after disaster. The introduction of change into any part of a long-held pattern has reverberations throughout the whole. These will be experienced by most people as being unsettling, however "good" or "bad" external observers may view matters.

A disaster disturbs a long-held pattern. The possibility of a new site to live on with new neighbors is a further disturbance. New materials that lead to new forms is a further disturbance. New conceptual knowledge that makes disaster-avoiding layouts possible and disaster resistant structures possible, offer further disturbances to long-held building practices. Unless all this change is strongly held in a comprehensible program and victims are led into its acceptance, chaos is seen to replace their former patterns. Program planners need to work with community leaders in order to ensure the permanent solutions are relevant in every sense.

To lead change, it has to be understood. We have some understanding of change yet not enough. Change can exhibit a number of characteristic forms - all demand a specific response:

(a) Sudden (i.e. the earthquake disaster).

(b) Fits and starts (i.e. floods, hurricans, boom and slump economics, onset of monsoon rains).

(c) Evolution(of institutions, forms, ideas, techniques).

(d) Diffusion of ideas, techniques, etc., leading to charges of perception with reference to the long-established pattern (i.e. perception that hazards can be mitigated).

(e) Spread of urban life; can be seen as a special case of (d)

(f) Original ideas.

A reconstruction housing project is likely to encompass many of these kinds of change. Unless people affected by disaster participate in the project formulation and are kept informed of administrative progress, particularly in the early stages, reactions are likely to group around the hostile end of the spectrum and be expressive of resistance, and reluctant acceptance; rather than be welcoming and accepting.

C. FORMATIVE ISSUES IN EARTHQUAKE RESISTANT ADOBE HOUSE DESIGN

1. Building Fabric

a, The Local Building Process

The building process is among the many processes that are formative to housing and shelter. The same recognizable elements are always found whatever the different form they take in different contexts.

- Initiation - someone sets in motion the notion of meeting the need.

* A design is a selected or a design specially commissioned.

* Preparation is made for construction - funds are organised, orders are placed, specifications are prepared.

* The construction sequence is organized.

* The building work is executed.

A little to one side of this process but integral to its success are the building material manufacturers and suppliers. These may be family or friends: or commercial.

The patterning that the building process takes is dependent upon the character of the developmental environment and the post-disaster situation. Characteristic differences can generally be recognised between practises in central urban areas, in middle income residential suburbs, in urbanizing rural regions, in squatter and freestyle housing settlements and in rural regions.

This underlines the importance in earthquake adobe project preparation of seeing post-disaster housing as:

* The meeting point of numerous processes.
  -building as an activity.
  -administrative.
  -financial, etc.

* As a built product
  -having an economic life
  -having a need for maintenance
  -adaptable to change and expansion

* As a tangible realization of a house image.
  -of what is long known
  -of the newness tht is now aspired to i.e. resistant to earthquakes

* As the modifier of human experience.
  -a base for family life
  -in the "wrong" place
  -just what is wanted and in the right place.

Even after the earthquake, when the emphasis on meeting fundamental human needs seems so obviously dominant. A house that is provided on sites far from employment, containing socially unacceptable materials and which fails to meet in plan some cultural requirement, may well be rejected.

b. Material Use

Building materials including adobe in most developing countries have been developed for use in everyday conditions. Only in a few countries have earthquakes been bath widespread and frequent enough (e.g. Turkey and Peru) to influence material selection and manner of use.

c. Structural Stability

This in most countries has been determined in relation to everyday use assuming dead loads of materials and live loads of people, furniture and weather factors such as rain, snow and sustained wing. It is essential in disaster prone areas that an understanding develop of the forces that lead to disasters, the reasons building fail and how economically they can be redesigned. This understanding is required of administrators, professionals and of the community at large. In each case this understanding will take a distinctive form in terms of detail and emphasis.

d. Permancy

Permancy can be related to the normal condition or to the withstanding the typical earthquake. Permancy of rural and middle income urban housing in most L.D.C.'s has usually been related to the normal everyday condition. This had led to a pattern of building forms and structural systems in many countries that are ill-suited to resist disaster forces. Changing these forms without social consultation may be perceived as an act of aggression.

e. Degree of Earthquake Risk

The adobe project preparation team will need to determine the nature of the disaster risk run in the selected development site and the extent to which material use, structural system, the notion of permancy and construction techniques can be changed (and afforded) to achieve a new specification of performance in face of earthquake, cyclone and flood. Appraisal of such risks is a task for technical expertise.

f. Conceptualized Knowledge of How Buildings May Be Made Resistant

This knowledge is still evolving worldwide. It is yet to be fully effective in relation to low income family housing that is owner-organized and which uses traditional forms of adobe construction.

Disaster resistant knowledge has evolved:

* From analogy, based on an examination of what types of adobe dwellings fail and why.

* From the application of structural design theory originally developed to obtain resistance to disaster forces in industrialized countries where the materials used and construction relate to different technical standards, construction and supervisory capabilities.

Joining these forms of knowledge to that of the customary building processes of the disaster-hit community had its difficulties. The local processes have evolved under different circumstances and are often held intuitively by craftsmen, in a sequential, mythical way. This way of knowing is severely disturbed by the attempt to intrude knowledge that is different in kind. Recognition of this difficulty is important to the successful construction management of contractor-built elements of a site

development project. It is highly significant to the success of the owner-managed stage of house completion of extension.

g. Continuity and Change in Construction Practices

A theme in adobe project preparation and design will be the focus upon providing initially what disaster victim households could not provide, or very readily provide, for themselves. In relation to dwellings, this usually means land, water supply, sanitation and the technical supervision of a earthquake-resistant, structurally-sound core or shell. Information-spreading and educational programs for key craftsmen and owners will be required as a component of any self-help program for the completion of adobe core houses if they are not to be structurally weakened by additions made later.

h. Completion and Extension Through Time

Because of the complexity, administrative and technical costs of trying to manage and inspect the self-help completion of core houses, it is probably best not attempted. Alternative routes of achieving the same end should be explored. These will include consideration of the establishment of a technical advice center on the development site, linked to a materials distribution point if possible; the use of roving building completion demonstrators; the use of models of completed houses (sometimes a failure in the past because of lack of local social/cultural knowledge by their designers); and use of training programs.

i. Innovations

The desire by project programmers to achieve rapid occupancy by victims has led in the past to consideration of innovative technical solutions. Experience shows that innovation in project administration, layout and phasing of occupancy of the site can contribute more to early settlement than attempts to innovate in construction. On the technical side, the introduction of earthquake resistant knowledge into traditional and conventional building processes is innovation enough.

2. Environment and Activity

a Climate

Climate is of interest ot the adobe house designer at four levels:

* Regional - the annual pattern plus the hazard region of rains and floods plus the expentancy of recurrent cyclonic storms.

* Local - the intetaction of physical setting, land forms and settlement with climate.

* The climate close to the ground buildings (i.e. induced breezes, shading through trees).

* Climate within buildings - influence of roof and wall thickness, position of openings, etc. on human comfort conditions.

The more the designer can exploit knowledge of the first two to modify the third so the more one can finally reduce the design effort and costs.

b. Place

Place of site location is of interest to the adobe house designer at four levels also:

* Regional - located on a gentle slope, in a flood plain, at the foot of mountains, near the sea. Every location will say something about safety relative to other regions in the face of rains, floods and earthquakes and land slides.

* Local - the density, spatial and visual pattern that existing buildings make will influence people's expectations of what new building work should be like.

* Ground conditions, faults soil bearing capacity, site drainage will influence use of the site.

* The layout and building placed on the site will change it from what it was before either positively extending its previous qualities of undermining them (i.e. either more or less pleasant to be on, more less safe from the point of view of the earthquake hazard, than previously).

The more the designer can exploit knowledge of the first three, in order to act sensitively in the fourth, the more effective and more economical the result.

c. Activity

Residential activity, together with the activities that is supports and support it, is of interest to the housing designer at four levels:

* Beyond the neighbourhood of development site (i.e. work, marketing, cultural sites, transport).

* Within the neighbourhood of development site (i.e. work, marketing, transport, water sanitation.)

* Between households in localized areas. groupings of lots and buildings, use of local communal open space.

* Within households of lots, clustering of buildings on lot, use of outdoor space, methods of cooking, place for sleeping, journeys for and storage of water, sanitation and culture.

Site development planning poses the incorporation of these factors into a total design in the context of climate and environment. While these are all

prime factors, local political, legal and administrative mores and standards will have a secondary but still significant influence on design decisions.

3. Social and Cultural

Activities can be seen and even measured, but the social and cultural environment, taken as a whole provides the designer with an atmosphere more difficult to appraise than that of the physical atmosphere. The reasons why people behave the way they do, react to disaster the way they do will be deep in the corporate mind of a people. This shared attitude, which is likely to underpin many personal and family variants, will also mold a people's view of change.

From the interaction of long-made appraisal of region, available materials, social patterns and beliefs have sprung such manifestations as:

* The grouping or clustering of rooms around a yard to form a home
* Single isolated dwellings widely spread.
* Row houses alongside narrow paths up mountainsides.

These patterns also reflect long held systems of land tenure and tenancy. Appraisal of such formative influences leads one to expect that house forms and dispositions are signs and symbols as well as artifacts. Appreciation of this assists in understanding the reluctance of disaster victims to accept new forms unless they were moving towards their acceptance prior to disaster; as is sometimes the case with rural people newly settled in peri-urban areas.

D. REGIONAL CHARACTERISTICS

Regional "building character is recognizable. It stems from building processes, settlement patterns and social and cultural mores interacting in a similar way throughout one large living space. It will change in parts of a region or throughout a region as change is embraced in any of the region's formative forces.

Traditional buildings and layouts of certain regions exhibit recognizable forms which offer clues to satisfactory solutions for day-to-day living. They may mislead as to their relevance to disaster situations, however. Where the period of recurrence of earthquakes is long, then its threat may not be seen as something to build against. It may even be categorized as "the will of the Gods". Regional traditional design may therefore not be suited to disaster resistance without changes in disposition of dwellings one to another or in structural design and architectural detailing.

E SOURCES OF INFORMATION: LOCAL HOUSING PRACTICES

The normal habitat and settlement patterns of most of the people is not a much studied subject in any country. The designer's need is not for prime sources but for secondary and for distilled knowledge. Most countries have one or two academics or professionals who have privately assembled data, drawings and sketches of traditional buildings and/or methods of strengthening them or developing a new design approach in the face of newly perceived regional needs. Such rare individuals can be tracked down through telephone calls to University Department of Architecture, Social Studies, Geography and to national professional institutes of architects or engineers.

Government executive departments in rural development may offer useful contants or leads to the name of a particular field officer with an understanding beyond the confines of his daily job. Government departments of housing and urban development ought to be able to offer leads, although the education of their administrative officers and technical staff overseas (or under the influence of overseas programs) has frequently cut such people off from the local formative roots of the building process.

Acknowledgements. Some of the ideas presented in this paper stem from a study undertaken under and USAID contract. The author is grateful fo the comments of Fred Cuny and Paul Thompson.

THE CULTURAL CONTEXT OF EARTHEN HOUSING IN SEISMIC AREAS

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ABSTRACT

When cultural mapping is related to the distribution patterns of seismic risk, soils and earth building, correspondences are revealed which have important bearing on housing, or housing modification programmes. Acceptability of innovations may be facilitated by understanding of the cultural contexts, the sources of communication failure, the necessity for user participation in design and construction and the processes of culture change.

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In February this year I was staying in a favoured part of Berkeley on the well-timbered slopes above the University. While there I took the opportunity to question a number of my acquaintances, architects, professors and retired professionals as to their attitudes to the risk of a major earthquake recurring in the area. Jokey responses, even a curious kind of glee at residing close to, or virtually on the fault lines greeted every enquiry. It was pointed out to me with a wry irony that most Berkeley schools had been sited on flat ground which masked dangerous faults. An expatriate Englishman, long resident in California, shrugged his shoulders and said "If your number's on it...", using the fatalistic phrase employed during the war by Londoners threatened by the silent menace of the V2's.

Not an unfamiliar attitude to those living in California no doubt. But I could not help but wonder how these sophisticated, highly intelligent, by Third World standards fabulously wealthy architects and educationalists with whom I shared so much culturally, could so readily screen the scale of the danger from their conscious thoughts. After the bitter cold of Wisconsin which I had just left, and living in the lush, sun-soaked environment of the Bay area I found myself rapidly slipping into the same frame of mind; if I'd stayed longer I would have soon joined them in their disregard of the earthquake risk.

That there is some anxiety in California is not in question, but the fact that it has taken so long for any serious action to be taken is indicative of the many forces at work in shaping attitudes and policies. In Berkeley there are some eleven thousand brick buildings which constitute a serious hazard; to reinforce them or to replace them would cost the Bay area a billion dollars; in Los Angeles the number is some nine thousand, the figure currently quoted for making them safe is in the region of three quarters of a billion - staggering sums to reduce the danger of collapsing buildings. According to a Seismologist at the University of Berkeley there is a high probability within the next decade of a major earthquake of 1906 proportions, but the Geological Survey in Washington disagrees - not in fifty years, the Chief Seismologist argues. (1) So time passes, though the fact that rebuilding and reinforcing might create jobs for building contractors and engineers may eventually provide the clinching argument for them to go ahead.

In the Bay area the cultural context is exceptional: the costs implied are high, but in scale with one of the richest regions in the world. What of the poorer countries where earthquake risks are as great and buildings as vulnerable? When even wealthy, literate, capitalist California cannot face the reality of earthquake hazard, is there any ground for surprise that in other cultures, with different values, marginal economies, rural populations and earth houses, perceptions of risk and measures to combat it are rare? Perceptions and anticipations of hazard and the measures that could be taken to minimise dangers, are intimately bound up with cultural factors that colour attitudes. To consider the problem of earthen housing in seismic areas solely as a technical one is to disregard those aspects of culture and society which may, or may not make acceptable any measures to alter building forms or modify existing types to render them safer.

Such cultural factors operate at many levels; if simple technical guidelines might be drawn up for all builders of earthen structures, no such

general guide-lines can be drafted that can apply to all cultures. The inter-play of hierarchies, beliefs, kinship patterns, economy, customs and mores is extremely complex and special to each culture, so that the dangers of oversimplification are considerable. Yet some measure of generalisation can be made with regard to the distribution of certain traits which may assist in the understanding of the cultural implications of building. Any discussion of the cultural context of earthen building in regions of high seismic risk must obviously demand that the regions of seismic risk, the distribution of soils suitable for adobe or earthen building, and the pattern of such building are identified.

Seismic regions of the land mass (which are the only ones to have serious cultural implications), are normally identified in terms of earth structure and fault lines. But a simplified map which considers their location in delimiting lines of longtitude and latitude enables cultural factors in those areas to be discussed on a comparative basis, FIG 1.

A swathe drawn across the northern hemisphere between latitude 20 N and 40 N encompasses a large proportion of the affected regions. However, the highest concentrations of earthquake activity in Central and South America occur in the Equatorial belt 0° - 20°N and earthquake regions of the Phillipines, Malaysia and Melanesia fall within the 0° - 20°S belt. Longtitudinal extensions of these swathes between 60°W and 80°W, and between 90°E and 120°E together contain a substantial proportion of the remaining areas at risk. Extensions in the northern hemisphere complete a configuration which, for the purposes of this paper I will refer to as the Quake Belts to distinguish them from any more scientifically defined seismic zones.

An important geo-physical factor related to earthen building is, of course, the nature of the soils, FIG 2. The lateritic and ferralitic red earths are among the most suitable for mass walling. They occur extensively through Sub-Saharan Africa, being the predominate types in most regions west of the Rift Valley - but these are not seismic areas. They also occur in South America, though again in areas of less seismic activity, and in South-East Asia. The fertile Podzolic soils of North America, Europe and Russia also provide useful building material though their fertility produces timber which is extensively used in these regions. The Quake Belts are largely comprised of mountain soils, which in the valleys are suitable for building but which are frequently combined with stone or rock; and a wide band of desert soils spreading across North Africa and the Middle East. Desertic soils in arid regions are often ideal for building and are fertile when water for irrigation is in sufficient supply. But others are sandy and less suitable both for construction and for agriculture.

When soils are compared with other environmental factors such as climatic regions and vegetation - a number of correspondences may be seen, FIG 3. North Africa and the Middle East are hot and arid with no forest growths; desert regions are also found in areas of low rainfall and generally dry conditions in the South-West United States and Mexico, and along the western seaboard of South America. On the other hand, the tropical rain forests with year-round high temperatures in Central America, much of the Indian Sub-continent and throughout South-East Asia and Malaysia correspond closely to the distribution of red tropical soils. This helps to explain one of the apparent anomalies of the distribution

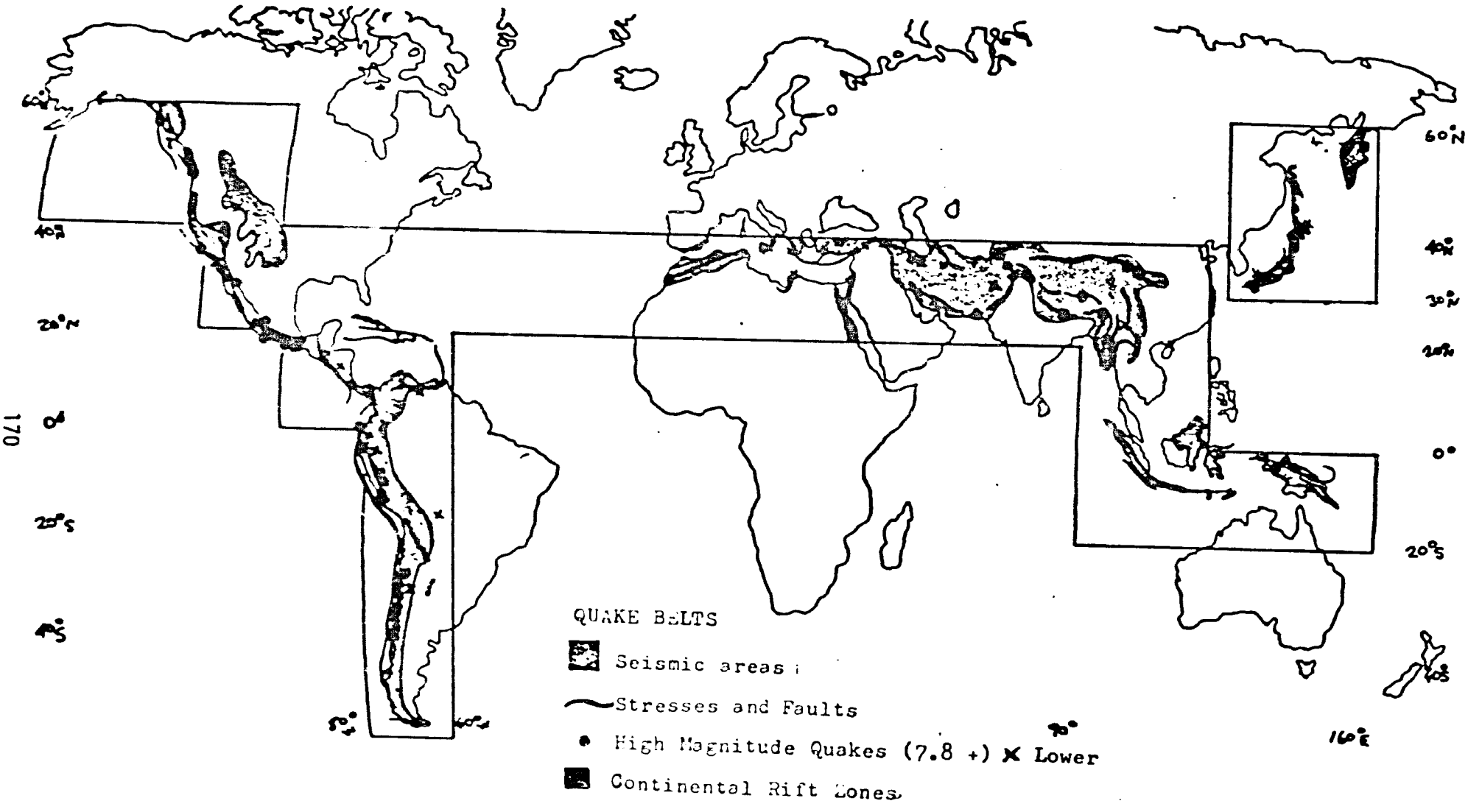


FIG 1

Map of Earthquake Belts

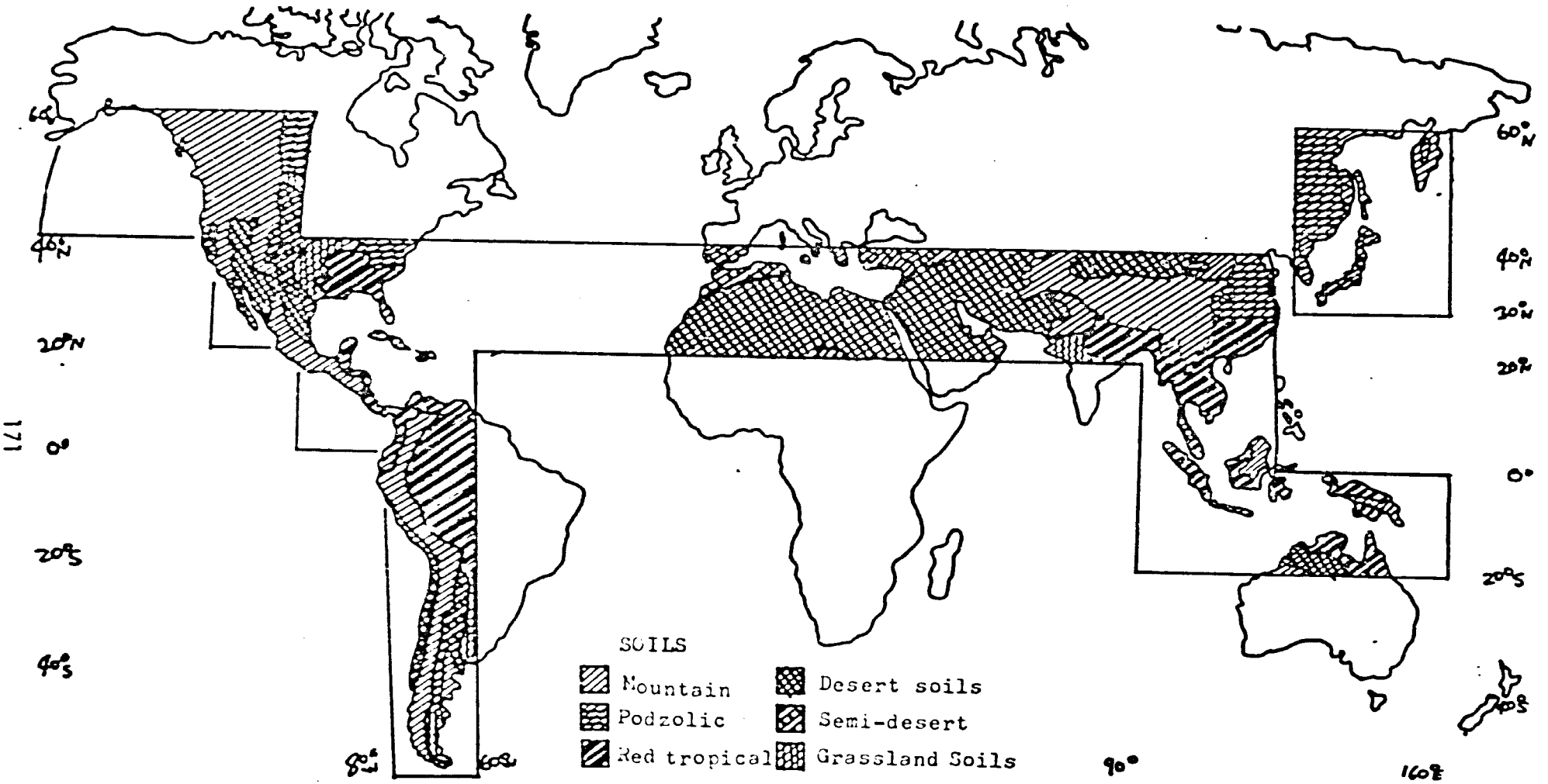


FIG 2

Map of Soils in Quake Belts

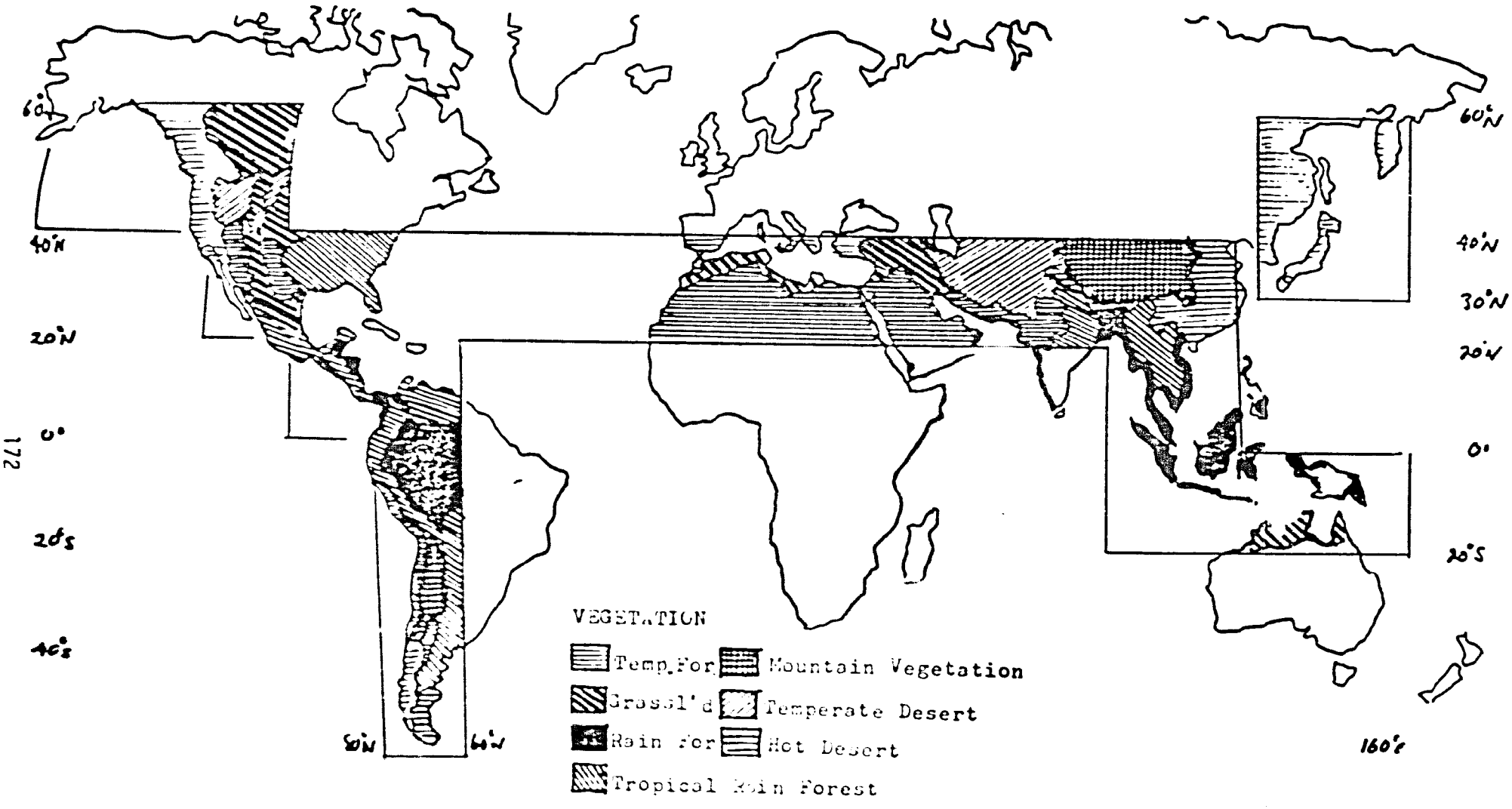


FIG 3

Map of Vegetation and Climate

of earthen construction in the Quake Belts: in spite of the suitability of the red soils to earth building their coincidence with areas of high temperature, high rainfall and high humidity demands that in much of South America and throughout South-East Asia, light frame constructions, and screen or lattice walls which permit the passage of air but retain privacy, are extensively used. In some tropical areas which also have readily available saplings and leaves for building materials - Yucatan for instance - frame structures are used with added clays to produce combined wood and mud constructions.

Though this conference is concerned with "earthen housing" in seismic areas, precise definition of the term remains elusive. Presumably however "earthen" includes all buildings made of unfired clays, and as such embraces those constructed of sun-dried brick, adobe, rammed earth, West African "swish", clay lump, Pisé de Terre and Devon cob. How much earth or clay must be present for a building to be "earthen"? Does the term include those that are constructed of both stone and clay, or made of stone bonded with clay? Does it include those that are timber constructed but earth covered? And are the wattle-and-daub, pole-and-daub, stick-frame and mud-packed dwellings of Central America or Malaysia "earthen"? To compound the difficulties, in some areas of the world, two, three or even more of these construction systems exist side by side, even following the same morphology.

These problems are exposed when one attempts to compile a map of earthen building, Fig 4. In tentatively offering such a sketch map I am acutely aware of the lack of detailed or even generalised information, as well as of the problems of definition outlined above. Here I have indicated only those areas where adobe, rammed earth or clay are used as load-bearing material. Sometimes in association with stone. Timber is generally employed in the roof structures but in many parts of the Middle East where there is little wood, barrel vaults or domes have been used. Some buildings are single cells, round or rectangular in plan but in other areas, Morocco , for example, multi-storeyed buildings are constructed. More refined maps would show these distinctions and might identify the diversity of house types within a comparatively small area. It would be one useful outcome of the Conference workshops if a more refined map could be produced.

From one point of view perhaps, the relationship of building types to materials and climate accounts for their diversity. Yet housing is a cultural expression, not a geo-physical or environmental fact; it is a response to them articulated through the forms appropriate to the values of a specific culture. But what is culture? Tylor's 1874 definition of "that complex whole which includes knowledge, belief, art, morals, law, custom, and any capabilities and habits acquired by man as a member of society" is still valid (2). Julian Steward believed that there would be no great disagreement with the bare statement "that culture consists of learned modes of behaviour that are socially transmitted from one generation to the next and from one society or individual to another"(3). The singularity of each culture within the universality of culture in mankind was one of the paradoxes which Melville Herskovits summarised: "Culture is universal in man's experience yet each local or regional manifestation of it is unique. Culture is stable, yet it is also dynamic, and manifests continuous and constant change, culture fills and largely determines the course of our lives, yet rarely intrudes into conscious

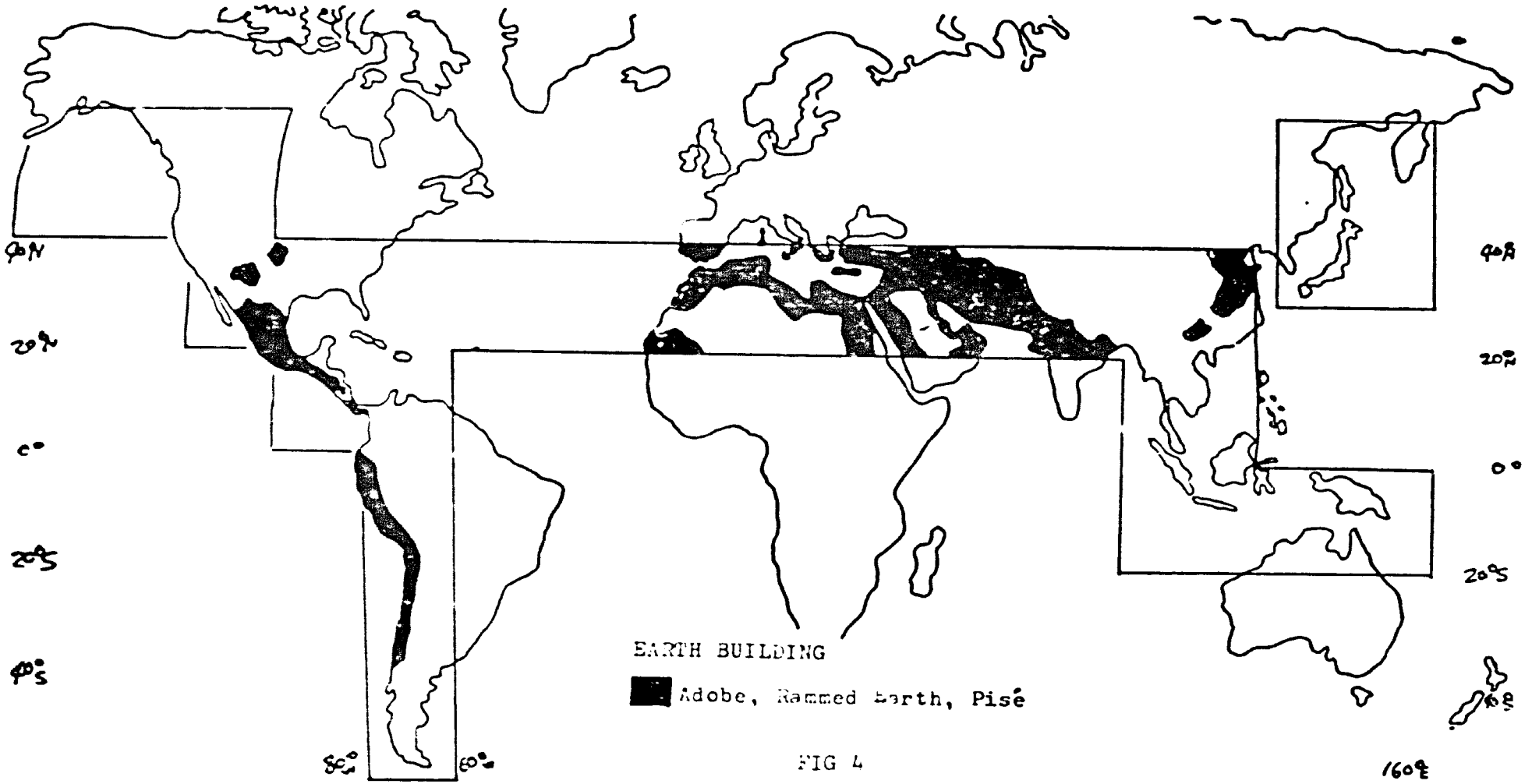


FIG 4

Earthen Building in Seismic Areas

thought" (4).

The sheer diversity of peoples and the complex of cultures even within a single "nation" has led many anthropologists to attempt larger classifications or groupings that may assist in identifying comparable cultural characteristics or traits. One such trait is language. Though population shifts have occurred in relatively recent historical times, broad linguistic groupings can be identified, FIG 5. Language and culture are not one and the same, as the widespread use of Spanish, French or English among indigenous peoples in various parts of the world indicates; nevertheless, the current uses of language give some important clues to cultural identification. So we find that the linguistic map overlaid on the Quake Belts reveals a widespread distribution of Arabic and Berber-Arabic speaking peoples in the central band which abutts the Iranian cluster that includes Armenian, Kurdish, Pushtu and Baluch. Indo-Aryan speaking peoples, Southern Mongoloids, Malaysians and Melanesians form other major linguistic groups in Asia. In the Americas, Spanish predominates in much of the Quake Belts where, among indigenous peoples, Indian dialects among them, Mayan and Quechua are still spoken. While indicating admixtures and extensive cultural exchanges these linguistic clusters still reveal cultural groups that are broadly identifiable and largely homogeneous.

In selecting papers presented in either English or Spanish the cultural bias of the present conference is immediately revealed. A glance at the linguistic map shows that Arabic, Iran-Armenian or Chinese each have equal claim as the lingua franca for such a conference. English may be spoken in most of those countries by the educated elites but this is less than satisfactory when it comes to the implementation of modification proposals at village level, while parallel maps of literacy rates or education opportunities among the total populace of nations would only reinforce the impression of cultural bias, or as some would see it, "cultural colonialism".

Language is an important index not only of culture but of culture change. Its transmission as a result of conquest or influence is comparable to that of religion, FIG 6. Here too, a marked separation of the prevalent faiths likely to be represented in this conference - Christian Protestant, Roman Catholic or Jewish - is widely at variance with those of the remaining earthquake belts. A substantial part of the populations of the Quake Belts are of the Islamic faith. All of North Africa, virtually all of the Middle East and Malaysia are Muslim while much of the Indian subcontinent has a substantial Muslim minority. Buddhism and Hinduism account for much of the remaining major religions in the belts, while there are pockets of animism in each of the continents.

Language and religion are cultural traits which need have no physical tangible manifestation. As an example of the relationship between culture and the environment agriculture is a significant indicator, FIG 7. Here we find that across a considerable expanse of the dry land regions nomadic herdsmen utilize the thin pastures. The irrigated dry land areas sustain subsistence agriculture and in the regions where Oriental rice farming prevails are to be found largely rural populations with peasant economies. The landholdings of large ranch owners do not necessarily imply high standards of living and income for those engaged in cattle or sheep ranching in the Americas. Again however, a clear cultural distinct-

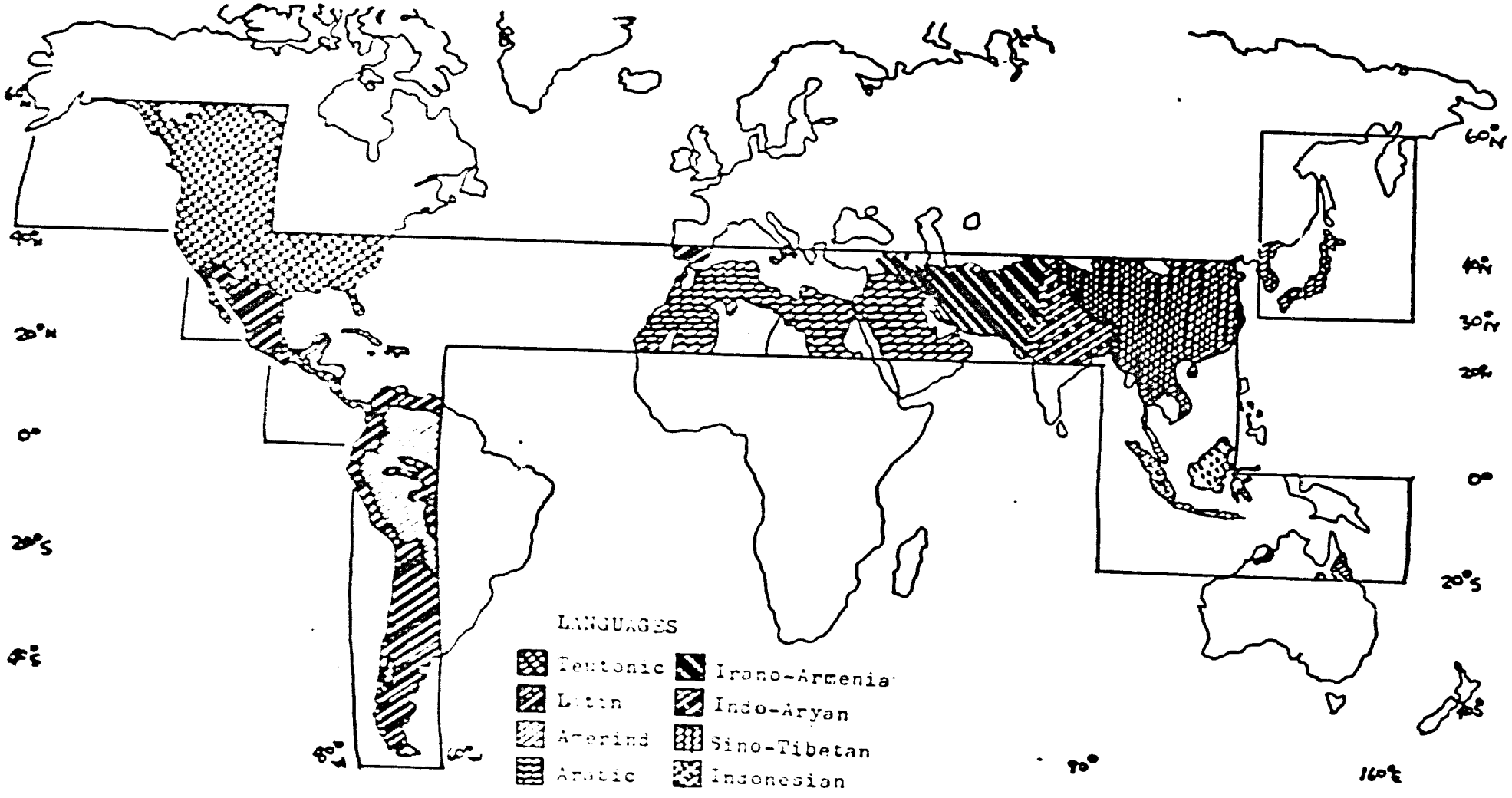


FIG 5

Principal Linguistic Groups

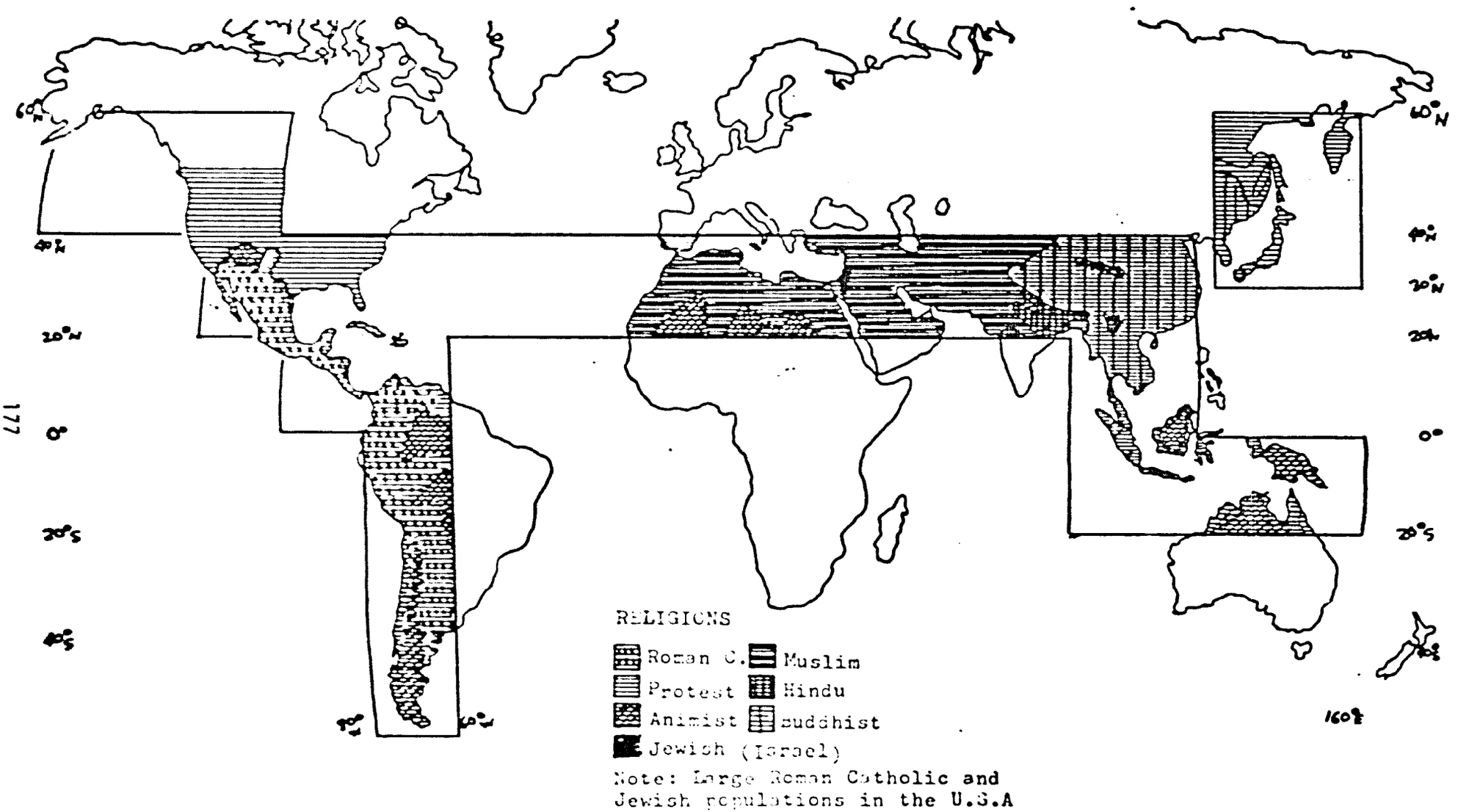


FIG 6

Distribution of Major Religions

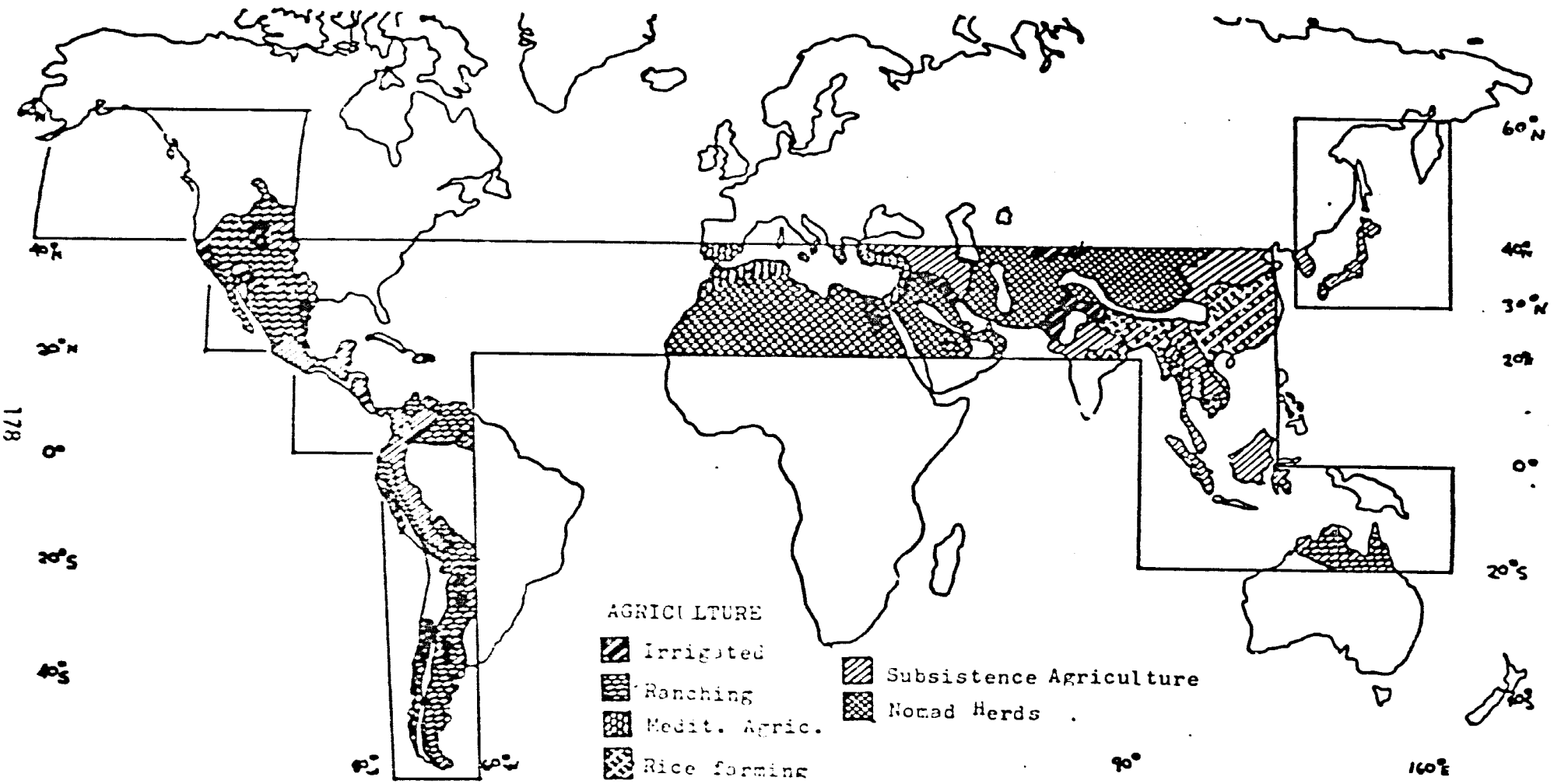


FIG 7
Agriculture within the Quake Belts

ion between the western hemisphere and the east is evident, the latter being further subdivided by different forms of native subsistence farming.

A score of cultural traits could be mapped at this generalised level to give a clearer profile of the cultural complexes that may be found within the Quake Belts. Political institutions, types of trade, forms of social organization, class structures, land tenure, technologies, ceremonials and so on could be mapped, their relationships giving a fuller understanding of the complexes of culture traits which may be found in a region. From such a profile deductions could be made on their bearing upon attitudes to disaster and disaster relief, housing modifications, new forms of housing, the acquisition of skills etc. Though this is, in my view, an essential undertaking, space and time does not permit further examples now. Can anything be gleaned from the two or three which we have seen?

Perhaps this can be best viewed from the position of a North American architect or engineer, a Seismic Area Building expert, who has proposals for change in housing earthen building methods. Linguistically, this SABE will find himself unable to share verbal communication with the people most affected, but only with the educated and the town-bred. If our SABE is Spanish speaking he will have the advantage of direct communication through the Quake Belts of the Americas, but even here the limitations of language comprehension both for the understanding of abstract ideas and technological innovations may present linguistic problems.

A SABE is unlikely to share the same religious beliefs as the people that he addresses. The major religions as observed in the Quake Belts are largely determinist. Followers of the orthodox doctrine of the Muslim theologian Al-Ashkevi "that all that has been and all that will be was decreed in eternity and written on the preserved tablet" have their Christian counterpart: St. Thomas Aquinas's Augustinian pronouncement that "it is manifest that whatever is of price is the effect of predestination", still has innumerable adherents among Roman Catholics. For the poor and illiterate peasant the esoteric arguments concerning free will, responsibility and predestination are remote; he is more likely to content himself with a fatalistic "As Allah wills" or "God moves in mysterious ways...." As a human being he may react to a disaster with similar fear and stress as his counterpart in other, more sophisticated societies. But his resignation and belief in divine intervention or retribution, may be paralleled by a reluctance to accept measures which would seem to attempt to frustrate God's intentions. Animistic peoples would be far more inclined to propitiate the angered spirits (5,6).

Economically, rural people in the Quake Belts are largely nomadic-pastoralists or they are rural cultivators or peasants. Many nomadic peoples follow set routes for the seasonal grazing of their herds leaving their womenfolk, children and elders in permanent, usually mud-built villages. Though the problems of seismic risk may not apply to their tented settlements they are just as applicable to the more settled home bases, as they are to the peasant villages. There are several peasant ecotypes employing different cultivation methods such as swidden, fallowing or hydraulic systems. Structurally they may differ but in general peasant communities tend to be tightly knit and to comprise extended families which are linked by complex kinship ties, have ritual-

ised or ceremonial calendars which reinforce the social structure and the cycle of the working year.

Symbols which underline their belief system and express family and community ties to the value systems of the culture are important. Frequently these are associated with the lands worked by their forefathers and with their buildings, which play significant parts in the rites of passage through birth, marriage, death and burial. In general peasant society is traditional, conservative, moralistic, unquestioning and uncommitted to change and innovation. Though peasant communities are linked to the market networks they are frequently suspicious of external authority or members of alien societies. For the SABE arriving with an endorsement of his intentions from a central authority, armed with proposals for new methods of building, the resiting of houses, or proposals for new and safer "designs", the outlook is not promising.

Such observations as these I am all too well aware, are dangerously stereotypical. They are generalisations which give no indication of the variables that are to be found in the multiplicity of cultures embraced by these broad headings and summarily shaded areas. Cultural mapping is concerned with the comparability of traits at the macro-scale; its evidence may assist in heightening awareness for certain kinds of cultural attitudes and behaviour patterns, but only as a preparation for the encounters at the micro-scale. Though anthropologists have their disagreements over the traits to be identified, "cultural area" mapping, such as that undertaken by G.M.Murdock for his <u>Ethnographic Atlas</u>, could be of considerable assistance to the well-briefed SABE.

For the specific examples of cultural context and response to housing modification or building in seismic areas we should be able to turn to case studies based on recent events. During the period 1950-1975 there were over fifty major earthquakes in the quake belts, claiming around 150,000 lives and a toll of five million victims. It would not be unreasonable to expect a substantial literature on the cultural responses to the measures taken following these disasters, and the programmes for housing or house modification that were implemented. Such is not the case; the literature on the cultural contexts of disaster housing generally is woefully inadequate - to the extent that in the 200 page UNDRO report on <u>Housing in Disaster-prone Countries</u> not a single reference is made to cultural issues (7,8). On the other hand, a considerable amount of attention has been paid by many writers to the effects on victims of stress induced by disasters, whose psychological disorders and problems have been frequently discussed (9,10).

Much of the available writing on psychological impact has concentrated on disasters in the west, particularly in North America, so that the effects of hurricane Agnes, the Oregon cyclone of 1962 or tornadoes in Waco and San Angelo, or the earthquake at Anchorage Alaska etc., have been extensively documented (11). Undoubtedly this is of great value, but it <u>is</u> culture-bound. The reasons are not hard to seek: the centres of such disaster research are in the United States, access to the disaster areas is fairly simple, the language of the researchers is English, communication with the victims is more readily possible, they are culturally more inclined to accept in-depth questioning from psychologists and may even view this as a therapeutic activity in itself. Insofar as human responses at the psychological level are

similar, general conclusions may be drawn of some validity for application in other cultures. Nevertheless, human responses are also shaped by culture, and little attention appears to have been paid to the role of cultural mores in conditioning responses to stress situations.

In a previous conference paper I endeavoured to differentiate between the Relief culture, with its fragile structure, its apparent authority and command of skills, resources and money, and the Victim culture (12). The Victim culture is at its most vulnerable, is subject to disorientation and demoralisation by its failure to cope through its existing social mechanisms with the magnitude of a disaster and is forced to be dependent on a temporary but authoritarian organisation which has a clearly defined purpose to bring aid to the victims. As recovery from disaster is manifest cultural factors take over; the lack of animosity that researchers have noted in immediate post-disaster situations may be followed by resentment at the behaviour of officials, and antipathy to aid and relief organizations (13). Cultural responses have been observed in the rejection of certain foods offered during relief or in the unacceptability of types of clothing and other articles of a more culturally defined nature. Illogical in the terms of the relief culture, but nevertheless inadmissible in terms of the victim culture. Rejection behaviour may be described to psychological disturbance but may also be perceived as an expression resulting from cultural incompatability.

As the recovery period progresses cultural characteristics related to family and community structure and behaviour, to hierarchies and law, to territory and even to housing may be seen to operate. After disasters most societies wish to return to the status quo as early as possible, and express this in a desire to rebuild on the traditional, if obviously vulnerable sites. Nevertheless, the impact of the disaster, and the likewise disastrous impact (in cultural terms) of the temporary assumption of responsibility by relief organizations, leave their scars and bring about culture change at a more rapid rate. So culture is unscathed or unchanged, either by disaster or by disaster relief.

In the specific context of the present conference it is the introduction of methods of building modification, the adaptation of existing technologies and structures, propositions as to the alteration of plan types and siting of buildings and other means of making more safe the earthen building in seismic areas, that have particular cultural implications. Houses, we have noted, are the focus of a large part of man's cultural activity and carry considerable symbolic associations, both in their organization and in their form (14,15). Their importance differs in emphasis with different societies and the entire semiotic associations of one house type cannot be assumed for others; the significance of the location of an entrance may have different meanings in one culture than another; the areas of security or privacy, those assigned to women or children, to men or important visitors, to particular domestic functions, shrines and ritual observances, are of varying degrees of significance. In the face of seismic risk are such factors of any importance? Indeed they are - for the perception of a risk that may manifest itself once in a lifetime is of a low order to the users, compared with the daily, even hourly observance of cultural mores within the home.

Modifications of building techniques and technology, introductions of new methods of building to make adobe and earthen structures safe, or

safer, against seismic disturbance can be seen as essentially a part of the process of culture change. But any such innovations are representative of <u>induced</u> change rather than of indigenous change from <u>within</u> the culture. Housing innovations which are not the result of evolution, individual discovery or invention within a culture, may be seen as representative of the most common form of innovation, resulting from diffusion. However, the emphasis in <u>diffusion</u> is placed on <u>borrowing</u> rather than on the acceptance of an externally imposed, or proposed innovation. As Kroeber pointed out, "items of culture that are isolated, not much woven into a pattern, and therefore relatively neutral in their functioning, and yet of an indubitable practical value, are least likely to encounter resistances to their diffusion: matches, for instance" (16). But housing is essentially woven into the cultural pattern and far more subject to rejection.

Extended culture contact provides the most fertile ground for the borrowing of culture traits, but few SABES have the time, the money or the patience to consider it. If, as I would recommend, careful documentation of the processes of acceptance, experimentation or rejection of an innovation is carefully made, SABES must be prepared for the diffusion (and rejection) of some of their own culture traits which were not on the programme of housing modification. These too, should be monitored, as they may provide useful clues to the means for successful information transfer, and to the long term adoption of a trait.

The introduction of modifications to buildings, let alone proposals to replace an existing building type with another designed by an SABES team, should be recognized as being potentially disruptive to a culture. Once the immediate danger has passed and the perception of risk receded a culture is likely to reject such innovations even if they initially accepted them, and in defence turn to established norms of building. In many instances "rational" proposals have been made for building modification - the substitution of a lighter-weight pitched roof of tiles for a heavy, timbered and mud surfaced flat roof for example have failed for the simple reason that the flat roofs are used for other purposes - drying fruit, even sleeping on. A western observer who perceives such uses as "illogical" in the face of seismic risk does not place his scale of values on the same axis, or with the same weighting as does the community that he advises. Even suggestions as to the re-siting of houses so that escape corridors exist between them, or to ensure that the collapsing walls of one do not bring danger to another, may be inimical to the spatial organization that reflects the social and family interactions of a given culture. They may be rejected because they interfere with such social interaction, or they may be accepted - perhaps under the force of law and the implementation of "codes" - to the ultimate detriment of the social fabric.

Though building modifications currently under discussion in this conference may be more modest than some of the wholesale alterations to plan form and building method proposed in the past, it is unlikely that they will come singly. Building innovations unlike matches, are in fact, rarely introduced alone. Modified building techniques employing for example, the use of cross-braced cables, requires the learning of new building skills, the introduction of new materials, a method of demonstration, or an educational package for instruction. Posters, booklets, even video films may be employed, each bringing with it, in subtle ways,

innovations in communication and exposure to new technologies and values. The introduction of any element may have, almost certainly will have, a chain reaction which may be instrumental in bringing about profound culture change. And it may also inhibit the initiative of the culture to attempt to meet a newly perceived risk in its own way.

In a carefully documented study of the Canadian "High-Aid" housing programme at San Andres Itzapa, Guatemala following the 1976 earthquake Chris M. Rosene recorded both the advantages and the disadvantages of the programme which left the people "as surprised by the arrival of Canadian aid as they were by the earthquake. To them it had no rationale; no history, no cause - it must have been preordained". The writer concludes that it was in itself a social shock which "destroyed the possibility for them to find their own solution... while it helped promote the social reform movement in the town, it restricted the movement by orienting it towards outside solutions..... In the final analysis the people of San Andres are no better prepared than they were before to find their own solutions to the problems which face them" (17). It would be valuable to know now, five years later, just what remains of the "High Aid" programme, and what the long-term effects have been upon the people of San Andres Itzapa.

It is certain any measures introduced are unlikely to persist if they are culturally unacceptable. Acceptability may depend on many things, but it may be made more possible by coupling the innovation seen necessary by the OAS with a need perceived and expressed by the populace. A low ceiling that inhibits the storage of cereals and generates smoke nuisance is unlikely to be accepted however much it reduces the problems of deflection aggravated by height. But a roof system which contributes to safety whilst improving the conditions of cereal preservation and storage and which channels away internal domestic smoke without encouraging parasites is likely to succeed. In the perception of the community the advantages of a changed roofing system may be immediate; to the OAS team the primary intention of safety in seismic areas may be achieved by riding on the back of the other, explicit advantage. It is indeed, largely a matter of perception of immediate need. In one of the few apparently authenticated examples of indigenous housing developed consciously to meet the threat of earthquakes, that of the Greek island of Lefkas on the Adriatic, Demetrius Porphyrios noted that "the overwhelmingly crucial factor in this environment is not just the threat but the actuality of periodically recurring earthquakes. Their destructiveness was so widespread and so devastating that it forced the inhabitants to evolve special building methods so that the buildings - and they themselves - might survive" (18). In this rare example an earthquake resistant building type was "developed and highly perfected" over "long traditional practice" as a direct result of the perception, from within the culture, of the extent of risk.

Whereas the people of San Andres had no say in the new housing in which they were to make their homes, the people of Lefkas had exclusive control. Both, it is safe to assume, were accustomed to building their own houses; the essential difference was one of perception of risk such that the Lefkians were obliged to develop an appropriate building type, which they did, and which has endured. The first responsibility of western OAS is not, in my view, to provide solutions, but to aid the

perception of risk. If building solutions or new construction techniques are proposed it is not satisfactory to expect the endangered society to provide the labour force for the building of a house type not of their own devising. The participation of the members of a community must be actively encouraged at all stages; not only in the building but in the decision-making related to site disposition, form, internal layout, roof system, construction and the development of new skills as well. Only through this kind of participation, which demands the end of architects' schemes for universally applied "disaster housing", can the accommodation of cultural issues important to the people concerned by achieved and some chance of success in the long term be attained.

All of which demands measures of long-term commitment, patience, knowledge and understanding of different value systems and priorities which are by no means shared by all who have an interest in shelter in seismic areas. Given preparedness and willingness to advise, to promote and participate in, but not to define or dictate the building solutions, not least of the problems confronting the ISDR relates to communication.

Children's party games in which whispered messages or line drawings are passed secretly along a line reveal the distortions of meaning that may occur in a closely-linked group of culturally similar individuals; experience of misunderstandings in chains of command or in management-union negotiations are familiar to many of us. Between people who are culturally very dissimilar, with quite different expectations of the conveying of information, of manners and codes of address, of gestures, body language, priorities and stresses, opportunities abound for confusion and misunderstanding on both sides. Formal and polite languages, appropriate modes of address, indelicate usages and coalified or symbolic references may seem to the ISDR intent on passing on a simple technological process to be irrelevant in the light of the seriousness of seismic risk - but to the recipient of his advice they may be more important at the time than the content.

Jugelsang's work on communication (19) has been augmented by occasional articles by Sowers and Ressler (20,21). They offer good advice on graphic communication in disaster housing contexts and give evidence of communication interpretation. The issues related to strip cartoon montage, graphic ambiguity, religious sanctions against figurative depiction, pictorial depth perception, geometric illusion have been the subject of extensive research some of it well summarised by Hudson (22). In some contexts, for example on the Indian sub-continent, where film is widely available, other more sophisticated media may communicate information more effectively. But even here, extraneous detail, unfamiliar dress and behaviour patterns depicted on the screen may distract attention creating further cultural barriers to communication of the message (23).

Where greater experience in the recognition of messages through mass media is to be found more complex systems may be used. This generally applies in the city, where some familiarity with advanced technologies and communication techniques is evident among the majority of the population. In the cities too, are to be found the technological innovations which have still to reach the villages or to have been generally accepted in them. Those who have moved to the cities and have built their homes in the peri-urban communities and squatter settlements, have already chosen to have a stake in modern society. In this sense they are

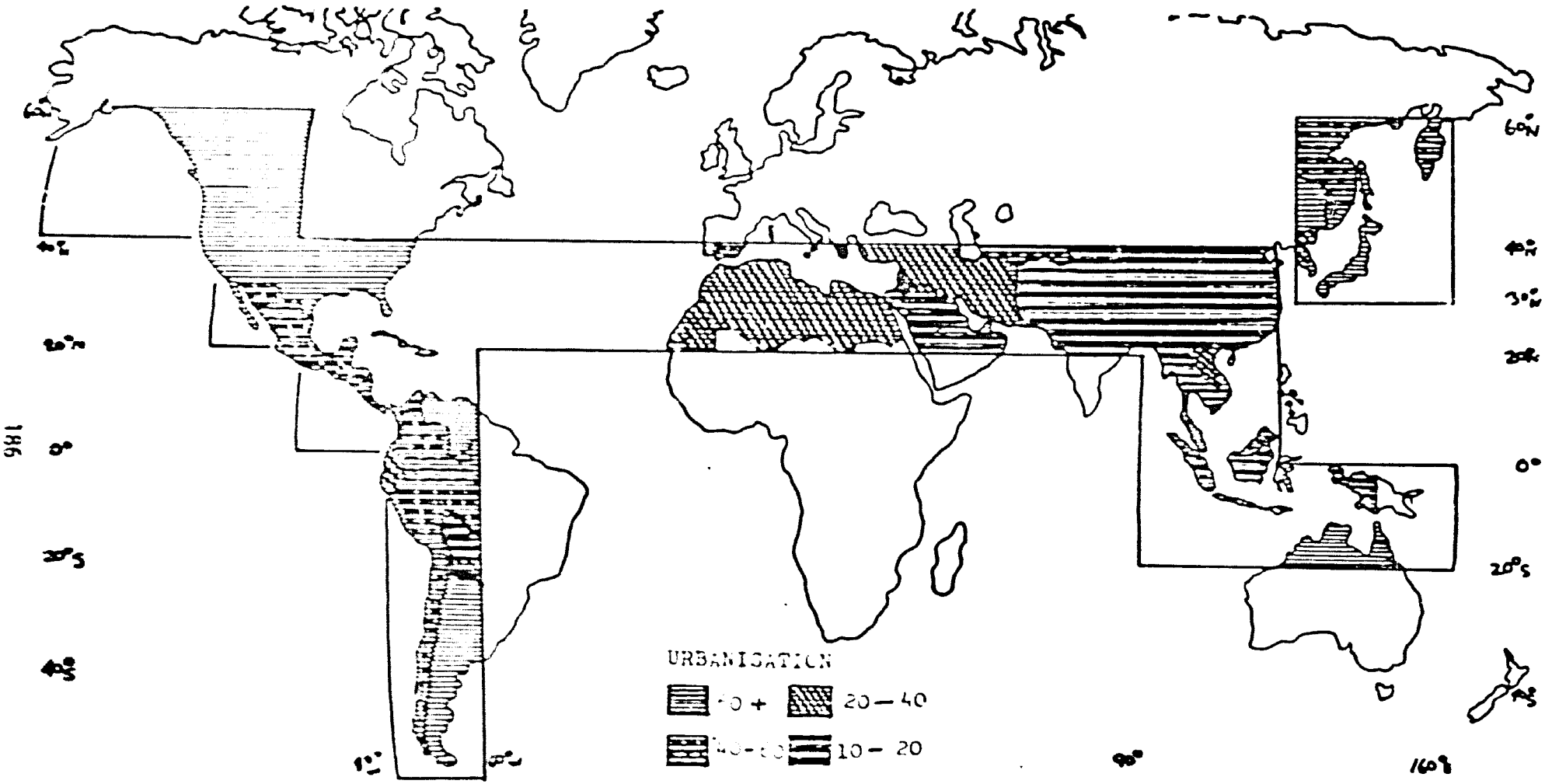
more open to innovation and have already experienced aspects of cultural change. To some extent the degree of change may be illusory; the "folk-urban continuum" of which Redfield wrote (24) has many and varied levels in different cultures. Linkages with rural communities, strong emotional and social ties, the persistence of traditional customs and observances, and the evidence of rural mores within the urban environment have been detailed by many anthropologists and in numerous countries (25). The acquisition of contemporary gadgets and transistor radios is not by any means a sign of total cultural transformation.

While the security of the traditional framework has been in part disengaged, the urban dweller in an earthquake-prone Third World city may still be employing largely traditional methods of building. Mapping the degree of urbanisation in the Quake Belts raises the problem of how much adobe building there is in the cities, FIG 8. Selecting four Iranian cities, Reza Razani reports that only a little over 4% of Teheran's buildings were of adobe and wood, while over 70% of those in Isfahan were of these materials (26). Clearly, much more needs to be known about this, and the processes of change whereby adobe buildings are being replaced.

In the early gecekondus of Ankara there was extensive use of adobe, but as Geoffrey Payne has shown, the adobe houses have been replaced by concrete block ones. The patterns of house forms have changed in response to the "reduction of Islamic customs in domestic life which gave women more freedom... the reduction of family size and the emigration and subsequent return of workers in western Europe which exposed them to new life-styles and forms of building which many sought to emulate on their return" (27).

It is important to realise that urban living in the Third World means a total commitment to a cash economy. Innovations that are not seen to have immediate benefit are likely to be converted into cash, while the slack periods in the farming year when village building traditionally takes place do not exist in the city. The immediate benefits that may accrue are more likely to appeal than the unspecific, long-term possible advantages of an untried but reputedly seismically safe building. Though the fact that Ankara is prone to severe earthquake damage is not in question among many seismologists, the perception of this is no more shared among the squatters of the gecekondus than it is recognised as an imminent risk by the residents of Berkeley. Moreover, the changes in building type within the gecekondus have arisen from changes within the culture of the communities themselves, and have not been imposed by agencies from outside.

Nevertheless, the potential for change and the acceptability of innovations is greater in the cities than in the villages, and those who are concerned with seismic risk may be advised to direct their attention to urban settlements that are especially vulnerable. Here as elsewhere, the necessity to involve the participation of the community in the decision making is of fundamental importance; the opportunities for effective communication may be greater but the independence of the newly urbanised may not make the process more easy. Given that a programme of building modification is achieved through demonstration and participation, the possibilities of slow but effective information transfer back to the



Urban populations expressed as percentages of Total population

FIG 8
Urbanisation in Quake Belts

villages is real. The threads that link the rural communities with the cities are also the communication channels by which elements of urban living are transmitted to the more conservative peasant cultures. That this is an instrument of culture change is undeniable, and the introduction of technological innovations in building types will contribute to the dissolution of traditional ways of life. But the changes will be assimilated from within, and at the speed most acceptable to the communities concerned. To the engineer or architect with a ready-made solution and little time to spare, the process may be impossibly slow - but it is more likely to succeed in the long term than any imposition of unenforceable building codes, or the introduction of unwanted new techniques for building.

Of course, the urgency recognised by SAMAS whether perceived by rural or urban communities may be considered by some to be justification enough for intrusive measures. And certainly, there will be many circumstances where persuasive argument, good communications, the participation of wise leaders and far-sighted household heads, or even the provision of demonstrably better levels of housing may make such introductions effective and permanent. In all instances detailed records and careful and repeated return studies should be made so that the nature of successful or failed overtures is fully documented. So far there is little precedent. Barr and Brown in recently in 1979 observed that "Systematic post evaluation of permanent housing built for disaster victims in the third world is unknown to these authors. Such evaluations may exist as in-house documents, but we even doubt this" (26). Anthropologists have been giving more attention to disaster studies. William L. Torry has written persuasively on the role that they can, and should play in disaster research (29), though he stops short of the issues central to this paper, namely the important contribution that the anthropologist can make to teams concerned with the problems of re-siting, rebuilding or rendering safe the earthen buildings prone to seismic risk.

Profound changes have taken place in the past in housing in some parts of the quake belts, with the introduction of adobe building itself. Though present among some pre-conquest societies its use in Central and South America was considerably extended by the Spanish. The Spanish adobe however, derives from the Arabic atob, (sun-dried brick) and was previously an importation during the occupation of Spain by the Moors. Such housing innovations were brought with much pain and duress. Hopefully the new changes planned for adobe housing will be introduced in a more enlightened and humane climate; but if there is not to be further unnecessary social distress and disruption it will be with full regard to the cultural contexts.

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INTERNATIONAL INVITATIONAL WORKSHOP ON EARTHEN BUILDINGS IN SEISMIC AREAS

Albuquerque, New Mexico

del 24 al 28 de mayo de 1981

Trabajo presentado por :

FUNDACION SERVICIO DE VIVIENDA POPULAR ": SERVIVIENDA "

Asistente :

Lic. Juan Manuel Perdomo Rivera

Bogotá, 30 de abril de 1981

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FUNDACION SERVICIO DE VIVIENDA POPULAR
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Sur América

I
OBJETIVO

SERVIVIENDA, es una Fundación sin ánimo de lucro, cuyo objetivo fundamental es desarrollar programas integrales de vivienda al servicio de las clases populares. Este objetivo debe entenderse, no solamente como el simple hecho de proporcionar una vivienda, sino ofrecer la posibilidad de disfrutar del conjunto de acondicionamientos culturales y económicos que le permitan al hombre y a su familia desarrollarse plenamente en comunidad. Por lo tanto, propugnamos por un desarrollo integral que comprende :

- el derecho de autodeterminar el tipo de sociedad que queremos, partiendo de los valores nacionales y de las realidades históricas y actuales del país.

- un cambio de las actuales estructuras económicas, sociales y políticas.

- una equitativa distribución de los bienes materiales y culturales.

- una participación activa y consciente de todos en la solución de los problemas nacionales.

- un fortalecimiento de lossistemas comunitarios.

II
RAZON DE SER

La marginalidad urbana, una de cuyas manifestaciones más clamorosas es la carencia de vivienda adecuada para todas las familias, es el fruto de la incapacidad de la sociedad de proveer oportunidades de producción e ingresos, o empleo productivo con una remuneración justa para todas las familias, de una inadecuada tecnología y sistemas de financiación que no está al alcance de la mayoria.

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Los planes nacionales de vivienda, tradicionalmente, consisten en la financiación de viviendas completas y terminadas que el Estado construye directamente o que han sido construidas por urbanizadores privados con el visto bueno del Estado; también hay otros casos en los que el Gobierno descarga parte de su obligación, creando y auspiciando, bancos de ahorro y préstamo, cuya única función es la captación de ahorro y el otorgamiento de préstamos destinados exclusivamente para la construcción. Estas políticas, sin embargo, no han sido una respuesta para las familias de menos recursos.

Cuando el Gobierno ha emprendido directamente la construcción de vivienda con destino a las familias de escasos recursos económicos, ha demostrado su incapacidad en promover verdaderas soluciones a precios razonables. Las razones pueden ser las siguientes :

- Las instituciones gubernamentales encargadas de adelantar la construcción han sido bastante ineficientes en el planeamiento, ejecución y control de las obras, lo que ha llevado inevitablemente a un costo demasiado alto por unidad, que está por fuera de las capacidades de pago de la mayoria de las familias de menores ingresos.

- El encarecimiento continuo de los materiales de construcción y el precio especulativo de los terrenos urbanos, han llevado a que cada vez se entreguen viviendas más reducidas y de peor calidad.

- Los diseñadores no han sabido interpretar las verdaderas necesidades y deseos que en cuanto a vivienda tienen las familias de menos ingresos, teniendo como consecuencia el ofrecimiento de "soluciones" de vivienda, para las cuales estas familias no están preparadas o interesadas.

Cuando se ha encomendado al sector privado la construcción masiva de vivienda, la oferta se canaliza hacia vivienda de alto costo, debido por una parte a la creencia equivocada de que la cartera de deudores con buenos recursos económicos es más sana que la correspondiente a deudores de escasos recursos económicos, y por la otra, a que los precios especulativos que se pueden obtener por la vivienda suntuaria producen jugosas utilidades para los constructores. En estos casos la demanda por vivienda de bajo costo queda insatisfecha, obligando a las familias más necesitadas de vivienda, a buscar posibilidades (tugurios, inquilinatos) que no se compadecen con la dignidad humana.

El problema de la vivienda es el resultado de una injusticia estructural. Su origen se encuentra en la desequilibrada distribución de los bienes materiales y en el inhumano

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ejercicio del poder, tanto al interior de los países pobres coma en las relaciones de éstos con las naciones ricas.

Dicho problema de la vivienda se agrava principalmente por el crecimiento de la población, las catástrofes, las migraciones internas y externas y el constante deterioro de los ingresos familiares.

SERVIVIENDA enfoca su labor hacia el 25% de la población colombiana que se encuentra confinada en los tugurios y en los inquilinatos hacinados. Esta población ocupa el 60% del área del país.

Dicho 25%, tiene ingresos per-cápita inferiores al salario mínimo estipulado por la Ley. Es un ejército cercano a los 7 millones de seres famélicos que van cercando las grandes ciudades con cinturones de miseria, mientras rumian en sus entrañas el odio y la desesperanza. Son víctimas inocentes de una sociedad enferma de injusticia crónica.

Injusticias que si no reciben audaces e inmedictas soluciones por la acción de instituciones públicas y privadas, se convertirá en tragedia de proporciones incalculables. Y como el proceso de urbanización es incontenible, urge desarrollar políticas de planeación urbana y regional, que limiten la especulación con la tierra, incrementen los capitales destinados a construcción de vivienda popular y apoyen soluciones audaces y masivas con tecnología apropiada al desarrollo del país.

Políticas con soluciones integrales, porque tener vivienda no es solamente poseer un techo físico, sino también aquellos elementos educativos, laborales, culturales y económicos que conduzcan al desarrollo y al bienestar social. Tanto en Bogotá, como en el resto del Territorio colombiano, los desequilibrios socio-económicos se manifiestan en la crudeza de los siguientes datos :

Hay un déficit actual de 840.000.00 unidades de vivienda, el cual se espera que para el año 1985, alcance la cifra de 900.000.

Cada día mueren de hambre 350 niños en Colombia. Dos de cada tres niños colombianos están desnutridos y sufren de enfermedades endémicas. La tercera parte del pueblo no tiene asistencia médica y cuando el pobre consigue trabajosamente que lo atienda un médico, no tiene dinero suficiente para comprar la medicina.

Existe un total de 6 millones 800 mil analfabetas. En efecto, en la población mayor de 5 años hay 2 millones 600 mil personas sin educación, viviendo en las ciudades, y 4 millones 200 mil en el campo.

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De los 28 millones de colombianos, se calcula que un millón 200 mil están desempleados, y un millón 800 mil reciben un ingreso de subsistencia a través de empleos disfrazados.

III

REFERENCIA HISTORICA

SERVIVIENDA inició sus tareas a finales de 1973, después de estudios teóricos sobre el problema habitacional en Colombia. Recibió el apoyo de SELAVIP INTERNACIONAL - Servicio Latinoamericano y Asiático de Vivienda Popular.

En abril de 1976, se constituyó en Fundación independiente, con el aporte de la Compañía de Jesús.

Fueron experimentados diferentes materiales, bajo un estudio cuidadoso de durabilidad, distribución de espacios, métodos de ensamblaje, costos y preferencias de los usuarios. Se pensó en la madera pero no tuvo mucha acogida. Luego se pasó al material de ciscana, con base en cascarilla de café y aserrín de pino con un aglutinante especial. Se abandonó este sistema por su poca durabilidad.

Posteriormente se utilizaron láminas de asbesto-cemento, con buenos resultados por su fácil transporte y rapidez en la armada. Esta línea se descontinuó a mediados de 1976 por los altos costos de los materiales. Por último, se construyen las casas con módulos de concreto. Este material ofrece mayor durabilidad, posibilidades de ensanche, mejor estética y resistencia a los movimientos telúricos.

El dinamismo del compromiso social de las personas que laboran en la Institución, ha hecho que en la actualidad se tengan 8 Seccionales distribuidas en el Territorio Nacional, atendiendo a las necesidades de vivienda de las diversas regiones, tanto en el campo como en la ciudad. Más de 6 mil casas han sido instaladas en el País, con un promedio de 36 mil personas beneficiadas.

Se ha prestado asesoría en la Isla de Monserrat (Las Antillas), en Togo (Africa), en Ecuador y en varios países centroamericanos. En Guatemala se instalaron 50 viviendas a raíz del terremoto.

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IV
TECNOLOGIA

Basados en las experiencias logradas en diversos países latinoamericanos por el Servicio Latinoamericano y Asiático de Vivienda Popular - SELAVIP, SERVIVIENDA ha diseñado y experimentado diferentes modelos, como intento de solución al problema de la vivienda popular, teniendo en cuenta que cualquier solución debe contemplar los siguientes principios :

- Debe acomodarse al nivel de ingreso de las clases populares

- Debe ser evolutivo y flexible para que se adapte a la naturaleza flexible y evolutiva de la familia.

- Debe ajustarse al nivel cultural de los usuarios y por medio de un sistema progresivo evolucionar rápidamente hacia una vivienda conformada que se acomode a las necesidades y capacidades.

- Debe ser integral, o sea, que debe contemplar soluciones también en el campo educacional, ocupacional, social y cultural.

SERVIVIENDA, utilizando materiales nacionales ha desarrollado una tecnología muy simple de prefabricación, con miras a socializarla entregándosela a las clases populares organizadas en comunidades. Dicha tecnología consiste en muros en placas de concreto no reforzado, con espesor de 32 mm. El módulo básico mide 97 x 97. Parales metálicos o de madera para la unión de las plaquetas, puertas en lámina metálica con estructura de madera, ventanas en ferroconcreto, o madera, con hojas de abrir en metal y cubierta en asbesto-cemento, o zinc o teja de barro, según preferencias de los usuarios.

Las bases o pisos pueden ser realizadas por el usuario, según especificaciones técnicas, o pueden ser construidos por nuestros propios operarios. Y para la armada, el usuario debe colaborar con dos personas, como auxiliares de nuestro equipo de armadores. del cuidado que se tenga con los diversos materiales de la casa, haciendo uso correcto de ella, depende el que se pueda desarmar cuando sea necesario, y transportarla a otro lugar.

El peso promedio de una casa es de 6 toneladas y se transporta fácilmente, sin importar las distancias rurales y urbanas. Dicho transporte se realiza en camiones propios de SERVIVIENDA o en vehículos particulares, según las posibilidades de la familia.

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Una casa de 35 MTs^2 se arma en solo 6 horas, sin utilizar maquinaria especial y comienza a ser habitable. El sistema conjuga con solidez y durabilidad de la vivienda, rapidez y eficacia en la producción, adaptabilidad de la vivienda a climas frios y calientes, a las irregularidades del terreno y a las necesidades de las familias y comunidades. Involucra a las familias y a las comunidades en el planeamiento, en la construcción y en el ensamblaje de las viviendas, potencializando así el fenómeno popular de la autoconstrucción progresiva. La producción de vivienda prefabricada permite una organización de tipo empresarial con su consiguiente racionalización en el empleo de los recursos.

En la actualidad se está perfeccionando un nuevo modelo de casa de dos pisos, de gran resistencia a los temblores de tierra y de fácil armada, el cual, sin lugar a dudas, revolucionará el mercado de la vivienda popular, y será un aporte de SERVIVIENDA para la economía de las tierras urbanas. Este modelo ya ha sido suficientemente probado al estar en uso en las oficinas de SERVIVIENDA de Bogotá.

La dotación de servicios y la decoración es un proceso que se deja a la iniciativa y criterios estéticos de los usuarios. En la mano de obra familiar hay un potencial de trabajo que se traduce en ahorro, en imaginación creativa de acuerdo con una serie de valores culturales y en una mística que une a los miembros de la familia cuando cada uno de ellos hace su aporte al mejoramiento de la vivienda. Es dedicar su tiempo a las tareas productivas que redundan en un mayor bienestar del hogar.

Las paredes tanto exteriores como interiores, pueden ser pañetadas, aplicárseles marmolina, enchapartas en madera o en azulejos o simplemente pintarlas al gusto. Los pisos pueden ser de cemento, de madera, de baldosas o de tierra pisada. Con el fin de aprovechar el espacio interior de las habitaciones, se sugiere el uso de camarotes para los niños. El cielorraso luce muy bien en madera y conserva la temperatura de la casa.

A los futuros usuarios, se les atiende personalmente en las oficinas de SERVIVIENDA y se les dá la información necesaria ofreciéndoles todas las facilidades en la adquisición de su casa. No se incluye el lote o terreno para aquellas casas que son adquiridas fuera de las urbanizaciones propias de SERVIVIENDA. Se les explica detenidamente las características arquitectónicas de la casa y se les complace con nuevos diseños cuando desean modificaciones lógicas con base en los modelos estandares que les ofrecemos.

Cada modelo tiene sus variaciones para tierra caliente o para tierra fria. El número del modelo se refiere al área construida en metros cuadrados. Así por ejemplo :

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El modelo 15, quince metros cuadrados; es el más pequeño. Cuenta con una alcoba, salita-comedor y sitio para la cocina. Es el más económico para familias de dos a cuatro personas.

El modelo 35, es el más solicitado y ofrece mejores espacios para familias numerosas. Consta de tres alcobas y sitios para el baño, la sala-comedor y la cocina.

V
FINANCIACION

Los problemas de las familias de escasos recursos económicos, van más allá de encontrar una vivienda que cumpla con los mínimos requerimientos físicos y sociales y que al mismo tiempo satisfaga sus necesidades y deseos particulares. Deben enfrentar también el problema de la financiación que no solamente es escasa sino que tiene esquemas que no se compadecen con sus ingresos monetarios.

SERVIVIENDA consciente de los grandes esfuerzos económicos que hacen las familias para conseguir su lote, tenía que conformar un sistema de financiación para la compra de la vivienda que estuviera al alcance de sus posibilidades. Con el apoyo económico de diversas instituciones internacionales, se constituyeron fondos rotatorios de crédito, que le imprimieron inicialmente una dinámica operacional a la institución. Posteriormente se obtuvo con la Caja Social de Ahorros un cupo de crédito para la conformación de un fondo rotatorio. El monto inicial del cupo fue de $1'000.000.00 y en la actualidad asciende a $40'000.000.00. Con un capital semilla correspondiente a un 10% del valor de la cartera y la garantía por parte de SERVIVIENDA, se ha podido conformar un fondo multiplicador, que ha permitido otorgar créditos por más de $60'000.000.00. Este mecanismo es sin lugar a dudas, uno de los éxitos de la Institución. La cartera es supremamente sana, pues, su morosidad es de apenas el 1.6% del total de la cartera.

Para familias de escasos recursos económicos, las viviendas se venden al costo y a crédito. Para personas pudientes se venden a precio comercial y al contado. Este excedente permite subsidiar a las familias más pobres. La cuota inicial se conviene con la familia y las cuotas mensuales se fijan de común acuerdo, de tal manera que no superen la cuarta parte del ingreso familiar y que sean iguales o inferiores a la suma que la familia pagaba por arriendo.

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VI

OTRAS CONSTRUCCIONES

SERVIVIENDA, además de responder a las necesidades de vivienda de las gentes más pobres de la población colombiana, tanto del campo como de la ciudad, también construye a precios bajos : residencias para familias de mayores recursos económicos, puestos de salud, oficinas, restaurantes, galpones, aulas escolares, etc.

VII

URBANIZACIONES COMUNITARIAS

Al considerar la vivienda como una necesidad básica de la familia, como un elemento promocional en sí mismas y como un medio de formación socio-económica y política de las comunidades, en busca de cambios sociales estructurales, SERVIVIENDA orienta sus esfuerzos hacia planes de urbanización.

La primera etapa de dichos planes urbanísticos consiste en la divulgación del programa, la selección, organización y formación de las familias participantes. Con ellas se estudia la realidad social. Se discuten los aspectos relativos a la consecución de la tierra, a la financiación, a los trámites legales, a la planeación de los trabajos y a la organización de la comunidad. Se pone especial cuidado en la formación de líderes y se enfatiza la participación democrática en las tomas de decisiones.

En la segunda etapa se procede directamente a la construcción, por ayuda mutua, bajo la dirección de un técnico. Se adecúan los terrenos, se instalan los servicios de infraestructura, se construyen y se ensamblan las viviendas. Durante todo este proceso continuan las reuniones comunitarias para tomar conciencia de la problemática social y para resolver los problemas que se van presentando.

La tercera y última etapa comienza con la aprobación y apropiación de las viviendas por sorteo, el mejoramiento de las áreas comunitarias también por ayuda mutua y el fortalecimiento de las organizaciones cooperativas que incrementen la participación política, para exigir sus derechos y determinar libremente su futuro de comunidad.

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VIII
CONCLUSIONES

Nuestra acción nos ha comprobado :

- Que existen sistemas alternativos de construcción que satisfacen la necesidad básica de vivienda y que están al alcance de las familias de bajos ingresos.

- Que se pueden encontrar fuentes nuevas de recursos y nuevos mecanismos de crédito.

- Que las clases populares cumplen sus compromisos crediticios.

- Que la vivienda construida conjuntamente con la comunidad, al mismo tiempo que satisface una necesidad básica de la familia, es un poderoso instrumento de organización comunitaria para un cambio social.

Estamos convencidos de que el problema de la vivienda es solucionable, si con decisión y con imaginación creadora se toman las medidas apropiadas.

La complejidad de la problemática social de nuestros países, no se soluciona únicamente con la construcción de vivienda. Son necesarios cambios profundos en las personas, en las comunidades y en las instituciones.

La fe en el hombre y en el poder de la comunidad organizada, es la base de una estructuración nueva y justa de la sociedad.

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ANEXO

PROCESO DE PRODUCCION - SERVIVIENDA

Las viviendas prefabricadas de SERVIVIENDA, constan básicamente de 4 tipos de materiales :

1. Concreto
2. Metal
3. Madera
4. Asbesto-Cemento

Estos a su vez, conforman las paredes, ventanas, uniones entre módulos, puertas, correas y cubierta.

A. Utilizamos una modulación desarrollada y perfeccionada en Colombia, cuya unidad es una plaqueta de hormigón sin refuerzo de .97 x .97 x .32 y resistencia de 3.000 P.S.I., (233 kg/cm^2), con un porcentaje de absorción del 9%, de humedad natural del 6% y resistencia a la flexión de 70 kg. para un esfuerzo máximo de 96 kg/cm^2.

Se funden sobre un mesón que puede ser fijo (ladrillo y plancha de hormigón) o móvil (mesas hechas con perfiles metálicos en L y lámina metálica) utilizando como formaleta dos perfiles metálicos en L de 1 1/4" x 1/8" x 6 m., de longitud intercalando perfiles de .97 m., para formar los cuadros de .97 x .97 y otras plaquetas especiales que son la resultante de la división modulada en cuartas partes de la unidad básica. Para darle rigidez a esta formaleta utilizamos varillas de hierro de 1/4" las cuales funcionan como tensores. El hormigón es vaciado en las formaletas y nivelado con una regla; finalmente colocamos sobre la mezcla láminas metálicas de 1 x 1 m. En esta forma se produce lo que llamamos una tendada. Cada tendada consta de 5 1/2 módulos y se funden una sobre otra hasta un máximo de 20 en cada mesa de fundición para un total de 110 plaquetas.

B. El otro elemento constitutivo del muro son los paales metálicos, los cuales se fabrican con lámina galvanizada calibre 22. Formando perfiles en "U"; los perfiles se unen con soldadura de punto según si el muro es en forma de L, I, o simplemente longitudinal.

Para la estabilidad de la vivienda se coloca una correa de amarre en los bordes superiores de los muros, fabricada también en perfiles "U" de lámina galvanizada.

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C. Los demás elementos como puertas, ventanas, correas y cubierta utilizan sistemas tradicionales de fabricación, por lo cual no nos detendremos a analizarlos.

D. Para la armada de la casa, el futuro usuario debe preparar el terreno, construyendo una base de hormigón de 2.500 P.S.I. (194 kg/cm^2) y sobre ella se instala la casa en 6 horas (35 mts^2) ensamblando los diferentes módulos con los porales metálicos, al igual que las puertas y ventanas. La cubierta utiliza el sistema tradicional de construcción.

DESARROLLO DE PRODUCTOS

SERVIVIENDA cuenta también con un Departamento de investigaciones y desarrollo de productos para introducir elementos que rebajen el costo, manteniendo o mejorando la calidad de los materiales actuales de la vivienda.

En esta área se trabaja principalmente en dos campos : Cemento y Tejas

A. CEMETITO : el cemento tiene como base principal, la ceniza de cascarilla de arroz, la cual se mezcla con cal y una proporción pequeña de cemento Portland, los tres elementos se muelen y mezclan en un molino de bolas durante 7 horas, al cabo de las cuales resulta un cemento de igual calidad que el Portland y a un costo mucho menor; la mano de obra es mínima puesto que la mayor parte la realiza el molino, y no requiere ningún conocimiento especializado para manejarlo. Este procedimiento ha sido desarrollado y probado ampliamente en la India durante más de 5 años.

B. Las tejas utilizan como materiales básicos el cemento, arena fina y una fibra que puede ser vegetal, mineral o sintética; en nuestro medio utilizamos fique o henequén. La forma de producción tampoco requiere mano de obra especializada y utiliza como formaleta una teja corriente de asbesto-cemento, un marco en madera o hierro y una masa plegable.

El Departamento evalúa y cuestiona continuamente el sistema actual utilizado por SERVIVIENDA para perfeccionarlo abaratarlo, es así como reemplazamos la tradicional ventana de madera por una de hormigón, armada mucho más sencilla y económica.

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La base de la casa representa un alto costo para el usuario y en ocasiones debe esperar un largo tiempo para poder instalar su vivienda.

En respuesta, el Departamento de Desarrollo de Productos, está elaborando unas viguetas prefabricadas de aproximadamente 1 m. de longitud en los cuales ensambla la plaqueta y puede instalarse en un terreno simplemente afirmado.

Para aligerar el peso de las plaquetas (una unidad pesa 70 Kg.) estamos probando una mezcla de hormigón con aserrín o viruta de madera mineralizada.

Casa de 2 plantas :

Debido a la escasez y el alto costo de la tierra urbanizable, vemos la necesidad de responder a este problema, con una vivienda de 2 plantas para aumentar el área construída en lotes muy pequeños.

Utilizamos 3 sistemas de entre-pisos :

- El primero consta de viguetas en madera y listón machihembrado soportado en una estructura independiente de los muros de la vivienda.

- El segundo también en viguetas de madera y listón machihembrado pero soportado directamente en los muros de plaquetas; presenta economía de material y espacio, con respecto al anterior pero en ambos existe el problema acústico y en este sistema están construídas las oficinas de SERVIVIENDA en Bogotá, donde funcionan desde hace 2 años.

- El tercer sistema es una placa de hormigón fundido en una formaleta de lámina doblada Cold rolled calibre 18, suspendida de los muros del primer piso, los cuales funcionan como estructura; la formaleta sirve también como armadura del entre-piso y cielorraso de la primera planta.

  Los parales metálicos van desde el suelo hasta la cubierta del 2o. piso a diferencia de los sistemas anteriores en los cuales el paral se interrumpe a la altura del entre-piso.

SOCIAL ASPECTS OF POST-DISASTER HOUSING: IMPLICATIONS FOR PROGRAM PLANNING

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ABSTRACT: This paper grows out of several studies of persons who received new houses after Hurricane Fifi in Honduras (1974). We evaluate such issues as housing site, materials, available services, etc., from the vantage point of the housing recipient. We found that in these Projects the recipients were very satisfied, but that several contextual factors and potential problems are often overlooked in such undertakings.

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Introduction

In constructing permanent post-disaster housing one must pay particular attention to the geography, building materials, and disaster risk, but one must not overlook social and cultural factors. As many of us know, the 'best laid plans' after disasters and even without disasters have failed because they did not take into account the reconstruction plans and processes from the vantage point of the users or recipients. Although user input does not assure success, it diminishes the possibility of costly and unnecessary decisions. This is particularly true in the third world.

This paper summarizes the study of nearly four hundred houses built for the victims of Hurricane Fifi (1974) on the north coast of Honduras. The data is the result of interviews with the occupants of these houses in 1976, 1977, and 1978. The first interviews (1976) were conducted in order to collect base data; the second (1977) to determine occupant satisfaction with the various facets of the housing projects; and the third to probe housing improvement and continued occupancy. The housing projects were sponsored by a North American voluntary agency which received some financial and material assistance from other agencies. Although the sponsoring agency had participated in building houses for victims of the Managua earthquake (1972), the Honduran work lacked systematic feedback from that experience.

The houses were built on three different sites not previously occupied by houses. The recipients had previously occupied houses on hillsides vulnerable to landslides or on the floodplane near rivers. These locations are indicative of these people's low socioeconomic status and their vulnerability. Most of the recipients lived in temporary quarters (makeshift houses, in public buildings, or with friends or relatives) while the houses were being built and approximately ninety percent assisted in the actual construction for which they received food. Thus, the lives of these people were dramatically interrupted for some months by the disaster, until the houses were completed.

In order to emphasize the importance and breadth of social, cultural, and economic conditions we begin with a brief description of Honduras, the Sula Valley, and the people who received the houses. Although this might appear impertinent, we are convinced the total context of reconstruction needs to be known. Some of the data we have collected is not applicable to other situations, but the questions and issues are important. The people served by these housing Projects share many characteristics with other peoples throughout the third world whose vulnerability to disasters grows from year to year. These are not tribal people who still adhere to the traditions of their precursors and to whom western ideas and technology are foreign. They are, as are hundreds of millions of others in the world, peasants and semi-peasants who are pushed or drawn to the regional urban centers in hopes of a better life.

The National Context

Honduras, commonly referred to as one of the Central American 'Banana Republics,' is poor and certainly one of the world's less developed nations. Its population of 3,500,000 is increasing at an annual rate of 3.5% which means that it doubles approximately every twenty years. The total fertility rate is 6.9 per woman. It is one of the two or three poorest countries in Latin America, approximately comparable to Guatemala, but not as poor as Haiti. Its literacy rate is 57%, life expectancy is fifty-four years and nearly 47% of its population is under fifteen years of age.

Two-thirds of its active working population is in the primary industries (farming, fishing, and forestry) and 20% live in cities of twenty thousand or more. Honduras is one of the forty-three "food-priority countries" so identified by the United Nations due to its especially low income, inadequate diet and large projected cereal-grain deficits.(1) Approximately one in five households have piped water, one in six electric, one in five toilets and slightly fewer have electric lighting. The average number of persons per household is 5.7. Commercial agriculture has increased its hold on much of the best land in the country at the expense of land available to the peasantry. During the earlier part of this century bananas were the major crop, but cattle and cotton have emerged more recently.(2)

The Regional Context

Much of the north coast of Honduras was devastated by Hurricane Fifi, but our study is concentrated in the rich Sula Valley in the north west sector of the country. The early part of this century saw an economic boom in the area and more recently an important industrial expansion. This development is reflected in the growth of San Pedro Sula, the capital of the Department of Cortez. "The population has increased from roughly 20,000 persons in 1950 to about 120,000 in 1970. Almost overnight San Pedro has become Honduras' leading manufacturing center, and the rising skyline of its central business district is indicative of its increasing importance as a seat of commerce. . .San Pedro Sula's growth has made it the largest non-capital city in Central America and it can now claim importance as a regional center for that geographical

area."*

As the above indicates, the economic environment of the Sula Valley is promising. The permanent housing we have studied and are reporting on herein is in the context of an expanding labor market for the populace. Not surprisingly, the authors have found that living in an economically depressed area after a natural disaster is very difficult for victims and non-victims.(3) Researchers found a similar situation after the Managua earthquake.(4) Thus, in the Sula Valley, unlike the usual post-disaster situation in less developed countries, the economy for those we studied held some promise.

Housing Recipients

The persons receiving the housing at the three sites were undoubtedly typical of the mass of peasants and semi-peasants living in the general area of San Pedro Sula. Of those employed, 53.1% were in agriculture (essentially subsistence,) 34.2 were unskilled workers, 9.8% were either employed as skilled or commercial workers, and 2.9% were unemployed. They have been a relatively mobile population with 36.4% living at their previous home three years or less, 32.4% living there from four to six years, 15.1% residing there from seven to ten years and the remaining 16.1% living there more than ten years. This mobility is undoubtedly related to reported mobility to the city of San Pedro Sula in recent years and documented by Croner. He states that, "Internal migration, particularly during the past two decades, has generated phenomenal rates of population growth for the city of San Pedro Sula. The fact that the city has grown nearly sixfold in twenty-one years, and that 79.9% of all heads of household are nationals born outside of the city, illustrates the profound and sudden impact of population movement upon the urban environment."** He goes on to say that, "With increasing industrialization in and around the city, internal population movement to San Pedro Sula could attain unprecedented proportions through the next three decades."*** Although very few

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*William Kenneth Crowley, San Pedro Sula, Honduras: The Order and Disorder of the Pubescent Period in Central America's Most Rapidly Growing City, A Dissertation at the University of Oregon, 1972, p.1.

**Charles Marc Croner, Spatial Characteristics of Internal Migration to San Pedro Sula, Honduras, A Dissertation at Michigan State University, 1972, p. 137.

***Ibid.

of the housing recipients lived in San Pedro Sula, they are undoubtedly part of the ongoing populations' movement to the general area. As Croner indicates, migration to large urban centers is often a stair step process for the migrants rather than a direct move to the big city.

The average years of formal education by the heads of household was 2.2 years. Approximately 10% of the houses were headed by women and the average household size was 5.3 persons. Household sizes were distributed as follows: 1-2 persons, 7.5%; 3-4 persons, 26.2%; 5-6 persons, 35.7%; 7-8, 25.2%; nine or more persons, 5.3%. Those under fifteen years of age account for 51.6% of the total population. Future residents were given the opportunity to participate in the construction of the houses and a full 91.2% did so. In addition, they were able to receive food for work and 89.5% of the total interviewed said they did.

As previously mentioned, these people are not recent migrants from a tribal past, but are oriented to the rapidly emerging urban-industrial sector. To measure their exposure to and integration in the national life we asked them three questions. First, we asked how many had voted in a public election and 57.5% said they had. Second, we asked how many could name all five of the Central American republics and 63.1% were able. Finally, we asked how many knew the name of the President of Honduras and 80.2% were able to name him. Thus, we were convinced of their national awareness and orientation.

Although it appears trite and unnecessary to ask how many of the post-disaster housing recipients were victims, it is an important consideration in light of the housing deficit that existed before the disaster as well as afterwards. In a statement on the housing situation prior to the disaster and in reference to new construction, "In Honduras a five-year plan called for 9,500 houses to be built in the public sector between 1965 and 1969, although population increase alone required 64,000 new houses in this period, and the housing deficit of 1965 was estimated 263,000."* We found that 82.8% of the persons living in the houses in 1976 had had their houses destroyed by the storm. We also asked how many of the occupants were owners of the houses they were inhabiting and 89.8% indicated that they were. The remaining occupants were either caring for houses for friends or relatives, had recently purchased the houses, or were renting them.(5)

The housing in which the recipients lived prior to the disaster was primarily traditional. Traditional houses or 'champas' are constructed by the owners and utilize indigenous materials such as thatch, bamboo, and mud plaster. Modern homes are constructed of either cement block or sawn lumber. Of those interviewed in the

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*"To Shelter Humanity" Summary Report of A Symposium on World Housing Needs and Environment, The American University, Washington, D.C., 1975, p. 34.

new housing 78.7% had lived in the traditional housing. The flooring of their previous houses was primarily dirt (75.8%) and only 20.9% had electricity. A total of 27.3% had running water (not necessarily inside their houses) and 6.2% had baths. As will be seen, moving into the post-disaster housing was a step up for most of these people.

Project Descriptions

Following are descriptions of the three projects discussed in this paper: San José, Flores de Oriente, and Santa Rita. They can be located on the maps provided.

San José contains 121 houses and is located on the primary highway between San Pedro Sula and the north coast near the city of Choloma. It has an excellent location with reference to the existing transportation net. Proximity to the highway permits easy access for the interior street system. The portion of the project near the highway is quite flat but considerable slope exists at the extremities of the site. Serious erosion has already affected the streets within the project. Houses are constructed of either concrete block or concrete panels which were poured on the ground and lifted into place and subsequently bolted together. The latter construction was found to be problematic, and abandoned. Houses contain approximately twenty-five square meters of space. Lots (approximately twenty by twenty-five meters) are large enough to provide space for gardens. Water and sanitary facilities are provided externally. The provision for a piped external water supply to each yard alleviates some of the potential health hazards posed by pit latrines.

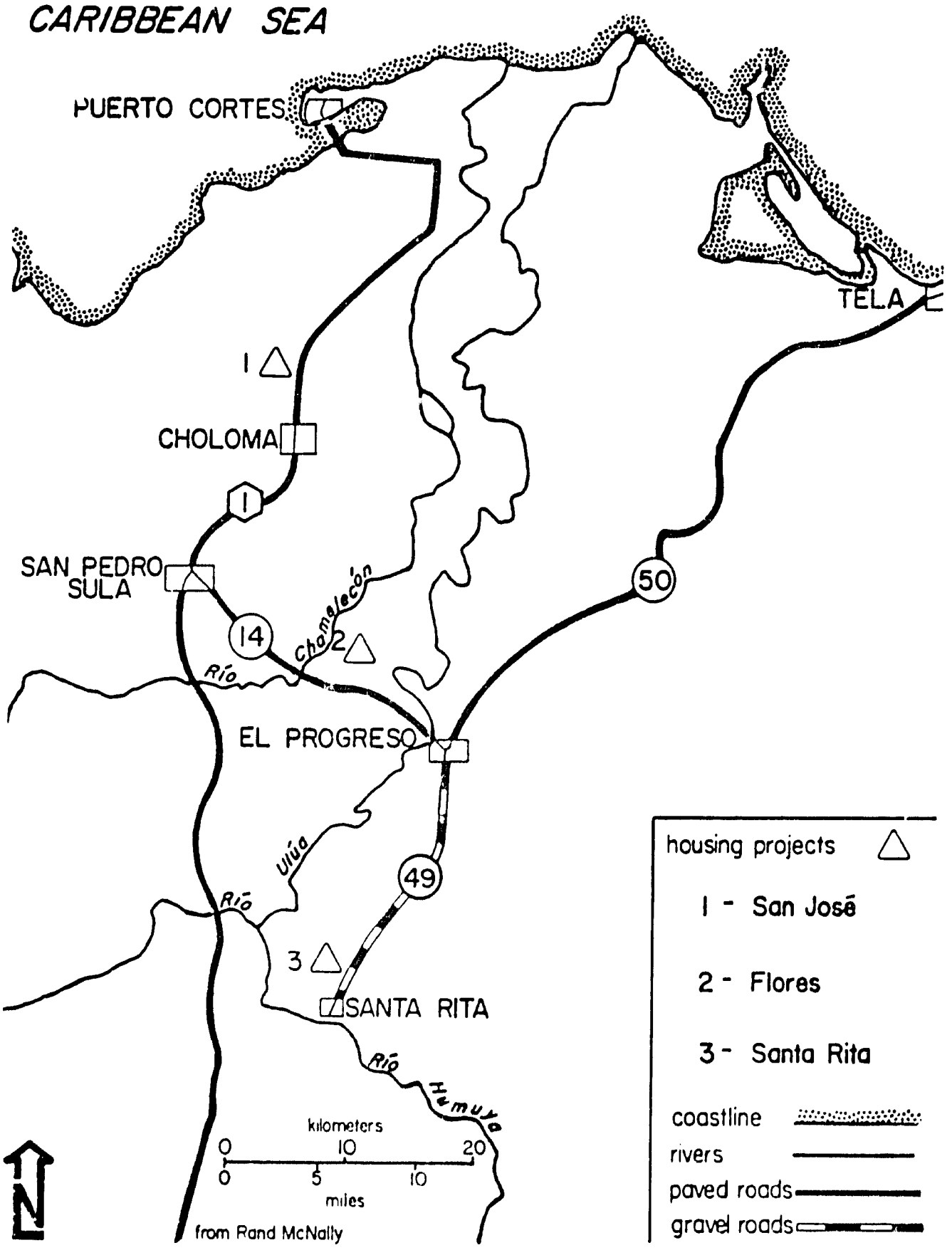
The household heads have the lowest mean age (33.2) and have the second lowest mean formal educational level (1.9 years). The large majority of the residents formerly lived in "champas" (83%) and only one in three had hard floors. In their pre-disaster houses they had fewer basic services than other project residents (only 2% had electricity, 4% had baths, and 10% lived in houses with water). Thus, compared to the other projects, residents of San José come from poor backgrounds, but have received very good houses in a well sited location.

Flores de Oriente contains 127 houses and is approximately two kilometers off the old San Pedro-El Progreso highway on an unimproved road. While this distance might not appear excessive, from a relative distance point-of-view it is perceived as being poorly

CENTRAL AMERICA

HONDURAS
STUDY AREA
N

Sula Valley


CARIBBEAN SEA
PUERTO CORTES
TELA
1
CHOLOMA
1
SAN PEDRO SULA
14
Chamelecón
2
Río
EL PROGRESO
50
Ulúa
49
Río
3
SANTA RITA
Río
Humuya
kilometers
0
10
20
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5
10
miles
from Rand McNally
N
housing projects
1 - San José
2 - Flores
3 - Santa Rita
coastline
rivers
paved roads
gravel roads

sited by the residents. The site is completely flat, occupying land formerly used for banana cultivation. It is often flooded during the rainy season and was inundated by two to three meters of water during Fifi. All houses were constructed of wood with earthen floors and contain approximately twenty-four square meters of interior space. The project provides ample space around the houses for garden plots, plus considerable farm land is available to the residents. Water was provided by eight wells and sanitary facilities were provided externally. Poor drainage characteristics, high water table, and the use of pit latrines pose a potentially serious health problem. This project was established to house persons from the general area as no village existed here prior to Fifi.

Our survey found that Flores had the highest percentage of single household heads and that more were engaged in agriculture (40%) than any of the other projects. It also had the lowest educational level per household head which is undoubtedly related to the large percentage in agriculture. More than 80% of the residents formerly lived in houses lacking hard floors and classified as champas. Over 90% lacked electricity and bathing facilities and 37% had water. Thus, the families were poorly housed prior to Fifi and have received comparatively small, minimal housing at the poorest site.

Santa Rita contains ninety-two houses and is the most remote project from the regional urban center, San Pedro Sula. It is located on a poorly maintained gravel road which provides regular bus transportation to El Progreso during all but the worst part of the rainy season. The project is adjacent to the town of Santa Rita which provides most urban functions (excluding water). The site is relatively level and the lots are adequate for garden plots. The most serious physical problem is the low water table. It is impossible for the residents to reach water by hand-dug wells. The availability of a regular market located at the edge of the project alleviates most of the transportation needs. All houses are of concrete block with concrete floors and contain approximately forty square meters of floor space. Sanitation facilities are provided externally, but no water is provided. Some of the pit latrines have proven inadequate due to poor construction; approximately one-fourth have been rendered useless due to collapsing of the pits' walls. This is the only project where a community center was built as part of the project.

This project has the highest rate of unemployment (19.4%) and contains the lowest percentage of female household heads. Compared to the other projects resident characteristics were very average. Prior to Fifi, residents lived primarily in champas with dirt floors. They also came from houses that rarely contained water, electricity, and baths.

Thus, residents came from rather poor housing and have received good housing with mixed advantages (adjacent to city services and market, good housing, but lacking an adequate water supply).

User Response To New Housing

In June, 1977, two years after the houses were completed, we interviewed a random sample of approximately forty percent in the three housing sites. The net completion rate in each project was in excess of 75%. Since more than two years had lapsed since the completion of the Projects the newness of the houses had faded and residents were well established in the routines of living. Responses to the new housing was elicited at three levels in order to evoke the most representative and valid responses. First, residents were asked two open-ended questions related to what they like most and least about living in their new residences. Second, they were asked to compare their present situation with their previous housing in terms of the ease of adjustment, the house itself, its location and neighborhood. Finally, they were asked 23 specific questions about various facets of their new residence and locations. Responses to these questions were either "Satisfactory," "Acceptable," or "Unsatisfactory."(6)

For both of the open-ended questions respondents were instructed to give what they considered the single most important response. Table I contains the responses to, "What do you like most about living in this Project. "Everything," reflects the wording of the respondents while "Quality of life" includes such statements as tranquility, security, and atmosphere. The more specific responses such as "Houses," "Water," and "Location" undoubtedly reflect significant improvements over their previous housing situations a very small percentage in Flores and Santa Rita found "Nothing" to like in their projects.

1
TABLE

What Do You Like Most
About Living In This Project?

	No.	Everything (%)	Quality Of Life (%)	Water (%)	House (%)	Location (%)	Nothing (%)
San José	(50)	4.0	32.0	10.0	28.0	26.0	None
Flores	(41)	9.8	51.2	2.4	26.8	4.9	4.9
Santa Rita	(34)	11.8	26.5	2.3	41.2	14.7	5.9
Total	(125)	8.0	36.8	4.8	31.2	16.0	3.2

Table 2 reports what the residents like least about their Project and these negative answers are undoubtedly more revealing for evaluative purposes. A number of categories in the Table stand out. First, the large number of persons in San José that have no complaints whatsoever. Second, the large percentage of persons in Flores and Santa Rita that indicate "water" as the central problem. In San José, 31.0% found that inadequate "Lights" were problematic. In each Project there were a very few who found "House Construction" to be that which they liked least.

2
TABLE

What Do You Like Least
About Living In This Project?

	No.	No Complaint (%)	Lights (%)	Water (%)	Location (%)	Streets (%)	House Const. (%)
San José	(45)	51.0	31.0	None	8.9	4.4	4.4
Flores	(35)	11.4	11.4	54.3	None	14.3	8.6
Santa Rita	(37)	11.1	11.1	75.0	None	2.8	2.8
Total	(117)	25.5	18.8	39.3	3.4	6.8	5.1

The four comparative questions are approximately mid-way between the previous open-ended questions and the specific questions that follow in terms of generality and focus. The first question asks, "Have you found settling and adaptation to the mode of life in this Project better, equal or worse than in previous places of residence?" Table 3 contains responses and it is clear that for most residents adaptation has been better or at least equal as compared to previous times. Only in Santa Rita (18.9%) have more than 10% of the residents found such adjustments more difficult.

3
TABLE

Adaption To The Way Of Life In
Present Residence As Compared To Previous Ones

	No.	Better (%)	Equal (%)	Worse (%)
San José	(50)	72.0	18.0	10.0
Flores	(42)	78.6	14.2	7.1
Santa Rita	(37)	62.2	18.9	18.9
Total	(129)	71.3	17.1	11.6

Table 4 contains responses to the question, "Is this house better than the one you previously lived in?" Generally, the response is very positive. Only in Flores de Oriente was the dissatisfaction level near ten percent.

4
TABLE

Is This House Better Than
The One You Previously Lived In?

	No.	Better (%)	Equal (%)	Worse (%)
San José	(50)	98.0	2.0	None
Flores	(42)	85.7	4.8	9.5
Santa Rita	(36)	91.7	5.6	2.8
Total	(128)	92.2	3.9	3.9

The quality of present and past house location is compared in Table 5. Satisfaction in this case is more widespread than in the two previous questions. Although it is clear that Flores de Oriente

and Santa Rita are remote by any measure, their location is better than where the residents previously lived.

5
TABLE

Is This Location Better Than
Where You Previously Lived?

	No.	Better (%)	Equal (%)	Worse (%)
San José	(50)	98.0	2.0	None
Flores	(42)	88.1	4.8	7.1
Santa Rita	(37)	91.9	5.4	2.7
Total	(129)	93.0	3.9	3.1

Neighborhoods of previous and present house locations are compared in Table 6. Satisfaction is again very high, only 4.8% in Flores de Oriente find it worse.

6
TABLE

Is This Neighborhood Better Than
Where You Previously Lived?

	No.	Better (%)	Equal (%)	Worse (%)
San José	(50)	98.0	2.0	None
Flores	(42)	83.3	11.9	4.8
Santa Rita	(37)	86.5	13.5	None
Total	(129)	89.9	8.5	1.6

On these comparative questions the new residences are clearly perceived as better than their pre-disaster housing situation. This is strong evidence that these people have improved their standard of housing, a situation one cannot generally expect in housing third world people after disasters.

In order to focus on the more specific facets of satisfaction among residents questions were asked concerning the following topics: (1) institutional services, (2) work, (3) housing, (4) housing facilities, (5) site characteristics, and (6) social environment. Responses to these questions were either "Satisfactory," "Acceptable," "Unsatisfactory," or "Do not know." "Satisfactory" and "Acceptable" have been combined and treated as positive responses. This was done due to the small number of respondents answering "acceptable." "Do not know" responses were omitted from our analysis. The Tables contain the percentage of persons responding "Satisfactory" and "Acceptable."

In order to provide a frame of reference for the responses and to maintain consistency of terminology we established four categories of answers ranging from positive to negative. These categories are: (1) "positive" when 85 to 100% respond affirmatively, (2) "moderately positive" for 70 to 84% affirmative answers, (3) 50 to 69% positive responses are labelled "moderately negative", and fewer than 50% positive answers are defined as "negative".

Institutional services include the availability and adequacy of churches, schools, markets and public transportation. The response concerning availability of church was negative at Flores. San José's positive response probably relates to the existence of churches within the project proper while Santa Rita's location next to an existing village makes church facilities readily available. All projects were positive in their response concerning the question of school.

Nearness to market was not problematic for residents of Santa Rita since a new market has recently been built at the edge of the Project. The situation is quite different for Flores and San José. Transportation does not pose a problem for residents of San José and Santa Rita, but is very negative for those in Flores. This is due to the Project's poor siting, at some distance from the main road.

Table 8 contains responses to two facets of work. Both categories indicate some problems in all three Projects. The percentage of persons indicating that there is sufficient work ranges from 61.9% to 76.0%. With reference to nearness to work the range is from 46.0% to 65.9%. The problems of adequate work are endemic in much of the third world and following disasters the situation is exacerbated. Seventeen months after the earthquake in Managua a survey indicated that, "Forty-six percent felt that their job situation

was worse than it had been before the quake."*

7
TABLE
Institutional Services

	Church		School		Market		Transportation	
	No.	(%)	No.	(%)	No.	(%)	No.	(%)
San José	(50)	96.0	(50)	100	(50)	26.0	(50)	94.0
Flores	(42)	40.5	(42)	100	(42)	2.4	(42)	31.0
Santa Rita	(37)	89.2	(36)	100	(37)	100	(37)	89.2
Total	(129)	76.0	(128)	100	(129)	39.5	(129)	72.1

8
TABLE
Work

	Sufficient Work		Nearness To Work	
	No.	(%)	No.	(%)
San José	(50)	76.0	(50)	46.0
Flores	(42)	61.9	(41)	65.9
Santa Rita	(37)	66.7	(37)	51.4
Total	(129)	69.0	(128)	53.9

Table 9 contains responses to house materials (walls, floors, and roof) and interior space. With the exception of flooring in Flores

*Patricia B. Trainer, Robert Bolin and Keyes Ramos, "Reestablishing Homes and Jobs: Families" in J. Eugene Haas, et. al., Reconstruction Following Disasters, The MIT Press, Cambridge, 1977, p. 198.

de Oriente the assessments are very positive (all above 90%). The new houses included walls of sawn lumber (Flores), cement block and reinforced concrete walls (in Santa Rita and San José), corregated tin roofs on all houses, and cement floors in Santa Rita and San José. The negative response in Flores is due to the earthen floors. Interior space, which ranged from twenty-five (San José and Flores) to forty square meters in Santa Rita, was also sufficient for these people. There were no partitions provided in any of the houses.

9
TABLE

Housing

	House Material		Floor Material		Roof Material		Interior Space	
	No.	(%)	No.	(%)	No.	(%)	No.	(%)
San José	(50)	98.0	(50)	98.0	(50)	98.0	(50)	96.0
Flores	(42)	90.5	(42)	31.0	(42)	92.9	(42)	95.2
Santa Rita	(37)	97.2	(37)	91.9	(37)	94.6	(37)	100
Total	(129)	95.4	(129)	74.4	(129)	95.4	(129)	96.9

What we call "Housing Facilities" is contained in Table 10. "Fresh air" or ventilation was provided through the doors, windows, and approximately two inches of space between the roof and the walls. Generally, this amount of ventilation was adequate. This was true also of toilets which were provided outside of the house itself. This was true even when many of them were beginning to sink or fall down when this survey was done. Provisions for "Baths" were simply not satisfactory. There was not specific provision for such in any of the Projects, but the response was not so negative in San José where piped water was available in the yards and bathing was made possible, at least for some of the family members. Interestingly enough there was no "Cooking space" provided at any of the sights, but the response was not overwhelmingly negative. The reason for this is that cooking is almost always done under a separate roof and usually constructed of traditional materials. In cities this situation is different, but in these Projects on the urban fringe and with people from traditional backgrounds it was, essentially, adequate.

10
TABLE

Housing Facilities

	Fresh Air		Toilets		Bath		Cooking Space	
	No.	(%)	No.	(%)	No.	(%)	No.	(%)
San José	(49)	85.7	(50)	98.0	(49)	38.0	(49)	86.0
Flores	(42)	83.3	(42)	92.9	(42)	4.8	(42)	71.4
Santa Rita	(37)	100	(37)	81.1	(37)	0.0	(36)	61.1
Total	(128)	89.1	(129)	91.5	(128)	16.4	(127)	74.0

"Site Characteristics" refers to "Garden Space," "Space between houses," and "General cleanliness." The availability of space on both counts is satisfactory. We felt they might want space for gardens, but that was not true. They use their yards for fruit trees and sometimes for pigs and chickens, but the available space was adequate as the responses indicate. Land is not actually scarce in this part of Honduras, but it is expensive due to commercial agriculture. Cleanliness was only a problem with some residents in Santa Rita.

11
TABLE

Site Characteristics

	Garden Space		Space Between Houses		General Cleanliness	
	No.	(%)	No.	(%)	No.	(%)
San José	(50)	92.0	(49)	95.9	(50)	98.0
Flores	(42)	85.7	(42)	92.9	(42)	95.2
Santa Rita	(37)	94.6	(37)	100	(37)	83.8
Total	(129)	90.7	(128)	96.1	(129)	93.0

Items under "Social environment" cover a variety of items we thought might identify areas of difficulty. Certainly, residents

are happy with the "Class of people" who live there (100%) and with neighborly interaction (99.2%). "Outsider's impression" of the Projects is very high (98.4%) and "Personal security" is not problematic for more than a very few (93.8%). They are certainly located sufficiently near to friends (96.1%), but many could be nearer to their relatives. These responses correspond directly to how far the residents are presently located from their previous domeciles. This is not something that is easy or even possible to control under these circumstances.

12
TABLE

Social environment

	Class of People No. (%)	Neighbor Interaction No. (%)	Outsider's Impression No. (%)	Personal Security No. (%)	Nearness of Friends No. (%)	Nearness/ Relatives No. (%)
S.J.	(50) 100	(50) 100	(50) 100	(50) 96.0	(50) 98.0	(50) 80.0
Flo.	(41) 100	(42) 97.6	(41) 97.6	(42) 95.1	(42) 92.9	(42) 69.1
S.R.	(37) 100	(37) 100	(37) 97.3	(36) 91.7	(37) 97.3	(37) 62.2
Tot.	(128) 100	(129) 99.2	(128) 98.4	(128) 93.8	(129) 96.1	(129) 71.3

The twenty-three questions referring to specific facets of permanent post-disaster housing reconstruction are generally very positive. Of the four categories of resident responses that we constructed 68.1% (47) were "Positive," 8.7% (6) were "Moderately Positive," 10.2% (7) were "Moderately Negative," and 13.0% (9) were "Negative."(Table 13) The problem areas that were identified are: siting and the availability of services to the Projects; work, which is also related to location; the exclusion of certain housing amenities; and a few site specific complaints. Siting or location problems include the availability markets, transportation, church, and to a certain degree resident's relatives. Work, aside from being to some degree locational, is associated with development in general. The exclusion of bathing facilities, floors at Flores, and to a lesser degree cooking facilities and adequate toilets created varying degrees of difficulty for the occupants. Some minor site specific issues were cleanliness and insufficient ventilation at Flores.

13
TABLE

Summary Of Responses By Projects

	San José	Flores	Santa Rita
Church	P	N	P
School	P	P	P
Market	N	N	P
Transportation	P	N	P
Sufficient work	MP	MN	MN
Near work	N	MN	MN
House material	P	P	P
Floor	P	N	P
Roof	P	P	P
Interior space	P	P	P
Fresh air	P	MP	P
Toilet	P	P	MP
Bath	N	N	N
Cooking space	P	MP	MN
Garden space	P	P	P
Between houses	P	P	P
Cleanliness	P	P	MP
Class of people	P	P	P
Interaction	P	P	P
Outsider/Impression	P	P	P
Security	P	P	P
Near-friends	P	P	P
Near relatives	MP	MN	MN

P = Positive.
MP = Moderately positive.
MN = Moderately negative.
N = Negative.

Implications For Post-Disaster Planning

This paper has assumed that satisfactory housing, in general or after disasters, demands more than appropriately constructed buildings. It also assumes that an essential ingredient in planning such satisfactory housing is continuous input from those most familiar with the recipients' needs and interests - the recipients themselves. This input should not begin with a post-disaster survey of how satisfied they are with what they have received, but continuously from conception through construction and completion. Hastily constructed housing without user participation may become temporary and/or residents may feel little commitment.(7)

After looking at nearly four hundred houses built in the Sula Valley for victims of Hurricane Fifi, in light of the interviews and other information we have gathered, we feel there are a number of things that can be said about planning post-disaster housing. Some suggestions, it must be mentioned, did not emerge in the interviews. Post-disaster interviews like the above and user input prior to construction are essential as we say, but other forms and sources of information are also important and not available from the recipients.

First, it is imperative that a thorough knowledge of the economic and developmental trends of the nation and region be known. (And/or a knowledge of the national development plans if they exist and are being consistently and reasonably implemented.) The three Projects we studied were successful in large part because they were in an economically healthy region. In a more recent study of victims of the same hurricane, but in a region of the country that was experiencing economic decline, recipients and non-recipients of aid were generally not better off than before the storm.(8) This is not to say these people should not be assisted, but the priorities and approach would be different. Less resources might be spent on housing materials and more on work generating activities. It is very possible that corregated tin and nails plus tools and cement would be provided and that other available resources be spent on developing a cooperative work place and/or enterprise. The cost of the structural houses at San Jose was $658, in Flores de Oriente $322, and in Santa Rita $759 and in a post facto evaluation of the effort by the architect-engineer, indicated that they spent more money per building in San Jose and Santa Rita than was necessary.

Such national and regional information must come from national or international experts who are thoroughly knowledgable about said countries. It is often difficult information to attain and equally problematic to determine who can provide it objectively and within a reasonable amount of time.

Second, it is necessary that information about the immediate area be known. Be sure, of course, that the site is not vulnerable to future disasters. Nearly half of those built in the three Projects we studied are vulnerable to future flooding.(9) Also, (as an example) be certain that the land you intend to build on has clear title and that it actually belongs to the sponsoring agency. The residents at San Jose and Santa Rita apparently own their houses, but as of 1978 the issue of land ownership had not yet been settled. We feel confident that it was being settled equitably in San Jose, but we are not certain in the case of Santa Rita. The land upon which Flores de Oriente was built belongs to the National Agrarian Institute and the residents cannot own the property. The arrangement, however, seems to be satisfactory as the residents are told they can live there as long as they wish, but if they move, the houses will be assigned to other families (in 1978 we found that some had already sold their houses to other families and left.)

Another related issue is how committed will the local government be to incorporating the Project into the local service net and infrastructure? Within a year after our survey the government authorities in the region of Santa Rita had provided water to each household and solved the major problem of that Project. They also improved the local roads which was very beneficial. In a locale experiencing economic decline this type of assistance cannot be expected. (It must be mentioned that in this case it was not expected either. The sponsoring agency had simply failed in its efforts to provide adequate water to this Project.)

The information necessary for this type of local knowledge is difficult to gather. Local persons with long term experience will need to be utilized unless the information is available from a reliable, local, regional, or national planning office. We have serious doubts about the latter possibility. This constitutes a particularly difficult problem to solve and takes more time than the average agency or agency representative wants to spend. But, as we are arguing, it is essential for a satisfactory post-disaster housing plan. The post-disaster period is a particularly difficult time to gather reliable information and to make reasonable business transactions. Prices for goods and the problems of fraud undoubtedly increase and outsiders are particularly vulnerable to these risks.

Finally, as we have been arguing, input at the level of recipients is an essential ingredient. They must be actively involved in planning, construction, and they should be expected to pay for some of the expenses incurred. In our study we found that, generally speaking, the housing materials, location, space(10), etc., were not problematic for the users. They fit their cultural and social experience in terms of being acceptable, familiar and useable. Their houses are sufficiently repair intensive, alterable, safe, and appropriate. We know of a case in the Dominican Republic where, after the hurricanes of 1979, post-disaster housing was constructed with plastic roofs. This was unacceptable in the short run because it did not provide sufficient protection from

the sun's rays and was unacceptable in the long run because it was not durable. We have asked over six hundred persons on the north coast of Honduras what they think about corrigated tin roofs and all but two like it and those two had previously lived in much more expensive houses. Part of the preference is due to the unavailability of traditional materials after storms, the fact that they must be replaced every two years, that they house insects and snakes, and that they present a fire hazard: A few good reasons for peasants preferring the material.

Recipients must also be expected to pay a reasonable amount of the costs incurred in such undertakings. Payments must not constitute a financial hardship for the recipients, however. Payments, also, may need to be spaced in relation to the recipients' income fluctuations. Those who depend on income from agriculture will be able to pay most during the harvest season. Turning over the responsibility for payment collection to a local agency may be a wise decision or it may not.

In closing we would like to quote from a report to the President of Guatemala two years after an earthquake devasted that country. It was written by representatives of a Committee of volunteer agencies and lists the five most important mistakes that had been made in their assistance effort.

> . . . too much aid was given away; too many of the houses constructed were merely of an emergency type; some organizations used large numbers of foreign volunteers; too much was done under pressure and without proper consultation, so that the victims became mere spectators of the work carried out rather than participants; a lot of reconstruction work was undertaken without first consulting the Government's Reconstruction Committee.*

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*Reggie Norton, "Disasters and Settlements," Disasters 4/3, 1980, p. 339.

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1. This is mentioned by S. Wortman, "Food and Agriculture," Scientific American 235 (3):31-39.

2. This point is made in William H. Durham, Scarcity and Survival in Central America, Stanford University Press, Stanford, Cal., 1979.

3. See D. N. Snarr and E. L. Brown, "The Impact of Post-disaster Aid: An Evaluation after Five Years," mimeographed, Wilmington College, Wilmington, Ohio 45177, 1981.

4. See J. E. Hass, et. al., Reconstruction Following Disaster, The MIT Press, Cambridge, 1977.

5. See D. N. Snarr and E. L. Brown, "Post-disaster Housing: Attrition & Housing Improvement," mimeographed, Wilmington College, Wilmington, Ohio 45177, 1979.

6. Much of this information is contained in two articles by D. N. Snarr and E. L. Brown, "Post-disaster Housing in Honduras after Hurricane Fifi: An Assessment of Some Objectives," Mass Emergencies 3 (1978), pp. 239-250 and "User Satisfaction with Permanent Post-disaster Housing: Two Years After Hurricane Fifi in Honduras," Disasters 4/1 (1980), pp. 83-92.

7. See No. 5 above.

8. See No. 3 above.

9. See E. L. Brown and D. N. Snarr, "Permanent Post-disaster Housing in Honduras: Aspects of Vulnerability to Future Disasters," Disasters 3/3 (1979), pp. 287-292.

10. See D. N. Snarr and E. L. Brown, "Spatial Aspects of Post-disaster Housing Satisfaction," Ohio Geographer Vol. 7, 1979, pp. 13-21.

INTERNATIONAL WORKSHOP

EARTHEN BUILDINGS IN SEISMIC AREAS

IMPLEMENTATION

The following individual made a keynote presentation:

Eric Carlson
UN Centre for Human Settlements
Nairobi, Kenya

The following individuals acted as Session Chairmen:

Mary E. McKay
Applied Technology Associates
McLean, Virginia

Babar Khan Mumtaz
Development Planning Unit
London, UK

Stephen O. Bender
OAS/Program of Regional Development
Montevideo, Uruguay

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THE EFFECTS OF THE 1976 GUATEMALAN EARTHQUAKE ON EARTHEN HOUSES IN GUATEMALA

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University of Georgia

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ABSTRACT

This paper reports on what has happened to earthen structures in twenty-six Guatemalan communities studied over a four-year period since the 1976 earthquake. The data were obtained from three waves of personal interviews with 1472 randomly sampled household heads. The results show that adobe, which was the primary housing material before the earthquake was heavily damaged in that event. As a consequence the number of adobe structures and of other earthen structures has been drastically reduced. The people of Guatemala individually and because of agency housing programs have abandoned adobe as a building material and turned to concrete block and wood.

Surviving earthen structures have not been improved substantially and remain with largely the same structural features as before the earthquake. The greatest improvement is in the use of corner posts or columns in the walls but most of these are made of untreated crude logs or lumber, subject to rot and termite damage. Little information on aseismic housing seems to have spread either within the earthquake area or in the unaffected areas surrounding it. A program to spread information on how to use adobe in aseismic designs needs to be conducted along with one to assist citizens to acquire the resources necessary to improve the earthquake vulnerability of houses.

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Dr. W. T. Tatrell and Dr. JoAnn E. Glittenberg are co-principal investigators of the larger project from which these data derive and contributed substantially to conceptualization and data collection related to it. Thomas E. Edwards and Walter G. Peacock assisted in all stages of the larger project.

This paper reports on the results of a three-year longitudinal study of the 1976 Guatemalan earthquake. Specifically it examines what has happened to housing in twenty-six sample communities and urban neighborhoods between the pre-earthquake period and 1980. The focus is specifically on earthen buildings as compared to other types of housing.

The data upon which this research is based were obtained from personal interviews with a random sample of household heads in three separate interviews conducted approximately one year apart. The first interview was conducted in 1978; the second in 1979; and the third in 1980. Data on pre-earthquake housing were obtained during the first interview which took place two years after the earthquake. Retrospective questions were used to determine pre-earthquake housing characteristics and to obtain data on what damage was caused by the earthquake to various housing features. The characteristics of subsequent housing structures were obtained by a combination of interview questions and on-site inspection by interviewers. It is useful to think of this study as furnishing data on five time periods, as shown in the following table.

1. T_1 Pre-earthquake (Feb. 3, 1976)
2. T_2 Earthquake (Damage on Feb. 4, 1976)
3. T_3 Post-earthquake 1978
4. T_4 Post-earthquake 1979
5. T_5 Post-earthquake 1980

Data on T_1, T_2, and T_3 were obtained in the first interview and data on T_4 and T_5 were obtained in separate interviews conducted a year and two years later. A final note which may prove useful is the fact that the second interview at T_4 was conducted with only a 15 percent sample of the households interviewed on the first interview.

Sample

The sample for this study was drawn to meet several criteria. First, some sample units (either communities or urban neighborhoods) were selected to represent units which were within the area heavily affected by the earthquake and others were selected to represent matching units outside the affected area. These two groups of communities, for convenience, are called an experimental group (those heavily affected by the earthquake) and a control group (those only slightly affected or totally unaffected by the earthquake).

Sample units were also selected to represent communities of various size and political status and to represent communities that are primarily Indian or primarily Ladino in population. Thus the pattern outside Guatemala City was to select communities to represent department capitols, municipios and aldeas which were Indian and Ladino. In Guatemala City a special case exists. There is no other city to serve as a control for it. Furthermore, insufficient financial resources existed to do a random survey of the entire city. Therefore four neighborhoods which represent different kinds of reconstruction housing areas were selected as sample units. Two represent planned housing developments, one for Ladinos and the other originally for Indians. A third represents a spontaneously generated refugee shanty-town and the fourth a government refugee style temporary housing development.

In each sample unit maps were drawn and a random sample of households interviewed. These same households were interviewed on successive interviews in a panel style design. All interviews were conducted at the housing site by a team of eight well-trained female Guatemalan interviewers. Where necessary, interpreters were used to translate between Spanish and an Indian dialect. It is important to remember in interpreting the findings that all data are based primarily on interviewee responses and not on engineering or architectural data collected by experts.

Change in Housing Types

In order to simplify the analysis of data revealing changes in housing styles, a housing typology based on wall-roof combinations was derived from the data. This typology is used in Table 1 to show changes in housing between the pre and post earthquake periods for the experimental group, control group and the city.

The first thing to note is the fact that the experimental group (earthquake impacted communities) contained 83 percent adobe walled houses in the pre-earthquake period as compared to around 40 percent in the control group. In the experimental group most adobe walled houses had tile roofs, while in contrast, most had lamina (corrugated galvanized steel) roofs in the control group. This seems to indicate that a trend towards abandoning adobe as a building material and tile as roofing may have been more advanced in the control group than in the experimental group before the earthquake.

The second fact to note in Table 1 is that by 1980 only about 11 percent of the buildings in the experimental group had adobe walls. Of these, only about seven percent had tile roofs. This represents a difference of 72 percent in the number of adobe housing units in a four year period. In comparison, the control group had dropped to 29 percent adobe walled buildings from a pre-earthquake 40 percent. The larger decrease in the experimental group of course reflects the destruction of adobe buildings in the earthquake and their replacement by non-adobe structures. In the control group little damage was suffered in comparison and a proportionately larger number of adobe structures survive. However, it is evident that control group members are also abandoning adobe as a wall material at a relatively rapid rate. Commensurate with the reduction in adobe as a wall material is the abandonment of tile for roofing and the substitution of lamina for it.

These changes in housing style are the consequence of both individual decisions and large-scale agency programs. Agency programs in particular featured either wooden structures, houses constructed of concrete block, or of half block-half wooden walls. These agency programs are reflected in changes observed in the experimental group where wooden structures increased from 0.75 to 23.37 percent; block from 1.74 to 24.70 percent; and half and half from 5.35 to 16.57 percent. These same sorts of trends, however, are reflected in the control group where no agency housing programs existed, but to a lesser extent. There changes are the consequence of individual decisions instead of outside agency policies.

Changes in the city reflect the same sort of trend observed in the experimental and control groups. Because of our sampling method, however, these data must be interpreted differently. Only new housing areas to which people had moved after the earthquake were studied in the city. Therefore, no one is living in the same house as before that event. In three of the four city samples all houses were "agency built" and none were adobe. In one area all were of wood; in two others all houses were of concrete block with lamina roofs. Only in the squatters settlement were buildings self-built or self-designed. Most of these fell into the patchwork category - meaning that they were made of scraps of any available material.

What this table does show is that 206 out of the 320 people studied in the city formerly lived in adobe structures, or about 64 percent of them.

Damage to Various House Types

In order to determine the amount of damage suffered by each household, the household head was asked to rate the damage to various house features on the following scale.

Damage Score	Damage Category
0	None
1	Slight (requiring only minor repairs)
2	Heavy (requiring extensive repairs)
3	Destroyed (needing complete rebuilding)

Table 2 shows damage scores for the average damage to the walls of a house by each house type. A score of 3.00 would mean the walls were destroyed; a score of 2.00 that they were heavily damaged, etc. With respect to adobe houses with tile roofs the figure shown in the table is 2.38. In other words, for the 410 such houses, the average damage to the walls was between "heavy" and "destroyed." The table also shows the average wall x roof damage. The figure 2.29 means that when damage to wall and to roof are averaged for the 410 adobe houses with tile roofs, the result shows that they suffered between "heavy damage" and "destroyed." Similar figures are presented for the control group and for each house type. These figures indicate that the control group suffered only slight damage on an average, while the experimental group suffered from very heavy to slight damage, depending on house type.

Adobe structures stand out as those suffering the greatest damage, while wood, block and thatch stand out as suffering only slight damage. Another thing that is apparent is that bajareque structures (cross-woven sticks attached to posts and filled with earth) fared considerably better than plain adobe. Another point which is surprising is the apparent fact that adobe buildings with lamina roofs fared slightly worse than those with tile roofing. This difference is significant for damage to walls but not for damage to the roof. In other words, there is a significant difference in the amount of damage suffered by adobe walls when they have lamina or tile roofs with the lamina roof being associated with greater damage. This may be due to the use of heavier timbers to support the roofs of houses using tile for roofing.

In Table 3 earthen and non-earthen structures are compared with respect to damage. Earthen structures include houses with walls constructed of (1) adobe, (2) bajareque, (3) tapia, or (4) half adobe and half light weight upper wall material. Non-earthen houses consist of all others. For the entire sample, including the control and experimental groups, as well as the city, earthen structures suffered much heavier damage (2.12) than non-earthen ones (0.64). The difference is highly significant statistically. Furthermore, this difference holds up in all sample groups. Even in the control group, where the damage was characteristically light, earthen buildings suffered significantly more damage.

It should be noted that almost all of the earthen buildings in this sample

were constructed of adobe. As a consequence these figures are heavily influenced by this type of structure.

Housing Features Combined with Earthen Structures

During the first interview data were collected concerning certain structural features of houses. Among the features studied were the following: (1) foundations, (2) columns or corner posts, (3) vegas or beams, (4) solera or roof plate and (5) cross bracing in the walls. Respondents were asked if their house contained such a feature and what material was used in constructing it. Tables 4 through 8 show the information obtained for pre and post-earthquake earthen structures.

First, with respect to foundations, most earthen structures either had no foundation, or one made of adobe or packed mud before the earthquake (55.61%). About seventeen percent had foundations of loose stones. Only about 20 percent had more stable foundations. Two years after the earthquake the proportion of earthen buildings with no foundations or with one of adobe or packed mud, had decreased to 52.40 percent and two years later to 45.61 percent. More structures show up as having stone, rock or cement foundations in 1978 and in 1980. There appears therefore to have been a slight improvement in the stability of foundations used in adobe buildings since the earthquake.

The use of columns or corner posts as shown in Table 5 has considerably increased. Before the earthquake over 75 percent of all earthen structures lacked corner posts. By 1978 only 35 percent were without them. This may be due to the greater survivability of adobe structures with such a feature rather than to the introduction of this practice in the post earthquake period. The greatest increases in the use of a given material for use in corner posts occurred with respect to rough logs or crude lumber, however. Since they are subject to rot and termite damage, the benefit may be only temporary. There is little support for the idea that stronger, more durable materials are being employed for this purpose.

Almost all houses made of adobe or other earthen materials used vegas or beams at the top of the walls running from front to rear. As shown in Table 6, almost all of these were made of rough logs or crude lumber before the earthquake. Since then, the proportion using more substantial materials has increased slightly, but not significantly.

Similarly, almost all earthen houses (91%) employed some type of plate or solera at the top of the walls to support the roof. Most were made of some form of sawed or milled lumber or of untreated logs. The proportion using each material has changed little since the earthquake, although it appears that more are using crude logs instead of milled lumber. (See Table 7)

Finally, cross bracing of any sort is very rare in earthen structures in Guatemala. Before the earthquake 94 percent lacked this feature. Since the earthquate proportionately fewer earthen houses employ any form of cross bracing. The change, however, is minor. (See Table 8)

The above discussion leads to the conclusion that except for a greater use of crude corner posts, there has not been much change in the structural features of earthen houses in Guatemala since the 1976 earthquake. In large part, this may be due to the fact that in the experimental group earthen buildings have dramatically decreased. People seeking greater earthquake protection are seeking it by abandoning adobe as a building material, rather than by improving adobe structures. Most of

the earthen structures remaining after the earthquake that are shown in the above tables are located in the control group area which lies outside the area experiencing the destructive effects of the earthquake. Here little information concerning earthquake resistance and earthen structures may have penetrated. A later section of this paper will examine the information people received concerning aseismic construction.

Damage to Earthen Structures Having Various Features

It is possible, given the data discussed above, to examine what respondents reported in terms of damage to earthen structures with various types of structural features. For example, what do the data show concerning what happened to earthen buildings without foundations or with foundations made of less stable materials such as adobe, packed mud or loose stones as compared to those with foundations of concrete, reinforced concrete, or rock and cement? Table 9 shows the results of this comparison.

As can be seen, our data show no difference in the amount of damage suffered by earthen buildings with different types of foundations. This is probably due to the fact that few of them contained columns or corner posts to attach them to their foundations.

A similar procedure can be followed with respect to how the presence or absence of support columns or corner posts affected the damage suffered by earthen buildings. Table 10 shows damage figures for earthen structures in the experimental group that used any kind of corner post or support column against those that employed none at all. This table shows that earthen buildings with corner posts suffered significantly less damage than those without them. This is true of wall and roof damage considered separately or together. Nevertheless, buildings with corner posts of the type used by the people in this survey (crude logs or rough lumber) still suffered rather heavy damage. On our scale it comes very close to "heavy damage" as opposed to "light damage" or "none."

The only other feature on which there were enough cases to test an hypothesis was "solera." The solera, as defined for our study, consists of the plate at the top of the wall upon which the roof structure rests. When houses with no solera, or with one made of crude logs or lumber, were compared to those made of milled lumber or concrete, either reinforced or not, the results shown in Table 11 were obtained. This table seems to show that houses with more elaborate soleras suffered more damage than those with simpler cruder ones. A test was made to examine those with no solera at all against those with them and similar results were obtained. Houses without soleras suffered less damage than those with them. When houses with soleras were examined to see how the presence or absence of corner posts affected damage, it was found that having corner posts or not having them did not affect the amount of damage if a house had a solera. In short, our data seem to show that earthen structures with some form of solera or plate at the top suffered more damage than those without them. This also seems to have been unaffected by the type of roof on the house. For example, when houses with soleras were compared on whether or not they had tile roofs or non-tile roofs, it was found that there was no difference according to the type of roof.

It must be remembered that these data are the result of a survey by a team of interviewers who recorded the evaluations of householders concerning damage suffered by their houses, and also reported the structural features of these houses. It is hard to imagine a psychological or attitudinal bias that would affect nearly 500

respondents in such a way that they would tend to misreport damage to houses with a given structural feature. We are left with the conclusion that soleras, as employed in Guatemala, produced greater damage than would occur without them.

Information Received and Actions Taken Concerning Aseismic Construction in Housing

During the first interview respondents were asked two questions designed to determine their perceptions of aseismic housing construction. First, they were asked what they had heard about how to make houses safer in an earthquake. Later they were asked if they had done anything to improve the earthquake safety of their homes and what it was that they did. Table 12 gives a tabulation of answers to these questions.

First, it is important to note that respondents volunteered these responses. They were not asked, for example, if they had heard that steel reinforcement in walls was a good thing. Instead, they had to supply the answer without prompting from the interviewer. The question asking what they had done to improve the safety of their home was asked in a similar fashion.

The most significant bits of information in Table 12 are that almost 73 percent of all respondents said they had heard nothing concerning the improvement of earthquake resistance in housing and almost the same percentage said they had done nothing to improve the aseismicity of their homes. When the control and experimental groups are compared, the data show that only slightly more people in the experimental group (heavily impacted communities) heard advice on this subject than in the control group. (Experimental Group about 29%; control group about 25%) The city sample shows the smallest proportion of people claiming to have heard something (24%). This is probably the result of the fact that the sample here consists of people who were completely rehoused by agency programs or by the founding of a squatters settlement. They were people without land, mostly renters, from the poorest segment of the city's population, making them an especially disadvantaged group. They were less likely to have access to mass media. Most of them were also rehoused by agency programs where advice on aseismic construction was not featured.

There is a much larger difference, however, between the control and experimental groups in how many respondents reported doing something. In the control group 79 percent said they did nothing as compared to 67 percent in the experimental group. The comparable figure for the city is 84 percent who did nothing.

These data show that surprisingly few respondents claimed to have heard anything about aseismic construction. More discouraging is the fact that even in the earthquake impacted area two-thirds did nothing to improve their situation. In the surrounding lightly impacted area of the control group, over 78 percent did nothing to improve the earthquake resistance of their houses. In other words, a relatively small spill-over of activity from the earthquake area to improve aseismicity in non-impacted areas occurred.

When the types of advice heard and the types of actions taken are examined in detail, it appears that the most frequent sorts of advice heard were: (1) use concrete columns (8.62%); (2) use block or brick for wall material (6.52%); (3) don't use adobe (5.98%). No other advice was heard by as many as 5 percent of the sample. The most frequent actions taken were: (1) use of wood bracing (7.61%); (2) use of concrete columns (6.73%); and (3) non-use of adobe (3.60%).

When those who received information on improvement in the earthquake resistance of their housing were asked where they obtained their information, the data shown in Table 13 were obtained. This table shows that the most frequent response was that they already knew what was safer before the earthquake (14.95%). After that the major source of information was from the informal network of neighbors and relatives (12.02%). Talks given by agencies reached only 6.72 percent and agency publications only 1.83 percent. In the experimental group proportionately more people (9.08%) obtained information from agency talks or from agency pamphlets (2.99%) than in the control group or city. Likewise, more obtained information from the informal network (13.06%). Interestingly enough, radio and television were the major sources of information in the control group (11.21%) after "previous knowledge," but radio and television were reported by only 3.11 percent in the experimental group and 3.44 percent in the city as their sources of information. This probably reflects the fact that control group members obtained almost all of their information about the earthquake's effects indirectly through the mass media since they were not first-hand witnesses to the event. On the other hand, experimental group members and members of the city sample were in the midst of the destruction and knew first-hand what was going on. They may not have listened to radio and television reports as frequently for this reason.

At any rate, this table seems to show that, to be effective, an information program concerning housing improvement in a disaster occurring in a country like Guatemala should be conducted on a face-to-face basis within the disaster area itself, using the informal network as a primary means of spreading information. The mass media seem to be of dubious value for this purpose. Television in particular is ineffective since it requires a power source which is apt to be destroyed and the set itself may be easily damaged. Furthermore, in poor areas there are likely to be few televisions available to begin with.

Furthermore, it is apparent that in Guatemala an educational program aimed at disseminating information on aseismic housing features, especially as they relate to earthen buildings, is needed if the future earthquake vulnerability is to be reduced. This must be accompanied by a governmental program designed to assist citizens to obtain the materials necessary to follow the practices prescribed by the educational program.

The situation is even more acute outside the high impact area of the 1976 earthquake than within it. In the impacted area changes in housing have occurred in the direction of safer housing, but in the surrounding unimpacted areas, housing remains largely as it was before February 1976. A future earthquake in these areas is highly probable and consequences similar to those of 1976 can be expected unless some change in housing takes place. The further away from 1976 we get the less likely lessons learned then will be applied to improving older structures and the more likely a new occurrence of a disaster becomes.

This research shows that the primary adaptation of people in Guatemala to earthquake vulnerability has been to abandon the use of traditional earthen buildings and to shift to the use of concrete block and wood as primary building materials. Wood is a scarce and expensive commodity. The country is already faced with a deforestation problem because of the use of wood as the primary fuel used in cooking. Concrete block is expensive, and if used improperly, as dangerous as adobe.

A more desirable solution to the problem of aseismic housing would be to find a cheap and effective means of improving the aseismic qualities of adobe. Some have suggested an emphasis on bajareque construction or the use of adobe de canto. Sporadic efforts by some agencies to promote these ideas have so far shown little success

outside of a few communities where the programs were highly concentrated. Whatever program is chosen must match the spread of technical information with methods to make the financial and material resources necessary to carrying them out available on a widespread basis.

TABLE 1

House Types Before and After the Earthquake in the Control and Experimental Groups

House Types (wall x roof)	Experimental Group						Control Group						Guatemala City					
	Pre EQ House (1976)		House Time 3 (1978)		House Time 5 (1980)		Pre EQ House (1976)		House Time 3 (1978)		House Time 5 (1980)		Pre EQ House (1976)		House Time 3 (1978)		House Time 5 (1980)	
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%
Adobe-Tile	410	51.00	54	6.71	49	7.25	59	16.95	29	8.33	23	7.52	20	6.25				
Adobe-Lamina	255	31.72	32	3.98	26	3.85	81	23.28	79	22.70	65	21.24	186	58.13				
Wood-Lamina or Duralita	6	.75	209	25.00	158	23.37	21	6.03	38	10.92	30	9.80	46	14.38	101	31.56	87	32.46
Block-Lamina or Duralita	14	1.74	128	15.92	167	24.70	25	7.18	45	12.93	61	19.94	27	8.44	150	46.88	129	48.13
Bajareque-Thatch	34	4.23	11	1.37	7	1.04	9	2.59	4	1.15	5	1.63	1	.31				
Bajareque-Tile	14	1.74	16	1.99	10	1.48	10	2.87	9	2.59	5	1.63	1	.31				
Cane-Thatch	14	1.74	16	1.99	13	1.92	45	12.93	31	8.91	20	6.54	1	.31				
Cane-Lamina, Duralita	8	1.00	54	6.72	44	6.51	36	10.34	37	10.63	31	10.13	5	1.56				
Patchworks-Any Roof	3	.37	68	8.46	41	6.06	1	.29	9	2.59	4	1.31	10	3.13	45	14.06	40	14.92
Half Block or Half Adobe-Half Light Material	3	5.35	128	15.92	112	16.57	13	3.74	19	5.46	19	6.21	6	1.88				
Other	43	5.35	88	10.94	49	7.25	48	13.79	48	13.79	43	14.05	17	5.31	24	7.50	12	4.48
TOTAL	804	100.00	804	100.00	676	100.00	348	100.00	348	100.00	306	100.00	320	100.00	320	100.00	268*	100.00
Missing Cases Due to Attrition			-		128		-		-		42							

* 52 of the original 320 cases were unavailable for reinterview.

TABLE 2

Average Damage To Various Types of Walls and Wall Roof Combinations in the Experimental, Control Group and City.

House Types (wall x roof)	Experimental Group					Control Group					Guatemala City					Total, Experimental, Control & City				
	Wall Damage			Average Wall-Roof Damage		Wall Damage			Average Wall-Roof Damage		Wall Damage			Average Wall-Roof Damage		Wall Damage			Average Wall-Roof Damage	
	N	Mean*	St. Dev.	Mean*	St. Dev.	N	Mean*	St. Dev.	Mean*	St. Dev.	N	Mean*	St. Dev.	Mean*	St. Dev.	N	Mean*	St. Dev.	Mean*	St. Dev.
Adobe-Tile	410	2.38	.92	2.29	.88	59	.98	.91	.88	.88	20	2.65	.49	2.52	.57	489	2.13	.99	2.22	1.02
Adobe-Lamina	255	2.58	.73	2.41	.90	81	.74	.73	.44	.56	186	2.42	.77	2.17	.96	522	2.02	1.11	2.23	.99
Wood-Lamina or Duralita	6	0.00	0.00	0.00	0.00	21	.04	.22	.02	.11	46	1.13	.98	1.01	.97	73	.64	.91	.77	.95
Block-Lamina or Duralita	14	.57	.85	.39	.79	25	.20	.50	.12	.33	27	.91	1.07	.70	.96	66	.41	.78	.58	.89
Bajareque-Thatch	34	1.71	1.17	1.44	1.19	9	.44	1.01	.44	1.01	1 1	1.00 1.00	-- --	.50 .50	-- --	44	1.22	1.21	1.43	1.23
Bajareque-Tile	14	1.64	1.22	1.68	1.17	10	.50	.97	.55	1.01	1	3.00	--	3.00	--	25	1.28	1.25	1.24	1.27
Cane-Thatch	14	.50	.94	.46	.91	45	.24	.68	.21	.62	1	0.00	--	0.00	--	60	.27	.70	.30	.74
Cane-Lamina, Duralita	8	1.88	1.36	1.81	1.41	36	.17	.61	.12	.53	5	2.20	1.30	2.20	1.30	49	.61	1.15	.65	1.16
Patchwork-Any Roof	3	1.33	1.53	1.33	1.44	1	1.00	--	.50	--	10	1.60	.84	1.20	.89	14	1.18	.95	1.50	.94
Half Block or Half Adobe Half Light Material	3	1.33	.57	1.00	.87	13	.23	.44	.12	.22	6	2.00	1.26	1.92	1.16	22	.73	1.09	.86	1.08
Other	43	1.74	1.27	1.69	1.17	48	.48	.71	.33	.53	17	1.18	.95	.97	.89	108	.98	1.09	1.09	1.16
TOTAL	804	2.27	1.02	2.15	1.03	348	.50	.78	.38	.67	320	2.01	1.04	1.79	1.12	1472	1.80	1.21	1.66	1.22

*0 = No Damage, 1 = Slight Damage, 2 = Heavy Damage, 3 = Destroyed

Table 3

Damage to Earthen and Non Earthen Buildings in the Experimental, Control Group and Guatemala City

	0 None		1 Slight		2 Heavy		3 Destroyed		Total		Mean	t	d.f.	Significant Level
	No	%	No	%	No	%	No	%	No	%				
CONTROL GROUP														
Non Earthen	131	86.75	12	7.95	6	3.97	2	1.32	151	100.0	0.20	- 7.30	342	.0001
Earthen	91	46.19	73	37.06	25	12.69	8	4.06	197	100.0	0.75			
Total	222	63.79	85	24.43	31	6.91	10	2.87	348	100.0				
EXPERIMENTAL GROUP														
Non Earthen	38	58.46	11	16.92	6	9.23	10	15.38	65	100.0	0.82	-10.99	72	.0001
Earthen	40	5.42	77	10.42	178	24.09	444	60.08	739	100.0	2.40			
Total	78	9.72	88	10.95	184	22.89	454	56.47	804	100.0				
CITY														
Non Earthen	36	33.64	30	28.04	28	26.17	13	12.15	107	100.0	1.17	-11.28	165	.0001
Earthen	4	1.88	23	10.80	63	29.58	123	57.75	213	100.0	2.43			
Total	40	12.50	53	16.56	91	28.44	136	42.50	320	100.0				
TOTAL SAMPLE														
Non Earthen	205	63.47	53	16.41	40	12.38	25	7.74	323	100.0	.64	-23.62	561	.0001
Earthen	135	11.80	173	15.08	266	23.15	575	50.04	1149	100.0	2.12			
Total	240	23.17	226	15.35	306	20.79	600	40.76	1472	100.0				

TABLE 4

Foundations of Earthen Buildings

Foundation Types	Pre Earthquake House 1976		Post Earthquake House 1978		Post Earthquake House 1980	
	#	%	#	%	#	%
None	141	12.27	123	29.57	76	24.76
Adobe	461	40.12	88	21.15	61	19.87
Packed Mud	37	3.22	7	1.68	3	0.98
Loose Stones	197	17.14	79	18.99	73	23.78
Rock or Cement	222	19.32	94	22.60	76	24.76
Concrete - No Reinforcement	5	0.44	3	0.72	2	0.65
Reinforced Concrete	6	0.52	3	0.72	3	0.98
Other	6	0.52	5	1.20	2	0.65
No Information	74	6.44	14	3.36	11	3.58
TOTAL	1149	100.00	416	100.00	307	100.00

TABLE 5

Columns or Corner Posts in Earthen Structures Before and After the Earthquake

Types Columns or Corner Posts	Pre Earthquake House T_1 1976		Post Earthquake House T_3 1978		Post Earthquake House T_5 1980	
	#	%	#	%	#	%
None	865	75.28	147	35.34	114	37.13
Rough Logs	154	13.40	162	38.94	110	35.83
Treated Logs	0	0.00	1	0.24	2	0.65
Crude Lumber	98	8.53	83	19.52	61	19.87
Treated Lumber	0	0.00	3	0.72	3	0.98
Unreinforced Concrete	5	0.44	2	0.48	2	0.65
Reinforced Concrete	12	1.04	14	3.36	11	3.58
No Information	15	1.30	4	0.96	4	1.30
TOTAL	1149	100.00	416	100.00	307	100.00

TABLE 6

Beams or Vegas in Earthen Structures Before and After the Earthquake

Types Beams or Vegas	Pre Earthquake House T_1 1976		Post Earthquake House T_3 1978		Post Earthquake House T_5 1980	
	#	%	#	%	#	%
None	1	0.09	1	0.24	0	0.00
Rough Logs	390	33.94	157	37.74	111	36.16
Treated Logs	5	0.43	5	1.20	4	1.30
Crude Lumber	740	64.40	250	60.10	188	61.24
Treated Lumber	8	0.70	3	0.72	2	0.65
Metal	0	0.00	0	0.00	1	0.33
No Information	5	0.43	0	0.00	1	0.33
TOTAL	1149	100.00	416	100.00	307	100.00

TABLE 7

Solera in Earthen Buildings

Types of Solera	Pre Earthquake House 1976		Post Earthquake House 1978		Post Earthquake House 1980	
	#	%	#	%	#	%
None	99	8.62	38	9.13	22	7.17
Milled Lumber	746	64.93	252	60.58	188	61.24
Concrete	3	0.26	0	0.00	0	0.00
Reinforced Concrete	13	1.13	8	1.92	4	1.30
Metal	0	0.00	0	0.00	0	0.00
Untreated Logs	269	23.41	118	28.3[illegible]	92	29.97
No Information	19	1.65	0	0.00	1	0.33
TOTAL	1149	100.00	416	100.00	307	100.00

TABLE 8

Cross Bracing in Earthern Structures Before and After the Earthquake

Type of Cross Bracing	Pre Earthquake House T_1 1976		Post Earthquake House T_3 1978		Post Earthquake House T_5 1980	
	#	%	#	%	#	%
None	1083	94.25	404	97.35	294	96.08
Wire	25	2.18	4	0.96	4	1.31
Wood	34	2.96	5	1.20	5	1.63
Iron or Steel	2	0.17	1	0.24	1	0.33
Other	2	0.17	0	0.00	0	0.00
No Information	3	0.26	2	0.48	2	0.65
TOTAL	1149	100.00	416	100.00	306	100.00

TABLE 9

Differences Between Earthen Structures with Stable and Less Stable Foundations in Amount of Damage Reported

Foundation Type	Average Wall and Roof Damage	Average Wall Damage	Average Roof Damage
None, Adobe, Packed Mud or Earth, Loose Stone	2.29	2.39	2.18
Rock & Cement, Concrete, Reinforced Concrete	2.23	2.35	2.11
t	.5635	.4103	.6193
df	737	737	737
Probability	.5732	.6817	.5359

TABLE 10

Differences in Damage to Earthen Structures with and without Corner Posts or Support Columns

Corner Posts	Average Wall-Roof Damage	Average Wall Damage	Average Roof Damage
Without	2.33	2.44	2.23
With	1.97	2.11	1.82
t	3.3101	3.0092	3.2712
df	146	143	152
Probability	.0012	.0013	.0013

TABLE 11

Average Damage to Earthen Structures With Various Types of Solera

Type of Solera	Average Wall-Roof Damage	Average Wall Damage	Average Roof Damage
None, Untreated Logs or Crude Lumber	2.10	2.18	1.99
Milled Lumber, Concrete, Reinforced Concrete or Metal	2.39	2.50	2.28
t	-4.0002	-4.0858	-3.4626
df	564	535	589
Probability	.0001	.0001	.0005

TABLE 12

Advice Heard and Actions Taken Concerning Improvement in Earthquake Resistance in Housing

	Control Group				Experimental Group				Guatemala City				Total			
	What Heard		What Done		What Heard		What Done		What Heard		What Done		What Heard		What Done	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Nothing	260	74.71	274	78.74	568	70.65	537	66.79	243	75.94	270	84.37	1071	72.76	1081	73.44
Stronger Foundation	10	2.87	12	3.45	26	3.23	38	4.73	12	3.75	0	0.00	48	3.26	50	3.40
Non-Tile Roof	8	2.30	5	1.44	26	3.23	18	2.24	4	1.25	2	0.62	38	2.58	25	1.70
Wood Bracing	7	2.01	19	5.46	22	2.74	71	8.83	4	1.25	22	6.88	33	2.24	112	7.61
Concrete-Columns	29	8.33	24	6.90	81	10.08	74	9.20	17	5.31	1	0.31	127	8.62	99	6.73
Block or Brick Walls	24	6.90	9	2.59	50	6.22	20	2.49	22	6.88	0	0.00	96	6.52	29	1.97
Non-Adobe Walls	19	5.46	5	1.44	48	5.97	40	4.98	21	6.56	8	2.50	88	5.98	53	3.60
Reinforced Adobe Walls	2	0.58	2	0.58	27	3.36	8	1.00	0	0	0	0.00	29	1.97	10	0.68
Safer House Site	0	0.00	0	0.00	3	0.37	3	0.37	1	0.31	1	0.31	4	0.27	4	0.27
Light Upper Walls	2	.58	3	0.86	19	2.36	19	2.36	8	2.50	0	0.00	29	1.97	22	1.50
More Space Between Houses	0	0.00	0	0.00	0	0.00	1	0.12	0	0.00	0	0.00	0	0.00	1	0.07
Balanced Door Placement	0	0.00	0	0.00	3	0.37	0	0.00	0	0.00	0	0.00	3	0.20	0	0.00
Doors Open Out	0	0.00	0	0.00	0	0.00	0	0.00	1	0.31	0	0.00	1	0.07	0	0.00
Smaller Door	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Lower Walls	3	0.86	1	0.29	7	0.87	8	1.00	0	0.00	0	0.00	10	0.68	9	0.61
Other	24	6.90	10	2.87	33	4.10	24	2.98	17	5.31	18	5.62	74	5.03	52	3.53
PERCENTAGE BASE	348	100.0	348	100.00	804	100.00	804	100.00	320	100.00	320	100.00	1472	100.00	1472	100.00

TABLE 13

Sources of Information Concerning Housing

Safety or Earthquake Resistance

Source of Information	Control Group		Experimental Group		Guatemala City		Total	
	#	%	#	%	#	%	#	%
None Heard	260	74.71	568	70.65	243	75.94	1071	72.76
Neighbor or Relative	34	9.77	105	13.06	38	11.88	177	12.02
Talks Given by Agency	7	2.01	73	9.08	19	5.94	99	6.72
Radio-Television	39	11.21	25	3.11	11	3.44	75	5.10
Newspapers	6	1.74	2	0.25	3	0.94	11	0.74
Agency Pamphlets	0	0.00	24	2.99	3	0.94	27	1.83
Previous Knowledge	45	12.93	135	16.79	40	12.50	220	14.95
Other	1	0.29	0	0.00	3	0.94	4	0.27
Percentage Base	348	100.00	804	100.00	320	100.00	1472	100.00

DISASTER PREPAREDNESS, LDC VOLUNTEER DEVELOPMENT PROGRAM MANAGEMENT AND TECHNOLOGY TRANSFER IN EARTHQUAKE ZONES

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ABSTRACT Volunteer development programs in LDC often deal with technology transfer; the management of these programs following a major earthquake so that they can disseminate techniques of earthquake resistant construction requires astute programming in the various post earthquake phases, identification of an appropiate technology and transfer media, and accomodation of existing disaster preparedness plans as exercised by the host countr, and volunteer institution.

* The views expressed in this paper are these of the author and do not necessarily reflect those held by the Organization of American States.

1. Introduction

In many of the earthquake prone areas of Lesser Developed Countries (LDC), building construction with earthen materials is prevalent; many of these areas are also the site of volunteer development programs. When a major earthquake affects one of these areas such as the case of Peru, Nicaragua and Guatemala during the decade of the 70's, these volunteer programs are often requested to assist in building reconstruction programs. This paper will focus on three general aspects of such participation - disaster preparedness, program management and technology transfer. Discussion of aspects of teaching development volunteers not directly involved in building construction programs will also be included.

No exhaustive and up to date survey or inventory is available which throughly documents the proceedures and capacities of the multitude of volunteer programs presently operating in earthquake prone areas but past seismic ocurrences such as those mentioned help to define for future reference the breadth and depth of resources these programs represent. To this end, the experience of the U S Peace Corps in earthquake prone areas will serve as a basic point of reference.* While generalizations can be made concerning the participation of volunteer programs based on the Peace Corps experience, invariably circumstances specific to the country, the occurrence of an earthquake, and the happenings that follow a disaster of this nature indicate that even for the same institution, each situation is unique.

2. Volunteer Program Disaster Preparedness

A disaster preparedness proceedure which includes provision for an institution's participation in post earthquake activities in an affected area is often evolved during a long period of time, spurred on by involvement in such disasters and the problems and opportunities that such occurrences bring with them. Be it formalized to the level of a written plan promulgated throughout the institution or otherwise considered in its operations, these are a few characteristics which premise the disaster preparedness process:

a. The first responsibility of the institution is to account for the safety and well being of its members and to plan and execute the proceedures necessary to that end. This activity includes personnel status reporting, establishment of the necessary communication network, evacuation and personal document requirements and contingency plans, disaster information reporting and dealing with news media and information inquiries by third parties, and personal preparedness. Above and beyond those proceedures directly related to the safety and well being of the institution's personnel, a disaster preparedness plan may include applicable skill identification, disaster causation, prediction and hazard location assessment, and precautionary measure analysis particularly for those volunteers in areas of significant seismic activity. Neither a disaster preparedness plan nor volunteer training programs in general deal with techniques of

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* Material prepared by the author for the Peace Corps Staff Country Disaster Preparedness Manual has been included in the preparation of this paper.

earthen building design and construction at any level beyond a basic orientation as to analysis of the structural integrity of prospective housing to be inhabited by the volunteer and the provision of written material concerning the basics of earthquake resistant construction.

b. The participation of an institution with an on-going assistance program in an affected country in post earthquake activities is normally at the discretion of the host country government. Once a request for such participation has been formulated it is usually the responsibility of the institution's international (or regional) staff to assess the situation and respond to the request. This situation reflects the protocol requirements under which the program operates in the host country through the auspices of the institution's own national government and the internal decision making structure of the institution.

c. On going volunteer development programs in LDC offer a wide range of technical assistance projects, usually organized on a sectoral and, as a function thereof, geographical basis. Although the evolution of such programs during the decades of the 1960's and 1970's has spawned more highly technical and management by objective projects than in earlier years, there are few such programs that specifically deal with construction of earthen buildings in earthquake prone areas. On the other hand, knowledge of the basic concepts of earthen building design and construction may be possessed by volunteers working in programs related to basic infrastructure development (roads and water resources for example) and in equipment and services installation projects (schools, hospitals, agricultural industries, etc.). The institution sponsoring such programs may have the ability to quickly identify personnel both inside and outside its own organization on a national, regional or worldwide basis who have knowledge of earthen building design and construction techniques and, perhaps, previous post earthquake experience. In general, however, most volunteer technical assistance programs, unless specialized in this area, are faced in the immediate post earthquake period with the task of resource indentification and operations formulation. Most volunteers are not usually involved in design and construction activities, particularly those related to housing construction at one significant scale. Nor are the volunteers often in a position to shape, influence or change generally held practices in earthen building construction unless intervening circumstances such as an earthquake modify or amplify the subject area of the volunteers' program.

Disaster preparedness for volunteer development programs, then, does not necessarily ensure or include preparation of the volunteers in techniques of earthquake resistant construction. Moreover, it is probable that few volunteers are instructed in those techniques as part of their program or project training unless their activities in the host country specifically include the design and construction aspects of earthen buildings. The volunteer institution is not likely to divert training and operations resources to this end above and beyond those elements needed for the volunteers' personal safety and well being or in the absence of a formal request from the host country government for assistance in this area.

At this point a note should be made concerning the disaster preparedness of the LDC. As in the case of the volunteer institution, the country's approach to disaster preparedness, has no doubt evolved over an extended period of time and is marked by major or minor seismic occurrences which have spawned further elaboration and modification to a formal plan. Behind the plan are existing codes, regulations, programs and projects which affect earthen building construction in

earthquake prone areas. The intent of these may be to discourage (if not prohibit) the construction of earthen buildings or to ensure the technical competence of their design and construction. While earthen buildings as a housing solution is the most general application of this material, public sector regulation and participation in the construction sector is most often observed in other areas - institutional, commercial and industreal buildings - where earthen buildings are scrutinized, impractical or prohibited. A major earthquake may be seized upon, then, as an opportunity to instigate a prepared plan to control or regulate the use of earthen buildings in these non-residential applications as well as in housing.

But their use in rural areas and among the urban poor is particularly difficult to subjugate to control and regulation. Most earthen buildings in these areas are owner-designed, owner-contracted or owner-built. This generally means that the ensueing design and construction processes are not intervened upon by established public safety or design professionals. Nor are the structures financed (or insured) through conventional means. Again the non-residential use of earthen buildings in these geographical and economic areas is more easily influenced by general public construction policies and post earthquake programs and projects. Housing, however, as the most numerous and critical use of earthen buildings in these two areas is a far more difficult segment of construction to foster technical competency.

Another aspect of LDC disaster preparedness is the relationship between the overall development plan for the country with its corresponding regional programs and the probable impact of a major earthquake. Such regional programs often contain a set of integrated projects covering the production and physical infrastructure sectors and volunteer programs may contribute to the execution of the integrated projects. The occurrence of an earthquake, however, may necessitate substantial modification of the regional program. This is due to the possibility that the geographical area affected by the earthquake may not coincide with the defined boundories of the development region.

Other elements which could thwart a close correlation between the existing planning process and the impact of a major earthquake are the substitution of the normal national or regional planning authority for some form of emergency direction, the distribution of centralized planning functions into separate (and autonomous) sectoral actions, and the destruction of or damage to the prime resources upon which the development plan was based. The degree to which a national disaster preparedness plan incorporates the normal development processes predicates the alterations which on going projects, including those of volunteer development institutions, will face both in their objectives as well as in their operational characteristics. Finite national resources may have to be shifted to newly established priority areas, thus limiting the support to below anticipated levels to many existing programs and projects.

3. Program Management

Once all personnel in the earthquake area are accounted for and a formal request has been made and approved for participation of volunteers in post earthquake activities, the institution will begin to amplify the indentification process of resources available, and on the basis of need assessment, program the activities of

of its personnel. Volunteer participation can be broken down into three distinct phases, one following another with a varying degree of overlap between one and another phase.

1. Emergency Relief Phase

The type of activities most often requested for volunteer participation are:

a. Distribution of relief supplies, (food, medicine, provisional shelter materials, etc.) and giving comfort to disaster victims.

b. Administration of relief supply distribution programs.

c. Damage assessment, identification of assistance needs, and assignment of relief resources.

d. Provision of scarce skills needed in relief operations (medical, construction, and communications personnel).

Distribution of relief supplies and administration of corresponding programs are set up in individual communities. These are activities in which volunteers at their project sites most quickly become involved following stabilization of their personal situation, reporting of their status and initial life-saving and debris clearing actions. Local entities, public and private in nature, organize these activities and most generally depend on national or international agencies for supplies. Volunteers program themselves into a variety of tasks and are urged to cooperate with local officials.

As comprehensive assessment of damage is undertaken and needed resources are identified, including scarce skills, volunteers may be asked to survey damaged areas and channel immediately available resources to needed locations. At this time volunteers may begin to make note of the characteristics of unaffected, damaged and destroyed earthen buildings, including siting, structural design, construction techniques employed and types of failures incurred.

The emergency relief period may last from one to four weeks depending on the type and scale of the disaster. Volunteers in the affected area will be making day to day decisions during that period concerning the kind and extent of their involvement and will communicate as often as possible with the institution's staff as to their present and anticipated activities and the need for assistance.

Activities which include decisions pertaining to the distribution of relief supplies should be monitored closely. Institution staff and volunteers may be asked to make such decisions. Responsibility for such decisions should be accepted with care, and institution personnel should strive to implement proceedures which place decisions as to distribution of supplies with host country nationals (individuals or organizations) or duly designated international relief agencies.

Use of volunteers brought in from other countries is extremely limited during the initial emergency relief period and may be limited to qualified medical people. Other scarce skill areas are of limited use during this time due to the need for equipment and transportation in order to mount effective programs.

2. Rehabilitation Phase

Following emergency relief efforts, which will be accomplished to varying degrees

in different locations, rehabilitation activities will be initiated. These activities will be concentrated in the areas of infrastructure, community facilities, communications, and housing. The rehabilitation phase typically occurs one to four months following the initial crisis and many of its activities will be funded into the reconstruction phase.

Specific activities which will be carried out include some or all the following projects:

a. Housing

1. Provision of temporary family shelters,
2. Distribution of building materials, and
3. Provision of shelter for orphans and child day-care centers.

b. Infrastructure

1. Opening of roads and repair or replacement of bridges,
2. Opening of rail lines and stations,
3. Restoration of electrical power,
4. Repair or potable water systems, and
5. Repair of sewerage systems, including tratment plants.

c. Community Facilities

The repair or provision of temporary structures for:

1. Hospitals and clinics,
2. Government administration and service facilities,
3. Educational facilities,
4. Markets, and
5. Transportation terminals.

d. Communications

1. Restoration of telephone service,
2. Restoration of telegraph service,
3. Restoration of postal service, and
4. Restoration of radio and television broadcasts.

At this time, the institution's staff takes the lead in programming volunteers into these activities. Abbreviated yet comprehensive programming procedures are sought which will ensure appropriate use of volunteers, particularly in these instances where personnel from outside the affected country are to be brought in for rehabilitation programs. The following programming issues would be discussed with requesting agencies and formal agreements reached between the institution and the participating agency before volunteers are assigned to programs. Particular emphasis should be placed on items a, b, f, and h.

a. Program structure with identification of the volunteer's immediate supervisor;

b. Job description outlining tasks and responsibilities;

c. Needed skills and skill levels;

d. Personal equipment and supply needs;

e. Food and lodging accommodations;

f. Transportation and use of vehicles;

g. Travel requirements;

h. Reimbursement for travel and supplies; and

i. Per diem expenses.

Most requests for volunteer support will be generated from international disaster relief, technical assistance and development agencies who will be working idependently or in close coordination with a particular host country entity at the local, regional or national level. These agencies have gained valuable experience through dealing with past disasters and most likely will be carrying out previously developed programs. The requests may include jobs for administration personnel to hire, fire and manage host country national staff as well as make critical decisions on the disbursement of building materials and supplies at the local level. The degree to which they will promote or allow host country nationals to participate in decision making in the areas of program management and distribution of goods varies greatly.

Rehabilitation assitance is competitive among international agencies as well as national entities, as evidenced in media reports on specific program policies and operations following past major disasters. This situation is often intensified by assignment of specific geogr.phical areas or communities to assistance agencies by de host country government, which obviates the competitive atmosphere. It must be remembered that most international agencies depend on donations and grants to support their relief programs and they must ensure the success of their activities to encourage funding. The institution will examine with particular care the role the volunteer is to carry out, discuss programming issues with the volunteer and apply existing programming criteria to ensure that the institution's goals are met, especially in the area of host country institution building and support. Volunteers should be placed with the understanding that changes in site or job description must have prior concurrence of the institution.

3. Reconstruction Phase

This phase usually lasts from one to five years and many of its programs are extensions or modifications of rehabilitation programs. Reconstruction programs are specifically designed to address any readjustment in post-disaster priorities as envisioned by the national government.

Assessment of participation in reconstruction should begin during the rehabilitation phase and follow established programming procedures. Both national agencies and the institution will revise and reset their priorities to include reconstruction assistance. For the institution this may mean the cancellation of planned programs, the mounting of specialized programs to meet specific reconstruction needs and/or an emphasis in programming special placement volunteers with unusual skills.

Care must be taken in assessing reconstruction needs in order that proposed programs will have adequate host country personnel and resources. Agency budgets and responsibilities can be inflated in the short term through infusion of post-

disaster loan and grant funds, only to be cut back, depending on the level of continued international reconstruction support and host country budget constraints and priorities, and national availability of resources.

Monitoring the development of the host country governmental reconstruction structure and its policies is essential. One of three general models is usually developed in dealing with reconstruction.

a. A new national agency and/or ministry is created to carry out reconstruction with policy and execution responsibility.

b. An existing national agency and/or ministry is charged with creating a national reconstruction policy and designating all reconstruction activities to take place. This entity may also execute reconstruction programs in any or all sectors.

c. A decentralized reconstruction policy is adopted with existing agencies and ministries carrying out reconstruction programs in their respective sectors. These entities may or may not create policy, depending on the existence or absence of a coordinating, policy making group.

In consultation with national government officials, the institution will undoubtedly want to revise program projections. This may take the form of new or expanded programs to include such skills as carpenters, and other construction trades, architects, engineers, physical and occupational therapists, demographers, cartographers, agronomists, environmental scientists, and soil conservationists for the following types of projects:

a. Housing construction,

b. Public building,

c. Irrigation systems,

d. Road systems,

e. Potable water and sewerage systems,

f. Rural electrification,

g. Public health, and

h. Food production.

Technical assistance in earthen biulding design and construction may be a formal, specific part of a reconstruction program for items a. and b. above, or it may be included as supplemental material for these and the other types of projects mentioned according to their use of earthen buildings. It is rare that a special technical assistance program in this area is requested in the absence of a major earthquake. Such a request may be for a few highly qualified professionals to participate in the preparation of building codes, zoning regulations, rural or low income housing development programs, or disaster preparedness plans. Otherwise programming technical assistance in earthen buildings faces the issues and variables mentioned earlier.

4. Technology Transfer

The panorama of volunteer participation in the transfer of earthen building technology through development programs in LDC is multifaceted and conditioned to the uniqueness of each country and each post earthquake situation. Aspects of that panorama to be considered include the following:

a. Development programs for LDC earthquake prone areas do not normally demand that participating volunteers have prior knowledge nor mandatory training in earthquake resistant construction of earthen buildings. Elementary acquaintance with this technology may be presented to facilitate the choosing of structurally sound housing for the individual volunteer.

b. Technical assistance programs could include earthen building technology if design and construction issues related to specific building use types, geographical areas or income classes so deemed necessary, but such technology generally receives high priority only following a major earthquake, in the formulation of disaster preparedness plans, or more commonly, in the preparation of technical segments of codes, regulations, and construction-related programs and projects.

c. Apart from the few instances where volunteer participation is centered on earthen building technology dissemination or where design and/or construction specialists must deal with the issue as part of a building development program, volunteers do not normally deal with the subject neither in its technical nor in its economic and social terms.

d. Following a major earthquake, volunteers in the affected area quickly program themselves into disaster relief, the first of the post earthquake phases. The succeeding phase of rehabilitation draws quickly on volunteer skill or specialty areas at hand and the reconstruction phase will consider earthen building technology as a possible project component according to program objectives and priorities.

Volunteers teaching and employing techniques of earthquake resistant construction of earthen buildings is quite feasible as part of reconstruction programs or as part non-earthquake instigated development activities. On a short term basis following a major earthquake it is probable that volunteers will neither have the knowledge nor will relief activities place a high priority on this particular area of technology transfer. Volunteers themselves may be victims of the disaster and share sentiments and doubts similar to their host country neighbours concerning earthen buildings, their design and construction. In any event, it is during the rehabilitation phase that the need for knowledge of earthquake resistant construction becomes quite apparent and volunteer participation in the dissemination of such technology becomes a special issue.

The context in which this participation may take place is shaped by a variety of forces. The need for technology transfer in the area in question is relative to the absence or lack of utilization of a presently available appropriate technology. It is not suprising to find within a relatively small geographical area affected by an earthquake (within, say, a 10 kilometer radius or less) widely varying degrees of damage to earthen buildings. Upon examination it is probable that the most important variable in explaining the absence or presence of extensive structural

damage to the buildings, is the proper design and construction of the buildings according to known earthquake resistant techniques as evident in the construction of some earthen buildings. Further investigation may identify a construction craftsman or family of craftsmen who erected each set of buildings grouped by degree of damage.

It occurs also that earthquake resistant techniques may have been known and practiced in past generations but for economic reasons (usually cost) or technical appraisals (no need for the technology because of belief that there is a low probability of a seismic occurrence, or the need for the application of old construction ways are antiquated and they are no longer necessary nor expedient) they are discarded, not accepted or not passed on to succeeding generations. Local unsupervised reconstruction activities in areas affected by an earthquake often show a resurgence of seismic resistant construction techniques which were lost or forgotten as exemplified by contemporary earthen structures built in the 20 years preceding the earthquake.

Other forces which shape the demand for an appropriate earthquake resistant construction technology include social aspects which border on the impenderable: tradition, superstition, availability of suitable building materials, economic costs versus social benefits as perceived by the craftsman and the user, the social relationship between qualified craftsmen and families having need of their services, etc.

These forces when viewed in their entireity tend to define a situation where the demand for a appropriate technology for earthen building construction and the transfer of such a technology turns to an analysis of spatial location, building design and construction techniques, social organizations, and economic feasibility on a building by building basis. As such it is a starting point for the formulation of a technical assistance program faced with the same constraints and problems as assistance programs at the grass roots level in other areas of development.

Other demand forces, however, serve to order an entrance into providing technical assistance and aggregate the possibly diverse individual needs for the technology in a form more susceptable to a volunteer development program. These forces include the dependence on craftsmen as a group for the majority of earthen building construction, particularly non-residential buildings (as opposed to the often held belief that every earthen building owner is the builder of his building). Another force which allows for an efficient dissemination of an appropriate technology is the impact one example of an adequately constructed building can make, particularly if it is a structure which has survived an earthquake without loss of life to its users and with no major structural failure. And, of course, if an example does not exist, one can be built and subsequent building construction may copy the technology utilized, particularly, if doing so assures the availability of a building permit, building materials, technical assistance and manual labor.

Against this backdrop of demand for an appropriate earthquake resistant construction technology, the offering of same by volunteer development programs, particularly in the rehabilitation phase following a major earthquake, is shaped by its own set of forces. Assuming that the volunteer is personally predisposed to participate (and having overcome such possible impediments as being previously prohibited from living in earthen buildings or being an earthquake victim injured by the failure of an earthen building), preparing him or her for the task requires expenditure of resources - time and money - of the volunteer institution and perhaps of other international and national agencies as well. Familiarization

with the basic concepts of earthqake resistant building design and construction techniques is not difficult in itself. Such knowledge can be assimilated rapidly by the volunteer.

The difficulty to overcome in the rehabilitation phase is to program such an activity in advance, make available the resources, identify the participants, develop the training program and execute. All this must be done during an extremely difficult period when volunteers, their staff and persons skilled in the necessary technology must exhibit a high degree of flexibility, utilize their time in the most efficient manner possible and respond to the demand, often rigidly self-imposed, that their efforts provide the greatest assistance possible. Under such circumstances, the volunteer generally chooses to rely on proven skills that he or she possess. These in turn must be combined into a coordinated effort to disseminate the technology. Those who understand the theory on which the technology is based direct those who can build as instructed to do so while those who can organize and communicate geographically or by spoken word, perform appropriate tasks. It is most difficult during the post earthquake emergency period to dissuade a volunteer from performing any task which he or she perceives to be a contribution irregardless of the objective, priority or skill level involved. Otherwise, they may become a victim of the earthquake aftermath. Likewise, during the development of a national development program, it is difficult to persuade a volunteer or trainer to learn skills for which they have little interest or dedication.

Volunteers are usually involved in technology transfer for which they must develop the skills and tools necessary to present and implement ideas. They most often work at the local level where interpersonal skills and command of the language make application of an appropriate technology possible. Report and a sharing of confidence provide the opportunity for assisting. These elements are built around one or another development area; they are not always transferable from one subject matter to another nor from one group of persons to another (access to an influential farmer may not provide access to an influential craftsman nor will acceptance of food processing technology presented by a volunteer allow them to have the same acceptance when explaining building technology). Moreover those means deemed expedient and employed to convince or coerce the local inhabitants to adopt a particular technology may not be acceptable to the volunteer or his institution.

None the less, good volunteers can generally adapt to new circumstances, acquire new skills and be effective agents of change. In the aftermath of a major earthquake or as part of a normal development program they can impart an earthquake resistant construction technology but they will undoubtedly be few in the face of many potential building construction projects which are worthy of close technical supervision. To that end their participation must have as great a multiplier effect as possible. In general the most effective use of volunteers has been in demonstration projects with high visibility and short term technical consultations with influential members of the local craftsmen group who in turn control a great deal of the actual construction in the community.

Presenting earthquake resistant construction techniques must also be coupled with assistance in areas of never ending concern in the construction trade: good quality materials and proper execution of general construction techniques not necessarily directly related to earthquake resistant construction. Attention to these issues may be just as important, if not more so, to building development because of their role in the structural integrity and stability of any building.

In the end, the concern for advancing the state of the art of earthen building construction as represented by identifying seismic dangers or the occurrence of an

earthquake and the reconstruction period that follows is a relatively new phenomenon as seen from the perspective of the long history of the building material itself. If the opportunity is seized, the history yet to be written might read a bit differently than previously envisioned.

RESEARCH AND PROMOTIONAL REQUIREMENTS FOR EARTH BUILDINGS IN DEVELOPING COUNTRIES

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ABSTRACT

Review of world shelter requirements. Efforts to develop improved adobe blocks through invention and utilization of CINVA-RAM soil cement portable blockmaker by different agencies in many countries over past 25 years. Properly stabilized soil blocks seen as one answer to avoiding many construction defects in adobe houses in earthquake areas, though other design and construction aspects also most important. Review of recent international experience with development and promotion of asfadobe technology in Peru, Sudan, etc. Positions of international agencies, UNEP-UNEHSF-UNCHS, and forthcoming international events focussing on human settlements technology. Importance of institutionalizing and supporting network of environment building centres. Possible model is Consultative Group on International Agricultural Research. Standing International Advisory Committee on Built Environment is needed.

RESEARCH AND PROMOTIONAL REQUIREMENTS FOR EARTH BUILDINGS IN DEVELOPING COUNTRIES

Improved methods for using earth as a basic building material for shelter and other structures are finally receiving increasing acceptance in many developing countries, and we can expect accelerated production of earthen buildings in the years ahead both for formal and non-formal (squatter) construction. That makes the subject of this workshop especially timely, as there are no inherent reasons why "earthen buildings" should be less safe than other forms of construction in seismic areas, provided that their characteristics are understood and simple design principles are incorporated to improve their structural integrity during earthquake movements.

Probably the majority of buildings in the world today are built with mud and earth as their major components. This situation is not likely to change for some time considering the dynamics of population growth and its effect on human settlements. The world population reached 4400 million in 1980, an increase of about 20% over the 1970 figure. About 75% lived in less developed regions with 30% in urban areas. The urbanization phenomenon is such that while in 1950 the proportion of world population living in towns and cities was 29% by the year 2000 it will be over 50%. This transformation involves enormous numbers of people: between 1970 and 1980 the urban areas of less developed regions absorbed about 320 million; between 1980 and 2000 the increase will be more than 1000 million. In 1950 there was only one developing country city (Greater Buenos Aires) with a population of over four million, by 1980 there were 23 such cities compared to only 15 in the more developed regions and by the year 2000 there will be about 60 compared to 20, with 18 of them expected to have more than 10 million inhabitants. At the same time, in connection with raising levels of health and productivity, there will be new emphasis on upgrading the quality of rural housing and settlements upon which so much of the world's food and resource expansion depends, with 50% of the total world's population still expected to be rural in character by the year 2000.

So the problems of providing shelter, buildings, infrastructure and services are immense. Moreover, the financial and energy constraints appear overwhelming especially for the many developing countries with per capita incomes of less than US$ 300 per year whose growth prospects look gloomy. In these circumstances, more and more governments will have to adopt new housing policies, modify their building codes and regulations, reduce their imports of building materials, establish more appropriate financial and credit institutions, allocate land with services to their low income populations and give them "freedom to build" in progressive improvement modes, a far cry from typical contractor-type construction. These efforts will involve fundamental professional reorientation linked with new national and international training, technical assistance, information, demonstration and development efforts for up-grading of the self-help and

cooperative construction that many families will be engaged in. The most common "building block" is likely to be mud and earth.

Fortunately, this whole area may offer some unique opportunities for promoting closer linkages between developed and developing countries. Who can forget the stimulating efforts of those depression era publications of the US Department of Agriculture and others on earthen buildings with adobe, rammed earth and other technologies. The traditional adobe construction of the West has been greatly enhanced by the commercialized production of stabilized blocks, asfadobe and others for a period of almost 50 years, if we take as an example the Hans Sumpf operation in Fresno. These products are used in the finest residences and even commercial structures, giving high respectability to earthen buildings. The new vogue of adobe construction has now spread widely for home building in a number of states, aided and abetted by such unique, innovative and practical publications as the Adobe News and training and demonstration efforts accompanied by growing acceptance in building codes. Even the Architectural Record, a McGraw-Hill New York publication, gave considerable space to the remarkable demonstration by 81 year old Hassan Fathy from Egypt of building a mosque right here in New Mexico using traditional mud architectural technology. I might add that the US Housing and Home Finance Agency had issued in 1957 a publication on "Mud Brick Roofs" featuring Hassan Fathy's work, so we cannot say that the government has not been aware and supportive of some of these developments, particularly for use in developing countries.

My own continuing promotional commitment and involvement with earthen buildings began in 1956 through my role then as Director of CINVA, the Inter-American Housing Centre in Bogotá, Colombia, a project of the Pan American Union. There a development team was concerned with improving the use of earth as a building material for the poor. This resulted in the invention of the CINVA-RAM machine, a hand-operated stabilized earth block maker which was originally designed to fit within the criteria of a $50 cost limitation and easy portability on muleback or other transport through roadless territory. The machine, whose direct development cost and prototype manufacture was less than $8,000, has now built hundreds of thousands of low-cost dwellings and schools around the world, and is manufactured locally in many countries, from Ghana to Indonesia. I brought the first one myself to Washington in early 1957, where we demonstrated it in the gardens of the Pan American Union, and received subsequent world-wide publicity in Time magazine and elsewhere. Though it is by no means a universal answer to production of shelter, the CINVA-RAM has served as symbol for self-help and mutual construction and community organization efforts in many places.

The distinguished Chilean engineer who devoted himself to designing the machine, Raul Ramirez, was himself a high technology expert on anti-seismic design of tall buildings in Santiago. At CINVA, we were soon to contract out with the University of Chile for a major report on Earthquake Proof Design of Low-Cost Dwellings, published in 1959. This work was further elaborated upon in two UN publications, one issued in 1975, on Low-Cost Construction Resistant to Earthquakes and Hurricanes, and another in 1977, on Repair of Buildings Damaged by Earthquakes.

The pace-setting work carried out by CINVA, the first regional housing centre, from 1951 to 1977, when it was discontinued by the

Organization of American States, had considerable influence throughout Latin America through its extension services, demonstration activities, publications, and produced a body of professionals and technicians many of whom continue today in the housing institutions of their respective countries. The first structures built in 1957 with the CINVA-RAM stabilized soil blocks still stand - a 50 square meter tile roofed "Casa Campesina" costing $300 on the grounds of the National University; a large parabolic single brick width arch, the primary schools at Tabio and Saucio, and others. So I have personal knowledge and evidence that the material is durable.

CARE was one of the first international organizations to use the CINVA-RAM Portable Building Block Press and placed an experimental order in early 1958. In the same year, the machines were first put to work in a building improvement project throughout rural villages in Mexico. CARE's next project using Cinva-Rams was to build 64 houses for North Korean refugees settled in an "assimilation" village on the Han River, north of Seoul in South Korea.

After that year, CARE began utilizing Cinva Rams in many of its community development projects to build homes, schools, clinics, school kitchens, community and health centers, latrines, rehabilitation centers, shelters for animals, warehouses, students' dormitories, teachers' quarters, post offices, churches and other public buildings. For example, in 1967 in Sri Lanka, CARE cooperated with the government, various community organizations and an American Catholic priest in a community development program to build low-cost housing for low-income farm families. With land donated by the government, labour supplied by the villagers and the use of the CARE-provided Cinva-Rams, CARE was able to construct 200 housing units to benefit approximately 1,050 people. In addition, a "bank" of Cinva-Rams was established in the village for use - on a loan basis - in other development projects. As another example, CARE's provision of Cinva Rams to the Vietnamese Government's Department of Land Development assisted in providing resettlement homes for thousands of displaced families and also encouraged them to additionally construct temples, public markets, meeting halls and schools.

CARE has also provided Cinva-Rams to use in large-scale construction projects such as the SCIDE (Servicio Cooperative Interamericano de Educacion) Project in Honduras. This organization, part of the Alliance for Progress, undertook to construct schools in 77 villages throughout the country. At the same time, teacher-training facilities were being improved so that it would be possible to staff the new schools with qualified teachers. CARE's provision of the Cinva-Rams made it possible to complete the project through the use of thinner, lighter and less-expensive materials and provided educational opportunities for thousands of rural Honduran children.

Perhaps one of the largest CARE programs in which Cinva-Rams were utilized was in Bangladesh (formerly East Pakistan) and began 1968. CARE initiated a housing program to assist victims of a tornado when the program developed into a long-range housing rehabilitation project under a partnership agreement with the government with partial support from USAID. A total of 3,500 homes were constructed in the Chittagong District under this program and a second agreement was signed for expansion of the housing construction. CARE had constructed 800 houses when the program was interrupted by the 1971 Civil War. Impressed by the success of the first two CARE projects and convinced of the need for

introducing low-cost permanent housing to the nation as a whole, the new Government of Bangladesh requested CARE to build houses throughout the country on the sites of villages destroyed during the independence struggle. In 1972, under a tripartite agreement between the government, CARE and USAID, CARE undertook the extensive 62-Village Housing Reconstruction Program in each of the 62 sub-divisions of Bangladesh. Although this project was carried out under extremely difficult conditions prevailing in post-war Bangladesh, CARE constructed a total of 8,600 houses in a period of about one year. This was the largest project of its type ever undertaken by CARE. In addition, CARE entered into another agreement to construct houses in Bangladesh; this time involving a proposed 15,000 houses in the Delta Coast region - one of the hardest hit during the 1970 Bangladesh cyclone catastrophe. The program was intended to be an expansion of the original housing program with the former government but due to change in priorities from rehabilitation to development, targets for this project were re-defined. By the program's completion in November 1974, CARE had constructed a total of 7,500 houses in the Delta area and had entered into an amended agreement for construction of godowns (storage facilities) and schools.

As in all such CARE projects, construction is done on a self-help basis, mainly by the people themselves, in cooperation with the local governments. Since the machine is designed for do-it-yourself construction, usually the only cost is the cement. The main ingredient, earth, is plentiful in even the poorest countries. The process is further simplified for unskilled peasants because no power source is needed. All it takes is a willingness to dig and sift the soil, mix it, hand-operate the machine, stack the blocks and then join them with a mortar of similar mix. Though sandy soil is best, almost any dirt free of vegetable matter will serve. Other stabilizers, such as lime which may be more available in some areas, can be used. Since the blocks are larger than conventional bricks (4" x 6" x 12"), this means more rapid construction since fewer blocks must be produced for each structure. Two men working together - one to operate the machine and the other to feed the mixture into the mold and remove the pressed block - can produce up to 600 blocks a day, depending upon their experience. With more workers, production is increased. In the town of Fuqueno, Columbia, for example, workers produced 130 blocks per hour per machine on two Cinva-Rams provided by CARE. To construct a health center, they made 8,000 blocks and a typical two-room rural house required 2,500 blocks. In addition, the machine - which is made of steel - weighs only 128 lbs. packed. This makes it light enough to be transported easily.

The most recent large scale low cost housing program using the Cinva-Ram was in Pakistan where in the latter part of 1970's over 4500 houses have been built in three different projects. These houses are both rural and urban and the projects provided for training in rammed earth block-making techniques and low cost housing methods. Block-making teams were trained which in turn worked with and trained the villagers.

According to tests by laboratories in various countries including the U.S. Bureau of Standards the blocks are comparable to, or even better than conventional cement or cinder blocks in strength and endurance under various climatic conditions. Under the machine's design, the pull-down lever moves a piston that produces a compression force of 40,000 pounds. The machine turns out either solid blocks or blocks with a rectangular indention, which are made by using a wooden form which can be placed inside the metal mold box. The indentation helps save on materials.

As of 1978, CARE had put some 3250 Cinva-Rams into service in thirty countries throughout Latin America, Africa, Asia and the Middle East. One reason for not arriving at a total is that many of the machines were left on loan with responsible local groups for independent projects after original CARE programs were completed. In Nigeria, for example, CARE launched an extensive reconstruction program after the Nigerian Civil War to include the repair of an undetermined number of public buildings such as health centers and schools. The Cinva-Rams were used to rebuild the walls of the structures and then many were left on loan for further rehabilitative and development projects since that time.

UNICEF, VITA, and the Peace Corps are among the other organizations which have made extensive use of the machine. Countries which have received CARE Cinva-Ram machines for development projects include, Afghanistan, Bangladesh, Belize (British Honduras), Chile, Columbia, Costa Rica, Ecuador, Gabon, Greece, Guatemala, Haiti, Honduras, India, Indonesia, Kenya, Korea, Liberia, Malaysia, Mexico, Nicaragua, Nigeria, Pakistan, Panama, the Philippines, Poland, Sierra Leone, Sri Lanka (Ceylon), Turkey, Uganda and Vietnam.

In some of these countries, and others, such as Tanzania, and Ghana, production of the machine has been undertaken either by public or private sector interests, and sometimes the machines have been modified. In view of the heavy pressures generated, it is vitally important that full quality control be maintained, together with maintenance and the availability of key replacement parts. In Kenya, for example, a somewhat heavier CINVA-RAM is currently being produced and sold at a cost of US$200.

Although it is now 25 years since the Cinva-Ram was invented, it is evident that there is still a large need and demand for a machine of this type, which ideally should be accompanied by more regularized technical assistance and training. Also the Cinva-Ram should ideally be part of a building system which could involve a Mobile Field Manufacturing Centre and Kits of Parts for whole single small shelter modules suitable for cooperative cluster construction. An example of an early demonstration of such an on-the-ground system was built for the World Housing and Planning Congress of 1960, held at San Juan, Puerto Rico. Three dwelling units were erected from Cinva-Ram blocks manufactured on site by unskilled labour. Two were of expandable design but varied in the use of roof span materials. The third unit was built from a kit of parts, including a unique butterfly corrugated aluminum roof which caught the almost daily rainfall and drained it into two steel tanks built into the maximum utilization. Screen fillers of split bamboo were applied to moving part. Basic minimum surface wired lighting, hung fold-down table and shelves formed the remainder of the kit, along with framing clips, reinforcing rod, cement for the blocks and a Cinva-Ram machine.

Main Construction Defects in Adobe Houses

Considerable attention has been given to the shortcomings of typical adobe structures during earthquakes. The United Nations publication, Repair of Buildings Damaged by Earthquakes, 1/ has the following to say on the matter:

When adobe structures are inspected after an earthquake, failures are very often found which are due to a total lack of verification in the process of design, construction and utilization of this material, magnifying the errors due to ignorance that are typical of the system of unguided construction usually encountered.

The most common defects are the following:

(1) there is no foundation, or it is not deep enough, or it is very poorly made;

(2) no consideration has been given to the important function of a foundation as protection of the wall against ground moisture (capillarity);

(3) poor overlapping of the adobe bricks;

(4) there is nothing to anchor the structure (tie-beam of adobe clay at least);

(5) the distance between columns, wall intersections or other load-bearing members is too great;

(6) the area of the openings in the walls (doors and windows) is excessive;

(7) the openings are too far away from wall intersections or junctions;

(8) there are not enough cross-walls to resist the horizontal forces of earthquakes;

(9) the roof is too heavy;

(10) the roof supports are inadequate;

(11) the eaves are not large enough to protect the walls from rain;

(12) elements of the pediment or gable are poorly joined to the rest of the structure;

(13) the height from floor to ceiling is too great or the structure is more than one storey high;

(14) the lintels are insufficiently embedded in the walls.

1/ United Nations, Repair of Buildings Damanaged by Earthquakes. New York, 1977. ST/ESA/60. Sales No. E.77.IV.8

The following may be said with regard to adobe bricks as material:

(1) use of inappropriate soil, poor proportions of stabilizing material and/or excessive water in fabrication;

(2) improper dimensioning, especially adobe bricks of excessive thickness.

The following are the main construction faults:

(1) use of very fresh adobe bricks;

(2) absence of filling in the vertical joints;

(3) poor workmanship in laying the bricks, which is reflected in the poor geometrical quality of the walls (bricks out of line or out of plumb);

(4) building during the rainy season without adequate protection;

(5) very rapid elevation of the wall causing settling in the lower courses.

Lastly, there is widespread over-burdening of adobe structures by occupants (materials leaned against the walls), lack of maintenance of the necessary outside protective elements, subsequent changes in the structure, and addition of new construction with greater rigidity than the original building.

The initial inspection of adobe structures must bear in mind all the above-listed aspects.

The above findings are corroborated by the United Nations publication, Low-Cost Construction Resistant to Earthquakes and Hurricanes 1/ which contains the following listing of main construction faults affecting the stability of adobe houses:

(1) poor adobe-making techniques;

(2) use of insufficiently dried adobe;

(3) incomplete covering in the horizontal layer between adobe blocks;

(4) incomplete fill of the vertical joints between adobe blocks;

(5) poor geometrical quality of the walls (undulations and sagging);

(6) poor interlocking at the wall intersections;

1/ United Nations, Low-Cost Construction Resistant to Earthquakes and Hurricanes. New York, 1975. ST/ESA/23. Sales No. E.75.IV.7

(7) lack of adjustment in the wall arrangement and introduction of adobe pieces to correct the arrangement;

(8) walls built too rapidly (the maximum vertical rate should be 1 metre per day);

(9) plastering without taking the necessary precautions to ensure adhension of the coating to the wall;

(10) failure during construction of the wall to insert the wooden plugs for fastening frames, partitions and ornaments;

(11) the courses must be laid along the whole contour of the walls, avoiding construction by complete or isolated panels, in order to prevent possible differential settlement cause by the loads or by different degrees of dryness;

(12) lack of continuity in the timber tie-beams because of careless execution of the joints at the corners and intersections (splicing, use of double-headed nails) and/or the splicing of the longitudinal parts;

(13) poor execution of the wall coverings designed to protect the adobe blocks.

In the Department of Commerce Publication, Design, Siting and Construction of Low-Cost Housing and Community Buildings to Better Withstand Earthquakes and Windstorms, 1/ a number of recommendations are given regarding structural configurations that result in improved behaviour under seismic loads. These are as follows:

(1) Low-cost housing construction should be limited to one - or at most two-story units. This practice permits maximum exploitation of locally available construction materials and increases the feasibility of producing better seismic-resistant structures.

(2) The weight of roofs and floors should be kept to a minimum.

(3) The shape of the building, the arrangement of walls, partitions and openings should be made in a balanced matter to obtain as uniform a stress distribution in the building as possible.

(4) Heavy elements should not be attached to non-structural walls.

(5) The size and spacing of openings should be governed by requirements of minimum width of piers flanking adjacent openings, maximum permissible length of lintels spanning across the top of openings, and uniformity of overall layout.

1/ US Department of Commerce, Building Science Series 48, Design, Siting and Construction of Low-Cost Housing and Community Buildings to Better Withstand Earthquakes and Windstorms. Washington, D.C. Jan. 1974.

(6) Exterior walls forming a rectangular enclosure may be prevented from separating at the top corners by providing a continuous collar or ring beam having sufficient tensile strength to resist forces acting on the upper peripheral junctions of the walls.

(7) Structural damage resulting from hammering of unattached adjacent walls may be avoided by providing connections between these walls for integral action against earthquakes, or by providing sufficient space between adjacent buildings to avoid impact.

As for Foundations, it is recognized that low-cost single story housing will have only superficial foundations, but the following requirements should be met to achieve more earthquake resistant construction:

(1) The base of the foundation should be below superficial or "top soil" level, and below the major vegetal root level. In locations subject to freezing, as in Turkey and Iran, the bottom of the foundation should be below the freezing level of the groung.

(2) Continuous wall footing should extend under the entire length of the wall and sufficient vertical dowel reinforcement should be provided between wall and footing to develop continuity and capacity for intergral action. This practice should minimize differential settlements and local damage to the walls and should permit a more uniform distribution of bearing pressures in the soil.

(3) For single story construction the width of the continuous footing should preferably be more than one and one-half times the thickness of the wall or 35 cm., whichever is larger. Depth should not be less than 45 cm.

(4) Foundation materials of gravel mixed with soil stabilized with asphalt or road oil may be used unless better materials are available at comparable cost. Stabilization of the foundation material provides protection against moisture and other deteriorating agents.

(5) Split cane, bamboo or wire mesh may be used for vertical reinforcement to provide continuity between walls and footings.

As for Walls, Frames and Shells, the report gives considerable attention to improving the seismic resistance of walls constructed out of stabilized adobe block by using locally available reinforcing materials, for example, using split cane for reinforcement with oil stabilized block may provide an increase of over 100% in resistance to static lateral force. Adobe walls may be further strengthened by the use of cane or wire-mesh reinforcement to inhibit brittle shattering and rupture of walls and to control cracking. An effective method of improving the strength of walls is to provide a ring beam at their top, to tie the top of the walls together and to prevent tensile cracking from developing at the upper corners. A ring beam should be reinforced with materials of high tensile strength such as bamboo, wire or steel

rods. Openings require special attention - especially their location and size and the need for effective reinforcement around them.

As for roofs, it is evident that the seismic performance of buildings will be improved if their weight is reduced. This can be achieved without loss of strength by substituting lighter-weight materials for roof covering in liue of heavy traditional materials such as mud or tile. Reduction of weight can also be achieved by using shorter spans which require the use of load-bearing interior partitions. This will also increase the lateral resistance of the system. The reduction of weight is greater than the reduction of the span, often by significant amounts.

It is clear that the improvement of the structural performance of earthen buildings during earthquakes depends on several key factors. But undeniably most important is the quality of the adobe block itself, and here every effort should be made to improve it. I have described the CINVA-RAM as one example of a low-cost machine for producing high quality soil-cement or lime stabilized blocks under compression. The basic techniques are not far different from traditional adobe block making and adequate experience is available after 25 years of the use of this technology in many countries. Its use should continue to be encouraged and promoted through much more widespread and consistent technical assistance, training and demonstration projects.

Another basic method is the production of adobe materials by the addition of asphalt emulsion, bunker oil or other petroleum derivatives. This produces asphalt-stabilized adobe brick of high durability and water repellent qualities. With good workmanship stabilized adobe bricks with high compressive strengths can be obtained. Mortars used with adobe units are mixtures of soil and cement, with asphalt added to give it the desired stability.

In my view, the production of this type of asfadobe brick has major potential, especially in the developing countries, and should help considerably in improving the structural quality of buildings in earthquake zones. With the present "oilglut" in the world today, conditions of supply and pricing of the additives required are likely to remain competitive in the years ahead compared to other materials. Getting far greater general acceptance and utilization of the relatively simple asfadobe technology will, however, require new and continuing efforts at both national and international levels. Let me briefly review a few of the efforts to date in this direction.

First, we can say that several factors have been responsible for reviving asfadobe technology. It is a technique of earth stabilization by processing with asphalt additives, its use historically recorded in the time of Assyria and Chaldea. It gives the soil greater durability without the need for firing it, greater stress-and-pressure-resistance whilst reducing the need for maintenance, rendering it insect-proof and waterproof.

One of the most unique and important properties of asfadobe is that due in part to its internal dryness, it is not generally an acceptable host for most biological pests (including rats), many bacteria and insects. It is therefore an extremely sanitary building material for both, domestic construction and storage for agricultural and other produce. Again, because of its internal dryness, it has excellent thermal qualities, its heat conductivity being less than that of poured concrete, concrete blocks or

fired brick. With proper consideration of roofs, floors, doors, windows, and other sources of heat loss or gain, asfadobe homes have very desirable heat transfer characteristics. Generally, asfadobe walls maintain heat equilibrium by functioning as heat storage and heat dissipation units and make an excellent medium for the design of "solar" houses. An acceptable mortar using asfadobe can also be used for dwelling construction.

Asfadobe meets the following criteria to be used in promotion and implementation of a low cost self-help housing programme:

(1) the basic material, the component soil, is familiar and economically accessible to the inhabitants since it is found in their region;

(2) it is also acceptable and usable as a modern building material, particularly in light of current ecological concerns and the economic re-assessment brought about by the energy crisis; it requires only sun for curing, a minimal amount of structural elements, if any and may also be used for foundations, floors, walls and roofs;

(3) the material is labour-intensive and can provide employment for unskilled people; the process of manufacture is simple, cost-efficient, requires minimal amount of equipment readily learned, therefore trained manpower could teach it to other unskilled workers in proposed areas of application;

(4) it provides adequate structural strength and conditions for comfort, health and sanitation;

(5) with the revival of traditional technologies of building in improved earth there is no disadvantageous "transfer of technology" in the use of this building material; the stabilizers required are readily available in many countries. Emulsions to suit individual soils, can usually be processed and produced at reasonable cost and adequate quantities can be made available for shipment in container or bulk form. The fact that many countries will be carrying on road building programs using asfalt and earth stabilizers is another factor adding to the rationality of application to building construction.

In 1965, while serving as chief of housing at the United Nations headquarters in New York, I was approached by Mr. Yonan Malek, a retired inventor of Iranian extraction, who had become convinced that building with asphalt stabilized earth represented the wave of the future for housing and shelter needs in developing countries. Mr. Malek recalled his youth in a mud built house in Iran, spoke of the centuries old structures built with asphalted earth, and was thoroughly familiar with the asfadobe commercial brick production in Fresno. Following our conversation, Mr. Malek's promotional zeal led him to interest Fresno State College, now the California State University, Fresno, to establish in 1966 an International Institute of Housing Technology one of whose prime purposes is to conduct research and development on soil stabilization for construction purposes, particularly to increase the resistant qualities of bricks made from soil without greatly increasing their materials cost. The Institute drew upon the collaboration of the Hans Sumpf Company, and organizations such as the Chevron Asphalt Company.

Though its funding and staff have remained modest and minimal, the Institute has made some notable contributions to developments in the field, such as its well-illustrated publication on The Manufacture of Asphalt Emulsion Stabilized Soil Bricks. The Institute has also conducted a number of training courses for developing country participants, and engaged in several pilot and demonstration projects on behalf of international organizations.

One such project was carried out in Peru, following the disastrous quake of May 1970 which destroyed or severely damaged most of the adobe buildings of a large section of the country, with a considerable loss of human life and material resources. A project for the establishment of a special Adobe Improvement Program was financed by the US AID. It included the development of two pilot housing projects, following testing and research activities, in the coastal region and the highlands of the earthquake zone. Thirty-one houses of asfadobe brick were built in Nepena, Peru. These projects included the production of stabilized adobe bricks, the construction of prototype dwelling units and the training of families in the new construction techniques. The report on the project indicated that block stabilization with rapid curing road oil had produced highly satisfactory results with the proportion of asphalt used varying between one and two percent. In order to improve the building structures, various building techniques and designs were also tested. New blocks were square instead of rectangular and the walls were reinforced with cane rods fitted vertically into holes in the blocks in much the same way as steel bars are used in conventional construction and with much the same effect. A two-room expandible experimental house built at the University had a sloping cane roof covered with stabilized soil, which offered a high degree of thermic insulation. Perhaps the most important feature of the model house was its capacity to reasonably withstand the action of earthquake forces, through a careful process of structural design and the use of improved construction techniques.

The IIHT has been involved in other training and demonstration projects in other countries of Latin America, including Guatemala, Honduras, Costa Rica and El Salvador. The Sudan, however, proved to be a breakthrough point for asfadobe production demonstration. The Sudanese Ministry of Construction and Public Works had become interested in the introduction of asfadobe technology in December 1975, and built an experimental asfadobe house. As the result of a government request to it, the United Nations Habitat and Human Settlements Foundation, with which I was then associated as Acting Director of Financial and Technical Services, approved in June 1977, a contract with Soil Technology International of Fresno, California, to provide technical assistance to transfer the asfadobe technology for large-scale production from Fresno to Sudan. The UNHSF assistance in total amounted to $300,000 for the Sudan project. A four man team of selected Sudanese personnel completed a training course in Fresno specifically for this purpose. A complete operational equipment system with the capability of producing 22 million bricks in one year was designed, fabricated, tested and shipped to the Sudan. Initial production was destined for a 200 house demonstration project. An evaluation mission undertaken in January 1980 reported that, although there had been certain delays and difficulties the Khartoum asfadobe plant was fully operational producing a good quality of brick from soil stabilized by bunker oil. Construction was underway on the first sixteen houses of the 200 house pilot project. It was clear also that asfadobe bricks and mortar as such were producing a high quality product at 30% lower cost than other available building materials. The United Nations Development Programme has also supported an asfadobe

research and development project in the Sudanese city of Juba, in association with the University there.

Currently, the UN Centre for Human Settlements is considering the use of asfadobe construction as one element in a 26 house demonstration project being undertaken in the large World Bank financed Dandora project.

So, these are indications of growing international interest in earthbuilding technologies, which, as stated earlier, can have major importance in improving the performance characteristics of adobe buildings in earthquake areas. There is a large role for the private sector to play in the future to accelerate utilization of stabilized earth blocks. At least three private organizations have been established to date for work in this field: Asfadobe Technology International (ATI) of Fresno, California; Asfadobe and Terra Systems Ltd., Nairobi, Kenya and Asphajor Corp., Tehran, Iran. The latter was established specifically for large-scale production of asphalt stabilized bricks and had been stimulated in part by Mr. Yonan Malek's demonstrations and construction of a model house in 1975.

The International Institute of Environment and Development of London has recently prepared a publication for wide circulation on Building with Mud, which reviews both national and international experience in this field. This is likely to stimulate further requests from both public and private sector interests for technical assistance, guidance and training.

Both the UN Conference on the Human Environment held in Stockholm in 1972 and the UN Conference on Human Settlements held in Vancouver in 1976 gave considerable attention to the development of building materials that are readily available locally. The UN Environment Programme (UNEP) in 1975 held an Advisory Group Meeting which drafted general guidelines for human settlements technology. This was followed up in February 1976 by an Expert Group Meeting on Human Settlements Technology for the regions of Africa and West Asia. For immediate action it was recommended that:

UNEP should sponsor a major effort to extend the application and improve the performance and acceptability of common mud as a building material. This effort will consist of two main sections:

(a) The evolution of a rationalized and simplified vault and dome technology, to be carried out by a development team in three stages:

(i) Assessment of existing materials, and review of local workshops and craftsmen;

(ii) In the light of resources found to be available, design a modified dome or vault constructing technology;

(iii) Transfer the technology to a selected country on a pilot scale. At least 10 structures should be built in different locations.

(b) Improving the performance of mud-based building technologies, also to be carried out in three stages:

(i) Compilation and assessment of information on requirements and resources;

(ii) Experimentation to improve existing technologies and, in some instances, evolution of entirely new methods to improve performance;

(iii) Dissemination of the successful results by means of pilot demonstration projects.

The five principal existing techniques for improving the durability, appearance, load-bearing capability and cleanliness of mud are:

Burnt brickmaking;

Coating with cement composites;

Soil cement;

Asfadobe;

Protective detailing.

In the course of the study other methods may also come to the fore.

UNEP should also sponsor a pilot demonstration project to establish the potential of asphalt adobe brick-making in several African countries. The programme would involve an initial feasibility study to determine the availability of suitable materials, followed by a second stage in which bricks will be produced on a pilot scale and houses constructed with the bricks. The project should be large enough to make a significant impression and promote widespread adaptation or imitation.

Unfortunately, relatively little has been accomplished to date to carry out the above recommendations. The UN Centre for Human Settlements (Habitat) was established in Nairobi in 1978, but to date has not done much in the way of research and development activities, though it does maintain an active technical cooperation programme for work in developing countries. The UN Environment Programme, based in Nairobi since 1973, has reduced substantially its support for human settlements projects. The UN Habitat and Human Settlements Foundation no longer exists as an independent agency, having been absorbed by the Centre for Human Settlements.

In one country after another, however, we do see evidence of considerable attention to both research and demonstration for the application of appropriate technology to the shelter-building process, with considerable emphasis on earth construction. The two countries which have established Ministries of Human Settlements, Mexico and the Philippines, have leadership roles in this field. A particularly good example is the publication, Indigenous Materials for Low-Cost Housing, published by the National Science Development Board of the Philippines in 1980 1/. This provides clear how-to-do-it text and illustrations and further reference sources.

As mentioned earlier, the work carried out in Peru in cooperation between the Ministry of Housing and Construction, the Housing Institute (INIAVI) and the College of Engineers, has been notable. The Central

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1/ National Science Development Board, Indigenous Materials for Low-Cost Housing. P O Box 3596, Manila. May 1980.

Building Research Institute (CBRI) in Roorkee, India, has carried out much practical research and work on the use of stabilized soil and mud for many aspects of the building process, as has the UN Regional Housing Centre in Bandung, Indonesia and the Building Research Unit in Tanzania, and the Housing Development and Research Unit in Kenya. In fact, there are literally dozens of institutions that have been doing good work in this field, though coordinated approaches and substantial financial support have usually been lacking.

While I served for only a brief period as head of human settlements for UNEP, we did make an effort to establish a networking concept which would promote increased interchange and concentrated building research between building centres and institutes within each region. This was to include such general areas for action as Ecodesign; Infrastructure; Services; Building and Energy. It was also to give special attention to ecologically-oriented principles such as: Maximum use of renewable resources; Utilization of industrial, agricultural and household waste material in construction; use of non-contaminating energy from wind and sun for lighting, cooking and heating purposes; recycling and minimum use of fresh water for household purposes; and waste reduction through modular design, rationalization and standardization of building materials and components.

The general objectives were:

(1) To develop interdisciplinary research capacity leading to a better use of human and material resources and establish permanent functional relations between research and other organizations in charge of implementing human settlement projects in every country.

(2) To arrive at ecologically sound solutions to human settlement problems with emphasis on the lowest income groups of the population through community participation, labour intensive methods, generation of small scale industries and development of improved technologies based on locally available resources.

(3) To train and retrain personnel to adequately staff human settlement programmes.

(4) To open regional and interregional channels of communication exchange, adaptation and generation of new information and cooperation among all countries.

(5) To provide a forum for global discussion of problems related to human settlements technology.

Only in Latin America, in Mexico, under the auspices of UNEP, the Regional Economic Commission and the Government, was a special regional office established to deal with objectives of the above type, and it is good to report that considerable progress has been made with the networking concept among concerned institutions in that region.

Several forthcoming events may provide opportunities for further promotion, demonstration, information exchange and discussion regarding earthbuilding techniques. These are the UN Conference on New and Renewable Sources of Energy, to be held in Nairobi from 10 to 21 August this year.

The non-governmental Environment Liaison Centre is organizing a series of meetings and exhibits in connection with this Conference, which will include techniques for earth construction. Another NGO, Technology for the People, based in Geneva, is currently organizing a Second Annual International Trade Fair, to be held in Mexico City, from 6 to 13 November 1981. The UN Centre for Human Settlements has proposed a Global Conference on Human Settlements Technology to be held in 1982 or 1983. The UN General Assembly this year will also consider a proposition to designate 1983 or 1984 as the Year of the Homeless, which would focus on the massive refugee and resettlement problems the world faces, including squatters and the housing and shelter needs of the low-income populations.

So, the agenda for the future in this field is full and still growing, but the need for more concentrated support for institution building and development is clear. We must look at achievements in other sectors, and here one of the most successful models may be the Consultative Group on International Agricultural Research (CGIAR) organized in 1971 jointly by the World Bank, the UN Development Programme and the Food and Agricultural Organization. The Group is an informal association whose members are countries, public and private foundations, and international and regional development institutions. In Calendar 1980, the donor members made grants amounting to about $120 million to support a network of 13 specialized international research institutions whose work is concentrated on those food crops and livestock most important in the diets of people living in developing countries. Similar concentration on building research, including earthquake resistant construction, will undoubtedly also produce very major results and high cost benefit ratios.

Many international financial institutions such as the World Bank and Regional Banks, the European Development Fund, the International Fund for Agricultural Development, etc., recently have been devoting more of their resources for lending in rural areas, particularly for integrated rural development projects and programmes, and increasingly some funding is available for related shelter requirements, especially if so directly linked to production. Just as there has been a vogue for provision of "sites and services" for the poor in urban areas, often sparked by international lending, similar compelling reasons may well prevail for the extension of credit to enable substantial improvement of rural habitat and settlements, perhaps also with a "sites and services" approach.

This will offer new opportunity for upgrading the traditional type of construction with adobe and heavy tile or mud roofs which are so disaster-prone. But without a more adequate institutional structure at international, regional and local levels, the basic concerns will remain of how to get the information about the improved construction technologies into the hands of the users, the people themselves. This will require well-organized training and demonstration efforts, new development-oriented curricula in the universities and in the architectural and engineering schools, and the production of "barefoot" builders, teachers, and settlement managers on a large scale. Certainly to achieve these objectives and others, at least 12 to 15 international-regional interconnected environment building centres should be established or designated and supported by a combination of international, public and private sector funding.

This sort of development will undoubtedly require the establishment of a Standing International Advisory Committee on the Built Environment, under appropriate auspices, perhaps under similar concepts as have guided the Consultative Group on International Agricultural Research. This would, at last, represent a solid and continuing commitment for the cause of improved habitat and human settlements for the peoples of the world, and the phrase "Building for Peace" will take on new meaning.

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IMPROVING EARTHEN HOUSING TO BETTER WITHSTAND EARTHQUAKES

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ABSTRACT

This paper describes major activities carried out under contract from the U.S. Agency for International Development (AID) between Carnegie-Mellon University (C-MU), INTERTECT, and the Oficina de Investigacion y Normalizacion (OIN) in Peru from 1977-1980.

The importance of the political, social, cultural, economic, technical and material context for housing programs is addressed.

KEY WORDS

materials research, information sharing and transfer, methodologies, field work, earthen construction in rural areas, indigenous architecture.

Premise

To successfully bring about the technical improvement deemed necessary, ie. to improve the safety of housing through changes in either planning, design, construction or material use, means to successfully and lastingly intervene in housing development processes. Often technical programs are too narrowly focused for profoundly impacting these developmental processes.

Informal housing processes (self-help, owner built or indigenous housing) provide the overwhelming amount of shelter in third world countries. When trying to improve housing built through informal processes, it is especially important to realize that the owners/builders have strong reasons for what, when and how they build. Improvements will only be accepted by these owner/builders if, within their cultural, social, economic and material context, the improvements make sense. The benefits clearly must outweigh the costs in eyes of the "client population".

The paper discusses aspects of the Carnegie-Mellon University (CMU)/ INTERTECT (I) and Oficina de Investigacion y Normalizacion (OIN) Project in Peru which illustrate the need to understand the development process, to identity the costs and benefits of the proposed intervention and to achieve an awareness of what kind of changes on the social, political, economic, material and technical levels have to occur in order to make proposed interventions successful, that is to positively affect present day practices as they occur in the informal sector.

Project Background

Building on the experience in post-disaster assistance of INTERTECT and a joint Carnegie-Mellon (CMU/INTERTECT (1) Feasibility Study of An Approach and Prototype for Ultra Low Cost Shelter (1) in relief situations in Bangladesh funded by the U.S. Agency for Development (AID), CMU/I received a contract (2) from AID in 1976 to explore typical disaster situations in various environments. Specifically, the contract called for the investigation of housing and shelter needs in earthquake-prone areas and drought situations, and an evaluation of the work undertaken in the Bangladesh feasibility study - a high wind and flood environment.

In examining the methods of producing emergency shelter units that could easily be incorporated into more permanent type housing, CMU/I identified five support activities:

1. Materials Research

   Varied methods of producing walls, including fabrication with various types of block machines, ferrocement and rammed-earth processes, as well as examining means of improving traditional construction, such as the improvement of bamboo detailing and the use of stabilizers in earthen block construction, was an important support activity.

2. Information Sharing

   Once the project was underway, it was realized that existing information was fragmented and unavailable at any central source. Therefore, a centralized information base and a system for classifying housing-related information for use in disaster-related programs had to be developed. An attempt was made to correlate data with specific information needs and to develop data where insufficient information existed.

3. Information Transfer

   A major emphasis of the program was a review of information. Different media for teaching housing skills were investigated and the project relied heavily on practical experience obtained from a review of the work by OXFAM (4) and World Neighbors in Guatemala (4), the Save the Children Alliance in Guatemala (5), the Foundation for Cooperative Housing in Nicaragua (6), the Appropriate Reconstruction Training and Information Center (ARTIC) (7), the Salvation Army in Andhra

Pradesh, India (8); and the Government of Turkey (following the earthquake in Lice and Gediz). (9) In addition, information on technology transfer, materials, and training aids was obtained from sources such as the Peace Corps and the Non-Formal Education Information Center of Michigan State University.

4. Methodologies

The development of working methodologies, used to provide housing and shelter in various post-disaster situations, was a fourth activity. This work encompassed the review of strategies and approaches normally used by relief agencies in shelter provision, evaluating their effectiveness, and correlating the experiences of each organization. Parallel research being conducted by the United Nations Disaster Relief Office (10) regarding the provision of emergency shelter and post-disaster housing (a portion of which was undertaken by INTERTECT), and the work of Paul and Charlotte Thompson (11) under a research fellowship from the Organization of American States, was of great assistance. In addition, Major William Mitchell's (U.S. Air Force Academy) (12) study concerning the earthquake reconstruction programs in Gediz, Turkey, was an invaluable source and provided new insights. INTERTECT'S other operation activities in disaster situations in Honduras, Lebanon, Guatemala, and India provided further information on strategies and approaches which were incorporated into the final work.

5. Field Work

In many aspects the most important activity carried out under the contract, was the field work. This field work, provided the opportunity for viewing disaster types and environments, and participating in a number of operational programs designed to test concepts developed in the program. By 1977, these field investigations led AID to conclude that it would be beneficial to shift the project's emphasis away from post-disaster response to pre-disaster mitigation, by concentrating on the improvement of existing housing stock in disaster prone regions. It was realized that this approach would be more difficult since a greater receptivity to new materials and techniques designed to meet specific needs, exists in post-disaster situations. However, it was felt that a greater contribution could be made by developing strategies, approaches, and diverse training materials that could offer new opportunities for materials use in pre-disaster situations, and in the long run, would facilitate

a greater housing change.

In late 1976 and early 1977, a number of potential study areas, where these ideas could be tested, were investigated. After visiting a number of potential areas, Peru was chosen as the study site for the project. In response to the 1970 earthquake in Huaraz, a number of new building techniques had been developed and the Government of Peru wanted to incorporate these into a demonstration project. The government hoped to integrate these new construction methods with existing building technology for use in earthquake-prone regions of the country. A technical cooperation agreement (13) was developed between Carnegie-Mellon/INTERTECT and the Government of Peru to jointly develop this program.

CMU/I/OIN Project In Peru

Summary

In 1977, Cmu/I initiated a study that developed into a two-year project with the Ministry of Housing and Construction in Peru. The purpose ofthe study was to work with the Housing Ministry in developing approaches and technical materials to promote housing changes in high risk, vulnerable areas of Peru and to develop strategies and materials for immediate post-disaster response in providing housing in rural, mountainous areas. CMU/I worked with the Housing Ministry to develop a complete package of training aids for use in both pre- and post-disaster programs concerned with improving traditional adobe housing. In the course of the project, numerous technical reports were produced on program approaches and strategies for intervention, as well as reports providing comprehensive information about traditional housing and potential improvements for reducing its vulnerability. (14)

In addition to the development of training aids and technical reports, two tests of the training aids in actual building projects in rural areas with high seismic risks were to be conducted.

In 1977, a memorandum of agreement was signed between the Ministry of Housing, (Ministerio de Vivienda y Construccion) of Peru, CMU and INTERTECI. The research office of the ministry (Oficina de Investigacion y Normalizacion, OIN), had been coordinating major research and demonstration efforts involving the National Engineering University and the Catholic University in Lima, Peru. The activities were supported by the AID mission in Lima. (15)

COBE - Construccion Con Bloque Estabilisado

Stabilized and horizontal shear resistant adobe construction was to improve the quality of earthen construction and reduce the vulnerability of housing in earthquake prone areas. The asphalt stabilized adobe, which was at the base of this work had originally been developed by Fresno State University, the U.S. National Bureau of Standards and Chevron Oil Company. (16)

By 1977 extensive tests had been conducted in Peru which determined the compressive strength of stabilized adobe block, water permeability, as well as resistance to horizontal shear of wall assemblies and building configurations. Housing Demonstration projects using the improved methods were complete and the Government was ready to begin a program

for dissemination about stabilized adobe construction throughout the country.

OIN/CMU/INTERTECT in their contract with AID were to help in the dissemination of COBE building practices, with the aim to lastingly introduce these practices into the formal and informal building sectors.

However, when CMU/I began work the price of stabilizer agent, while still affordable in various areas, was rapidly rising. It therefore appeared that soon the price of the material would prohibit its use in any but a few select areas. As a result, CMU/I began examining various alternatives to the use of asphalt. The alternative, which was developed in the Chemical Engineering Department at CMU, was calcium acrylite. (17) Here too, however, the projected costs were not encouraging. Because of the cost increases of petroleum based chemicals in general, the team expanded the focus to include the reconnaisance of indigenous material usage in an effort to developing an understanding of how to improve the performance of indigenous building techniques. (18)

Approach

Responding to previous experience and contract requirements, the CMU/I/OIN team attempted to introduce technical improvements in adobe construction in both the formal and informal sectors of the Peruvian building industry through three means:

1.) Appropriately selected sites for pilot test programs; and

2.) Reconnaissance of indigenous building practices, material usage and improvement potential.

3.) Development of training aids.

1.) Site Selection for Pilot Test Program.

Given the dual focus on predisaster planning and post disaster assistance the team concentrated on the outset on selecting high risk seismic areas for potential sites of the pilot projects. In addition to reviewing objective data such as frequency and strengths of individual earthquakes, geological patterns (faultlines, history of avalanches) and disaster histories it was important to achieve an appreciation of the perception of the inhabitants regarding earthquake risk. A high risk area was then defined by being both objectively and subjectively high risk.

Within such high risk areas the following local reconnaissance was to be conducted:

*Structural analysis including housing types, history of vulnerability, material quality and type, joining techniques and quality of building components, traditional building configurations and layout.

*Site analysis including relationship of houses to general environment: climatic suitability (cannot any longer be taken for granted particularily in areas of increased population mobility).

*Geological suitability (i.e. is the site on an ancient, but potentially active avalanche, or the potential target of rock fall?)

*Housing Demand Analysis; indicators are degree and pace of urbanization, strength of local economy, percentage of young population in household forming age, migration patterns, potential loss of housing in disasters.

*Sociological Profile Analysis including identification of coping mechanisms (i.e. social mechanisms of individual or community response to disasters or normal life situations, description of social structure, identification of receptivity to innovation and the social obstacles potential new ideas might be faced with as well as the identification of a potential target group for the housing program. (The target group should contain key decision-makers in indigenous housing processes such as carpenters, masons, etc.)

Finally, it was recognized, it was of outmost importance to select a community with a high commitment towards participation in the construction and demonstration program.

2.) Reconnaissance of Indigenous Building Practices, Material Usage and Improvement Potential.

Before recommendations for changes in either housing design, construction or material usage can be made, with the intention to lastingly improve housing, a full understanding of present housing processes must be achieved. Key questions are who are the participants? (builders, owners, renters, community officials, etc.) What building skills are available? Which materials are used? Which are the preferred materials for construction? Is there a preferred building season? Is housing financing available? Is housing built on a mutual aid basis? What shortcomings exist in present practices? How are these shortcomings perceived by the affected people - if at

all? Is there a potential to combine existing building techniques in innovative ways to achieve higher performances under earthquake loading?

3.) Development of Training Aids

Training aids were developed in response to the requirements of two potential user groups:

a) instructors and community leaders; and

b) builders (carpenters, masons as well as self-help builders.)

Both sets of training aids were based on an understanding of the normal building process. In order to guage the effectiveness of different visual aids, brief field tests were conducted to see whether potential users understand the message to be communicated.

In developing the aids much emphasis was placed on evoking within the user, an identification with the new ideas. The representations of people, places, tools and materials were to be culturally familiar in both appearance and method of representation, this was to encourage the viewer/reader to comprehend the project within his own cultural milieu rather than suggesting a foreign setting.

The teaching aids were available in draft form at the start up of construction of the field tests. Through discussion and observation the aids were refined and finalized during and after the period of construction in order that all recommendations which came from the field experience could be incorporated.

During construction a series of video tapes were taken in order to document the construction process of the model house for future demonstration projects.

Field Test - Acomayo

For reasons other than the project objectives (demonstration, dissemination, technical improvement); OIM selected the Department of Huanuco and the town of Acomayo as the site for a demonstration project.

Acomayo is a small rural town of about 1,000 total inhabitants, 45 minutes by car from Huanuco, Department of Huanuco, on the new road to Tingo Maria.

Almost all buildings in Acomayo are constructed to tapial. A few buildings along the road are constructed of Quincha and almost

none are made of adobe. (rammed earth, see plate)

Most people work in agriculture. A handfull of small stores exist. A few dozen people appear to work as drivers of collective taxis and trucks. Acomayo appears to have lost population as there are vacant houses.

Acomayo also functions as a school center for approximately 300 children. Part of the existing school building was rendered useless through a flood caused by an overflowing aquaduct which eroded a part of the foundation and 4 out of 10 classrooms had to be abandoned.

Acomayo is located in a zone of low earthquake risk. The people of Acomayo do not perceive earthquakes as a threat.

Demonstration Project:

Again, for reasons other than project objectives, it was decided for the team that the project was to build additional classroom space for the community.

The model house which was also contemplated, since there was no apparent need for housing, was to serve as another community facility.

Considering these basic site conditions and the demonstration project's focus it became clear that the site and the demonstration project (school additions and model house) were in-appropriate for the overall project's intentions for the following reasons:

1) The department of Huanuco was not subject to frequent, violent earthquakes. People, therefore, did not perceive earthquakes to be a major risk factor. Consequently, any proposed alterations of existing construction techniques for reasons of earthquake safety would likely be viewed as unnecessary.

2) Acomayo did not appear to need new housing.

3) Present building techniques in Acomayo favored tapial construction.

4) Additions to a school building did not constitute an adequate vehicle for the demonstration of housing improvements.

In summary, it was felt that no spread effect of the improved adobe construction techniques could be expected because earthquakes posed no serious problem, little if any new housing would be con-

structed, and adobe was not a major building material in Acomayo.

While there existed a need for additional classroom space, the process by which the community was invited to participate in the demonstration project turned out to be counter productive. The community was not sufficiently required to collaborate in the planning, financing, and construction of the school. All in all, seven classrooms, a new toilet facility, and an eating area were to be constructed. Almost two years after the beginning of the project, the two aulas (classrooms) (Phase I) are not complete. While they are being used, both miss plastering of inside and outside, concrete floors, and windows.

There is no indication that the remainder of the project will be constructed. The attitude in the Alcaldes office is that the community is poor and the government promised seven classrooms. The model house was completed and served as a useful test for the teaching aids, but since it did not respond to a fundamental need in Acomayo, it's effect on construction after its completion has been negligeable.

Results, Lessons and Recommendations

From a community development point of view the fieldtests were a failure, generating expectations in the community which cannot be met by the government, given present resources. The projects were not embedded in a community participation and development process because there existed no appreciable need for construction improvements to reduce earthquake risk, no appreciable need for new housing, and because the major building material was tapial (rammed earth, plate) and not adobe. Improvement suggestions on the basis of adobe must have appeared esoteric at best.

In retrospect it appears that even though additional classroom space was being produced, it would have been better not to have a project in Acomayo at all, instead of encouraging selfhelp, the project might have created greater dependency. Clearly a need to build must originate within the community itself. It should not be "stimulated" from the outside.

In the case where such a need exists it is no less imperative that:

* the need to improve present practices must be able to be recognized by the community;

* the material usage is compatible with the proposed material usage of the demonstration project (do not demonstrate improved adobe practices in a place which builds with tapial);

* the costs of the improvements clearly do not exceed the benefits in the eyes of the people to be assisted; and

* that the costs of the improved material do not begin to approach the costs of the material just above in the materials hierarchy. (Example Peru: in most areas of the country the following perceived values exist: steel/glass, concrete, concrete block, brick, adobe, tapial, wood, quincha, (plate) in decending order of perceived value and status). Therefore if the cost of improved adobe begins to approach the cost of brick, people would prefer to build with brick instead of adobe.

While team members were aware of this fact, the project selection process did not allow for sufficient interaction between technical project personnel and political decision makers.

Technical Lesson With Political Dimension:

Besides the more obvious political dimensions of a large scale technical improvement program in housing, such as socio economic status of target population, resources to be devoted to project, degree of local participation and determination, etc., great care should be devoted to determine precisely where and how in the housing development process the intervention to improve that process should be carried out.

In the general case of housing construction in Peru, what are the social dynamics of building materials and assemblies; including status, affordability, etc.? What role does earthen construction play in this context? What are future trends affecting earth as building material? Where does adobe fit in all this? In the case that adobe emerges as a highly prominent building material with a certain future, in order to increase it's safety where should the intervention be placed? In material improvements, joining techniques, or building design recommendations? If in all of the above, what are the most important factors? How many changes can one technical program advocate with a good chance for social acceptability, reasonable cost, etc?

The Importance of the Development Process

To successfully bring about (to lastingly introduce) the technical improvement deemed necessary (generally from the point of view of the outside technician) - ie. in the case of housing in seismic areas to improve the safety of housing through either alterations in planning, design, material usage, construction practices or use-means to successfully and lastingly intervene in what is always (from the point of view of the users) an extremely well worked out and efficient housing development process.

Informal housing processes (self-help, owner-built, or indigenous housing) provide the majority of shelter in 3rd world situations. When trying to improve housing built in the informal sector, it is especially important to realize that owners/builders have very good reasons for what and how they build.

Improvements will only be accepted as necessary and desirable, by these owner/builders if, within their own cultural, social, economic, and material context, the improvements make sense. The benefits must clearly outweigh the costs in the eyes of the people affected.

Technical programs often fail to profoundly impact informal

housing development processes because:

they are too narrowly focused on technical concerns;

they reflect more the view and needs of the donor organizations than the view of the people to be assisted;

giving other pressing needs - food, employment, etc., safer housing by necessity may have to assume a lower priority in the eyes of the user than is assumed to be acceptable by donors and/or technicians;

they try to change too many things (materials, structures, components, joints, etc.) at one time.

As a general rule, housing programs should try to take the point of view of the ultimate users. When this point of view is taken, solutions can be attempted which satisfy technical requirements of governmental and donor organizations and which have a chance of user acceptance. The following might serve as an illustration of this point. In many locations in Peru, population migration and scarcity of land have led to high population densities. Consequently owner built houses tend to be two and more stories high and because of the high cost of street frontage tend to be narrow and deep. In the case of earthen construction this leads most of the time to houses which are unsafe in earthquakes. Instead of advocating housing "solutions" which are one story high and square in plan, which, given earthquake considerations only, would be desirable, users should be presented with methods that accept that houses are two or more stories high, long and narrow. Then, other technical solutions to the problem of safety offer themselves to the technician, such as the layering of construction techniques - for example adobe or tapial construction for the first floor and quincha above, and the "breaking up" of one long and narrow structure into two square parts through the introduction of crush zones.

At the end the CMU/I/OIN project in Peru posed more questions than answers. Despite the obvious shortcomings of the field test, useful training aids were developed and far better insights into the development process were obtained than were available before. Observing the lessons discussed here in future projects, and creating strong bi-national multi-disciplinary teams in close touch with appropriate target populations, should provide the setting for further work in pre-disaster assistance.

Discussion Of Plates

The following plates were arranged to illustrate some of the points made in this paper. There are seven plates. Plates 1 - 4 relate to recommendations made in The Report Indigenous Building Techniques of Peru and their Potential to better withstand Earthquakes. Plates 5 - 7 are sampling of the visual teaching aids.

Tapial Construction

Plate One - gives impressions of this technique practiced in pre-Inca cultures on the coast of Peru (example Puruchucu, close to Lima and prevelant in present day Peru in the Alti Plano and mountainous areas.

Plate Two - the rural house pictured represents a common example of present day construction. The example here is located on the outskirts of Cusco. The house is two stories high, made of adobe. The long walls are weakened through unevenly spaced window and door openings. Fortunately the roof is relatively light weight. The 19th century house in Lima, exhibits an interesting potential to better withstand earthquakes in that it's second floor is made of quincha, thereby reducing the weight of the second floor and having the potential to absorb quake induced movements through deformations in the flexible structure.

The model house located in Acomayo and constructed in the field test described in the paper demonstrates how to build a single story adobe building using most of the techniques illustrated in the teaching aids, examples of which are given in Plates 5 - 7.

On a country wide basis single story demonstration projects do not appear to impact present day construction methods because most rural and certainly urban counstruction is at least two stories high.

Plate Three - is an illustration of some of the recommendations made in the report named above. Material combinations, advantageous under earthquake loading, are presented with the idea to promote adaptations of indigenous techniques while encouraging self-help construction, instead of importing foreign, more costly technologies.

Plate Four - shows the use of some of these adapted techniques in a two story structure. This structure would be composed of square about 6 x 6 m building segments. The first floor could be of either

adobe or tapial, the second floor of quincha; produced in methods as shown. The lighter second floor would create lesser forces acting on it under earthquakes, and the flexible structure would tend to absorb forces through flexure.

Plates 5 - 7 are examples of the graphic teaching aid entitled "How to Build a House of Modern Adobe." The booklet contains 23 drawings in toto, 9 of which are reporduced here. The accompanying text is in a didactic question and answer form. The illustrations are by the artist A. Andia of OIN, Lima Peru.

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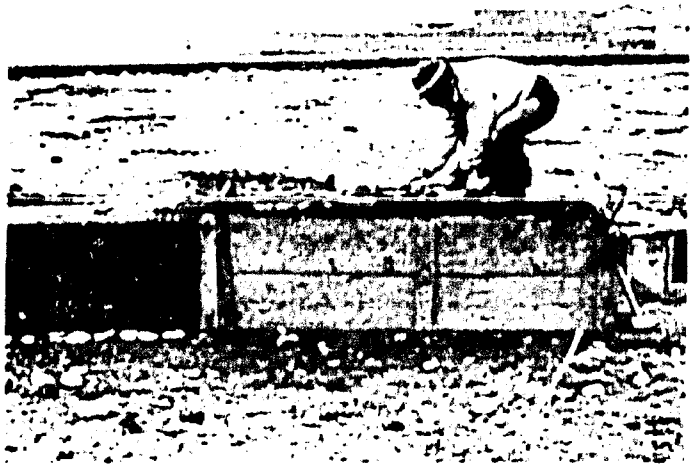
17. Study of Building Material from Polymer Stabilized Soil, Karl A. Zipf, Jr. (M.Sc. Thesis, Department of Civil Engineering, CMU, 1978).

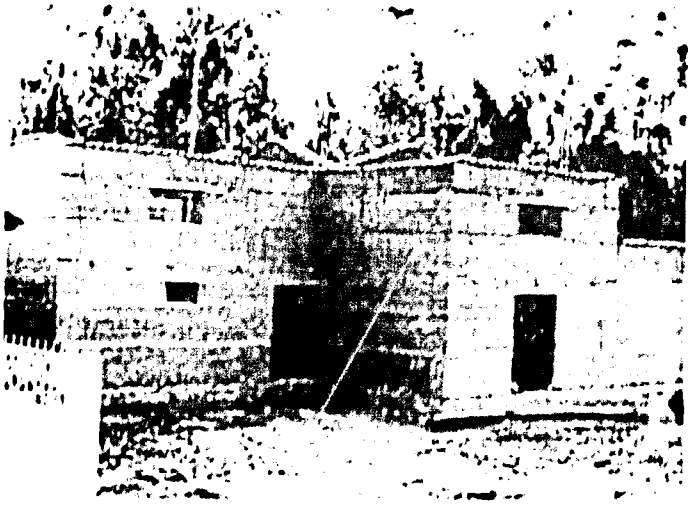
18. Indigenous Building Techniques of Peru and their Potential for Improvement. Carnegie-Mellon University, 1981.

19. Fred C. Cuny, Scenario for a Housing Improvement Program in Disaster Prone Areas. Proceedings: Disasters and the Small Dwelling.



Compacting Soil

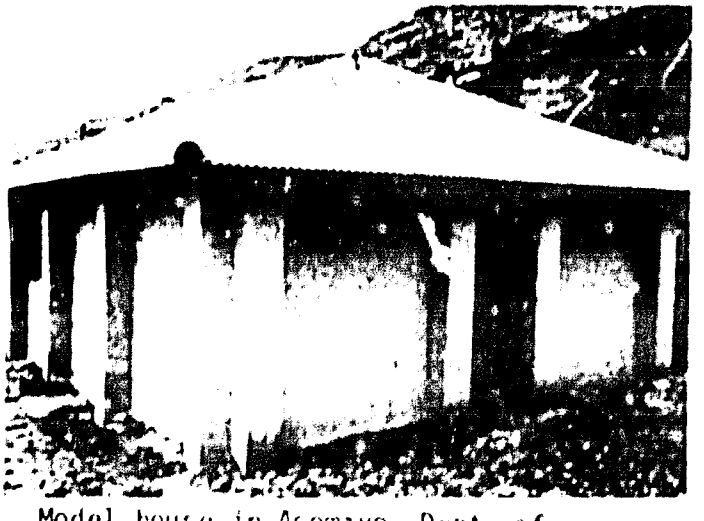
Fastening Form-Work



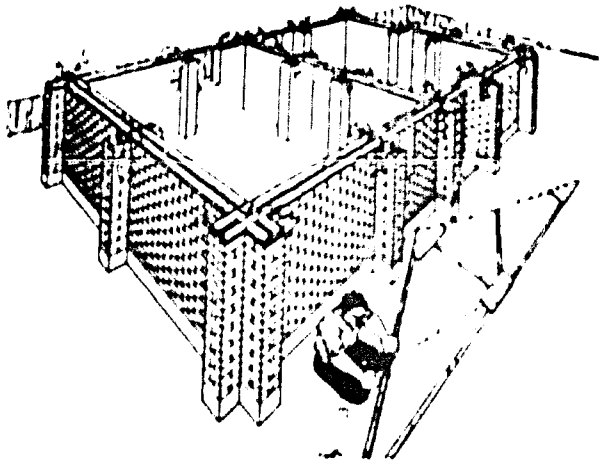
Completed Tapial Walls
(Huamcayo, Peru)

Rural 2 story, oblong house with uneven distribution of openings

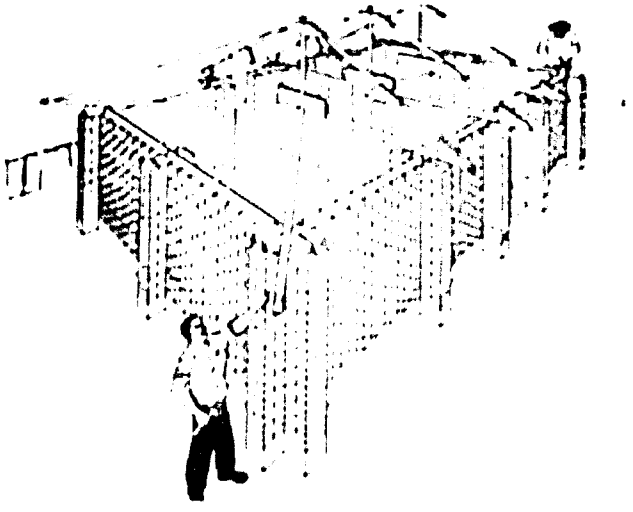
19th Century house in Lima, Peru
1. floor adobe
2. floor quincha



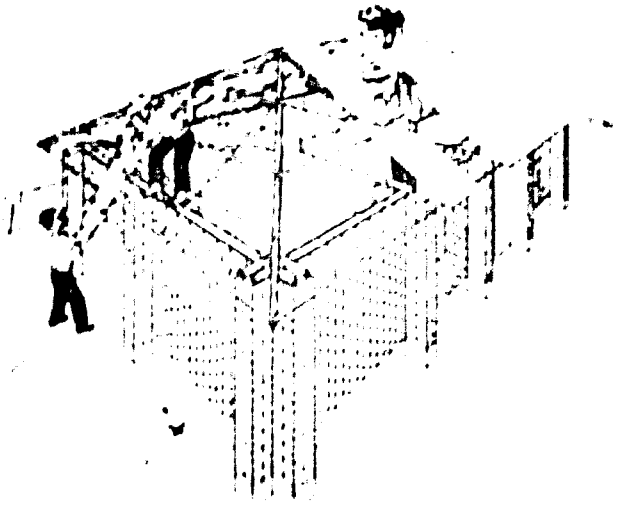
Model house in Acomayo, Dept. of Huamuco, Peru



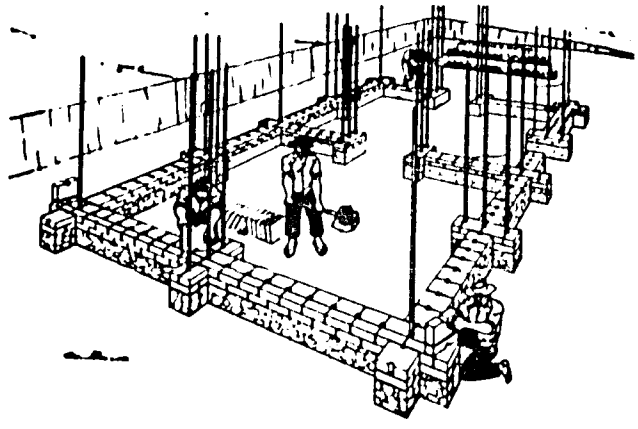
Trussmaking



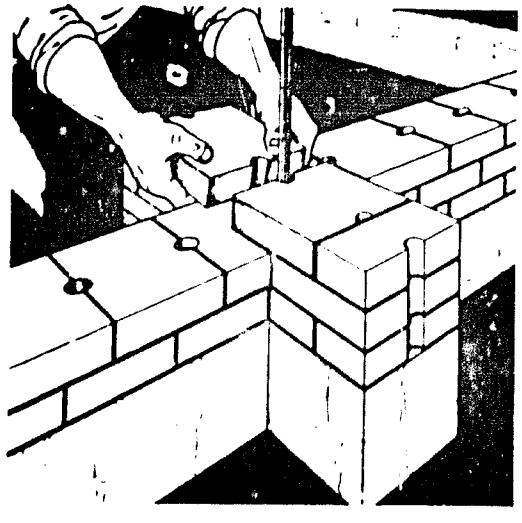
Making a roof of "quatro aguas"
(no gables)



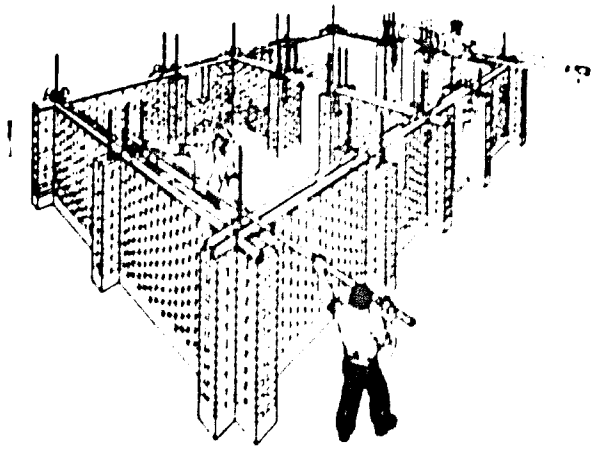
Roof covering



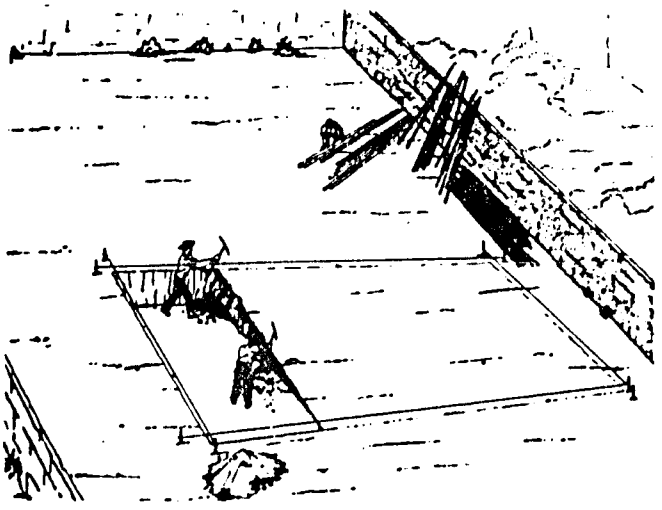
Laying adobes



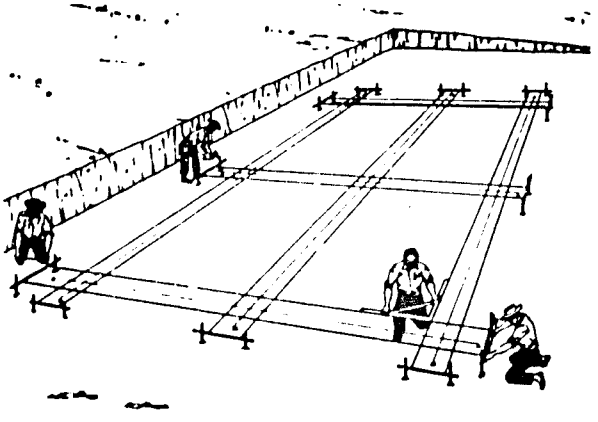
Making a pilaster



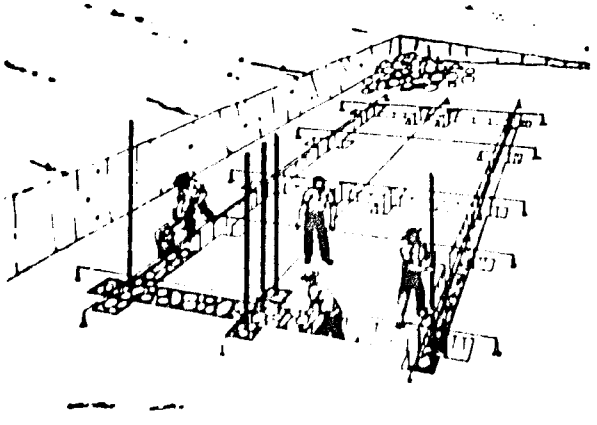
Installing the collar beam



Making a level site



Delineating the foundation



Placing reinforcement and laying foundation.

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EARTHQUAKE RESISTANT BUILDING
PERU

CHAPTER TITLE

TOPIC

NUM KEY | PART
PAGE NO

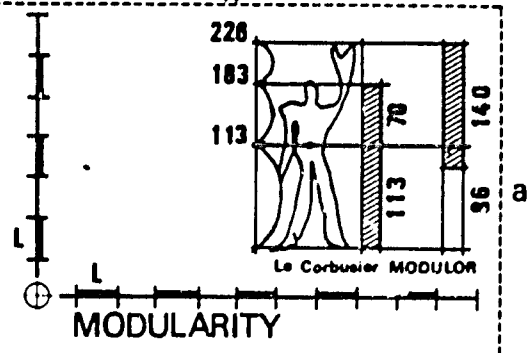
a

Composite Design
Superimposition of Structure

General

In order to achieve symmetry for earthquake improved design, a modular concept as an organizational basis for layout and structural design can be applied.

The square or rectangular shaped floorplan will be generated from a grid of a single modular length and a single modular width. (p Ia)



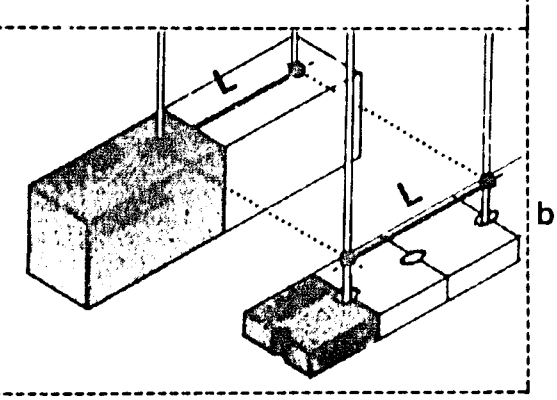
a

b

For Tapial walls the dimensions of the slipform, which produces the tapial layers will be based on this grid. Accordingly, the vertical reinforcement members of the wall will follow this system.

Similarly the sizes of the adobe brick will be related to the modular dimensions. (p Ib)

In the case of a superimposition of either an adobe or tapial structure and a quincha - bahareque structure, the vertical members of reinforcement and construction can then be simply attached to each other. (p IIb)



b

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EARTHQUAKE RESISTANT BUILDING
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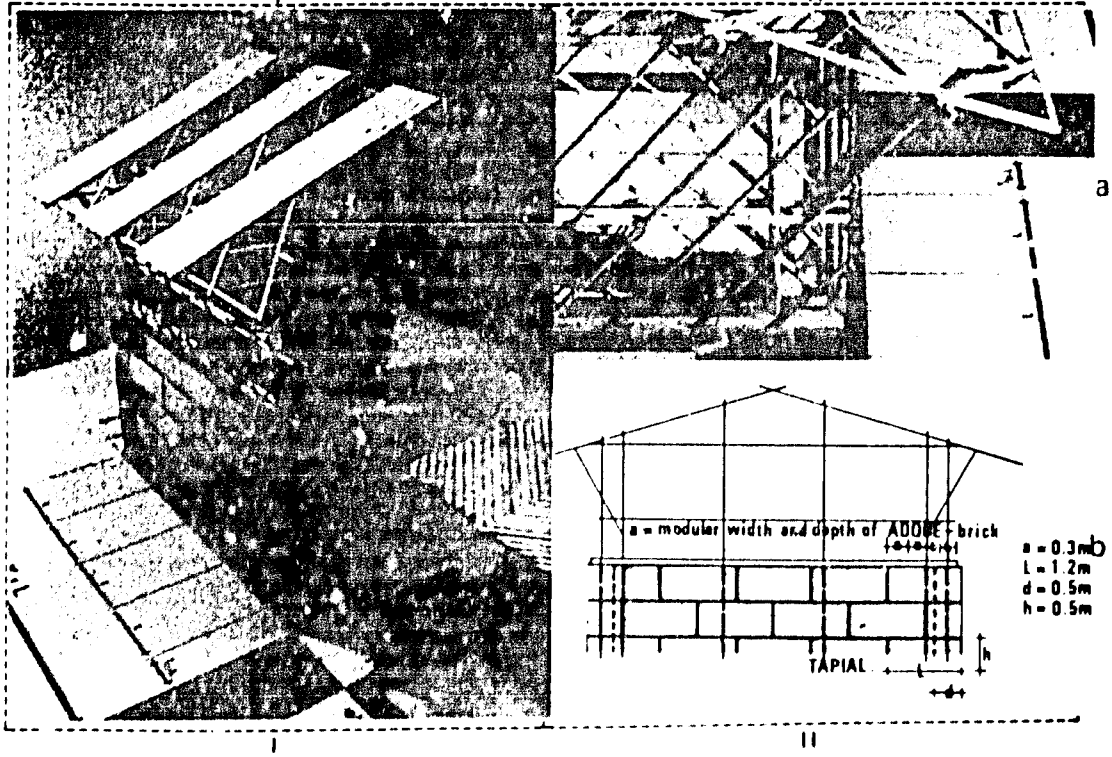

b

Proposed Stating of Construction Methods

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I II

a

Finishing Quincha - Bahareque Walls

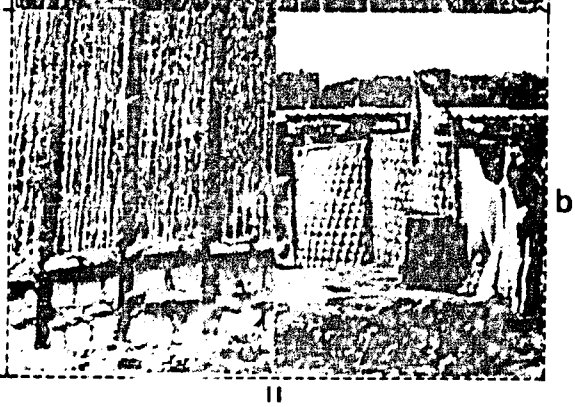
Traditionally, the branches used for infill also can serve as a support for the plaster.

a

b

Another potential sup rt structure is shown on the picture IIb, whe 'cancs' are inserted in a wooden frame.

The 'criss-cross' straw-mats are very effective lightweight walls.



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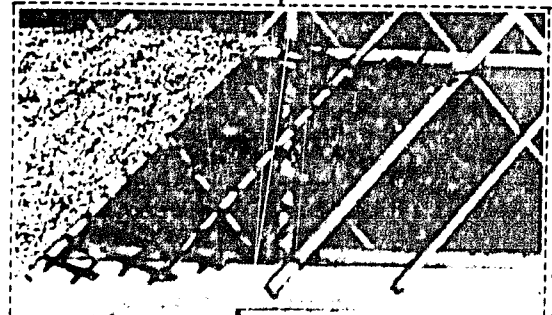
I II

CARNEGIE-MELLON UNIV Advanced Bldg Studies Program Pittsburgh, PA 15213 | EARTHQUAKE RESISTANT BUILDING PERU | CHAPTER TITLE | TOPIC | NUM KEY | PART | PAGE NO

I II

a



Finishing Quincha/Bahareque Walls

Proposed Improvement

The production of grass-rope nets of appropriate density and strength could serve two purposes.

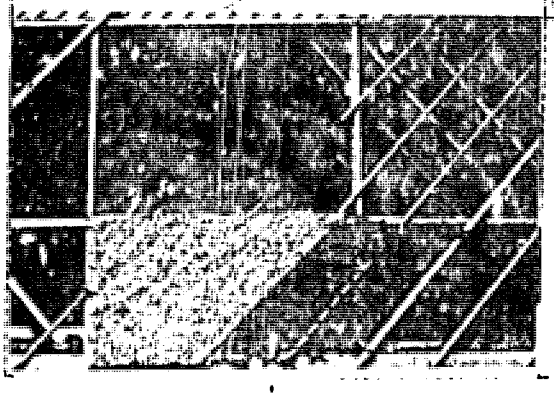
1. In the villages a new market for manufacturing of such grass-rope nets could create employment.

2. The application of the rope net as shown in picture Ia, Ib structurally would enhance structural stability. An advantage is light-weight.

An infill material such as paper, grass, mud, branches, etcetera could serve as thermal insulation of the wall.

a

b



b

I II

Indigenous and Proposed Material Combination

EARTHQUAKES IN TURKEY: RECONSTRUCTION PROBLEMS, DAMAGE PREDICTION, AND RECOVERY FORECASTING FOR EARTHEN STRUCTURES

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William J. Weida
Department of Economics and Management
United States Air Force Academy, CO 80840

ABSTRACT

Field research after the Gediz, Lice, and Caldiran-Muradiye earthquakes in Turkey has revealed various problems dealing with the post-disaster restoration and reconstruction. Based on lessons learned from Turkish earthquakes, suggestions to improve reconstruction are offered. Further, research from Turkish disasters has led to the construction of two models. One predicts the number of houses destroyed based on earthquake magnitude and discriminates between housing types. The second model predicts recovery progress at any given time after the quake has occurred.

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Since about four out of ten people in the world live in the over 30 countries which are located in active seismic zones, earthquakes provide a continual catastrophic threat.[1] The threat is very real for the Republic of Turkey.[2] Turkey is one of the approximately 30 countries that has historically experienced earthquakes, and it is located on one of the earth's two major seismic belts. Earthquakes in that country are very common occurrences.

This research was undertaken to identify problems in rural reconstruction following earthquake disasters in Turkey and to provide a model for authorities in predicting recovery times following disasters.[3] The model would link time to the way resources are expended in the reconstruction effort, and thus act as a guide for the insertion of appropriate amounts of money and material into the affected area through the reconstruction period. Such a model could be used to deal with any earthquake occurrence since it is based on a generalized data scheme which presents all data in a percentage format. The model can also perform a "rationality check" on the reasonableness of initial recovery estimates very early in the reconstruction phase.

The Earthquake Threat in Turkey

Earthquakes, one of the worst natural hazards, can cause catastrophic disasters.

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[1]For an understanding of the problem, see the Summary in Earthquake Engineering Research, A Report to the National Science Foundation (Washington, D.C.: National Academy of Sciences, 1979), particularly pages 1-7 and 19-20, Also, Thomas C. Nichols, Jr., "Global Summary of Human Response to Natural Hazards: Earthqakes," in Natural Hazards, Local, National, Global, edited by Gilbert White (New York: Oxford University Press, 1974), pp. 274-284, and Tapan Mukerjee, Economic Analysis of Natural Hazards: A Preliminary Study of Adjustments to Earthquakes and Their Costs. Natural Hazard Research Working Paper No. 17, Institute of Behavioral Science, University of Colorado, Boulder, Colorado, 1971.

[2]William A. Mitchell, "Reconstruction After Disaster: The Gediz Earthquake of 1970," Geographical Review, Vol. 66, No. 3, July 1976, pp. 297-298.

[3]The authors express their appreciation to Mr. Teoman Guzey, Executive Director, Turkish Ministry of Reconstruction and Resettlement; Mr. Oktay Ergunay, Head of the Turkish Earthquake Research Institute; Professor Erol Tumertekin, Head of the Geographical Institute, University of Istanbul, for assisting on the research, and to the Frank J. Seiler Research Laboratory, USAFA, and Dean of the Faculty for partial funding of the project.

They have the potential to release concentrated energy on the order of nuclear weapons.[4]

When an earthquake strikes, there are many independent variables that may influence the severity of the disaster. The actual impact of the natural event, or damage to humans, depends on physical characteristics of the event, and socioeconomic adaptations by the threatened community. The affected area can be very vast; in fact, a high magnitude earthquake can inflict widespread damage and casualties over a 50,000 square mile area.[5]

Severe and major earthquakes in densely populated areas can have catastrophic consequences. Why? In general, because the hazard damages and destroys man-made structures.[6]

Earthquakes occur because the earth's crust is dynamic, not static, and is not a single rigid shell but floats as ten major and minor plates on a body of hot plastic rock. When movement along these plates occurs suddenly, the result is an earthquake. Because of location on or near these plates, or faults, some countries are particularly vulnerable to earthquake disasters.[7] The Republic of Turkey is one such country.

Turkey was chosen as the study area for several reasons. The most obvious is that frequently both severe and major earthquakes occur there. The country is crossed by the Alpide seismo-tectonic belt, in which seventeen percent of the world's earthquakes occur. Destructive earthquakes have occurred there since the earliest days of recorded history. In very recent years, many Turks have been killed in earthquake disasters (Table 1). For example, 2,394 were killed in 1966 (Varto), 116 in 1967 (Adapazari and Pulumur), 1,143 in 1970 (Gediz and Burdur), 870 in 1971 (Bingol), 2,385 in 1975 (Lice), and 3,700 in 1976 (Muradiye).[8]

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[4]A classified study evaluating the similarities of damages caused by earthquakes and nuclear disasters has been completed using data from the People's Republic of China and the USSR. Timothy H. Miner, William A. Mitchell, and William J. Weida, Analyzing and Modelling Natural Disasters: Implications for Recovery from Nuclear Disasters (U), United States Air Force Academy Technical Report 79-3, DFEGM, USAFA, Colorado 80840, report classified Secret, February 1979.

[5]Harold C. Cochrane, Natural Hazards and Their Distributive Effect--A Research Assessment, University of Colorado Monograph NSFRAE 75003, 1975, p. 2.

[6]Weisbecker and others describe very well what earthquakes do. See Leo W. Weisbecker and others, Earthquake Prediction, Uncertainty, and Policies for the Future: A Technological Assessment of Earthquake Prediction, prepared for the National Science Foundation, Stanford Research Institute, Menlo Park, California, Final Report, January 1977, p. 7.

[7]See Robert Iacopi, Earthquake Country (Menlo Park, Calif.: Lane Books, 1976), pp. 26-27.

[8]Provided to Mitchell by the Earthquake Research Institute, Ministry of Reconstruction and Resettlement, Government of Turkey. Diacritical markings for Turkish place names are omitted in this paper.

TABLE 1

Major Earthquakes in Turkey (1925-1976)

Date	Location	Intensity I_o	Magnitude M	Deaths	Houses Destroyed
7 Aug 1925	Afyon-Dinar	IX	5.9	330	2,500
31 Mar 1928	Izmir Torbali	IX	7.0	170	2,600
18 May 1929	Sivas-Susehri	VIII	6.1	64	1,357
19 Jul 1933	Denizli-Civril	VIII	5.7	20	200
4 Jan 1935	Erdek	IX	6.7	5	600
19 Apr 1938	Kirsehir	IX	6.6	155	2,500
22 Sep 1939	Izmir-Dikili	IX	7.1	150	1,500
26 Dec 1939	Erzincan	X-XI	7.9	40,000	140,000
20 Feb 1940	Kayseri-Develi	VIII	6.7	40	500
10 Sep 1941	Van-Barbale	VIII	5.9	192	600
15 Nov 1942	Bigadic-Sindirgi	VIII	6.1	16	750
20 Dec 1942	Niksar-Erbaa	IX	7.0	3,000	32,000
20 Jun 1943	Adapazari-Hendek	IX	6.6	285	1,000
26 Nov 1943	Tosya-Ladik	IX-X	7.2	5,000	40,000
1 Feb 1944	Bolu-Gerede	IX-X	7.2	2,831	50,000
25 Jun 1944	Gediz-Usak	VIII	6.2	20	3,500
6 Oct 1944	Ayvalik-Edremit	IX	7.0	30	5,500
20 Mar 1945	Adana-Ceyhan	VIII	6.0	13	370
21 Feb 1946	Kadinhan-Ilgin	VIII	5.6	12	400
31 May 1946	Varto-Hiniz	VIII	5.7	650	3,000
23 Jul 1949	Karaburun-Izmir	IX	7.0	7	865
17 Aug 1949	Karliova	IX	7.0	450	3,500
13 Aug 1951	Kursunlu	IX	6.9	50	3,354
3 Jan 1952	Hasankale	VIII	5.8	94	1,570
18 Mar 1953	Yenice-Gonen	IX	7.4	265	1,750
7 Sep 1953	Kursunlu	VIII	6.4	22	430
16 Jul 1955	Soke-Aydin	IX	7.0	23	470
20 Feb 1956	Eskisehir	VIII	6.4	1	1,440
25 Apr 1957	Fethiye	IX	7.0	67	3,100
26 May 1957	Bolu-Abant	IX	7.1	66	5,200
25 Apr 1959	Koycegiz	VIII	5.7	3	630
18 Sep 1963	Cinarcik	VIII	6.3	1	230

TABLE 1

Major Earthquakes in Turkey (1925-1976)

Date	Location	Intensity I_o	Magnitude M	Deaths	Houses Destroyed
14 Jun 1964	Malatya	VIII	6.0	8	678
6 Oct 1964	Manyas	IX	7.0	30	5,523
13 Jun 1965	Denizli-Honaz	VIII	5.7	14	468
7 Mar 1966	Varto	VIII	5.6	14	1,100
19 Aug 1966	Varto	IX	6.9	2,394	20,007
22 Jul 1967	Adapazari	IX	7.2	89	5,569
26 Jul 1967	Pulumur	VIII	6.2	97	1,282
3 Sep 1968	Amasra-Bartin	VIII	6.5	29	2,072
23 Mar 1969	Alasehir	VIII	6.9	41	3,700
28 Mar 1970	Gediz	IX	7.3	1,086	9,452
12 May 1970	Burdur	VIII	5.9	57	1,487
22 May 1971	Bingol	VIII	6.2	870	5,356
6 Sep 1975	Lice	VIII	6.9	2,385	8,165
24 Nov 1976	Caldiran-Muradiye	IX	7.1	3,840	9,232

Source: Earthquake Research Institute, Republic of Turkey, Ankara, June 1977.

There is every reason to believe that Turkey will continue to experience earthquakes! Hence, it is an excellent laboratory in which to model recovery.

Presently, adjustment to earthquakes is primarily in the form of distributing losses through emergency relief, since the hazard cannot be reduced and modification of vulnerability is not now practical. An ideal adjustment would be to have the people live only in safe areas. Turkey, however, is a country about the size of Texas, with a population of over 45 million people, of which over ninety percent is seismitically active (Figure 1). Consequently, there is insufficient space even if it were economically and culturally feasible to relocate the population.[9]

Dwellings in Turkey

There were approximately 6.5 million housing units in Turkey in 1970.[10] Three million, nine thousand dwellings were located in rural settlements with populations under 10,000. There were in 1970 about 65,000 villages containing approximately 61% of the population.

About 2.6 million dwellings were located in towns and cities with more than 10,000 inhabitants. These also included shanty town dwellings.

In terms of earthquake-resistent housing, there is a severe shortage in Turkey. The Turkish delegates to the "Intergovernmental Conference on the Assessment and Mitigation of Earthquake Risk" held in Paris in 1976 revealed that 30% of the rural dwellings require immediate structural repair and strengthening while 17% are in a condition beyond repair (Figure 2).[11]

Rural dwellings in Turkey are about 50% stone and brick masonry, about one-third adobe, and approximately 13% timber frame structures. About 11% are a mixed or hybrid types (Figures 3 and 4). Village houses are mostly one-story units (58%). The remainder are two story. The average house has less than 100 square meters of

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[9] An attempt to estimate casualties and damages within minutes after an earthquake occurs in Turkey was made by William A. Mitchell, Richard Wolniewicz, and John F. Kolars, "Predicting Casualties and Damages Caused by Earthquakes in Turkey: A Preliminary Report," United States Air Force Academy Technical Note 78-2, DFEGI, USAFA, Colorado 80840, March 1978.

[10] Housing data taken from Country Monograph of Turkey, UNESCO, Ankara, 1976, and from the Ministry of Reconstruction and Resettlement, Government of Turkey, Ankara, June 1977 and 1978.

[11] Country Monograph of Turkey, p. 27.

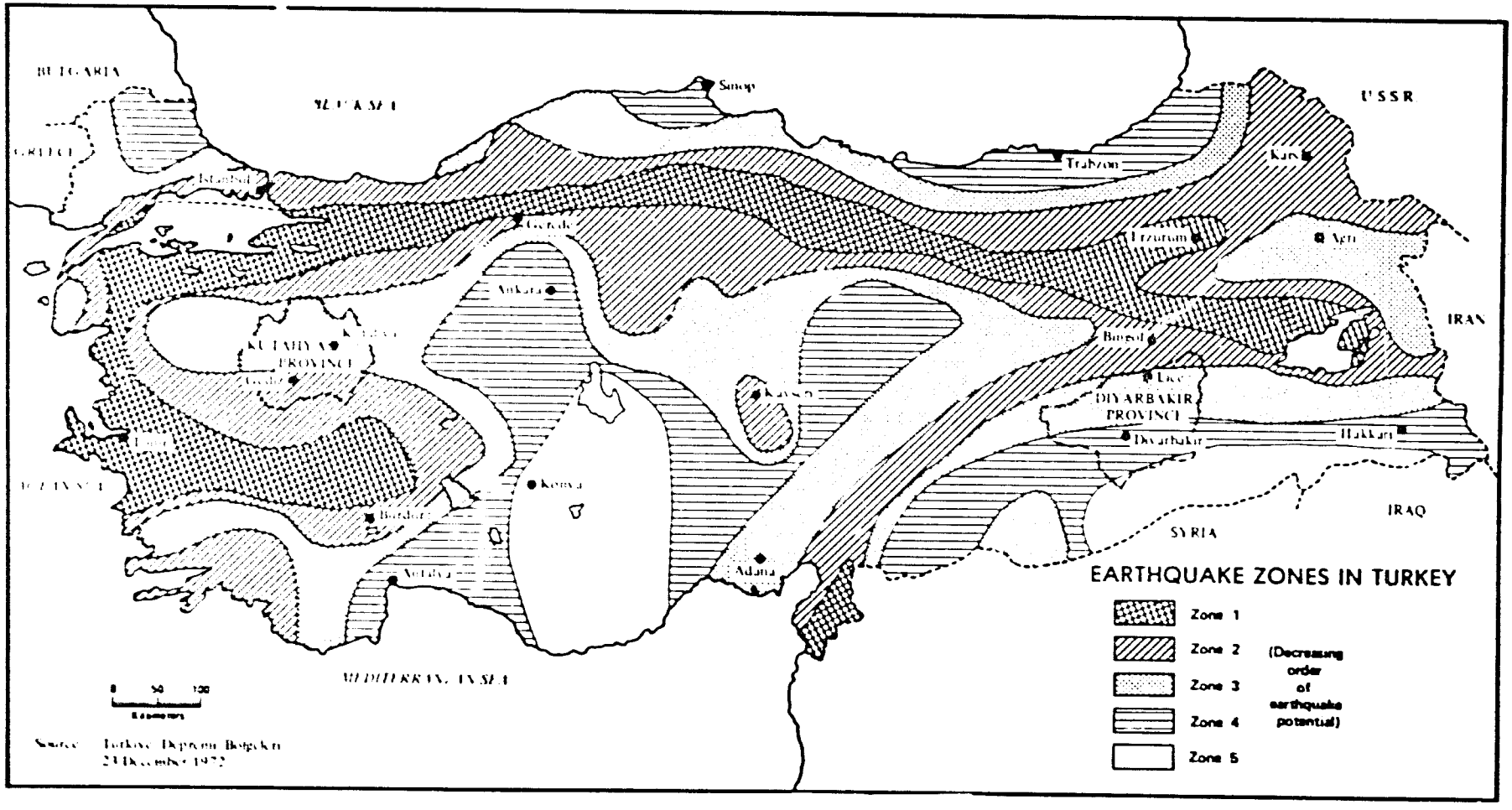
BULGARIA
GREECE
BLACK SEA
Sinop
Trabzon
USSR
Kars
Erzurum
Ağrı
IRAN
Ankara
KUTAHYA PROVINCE
Bingol
Elaziğ
DIYARBAKIR PROVINCE
Diyarbakir
Hakkari
Konya
Burdur
Antalya
Adana
SYRIA
IRAQ
MEDITERRANEAN SEA
EARTHQUAKE ZONES IN TURKEY
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
(Decreasing order of earthquake potential)
0 50 100
Kilometers

FIG. 1

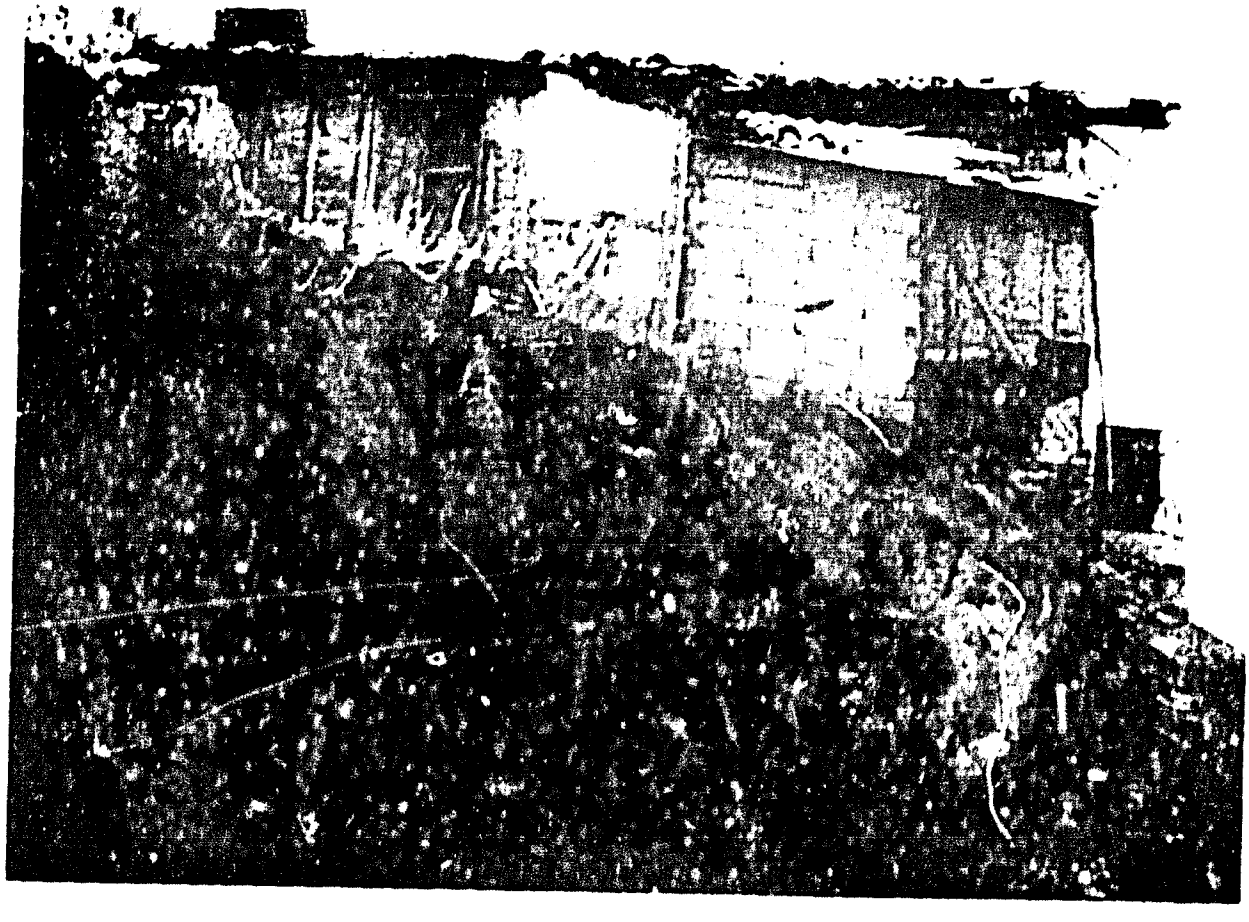

FIG. 2

An example of a house beyond repair.
This dwelling is of hybrid construction
on a precarious site in old Gediz (1978).

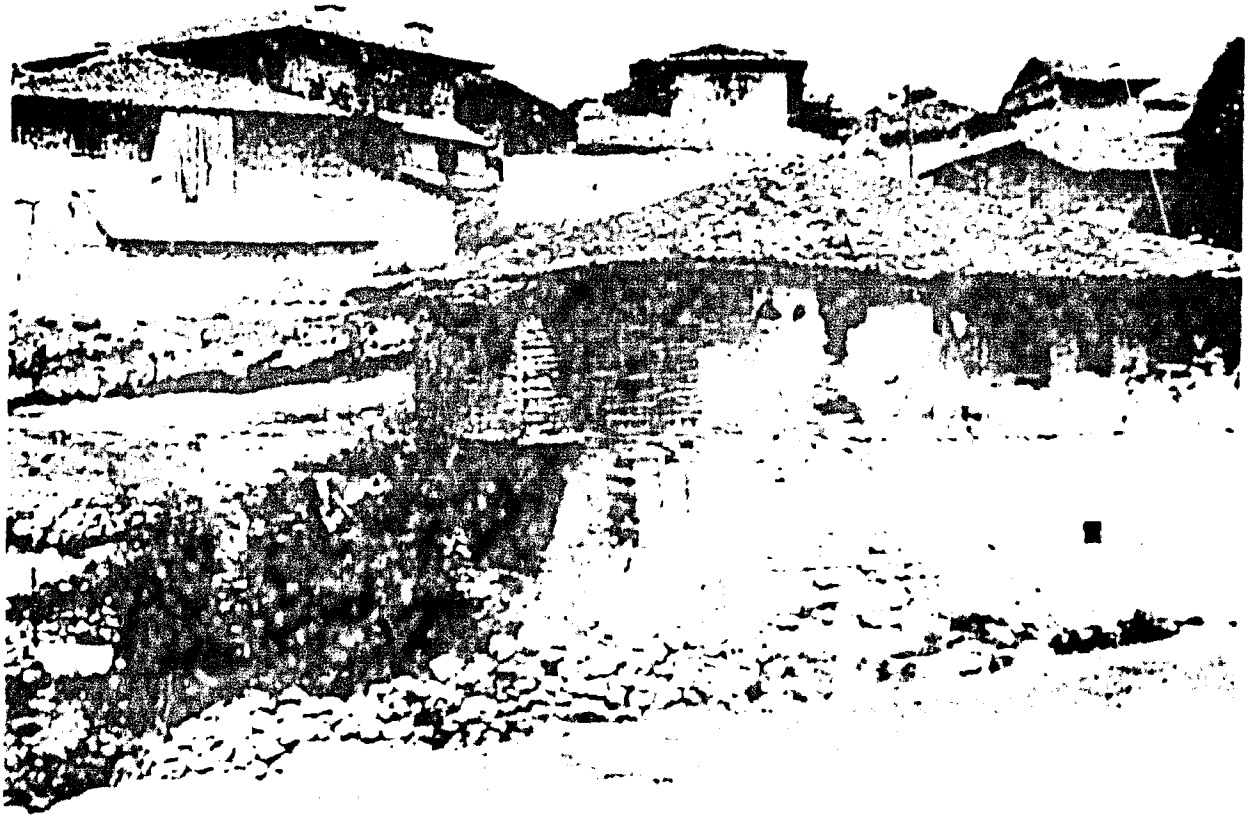

FIG. 3

Fieldstone/adobe wall-bearing construction in western Turkey.

FIG. 4

Representative 2-level wooden frame structure in western Turkey. Infilled with adobe and stone covered with mud/straw mortar.

floor space.[12] Houses in villages were populated at an average of 5.97 per unit in 1965, with an average of 2.2 rooms per dwelling.

Villagers in Turkey usually construct their own homes. Materials include mud and straw adobe bricks, mud for mortar and plaster, rocks for filling, roof tiles, and in some cases high-quality concrete blocks or kiln-fired bricks. Some wealthy villagers may have houses of masonry laid in cement.[13]

Based on our observations in the Gediz, Lice, and Caldiran areas, we can draw several conclusions. First, the fieldstone or mud-adobe wall-bearing construction is not able to withstand even moderate earthquakes (Figures 5 through 10). Second, the wooden post timber-frame construction is also vulnerable to moderate and greater shocks. Sawn timber withstands stress better. And finally, brick buildings without concrete columns are also very vulnerable.[14]

Problems in Reconstructing Village Dwellings

Decisions made hastily following a disaster can themselves be disasterous. Many difficult issues face the survivors. Should they try to patch up their damaged homes? Should they move out of the settlement? Who would help them? Would future disasters occur? How could they leave the place where their ancestors had lived and died? How would they obtain employment in a new place? All of these questions are very real and must be dealt with by external and internal organizations.

The Gediz, Lice, and Caldiran disasters provided examples of why research is absolutely essential if the effects of earthquakes on victims are to be minimized. The government hastily built thousands of houses soon after the disaster. A short time later, villagers began expressing dissatisfaction with the houses. Complaints in Gediz were not unlike those in Lice and other areas.

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[12] Country Monograph of Turkey, p. 28.

[13] Mitchell, "Reconstruction After Disaster," pp. 304-305, 309.

[14] This is also concluded by Joseph Penzien and Robert D. Hanson, The Gediz, Turkey Earthquake of 1970 (report to the National Science Foundation for the Committee on Earthquake Inspection, National Academy of Sciences, Washington, D.C., 1970), pp. 79-80.

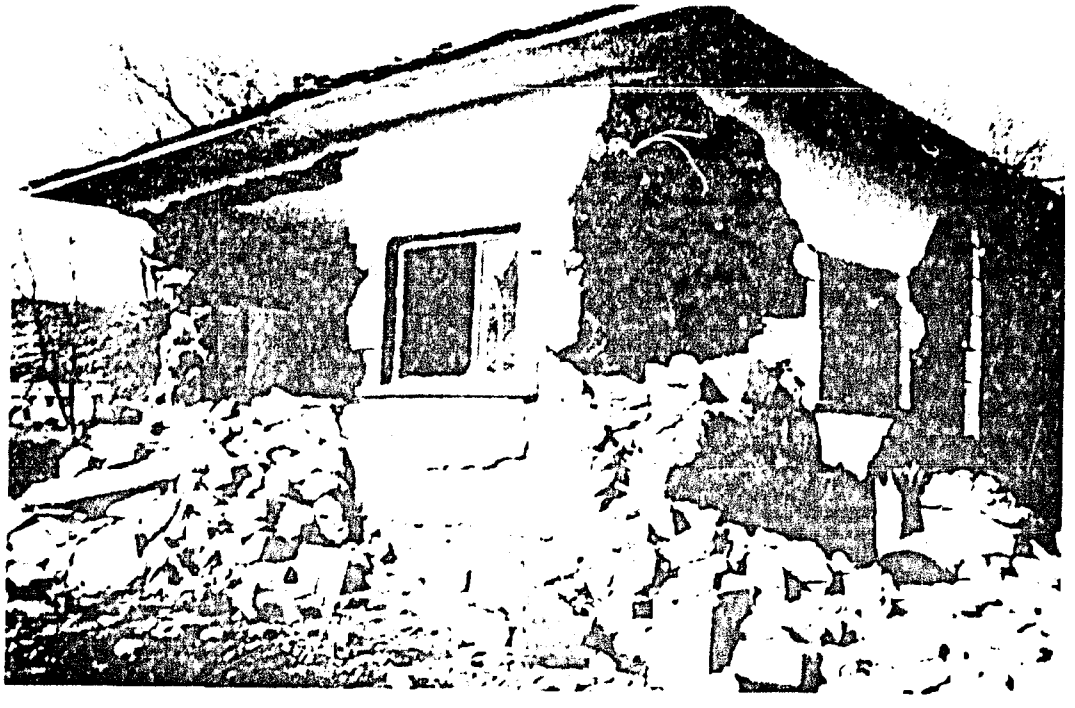

FIG. 5

Stone masonry home after the Muradiye earthquake.

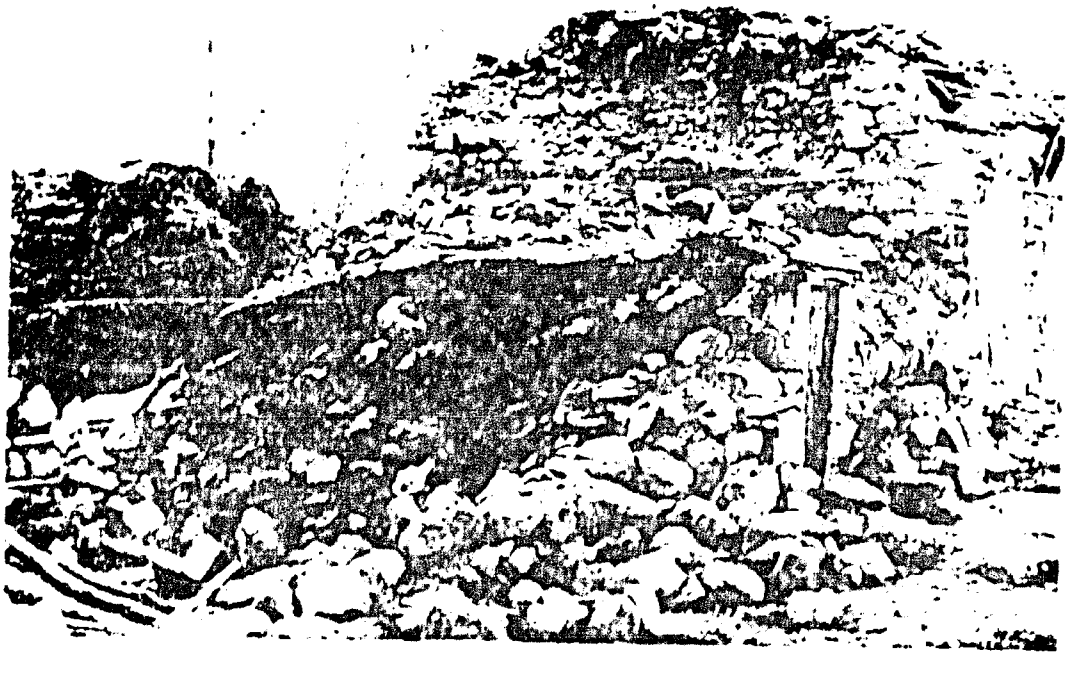

FIG. 6

Stone house in Caldiran. Notice the thickness of the roof. No lateral/horizontal bracing.

FIG. 7

An adobe masonry home in Muradiye, eastern Turkey.

FIG. 8

An adobe house after the Caldiran earthquake in eastern Turkey.

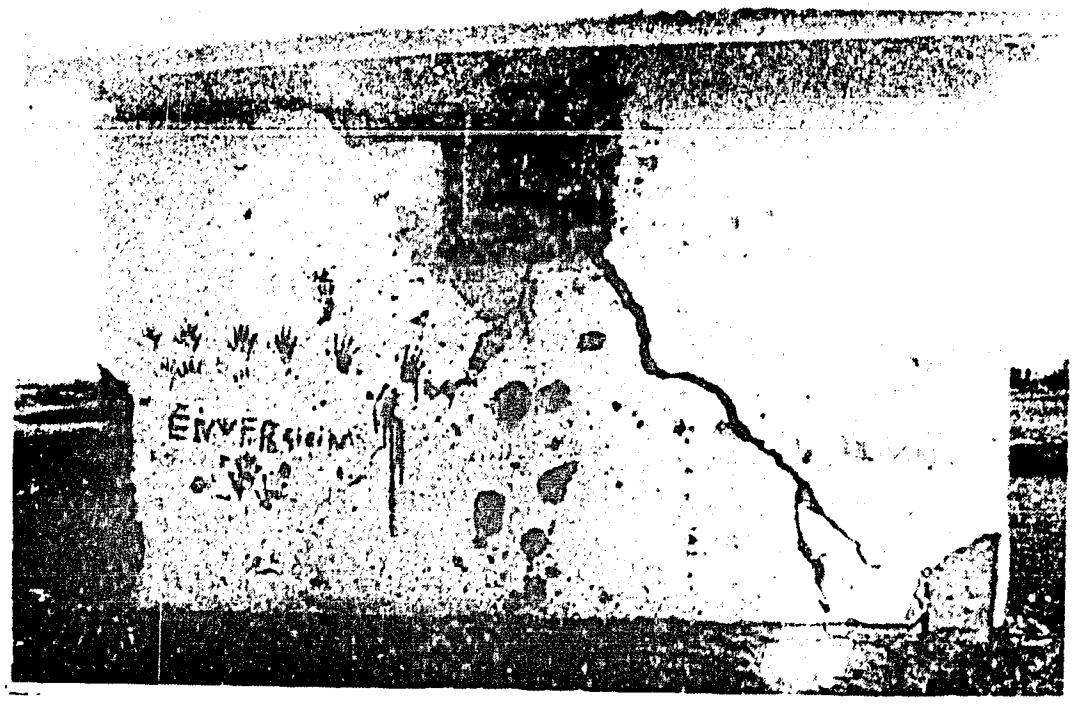

FIG. 9

Concrete block outhouse near Caldiran.

FIG. 10

Adobe house in Muradiye.

The basic problem was external control and input at the expense of the victim. For example, as we have reported before,[15] many villagers would move into the new houses, stay for a short time, then return to the old site and rebuild their damaged homes. Consequently, several years later the new houses were in many instances uninhabited, were deteriorating, and were not being paid for. Why? Generally because of disagreements in regard to location, quality of construction, size of the houses, glass windows, and lack of water (Figure 11).

General Location

The general location for new homes was largely based on the availability of geologically stable sites. However, the specific site and the physical arrangement of new houses was determined by the planners. Had several patterns of possible formations been offered to the villagers, they could have participated in the layout and would have been more satisfied.

Quality of Construction

Quality of construction and materials is a serious problem. Hundreds of new houses in villages have large structural cracks, fallen plaster and broken tile roofing In most damaged villages, large chunks of plaster have fallen from fronts, sides and backs of many new houses. Since construction materials are expensive and scarce, a more adequate quality control of materials for new houses would be beneficial.

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[15] Mitchell, "Reconstruction After Disaster," and William A. Mitchell, "Partial Recovery and Reconstruction After Disaster: The Lice Case," Mass Emergencies, Vol. 2, 1977, pp. 233-245.

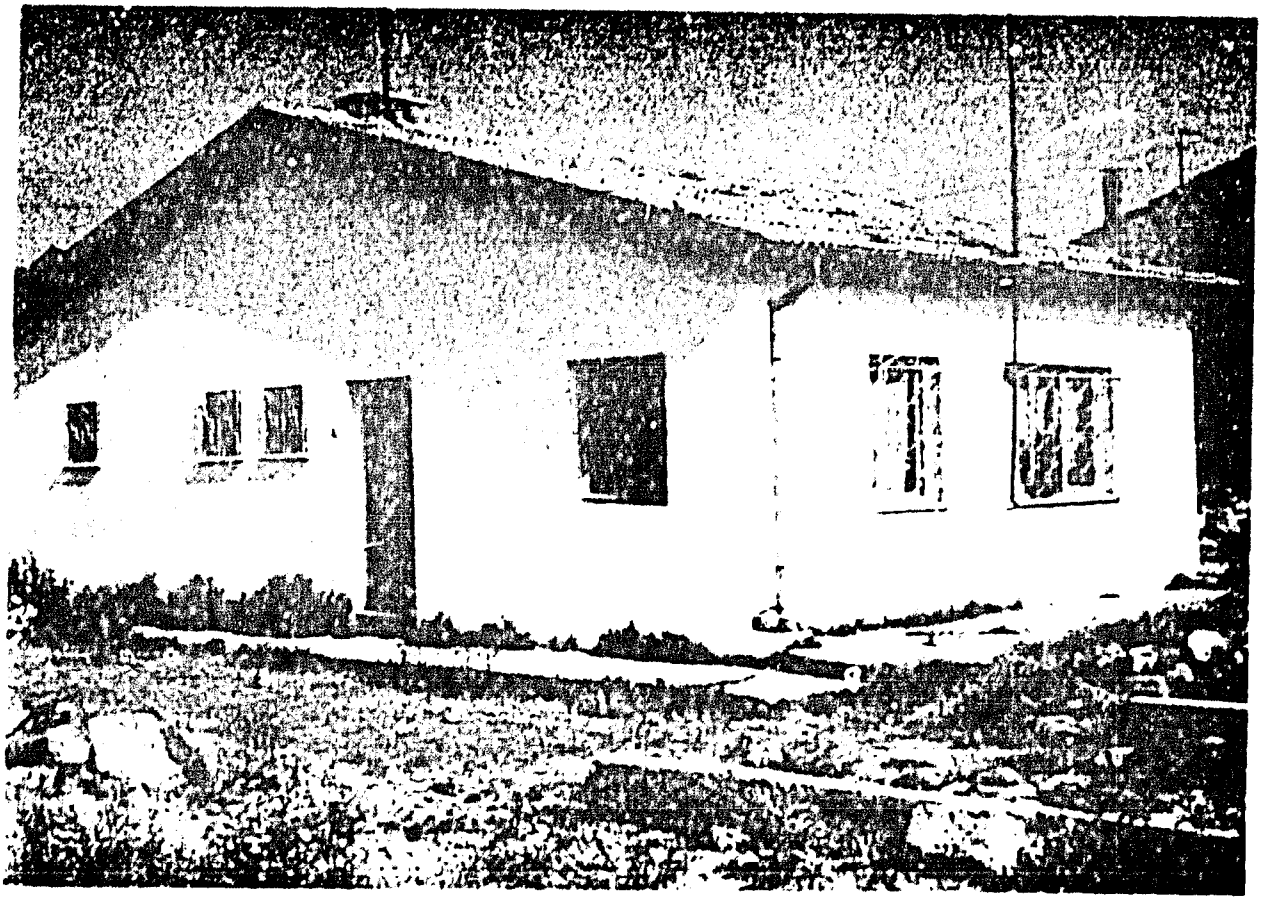

FIG. 11

A new, single-unit dwelling built in 1976 after the Gediz earthquake.

Size of the Shelter

Most villagers complain about the small size of the houses. Traditionally, many kept animals on the first level and lived on the second. The new village houses are one level--thus, no place for the animals.

Glass Windows

Many glass windows had been replaced by boards. The planners suggested that children were breaking the glass windows and that glass was too expensive to replace. The villagers agreed with this, but they expressed a desire for windows much higher or closer to the ceiling than the new houses provided. Traditional houses in Kutahya province have windows high on the wall, close to the ceiling.

No Water

A final complaint concerned water, or the lack of water. In many damaged villages, the new houses have plumbing installed with kitchen sinks and an indoor toilet. Yet, none of the new village houses had water inside. Thus, water for domestic use had to be carried to each new house from the old village. The indoor toilet and kitchen sink could not be used because a cesspool sewage system had not been built.

Policy Implications

The Turkish government makes sincere efforts to alleviate quickly the hardships experienced by thousands of Turkish villagers when disasters occur. However, it is quite obvious that many villagers are not happy with the new houses.

Restoration of the devastated area is an enormous and expensive task. Time limitations, economics, and other parameters establish constraints which strongly influence restoration. Considering these constraints, and considering the experience of these disasters, we suggest that future restoration efforts consider plans for construction of "family units." These "units" would include: (1) a house modified to eliminate complaints previously mentioned; (2) an animal shelter detached from the house; and (3) a water source closer to the house than in the original traditional home. This "family unit" approach would cost more, so probably fewer houses could be built. However, a smaller number of inhabited houses is more beneficial than a larger number of uninhabited ones. Funds expended for houses which may never be occupied could be more wisely distributed for repairs of damaged houses. This approach requires that adequate measures be taken to insure that wells are drilled while the new "family units" are being constructed. Building the houses and waiting for extra appropriations for a central water supply has proved to be unfeasible.

Close coordination and understanding between the government planners and the villagers could alleviate most of the mutual dissatisfactions. Specifically, modification of the house plans could solve the window problem. And finally, since there seems not to be a need or desire by the villagers for the equal and wide spacing between new houses, perhaps a clustering or circular arrangement is feasible.

A Model for Disaster Recovery

A recovery effort after a disaster is essentially a model of human endeavor in a new or developing field. Every element of activity from initial planning to the eventual completion of a project is present, and the project is always a totally new and different undertaking. No two disasters are alike, even if they occur in the same location. The recovery effort must therefore always break new ground, handle new problems, and implement new solutions.

This type of process is well known in the economic and business communities. New products are invented, prototypes are constructed, markets are developed, and, eventually, industries grow and become mature. In the 1930s, techniques which had been originally developed to study the biological growth rates of different organisms began also to be applied to the growth of new industries in the United States. These studies showed that both biological and industrial growth could be modeled with a S-shaped curve (a "growth" curve) which resembles that in Figure 12.[16]

[16] Raymond Pearl, Studies in Human Biology (Baltimore, MD: Williams and Wilkins Company, 1924), Chapter 24.

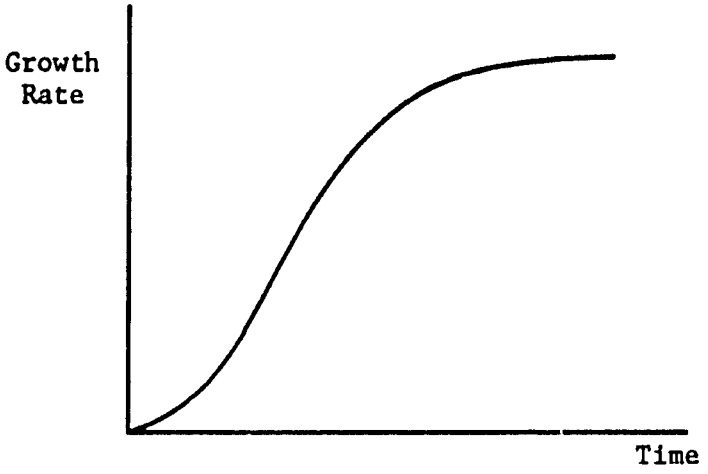

FIG. 12

A Growth Curve

However, problems in forecasting growth rates from the S-shaped curve prohibited its acceptance as a useful tool for predicting future actions in a developing industry. In 1977, Weida showed that the S-shaped curve not only described all research and development activity in the Air Force, but that it could also be a useful forecasting tool if the data used in constructing the curve was plotted in a manner which allowed normalization of both axis of the graph.[17]

Using the S-Shaped Curve

Since earthquake recoveries do exhibit all of the characteristics of developing industries, it is logical to assume that they, too, will proceed in a manner which is characterized by an S-shaped growth curve. However, to relate recoveries in different areas, a method must be devised which will allow data containing dissimilar recovery efforts and time periods to be compared. One solution to this problem is to normalize all recovery data in the following manner:

(1) Let the period of time at which the earthquake occurred be zero, and the time at which recovery is complete be 100%. Then all other times for which data are known in a recovery effort may be plotted as occurring at X% of the recovery time.

[17] William J. Weida, A General Technique for R&D Cost Forecasting, United States Air Force Academy Technical Report 77-12, September 1977.

(2) In a similar manner, let complete recovery (in terms of either restoring the old structures or building new ones) be 100%. Then all levels of intermediate recovery can be defined as being Y% of the recovery effort. Obviously, this method assumes that activity and time data are both structured as cumulative percentages and plotted as shown in Figure 13.

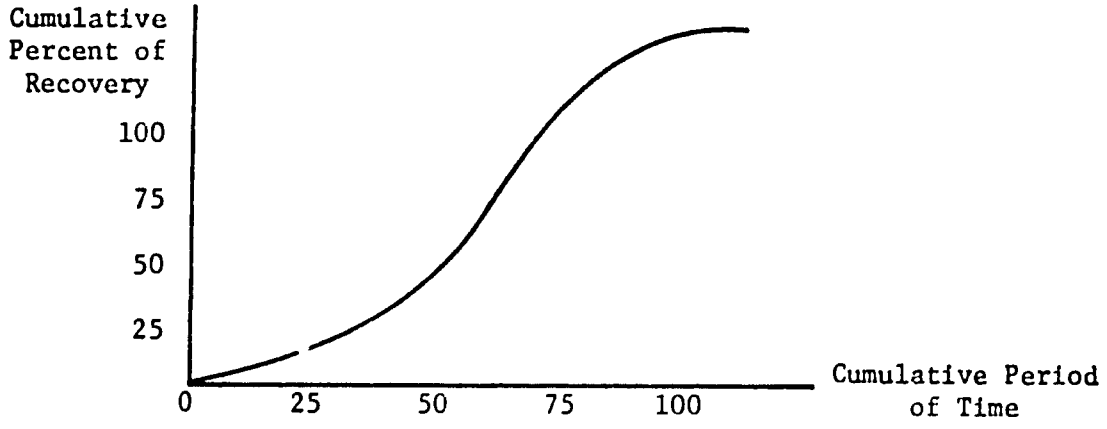

FIG. 13

Growth Curve Based on Normalized Data

This method of handling earthquake data has the advantage of allowing one to compare all earthquake recovery efforts on the same set of axis. It also allows one to use many different recovery efforts as additional observations from which data may be gathered to construct a general curve describing earthquake recovery.

When the recovery data for the 1906 San Francisco, 1963 Skopje, 1964 Alaska, and 1972 Managua earthquakes were investigated, it was no surprise to find that no single recovery effort had been sufficiently monitored to provide enough data to construct the entire S-shaped curve proposed in the above paragraphs.[18] However, among all of the recovery efforts, enough points did exist in housing data to allow a single, general curve to be constructed. This curve, and the specific recovery efforts which accounted for each data point, are shown in Figure 14. Figure 14 was constructed in the following manner.

(a) A level at which complete recovery was attained was determined for every recovery effort. This was then designated as the 100% of recovery point for that earthquake.

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[18] For example, see Martyn J. Bowden, "Reconstruction Following Catastrophe: The Laissez-Faire Rebuilding of Downtown San Francisco After the Earthquake and Fire of 1906," Proceedings, Association of American Geographers (1970): 22-26; Ian Davis, "Skopje Rebuilt," Architectural Design (November 1975): 660-663; Howard Kunreuther and Elissandra Fiore, The Alaskan Earthquake: A Case Study in the Economics of Disaster (Washington, D.C.: Institute for Defense Analysis), February 1966; and Ian Davis, "Disaster Housing: A Case Study of Managua," Architectural Design (January 1975): 42-47.

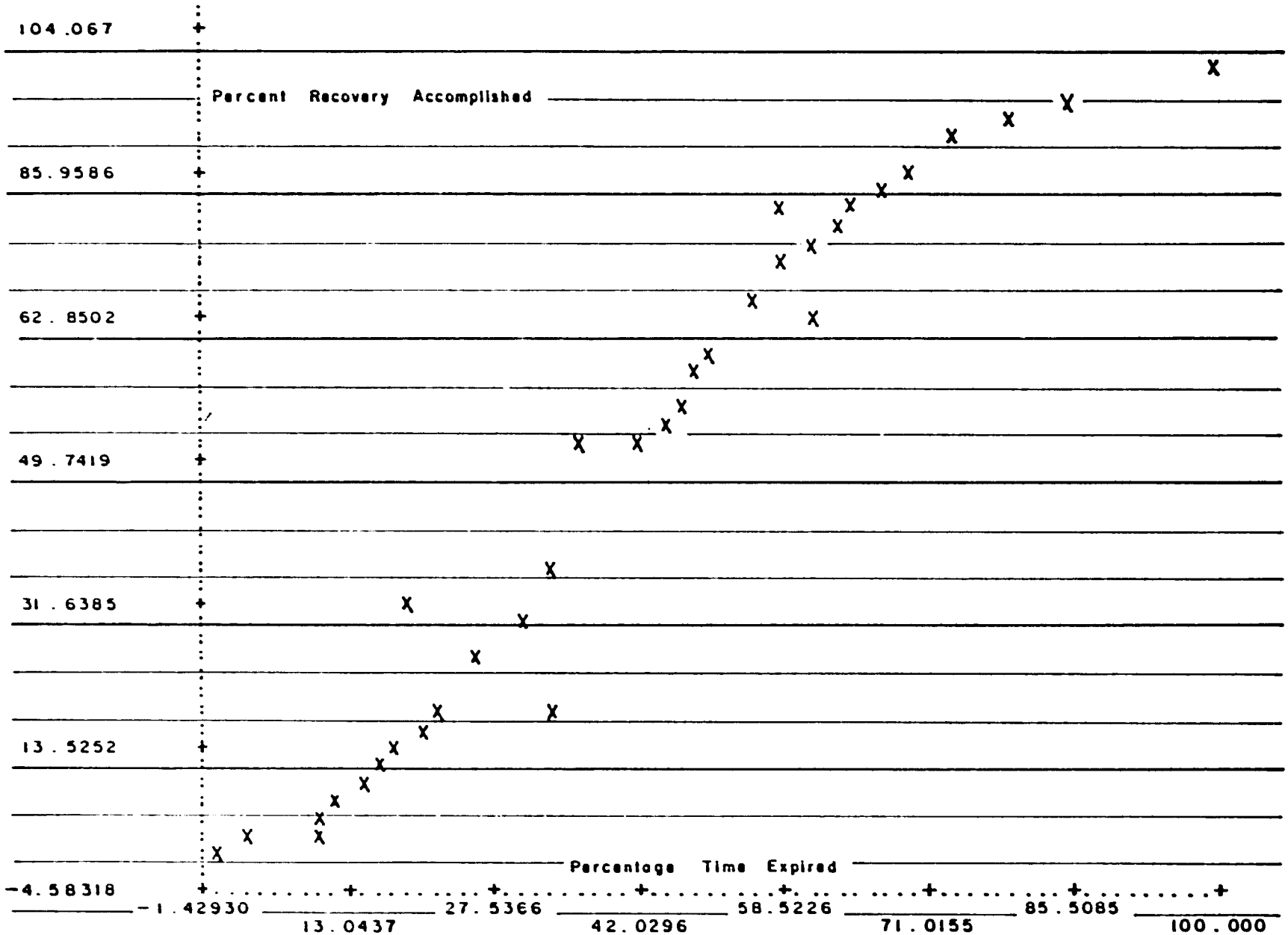

FIG. 14

General Curve for Earthquake Recovery

(b) The time interval required to achieve 100% recovery was noted, and this became the 100% of time point for the same earthquake.

(c) Steps (a) and (b) were performed for each recovery effort. Then the available data for each earthquake recovery was converted to a percentage of total recovery and total time.

In this manner, the points shown in Figure 14 were derived and plotted. For this plot to be a useful tool in forecasting future recovery efforts, two items must be kept in mind.

(1) First, the data which are depicted in Figure 14 are the result of subjective estimates about the earthquake recovery. These subjective estimates were necessitated by a lack of data concerning the day-to-day functioning of a recovery operation. A lack of data is a common problem in areas where little research has been performed since data generally follows increasing research emphasis, and is structured to serve the needs of the researcher. It is therefore suggested that the curve depicted in Figure 14 serve as a straw man against which one or more entire recovery operations may be compared at some future date. At the present time, this curve provides as accurate an estimate of the manner in which recovery is likely to proceed as can be gained from current data sources.

(2) Using the type of S-curve shown in Figure 14 to forecast recovery from a new earthquake will first require an estimate of the amount of time which will be required to complete the recovery effort. We believe it is reasonable to expect that such estimates will be available and, due to the vagaries of the economy, they are likely to be much more accurate than estimates of the amount of money and material necessary to complete the reconstruction.

Throughout the course of this research, it has become increasingly clear that the amount of time required to attain a level of complete recovery is dependent both on the severity of the earthquake and on the technological level of the community involved in the recovery effort. The severity of an earthquake and its resultant destruction are fairly simply determined by the normal measurement and analysis methods available. However, determination of the effect of the technological level is much more difficult to make. Preliminary results indicate that a higher level of technology in the affected community will tend to <u>increase</u> recovery time, but this area is one in which much additional data must be gathered.

The estimate of time to complete 100% of recovery is then used to dimension the time axis of the general recovery curve (Figure 14). When that is done, forecasting from the curve may begin.

Using the S-Curve to Forecast Recovery

To assist in using the S-shaped curve in Figure 14 as a forecasting tool, regression analysis was performed to derive the equations for the two halves of the curve. To do this, the curve was broken at the inflection point as shown in Figure 15.

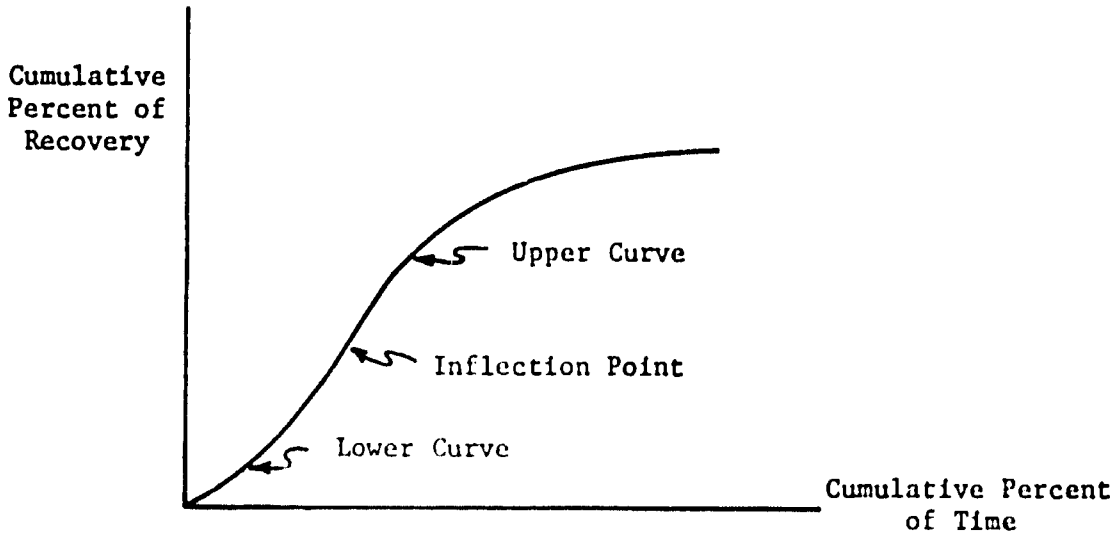

FIG. 15

Breaking the Curve for Computer Analysis

The lower and upper parts of the curve were then fitted using a quadratic equation of the form:

$$Y = a + b_1X_1 + b_2X_1^2.$$

By separating the S-shaped curve in this manner, we were not constrained to the very limited number of S-shaped curves for which an equation is available to fit the entire curve at one time. The inflection point which was used to separate the two parts of the S-shaped curve was determined by taking that time period with the largest incremental change in recovery which was followed by two succeeding time periods of decreasing recovery activity. Equations for the two parts of the curve are then derived using a regression technique based on Generalized Least Squares which incorporates an autoregressive routine to correct for the autocorrelation caused by the time-dependent nature of the model.[19]

The two equations for the curves which comprise the S-shaped growth curve in Figure 14 are:

(1) For the lower part:

$$Y_{Lower} = -.649322 + .595883X_1 + .0128385X_1^2$$

[19] The specific rational for this entire procedure may be found in Weida's A General Technique for R&D Cost Forecasting.

(2) For the upper part:

$$Y_{Upper} = -30.4028 + 2.49767X_1 - .0118556X_1^2$$

At this point, one should note that the inflection point which served as the division between the upper and lower curves has a considerable degree of meaning in earthquake recovery analysis. This point is, by definition, the point at which recovery effort stops increasing in magnitude and begins decreasing until the recovery is complete and effort ceases. The passing of this point must represent a conscious decision on the part of the individuals responsible for managing the recovery effort that the period of maximum crisis in housing, services, and general well-being of the populace has passed. At this point, a return to normalization begins and the effectiveness of the social unit which has suffered the disaster will begin to increase. In essence then, after the inflection point is passed, the focus of the social unit involved in the disaster or attack can begin to shift away from the immediate problem of recovery. This concept has tremendous implications in forecasting when the affected area may once again start to become a viable economic, manufacturing, or political body.

Forecasting Recovery with the S-Curve

Forecasting the likely recovery effort following an earthquake will probably begin immediately following the incident. At this point, no data, with the possible exception of the magnitude of the disaster, will be available. Under these circumstances, a general S-curve, derived from a number of previous similar disasters, can be used as a proxy until hard data become available. This can be accomplished if the researcher can assign a meaningful value to the time required for recovery based on the severity of the disaster and the technological level of the community affected as explained earlier.

However, as soon as hard data become available on the recovery effort, the original estimates concerning the time dimension can be easily verified. Since the size of the disaster and, hence, the amount of recovery effort required, will become clearer as reconstruction progresses, the following situation will occur.

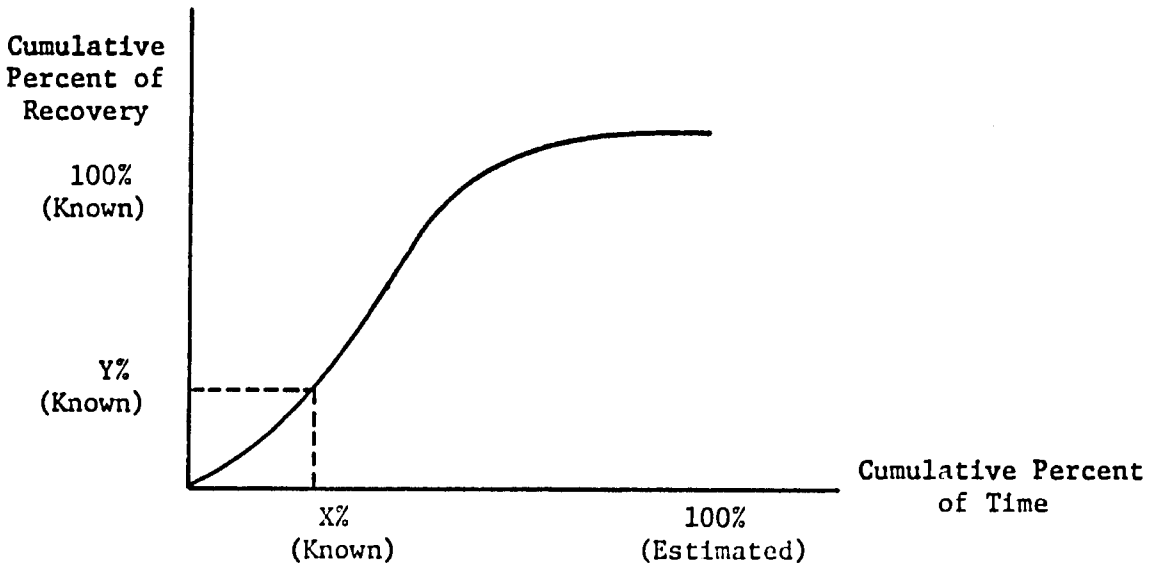

FIG. 16

Checking Estimates from Early Data

Assume you are involved in the early stages of a recovery effort. X time and Y resources have been used. X, which is known, can be related to Y (which is also known) through the general reconstruction curve to check the figure which was estimated to be 100% of time to recovery.

This type of early check can be used to determine the validity of the general curve in each specific recovery effort. If the curve proves to be generally valid, the following methods can be used to derive specific recovery forecasts.

Method (1): Using the general equation for the lower part of the curve

$$Y_{Lower} = -.649322 + .595883X_1 + .0128385X_1^2$$

which was previously derived, substitute for X the percentage of time figures which represent the time increments (weekly, monthly, etc.) in which one wants to forecast the recovery. This will allow the calculation of the percent of recovery at these points. This may be done up to the inflection point, after which the equation for the upper part of the curve

$$Y_{Upper} = -30.4028 + 2.49767X_1 - .0118556X_1^2$$

should be used in the same manner. This method of forecasting will suffice in most cases.

Method (2): When a sufficient number of actual data points have been recorded (at least 7), and if these points seem to be deviating from the general curve, use the actual data to calculate a new lower curve using regression

analysis. Retain the same inflection point previously used in terms of the time involved and calculate a new Y (% of recovery) for this inflection point. This new Y value will now become the first Y value in the original equation for the upper part of the S-curve in the following manner:

(1) The original equation for the upper part of the S-curve was

$$Y_2 = -30.4028 + 2.49767X_1 - .0118556X_1^2$$

(2) Let the Y value at the inflection point which is calculated from the new lower equation be Y_{IP}

(3) Then let $Y_{IP} = Y_2 = a_{2,new} + 2.49767X_1 - .0118556X_1^2$

where X_1 is the time at the inflection point.

(4) Then solve for the unknown $a_{2,new}$

where $a_{2,new} = 2.49767X_1 - .0118556X_1^2 + Y_{IP}$

(5) Now the revised equation for the upper part of the S-shaped curve is

$$Y_2 = a_{2,new} + 2.49767X_1 - .0118556X_1^2$$

This equation can be used to forecast the level of the recovery effort during the second part of the recovery.

Obviously, as more and more data points become known, the new lower curve will be better and better defined. As this stream of actual data moves past the inflection point, the upper part of the curve can also be directly derived from those observations.[20]

Policy Implication from the Recovery Model

The major implication to be gained from the S-shaped curve lies in the lower or early part of the curve. Note that the slope of this part of the curve implies that recovery from a disaster must start slowly and build in ever-increasing steps. This is, unfortunately, not the way that recovery aid is supplied. It is far more common to see massive amounts of aid rushed immediately to the site of the disaster (when the ability to use other than emergency relief supplies is at its lowest) and then to see the disaster forgotten and little aid supplied in the

[20] The specific techniques used in these types of forecasting may be found in Weida's A General Technique for R&D Cost Forecasting.

later period when the impacted area is best able to absorb reconstruction help. The need for a central agency which will administer aid in the proper doses is clearly indicated.

In addition, infusions of cash and loans for reconstruction (not emergency relief) should be timed to coincide with the steepest part of the recovery curve, peaking when the effort peaks at the inflection point of the curve. Money applied too early will be wasted on an effort which is not ready to absorb it, and money which is applied too late will only be able to "gild a lily" which is almost completed.

As the Turkish example demonstrates, reconstruction efforts often meet with very mixed degrees of success. This lack of success can be traced to two major areas of concern: lack of cultural awareness and improperly phasing the recovery work. Although our recovery model can add nothing to the cultural question, it does indicate the manner in which the recovery efforts should be phased to assure that work is accomplished as quickly and as inexpensively as possible.

The obvious answer to the entire recovery problem is to establish a team of knowledgeable experts which could act as a central point of contact for recovery operations. Modelers, who would help phase the questions, could be provided to the stricken country from a central pool of available talent. Team members who were experts in the specific cultural aspects of the impacted area could be provided from a similar pool, or from the country itself.

To do this, several steps must be accomplished. First, the model we have suggested must be further validated as recent earthquake data become available. Second, a central location for the storage and manipulation of earthquake data should be established. This location could also serve as the point of contact for recovery modelling experts from government, industry, and academic sources. Third, specific cultural identities of earthquake-prone areas should be established, and specialists in the backgrounds and values of these areas should be identified. And fourth, a general agreement between potential team members and potential customers (earthquake-prone countries) should be established. This agreement should include guidelines for call-up procedures, reporting protocol, and expected team activities in potential earthquake areas.

In this manner, a concerted, worldwide effort may be brought to bear on any recovery process. And the affected country will be better able to say that the recovery process will be well planned, as economical as possible, and accomplished in a manner which accounts for the cultural differences which will be inherent in each of the impacted areas.

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PROBLEMS IN PROGRAMME IMPLEMENTATION

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ABSTRACT

The paper looks at the implementation of programmes or projects of technically improved housing and argues that the problems in programme implementation increase in direct proportion to the "distance" between the programme's designers and its implementors. The distance measuring the gap not just in physical terms but also in political, technical, financial and socio-cultural terms.

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Every country, every city in the world has its "housing problem", usually expressed as a shortage of housing units, or of inadequate housing units. The solution to most of this kind of housing problem is easy enough to devise on the drawing board. This is particularly true of the technical aspects of housing construction. After all, in engineering terms the calculations required are of the most basic kind and even a large project, or programme, is made up of an assembly of single units. Similarly, the onsite operations can be controlled by straightforward management techniques such as PERT & PPBS, critical paths and the like. Yet the track record of programme implementation remains poor if not abysmal. The actual number of housing units built are far below the numbers required, and even below the numbers programmed. Why should this be?

To some extent this is because of the nature of housing. To quote Yona Friedman, "Housing is everybody's concern...." and thus subject to kinds of enquiry as other projects such as highways and dams are not. At the same time, housing projects are also subject to all the other problems that beset other programmes during implementation.

In order to examine some of these problems, let us assume we have a technically competent design for a housing project that is intended to improve upon the existing house types with better, cheaper, safer and more durable units. Despite this, the chances are high that either no programme implementation will take place, or if it does, it will be far short of the original programme. The problems that are likely to be encountered are categorised in this paper for ease of reference into political, socio-cultural, technical, financial and are looked at in turn. However, before we do so, it is important to indentify the primary actors concerned with programme design and implementation. 1) The Client; that is the person or institution commissioning the designer; in housing programmes, increasingly the client is a public authority carrying out its designated function rather than one personally involved or concerned with the use of the eventual end-product. 2) The Designer; that is the person or team of persons commissioned to produce a design solution in response to a given brief and includes such professionals as architects, engineers of various specialisation, economists and sociologists. 3) The Executor; that is the person or institutions who will be responsible for implementing the project or programme in accordance with the design specifications and include contractors and builders. 4) The User; that is the persons who will eventually move into and use the end-product built by the other three. Often, of course, two or more roles may be combined, as for instance that of the executor and the user in self-build projects.

Now as to the different kinds of problems in programme implementation:

<u>Political</u>: The various political problems that beset programme implementation can be summed up by the word "Motivation", or the lack of it. The designer should ask "Why does the client want to

build these houses?" or better still "Does the client want to build these houses?". In practice most designers are so keen to get on with the job of solving the technical problems involved (quite apart from the benefits of being commissioned) that they do not want to question the fundamentals - or if they do, are content with the public/humanitarian reasons put forward by the client as part of the brief. No doubt the publicly stated reasons play a part in the motivations of the client, but often there are deeper, overriding private reasons and expectations that the client has in commissioning a designer. Thus, though "affordable shelter" might figure large in the brief, few clients are happy at the prospect of unveiling a project of one-roomed mud-houses or of improved sewerage or anything else which might be construed as a "lowering of standards" below the dreams of modernity that he has been selling as a politician.

On the other hand, the client may well agree to commission the designer for a project if that enables him to achieve other ends. For example, aid or loan packages might come with preconditions that some or all of the funds be spent on housing the poorest of the poor. In which case, once the programme has been designed, approved, and the loan secured, its implementation is allowed to lapse or its costs allowed to drift upwards so that the houses can only be afforded by better off sections of the community. This is, for example, the fate of most site and services type projects. Similarly, when most finance ministers push ministers of housing to agree to accept loans from other countries, it is not because of their interest in housing, but because of the softer terms at which the foreign exchange thus becomes available to the Treasury.

Then there are the more straightforward political motivations of using housing projects as a 'payoff' for electoral support, and conversely of lack of motivation to implement a predecessor's project for which no kudos will accrue to the current incumbent.

Likewise, an "interim government" is unlikely to favour projects which have a longer term maturity than their own period in office, and such projects are likely to be shelved.

Since these kinds of objectives are not stated publicly, a designer who is unaware of them is likely to produce a solution that is not going to be implemented, or if it is, will not be pursued vigorously. The nature of these problems is such that they can be overcome only by a designer who is aware of the political motivations of the client and this can best be done through first hand observation or a familiarity with the situation. A design is likely to be less than satisfactory if it is done in isolation or removed from the realities of the environment in which it has to be implemented.

Socio-Cultural: The kinds of problems that are likely to crop up under this category have to do with acceptability. If the design is not acceptable in socio-cultural terms, it is

not likely to be implemented with enthusiasm.

We have already mentioned the role modernity plays in political terms. It is even more important for the users of the project. A design might well wish to replicate the prevalent forms of indigenous housing in his solutions by invoking the form of the traditional African round houses or the conical thatch roof in an effort to make the new designs acceptable - whereas the reality may be that for those presently living in these traditional houses, the forms are not romantic but symbols of their backwardness and lack of development. The users may well yearn for the sterile concrete box that passes for "modern".

House plans that orient doorways, beds and toilets to culturally unacceptable directions might well be spurned, regardless of their technical advantages. Similarly, concern for privacy might well outweigh considerations of cost. Fear of "ill-winds" or of insects and reptiles or of burglars might well lead to blocking up of the permanent ventilation vital for comfort.

Whereas in the design of a new or unfamiliar structure like a grain silo or a school, people might overcome their own reservations and accept technocratic answers because they may have no yardstick against which to judge, housing is a different matter. Housing is everyone's concern.

For better or for worse, the houses they have been living in are known to them and are an intimate part of their lives. The introduction of a new design is, ipsofacto, suspect. It is not that people are conservative and traditionalist, but rather like Michael Lipton's farmers, they are "risk-minimisers". Especially if they are poor, a house represents too big an investment to be experimented with - particularly at the say so of some outsider. The rich can afford to be fashionable, the poor must stick with the tested and the tried.

If the designer is not familiar with the socio-cultural environment it is likely that the project will meet with objections and again, any implementation will be less than enthusiastic. The least that can be expected is that the house designs will be altered by sub-divisions and additions. Door frames will be removed and widened if, as in Anguri Bagh in Lahore, people cannot push their motor-scooters through, or if as in Korangi in Karachi, the dead can't be carried out on their beds. At worst, of course, the houses will lie empty and abandoned, as was the case for years with the flats at Iqbal Town, Lahore, and the construction of further units will be stopped. Here again, a designer working at a distance from the users will find it difficult to ensure the acceptability of his designs. Social surveys might help, but they can cope mainly with those questions that the designer has already thought to ask, and in any case most surveys are done before the designer has any concept of what he is going to produce. Very few surveys are of the market research/user reaction type which test acceptability or satisfaction with a given design.

Obviously all other things being equal the greater the familiarity of the designer with the socio-cultural environment, the fewer the problems when it comes to implementation.

Technical: The problems in this category arise largely because of a lack of familiarity. Working in a particular context, designers tend to use conventions in their technical drawings and instructions, to the extent that like users of jargon, they do not even realise that they are doing so until someone misunderstands their instructions while implementing their design. Take the case of the designer of a four-storey building for which he wanted to have a facade of perforated cement blocks. Since he was not sure of the particular patterns available, he left the facade blank with an asterisk drawn in one corner. In the note below he pointed out that the actual screen block will be decided later. Imagine his surprise when he made a visit to the site and found the front wall made of solid blocks with an asterisk neatly sculpted to scale, in one corner. Careless or incompetent reading of technical drawings and specification has often led to misplacement of reinforcement bars, often of wrong sizes. The classic example must be of the inexperienced contractor who shuttered up a roof, poured in the concrete and then proceded to stick in two-foot lengths of reinforcement at regular intervals so that they stuck out like the starter bars he had seen on other sites - with no steel in the slab at all. That these kinds of practices do not lead to more disastrous results is largely due to the belt and braces recommendations of archaic building codes but a designer unfamiliar with execution practice in many countries could end up with problems if he produced a finely calculated structure in order to cut materials and costs.

Given the chronic shortage of water in Karachi, recommending normal water borne sewerage systems is a risky business and fraught with problems at the best of times. Furthermore, the designers of Karachi's metroville scheme had been alerted to the local sanitary practices and had designed and sized the sewerage systems accordingly to allow for bits of stones, bricks, tiles and clay pots as well as the usual toilet paper. Nevertheless, by connecting pairs of back to back toilets to the mains sewer using a single waste pipe, which makes good economic sense, they introduced a built-in problem source. The cost savings were nothing compared to the subsequent squabbles and disputes that arose each time someone blocked up, not only his, but also his neighbours pipes.

That a little technical expertise can be worse than none was demonstrated in South India where the indigenous stoves which filled the small windowless rooms with smoke, were replaced by a new smokless version at the recommendation of visiting experts. Within a year the thatched roofs started collapsing as the vermin that infested them were no longer being kept at bay by the fumes from the stoves. In another context, much of the hard work of designers spent on reducing costs is negated by contractors who price work on the basis of previous experience - for example the

designer might very carefully worked out the sizes of precast members to avoid using lifting tackle, but the contractor will probably not appreciate this from the drawings and specifications and so not reduce his quotation and the hoped-for savings are not passed on to the client. Similarly, savings that one would normally expect by leaving block or brickwork unplastered, or concrete 'as struck' are lost because of the poor quality of workmanship means that the contractor will plaster over the work in sand cement and finish it off so as to appear unplastered.

Often the reintroduction of previously common place technology proves difficult. That is the case with barrel vaults or lime mortar in Lahore. Though these were traditional indigenous techniques and materials their usage has virtually disappeared and current practice has meant that contractors charge more for working with these "new" methods, thus making them no cheaper than the more acceptable and ubiquitous concrete slab and sand-cement mortar. So, here too we see that designs that would appear to be technically sound can be problematic in practice and the designer who is unfamiliar with the context could inadvertantly increase rather than reduce or solve problems.

Financial: These problems arise basically due to the fact that the costs of building are higher than the ability of users to pay for them. There are two causes for this: either because not all the costs have been calculated or because special circumstances were created which distorted the incomes of the users upwards or the costs of construction downwards. The most common example of the first condition is in projects which provide some part of a house and expect the user to complete it later on. More often than not, the repayment for the initial allotment exhausts the users capacity to pay for housing. The further additions are then beyond their capability to implement. This is particularly so if the additions have to be built to predetermined designs or standards which are invariably higher than the minimum and so more expensive. The possibility of augmenting incomes by taking in lodgers or using the building for work or commercial or other non-residential use is usually inadmissable under the terms of most allotments.

Housing programmes are often subsidised by the government or the funding agency which means that it is unlikely that the programme can be self-sustaining and will come to an end as soon as the subsidy is withdrawn. Secondly, the fact of the subsidy means that resources are being transferred at below their market price and there will be great pressure to exchange the house for its market value in order to capitalise on its current value, and so the subsidy has the effect of helping, not the groups for which it was intended, but the better off ones. The larger the subsidy element, the less the benefits are likely to remain with the group for which it was intended.

A very common procedure for implementing housing and other programmes is the Pilot project approach. In theory it makes

sense to initiate construction by building one or a few units which can be used to test the appropriateness of the design as well as user reaction before embarking on full-scale implementation.

In practice there is the problem that as a "test-case", the pilot project is treated with extra care of the sort that will not be available for the rest of the programme. Much attention is focussed on the Pilot project, both by the people working on the project as well as the general public and the media. Technical supervision and manpower is to hand, as are materials, authorities to proceed and a very high level of motivation. It is in everyones interest to ensure the success of the Pilot project. Once that is completed, the implementation of the rest of project is handed over to more "normal" processes which are subject to delays and deterioration in quality as the level of technical supervision drops, supply of materials slows down and so on. Often, of course, the Pilot project is seen as an end in itself, and little or no thought is given to the implementation of the rest of the programme.

A lot of the problems in implementation arise from the conceptual separation between designing and implementation. Often the design is altered for the convenience of the designer, rather than with a view to its execution. For example, the grid-iron layout owes as much if not more to the T-square than to any considerations of servicing let alone the physical features of the site. Most designers feel that once the design documentation is completed they have completed their job and some one else should be responsible for its execution. Implementation would improve if designers took as much care of the details of implementation of design and identified who was to do what at each stage and ensured that each executor was in fact available and capable of implementing his particular task.

Particularly for large projects the administrative and organisational capacity is usually less than ideal. Often the procedures that exist or the experience to date has been in the implementation of small schemes and the mere enlargement of these is not sufficient since the difference is not merely quantitative but qualitative.

Conclusion: It is evident that the problems that arise during implementation are such that they cannot be easily foreseen, since they emerge out of the peculiarities of each situation. To produce a programme that can be implemented without many problems would require an intimate knowledge of the political, socio-cultural, technical and financial environment of the executors. For this, it is not enough to be from the same environment as that where the programme is to be implemented but rather to know it.

To the extent that the designer is familiar with the environment of the executor, he will be able to forsee and forestall

problems in implementation, but the larger the gap between the designer's environment and that of the executors, the more and more likely it is that problems will occur during implementation.

A lot of what has just been said might be thought to apply only to a situation where the designer is a "foreign consultant" and not to professionals working in their own country. In fact the contention is that the ability to foresee potential problems is lessened whenever the "distance" between designer and implementer is increased. This distance is not merely one of physical distance as there is when a designer sits in the United States and produces a programme for implementation in Pakistan or indeed if the designer sits in an air-conditioned office in the capital and designs projects for implementation in the country-side. The "distance" that creates problems in implementation is also one that can be used to measure the gap in socio-cultural, technical or political terms between designers and implementors.

The same processes that transform us into professionals tend to alienate us from our environment and our country-men. In order to become "good modern designers" we study the work of the big prima donnas: the Corbusiers and the Mies Van der Rohes. We undertake design projects at school that have walk-in cupboards if we've seen an American magazine, or a bidet if we've seen one from Europe. Our drawings are done using modular co-ordination and have finely calculated tolerance levels. In the end, neither client nor contractor understands the drawings and specifications which we produce in copy-book imitation of RIBA and AIA recommendations. We expect contractors and workmen to understand our technical drawings yet do not think of producing design drawings in a way that can be understood by the executors.

Indeed if we were to design for alien clients we would perforce enquire into their lifestyles, yet when we design for users from whom we have been alienated by our technical, professional education, we proceed as if there was no difference - no distance between us the designers and them the implementors. Then, when this leads to problems, we say the clients/users do not appreciate good design or that the contractors are uneducated and the building industry is underdeveloped.

To return to our original question the implementation record is so poor because most of the designers come from environments considerably removed and at a distance from that of the implementors. The political motivation of the designer is far different from that of the implementors. Usually the cultural context, if not the culture of the designer, is quite other than that of the builders, as is the level and kind of technology that each is used to and as indeed are calculations

and commitments of finance - and in any case the designer does not usually see himself as part of the implementation process, but is removed from it. The further removed he is, the greater the problems.

Thus, one can argue that the problems in programme implementation increase in direct proportion to the "distance" between programme's designer and implementor. The distance measuring the gap not just in physical terms but also in political, technical, financial and socio-cultural terms.

INTERNATIONAL WORKSHOP

EARTHEN BUILDINGS IN SEISMIC AREAS

CODES, SPECIFICATIONS AND STANDARDS

The following individual made a keynote presentation:

Paul G. McHenry, Jr.
Architect
Albuquerque, New Mexico

The following individuals acted as Session Chairmen:

P. G. McHenry
Architect
Albuquerque, New Mexico

William T. Haney
Architect
Santa Fe, New Mexico

Julio Vargas Neumann
National Catholic University
Lima, Peru

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EARTHEN BUILDINGS IN SEISMIC AREAS OF TURKEY

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ABSTRACT

Architectural and structural properties of traditional adobe buildings in seismic areas of Turkey are described, emphasizing the wide application.

Charasteristic examples of earthquake damage are given with explanations, and ways of improvement are recommended.

Attempts for training local builders, related Turkish Code provisions, and the extremely limited extent of utilization of stabilized adobe are briefly discussed.

Finally, areas where research is needed are identified.

EARTHEN BUILDINGS IN SEISMIC AREAS OF TURKEY

1. Introduction

1.1. The Earthquake Danger in Turkey

Turkey is located on one of the most active seismic belts of the world, the Al - pide Belt, from the tectonics point, and Anatolia represents an area where three diffe - rent plates come together. Statistically a major earthquake occurs every 1.5 years, causing considerable loss of life and property. The annual average loss of life is approximately 1,000 . Considering the present population of 44 millions, this corresponds to an annual death ratio -due to earthquakes- of 2.5 per million. This figure comes mainly from rural areas.

In APPENDIX 2 , a map of earthquake danger zones of Turkey is given (2), where 1 st degree zone indicates the highest risk zone. No-danger zone is designated by the blank field. The three intermediate zones represent gradually decreasing seismic risks. The highest risk zone is inhabited by 1/5 of the population, whereas the cor - responding area is 1/7 of the land.

1.2. Rural Dwellings in Turkey

It is estimated that the existing rural dwellings in Turkey amount to approximately 4 millions. Of this number, about 28 % is adobe construction (48 % is stone or brick masonry, 13 % is timber frame, 11 % is miscellaneous), (3).

Adobe construction is popular where soil is suitable for adobe making and where other alternatives are either difficult to realize or much more expensive. In APPEN - DIX 3, the areas where adobe buildings dominate, are roughly shown (3). One may wish to check the areas of adobe domination against pertinent earthquake danger, and such a map is given in APPENDIX 4 .

2. Architectural Properties of Adobe Buildings in Turkey

Almost all of the rural buildings are of traditional construction, so the adobe buildings. They are mostly one storied structures whereas occasionally two storied buildings exist (FIGS. 10 and 11). Although adobe is a building material characte - ristic to rural areas (FIGS. 1 and 2), one can see adobe buildings in cities too, that may be classified as urban (FIGS. 6 and 7), however, structurally they are not much different. The distinguishing features of urban types are larger window openings, longer eaves and the land plot arrangement. Most of the rural buildings don't have eaves and the wall thickness gradually decrease along the building height. It means thicker plaster is provided both in the roof and in the lower parts of the walls. FIGS. 3, 4 and 5 represent a transition from rural types to those of urban.

In villages, the people are much more involved in agriculture and animal bree - ding (FIG. 3), the organization and utilization of the interior space is also somewhat

different, e.g. earthen cooking pits in the ground, locally called "tandır" are popular. Parallel to the way of living, the individual buildings are quite separated. In the cities there are jobs other than agriculture, and one may see row housing (FIGS. 6 and 7). Insulation is sufficient, both in hot and cold regions.

3. Structural Properties of Adobe Buildings in Turkey

3.1. General Description

A typical adobe building in Turkey has a stone masonry foundation wall, with cement-lime mortar, reaching about 0.75 m above the ground level (FIG. 5). The underground portion is slightly deeper. This masonry wall provides resistance to the building against rain and surface waters, and forms a steady base for the upper adobe portion.

The rest of the wall, to the level of the roof, is formed by laying adobe blocks, leaving appropriate door and/or window openings, inserting timber bond beams at various levels. These levels are those at masonry wall top, window bottom, window top and the wall top. Wherever smaller doors or windows are to be formed, lintel beams are placed on the top of the openings, with enough supporting length on both sides to carry the wall portion and roof above. It is possible to observe various extents of realization of the bond beams, at the mentioned levels. There even exist cases where no bond beams are cared for, but only the lintels. Of course they constitute the worst group, from the point of resistance to seismic effects (FIG. 17).

Finally the building is covered by a roof. Although examples of double-slope light roof exist (FIG. 13), the most popular type is the flat earth roof. Its load bearing system is consisted of horizontal roof beams, which are actually timber logs, placed on the top of walls, with a certain spacing (FIG. 14). The spaces between logs are covered with slender branches, shrub and mat, in order to support the thick layer of earth.

Both the roof and the walls require maintenance, as they deteriorate due to the atmospheric effects, such as rain. The frequency of maintenance depends on the type of soil and the severity of the climatic zone. However one year is typical, for most of the adobe buildings in Turkey. Due to repairs, the plaster layer may get thicker than the original.

3.2. Foundations

The foundation wall in buildings with or without a basement, constitutes the basis for the upper structure. The conditions for the foundations are given in Paragraph II.2- of the Turkish Code (see APPENDIX I). The depth should be below the frost level, but in no case shallower than 0.80 m . A reinforced concrete strip footing is desirable for the wall -especially in zones of higher earthquake danger and in case of soft soils- . However, the realization of reinforced concrete elements in rural areas may prove to be extremely difficult.

FIG. 1

Part of a village (Özalp, Eastern Turkey), where adobe is the main building material. In the foreground (left) a stack of adobe blocks is seen. Right behind the adobes, a small hill of straw exists. Even the garden walls are constructed with earth (center). Note that some of the buildings have eaves, while others have not.

FIG. 2

A view to the entrance of a village of adobe buildings. In fact, the lower photo is the right-side continuation of the upper photo.

FIG. 3

An individual adobe building. Note the stacks of dung and straw, two essential materials, used for heating and for animal breeding, respectively. The latter is also used in producing adobe blocks, while the former is more desirable as a fertilizer.

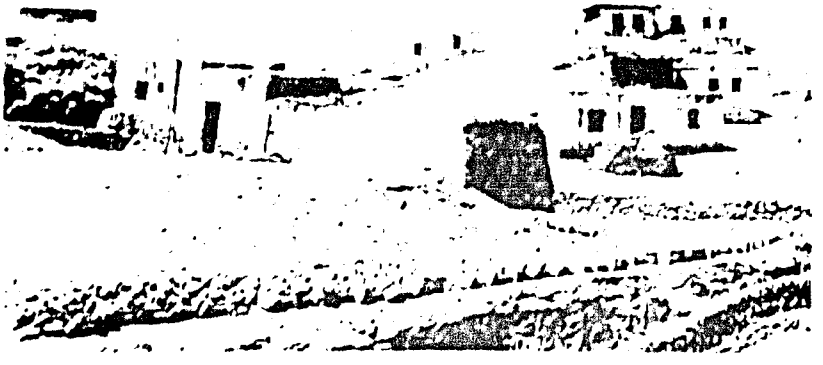


FIG. 4

A view of a village. In the foreground, over the set, a row of fresh adobes are seen, laid for drying under the sun.

FIG. 5

Adobe buildings in a small town. In fact the three photos above represent a transition from rural types to those of urban.

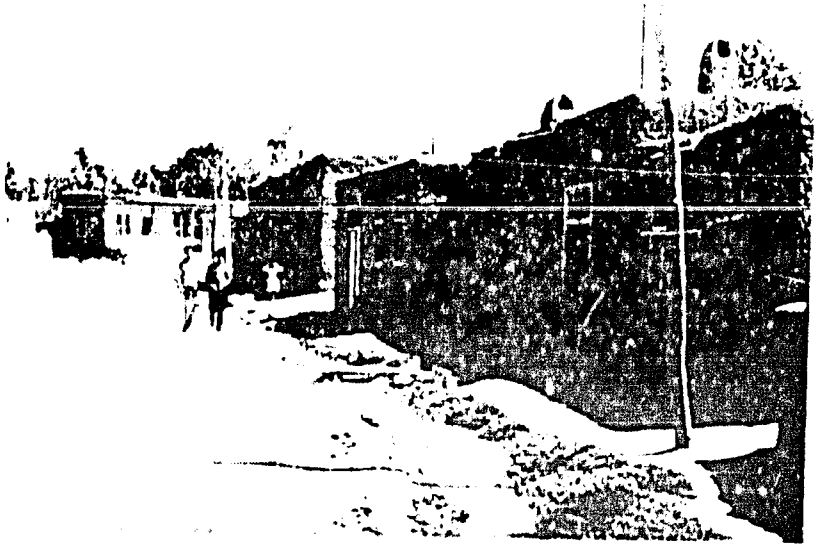


FIG. 6

A row of urban adobe buildings (Van, Eastern Turkey) . Note the lack of eaves.

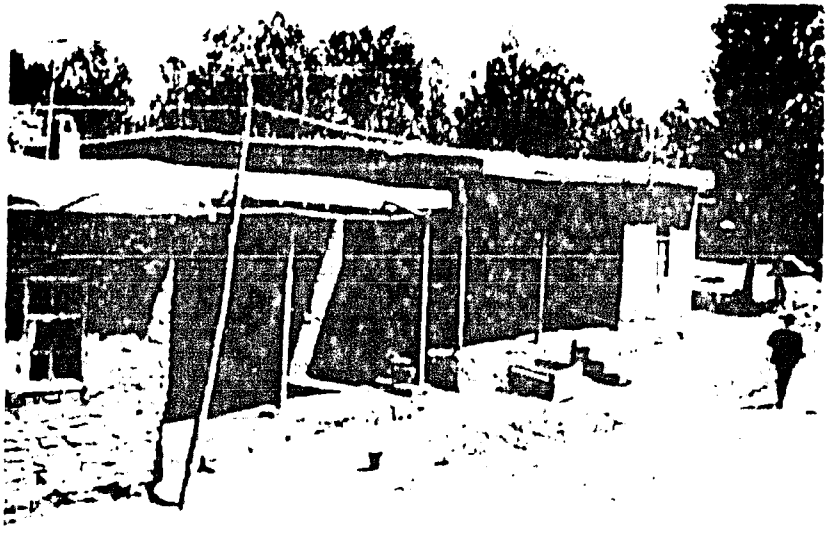


FIG. 7

A row of urban adobe buildings (Van, Eastern Turkey) . Note the eaves.

3.3. Stability of and the Openings in the Walls

The main members to resist vertical and/or lateral loads, in traditional adobe buildings, are the bearing walls. The bearing walls are either solid or contain openings (FIG. 4), as required by architecture. It is obvious, in the latter case the strength of the wall is weakened to some extent. However, if some limitations are imposed, still some resistance is offered by the solid portions - "piers" - between the openings, and it may be sufficient against earthquake effects. The "pier" tops are connected by the wall portions over the openings and also by the bond beams (if any) along the window tops and along the wall top.

The lateral earthquake force is finally transferred to the wall top, either in-plane or perpendicular to the plane. The resistance of the wall to perpendicular lateral forces is very small, since it behaves as a free cantilever. The bending moment and tensile stresses at the bottom, can easily form a horizontal crack on the pushing side, which may further develop into a separation, ending in tilting or overturning of the upper portion. As the earthquake force is of reversing character, the crack may occur on both sides in alternation, with corresponding crumbling on the opposite side under the temporal compression effects. Due to the slenderness or height of the wall, the cracking surface may take place at higher levels. The height of the wall should be limited and it should be intersected by strong perpendicular walls with limited spacing (e.g. 4.50 m), and the wall tops should be securely connected to the ceiling diaphragm, so the forces perpendicular to the wall plane can be transferred without doing much harm. The Code brings provisions about this (see APPENDIX I, Paragraph II.3.3.1-). FIGS. 11 and 12 show that the lack of such connections may lead to the collapse of the wall.

The "piers" may react either in shear or in bending, depending on the height-to-width ratio. If this ratio is higher than 2, bending may dominate, subject to the extent of vertical load. Otherwise shear dominates. The vertical load helps to force the bending conditions toward shear conditions, and if the compressive strength of the blocks is sufficiently high, this is an improvement. However, in most cases the adobes don't possess high compressive strength. Consequently the height-to-width ratio should be kept under 2, and the excessive vertical loads should not be given to the "piers".

A sort of load distribution is provided as a result of common deflection of the "pier" tops, to the extent at which connecting elements fulfill their function. However, the differences should not be too abrupt. The Turkish Code (see APPENDIX I, Paragraph II.3.3.2-) limits the size of window and door openings and specifies minimum lengths of solid wall portions between openings and between an opening and the corner. These provisions aim at assuring shear resistance domination and pooling the strength of elements that are not abruptly different.

3.4. Plan Arrangement

As a general principle for providing earthquake resistance, the plan must be simple (preferably a rectangle) and the bearing walls both in longitudinal and transversal directions must be arranged symmetrically about the two principal axes (APPENDIX I, Paragraph II.1-). The symmetry, mentioned above, should cover also the openings in the walls. Partial basements should be avoided. Otherwise, torsional effects of unpredictable extent may be confronted.

3.5. Bond Beams

Timber beams are employed traditionally. The most popular kind of timber is poplar, as it is easily grown in Anatolia. The Turkish Code allows the employement of either timber or reinforced concrete bond beams on foundation or basement walls, requiring asphalt treatment in the former (APPENDIX I, Paragraph II.5.1-). They should be constructed in the manner shown in FIG. 8 and in Paragraph II.5- of APPENDIX I. The bond beams have a number of functions and if provided sufficiently, increase the earthquake resistance of an adobe building considerably, as follows :

(a) As described in 3.3. , they act as a load distribution means, relieving the stresses from the weaker members, and increasing the share of more rigid (generally stronger) ones.

(b) In general, diagonal cracks are formed in the walls, as a result of high shear stresses, and X-shape is then assumed due to stress reversals. The bond beams prevent the propagation of these cracks to the other portions of the wall. In a way, they act as "suppressors" by limiting the damaged area. This may lead the creation of secondary failure zones at other locations. However, this is usually desirable as a kind of distribution is performed.

(c) The adobe wall is equipped with a tensile strength in the direction of the bond beams, provided that they have enough continuity. The tensile forces are turned into shear forces within the wall. So, occurence of vertical tension cracks are suppressed. This also improves the vertical load bearing capacity, in the same way as stirrups do in reinforced corcrete columns.

(d) The adobe wall is equipped with a shear strength, perpendicular to the direction of bond beams. The wall can, then, tolerate differential settlements or ground ruptures with vertical movement, probable occurences in seismic areas.

The merits of timber bond beams, as mentioned in (c) and (d) above, are seen in FIG. 9 .

(e) The lateral connections between the two members of the bond beams, prevent the adobe wall from splitting into vertical layers (FIG. 8), as observed in some thick walls. The wall thus functions in its full thickness.

(f) The bond beams, with their bending rigidity, perpendicular to the wall plane, increase the bending resistance of the wall, about a vertical axis. This allows the construction of walls with as long a span as 4.50 m, even with openings.

(g) The bond beams, connected together in the corner of two (or three or four) joining walls, provide the monolythicity of the load bearing system (FIG. 8) , preventing separation under seismic actions.

FIGS. 11, 12 and 13 show the cases where this function lacks.

Summarizing, the bond beams incorporate ductility to the adobe wall, substantially increasing its earthquake resistant qualities.

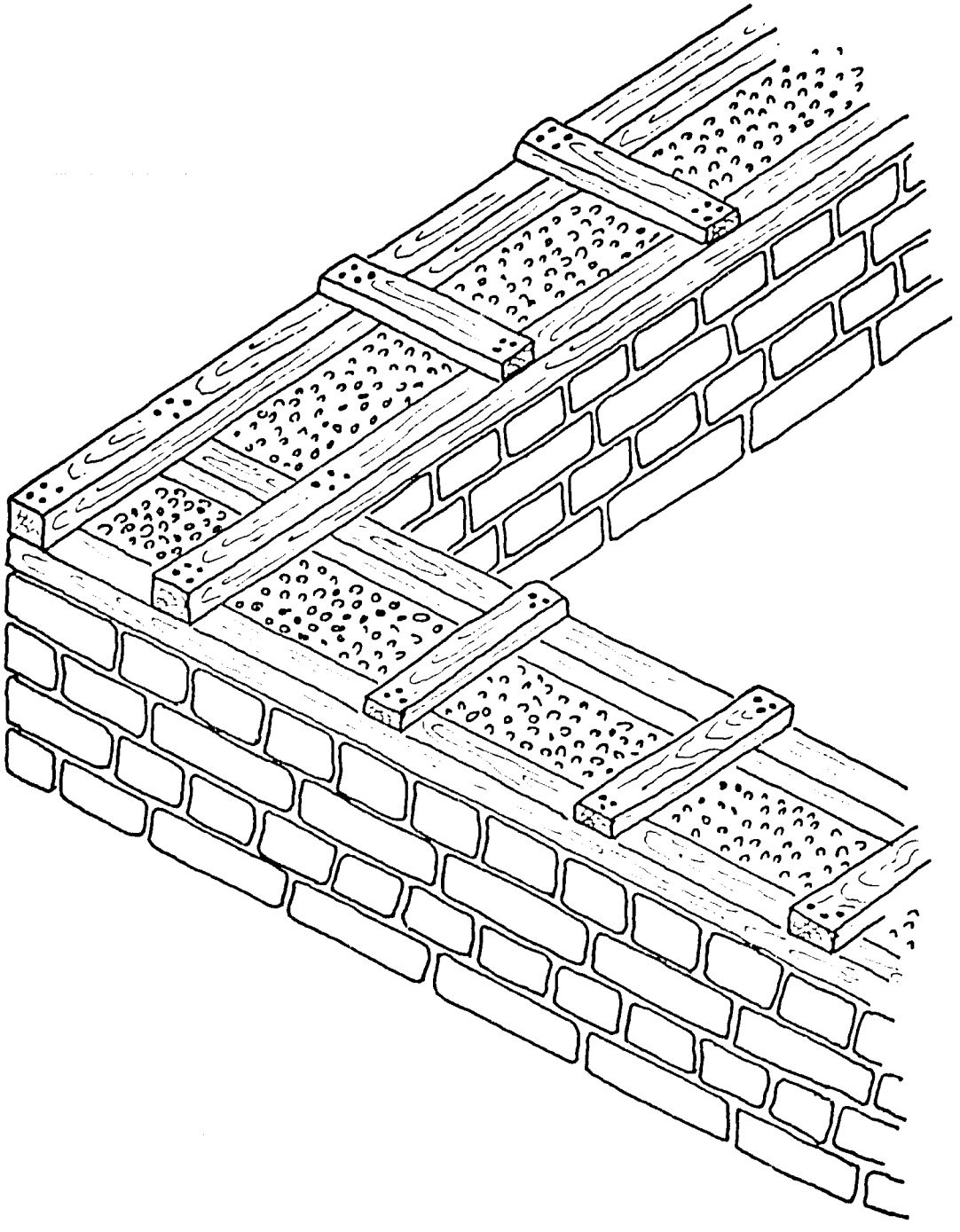


FIG. 8

Timber bond beams, to be provided at certain levels of the adobe wall. The bond beams have numerous functions in increasing the earthquake resistance of adobe buildings.

FIG. 9

A two storied brick building (right of the ground rupture, after Gediz (Western Turkey, 1970) earthquake. The wall at ground floor absorbed considerable amounts of deformation, leaving the upper story practically intact, thanks to the horizontal timber bond beams provided at various levels. Although the material of the wall is not adobe, it gives an idea as to the effectivity of bond beams in such buildings.

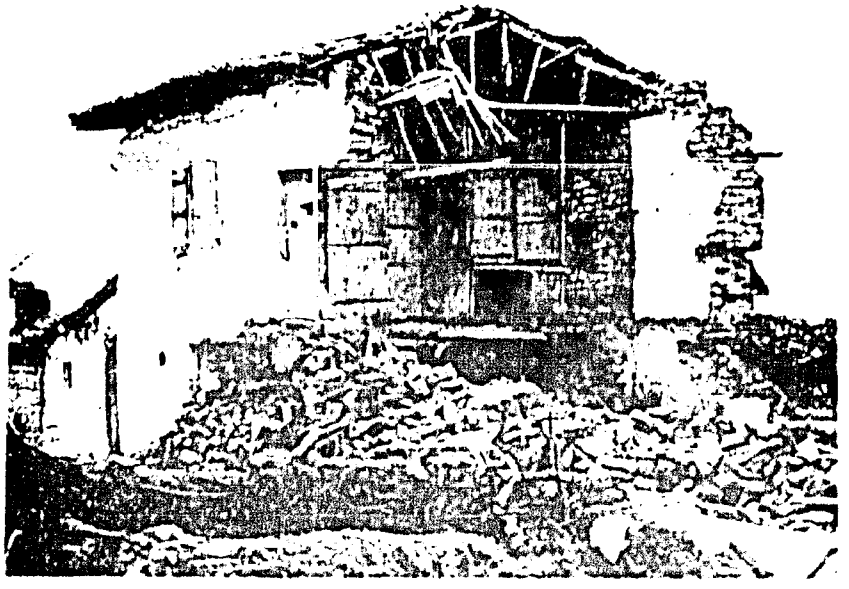


FIG. 10

Two storied adobe building with timber floor and ceiling. Timber bond beams are seen in the rear wall (right) , provided at two levels in the upper story, however of inadequate continuity. No lintel exists over the entrance door. Adobe blocks from the collapsed walls are seen in the foreground (right) .

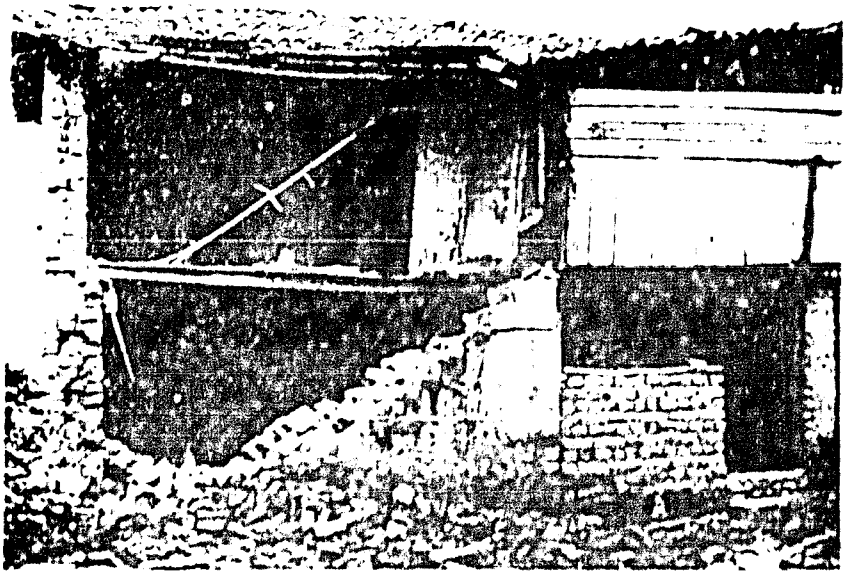


FIG. 11

Another two storied adobe building. Wall thickness of the ground floor is 1 1/2 times that of the upper floor. The upper floor is covered by a timber roof and tiles. Fireplaces are seen in both stories, indicating that the related spaces are for living. Timber floor and ceiling are able to provide sufficient diaphragm effect. However, the front walls neither had enough connection to the side walls, nor to the diaphragms. Cracks are observed in the non-bearing walls, over the fireplace arches.

FIG. 12

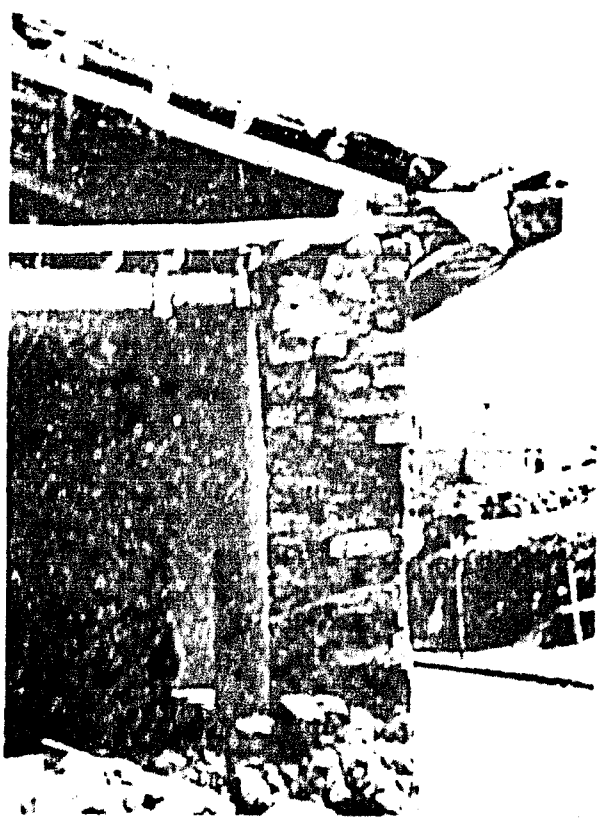
Separation of an adobe wall, from the adjoining perpendicular wall. Looking from inside. The timber stud, in the corner, supporting the main beam (that in turn supports the ceiling beams), worked well for the wall facing the reader. However, the connection to the other wall was poor. The ceiling beams too, didn't help the adjoining wall.

The rectangular light spot on the left is a window opening.

FIG. 13

The section of an adobe building, as revealed by Alaşehir (Western Turkey, 1969) earthquake. The thickness of the wall is of 1 1/2 adobe length. Adequate diaphragm action is provided by the ceiling, where rectangular timber beams are employed. However, insufficient connection at corner and ceiling caused the partial collapse of the front wall.

Note the lack of proper bond beams in the wall. Although the roof did not cause any damage in this case, the irregularity of the sections and the axes are noted.



3.6. The Roof

Heavy, flat earth roofs have caused most of the loss of life in adobe buildings, as they can easily weaken and destroy the load bearing walls, and fall down, (FIG. 16). It consists of logs, placed on top of walls with a certain spacing -typically 0.35 m from center to center - (FIG. 14). The spaces in between, are spanned with branches, then with shrub and foliage, in order to form a base to hold the thick earth layer. In regions where cane grows, dried and flattened canes are used to make a basket-like fabric or mat, to substitute the foliage. The observed thickness of the earth layer varies between 0.15 m and 0.50 m . This provides sufficient thermal insulation.

The roof also functions as a platform for such family activities as drying fruits or vegetables, for certain housework, for preparing food for the winter, even for sleeping at night during the hot season. A slope of 2.5 % is sufficient for draining the rain water in most cases, still not adversly affecting the above functions.

Addition of straw -as in adobe block making- to the thick earth layer, suppresses shrinkage cracks, improves the water and thermal insulation properties. Lime also improves waterproofing. The houseowner generally keeps a roller stone in order to to compress the new material, after the repairs of the top plaster. Such a repair is normally required every year.

In 1 st and 2 nd earthquake danger zones, the flat earth roof is prohibited. The thickness of the earth layer is limited to 0.15 m in the remaining zones (APPENDIX I, Paragraph II.6-). In FIG. 14 various ways of constructing an earth roof are shown. The building in FIG. 3 has the roof type shown in FIG. 14 (a), and the building in FIG. 5 corresponds to FIG. 14 (b) .

(a) In the type shown in FIG. 14 (a) the roof beams directly rest on top of adobe wall. The supporting length is approximately half the thickness of the wall. There are no eaves. As the rain washes the wall plasters, frequent repairs are needed.

In case of an earthquake, the ends of the roof beams may undergo large relative displacements with the supporting wall. As the earthquake force is of reversing nature and the bearing length is small, this may result in either pulling off the beams or local compression failures in the bearing portion of the adobe wall. In both cases, the heavy roof constitutes a great danger for the inhabitants (FIG. 16).

(b) In the type in FIG. 14 (b), the longer roof beams allow the formation of the eaves, and reduce the probability of pulling off. However the danger of wall failure, as initiated by the local compression failures under the beams, still remain.

(c) In FIG. 14 (c) collar beams are seen, along the wall top, functioning as a load distributor. The heavy load of the roof beams are no more concentrated on the adobe blocks, but is now distributed more evenly. Moreover the collar beam possesses all the merits of the bond beams, as mentioned in 3.5. above.

Most of the earthquake force comes from the roof, due to its large area and huge mass. The load should bear this lateral force, in addition to the previously existing vertical forces. As mentioned before (3.3. above) the wall resists the in-plane lateral forces in shear mode. For materials of high compressive strength,compression

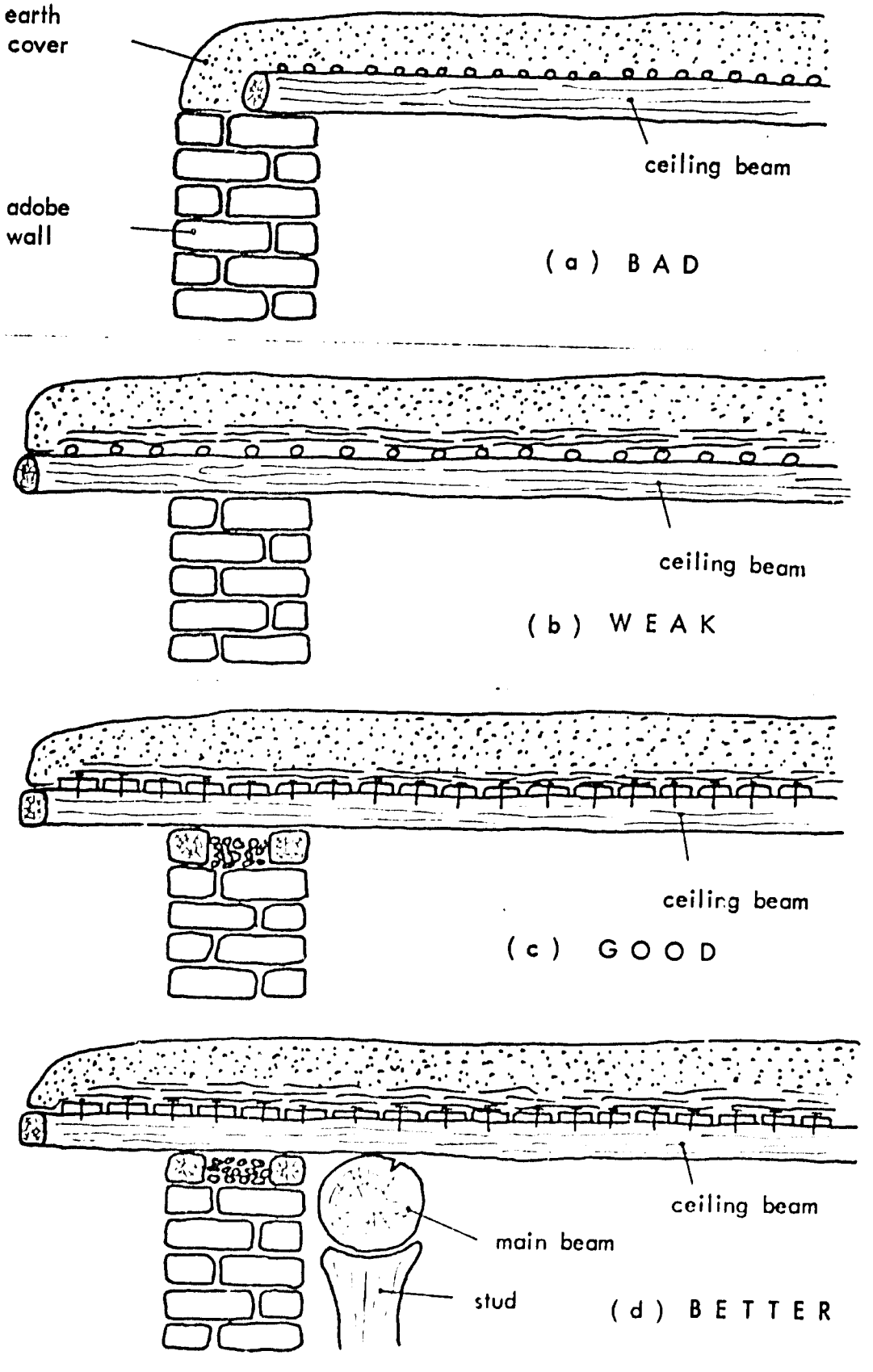


FIG. 14

Various ways of constructing an earth roof. The above four pictures represent gradually better solutions, from the top to the bottom.

has an improving effect on the shear resistance capacity. But the majority of the a - dobes used in Turkey, are of low compressive strength. Consequently, the combining of compression and shear could cause local failures, especially between wall openings. So, FIG. 14 (c) is not the best solution.

(d) In FIG. 14 (d) a larger main beam supports the roof beams, the latter still rest on the collar beams of the wall. The main beam, in turn, is supported by vertical studs. The heavy load of the roof is now relieved from the walls, and also a second line of defense is obtained.

The cases (a), (b), (c) and (d) in FIG. 14, represent gradually better solutions, respectively. Another improvement in (c) and (d) is the employment of flat timber boards, nailed on each roof beam. These connections provide the integrity of the roof, thus improving the earthquake resistance of the whole building, as it functions as a rigid diaphragm. Otherwise, the diaphragm effect is only partly obtained through the transversal slender branches and the earth layer. This effect works only in case of low intensity earthquakes. The employment of nailed timber strips, considerably raises the extent of intensity of the earthquake, under which the buil - ding can still hold itself. The same material as mat and/or foliage should be used between the timber strips and the earth layer, both for thermal insulation and preser - vation purposes.

In FIG. 15 a roof is seen from inside, in the type shown in FIG. 14 (d). The stud is built in the wall. As its lateral rigidity is provided by the wall, cracks and a permanent lateral deformation are seen due to earthquake excitation. However, the limitation of the openings, sufficient solid wall portions, and the bond beams, in addition to the stud and the main beam system, described above, all contributed to the survival of the building.

3.7. Floors, Ceilings

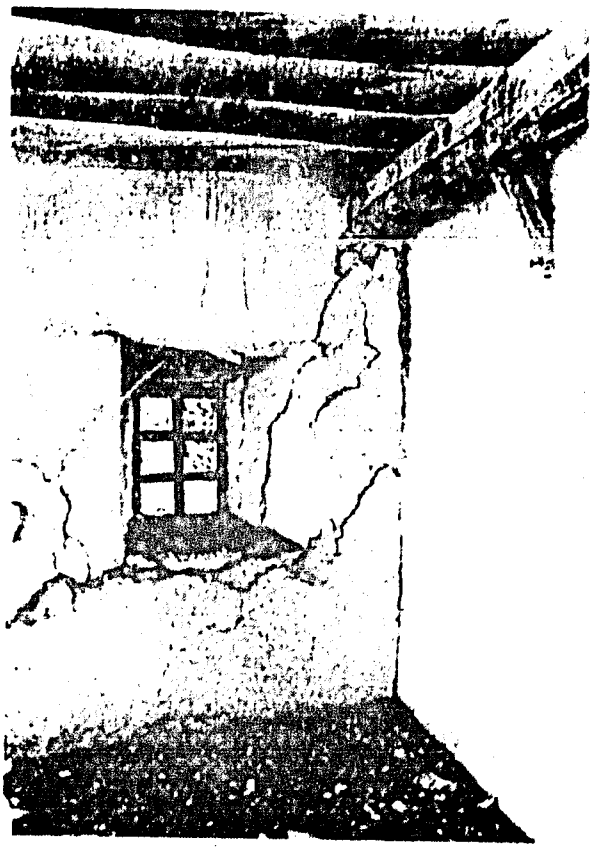
In case of double-slope light roofs (FIGS. 10 and 13), and in case of two storied buildings (FIGS. 10 and 11), a ceiling capable of resisting in-plane forces and de - formations is essential. They should be securely connected to the walls, on which they rest. FIGS. 11 and 13 show the lack of these connections, although such ceiling diaphragms exist.

3.8. Chimneys and Appendages

Chimneys and appendages are generally the most sensitive portions of adobe buildings. Even in earthquakes of low intensity, they break off easily. Appendages are not common in adobe buildings in Turkey. The Turkish Code has provisions on chimneys (APPENDIX 1, Paragraphs 4.1.2- and 4.1.3-).

Wherever possible, the chimney must be an independent structure, resting on its own foundation (FIG. 11), instead of transmitting its weight to the roof. Pipes of sufficient diameter should be preferred, because of their strength and lightness.

FIG. 15

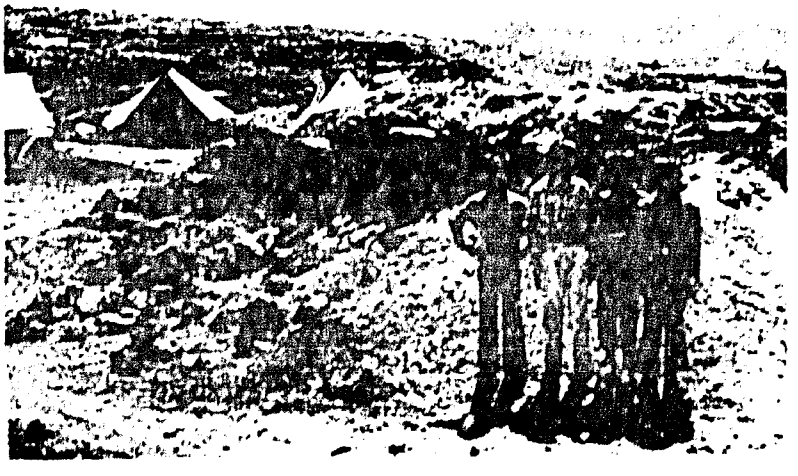


Interior of a single storied, stone masonry building, in which the main beams, that carry the ceiling beams, are supported by vertical studs. As the studs are built in the wall, they are not visible to the reader. This relieved the wall from the vertical loads of the heavy roof, however, lateral (to left) deformation of the main beam caused some diagonal cracks.

Note that limiting the openings, the solid wall portion provided between the opening and the corner, and the horizontal bond beams (not seen in the photo) all contributed to the survival of the building at this major earthquake (Kiğı, Eastern Turkey, 1968).

One may extend the same to adobe buildings too.

FIG. 16



A collapsed stone-adobe mixed building, after Çaldıran (Eastern Turkey, 1976) earthquake. The heavy earth roof, carried by thick and round wooden beams, now rests on the wall material, which has turned into a heap of soil and stone, after the rains, following the earthquake.

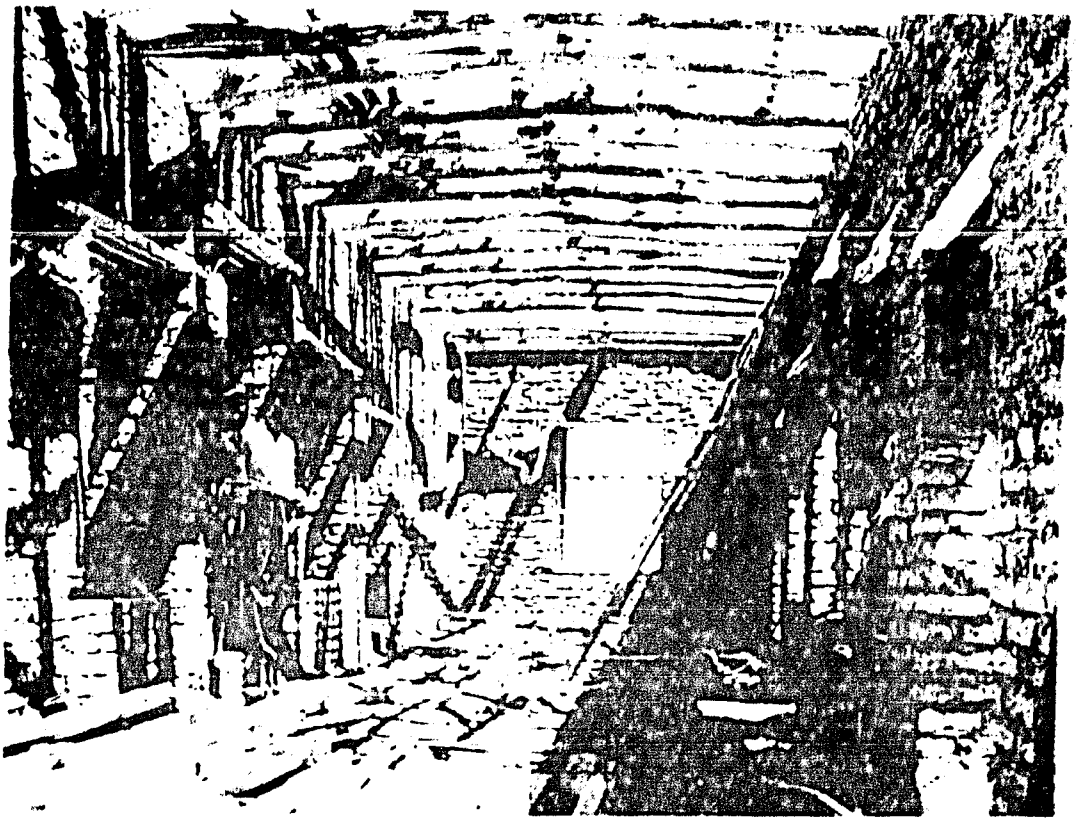


FIG. 17

Interior of an adobe building, during construction (Özalp, Eastern Turkey) . The window and door openings have timber lintels on the top, and sills in the bottom. However, no continuous timber bond beams exist in the walls, at proper levels. Also note the lack of collar beams, along the supports of the ceiling beams ; the latter rest on the adobe walls, directly. The solid wall portions between openings , are not adequate. Finally : this is not a good example for an earthquake resistant adobe building.

4. The Need for Training the Local Builders

Although the existing Earthquake Code of Turkey (I) has a section on adobe buildings (APPENDIX I), still in rural areas various problems exist in implementation (4). FIG. 17 shows the interior of an adobe building in a major earthquake zone. The deficiencies are described under the figure. Considering this reality, education of the local builders should be given due consideration. The Ministry of Reconstruction and Resettlement has conducted local courses for builders, and also prepared and distributed colored posters, carrying practical, illustrated instructions.

5. Conclusion and Areas where Research is Needed

Adobe is a heavy, weak and brittle building material. The heavy roof makes it more vulnerable. As understood, the elastic and rigid behavior can be expected only in earthquakes of low intensity. In earthquakes of moderate or higher intensity, cracks will inevitably occur, impairing the monolythical behavior of the building. Still, considerable improvements in strength and ductility can be achieved through the provision of the mentioned measures. The recommendations made in the previous sections, are also applicable in repair work of adobe buildings.

The adobe buildings should not be expected to be as resistive as reinforced concrete buildings, however, by using the good quality adobe blocks, they can exhibit better earthquake performance than rubble stone - mud mortar, and even better than some brick masonry buildings.

Although there are works to improve and stabilize the adobe blocks in Turkey, no extensive implementation has ever been involved.

(a) Benefits of adobe stabilization should be investigated for Turkey. As adobe buildings constitute 28 % of the rural houses in Turkey (I.2. above), the introduction of stabilization will have imporving effects. However, problems of education and acceptability should be considered.

(b) The utilization of stabilized adobe blocks -if possible- in basement or foundation walls, should be investigated. The problems of conforming with traditional adobe and repairability should also be considered.

(c) The utilization of stabilized mixtures for plastering should be investigated. This should also cover the bonding to the traditional adobe. For acception, the continuous availability of the stabilizing agents is important.

(d) Better and simpler details of connection of adobe walls to timber bond beams should be investigated, as presently suggested details (FIG. 8) offer some difficulties in laying the first row of adobes, immediately on the bond beam.

(e)Possibility of construction of buildings of more than 2 stories should be investigated, by improving the compressive strength. Considering the energy required in brick making, and the low quality of bricks in general, adobe blocks may prove to be a better alternative.

APPENDIX I

REGULATION FOR BUILDINGS TO BE CONSTRUCTED IN DISASTER AREAS

PART : I

GENERAL PROVISIONS

Section 1 - Scope of the Regulation

1.1 - This Regulation, promulgated in accordance with Paragraph 3 of Act 7269 -as revised by Act 1051- , applies to all buildings, governmental or private, in disaster areas as determined and declared in accordance with Paragraph 2 of the above mentioned Act. The technical conditions regarding the construction of new buildings or structural modification, or expansion, or major repairs of the existing ones shall conform to the provisions set forth in this Regulation.

1.2 - The materials and workmanship of buildings to be constructed in disaster areas, shall conform to the applicable Turkish Standards and to the "General Technical Specifications" of the Ministry of Public Works.

Section 2 - Sites on which building construction is prohibited

2.1 - No new buildings or dwellings shall be constructed, nor shall existing ones be repaired, on a site determined and declared as prohibited for construction, in accordance with Paragraph 14 of Act 7269 -as revised by Act 1051- . Furthermore, no buildings or dwellings shall be constructed on artificial fills with a past of less than 30 years, unless sufficient soil compaction is provided.

2.2 - No new buildings or dwellings shall be constructed, nor shall the existing ones be repaired on sites affected by at least one of such hazards as avalanche, rockfall or landslide, and furthermore determined and declared as a disaster area through a decree, depending on Paragraph 2 of Act 7269 -as revised by Act 1051

PART : II

PROTECTION FROM FLOOD AND FIRE DISASTERS

Section 3 - Protection from flood disaster

3.1 - At a site determined and declared as flood disaster area through a decree, in accordance with Paragraph 14 of Act 7269 -as revised by Act 1051- , new buildings may be constructed or existing buildings may be repaired, provided that the site is not prohibited for construction, and furthermore the provisions set forth in

the following Subsections (3.1.1), (3.1.2), (3.1.3), (3.1.4) and (3.1.5) are complied with.

3.1.1 - In those portions of buildings that may come into direct contact with water, no natural or artificial building material unable to withstand the effects of water shall be used (e.g. adobe, timber, tuff, gypsum, or wall with mud mortar etc.) .

3.1.2 - Those portions of buildings extending from the foundations up to at least 0.30 m above the water level -determined as highest possible- , shall be built of stone masonry with a mortar of 250 kg/m^3 cement content, or of cyclops concrete with a 150 kg/m^3 cement and 1/3 coarse aggregate content, or of other material with higher durability.

3.1.3 - Necessary precautions shall be taken where the possibility exists that the foundation soil be flooded.

3.1.4 - Those building portions subject to structural modification, or expansion, or major repair work shall be so treated in such a way as to increase the flood durability of the whole building.

3.1.5 - No storage, or laundry, or shelter spaces shall be built so as to be left under the water level, determined as highest possible.

Section 4 - Protection from fire disaster

4.1 - At a site determined as fire disaster area, in accordance with Paragraph 14 of Act 7269 -as revised by Act 1051- , the following precautions shall be taken as a minimum, in buildings to be constructed or repaired, until the relevant Turkish Standard comes into effect.

4.1.1 - Timber or other inflammable materials shall not be employed in the exterior walls of buildings arranged in rows.

4.1.2 - The thickness of the exterior wall of the chimney, resting on the roof slab, shall be at least one brick length (19 cm as to the relevant Turkish Standard) . In working halls and in centrally heated buildings, the thickness shall be no less than 1 1/2 brick length (29 cm as to the relevant Turkish Standard) . The chimney shall in no case come into contact with any timber elements, furthermore a clear space of at least 5 cms shall be provided between the chimney and any timber elements. Exterior surfaces of chimney shall be plastered and the joints between bricks or blocks shall properly be filled with mortar, using forms of planed timber or sheet metal. One of the non-flammable materials such as common brick, concrete block or similar shall be employed in construction of chimneys .

4.1.3 - The chimney top shall be at least 0.75 m above the level at which it intersects the roof covering.

4.1.4 - Beams and columns susceptible to fire damage in multistory steel frame structures, shall be protected by a covering of suitable non-flammable material.

Preventive and protective measures shall be taken where accumulation of inflammable materials or vapors is possible.

4.1.5 - Timber frame buildings shall not be built in rows. The faces of an individual timber building shall be at a clear distance of 5.00 m from the nearest boundary of the relevant land plot.

4.1.6 - In case where buildings adjoin, a fire shield shall be provided in between, along the common boundary, starting from the roof slab level and reaching to a height 0.60 m above the roof surface, the top line being parallel to the line of maximum slope of the roof. The shield shall be a wall of masonry or another similar non-flammable material, with a thickness of at least one brick length (19 cm as to the relevant Turkish Standard) , and be plastered on both sides.

4.1.7 - Those building portions subject to modification, or major repair work, or renovation, shall be so treated in such a way as to increase the fire resistance of the whole building.

PART : III

PROTECTION FROM EARTHQUAKE DISASTER

Section 5 - Applicability

5.1 - The provisions applicable to engineering structures such as dams, bridges etc., and to those types of buildings not presently covered by this Regulation, -from the point of their structural conditions and design principles- shall be determined by the relevant Ministries that are presently involved in the management of such construction work.

5.2 - The earthquake danger zones referred to herein, are those indicated in the "Map of Earthquake Danger Zones in Turkey", prepared by the Ministry of Reconstruction and Resettlement, and put into effect by the decree 7/5551, dated December 22, 1972 , depending on Paragraph 2 of Act 7269 -as revised by Act 1051- .

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Section II - Adobe buildings

II.1 - Scope and general provisions

Buildings with foundations and, if any, basement walls of stone masonry, and with bearing walls made of adobe, either of individual blocks or cast-in-situ , shall hereafter be referred to as adobe buildings.

Adobe buildings may be constructed only in one story configuration, provided

that the construction rules in specifications relevant to masonry buildings are adhered to, unless the contrary is prescribed in this Regulation. The story height shall not exceed 2.70 m , nor shall the height of the basement, if any, exceed 2.40 m .

The plan layout of adobe buildings should preferably be a rectangle, and the bearing walls both in longitudinal and transversal directions shall be arranged symmetrically about the two principal axes. Any deviations from symmetry shall be kept within negligible limits. Partial basements should preferably be avoided.

II.2 - Foundations

II.2.1 - The foundation walls, in all earthquake zones, shall be made of rubble stone masonry, utilizing cement mortar, or cement reinforced lime mortar -in the quality corresponding to a volumetric ratio that cement:lime:sand = 1 : 2 : 9 - . The thickness shall be at least 0.50 m and the wall shall rise to a height at least 0.50 m above the ground level.

II.2.2 - The foundations shall be constructed at a depth below the frost level, but in no case shall they be shallower than 0.80 m .

II.2.3 - In buildings with a basement, the thickness of the foundation walls shall be 0.60 m , with a corresponding thickness of 0.50 m for the basement walls. These walls shall be made of rubble stone masonry, utilizing cement reinforced lime mortar -in the quality corresponding to a volumetric ratio that cement:lime:sand = 1 : 2 : 9 in the first degree earthquake danger zone, and in the quality corresponding to a volumetric ratio that lime:sand = 1 : 3 in second, third or fourth degree earthquake danger zones.

II.3 - Bearing walls

II.3.1 - The materials

The production of adobe blocks shall be performed in accordance with the provisions in the specifications relevant to masonry buildings.

The rubble stone masonry walls shall be constructed utilizing cement reinforced lime mortar -quality described above- , whereas the adobe walls shall be constructed utilizing the same mixture used in producing the adobe blocks, as mortar. Moisture insulation shall be provided at the joint between the stone masonry and the adobe wall.

II.3.2 - Wall thicknesses

II.3.2.1 - The thickness of rubble masonry walls of the basement, if any, shall be no less than 0.50 m .

II.3.2.2 - Exterior and interior bearing adobe walls shall have a thickness of at least 1 1/2 and 1 adobe length, respectively. The main and complementary adobe block dimensions shall be 0.30 m X 0.25 m X 0.15 m and 0.30 m X 0.15 m X

0.15 m , respectively.

II.3.3 - Stability and openings in walls

II.3.3.1 - Stability

a) The stability of the bearing walls against lateral loads, shall be provided by the adjoining perpendicular walls. The thickness of such a wall shall be no less than an adobe block length.

b) The free span of the bearing wall, measured between the axes of the stabilizing walls, shall not exceed 4.50 m .

c) Utmost care shall be exercised in the construction of chimneys. In case the material of the chimney is different from adobe, a construction joint shall be provided, and the chimney shall be constructed in such a way so as not to disrupt the continuity of the bearing walls.

II.3.3.2 - Openings in the bearing walls

a) A solid wall portion of at least 1.00 m length shall be provided, between the door or window opening and the corner of an exterior bearing wall.

b) The distance of the side of an opening in the bearing wall to the nearest intersection with the perpendicular wall, shall be at least 0.50 m .

c) Door openings in the walls shall be no larger than 2.10 m X 1.00 m . No more than one door opening shall be provided in any portion of the bearing wall, between two adjoining perpendicular walls.

d) Window openings in the bearing walls shall be no larger than 1.40 m X 0.90 m .

e) A solid wall portion of at least 0.60 m length shall be provided between two consecutive door and/or window openings. In case where this is not possible, two 0.10 m X 0.10 m timber studs shall be provided at each side of the opening - a total of four studs - , furthermore they shall be connected to the lintel at the window top and to the bond beam right below the window.

II.4 - Floors

Floors shall be made to rest on and be connected securely to the bond beams between the foundation or basement walls, if any, and the adobe walls.

II.5 - Bond beams and lintels

II.5.1 - Reinforced concrete or timber bond beams shall be provided on foundation or basement walls, if any, of 0.15 m height and with a width not less than the wall thickness. In case the bond beam is made of reinforced concrete, the cement

content shall be no less than 250 kg/m^3 and the beam shall have a longitudinal reinforcement of 4 bars of 10 mm diameter. They shall be laterally tied by stirrups of 6 mm diameter, spaced at 0.25 m .

In case where the bond beam is made of timber, it shall consist of two 0.10 m X 0.10 m asphalt treated longitudinal members, connect to each other laterally by nailing 0.05 m X 0.10 m pieces, at every 0.50 m . The space in between, shall be filled with crushed stones.

11.5.2 - In adobe walls timber bond beams, similar to those in 11.5.1 , shall be provided right below and above windows, along the walls, and also on the wall tops, on which ceiling beams or roof trusses rest.

11.5.3 - In regions where cane grows, the bond beams -except those of base beams, the roof beams and except door and/or window lintels- may be made of canes, spaced 0.05 m apart and tied together at every 0.50 m by thin wires.

11.6 - Roofs

11.6.1 - Roofs of adobe buildings shall have eaves of at least 0.50 m , beyond the external walls. Due care shall be exercised to make the roof a light one. Necessary precautions shall be taken in the construction of bearing adobe walls, so that the bearing characteristics are not impaired by external -atmospheric- actions.

11.6.2 - No flat earth roofs shall be constructed in the first or second earthquake danger zones. The thickness of the earth layer shall not exceed 0.15 m in third or fourth degree earthquake danger zones.

Section 12 - Repair and renovation

12.1 - The repair work of structures damaged by earthquakes shall be conducted through the proper design work performed adhering to the provisions prescribed in this Regulation, and further approved by the related building authorities, in order to provide sufficient strength against future earthquakes.

12.2 - Those buildings and portions thereof, in earthquake danger zones, subject to modification, expansion, or renovation, shall be so treated in such a way as to incorporate sufficient earthquake resistance through proper design work performed adhering to the provisions prescribed in this Regulation, and further approved by the related building authorities.

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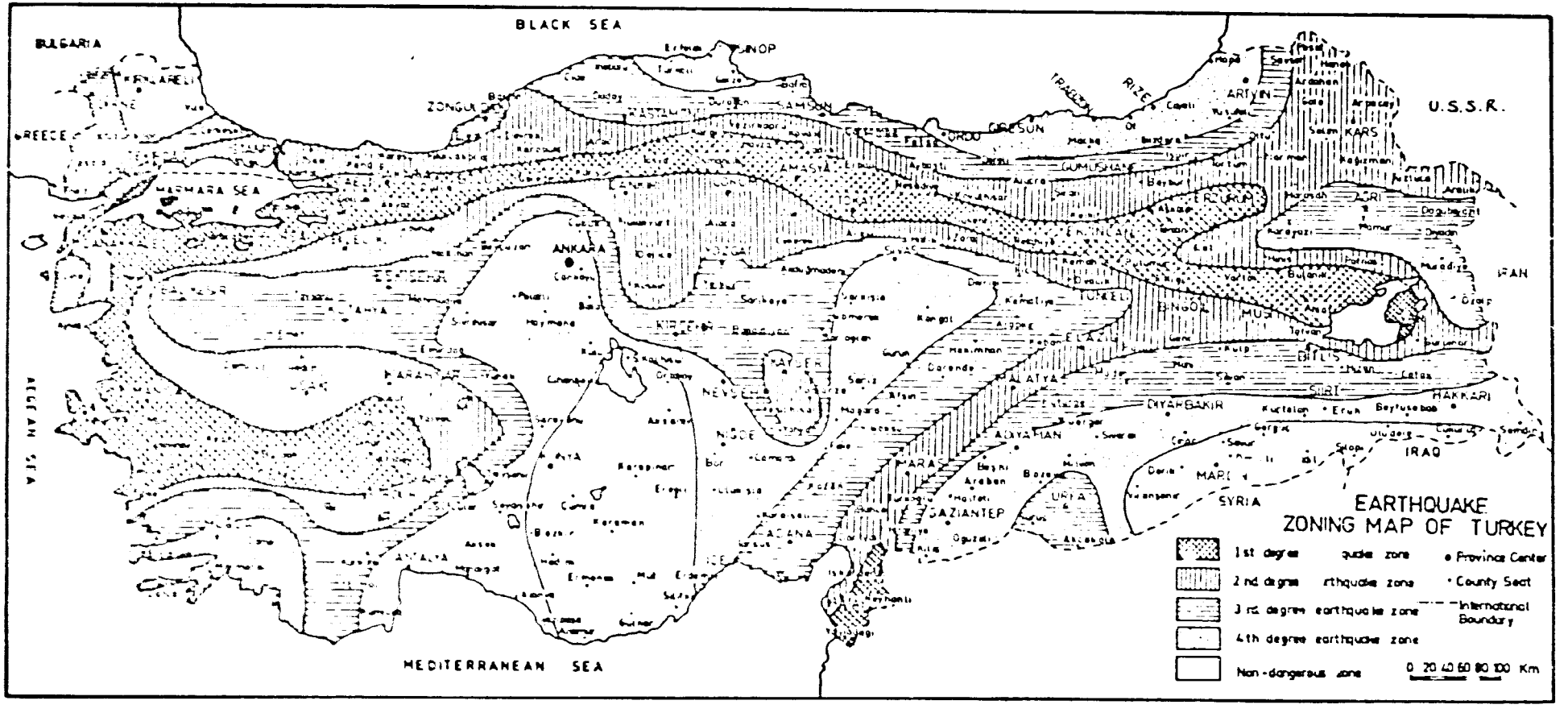
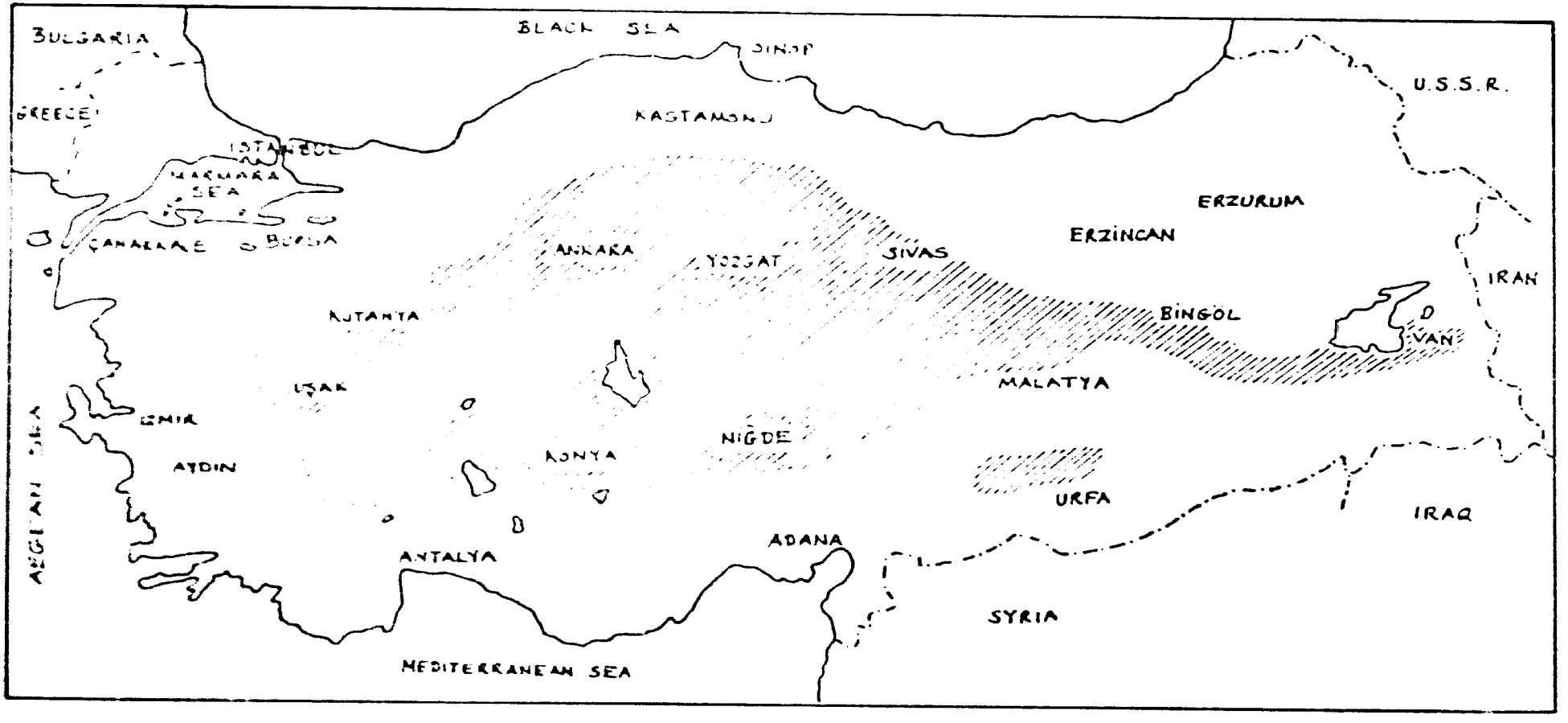
APPENDIX 2

MAP OF EARTHQUAKE DANGER ZONES IN TURKEY



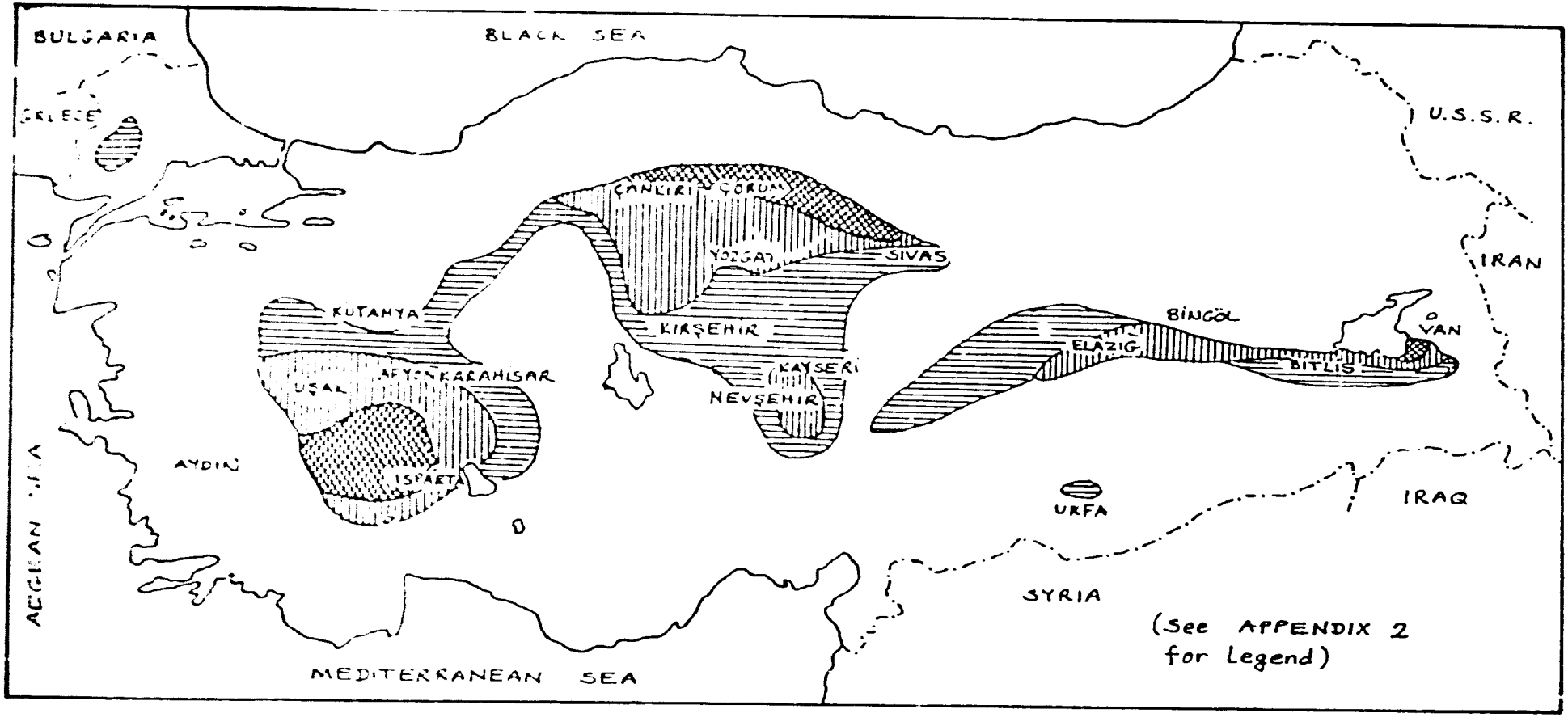
APPENDIX 3

MAP OF TURKEY, SHOWING THE AREAS WHERE ADOBE BUILDINGS DOMINATE



APPENDIX 4

MAP OF TURKEY, SHOWING THE AREAS WHERE DOMINATING ADOBE BUILDINGS ARE UNDER MAJOR EARTHQUAKE DANGER



REFERENCES

1. "Regulation for Buildings to be Constructed in Disaster Areas" (in Turkish), Ministry of Reconstruction and Resettlement, (presently in effect, through the Decree 7/5551, dated Dec. 23, 1972), Ankara, Turkey (1972) .

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CURRENT ARIZONA PRACTICE
and
OBSERVATIONS OF THE WESTMORLAND EARTHQUAKE

Robert E. Barnes
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Code Committee Chairman, Arizona Adobe Association

ABSTRACT Overview report of adobe practices and codes in Arizona. Observations and practices of Robert E. Barnes, Architect and Adobe Builder. Photos and observations of The Westmorland Earthquake of April 28, 1981.

Current Arizona Practice

A renaissance of Earth Construction has been occuring in Arizona over the last five years. Stimulated by the need for energy efficiency, high thermal mass structures utilizing earth techniques of adobe and rammed earth are being built by numerous contractors, and owner-builders throughout central and southern Arizona.

Practically all structures now being built are single family residences, most limited to one story, and most are sponsored by owner-builders or adobe oriented small custom builders. No earth structures have been constructed by the large mass builders, who supply 90% of the housing units within the state, or by goverment in public housing projects. Only a church built of rammed earth in Saint David, Arizona has been built for institutional or commercial purposes.

This limited start for earth structures has been stimulated by the nontraditional craft oriented builders and has been widely publicized. Public response to the renaissance has been very high with the founding of several adobe associations.

While current construction volumn is low due to the high interest rates on home mortgages, subcontractors who are currently short of work are becoming more interested in adobe.

Few architects, and fewer engineers, have expressed interest in adobe, and the state of earth building appears to be non industrial, local, and traditional. Few, if any, structures are designed for seismic forces and local codes have been stimulated by political pressure of adobe's historic rather than its technical nature.

Most builders, especially the owner-builders, have tried to avoid involvement of structural analysis professions in their projects beyond simple tabled evaluations of roof structures.

Codes

Local jurisdictions in Arizona are responsible for preparation and adoption of building codes and most have adopted the Uniform Building Code as their basic code. Several counties have no codes at all and there is strong political pressure to avoid them. Several cities and counties within Arizona have adopted local adobe codes to be used in conjunction with the U. B. C., but which are more substantive than the U. B. C. references to adobe. Most of the local code ammendments are derived from the New Mexico Code and all vary in detail. Many do not require

seismic analysis for residential structures despite the U.B.C. designation of Zone 2 for most of Arizona.*

All of the local ammendments are specific codes rather than performance largely due to the nonengineering orientation of the adobe builders.

Most local codes do not require the minimum percentage of steel (UBC Section 2418j3) required for masonry structures in seismic Zone 2 with Maricopa County being the exception.

Construction techniques as required by the local codes are based upon the accepted standards for well built adobe structures but have not been innovative or liberal in allowing design professionals latitude in solving the seismic solution.

Code bodies, although cooperative in allowing adobe, have been resistant to allowing adobe out of the home construction market.

As previously mentioned Maricopa County has required steel reinforcing as specified in UBC Section 2418j3 for adobe construction with the apparent intent to provide ductility for seismic loading. This structural concept of heavy gage steel reinforcing for earth structures is in my opinion without sound engineering logic. Earth structures have few similar properties to concrete and fired brick structural systems. The shock absorbing properties and non brittle properties of earth construction have not been reflected in current codes. Techniques appropriate to concrete masonry such as heavy gage grouted steel reinforcing and anchor bolts are in sharp contrast to earth's lower allowable stresses and higher shock absorbing qualities.

It seems that new conceptual thinking is required for earth construction. Simply applying structural methods from other building materials can be misleading and structurally inadequate.

F. H. A.

F. H. A., H U D, and federal agencies have been mixed in their support for earth construction. While funding an adobe training yard for the Tucson Barrio Association they have offered no assistance in drafting F. H. A. property standards for adobe construction which would provide mortgage loan guarantees. F. H. A. loan

* 1. International Conference of Building Officials, Uniform Building Code, International Conference of Building Officials, Whittier, California (1979)

guarantees now are are used by 75% of the Tucson Homebuilders and it is obvious that without such programs earth construction has and will be restricted.

F. H. A.'s major concern seems to be seismic design of adobe structures and unless the science of such engineering is improved earth building on a large scale will be limited.

The Department of Housing and Urban Development through the Federal Housing Administration has on repeated occasion stated that the adobe industry has not presented sufficient technical data to support guarantees for loans, somehow forgetting the substantial role the federal government had in the 1940's and 1950's testing and encouraging adobe and rammed earth use.

The National Bureau of Standards sponsored testing of Earthen Structures in 1941 and published its findings in a report "Structural, Heat-Transfer, and Water Permeability Properties of Five Earthwall Construction."* In this study structural properties of wall specimens under compressive, transverse, concentrated, impact, and racking loads were performed.

In March, 1955 the U. S. Department of Housing and Urban Development published an article "Earth for Homes."* In this publication they state "in the opinion of some authorities well bonded earth will withstand seismic loads of moderate intensity if properly incorporated into a building of low, compact, and regular plan. In this case well bonded bearing walls should have a slenderness ratio not greater than eight. The foundations should be monolithic and a substantial continuous reinforced concrete bond beam should be placed on top of the wall bonded to all wall plates. Lightweight ceilings and roof should be used, with the trusses or rafters and joists tied together and so placed on the plate as to avoid eccentric wall loading. Ceiling and roofs, should be anchored to both side and end walls and constructed to serve as diaphragms to resist distortion."

Earth construction without a technically supported and strong federal lobbying effort will not be able to win over the Federal Agencies.

Current Work by Robert E. Barnes & Associates, Inc.

Our work in earthen structures has involved design and construction of five stabilized adobe homes in Tucson and design of three others not yet constructed

* 2. Herbert L. Whittemore, et al, Structural, Heat-Transfer, and Water Permeability Properties of Five Earthwall Construction, National Bureau of Standards, Washington, D.C. (1941).

3. U.S. Department of Housing and Urban Development, Earth for Homes, Washington, D.C., (1955).

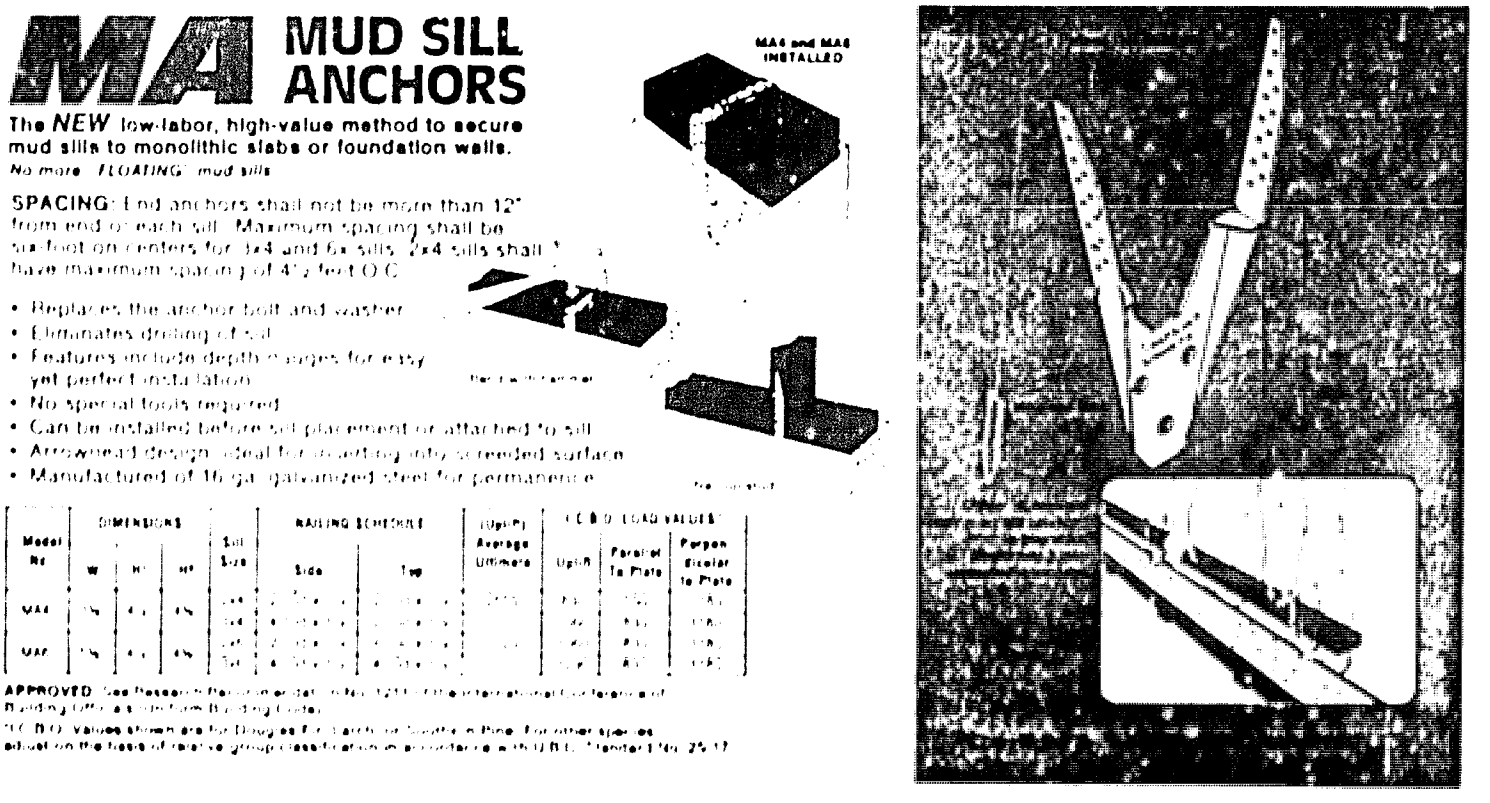
plus a prototype solar adobe rental unit which would be built in multiple groups.

Several structural techniques have emerged from this work. Our homes have been constructed of 14" thick stabilized Adobe Masonry Units (10" x 14" x 3½") laid with full head and bed joints of stabilized adobe mortar. Nine gage by twelve inch wide "Durowall" ladder or truss type joint reinforcing has been placed 16" o.c. horizontally throughout the structures and at every course, five courses thick, at the bond beam. We have used no concrete bond beam but refer to this connection as the "zone of reinforcing." All walls are supported by continuous concrete footing and stem walls.

Several methods of roof attachment have been designed, two have been constructed. Our first two homes were constructed in accordance with local code requirements utilizing 1/2" x 20" anchor bolts. This method of attaching the roof to the wall proved too costly and in retrospect structurally insufficient due to the concentration of forces at the bolts.

Our next three homes utilized roof joists set into the wall, each joist anchored by a "Simpson Mud Sill Anchor".* This device shown in FIG. 1 transfers forces from the joists to the wall.

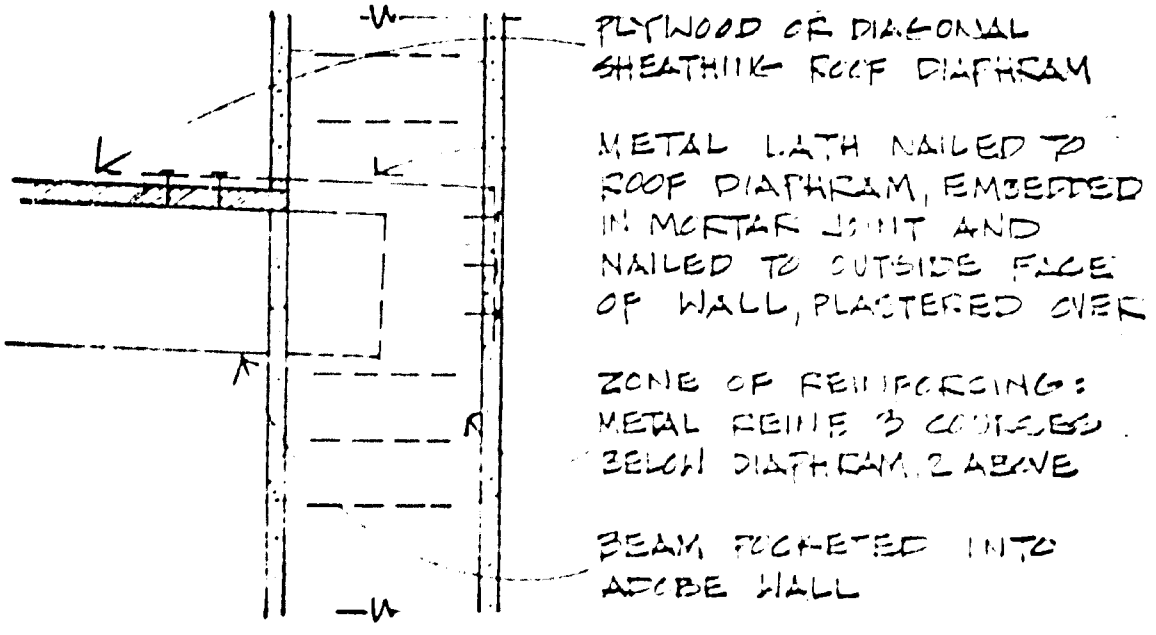
FIG. 1



* 4. Handbook of Structural Designs & Load Values, Simpson Company, San Leandro, California, 1979 (Reproduced with their permission).

Current designs utilize "Low Stress" detailing methods. Transverse loads transferred to and from a lightweight wood or plywood roof diaphram are continuously transferred to the wall system utilizing expanded metal lath laid into the wall and attached to the diaphram. No anchors are needed on the joists. No bolts are used (FIG. 2).

FIG. 2



We feel this system to be economical and the most structurally sensible method of transferring loads between the wall and roof system.

Observations of the Westmorland Earthquake

By: Robert E. Barnes
Photography by: "Bill" White
Processing by: David Burkhalter

Sunday, April 26, 1981, at 5:00 a.m. PDT the Town of Westmorland, California was struck by an earthquake measuring 5.6 on the Ricter Scale. During the previous several days over 40 quakes measuring above 3.0 had shaken the city.

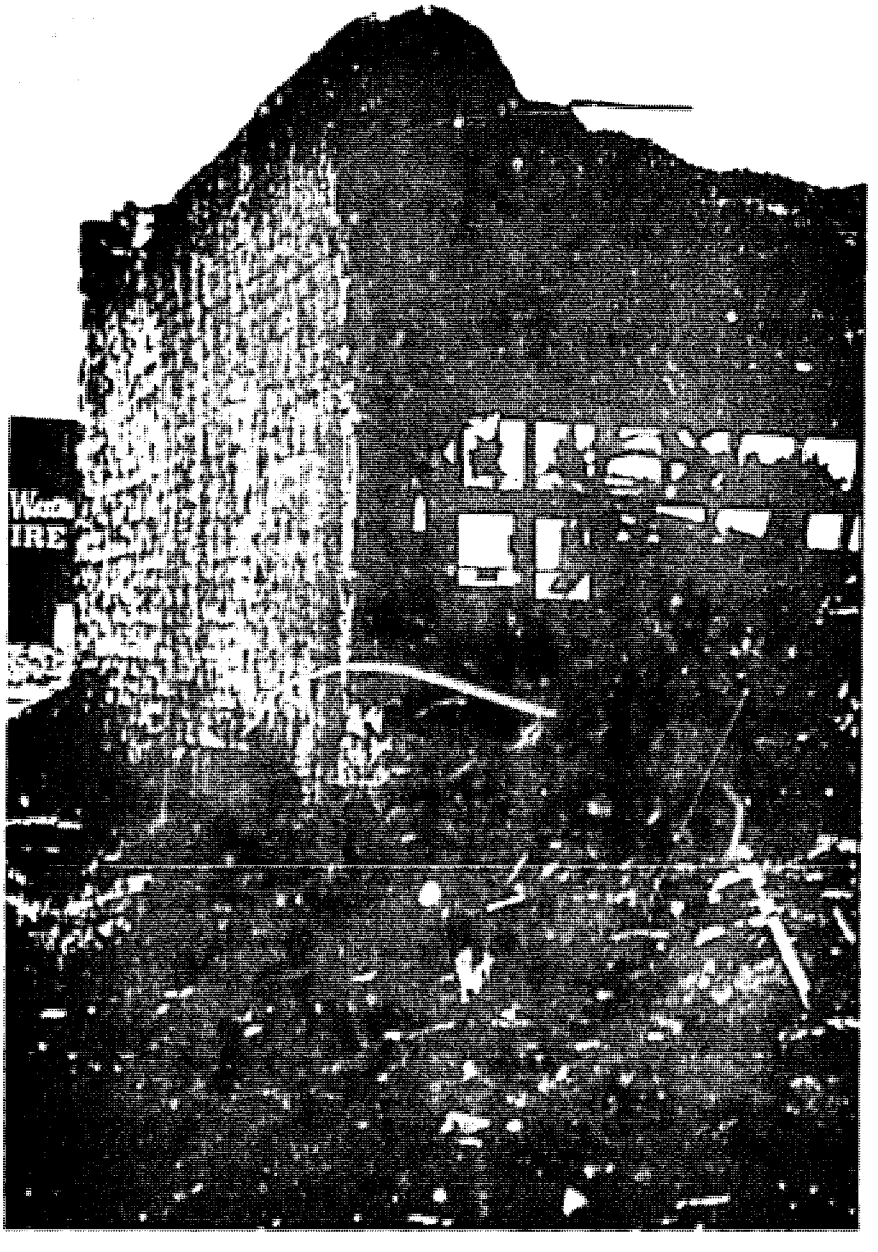
On Monday morning, the 27th, The Arizona Daily Star published the news of major damage to the town and especially the adobe structures. "Anything with adobe in it is in trouble, and any buildings that are damaged are being condemned" according to Ron Rogriguez, Mayor of Westmorland.

Bill White and I, curious about the effects of earthquake on adobe, left Tucson at 10:00 a.m. Monday and drove to Westmorland with the intention of recording and perhaps analyzing the effect of the quake.

Upon arriving at approximately 4:00 p.m. we noticed two severly damaged structures along the main street. One structure was of frame construction (FIG.1) and the other was an abandoned adobe (FIG.2).

FIG. 1

FIG. 2



Conversations with neighbors and later the police department told us the adobe structure had been abandoned for several years and was in structurally poor condition before the quake.

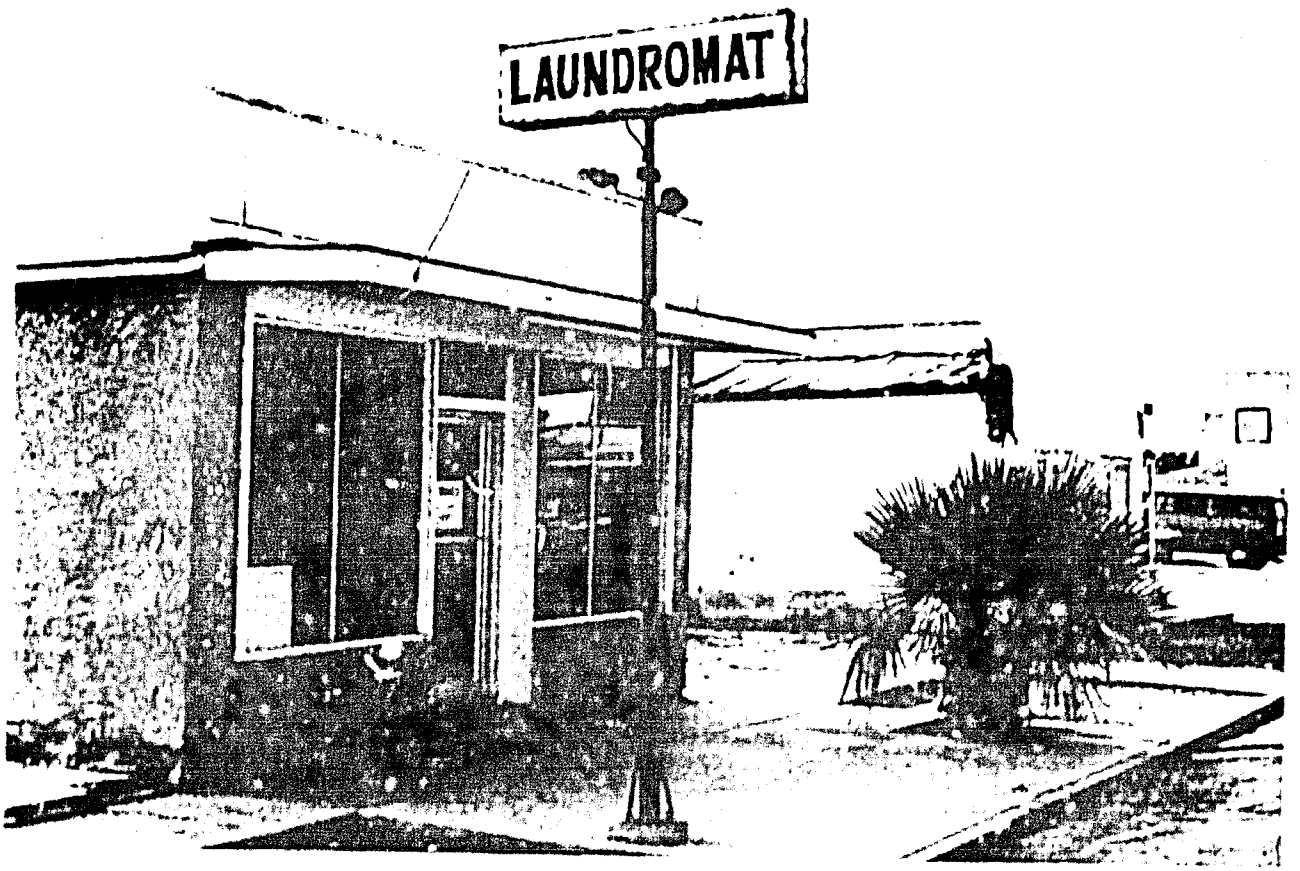
Detailed photographs (FIG. 3) show the wall/roof connection, no bond beam or anchors were used and all materials showed signs of rot and deterioration. The wall immediately south of the wall failure was severly under cut from rising damp. There was no indication of a foundation.

FIG. 3

The wall that failed was only cantilever supported at the ends by poorly constructed frame walls, the roof was not constructed as a diaphram.

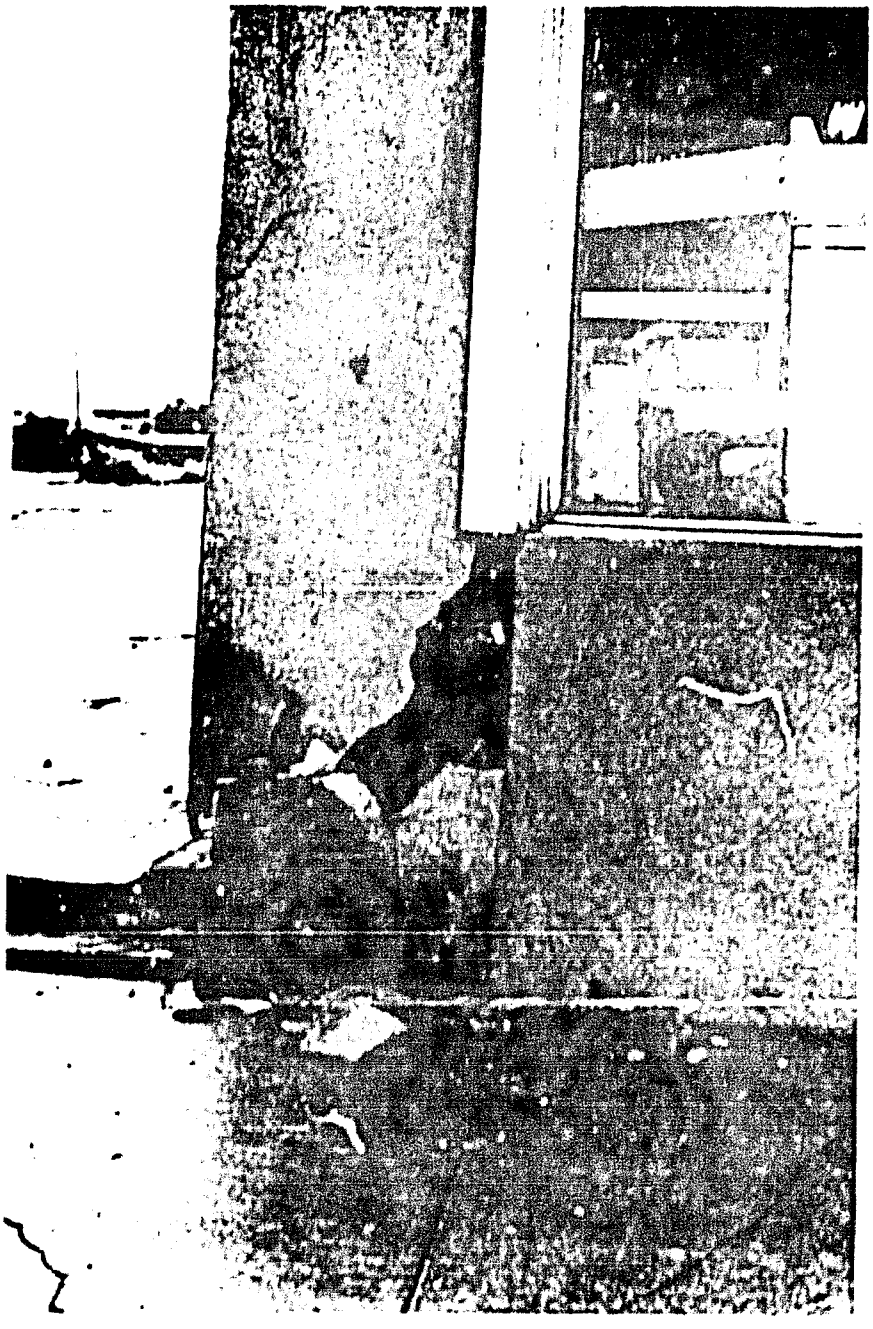
Several other structures, both conventional construction and adobe, were damaged in the quake.

FIG. 4



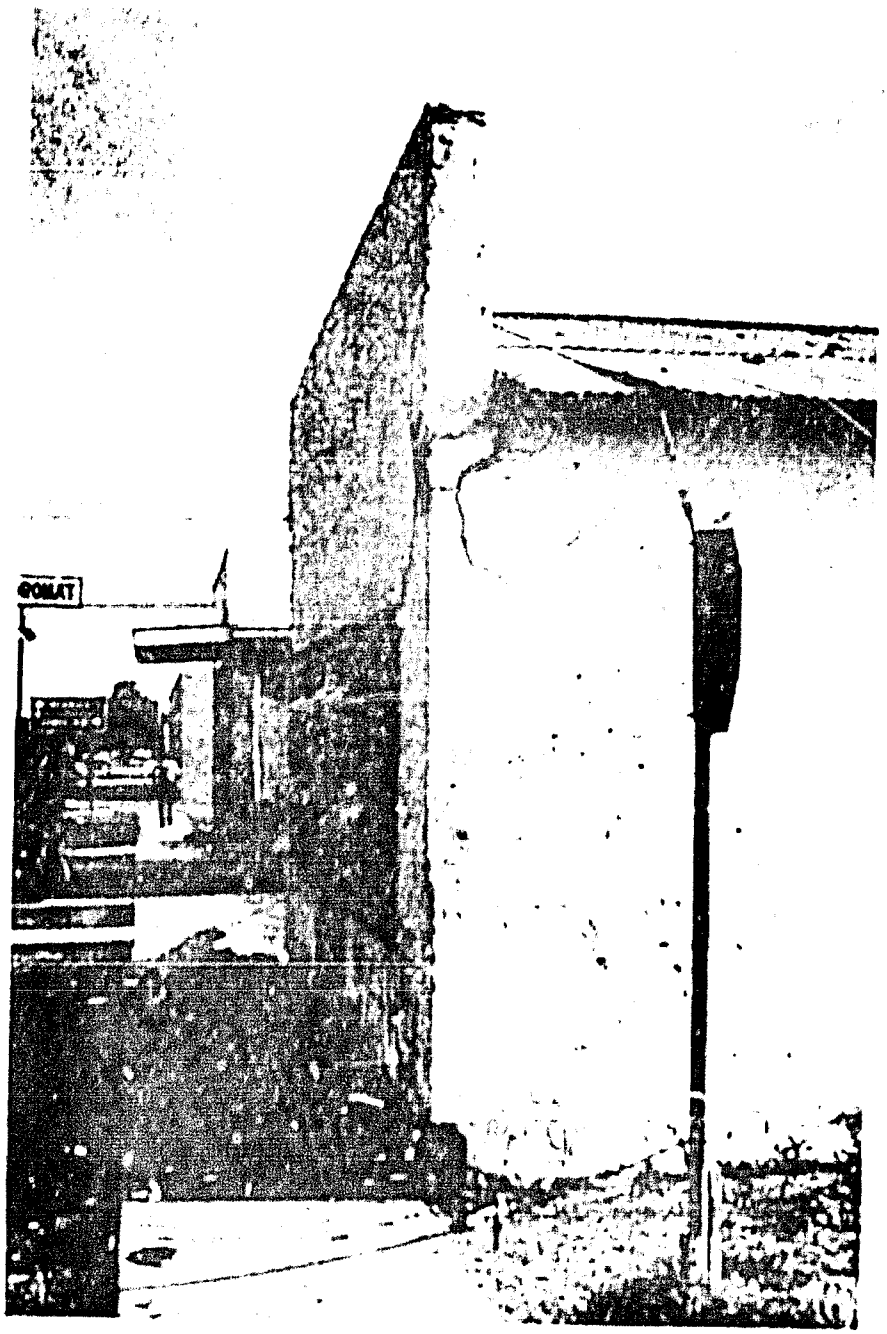
Two adobe structures, the Laundromat and an adjacent Warehouse, were moderately damaged (FIG.4). Damage was confined to the front of both of these structures, to wall sections poorly braced adjacent to storefront openings of large dimension.

FIG. 5



The Laundromat damage (FIG.5) was confined to the lateral movement of an unbraced wall adjacent and untied to the front wall.

FIG. 6



Damage to the parapet wall above the storefront opening of the warehouse (FIG.6) appears to have been concentrated in the small cross sectional area at the connection of the front and side wall. No bond beam was evident on this structure.

FIG. 7

Extensive damage to the Third Street residence (FIG.7) was concentrated at the ground level (FIG.8). Carefull examination revealed extremely wet adobe within the wall at the point of failure.

FIG. 8

This residence, without foundation, showed signs of poor drainage and extensive irrigation.

Failure occurred due to the thorough softening of the adobe at the ground line. Minor cracks occurred in other parts of the structure when its base failed, but the upper structure remained intact when collapse occurred.

This structure has been retrofitted with wood bond beams and tension cables after the 1940 Imperial Valley Quake according to its former owner. An identical structure adjacent to it failed completely and was removed after that quake.

An example of properly designed and maintained adobe structure capable of withstanding severe seismic movement is the Westmorland Town Hall (FIG.9, 10, 11). This structure built by the W. P. A. is constructed of unstabalized adobe with approximately two foot thick walls. A bond beam at the lintels and roof, high foundation wall and carefull construction methods have produced a structure that has had no signs of structural failure since it was constructed in the mid 1930's.

FIG. 9

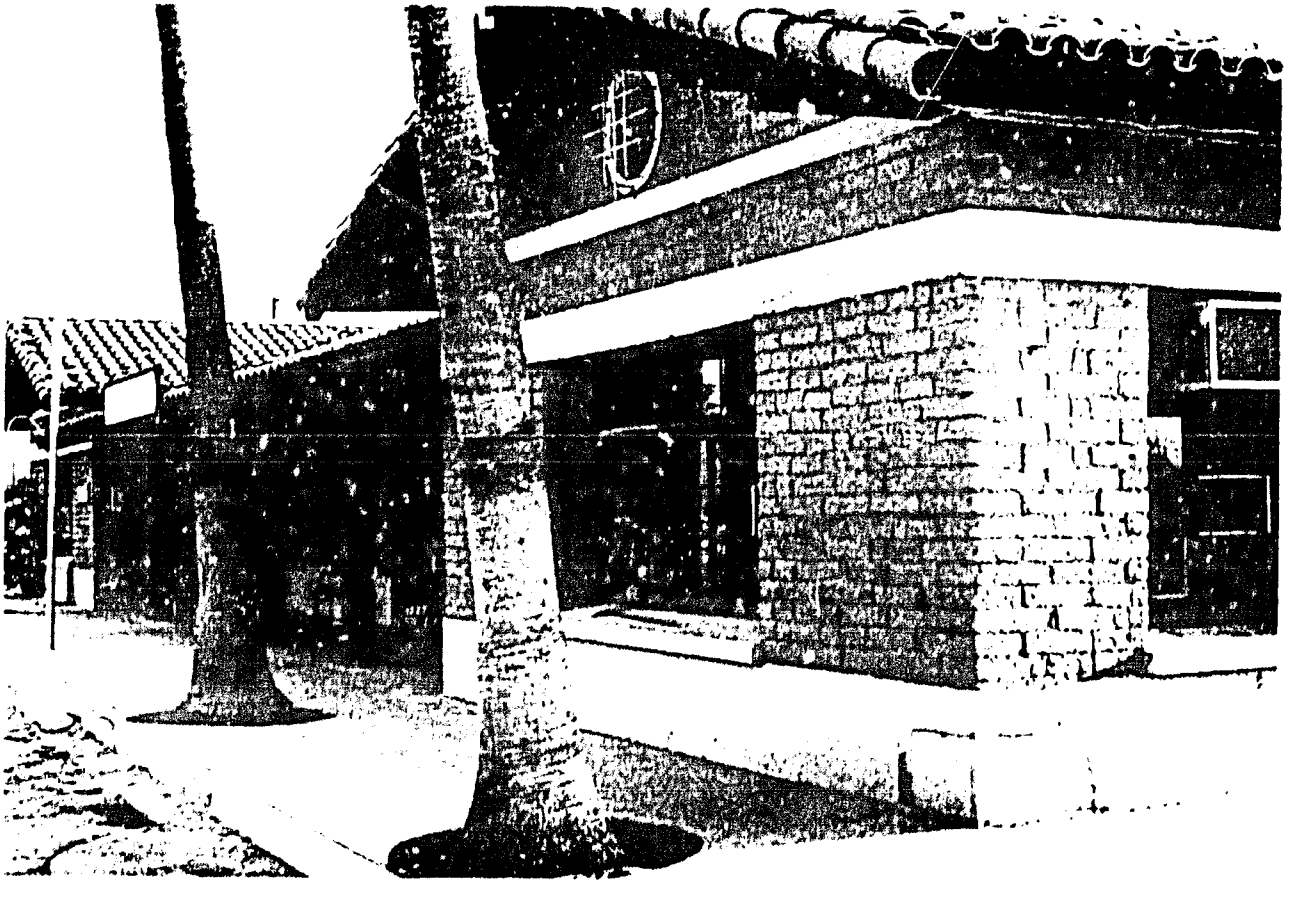


FIG. 10

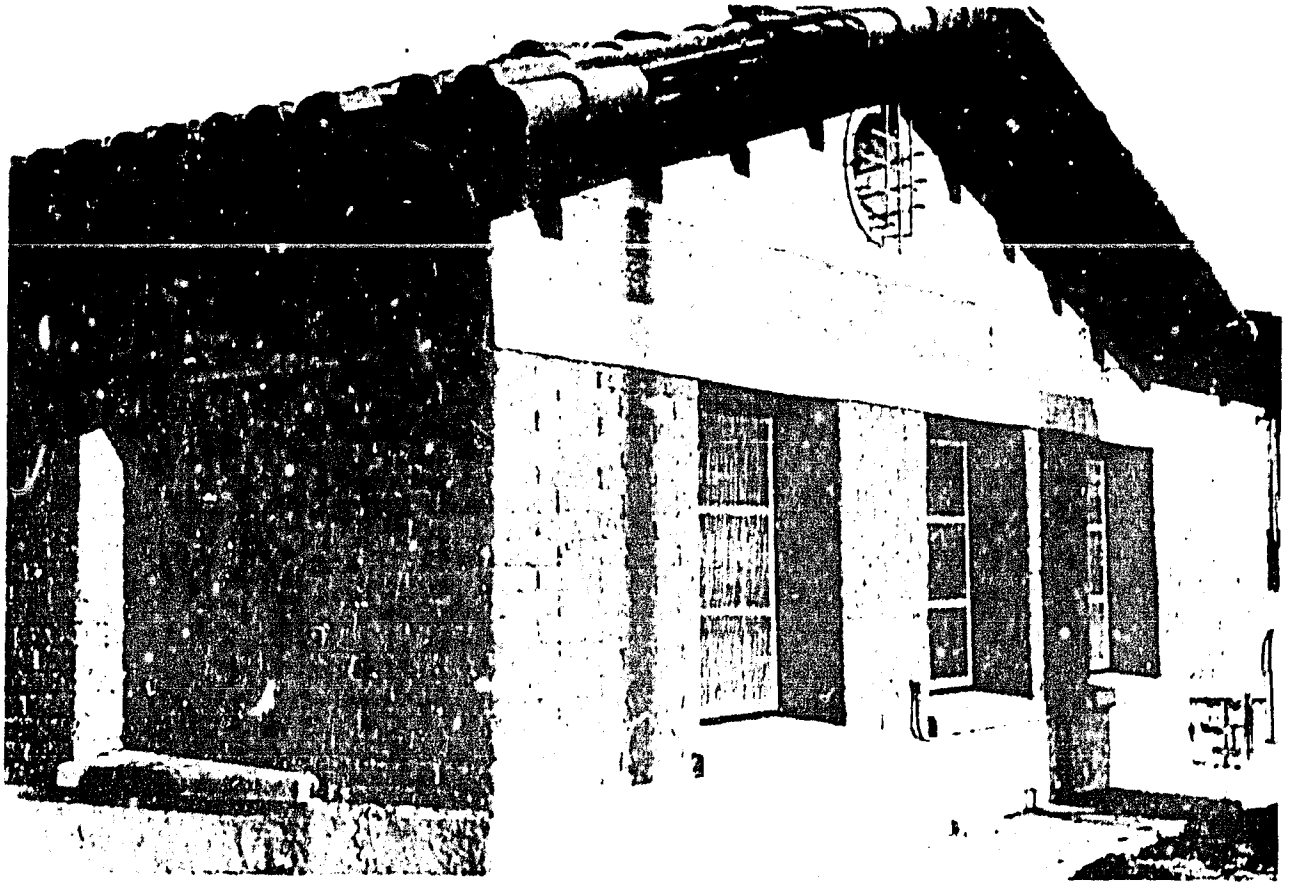
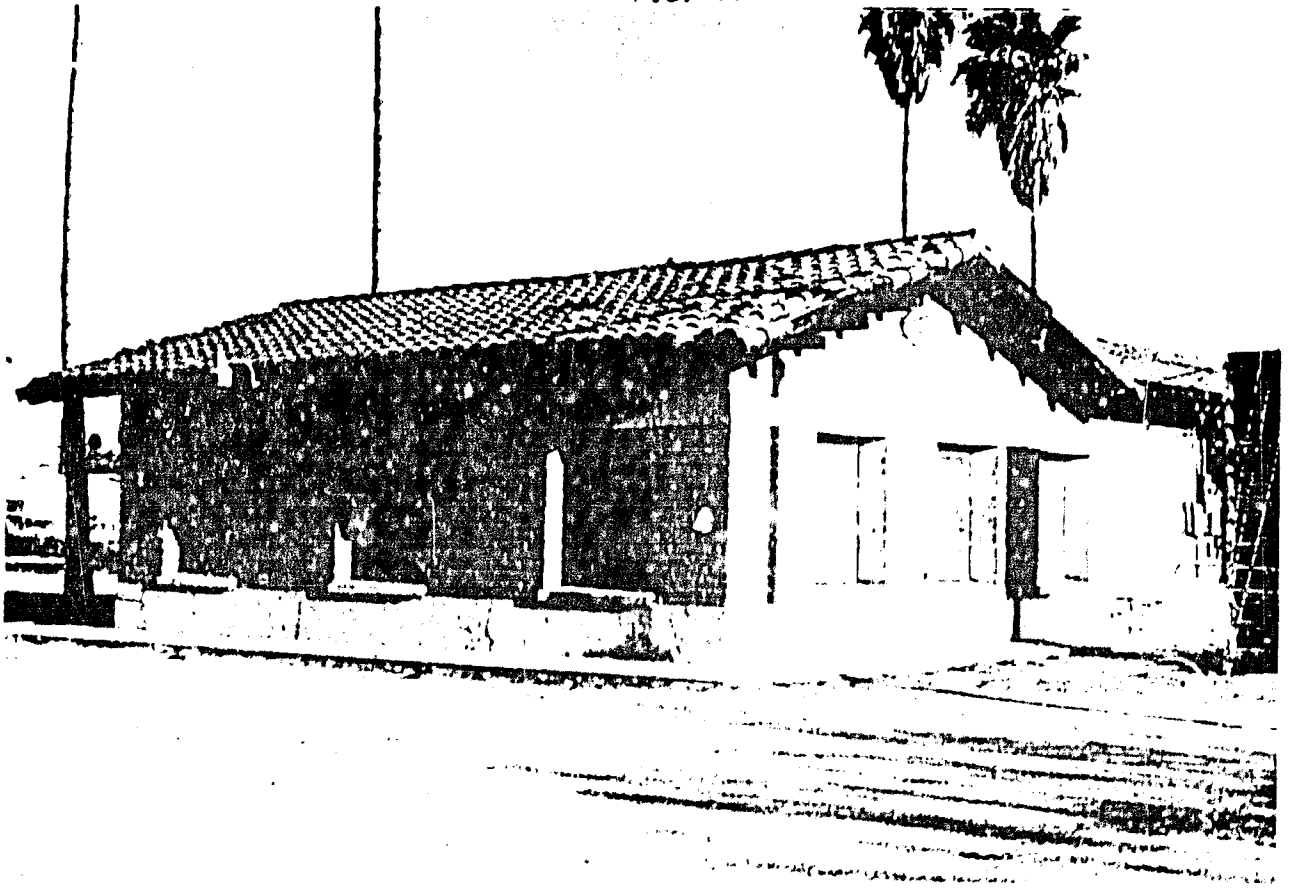


FIG. 11



During our tour of the town we saw several other adobe structures that were undamaged, clearly not all adobe structures were in trouble as stated by the Mayor.

Conclusions

Well built and maintained structures can survive seismic activity whether they arc built of adobe or conventional materials.

Structures poorly constructed of any material may fail during earthquakes.

Poorly maintained structures are destined to failure.

RECOMENDACIONES PARA LAS CONSTRUCCIONES DE ADOBE EN REGIONES SISMICAS

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ABSTRACT

The extended use of adobe in Chilean rural house building is primarily a consecuence of its low cost. The availability of the components of adobe and the weight of four centuries of continued use also contribute, to keep this type of construction as a part of life in Chilean countryside.

Though the use of adobe in highly seismic areas should not be particularly encuraged, guidelines for safety improvements in this type of buildings, within reasonable costs, can be made, for use where other alternatives are not viable.

RESUMEN

El adobe como material para edificar viviendas rurales se basa en poderosas razones de carácter económico; en las facilidades para la obtención de la materia prima y en la persistencia de una tradición de siglos en su empleo, ya que este tipo de construcción está incorporado a la vida y al ambiente campesino de Chile.

Si bien no es recomendable para un uso indiscriminado en regiones sísmicas, es posible dar Recomendaciones que lo hagan razonablemente seguro dentro de la economía que le es propia.

RECOMENDACIONES PARA LAS CONSTRUCCIONES DE ADOBE EN REGIONES SISMICAS

Presentación del Trabajo

El adobe es un material de construcción cuyo uso está aún vigente en la zona central de Chile, para dar solución a la vivienda económica rural.

Desde el Terremoto de 1939 que afectó a la zona sur-central de Chile, en que el 80% de la construcción afectada era de adobe, existe la preocupación del autor, respecto del comportamiento sísmico de las construcciones hechas con este material.

El hecho de vivir en aquella época, en la zona afectada, y haber sufrido muy de cerca los efectos del terremoto, fué estímulo suficiente para investigar en el terreno mismo y durante la reconstrucción, los vicios y los aciertos constructivos con este material.

La observación de las construcciones dañadas y aquellas que respondieron eficazmente al sismo, permitió en primera instancia detectar un conjunto de prácticas inadecuadas que era preciso modificar buscando otras disposiciones constructivas que, a la luz de la razón parecieran, más aconsejables.

Reconstrucciones ejecutadas utilizando estas nuevas disposiciones constructivas y bajo la vigilancia profesional (aquí destaco el entusiasmo del Arquitecto don Carlos de la Masa por esta investigación), han permitido comprobar durante la ocurrencia de posteriores terremotos en la misma zona, las ventajas de las modificaciones constructivas y de diseño, introducidas.

Esta misma metodología se ha seguido empleando a través de los 40 años transcurridos y sus resultados han permitido establecer todo un cuerpo de recomendaciones constructivas y de diseño que permitan conseguir una seguridad razonable en las construcciones de adobe.

El Material.

Este material, dadas sus características de durabilidad, requiere ante nada de una confección prolija y de una protección posterior bastante exigente. Los agentes atmosféricos: Viento, lluvia, etc., lo afectan con mucha facilidad.

Se requiere una buena selección de la materia prima y una buena mano de obra a fin de mejorar su durabilidad.

El proyecto por su parte debe asegurar una buena protección frente a la acción externa, lo que involucra un buen estudio del emplazamiento de la construcción y una buena aislación frente a los agentes agresivos.

El hecho de que este material, según sea la calidad de su confección resulte más o menos sensible frente a la acción del agua obliga a estudiar emplazamientos, y disposiciones de diseño que eviten la acción de la humedad proveniente del terreno de fundación y la acción del agua de lluvias, ya sea directa o escurrida superficialmente sobre el terreno circundante.

Es preciso evitar la degradación que puede sufrir el material, bajo la acción externa.

Se ha podido observar que, en muchos casos, la falla producida se debió a la presencia de material debilitado por efecto de la lluvia, en las zonas más críticas de los muros soportantes.

El Diseño Estructural.

La estabilidad de las construcciones de adobe se basa muy principalmente en la acción de contrafuertes que ejercen los muros, unos sobre otros, en direcciones perpendiculares entre si. La perpendicularidad de los muros entre si, constituye una recomendación que es conveniente respetar siempre.

Para que esta acción estabilizadora de los contrafuertes se ejerza eficazmente es preciso que se cumplan una serie de condiciones. La práctica, a través de la observación del comportamiento de las construcciones de adobe en sismos reales, permite establecer las condiciones más importantes que es preciso respetar.

- La distancia entre contrafuertes o muros transversales, no debe ser grande. En la construcción de la vivienda económica esto se cumple fácilmente ya que las particiones interiores de una vivienda no van a distancias mayores de 3 ó 3.5 m.

- El espesor de los muros debe ir de acuerdo con la distancia entre muros transversales. Observaciones realizadas en Chile permiten recomendar $L/e < 10$.
  L = distancia entre Contrafuertes
  e = espesor del muro de adobe.

- Para que el contrafuerte cumpla su objetivo es preciso que posea una longitud adecuada. Esto obliga, en el diseño de una vivienda, a fijar un mínimo para la distancia entre el cruce de muros y el vano de una puerta o ventana. La experiencia chilena permite fijar en 1.20 m esta distancia mínima.

- La indeformabilidad del cruce entre muros, tiene gran importancia en el comportamiento sísmico de éstos.

  Las dimensiones de los adobes y sus proporciones tienen un interés vital en este aspecto. Una buena unión en el cruce se consigue con adobes colocados de soga, en forma de que la superficie de traslapo, en el cruce, corresponda a medio adobe (es el máximo), que, a su vez corresponde al espesor del muro.

  Esta condición conduce a adobes cuya longitud es del orden del doble de su ancho.
  Por otro lado el espesor del elemento debe ser pequeño con el mismo objeto: Mayor rigidez de la unión. Espesores del orden de 10 cm han dado buenos resultados.

  Por el contrario adobes muy gruesos o de longitud muy inferior al doble del ancho, han llevado a soluciones que han tenido un pésimo comportamiento en sismos reales, debido a la falta de rigidez de la unión.

- La indeformabilidad en el cruce de muros debe mantenerse a lo largo de la altura de los muros.

  El peso propio de los muros y un buen traslapo de los adobes en el cruce, en la forma descrita en el punto anterior, asegura un buen comportamiento

de la unión en su parte inferior. En cambio, la parte superior, sin el peso de los muros que se cruzan, hacen que la unión no quede igualmente indeformable.

En esta zona es preciso recurrir a la acción de una cadena superior, que sea lo suficientemente indeformable en el plano horizontal para que contribuya a la indeformabilidad a la unión entre muros.

La experiencia chilena aconseja utilizar una cadena superior constituída por elementos de madera, paralelos, a una distancia igual al espesor del muro, trabados entre si, formando una celosía. Esta disposición permite dar al conjunto la suficiente rigidez horizontal, que contribuya a la indeformabilidad superior de la unión entre muros.

Resulta aconsejable dar peso a la cadena de madera. Además del peso de la techumbre se ha utilizado la colocación de unas dos o tres hiladas de adobe sobre la cadena. Esta práctica, sin embargo ha mostrado muy mal resultado de acuerdo a nuestras observaciones.

En cambio, el peso sobre la cadena, obtenido, mediante amarras de alambre grueso galvanizado, próximas a las esquinas, que incorpore el peso de dos o tres hiladas por debajo de la cadena, ha tenido un comportamiento bastante satisfactorio.

Una experiencia realizada con cadena de hormigón armado tuvo mal resultado, por daños producidos en la interfase, bajo la acción de pequeños temblores.

También debe ser condición del diseño estructural, el conseguir reducir la acción del sismo.

En este sentido, la limitación de la altura de la vivienda, el uso de una techumbre liviana y evitar la colocación de todo elemento pesado no necesario, constituyen recomendaciones que es conveniente respetar.

Construcción.

Ninguna de las disposiciones recomendadas para el proyecto resultará eficaz si no va acompañada de una ejecución prolija, tanto en la confección del adobe, como en la construcción misma.

La ejecución en período de buen tiempo (días de sol, poca humedad ambiente) y la protección del material acumulado en obra, o de la obra misma, frente a lluvias imprevistas, son precauciones que es preciso tener en cuenta al organizar la faena.

La colocación de tacos o soquetes de madera para anclar los marcos de puertas y ventanas, a medida que se levantan los muros, y no su colocación posterior a la ejecución de éstos, es un detalle constructivo que no se debe descuidar. El debilitamiento del muro que representa la introducción a posteriori de estos tacos, es causa de fisuras y aflojamiento de los marcos, precisamente en las zonas más críticas de la construcción.

En general toda perforación posterior a la ejecución de los muros son causa de debilitamiento que es preciso evitar en lo posible. Las tuberías y canalizaciones embutidas no corresponden a una construcción de adobe. Siempre será posible encontrar una solución para que, dejando estos elementos a la vista, ellos no atenten a la estética de la construcción.

Finalmente, un buen drenaje del terreno circundante de la vivienda, constituye un detalle constructivo que no hay que olvidar.

Modificaciones y Reparaciones.

En general la construcción de adobe una vez terminada, no acepta modificaciones.

Traslados de puertas o ventanas, eliminación o desplazamientos de muros, deben ser evitados, o más bien, prohibidos.

Sin embargo es posible proceder a ejecutar algunas reparaciones cuando se han producido desordenes estructurales: Fisuras o agrietamientos junto a los vanos o en los encuentros de muros.

Evitando todo cambio en la concepción estructural de la construcción, se han practicado algunas reparaciones, en Chile, con bastante éxito.

Las reparaciones incluídas en el documento, "Recomendaciones para las Construcciones de Adobe en Regiones Sísmicas", corresponde a aquellas que se han practicado en Chile y cuya eficacia se ha probado en sismos posteriores de igual o mayor intensidad que aquellos que provocaron la falla.

I INTRODUCCION

LA UNIVERSIDAD CATÓLICA DE CHILE, entrega una serie de recomendaciones sobre construcción y reparación de casas de adobe. El propósito está dirigido, fundamentalmente, a prestar colaboración para solucionar el problema de la vivienda en los sectores rurales y suburbanos, donde se hace difícil llevar orientación tecnológica y personal directivo para este tipo de trabajo.

El hecho de referirse al adobe como elemento para edificar viviendas económicas se basa en poderosas razones de carácter económico, en la más fácil obtención del material y en la persistencia de una tradición de siglos en su empleo, ya que este tipo de construcción está incorporado a la vida y al ambiente campesino de Chile y Latinoamérica. El reemplazo del adobe por otras formas tecnológicas de mayor eficiencia y duración, necesita de un proceso evolutivo gradual.

Así, se ha preferido enfrentar una realidad y partir de ella para lograr, con el tiempo la introducción de modalidades más avanzadas

Lo anterior no significa que el adobe constituya un material óptimo en un país de elevada frecuencia e intensidad sísmica, pero las experiencias aportadas en ocasión del sismo de julio de 1971, segundo en menos de diez años, confirman que es posible levantar viviendas aceptables, siempre que se ciñan a normas como las que aquí se presentan.

Estas recomendaciones fueron preparadas por primera vez por la Escuela de Ingeniería Civil de la Universidad Católica, como parte de un documento sobre Asismicidad en viviendas económicas (1), que le encomendó OEA en 1959. Posteriormente, con motivo del sismo de 1965 en las provincias centrales de Chile, las recomendaciones se sistematizaron en un folleto (2) que se distribuyó ampliamente en la zona afectada. En 1970, con motivo del terremoto que asoló Perú, un grupo de Profesores de la Escuela preparó un informe (3),

uno de cuyos capítulos incluía recomendaciones sobre la vivienda de adobe. En este informe y en la experiencia peruana se basó el Manual (4) que fue preparado por el Proyecto Experimental de Viviendas (PREVI) y fue editado por la Oficina Nacional de Desarrollo Comunal de Perú. De este manual se ha tomado la base de este folleto. Con posterioridad, el Instituto de Investigación y Acción para la Vivienda del Perú, preparó otro manual denominado, Construyendo con Adobe (5). Con todo este conjunto de información hemos puesto al día esta versión que entregamos a la OEA en el año 1978.

El empleo del adobe como material de construcción es una realidad en América Latina y otras partes del mundo. Si bien no es recomendable para el uso indiscriminado en regiones sísmicas, es posible dar indicaciones que lo hagan razonablemente seguro, dentro de la economía que le es propia.

Esperamos que por medio de esta labor de divulgación se pueda promover un mejoramiento de las condiciones de vida, en especial en cuanto a seguridad sísmica, de los habitantes de zonas rurales y pequeñas comunidades, en las que el adobe es el material más económico y adecuado a sus condiciones de vida. Si esto se logra en alguna medida, se habrá conseguido el objetivo de este esfuerzo.

II EL ADOBE

dimensiones

Es recomendable que las dimensiones de los adobes cumplan con las siguientes condiciones

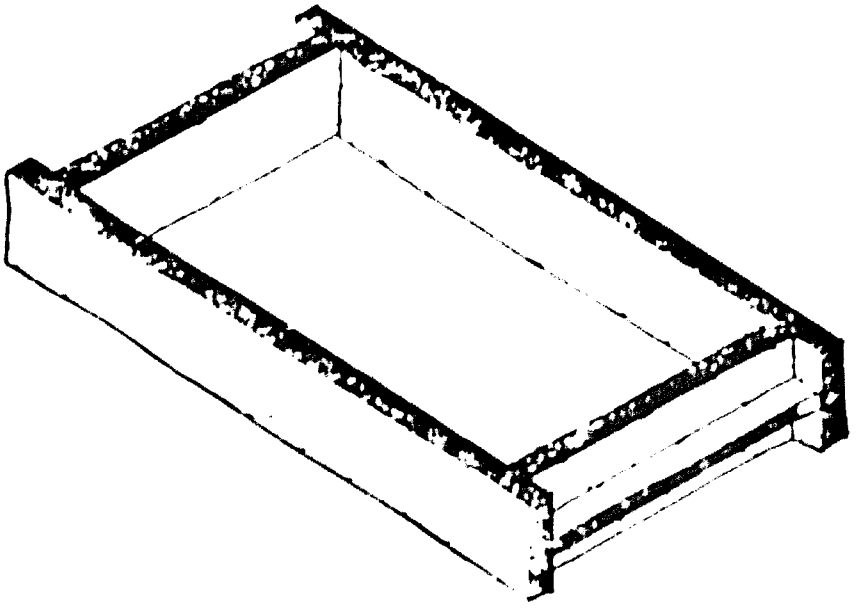
- La longitud del adobe debe ser igual al doble del espesor del muro considerando el espesor de la pega
- La altura del adobe debe ser menor que diez centímetros

De este modo, las dimensiones más usuales son

58 x 30 x 8 (a)
78 x 40 x 8 (b)

fabricación

1. MOLDE



2. SELECCIÓN DE LA TIERRA

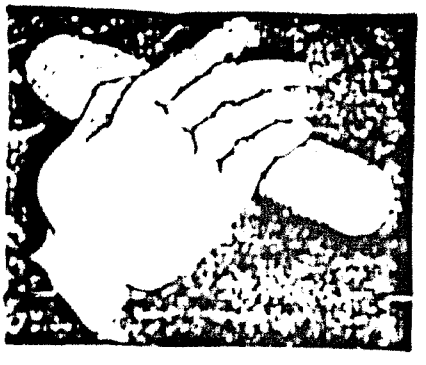
La tierra para hacer adobes debe ser limpia y formada por arcilla y arena. No debe contener piedras ni restos vegetales.

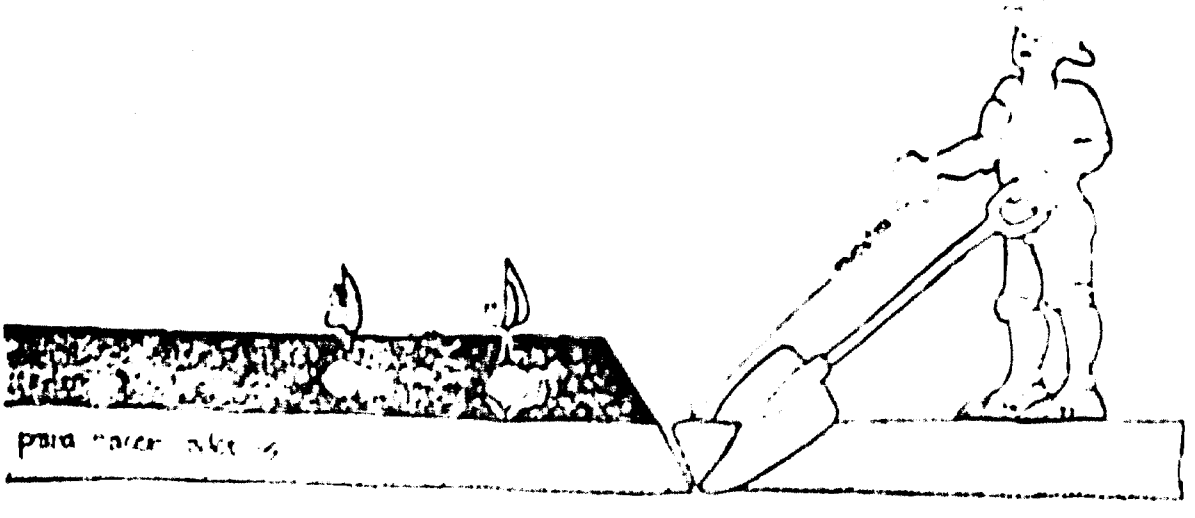
La tierra vegetal o de cultivo no es buena para hacer adobes.

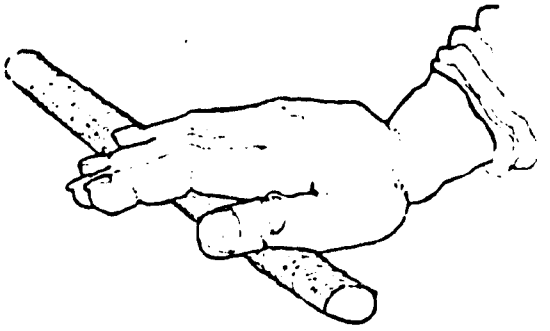
PRUEBA PARA SABER SI LA TIERRA ES BUENA PARA HACER ADOBES.

(A) TOMAR UNA MUESTRA DE TIERRA COMPUESTA POR ARCILLA Y ARENA

(B) HACER UN ROLLO DE BARRO CON POCA AGUA (NO DEBE PEGARSE A LAS MANOS)

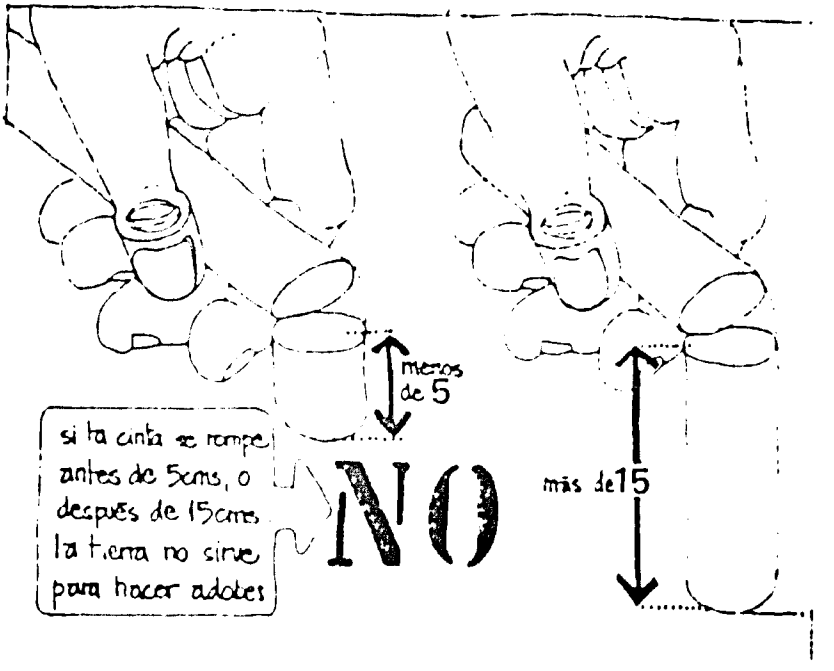


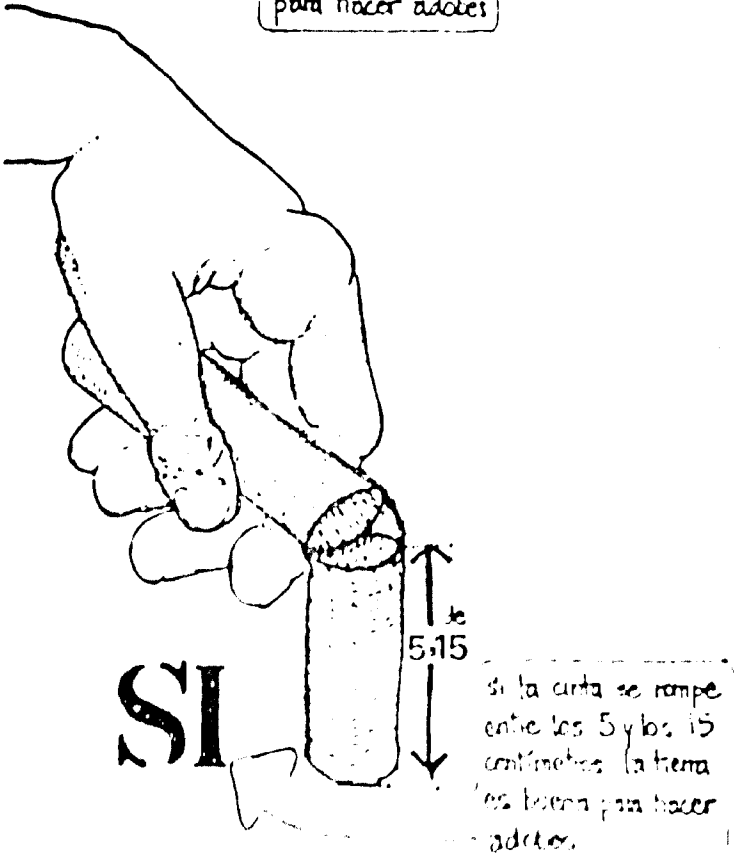




Ⓒ CON MUCHO CUIDADO, PRESIONANDO CON LOS DEDOS, HACER UNA CINTA DELGADA, LO MAS LARGA QUE SE PUEDA.

Ⓓ OBSERVAR QUÉ LARGO, SIN APOYO, PUEDE ALCANZAR LA CINTA SIN ROMPERSE:





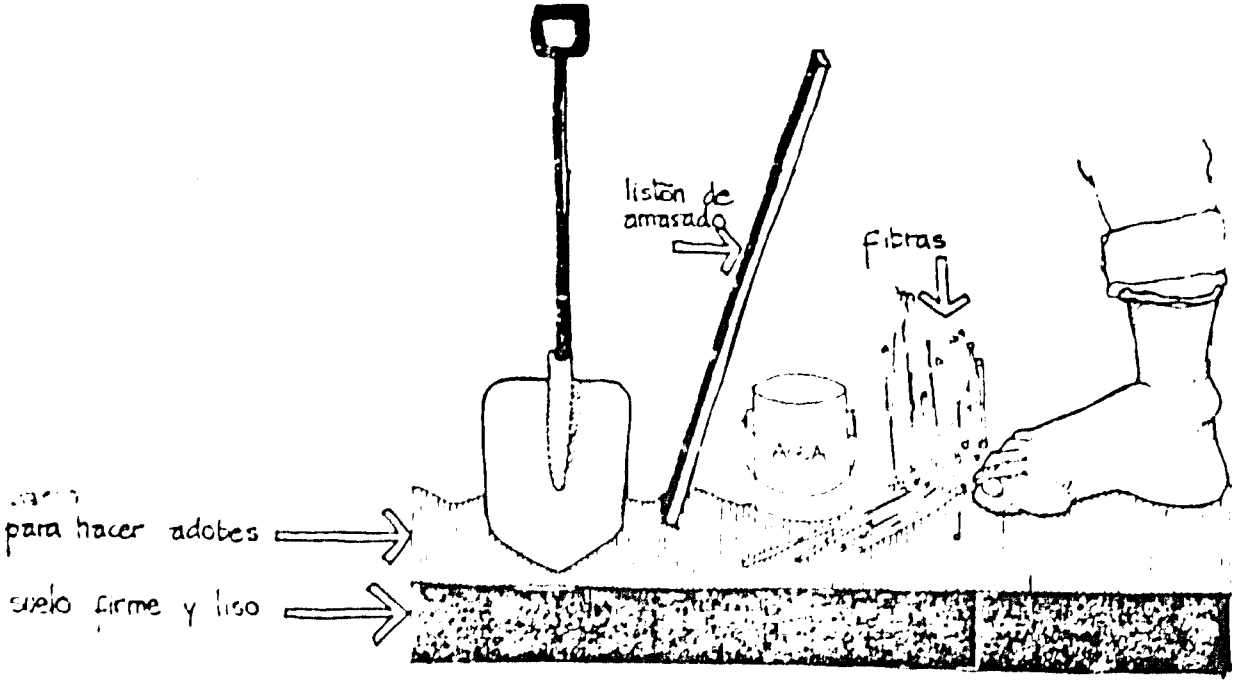
3. PREPARACIÓN DEL BARRO

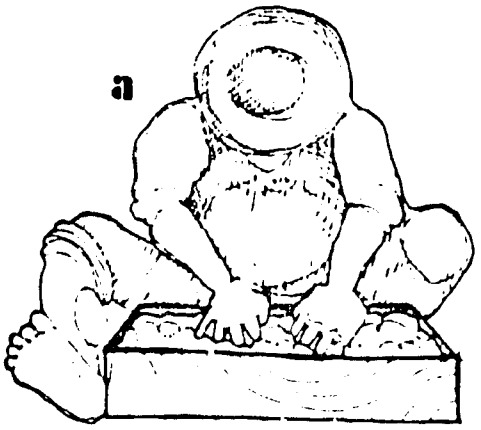
Sobre un suelo liso y firme, triturar la tierra seleccionada, agregando agua hasta lograr un barro bien batido y macizo.

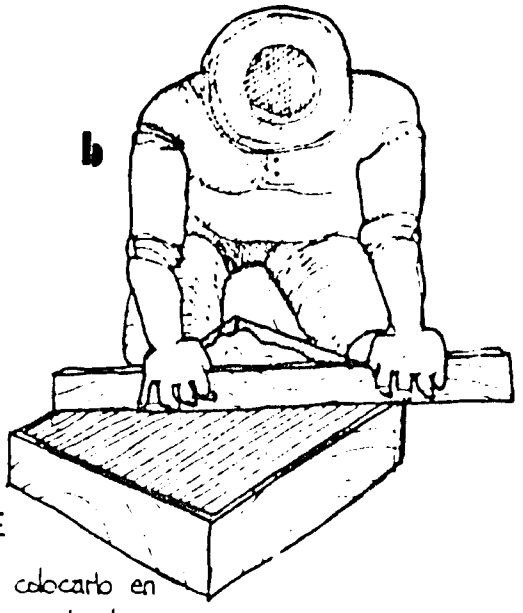
A este barro, agregar fibras tales como paja, crines, etc, en cantidad suficiente, como ser un puñado de adobe. El largo de la paja será de 10 a 15 cm.

El amasado del barro se puede hacer con pala, listón de amasar o con los pies.

Se debe dejar descansar el barro dos días para emplearlo en la faena de moldeo de los adobes.







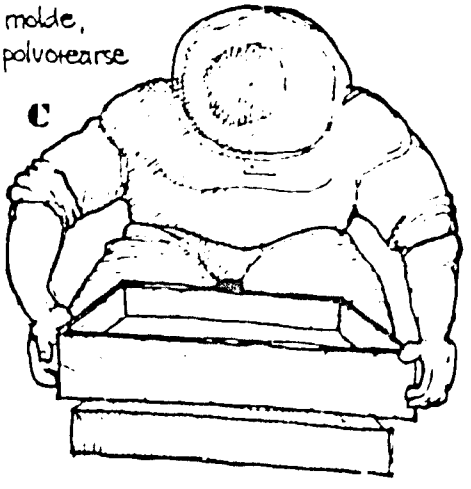
4. MOLDEO DEL ADOBE

a Batir nuevamente el barro y colocarlo en el molde, llenando bien las esquinas y compactando con las manos o con un pequeño pizón de madera.

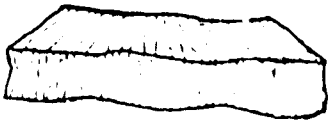
b Enrasar la superficie con una regla de madera, cuidando que no queden depresiones.

c Retirar el molde, lentamente y con cuidado.

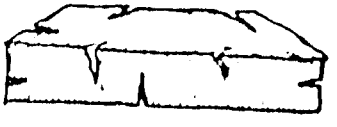
Para evitar que el adobe se pegue al molde, éste debe limpiarse con un trapo húmedo y espolvorearse con arena antes de cada uso.



si al retirar el molde, el adobe se deforma, es porque el barro tiene mucha agua



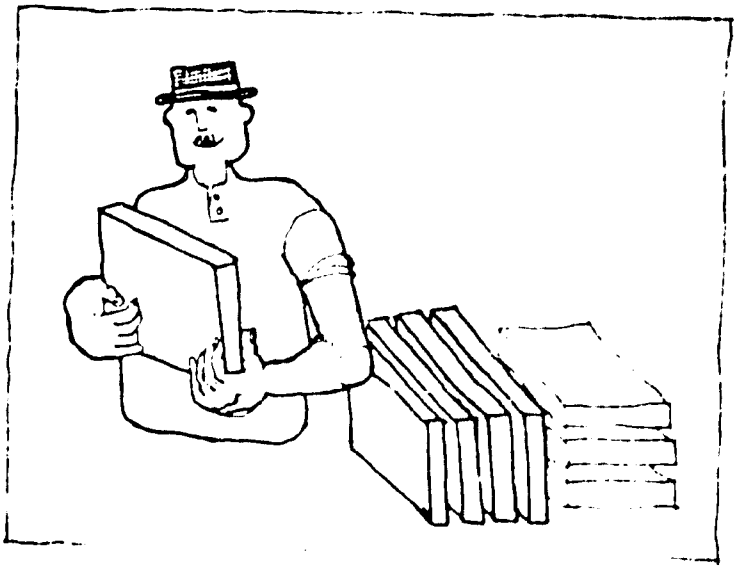
si el adobe se fisura es porque el barro está muy seco



5. SECADO Y ALMACENAMIENTO

• A LOS TRES DÍAS DESPUÉS DE DESMOLDAR, SE DEBERÁ PARAR LOS ADOBES PARA ACELERAR EL PROCESO DE SECADO.

• A LAS TRES SEMANAS SE PUEDEN CARGAR Y APILAR.

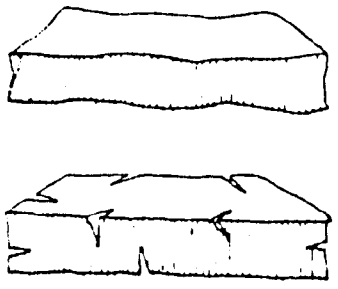


6. CONTROL DE CALIDAD

A las cuatro semanas, normalmente, el adobe estará seco. No deberá tener defectos aparentes.

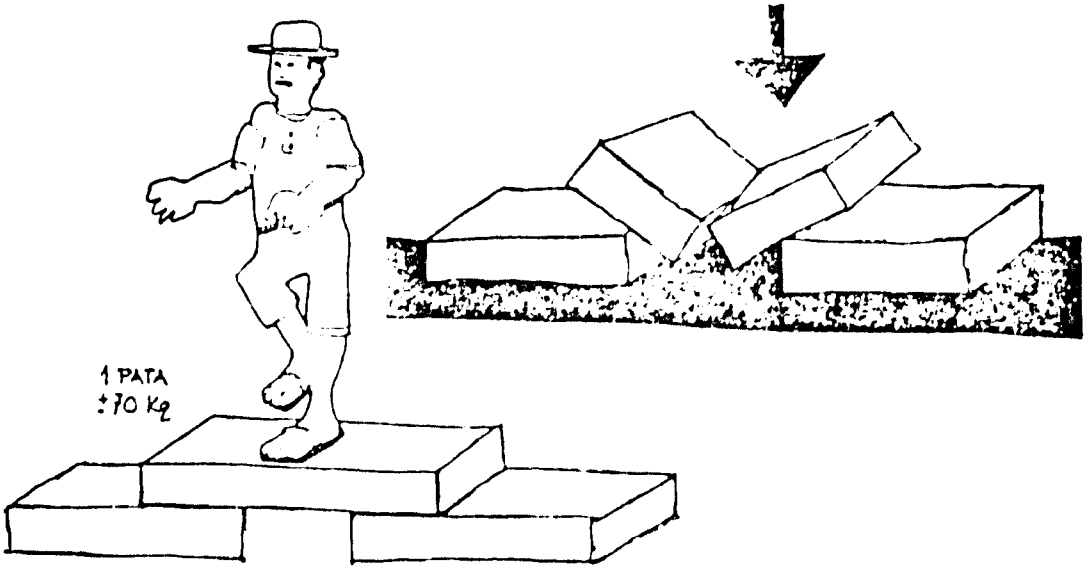
Se le someterá, entonces, a la prueba de resistencia.

Si a las cuatro semanas el adobe presenta grietas o deformaciones, significa que falta arena o paja al barro. En este caso, se le debe desechar.



NO

Si a las cuatro semanas el adobe no resiste el peso de un hombre (prueba a la flexión) significa que el barro contiene poca arcilla (greda). Se le deberá desechar.



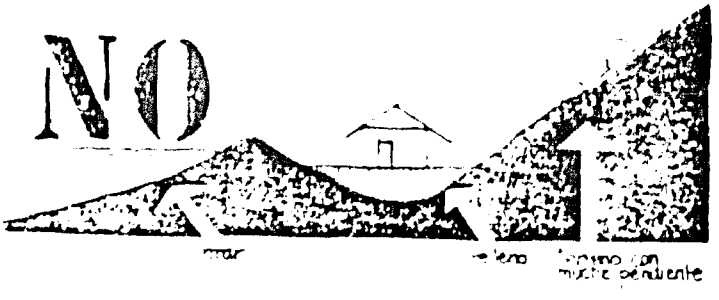
III LA CASA DE ADOBE

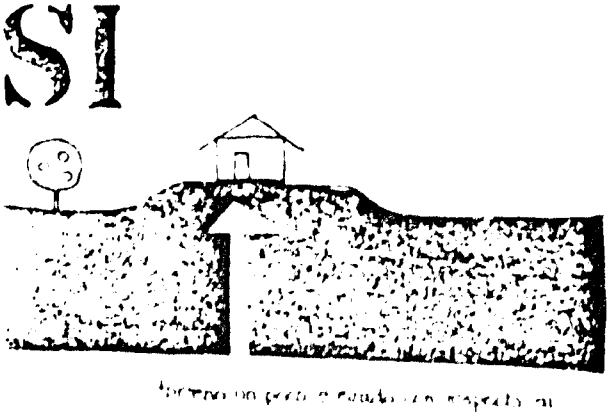
1 CONSTRUCCION

1 UBICACIÓN

Debe elegirse, para localizar la vivienda, un terreno seco, firme y plano, de preferencia ligeramente elevado con respecto al terreno adyacente y fuera del sitio de posibles aluvies e inundaciones.

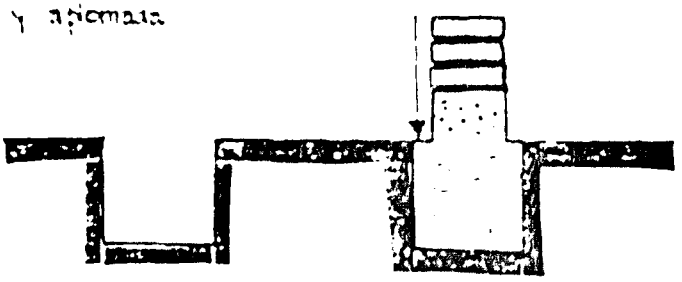
Debe evitarse la proximidad de pantanos, ríos o mar, las zonas de relleno o antiguos basurales, las zonas bajas y los terrenos con mucha pendiente.

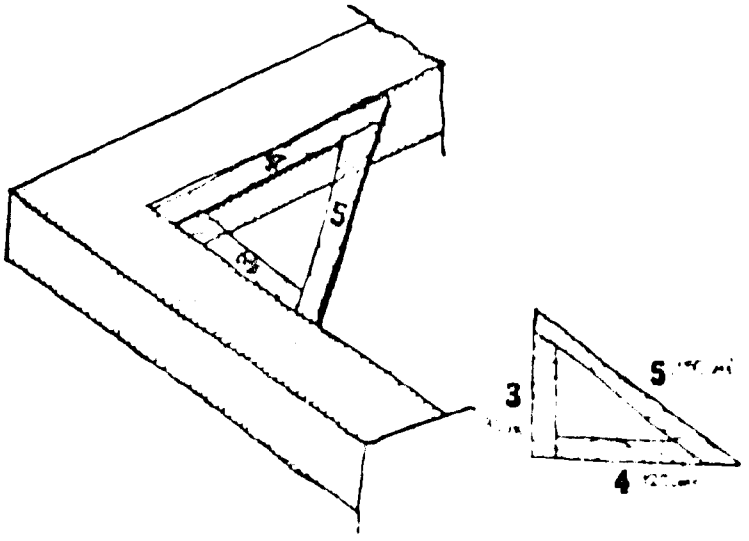




terreno un poco elevado con respecto al terreno adyacente

2. Las excavaciones tendrán fondo horizontal y la construcción se efectuará perfectamente nivelada y aplomada.





3. Los cimientos, sobrecimientos y muros deben quedar perfectamente a escuadra.

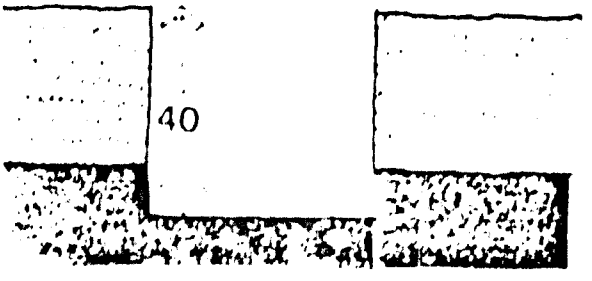
Una escuadra se hace con medidas de

80 120 150 centímetros

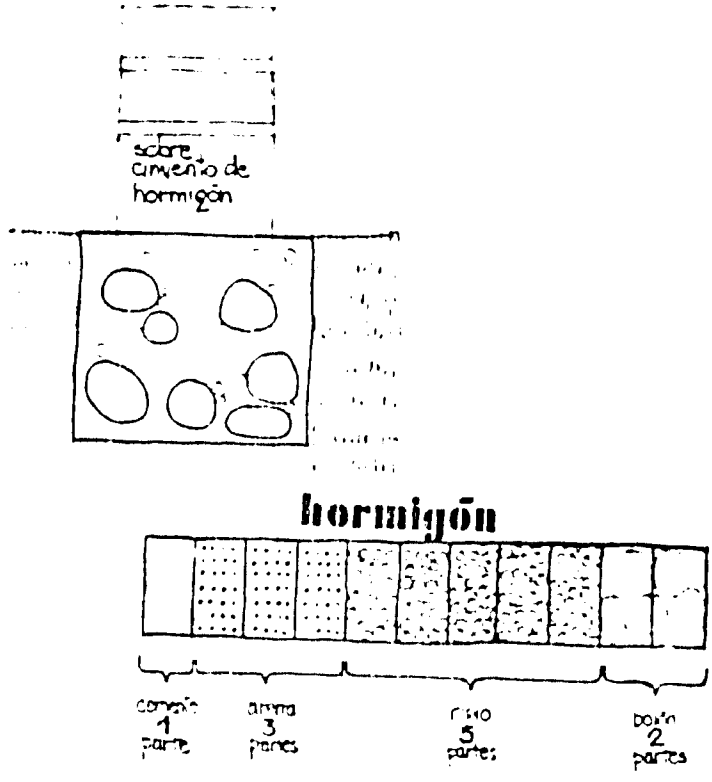
u otras en proporción **3 : 4 : 5**

4. El ancho de las excavaciones para cimientos debe ser mínimo una vez y media el espesor del muro.

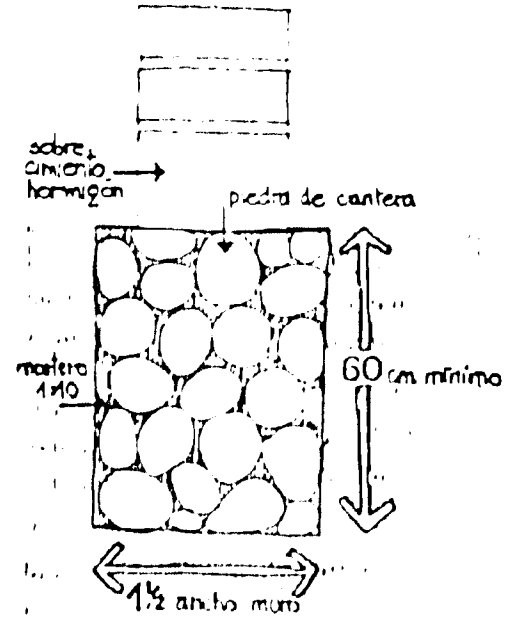
Se debe excavar mínimo cuarenta centímetros de profundidad penetrando diez cms en terreno ribloso o firme.



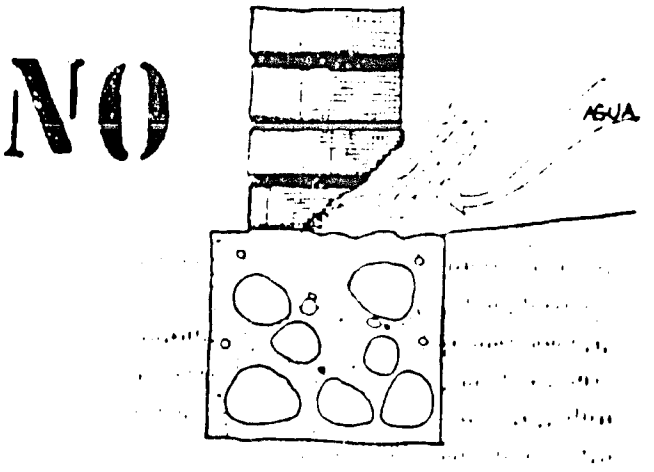
5. Los cimientos deben hacerse, de preferencia, de hormigón con 30% de bolón desplazador



6. Cuando se dispone de piedra de cantera puede hacerse un cimiento de albañilería de piedra

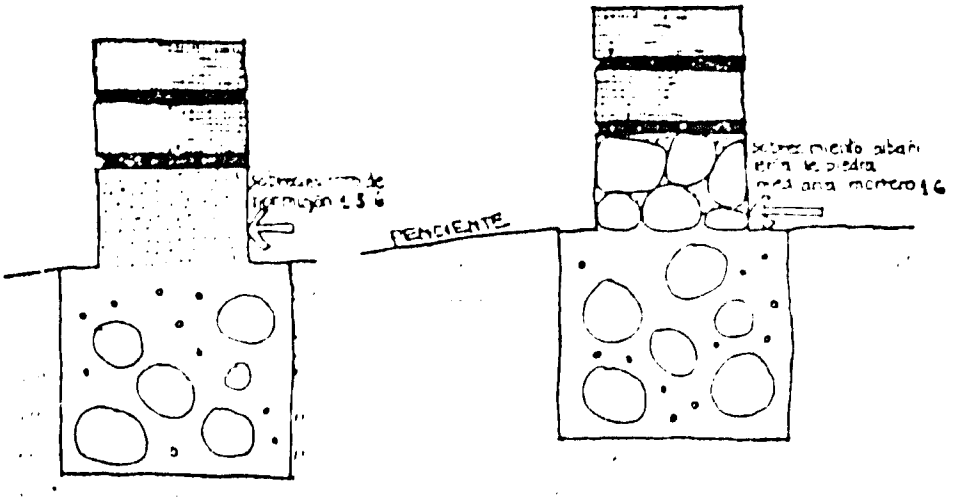


7. Hay que proteger de la erosión las primeras hiladas de adobe, lo cual se consigue:



ⓐ Haciendo un sobrecimiento de hormigón del ancho del muro

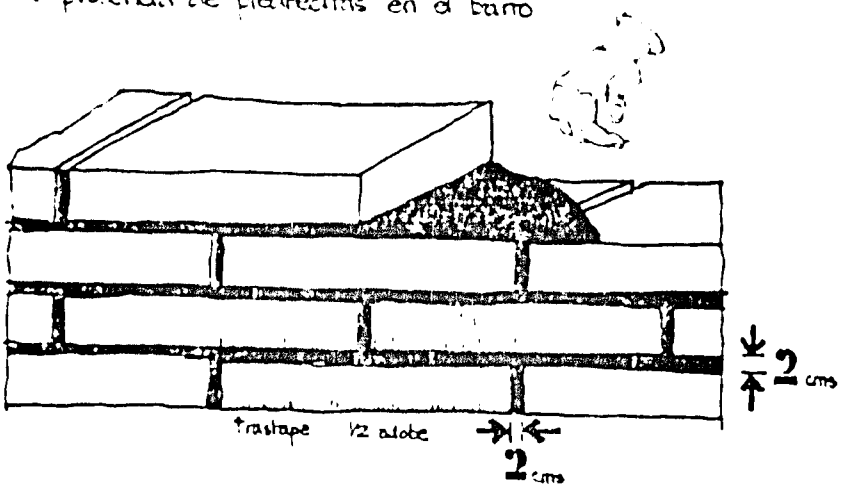
ⓑ Haciendo un sobrecimiento de albañilería de piedra, con mortero de cemento o cal



ⓒ Disponiendo de vanos altos en la techumbre

ⓓ Facilitando el escurrimiento de agua hacia el exterior, introduciendo una pendiente adecuada al terreno circundante

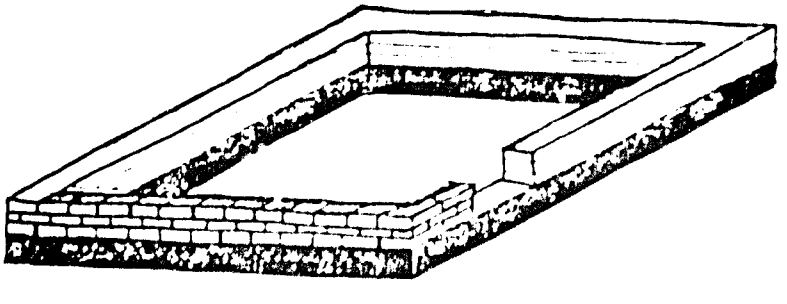
8. Las uniones entre los adobes, tanto horizontales como verticales se hacen con el mismo barro del adobe, su espesor debe ser de dos centímetros. Debe evitarse la presencia de piedrecitas en el barro



9. Todos los adobes deben quedar trabados con un trasape de medio adobe

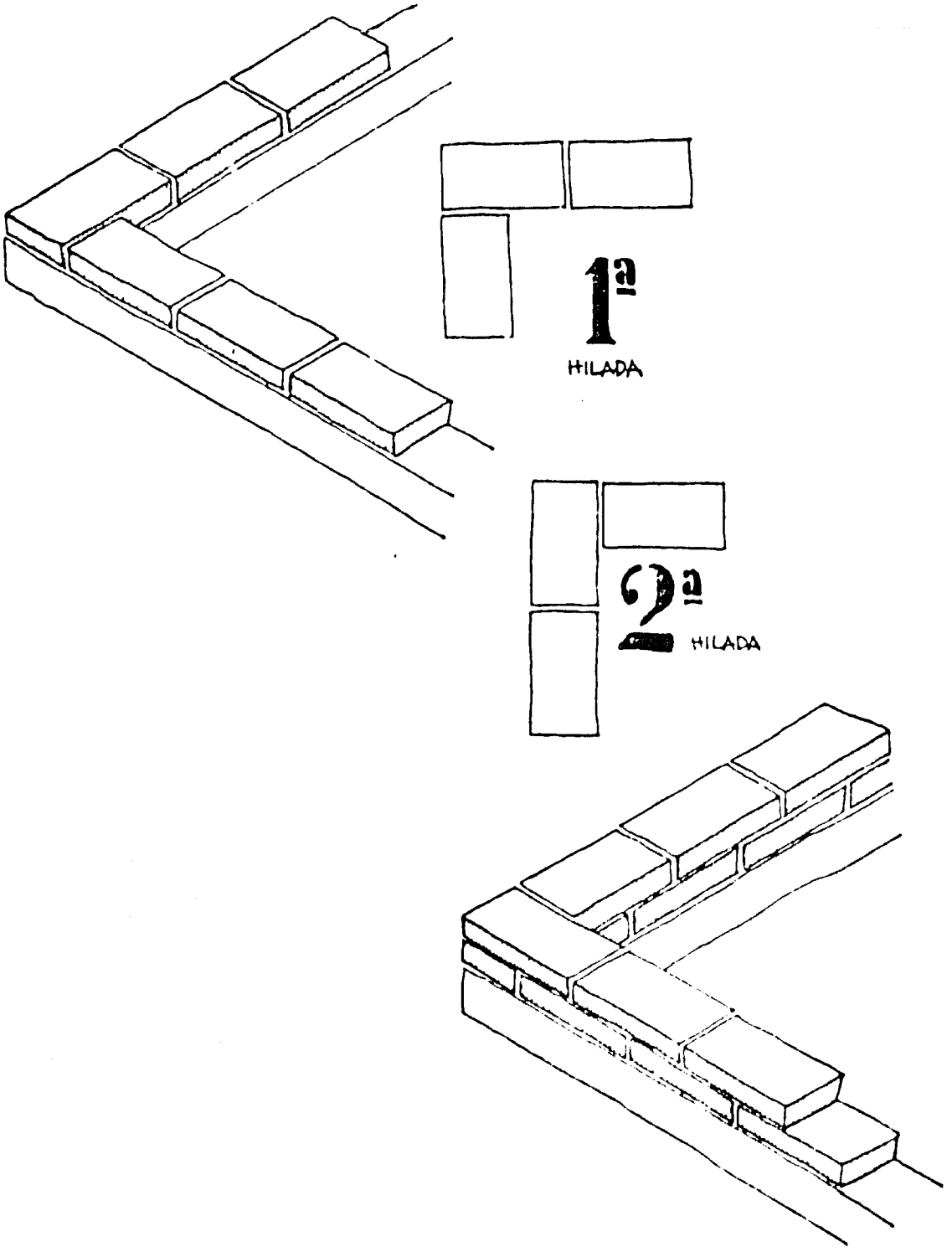
10. Los adobes se colocan en hiladas horizontales, siguiendo el contorno total que tendrá la vivienda, de modo que la construcción avance a nivel

Para evitar el aplastamiento del muro por su propio peso, la altura máxima de avance por día no debe ser mayor que un metro

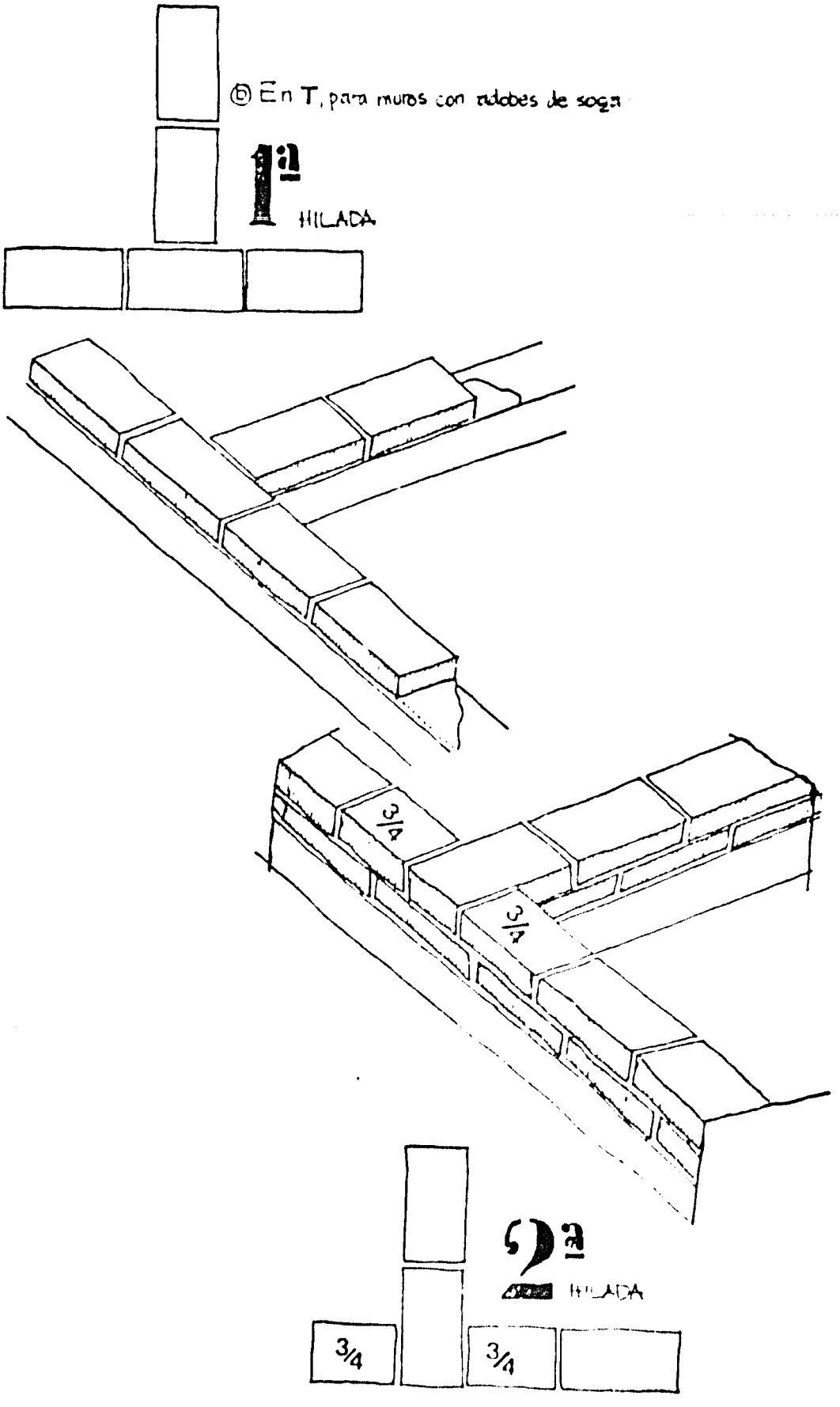


11. Los adobes deben quedar perfectamente trabados en todas las situaciones de encuentro de muros.

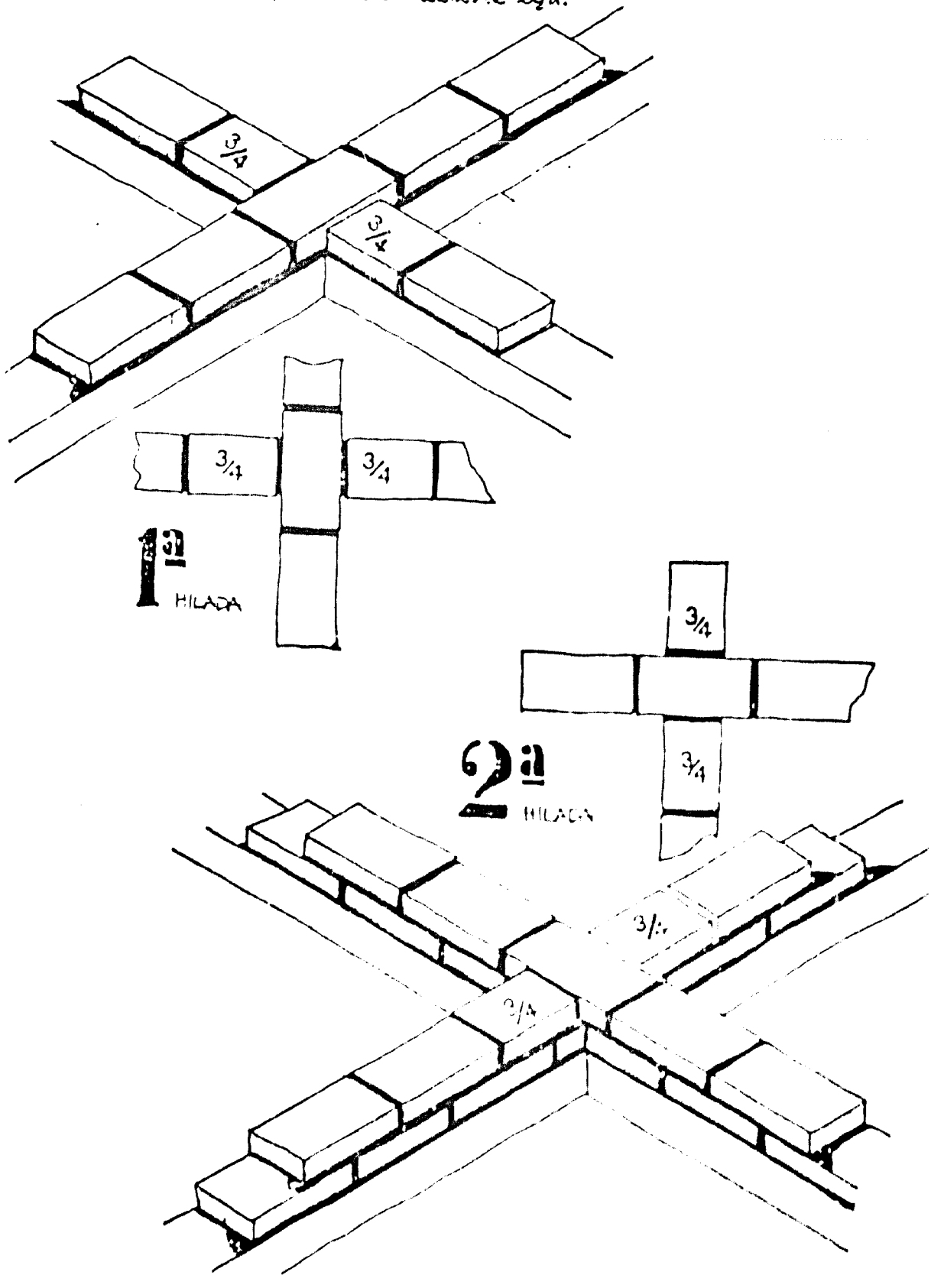
a) En "L" para muros con adobes "de soga":



ⓑ En T, para muros con adobes de soga

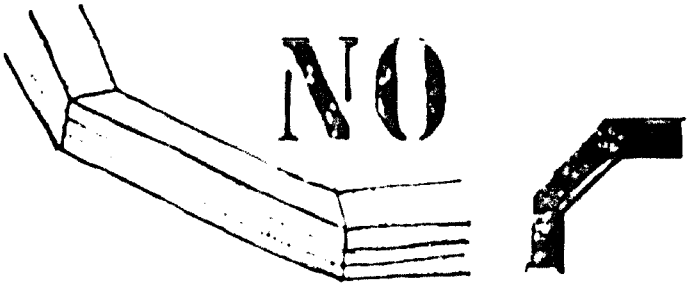


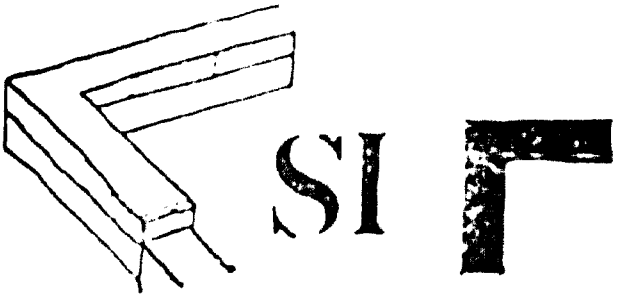
© En "cruz" para muros con adobes de soga:

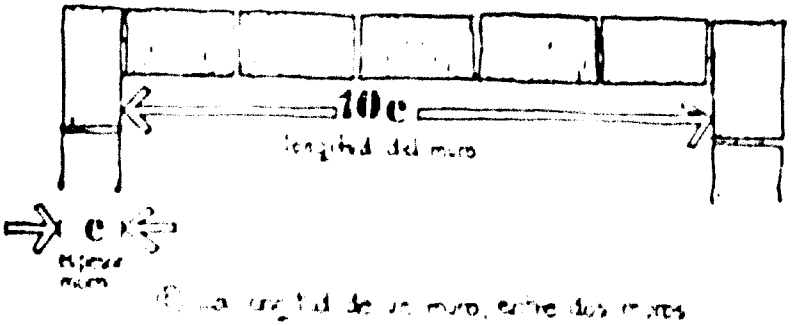


12. Con respecto a los muros, se deben tomar en cuenta las siguientes normas básicas:

① Las intersecciones de muros deben ser ortogonales: las esquinas no se hacen en ochavo

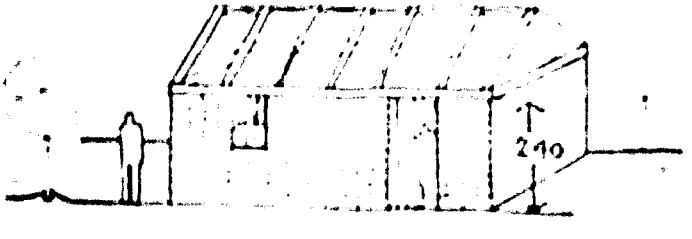




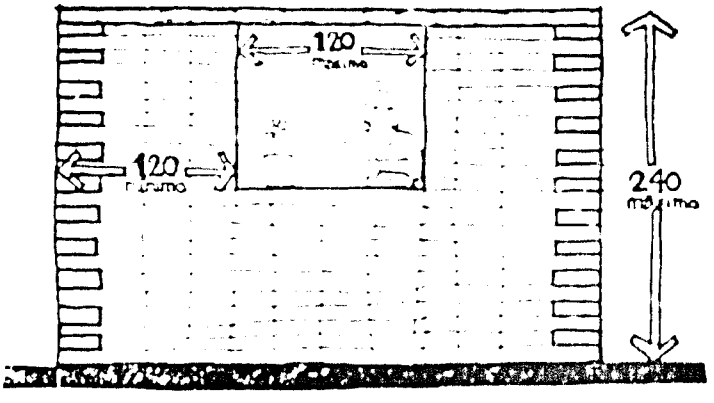


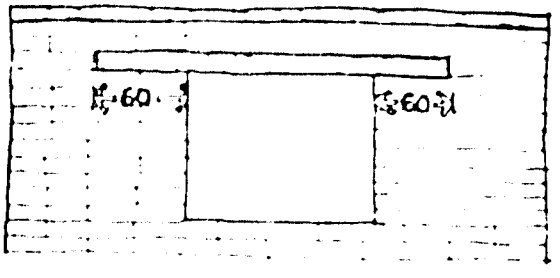
② La longitud de un muro, entre dos muros perpendiculares, no debe ser mayor que diez veces su espesor. Cuando se necesite una longitud de muro mayor, se debe reforzar con un contrafuerte vertical adosado.

③ La altura máxima de un muro no debe ser mayor que cinco veces su espesor. Su altura no debe pasar de 2.40 mts.



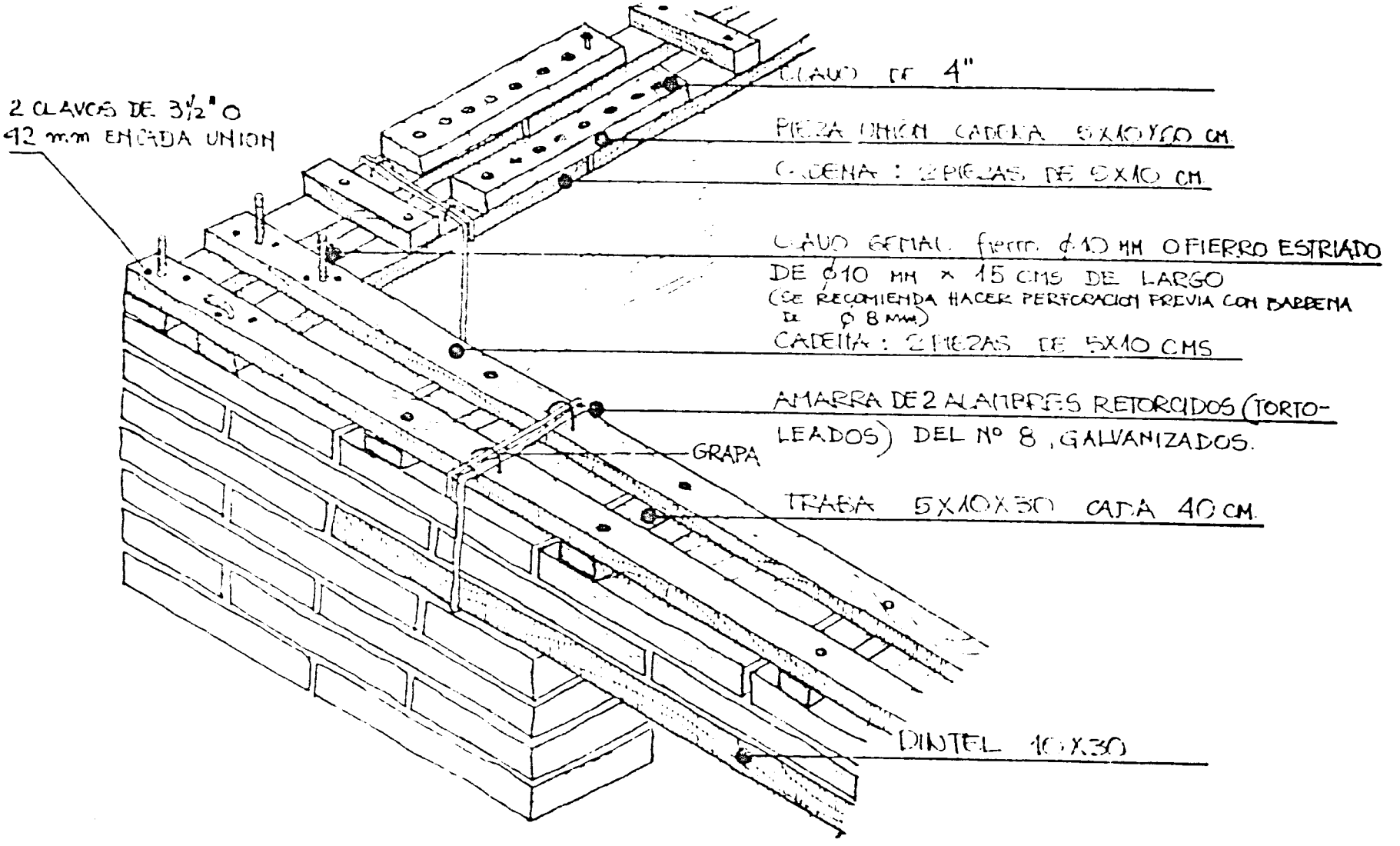
(d) El ancho de un vano no debe ser mayor que 1.20 mts, la distancia entre una esquina y un vano no debe ser inferior a 1.20 mts, y la suma de los anchos de vanos en un muro no debe ser mayor que la tercera parte de su longitud, entre dos cruces sucesivos. Los nichos vanos rellenados, o cualquier otra abertura en el muro, se considera como hueco. No se considerará como estructural un muro de menos de 1.20 de longitud.

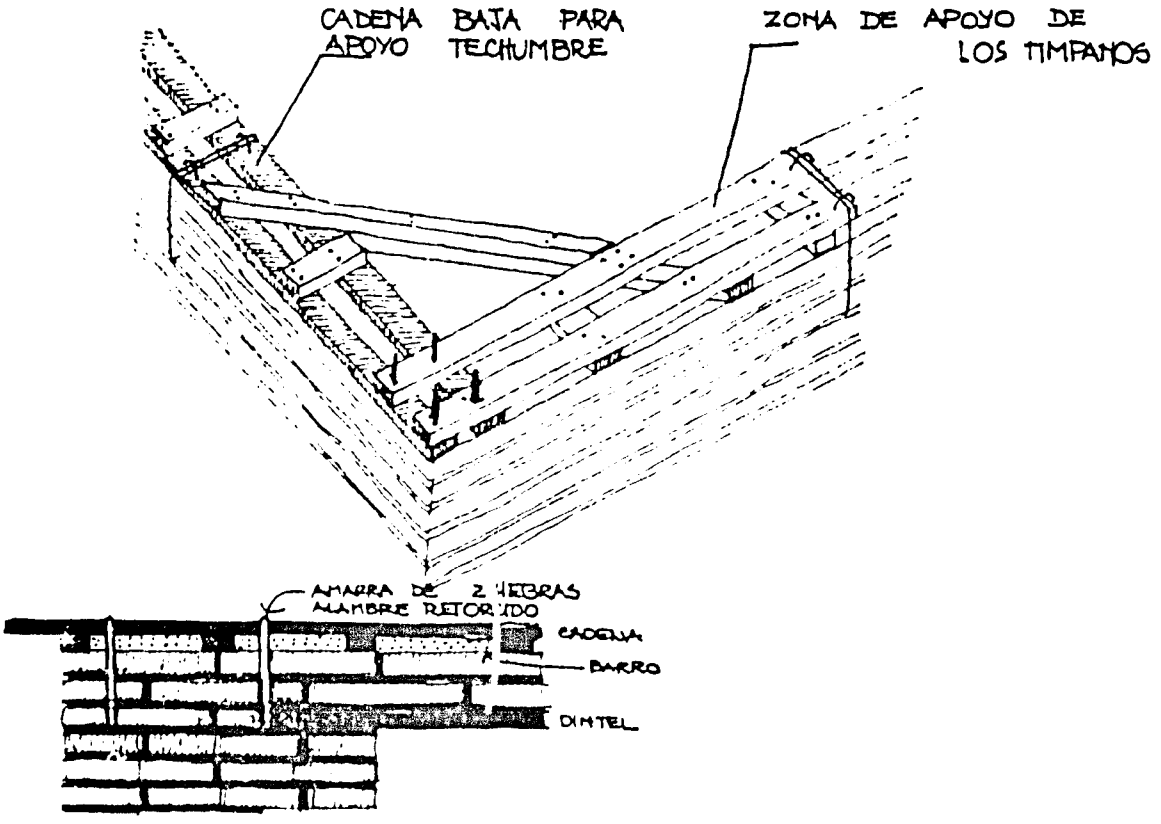




(e) El empotramiento de un dintel aislado deberá ser de mínimo 60 centímetros.

13. En la parte exterior de los muros se debe colocar un [illegible] entre la armadura o [illegible] de la [illegible] o pretil. Este coincidir con los [illegible] de puertas o ventanas. Podrá estar constituido por dos [illegible] paralelas, unidas por [illegible] o trabas. En lo este conjunto se [illegible] en [illegible], debe [illegible] firmemente [illegible] en las [illegible] que se abra y debe [illegible] al mismo tiempo que se [illegible] para [illegible] los estudios.


2 CLAVOS DE 3½" O
12 mm EN CADA UNION
CLAVO DE 4"
PIEZA UNION CADENA 5X10X60 CM.
CADENA : 2 PIEZAS DE 5X10 CM.
CLAVO GEMAL fierro ϕ10 MM O FIERRO ESTRIADO
DE ϕ10 MM x 15 CMS DE LARGO
(SE RECOMIENDA HACER PERFORACION PREVIA CON BARRENA
DE ϕ 8 MM)
CADENA : 2 PIEZAS DE 5X10 CMS
AMARRA DE 2 ALAMBRES RETORCIDOS (TORTO-
LEADOS) DEL Nº 8 , GALVANIZADOS.
GRAPA
TRABA 5X10X30 CADA 40 CM.
DINTEL 10X30



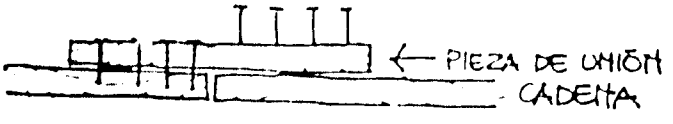
La cadena debe ser continua y quedar lastrada por el peso del techo y por amarras de alambre inoxidable, incluyendo dinteles y, por lo menos, tres hiladas de adobes.

La cadena está formada por dos piezas de madera de 5X10 cms (2X4")

La esquina puede ser reforzada por una diagonal horizontal que asegure la escuadra

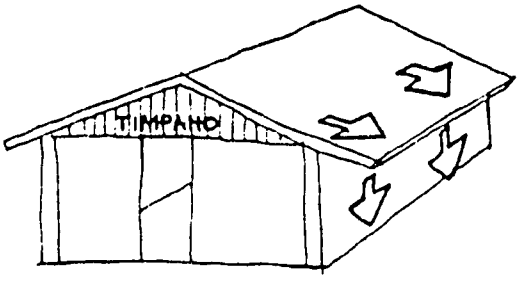
Es recomendable colocar, en las esquinas, clavos gemelos, hechos con fierro de sección redonda de diez milímetros que penetran en el adobe, asegurando la unión con la cadena

La continuidad de la cadena se asegurará cubriendo uniones con una pieza de 2X4" de 60 cms de largo, fijada con clavos de 4" (4 clavos por lado)

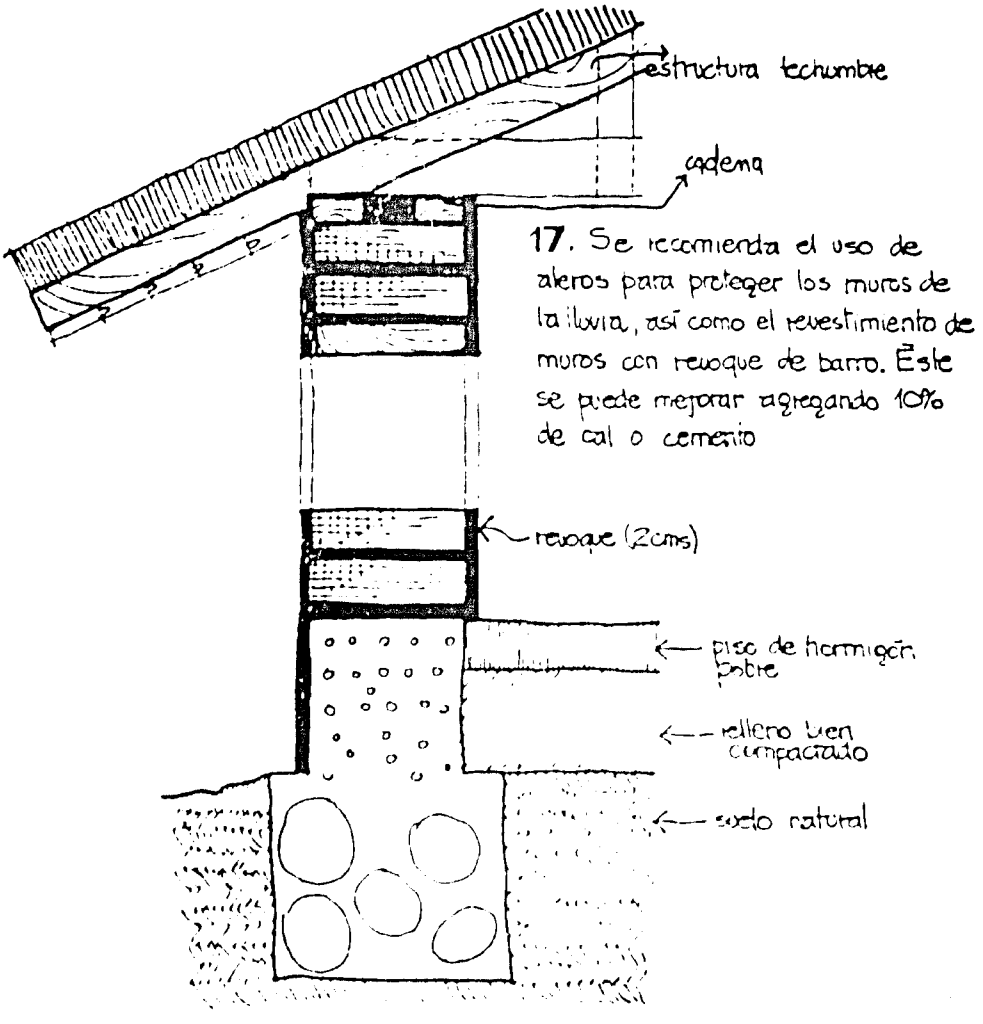


14. Las cadenas que coronan los muros que soportan el peso de la techumbre, irán directamente sobre la última hilada de adobes. Las trabas se colocarán sobre la cadena. En los muros bajo los tímpanos, se procede a la inversa las trabas se colocan sobre la última hilada de adobes, encima irá la cadena.

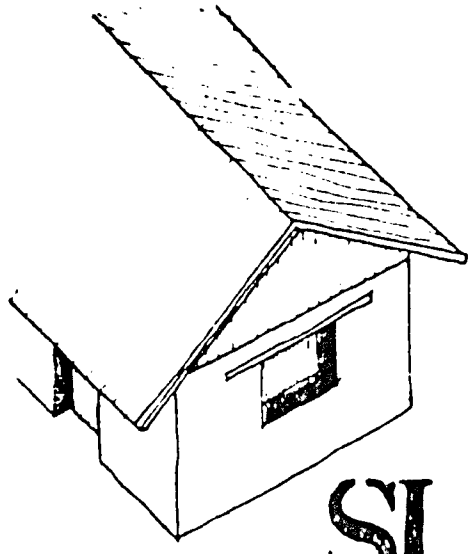
15. En lo posible, el techo debe ser liviano. En caso de que una viga de techumbre descanse sobre un vano de puerta o ventana, deberá reforzarse el dintel



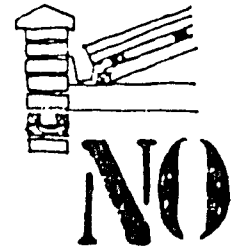
16. El techo se colocará apoyado directamente en la cadena, para facilitar repartición de carga sobre el muro de adobe.



17. Se recomienda el uso de aleros para proteger los muros de la lluvia, así como el revestimiento de muros con revoque de barro. Éste se puede mejorar agregando 10% de cal o cemento



Los antetechos son prohibidos:



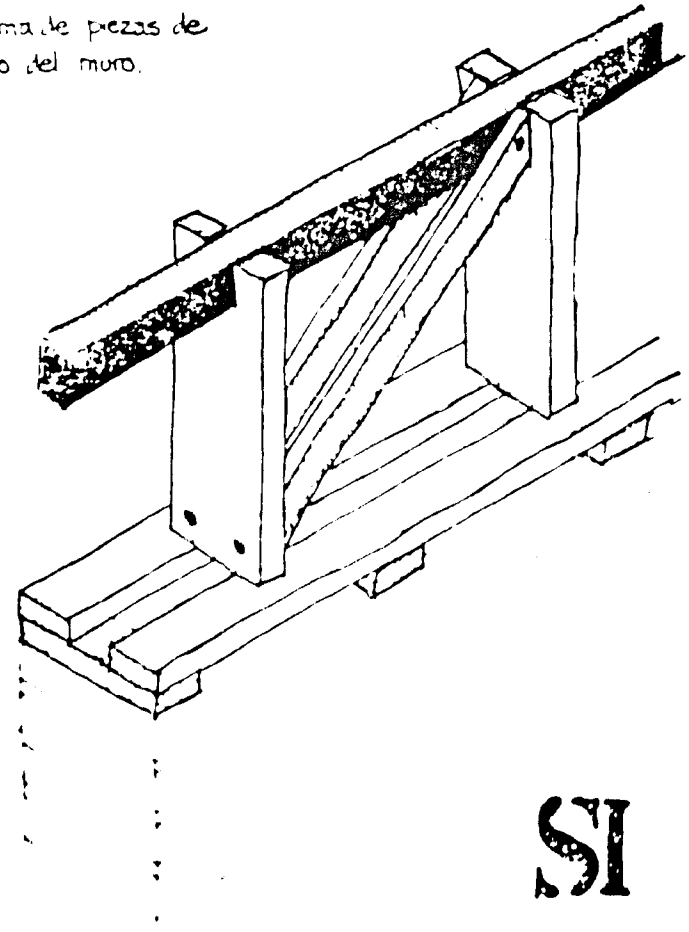
NO

SI

18. Evitar todo elemento suelto sobre la cadena No se permiten los antetechos y frontones de adobe.

Los frontones o tímpanos deben ser de material liviano y autosoportante. Por ejemplo de madera machiembrada sobre bastidor de madera -

Cuando, sobre los muros interiores, los tijerales necesiten más de 2,40 mts de altura, no se subirá el muro sino que se dispondrá de un sistema de piezas de madera colocado sobre el cercramiento del muro.



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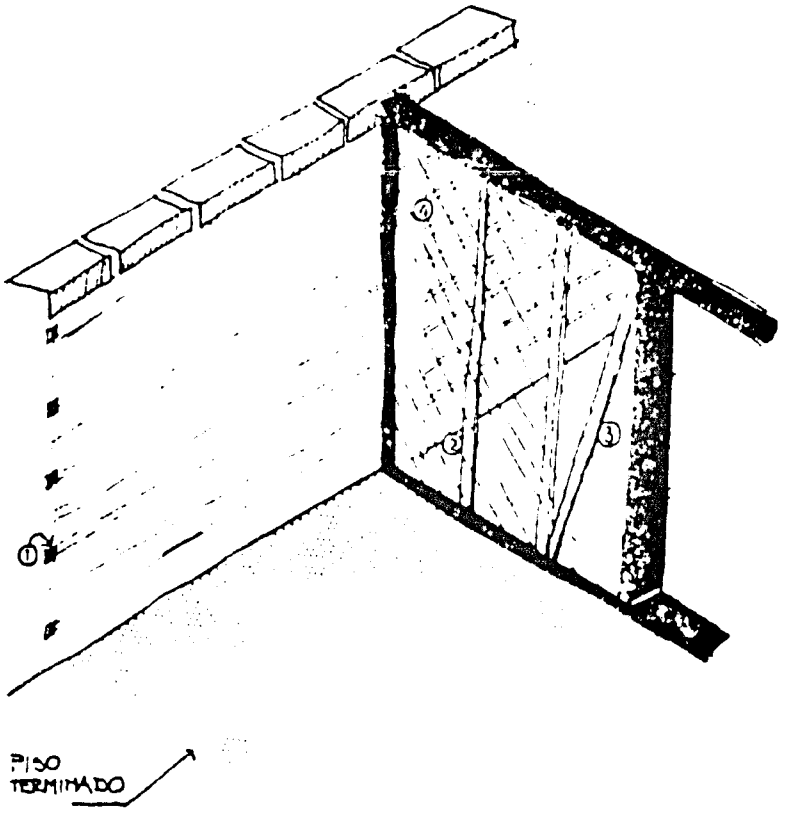


19. Las divisiones no resistentes pueden hacerse de tabquería de adobe. Estos tabiques quedan unidos al muro con tacos de madera que se dejan colocados durante su construcción.

Los tabiques deben quedar firmes en sus cuatro bordes.

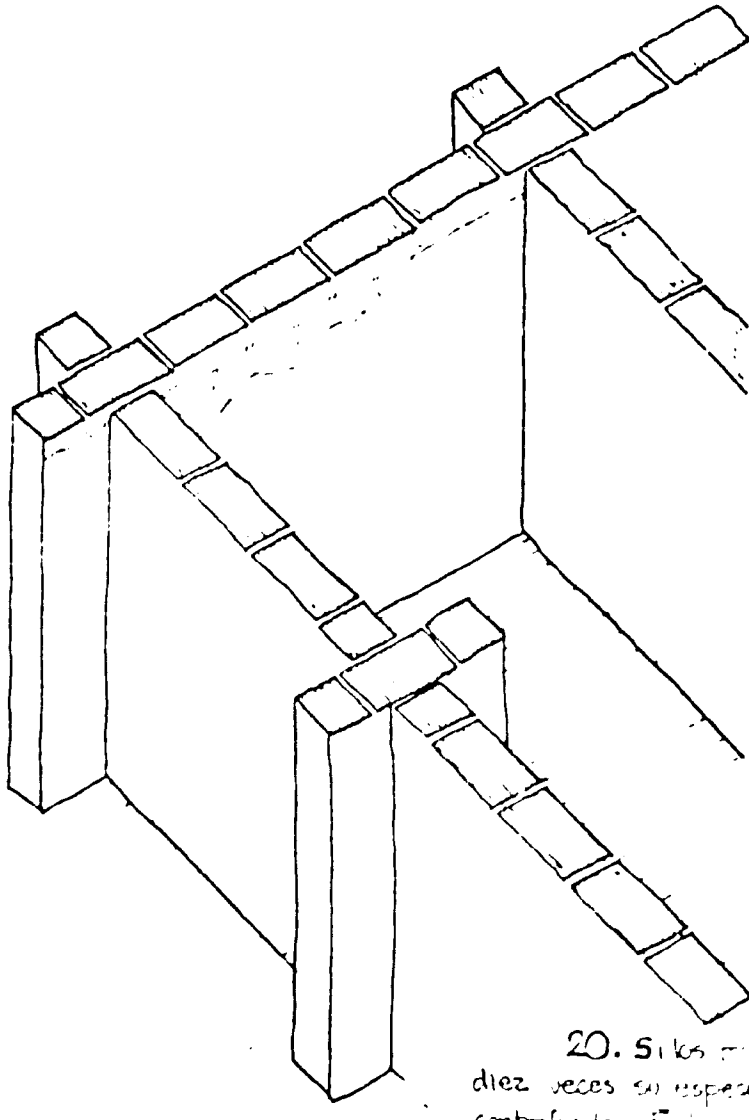
③ Los pies derechos están fijados a largo de adobe.

Ⓔ No usar trozos incompletos de adobe en una misma hilada.

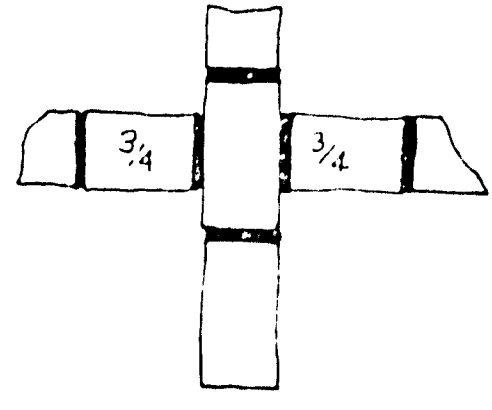
Ⓒ Alambrar a 45° y cada 20 cms con alambre inoxidable (de 2 a 3 mm).

Ⓓ Usar maderas preservadas para evitar, en lo posible, su descomposición.

① taco clavado de madera de sección y altura interior
② pie derecho madera preservada cada un adobe de adobe
③ diagonal madera preservada
④ alambre 2 a 3 mm inoxidable a 45° y cada 20 cms



20. Si los muros tienen un largo mayor que diez veces su espesor, se le incorporarán contrafuertes. Estos se solucionan como un encuentro en cruz y dan mayor rigidez y seguridad a la construcción. El contrafuerte de [illegible] permite materializar mejor el encuentro de los cabezas



RECOMENDACIONES BASICAS

① Una buena casa de adobe tradicional debe ser de un solo piso.

② El largo máximo de los muros será de 10 veces su espesor

③ Los muros soportantes serán con adobe de soga con un espesor mínimo de 30 cms sin considerar revoque

④ La altura máxima de los muros será de 6 veces su espesor

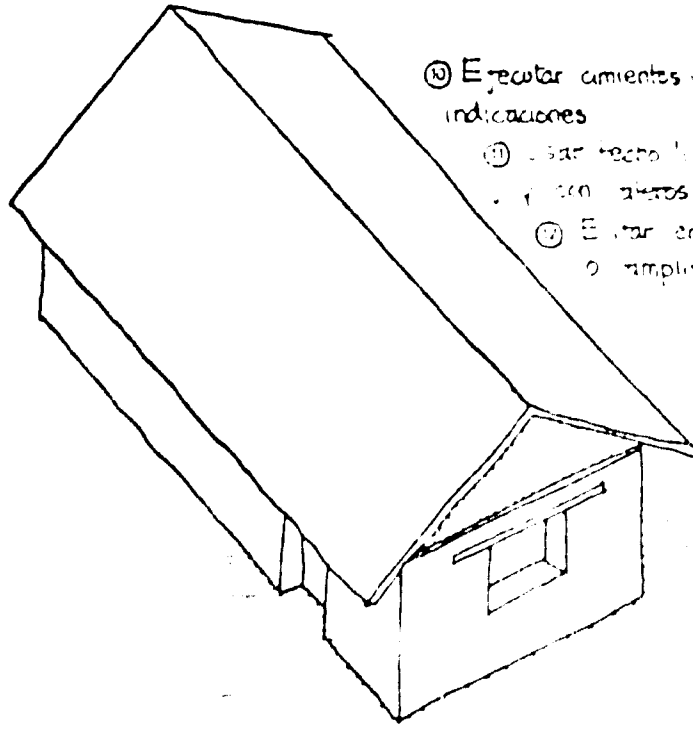
⑤ Se cuidará la buena traba entre adobes así como el relleno de juntas

⑥ Usar elementos horizontales cadena continua o solera en todos los muros

⑦ Los vanos estarán alejados de las esquinas (mínimo 1.20 mts)

⑧ El [illegible] mínimo de dintel será de [illegible] cms

⑨ El [illegible] de muros será a escuadra Se cuidará los ángulos

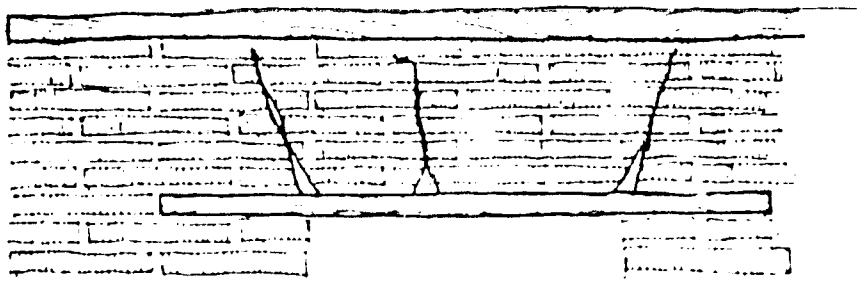


⑩ Ejecutar cimientos y sobrecimientos según indicaciones

⑪ Usar techo liviano bien ligado a los muros y con aleros

⑫ Evitar en lo posible, transformaciones o ampliaciones de la vivienda

6D REPARACION



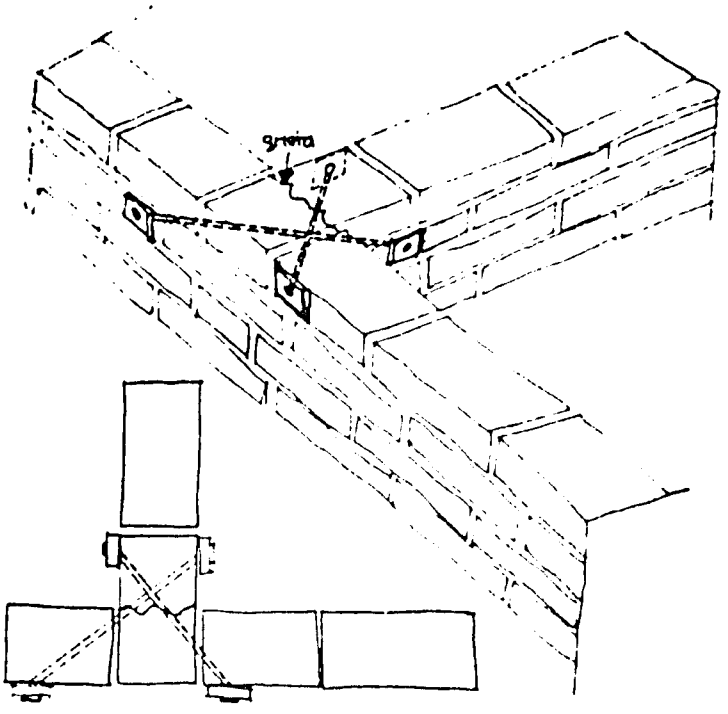
Un muro de adobes que presenta grietas que lo atraviesan, desplomes, o destrucción parcial, debe ser reconstruído No basta con parcharlo En general debe aprovecharse esta oportunidad para bajar la altura de los muros, y si se trata de una casa de dos pisos, reconstruir en uno solo Es más seguro y cómodo

Para reparar grietas de dintel o separación de encuentros de muros, se dan, a continuación, algunas sugerencias

La grieta de dintel es una de las fallas más frecuentes y, generalmente, se inicia en las esquinas de puertas o ventanas. Las posibles causas de rotura son:

ⓐ Dintel débil
ⓑ Poco empotramiento de dintel
ⓒ Carga excesiva de adobes sobre el dintel
ⓓ Ancho excesivo del vano
ⓔ Tijeral apoyado en el centro del vano
ⓕ Falta de la cadena

La reparación consistirá en cambiar el dintel, rebajar la carga de adobes, angostar el vano, colocar la cadena de confinamiento y ordenar la carga de techumbre.



"Costura" de grieta de encuentro de muros se hace con br .a de 6 a 10 mm de diámetro y con tacos de 2"x4"x4". Esta costura se hace cada 50 cms (cada 4 o 3 hiladas), en forma alternada.

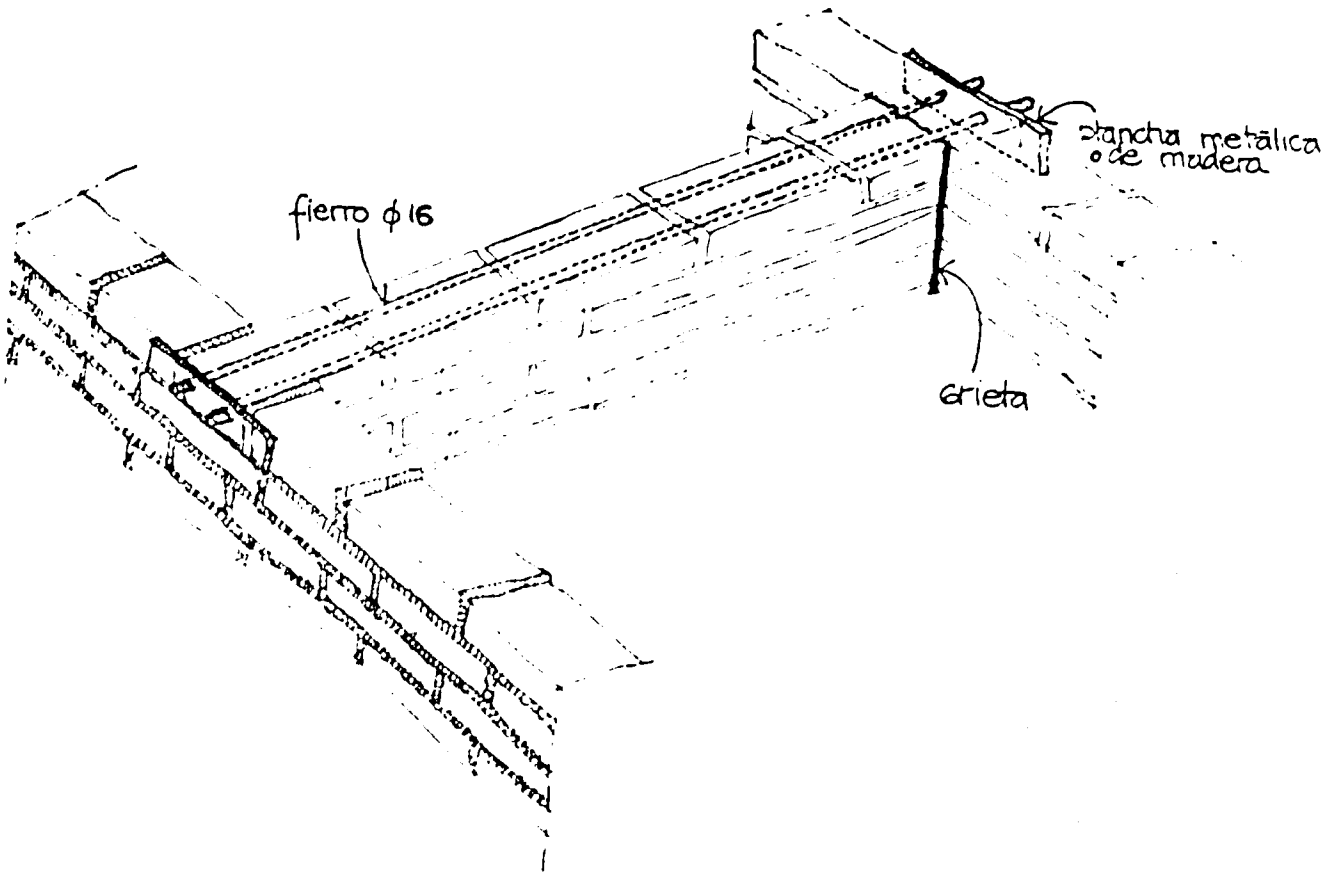
Separación de encuentros de muros: por efecto de temblores aparece una grieta vertical en las esquinas (encuentro de muros). Si no hay desplome de importancia (un centímetro por cada metro de altura, máximo 3 centímetros), se pueden practicar los siguientes procedimientos.

ⓐ Colocar la cadena de coronamiento

ⓑ Reforzar el conjunto con traviesas de madera y dos barras de fierro.

Se procede de la siguiente forma: se colocan dos barras de 16 a 25 mm de diámetro con tuercas y golillas apoyadas sobre traviesas de roble de 2½"x8" o plancha de fierro de ½"

El muro se mantendrá en su posición, sin intentar volverlo a la ubicación primitiva. La grieta se rellena con barro empajado.



APPROPRIATE BUILDING CODES AND SPECIFICATIONS FOR ADOBE CONSTRUCTION

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Albuquerque, NM

ABSTRACT

An examination of the existing regulations governing adobe construction, including the logic, shortcomings, and suggestions for appropriate change. A pragmatic approach is provided for the determination of parameters in the selection of materials, manufacturing techniques, significant testing, structural and physical requirements. These parameters recognize and are applied to meet practical economic, cultural, and social needs.

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The formulation of building codes ia a perplexing task. Perhaps Hammurabi (ca 1700 B.C.) had the right idea when he wrote the first building code. It was very simple and direct. If a building collapsed and killed the owner, the builder was killed. If the collapse caused the death of the owner's son, the builder's son was likewise killed. With the limits imposed by our legal system, we cannot have such a simple solution.

Our task here is to determine what is currently required by law, what is important, and to offer acceptable practical limits for control. Building codes are formulated ostensibly for public safety and the maintainance of minimum construction quality standards. Often, however, specific details seem due to a number of other influences. Of primary importance is safety. Secondly perhaps the elusive term "quality". Other obvious input factors should include climate, local conditions, time tested local tradition, and other less clear considerations for social and economic conditions which might prevail for the area the code is to govern. When we attempt to formulate a national building code, for wide geographical use, it must necessarily ignore many of these influences. The authors of building codes frequently do not have first hand information on the practical use of locally specialized materials like adobe, little of local conditions, and logically must rely on standards for more conventional materials. Adobe does not neatly fit this pattern. The technology of adobe construction is a prime example where secondary factors assume prime importance.

Man has been using adobe for at least 10,000 years and it is currently used by a large percentage of the total population of the world today. Areas predominated by its use are more often in the underdeveloped countries of the world where its use is of vital economic importance. Very little accurate, documented, technology is available for adobe as a building material and logical reasons for these shortcomings are understandable.

For adobe to acheive its maximum effective use, the soil source must be close to the building site. The soil for the makeing of bricks and mortar must be useable as it occurs, with only minor modifications. If elaborate modifications procedures are required for its use, it then becomes too costly to consider. Consequently, standards must recognize the expected variations and determine acceptable limits. Tradition and successful use of adobe indicates very wide tolerance limits for the material, makeing the stablishment of narrow limits unrealistic.

Indigeneous builders of adobe structures historically had no access to testing laboratories we use today, but in their place developed a "seat of the pants" engineering and technology. The builder makes a value judgement based on his experience that a material was right or wrong, and what needed to be done to correct it, based on trial and error of the past. This personal judgement factor is unacceptable to the engineering community and regulatory officials, and some parameters must be established.

Building codes make use of technical engineering tests and can determine the requirements for beam strength, column size, shear value for bolts, etc., where consistency and quality control standards have been established. When we attempt to superimpose this technology on most adobe construction, it runs into serious difficulty. The soil source for bricks and mortar will vary considerably in material make-up and proportions. Tests on samples from buildings of great age (see Table A) show such a wide range of material proportions that it casts doubt on the necessity of making any tests at all. Richard Clough, in his examination of material qualities for adobe[1] concludes that "Mechanical analysis of a soil is not an infallible index to the soil's behavior in an earth wall". and quotes Schwalen that satisfactory bricks can be made from soils covering a wide range in texture and having a clay content varying between 9 and 28%. Comprehensive testing represents substantial expense, and in the light of wide tolerance limits, may have limited value. Local vernacular tradition seems to have its roots in sound practice. A common belief of worldwide scope is that adobe bricks must have straw to be sound. The mid Rio Grande valley of New Mexico, where adobe construction has been extensively practiced for centuries, has a well balanced, naturally occurring soil that requires little if any modification, and bricks are customarily made without straw. Clough further remarks that contradictory results have occurred in the testing of adobe bricks with and without straw, and that its presence does minimize shrinkage cracks during drying. It is my conclusion that straw is traditionally added to soils whose clay content is too high, a common occurrance. Shrinkage cracks result from too much clay, therefore areas with high clay soils require straw to minimize shrinkage cracks and make usable bricks.

Current building codes in various areas differ greatly in their requirements for "Unburned Clay Masonry" (adobe). The "Southern Building Code" (Southern Building Code Congress International, Inc. 1976 Ed. with 1977-78 revisions) makes no mention of this material. The "Uniform Building Code" (International Conference of Building Officials, Whittier, CA 1979 Ed.) in wide use in the western United States, recognizes the material but limits its regulation to four paragraphs, which are strongly restrictive. (see Figure 1.) The "One and Two Family Dwelling Code", 3rd Ed. 1979, a code compiled by several code authorities for residential construction makes no mention of Unburned Clay Masonry.

Various State, County, and Municipal bodies may be generally governed by the jurisdiction of one of the major codes, but add amendments or make substitutions in the light of local tradition or economic pressures. The State of New Mexico has adopted (Amendment 46, 4/15/80) the most comprehensive adobe code, which has been and is being adopted by other bodies (El Paso, TX, Tucson, AZ , and others). However, many of these bodies have modified the New Mexico Code, sometimes reflecting local climate and traditions, and sometimes adding regulations of concern to the author of the amendment. (see Appendix A for complete NM code)

Where the assumed f'_m exceeds 2600 pounds per square inch, field tem in accordance with Section 2404 (c) 2 shall be required.

Unburned Clay Masonry

Sec. 2405. (a) General. Masonry of stabilized unburned clay units shall not be used in any building more than one story in height. The unsupported height of every wall of unburned clay units shall be not more than ten times the thickness of such walls. Bearing walls shall in no case be less than 16 inches. All footing walls which support masonry of unburned clay units shall extend to an elevation not less than 6 inches above the adjacent ground at all points.

(b) **Units.** At the time of laying, all units shall be clean and damp at the surface and shall have been stabilized with emulsified asphalt in accordance with U.B.C. Standard No. 24-14.

(c) **Laying.** All joints shall be solidly filled with Type M or S mortar. Bond shall be provided as specified for masonry of hollow units in Section 2411.

(d) **Stresses.** All masonry of unburned clay units shall be so constructed that the unit stresses do not exceed those set forth in Table No. 24-B. Bolt values shall not exceed those set forth in Table No. 24-C.

Gypsum Masonry

Sec. 2406. (a) General. Gypsum masonry is that form of construction made with gypsum block or tile in which the units are laid and set in gypsum mortar. Gypsum masonry shall not be used in any bearing wall or where exposed directly to the weather or where subject to frequent or continuous wetting.

(b) **Materials.** Gypsum masonry shall be gypsum block or tile laid up in gypsum mortar composed of one part gypsum and not more than three parts sand by weight.

(c) **Stresses.** All gypsum masonry shall be so constructed that the unit stresses do not exceed those set forth in Table No. 24-B when computed on the gross cross-sectional area.

(d) **Bond.** The bond in gypsum masonry shall conform to the requirements for bond in masonry of hollow units specified in Section 2411.

(e) **Method of Laying.** All units in gypsum masonry shall be placed in side construction with cells horizontal. The entire bearing surface of every unit shall be covered with mortar spread in an even layer, and all joints shall be filled with mortar.

Reinforced Gypsum Concrete

Sec. 2407. (a) General. Reinforced gypsum concrete and precast reinforced gypsum shall conform to U.B.C. Standard No. 24-12.

Reinforced gypsum concrete shall develop the minimum ultimate compressive strength in pounds per square inch set forth in Table No. 24-D when dried to constant weight, with tests made on cylinders 2 inches in

FIGURE 1. Uniform Building Code, 1979 Ed.

A Cross Index Matrix is appended to this paper (Appendix B) which makes comparisons between various code provisions and authorities. For the purpose of simplification and clarification of language, individual provisions have been simplified to key words and phrases that identify the intent of the specific provisions. The areas of specific regulation are briken down into six main headings, and varying requirements within each main heading are broken down into sub heads, and summarized in the Matrix.

A. Structures
B. Specifications For Untreated Bricks
C. Specifications For Treated Bricks
D. Foundations
E. Mortar
F. Plaster and Protective Coatings

Each of the six categories will be dealt with individually, indicating current provisions, areas of greatest importance, and points for discussion. In our determination of the value for each provision, it will be necessary to recognize the basic limitations imposed by the materials and technology, and to strive for adequate minimums. The key word is "adequate" rather than "best." The use of adobe may well be an economic necessity, and if we burden its use with provisions that might seem desireable for heroic applications, we may defeat our purpose. Many geographical areas have no codes, or do not enforce them, so our purpose here may be one of establishing "guidelines" rather than regulations.

A. Structures

Building Height is limited by most codes to a maximum of one or two stories. This would seem an arbitrary provision, reflecting perhaps a suspicion of the soundness of earth materials. Buildings in the Middle East of 60-80 ft. in height are common.

Wall Height-Thickness Ratios are specified in some codes. Most restrict the unsupported height of a wall to a maximum of ten times the wall thickness. No measurements are available for Middle East structures, but lower walls for higher structures are substantially thicker.

Wall Length Without Cross Support is an important consideration, particularly when considered with wall height/thickness ratios. The seismic implication of these are significant.

Wall Thickness is related to brick size, wall height, and other factors above. Single brick walls are common, where bricks are 10" (25 cm) or more, the mass providing stability. Good masonry practice would recommend multiple brick walls.

Brick Bonding (overlap) is specified as a minimum of 4" (10cm) in most codes, and surprisingly seems to be the standard in the Middle East as well. Efficient brick size would generate at 50% bond (one half brick).

Tie Beams are a basic part of good masonry practice. Codes vary in requirements for adobe walls, but most allow either wood or concrete, functioning doubly as a plate to support roof and floor structures, and as a "collar beam" to prevent wall separation at the corners. Another consideration not dealt with by most codes is the attachment of the tie beam to the top of the wall. Some determination of uplift wind forces acting on the roof structure and seismic forces needs be made. Some authorities accept the weight of the roof structure, tie beam, and parapet wall above the tie beam as sufficient anchorage.

Attachment of Roof Structures must be considered, possibly in conjunction with the tie beam.

Lintels are a necessary part of any masonry wall, and often the flat-arch effect is ignored in determining lintel strength requirements.

Attachment of Abutting Frame Walls requirements vary from "adequate" attachment to detailed directions specifying bolt size and spacing.

Piers and Columns of adobe brick are generally required to have minimum dimensions, reflecting multiple brick construction.

Parapet or Fire Walls are common in some architectural styles and not in others. If these are of masonry, they can act significantly to add weight anchorage for roof structures.

Earthquake Regulations are not generally delineated specifically for adobe construction, but in general structural requirements, which will vary with Earthquake Hazard Zone designation. The State of California, for example (Zone 4) enforces reinforcement requirements, while The State of New Mexico (Zone 1-2) makes no requirement.

B. Specifications for Untreated Bricks

The soil used for both bricks and mortar will be made up of five major elements: Gravel, Coarse Sand, Fine Sand, Silt, and Clay. These might be compared to concrete, with the Gravel and Coarse Sand representing the aggregate, the Fine Sand and Silt representing Sand, and the Clay representing the Cement. A major difference between adobe and concrete drying and curing however, is that where concrete represents a chemical action, adobe is purely a physical one. In the most general terms, a high percentage of clay makes the bricks less subject to water erosion, but can cause shrinkage cracks and a loss of strength. A high percentage of sand reduces cracking, increases strength, but makes the bricks more subject to erosion.

Aggregate Size might seem to be important, although many examples of usable adobes can be found where a large percentage of coarse gravel and stones of 1" diameter or more occur. It is common practice to remove by hand, only the large stones. Screen-

ing to control the particle size will add greatly to the cost of the bricks, and reduce the economic effectiveness of this material. A balance between quantities and proportions of gravel, sand and clay obviously must be considered, and tolerable limits, however wide, must be determined.

Clay Types are not generally noted in codes, and might seem to be a matter for concern, because some types are highly expansive when moistened, as in the case of Montmorillinite, or relatively inert as in Kaolinite clays. Determination of clay types, by X-Ray diffraction, is a costly procedure, and may not be necessary. The testing of a number of samples from obviously successful adobe buildings of considerable age was done by the National Park Service Soils Laboratory in Tucson, AZ. Table "A" indicates the wide range limits found.

Brick Size will vary with locality, local custom, and the materials available to the builder, and are seldom specified in codes. A common size for the mid Rio Grande valley is 10"x4"x14" (25 x 10 x 35 cm). Any size might be possible, determined by the curing time (thickness) and handling weight for efficient construction. Older bricks tended to be somewhat larger and current sizes in the Middle East and North Africa are somewhat smaller.

Compressive and Tensile Strength are emphasized by current codes. Of major importance would be the compressive strength to support loads imposed by the wall and roof structure weights. Tensile strength (modulus of rupture) would represent toughness of the bricks required for handling and stacking. Most codes require a compressive strength of 300 psi, but historic examples[3] have been tested as low as 109.5 psi. Simple calculations will show that in most instances, actual compressive loadings are less than 10 psi. It might appear that compressive strength requirements are excessive. Representative testing of New Mexico adobe bricks is given in Table B.

Curing Time requirements will vary with climatic conditions. Some codes address this with minimum time requirements for cureing, but bricks that are not cured cannot be handled or stacked, so this provision may not be required.

Water For Mixing is seldom addressed by code requirements, but can be significant. Water with a high slat content (in solution) may re-crystalize during drying, causing structural damage to the bricks.

C. Specifications for Treated Bricks

In addition to the testing outlined for untreated bricks, qualifications for the designation of "treated" bricks include qualities limiting moisture absorption and resistance to erosion. Allthough some codes do not specifiy the type of stabilizer, the most successful in terms of practicality and cost considerations would seem to be asphalt emulsions. The amount of stabilizer required to meet "treated" standards will vary with the basic soil qualities, thus the test standards must be met.

TABLE A-1.

Soil Material Composition
Adobes-Mortar-Mud Plaster
Average Percent of Total Sample

	Gravel	C. Sand	F. Sand	Silt	Clay	Porosity (Partial Samples)
TUMACACORI, AZ.[1]						
Adobes P① 10 samples	14.4	20.2	24.8	27.8	13.9	32.3
② 8 samples	10.7	23.7	30.1	25.8	9.7	33.1
③ 12 samples	10.5	22.2	28.9	27.0	11.2	34.6
④ 8 samples	12.1	24.4	29.8	24.9	9.0	31.0
⑤ 13 samples	8.0	18.6	30.1	26.7	18.0	34.2
⑥ 10 samples	8.22	19.7	29.4	31.1	11.5	—
GALLISTEO, NM — Soil Source	6.0	10.0	43.0	34.0	7.0	—
Fire Bricks	2.5	2.5	25.0	49.0	21.0	—
JEMEZ SPRINGS, NM — Mud Plaster	5	6	51	26	12	—
	12.5	18.6	23.2	36.1	9.6	—
TRAMPAS, NM — Mud Plaster	4.6	5.4	14.4	50.5	25.1	-
	10.6	21	23.1	28.3	17.0	—
OJO CALIENTE, NM — Mud Plaster	.3	9.0	24.9	48.1	17.7	—
GUNNISON, CO — Intra Mud Plaster	0	12	51	21	16	—
SASABE, MEXICO — (High Clay Mud for Mixing)	1.9	23.1	28.9	16.3	29.8	—
(Std Soil/Bricks)	7.9	17.1	16	40.9	18.1	—
AVERAGE	7.2	15.8	29.6	32.1	15.4	33.0

1. TUMACACORI MISSION BULT CL 1520 ND

NOTE: Definition of particle size not given.

TABLE A-2.

Soil Material Composition
Adobes-Mortar-Mud Plaster
High/Low percent of Total Sample

	GRAVEL		C. SAND		F. SAND		SILT		CLAY	
	HI	LOW	HI	LOW	HI	LOW	HI	LOW	HI	LOW
TUMACACORI P①	37	6	29	11	35	16	39	14	17	9
②	30	4	30	16.5	45	20	43	10	17	1
③	25	2	26.5	14	40.5	18	39	19	25	5
④	26	3	34	20	39	22	35	17	14	5
⑤	19	1	23	15	41.5	19	41	20	24	11
⑥	21.8	4.4	28	11.3	44.2	23.4	40.9	16.2	16.7	7.1
TOTAL 61 AVG	26.4	3.4	28.4	14.6	40.9	19.7	39.6	16.0	19.3	6.4

CONCLUSIONS - SOIL COMPOSITION VARIES WIDELY WITH LITTLE EFFECT
AVERAGES FROM 71 SAMPLES
HI/LOW FROM 61 SAMPLES (TUMACACORI)

		%	NOTE
GRAVEL	HI	26.4	
	LOW	3.4	
	AVG	7.2	LOWER % IN PLAS MIX
C. SAND	HI	28.4	
	LOW	14.6	
	AVG	15.8	
F SAND	HI	40.9	
	LOW	19.7	
	AVG	29.6	
SILT	HI	39.6	
	LOW	16.0	
	AVG	32.1	
CLAY	HI	19.3	
	LOW	6.4	ONE SAMPLE P③ WITH 17% CLAY INCURRED SEVERE EROSION
	AVG	15.1	SLIGHTLY HIGHER IN PLASTERS
POROSITY	HI	—	
	LOW	—	
	AVG	33.0	

NOTE: Definition of particle size not given.

TABLE A-3.

Soil Material Composition
Adobes-Mortar-Mud Plaster
Types of Clay Found

	Montmorillonite	Mica	Vermic	Chlorite	Kaolin	Illite
Tumacacori P(1)	3	3	0	0	2	0
	3	3	0	0	2	0
	3	3	0	0	2	0
	2	3	0	0	2	0
	3	3	0	0	2	0
	3	3	0	0	2	0
	3	3	0	0	2	0
	3	3	0	0	2	0
	3	3	0	0	2	0
	2	3	0	0	2	0
P(2)	1	4	0	0	2	0
	1	4	0	0	2	0
		4	0	0	2	0
	1	3	0	0	1	0
		4	0	0	2	0
	0	2	0	1	1	0
	1	3	2	0	0	2
P(3)	0	4	0	0	2	0
	1	4	0	0	2	0
	1	4	0	0	2	0
	1	4	0	0	2	0
	1	4	0	0	2	0
	1	4	0	0	2	0
	0	4	0	0	2	0
	2	3	0	0	2	-
	1	3	0	0	2	0
	3	3	0	0	3	0
	2	4	0	0	2	0
	3	4	0	0	3	0

	Montmorillonite	Mica	Vermic	Chlorite	Kaolin	Illite
Tumacacori P(4)	1	3	0	0	2	0
	1	4	0	0	3	0
	1	4	0	0	2	0
	1	4	0	0	2	0
	2	4	0	0	2	-
	1	4	0	0	2	0
	2	4	0	0	2	0
P(5)	3	2	0	0	2	0
	3	3	0	0	2	0
	2	3	0	0	2	0
	3	3	0	0	2	0
	1	3	0	1	2	0
	1	3	0	0	2	0
	0	3	0	1	2	0
P(6)	—	—	—	—	—	— NOT MADE
Gallisteo NM	2	3	0	0	3	0
	4	2	0	0	3	0
Jemez Springs NM	4	2	0	0	2	0
	0	2	1	1	2	0
Tramway NM	0	2	0	0	1	0
	2	2	0	0	2	0
Quemado NM	1	1	0	0	2	0
Gunnison CO	2	3	0	0	2	0
Saylorville Iowa	—	—	—	—	—	— NOT MADE

CODE:
5. Dominant
4. Large Amount
3. Medium Amount
2. Small Amount
1. Trace
0. Looked for, none found

TABLE B

SUMMARY OF PHYSICAL PROPERTY TESTS OF THE LARGE SCALE ADOBE PRODUCERS*

ADOBE PRODUCERS **	TYPE ADOBE BRICK	SIZE (In Inches)	AVERAGE ADOBE WEIGHT IN LBS.	COMPRESSIVE STRENGTH(psi)	MODULUS OF RUPTURE(psi)	WATER ABSORPTION (percent by weight)	MOISTURE CONTENT (percent by weight
New Mexico Earth Alameda, New Mexico	Traditional	10x4x14	30	409	66	11.6	0.9
	Semi-Stabilized	10x4x14	30				
	Stabilized	10x4x10	32.4	499	89	1.3	0.5
Adobe Enterprises, Inc. Albuquerque, New Mexico	Semi-Stabilized						
	Stabilized	10x4x14	30				
Eight Northern Indian Pueblos San Juan Pueblo, N.M.	Semi-Stabilized	10x4x14	30.3	317	99	4.3	0.9
	Stabilized	10x4x14	31.6	382	71	6.0	1.0
The Adobe Patch Alamogordo, New Mexico	Stabilized	10x4x14	33.8	578	157	2.2	0.6
The Adobe Farm Espanola, New Mexico	Semi-Stabilized	10x3½x14	33	322	82	2.1	1.1
Victor Montano Santa Fe, New Mexico	Traditional	10x3½x14	30	438	46	N/A	N/A
Western Adobe Albuquerque	Semi-Stabilized	10x4x14	32	456	96	N/A	1.0
Eloy Montano Santa Fe, New Mexico	Traditional	10x3 3/4x14	30	320	42	N/A	N/A
Manual Ruiz Corrales, New Mexico	Traditional	10x4x14	30	311	55	N/A	N/A
Rio Abajo Adobe Works Belen, New Mexico	Semi-Stabilized	10x4x14	30				
	Stabilized	10x4x14	27	486	101	1.8	0.76

*- Specification requirements for U.B.C. and New Mexico State Adobe Code:

Compressive Strength: average of 5 bricks- 300 p.s.i. minimum
1 out of 5 bricks- 250 p.s.i. minimum
Modulus of Rupture: average of 5 bricks- 50 p.s.i. minimum
7-Day Water Absorption: 2.5% maximum by weight
Moisture Content: 4.0% maximum by weight

**Note: Test Results are from limited sampling of adobe bricks from each adobe yard and may not be representative of the total annual production averages. The N.M.adobe code recommends testing of samples selected at random from each 25,000 bricks produced.

D. Foundations

Basement and Foundation Walls are generally prohibited by code. Moisture infiltration into mud brick walls robs them of their compressive strength when unsupported on the sides, and can cause collapse. Below grade walls should be impervious to moisture.

Foundation Wall Height and Thickness generally are required to be the same thickness as the wall supported, and are to extend 6" - 8" above exterior finished grade. Capillary action, rain splash, and salt re-crystalization cause extensive damage at the base of adobe walls.

Footings for adobe walls are usually given the same design considerations as any other type of wall construction. Historic structures would seem to have inconsistent patterns, often using adobe bricks or stone. Current codes require steel reinforced concrete, consistent with conventional building details, but taking note of possible increased weight of the wall. It may be significant that early foundations of stone were less rigid, and could more readily absorb movements in the wall and supporting ground without extensive wall damage.

E. Mortars

Mud Mortar is most commonly made from the same soil sources used for bricks, and subject to the same criteria, with one exception. The mud mix must be free of all but the smallest stones. The presence of stones in the mortar mix will prevent the even bedding of the bricks as laid. Stones of 1/4" or larger must be removed by screening, or removed as the mortar bed is laid up. If stabilized bricks are used, it would seem desirable that the mortar be stabilized as well. Untreated mud, if of the right proportions, will adhere to the mud brick surfaces, making a homogenous mass, unlike conventional bricks and mortar. Problems of adhesion sometimes occur between stabilized surfaces, perhaps from an oxidation of the older surface.

Surfaces to receive a mortar bed should be solid, free of dust and friable particles, and perhaps damp. Most codes specify that the surface be "clean and damp", but the common practice of spraying stacks of bricks of conventional masonry would not be suitable for adobe. Common practice avoids the dampening step and uses a slightly wetter mortar.

Types S and N Mortar may also be used, but it increases the cost and the wall loses its homogenuity. An advantage of conventional mortars is the increased laying speed, as mud mortar requires more drying time, restricting the number of courses laid up each day in one location.

Joints are differentiated in some codes between adobe walls that are to be plastered, and those to be left exposed. If the wall is to be plastered, open or partially filled head joints are allowable and desirable to offer a key for supporting the plaster

coat. Joints in walls to be unplastered need to be carefully filled and smoothed, with solid head joints. All codes specify, if mentioned, that bedding joints shall be full slush (solid) joints.

F. Plastering

Exposed Adobe Walls , even though unprotected, are resistant to rainfall. It has been measured[4] at approximately 1" per 20 years, in areas where rainfall is 10" to 20" per years. Exposed brick walls or mud plaster are viable as an economic alternative, where little possibility for flooding exist.

Cement Stucco is required by most codes. It is normally applied over galvanized stucco netting, attched to the wall at specific intervals. The cement stucco provides a waterproof coating that limits erosion of the mud surface. It also has the negative effect of concealing any moisture and erosion of the wall from leaking roofs and scuppers which allow water seepage into the wall underneath the stucco. If these leaks go undetected, damage can occur to the wall that can lead to structural collapse without warning. In flood prone locations, cement stucco and interior cement or gypsum plaster is a desirable treatment. Severe flooding and standing water will immediately destroy most unprotected adobe walls, while waterproof plaster will save the structure.

Mud Plaster is a traditional treatment that functions well except in areas prone to flooding mentioned above. It is not allowed by most codes, which insist on cement stucco, or stabilized bricks and mortar.

Stabilized Plaster is not mentioned in existing codes, but may offer a viable exterior wall finish. Problems with existing applications sometimes occur in terms of lack of adhesion between subsequent layers.

Motel shall mean hotel as defined in this code.

Sec. 420. "S"

Sec. is the abbreviation for Section as referred to in this code.

TELEPHONES

Sec. 1713. Where public telephones are provided, at least one shall be installed so that the handset, dial and coin receiver are within 48 inches of the floor. Unobstructed access within 12 inches of the telephone shall be provided. Such access shall be not less than 30 inches in width.

AMENDMENT 6: CHAPTER 24 - MASONRY

UNBURNED CLAY MASONRY

Sec. 2405. (a) General. Masonry of unburned clay units shall not be used in any building more than (2) stories in height. The height of every laterally unsupported wall of unburned clay units shall be not more than 10 times the thickness of such walls. Exterior walls, which are laterally supported with those supports located no more than 24 feet apart, are allowed a minimum thickness of 10 inches for single story and a minimum thickness of 14 inches for the bottom story of a two story with the upper story allowed a minimum thickness of 10 inches. Interior bearing walls are allowed a minimum thickness of 8 inches.

(b) Compressive Strength. The units shall have an average compressive strength of 300 pounds per square inch when tested in accordance with ASTM C-67. One sample out of five may have a compressive strength of not less than 250 pounds per square inch.

(c) Modulo of Rupture. The unit shall average 50 pounds per square inch to modulus of rupture when tested according to the following procedure:

PROCEDURES:

(1) A cured unit shall be laid over (cylindrical) supports two inches (2") in diameter, located two inches (2") from each end, and extending across the full width of the unit.

(2) A cylinder two inches (2") in diameter shall be laid midway between and parallel to the supports.

(3) Load shall be applied to the cylinder at the rate of 500 pounds per minute until rapture occurs.

(4) The modulus of rupture is equal to $\frac{3WL}{2Bd^2}$

W = Load of rupture
L = Distance between supports
B = Width of brick
d = Thickness of brick

(d) Soil. The soil used shall contain not less than 25 percent and not more than 45 percent of material passing a No. 200-mesh sieve. The soil shall contain sufficient clay to bind the particles together and shall not contain more than 0.2 percent of water-soluble salts.

Most clayey loams, except those with a high clay content, are suitable, but it is not practicable to make a selection on the basis of soil analysis only. Soil having a high clay content shrink or crack badly when drying, and sandy soils do not have sufficient binding material to prevent crumbling. Neither of these soils should be used alone for brick, but a very good building material can be obtained by mixing the two soils together in proportions that will overcome the undesirable qualities of each. The best way to determine the fitness of a soil is to make a sample brick and allow it to cure in the open, protected from moisture. It should dry without serious warping or cracking.

(e) Classes of Adobe

ADOBE TYPES: (1) Treated Adobes. The term "treated" is defined to mean adobes made of soil to which certain admixtures are added in the manufacturing process in order to limit the adobe's water absorption in order for it to comply with paragraph (h) below. Exterior walls constructed of treated adobe require no additional protection. Stucco is not required. In order for the wall to so comply, the mortar must be of Type 5 of adobe soil treated with an additive to make the mortar comply with the same water absorption requirement in paragraph (h) below.

(2) Untreated Adobes. Untreaded adobes are adobes which do not meet the water absorption specifications of paragraph (h) below. This shall hold even if some water absorption protection agent has been added. The determination as to whether an adobe is treated or untreated is to test for compliance with paragraph (h) below. Exterior walls of untreated adobe are allowed but must comply with paragraphs (o) requiring Portland cement plaster applied to the outside. Use of untreated adobes is prohibited within 4 inches above the finished floor grade. Treated adobes may be used for the first 4 inches above finished floor grade. Mortar must be Type 5 (or masonry mortar) or adobe soil (either treated or untreated.

(f) Sampling. Each of the tests prescribed in this Section shall be applied to five sample units selected at random from each 25,000 bricks to be used.

(g) Moisture Content. The moisture content of the unit shall be not more than four percent by weight.

(h) Absorption. A dried four-inch (4") cube cut from a sample unit shall absorb not more than two and one-half percent moisture by weight when placed upon a constantly water saturated porous surface for seven (7) days.

(i) Shrinkage Cracks. No units shall contain more than three shrinkage cracks, and no shrinkage crack shall exceed three inches (3") in length or one-eighth inch (1/8") in width.

(j) Use. No adobe shall be laid in the wall for at least three (3) weeks after making, dependent on weather conditions.

(k) Foundations. Adobes shall not be used for foundation or basement walls. All adobe walls, except as noted under Group M Buildings, shall have a continuous concrete footing at least eight inches (8") thick and not less than two inches (2") wider on each side than the foundation walls above. All foundation walls which support adobe units shall extend to an elevation not less than six inches (6") above the finish grade.

Foundation walls shall be at least as thick as the exterior wall as specified in Section 2405 (1). Where stem wall insulation is used, a variance is allowed for the stem wall width to be two inches (2") smaller than the width of the adobe wall it supports.

(l) Exterior Walls. All walls of adobe (treated or untreated) shall not have thicknesses less than that allowed in paragraph (a) above. Mortar shall be in accordance with paragraph (e1) and (e2) above depending on the class of adobe being used. All adobe brick shall be laid up with full slush (bed) joints and shall be bonded (overlapped) not less than 4 inches. Walls of treated adobe which do not require a protective outer coating must also be laid up with full head (end) joints. All exterior adobe walls shall be topped with a continuous belt course or tie beam (except patio walls less than 6' high above stem). At the time of laying, all units shall be clean and damp at the surface.

(m) Concrete Tie Beam. Shall be minimum size six inches (6") by width of wall up to a ten inch (10") width. For walls thicker than ten inches, a ten inch (10") tie beam will suffice. All concrete tie beams shall be reinforced with a minimum of two No. 4 reinforcing rods each floor and ceiling plate line.

(n) **Wood Lintels or Tie Beams.** Shall be minimum size six inches (6") by wall width up to a ten inch (10") width. For walls thicker than ten inches, a tie beam of ten inch (10") thickness shall suffice. The wooden tie beam shall be overlapped, or spliced, at least six inches (6") at all joints. All joints shall have a wall bearing of at least twelve inches (12"). Wood tie beams may be solid in the six inch (6") dimension or may be less than one inch (1"). Wood joists, vigas or beams shall be spiked to the wood tie beam with large nails or large screws. All lintels, wood or concrete, in excess of nine feet (9') shall have specific approval of the building official.

(o) **Plastering.** All untreated adobe shall have all exterior walls plastered on the outside with Portland cement plaster, minimum thickness ½" in accordance with Chapter 47. Protective coatings other than plaster are allowed provided such coating is equivalent to Portland cement plaster in protecting the untreated adobe against deterioration and/or loss of strength due to water. Metal wire mesh minimum 20 gauge by one inch (1") opening shall be securely attached to the exterior adobe wall surface by nails or staples with minimum penetration of one and one-half inches (1½"). Such mesh fasteners shall have a maximum spacing of sixteen inches (16") from each other. All exposed wood surfaces in adobe walls shall be treated with an approved wood preservative before the application of wire mesh. No [illegible] bricks shall be used for isolated piers, porch columns or wall section of less than 25" x 10". A minimum twelve inch (12") wall section will be permitted between openings provided a continuous lintel of concrete or lumber be installed spanning both openings and wall section.

EXCEPTION:

(1) Exterior patio, yard walls, etc., need not have Portland cement coating.

(p) **Floors and Roofs.** Floors and roofs may be constructed of wood, the sizes and spans to be in accordance with Chapter 25.

(q) **Floor Area.** Allowable floor area shall not exceed that specified under Occupancy (Part III). Adobe construction shall be allowed the same area as given in Table No. 5-C, Type V construction, Column N.

(r) **Wood Partitions.** Partitions of wood shall be constructed as specified in Chapter 25, wood partitions shall be nailed to nailing blocks laid up in the adobe wall or bolted through the adobe wall the height of the partition with ½" bolts @ 24" on center with large washers or plates.

(s) **Stop work.** The Building Official shall have the power to stop work whenever adobes have not been thoroughly cured and shall give prior approval to the use of any hardeners, stabilizers or other so-called preservatives.

ANALYSIS AND COMPARISON OF BUILDING CODES FOR UNBURNED CLAY MASONRY (ADOBE)

CODE MATRIX

In order to make a more useful comparison, the building codes governing adobe construction have been synopsized to managable phrases or short descriptions. State, County and community variations are codified in a matrix code, so that comparisons may be more easily made. As the structures of most building codes are complex and differ in organization, the matrix code is broken down into six parts:

A. Structures

B. Specifications for bricks, general

C. Specifications for Treated Bricks

D. Foundations for adobe structures

E. Mortars for adobe bricks

F. Plastering of adobe structures

Certain portions of each code are similar, and perhaps some sub-categories might be unneccesary, but an effort was made to make fine distinctions where it seemed pertinent. The matrix code definitions follow, and the comparison sheets refer to matrix code designations. For a precise interpretation, it is suggested that the appropriate specific building code for the State, County, or community be carefully examined. It should also be noted that in many instances, variations and exceptions to the code may be allowed, if sufficient justification can be shown.

A. STRUCTURES

A. 1. ...not to be used for more than 2 stories.

1.a....not to be used more than one story.

2. ...wall height not more than 10 times wall thickness (laterally unsupported)

2.a....wall height or length not more than 10 times wall thick.

3. ...exterior walls not more than 24 ft long (without cross wall)

3.a....when supported at ceiling line by joists or rafters. (wall length of 24 ft. is allowed)

4. ...minimum wall thickness 10 in. for single or upper story.

4.a....minimum exterior wall thickness not less than 10 in.

4.b....bearing wall not less than 16 in. thick.

5. ...minimum wall thickness 14 in.(lower wall of 2 story)

6. ...minimum wall thickness 8 in. for interior bearing walls.

7. ...not used

8. ...not used

9. ...brick bonding not less than 4 in.

9.a....brick bonding provided per Sec. 2104.7 or 2104.8

9.b....brick bonding as specified for hollow units (Sec. 2411 = 4")

9.c....brick bonding to be "running bond", 50% lap.

10. ...tie beams required for all exterior walls more than 6 ft. high.

10.a....Bond beams provide support and anchorage for roof structure. If of adobe, use continuous rows of joint re-inforcement between "required" number of courses to resist uplift forces.

A. STRUCTURES (cont.)

A. 10.b....all adobe walls to contain continuous tie beam at point of bearing.

11. ...tie beam of concrete 6 in. x wall thickness(to 10 in.) with 2 each #4 rebar at plate line.

12. ...tie beam of wood 6 in x wall thickness (to 10 in.) solid or spliced, 1 in. laminations, minimum over-lap 6 in.

12.a....protect all wood tie beams with preservative.

12.b....joists, vigas or beams spike or screw to tie beam.

13. ...lintel wall bearing not less than 12 in.

13.a....all lintels of wood or concrete over 9 ft. long require specific approval.

13.b....lintels to be of reinforced concrete, masonry or steel, an adobe overhang of not more than 2 in. each side is permitted.

13.c....all lintels to be designed in accordance with city code.

14. ...wood partitions to be attached to adobe walls with nailing blocks laid up with the wall, or through bolts, 1/2" D., 24 in. o.c. with large washers or plates

14.a....ledgers and partitions bolt through wall with plate washers 1/8 in. x 4 in. x 4 in., Table 24-C for shear values.

14.b....Interior stud partitions to be adequately secured.

14.c....Bolt values not to exceed Table 24-C

15. ...inspector has power to stop work if bricks not cured and shall have power to approve stabilizers or so called preservatives.

16. ...not used

17. ...units must be stabilized with emulsified asphalt.

18. ...adobe not to be used for piers or columns in bearing capacity less than 24 in.

18.a....no isolated piers or columns less than 28 in. x 10 in. or a minimum of 12 in. is premitted if lintel over is continuous.

19. ...all adobe parapet walls shall be waterproofed.

A. STRUCTURES

A. 20. ...masonry wall shall comply with empirical requirements designed in conformance with approved requirements of Sec. 2106.

A. 21. ...top wall plates and anchor bolts designed to resist uplift forces, minimum 1/2"D x 20" imbedment, with 1/8" x 4" x 6" plates in adobe, 2"D washers on wood plates.

A. 22. ...fireplaces and chimneys of adobe shall be lined with firebrick not less than 4" thick.

A. 23. ...Floors and roofs of wood permitted, sizes and spans in accordance with Chap. 25

A. 24. ...allowable floor area not to exceed occupancy Part III, adobe allowed same area in Table 5-C, Type IV, Col.N

A. 25. ...Do not lay more than 10 courses per day with mud mortar.

A. 26. ...Every structure designed to resist seismic stresses (UBC Section 2312. (Earthquake Regulations)

B. SPECIFICATIONS FOR BRICKS

B. 1. ...compressive strength average 300 PSI (ASTM C-67)

B. 1.a....unit stresses not to exceed Table 24-B (30 PSI)

B. 2. ...one sample of 5 may have minimum 250 PSI

B. 2.a....one sample of 5 may have minimum 200 PSI

B. 2.b....five samples per 25,000

B. 2.c....five samples per 5,000

B. 3. ...Modulus of rupture average 50 PSI ($3WL/2Bd^2$)

B. 4. ...soil not less than 25% or more than 45% pass through a #200 mesh screen.

B. 4.a....soil to pass through a 1/4" screeen (100%) free from deleterious matter.

B. SPECIFICATIONS FOR BRICKS (cont.)

B. 5. ...soil to have sufficient clay to bind

B. 5.a....suitable mixture of soil, clay and stabilizing agent

B. 6. ...soil to contain not more than .20% water soluble salts.

B. 6.a....soil to contain not more than .10% water soluble salts

B. 7. ...most clayey loams suitable, not practical to make soil tests only.

B. 8. ...high clay or unsufficient clay soils may be mixed.

B. 9. ...make test bricks, to dry without serious warping or cracking.

B. 10. ...moisture content maximum 4% by weight

B. 11. ...not more than 3 shrinkage cracks 1/8" x 3"

B. 12. ...Minimum curing time 3 weeks

B. 12.a....sun baked 1 week, stack 2 weeks before use, or longer

B. 13. ...use potable water

B. 14. ...protect from moisture

B. 15. ...all units clean and damp for laying

C. SPECIFICATIONS FOR TREATED BRICKS

C. 1. ... certain admixtures to limit water absorption

C. 2. ...certain admixtures or emulsified asphalt to limit water absorption, to comply with Sec. 2405.(c)

C. 3. ...emulsified asphalt mixed to provide required resistance to moisture.

C. 4. ...a dried 4" cube, cut from brick, shall not absorb more than 2-1/2% moisture by weight when placed on a constantly water-saturated porous surface for 7 days.

C. 4.a....if sample absorbs more than 2-1/2%, are to be classified "unstabilized"

C. 5. ...soil must be compatible with stabilizing material

D. FOUNDATIONS FOR ADOBE STRUCTURES

D. 1. ...adobes not to be used for foundations or basement walls,except Group M buildings (garages, outbuildings,etc

1.a....adobes not to be used for foundation or basement walls.

2. ...continuous concrete footing 8 in. thick x wall thickness plus 2 in. on each side.

2.a....continuous footing, width and depth governed by allowable soil bearing pressures and concrete strength.

3. ...foundation wall to extend 6 in. above finish grade.

3.a....foundation wall to extend 8 in. above adjacent ground.

4. ...foundation wall to be as thick as wall above, except may be reduced by 2 in. for perimiter insulation.

4.a....foundation wall to be as thick as wall above.

5. ..."treated" adobes to be used for 4 in. above finish floor.

5.a....no "raw" adobes used within 4 in. of finish floor.

E. MORTARS FOR ADOBE BRICKS

E. 1. ...for treated bricks, type S or treated mortar, with full slush bedding and head joints.

1.a....treated exterior walls without plaster are to have full head joints.

2. ...for untreated bricks use type S or untreated mortar with full slush bedding joints.

3. ...all joints solid with mortar

4. ...mud mortar to be the same as units, type M or S and acheive bond.

5. ...mortar type O or adobe soil mortar, treated or untreated.

6. ...mortar type N or treated adobe soil mortar

7. ...mortar in accordance with adobe type.

8. ...all joints with type M or S mortar

9. ...fill all joints solid with type S or M mortar

F. PLASTERING FOR ADOBE STRUCTURES

F. 1. ...untreated brick exterior walls must be protected with Portland Cement plaster

F. 2. ...add to the above...3/4" thick...

F. 3. ...other treatment allowed if equivalent to Portland cement plaster

F. 4. ...stucco net required 20 ga. x 1", fastened 16" o.c. with 1-1/2" penetration of fasteners

F. 5. ...if wall 14" thick, mud plaster allowed

F. 6. ...use stucco net on wood surfaces to be plastered

F. 7. ...treat exposed wood under stucco net with preservative

F. 8. ...patio/yard walls do not require cement stucco

F. 9. ...untreated adobe exterior wall permitted without plaster if: Cornice cap drains to roof
Canales long enough to keep water off wall
Window sill brick or concrete with lip to prevent drip on walls.

F. 10. ...treated bricks for exterior walls with Type S or treated mortar do not require plaster protection.

CODE MATRIX Appendix B-8

PROVISIONS SUMMARY	NEW MEXICO (UBC)				ARIZONA (UBC)			TEXAS (-)		CALIFORNIA (UBC)	
	STATE CODE (UBC 79)	STATE MODIF.	CITY OF ALBQ (MOD)	CITY OF SANTA FE	CITY OF PHOENIX	CITY OF TUCSON (MOD)		STATE CODE	CITY OF EL PASO (UBC-MOD)	STATE CODE (UBC-79)	CITY OF LOS ANGELES (MOD)
(A) STRUCTURES											
Stack Bond	(D)11	–	–		–	–		NO CONTRACTOR LICENSING OR PERMITS REQUIRED. CITIES HAVE ADOPTED BUILDING CODES.	–	UBC	–
Bldg Height Allowed	(D)1a	(D)1	(D)1		(D)1a, 20	(D)1a			–		(D)1a
Wall Height Bldg Bldg	(D)2	(D)2	(D)2		(D)2	(D)2a			(D)2		(D)2
Wall Length	–	(D)3	(D)3		–	(D)3a			(D)3		–
Wall Thickness	(D)4a	(D)4,5,6	(D)4,5,6		(D)4a	(D)4a			(D)4,5,6		(D)4a
Bearing Bearing	(D)9a	(D)9	(D)9		(D)9a	(D)9c			(D)9		(D)9a
Fire Resist Code	–	(D)10,11	(D)10,11		–	(D)10a			(D)04,11		–
Fire Resist Bldg	–	(D)12	(D)12		–	–			(D)12,12a		–
Fire Separation	–	–	(D)14		–	–			–		–
Floors	–	–	–		–	–			–		–
Unlimited	–	(D)15a	(D)15a		–	(D)15a			(D)15c		–
Max Height Bldg	–	(D)14	(D)14		–	(D)14a			(D)14a		–
Floors & Cols	–	(D)8a	(D)8a		–	–			(D)12		–
Parapets	–	–	–		–	–			(D)15		–
Fireplaces	–	–	–		–	–			–		(D)22
Misc.	(D)14c,26	(D)26,24	(D)26,24		(D)26	(D)20,25,26			(A)26		(A)26
(B) FIRE PROTECTION											
Comp Strength	–	(B)1	(B)1		–	(B)1			(B)1		(B)1
Mech Strength	–	(B)3	(B)3		–	(B)3			(B)3		(B)3
Bldg Strength	(B)1a	–	–		–	(B)1a			–		–
Tension Cols	–	(B)2,2a	(B)2		–	(B)2			(B)2a		(B)2,2c
Shell	–	(B)4,5,6,7,8,9	(B)4,5,6,7,8,9		–	(B)4,5,6,7,8,9			–		(B)4,5,6
Mechanical Equipt	–	(B)10	(B)10		–	(B)10			(B)10		(B)10
Anchorage	–	(B)11	(B)11		–	(B)11			(B)11		(B)11
Water Supply	–	–	–		–	(B)13			–		–
[illegible]	[illegible]	(B)14,15	[illegible]		[illegible]	(B)14,15			–		(B)15

PROVISIONS SUMMARY	NEW MEXICO (UBC)				ARIZONA (UBC)			TEXAS (-)		CALIFORNIA (UBC)	
	STATE CODE (UBC '79)	STATE MODIF. '6 4/1/80	CITY OF ALBQ (MOD)	CITY OF SANTA FE	CITY OF PHOENIX	CITY OF TUCSON (MOD.)		STATE CODE	CITY OF EL PASO (UBC-MIP)	STATE CODE (UBC '79)	CITY OF LOS ANGELES (MOD.)
(C) SITE PREPARATIONS											
ALKATIVES	–	(C)1	(C)1		–	(C)2		NO CONTRACTOR LICENSING OR PERMITS REQUIRED - CERTAIN CITIES HAVE ADOPTED BUILDING CODE -	(C)1	SEE COL. 1	(C)3
TESTING	–	(C)4	(C)4		–	(C)4a			(C)4		(C)4
MISC.	–	–	–		–	–			(C)5		–
(D) FOUNDATIONS											
BASEMENT FOUND WALLS	–	(D)1	(D)1		–	(D)1a			–		–
FOUNDATION WALL HT	(D)3	(D)3,5	(D)3,5		(D)3a	(D)3,5a			(D)3a,5		(D)3
FOUNDATION WALL THK	–	(D)4	(D)4		–	(D)4a			(D)4		–
FOOTINGS	–	(D)2	(D)2		–	(D)2a			–		–
MISC.	–	–	–		–	–			–		–
(E) MORTARS											
TYPE & BRICK	–	(E)1,2	(E)1,2		–	–			–		–
JOINTS	–	(E)1,2	(E)1,2		(E)3	(E)3			–		(E)3
TYPE	(E)8	(E)1,2	(E)1,2		–	(E)4			(E)5,6,7		–
MISC.	–	–	–		–	–			–		–
(F) PLASTERING											
CEMENT STUCCO MIX	–	(F)1	(F)1,1a		–	–			(F)1		–
THICKNESS	–	(F)2	(F)2		–	(F)2			(F)2		–
STUCCO MIX	–	(F)4	(F)4		–	(F)4			(F)4		–
[illegible]	–	(F)8,10	(F)8,10		–	–			–		–
MOISTENED	–	–	–		–	–			–		–
MISC.	–	(F)5,6,7	(F)5,7		–	(F)8,9			(F)5,6		–

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ADOBE, ITS PERMITTED USES AND RESEARCH NEEDS

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ABSTRACT Abstract: The uses of adobe or unburned clay units as allowed by several California building codes are described. Suggestions are made for research needs for the acceptance of adobe are also provided.

As suggested by the committee for this workshop, this author was requested to present his views on the following three issues:

1. California Use of Adobe
2. Codes and Specifications
3. Research Needs and Gaps

In order to place these viewpoints in proper perspective, it should be pointed out that this author has, for many years, been enforcing the California statutes concerning public school buildings and hospital construction for seismic safety. To explain this a bit further a brief description of our process will be described.

The Education Code Section 39140 through 39156, (1) requires that public school buildings be designed and construction "... for the protection of life and property." Whereas the Health and Safety Code Section 15000 through 15023 (2) requires that hospitals "... must be completely functional to provide all necessary services to the public following a disaster...". This clearly points out the higher level of performance or damage control required by the legislation for hospitals. Both occupancies require the design to be prepared by architects or structural engineers. In the case of hospitals it requires the structural design by a structural engineer. In both cases geologic investigations are required and the drawings and specifications are reviewed by the Structural Safety Section in the Office of the State Architect for conformance with the adopted regulations. Continuous construction inspection is required and the architect, engineer, inspector and contractor must provide reports verifying, under oath, that the construction conforms to the approved construction documents. False reports on schools carry a felony penalty and hospitals carry a misdemeanor penalty.

California Use of Adobe

The use of unburned clay products is not permitted for structural use in hospital and public school construction. However, it has been used occasionally on schools as veneer for architectural reasons. This is not to say that adobe will always be unaccepted for structural purposes in California school and hospital construction. It has always been the attitude of the Structural Safety Section that if it can be demonstrated by the responsible designer that a new product will provide the same level of safety and performance as that of specified products or that the new product will meet all of the adopted performance criteria, the new product could then be acceptable.

The use of adobe is acceptable in other jurisdictions. This is further described below; however, it currently is limited to one-story dwellings or in some locations it may be acceptable in one story buildings.

Codes and Specifications

Title 24, California Administrative Code (CAC)

This is the code used for hospital and public school construction and as indicated above, these codes do not permit the use of adobe. However, other codes do permit the use of adobe or unburned clay units which is the term used in the codes. The reason the Structural Safety Section has found that this material is not acceptable for California public schools and hospitals is because of its low strengths and poor performance during earthquakes. Part of the problem also relates to the variability of its physical properties. One of the keys to the acceptance of material is its dependability of properties. Materials having a wide range of properties must be classified or grouped into defined limits. In order to accomplish this, the controls such as those developed in the Standards of the American Society for Testing and Materials and the controls for job testing and inspections must be clearly established. These strongly relate to the construction technologies and the practice or ability of the trades.

This can be summed up into the statement that "Allowable code values will result with dependable performance". A general policy in the Structural Safety Section is:

> "Let the industry tell us what they will produce and provide us with its physical properties and we will establish where they can use it."

Tentative Provisions for the Development of Seismic Regulations For Buildings (ATC 3-06)

These provisions will permit the use of unburned clay units under certain provisions They are:

1. It can be used throughout any occupancy of a one story building located in the most inactive seismic geographical areas, that is, Seismic Performance Catagory A in areas with Seismicity Index of 1. These areas are defined in ATC 3-06.
2. It can be used in any occupancy of a one story building only for non-structural purposes in areas with a bit more seismic activity, Seismic Performance Catagory B in areas with Seismicity Index of 2.

In all other areas and seismic performance catagories, unburned clay units are not permitted.

Where it is permitted, type M or S mortar is required and the allowable compressive stress is 30 psi and the shear or flexural tension is 8 psi where inspection is provided and 4 psi where no inspection is provided. For structural uses the ratio of unsupported height or length to thickness shall not exceed 10 and where there is no structural significance to its use the ratio shall not exceed 16. Foundation supporting walls of unburned clay units shall extend at least 6 inches above the adjacent ground at all points. Bolt values are also given.

Tests for the units and mortar are required. Also cores must be taken from the finished wall and shall be tested to not less than 100 psi in shear.

1979 Uniform Building Code

The physical properties, allowable stresses and bolt values in the 1979 Uniform Building Code (79 UBC) are basically the same as those given in ATC-3. The limitation to the use of unburned clay units to only one story building is also contained in the 79 UBC.

Section 2312(J)(2)(B) 79 UBC requires that all masonry elements within structures located in Zones 2, 3 and 4 must be reinforced so as to qualify as reinforced masonry. As such, generally accepted forms of reinforced masonry of unburned clay units are not available to the design profession. Therefore unburned clay units may be used in bearing or non-bearing walls of one story buildings in Zone 1.

City and County of San Francisco Building Code

The City and County of San Francisco Building Code does not permit the use of unburned clay units within its jurisdiction. That is, Section 2405 of the 79 UBC has been deleted from its enforcement provision and Section 2312(J)(2)(B) is maintained.

Los Angeles Municipal Code

The Los Angeles Municipal Code commonly known as the Los Angeles City Building Code has the same limitation as the 1979 UBC; however, they will permit the use of unburned clay units in one story buildings. That is, they will not enforce the provisions of 79 UBC, Section 2312(J)(2)(B) for one story buildings. However, designers in the Los Angeles area have used very little of this material.

County of Los Angeles Building Code

The County of Los Angeles Building enforces the provisions of 79 UBC, Section 2312(J)(2)(B), therefore unreinforced masonry construction will not be permitted in the county of Los Angeles.

City of Sacramento

The City of Sacramento will accept the use of adobe only for one story dwellings. It will not accept it in commercial construction.

City of San Diego

The City of San Diego will not accept adobe construction.

County of San Diego

The County of San Diego will accept the use of adobe only for one story dwellings. They will not accept it in commercial construction.

Research Needs And Gaps

There is a considerable amount of information needed to justify the use of unburned clay units in buildings located in seismic areas.

For instance, this author is not aware of any shear wall or bearing wall tests on specimens fabricated from unburned clay brick.

Tests should be performed to determine the f'm values and shear values on ordinary unreinforced adobe, and on various forms of reinforced grouted adobe construction. Cyclic load deflection information is needed as well as height, width and thickness. Influences must be determined. Bolt values on these assemblies should also be verified. The durability of the product must also be investigated and established.

The influence of wire mesh load both in the horizontal joints or plastered onto the surface of the wall should be explored. The influence of such reinforcing on the bolt values should also be determined. The detail of such reinforced plaster connection to the foundation must be addressed. The crushing strength of adobe under concentrated loads from bending members such as beams and headers should be determined.

References

1. California Education Code, Section 39140 through 39156 and Section 81130 through 81141.

2. California Health and Safety Code, Section 15000 through 15023.

3. Title 24, California Administrative Code, Part 6, Division T21 and T22.

4. Tentative Provisions for the Development of Seismic Regulation for Buildings, ATC 3-06, Chapter 1, 3, 12 and 12A.

5. 1979 Uniform Building Code, Chapter 23 and 24.

6. City and County of San Francisco Code, 1975.

7. Los Angeles Municipal Code, 1980

8. County of Los Angeles Building Code, 1977.

PRELIMINARY ABSTRACT

Title of Paper: Adobe Testing. Basis for a Seismic Resistant Code.

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Abstract: A brief outline of test, studies and conclusions on adobe constructions are given, based on the work carried out at the Catholic University of Peru between 1973 and 1980.

These results were used as a basis for the enclosed modified propose for the Peruvian Seismic Resistant Code.

ADOBE CONSTRUCTIONS. BASIS FOR A SEISMIC RESISTANT CODE

J. Vargas Neumann (*)

S U M M A R Y

Basis for a Seismic Resistant Code are presented, using data obtained from tests performed at the Pontificia Universidad Católica del Perú Laboratory.

Tests have been carried out over a period of six years, allowing us to draw some general conclusions regarding types of materials to be used, different ways of placing the reinforcement elements and stress distribution for a wide variety of relatively simple adobe structures.

This information is presented in the form of general guidelines to be used for design and construction purposes.

B A C K G R O U N D

Many countries have been looking into the convenience of standarizing adobe constructions. Peru, a country located within a seismic region, has opted for the inclusion of a chapter regarding that kind of constructions as part of its seismic resistant code.

In April 1977, a National Building Code (1) was approved, which took into account this fact. Nevertheless, no results from the research work carried out before that date (2) and after (3, 4, 5, 6) have been yet incorporated into it.

S C O R E

Results reported in this paper can be used for design and construction purposes of adobe and "tapial"(**) walls, as well as being a reference for brick, artificial or natural stone and soil-cement masonry using mud mortar.

Adobe constructions with and without reinforcement are considered, the rural or urban nature of the building being determined by the type of material used as reinforcement elements. When dealing with urban buildings, enriched mortars will be considered as one of the possible reinforcement materials.

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**Local term applied to walls made cut of compacted mud.

MATERIALS

1. Units

a) Types of Units

No size restrictions are imposed upon units employed in structural elements of masonry, but it is advisable to use 1:1:3 to 1:4:8 parallelepipeds for both the adobe and tapial. Units should be well compacted and used only after a one-month drying period.

As for the mixture composition employed for the preparation of the units, the following is recommended:

- The basic components will be water, clay, silt and sand. Particles below 0.002 mm will be considered clays, those between 0.002 and 0.02 mm silt and the ones between 0.2 and mm, sand. A small percentage (up to 5% in weight) of gravel can also be allowed in the mixture.

- Clay content must be between 10 and 20% in order to assure plasticity and prevent fissures during the drying stage.

- Silt and clay content should be similar, but the total content of both must be kept below 30%; the rest being sand with or without additional components such as straw, fine gravel, dung or others.

- The inclusion of straw is recommended, as long as it does not exceed 1% in weight.

- The use of agglomerates is also advisable. A 1:4 gypsum or cement/mud ratio can be used to increase the quality of the units.

- It is also advisable to incorporate bituminous emulsions to the mixture (stabilized adobe) in order to preserve the construction from humidity and erosion. Normally, 1.5 - 2.0% (on a dry weight basis) of RC-250 asphalt. (7)

b) Compressive Strength

The compressive strength will be determined by testing shaped cubes, the size of which will be equal to the shortest dimension of the adobe unit.

For design purposes, the compressive strength (R_o) is chosen in such a way that 80% of the specimens tested exceed R_o. A safety factor of 2.5 is then applied to that value, so:

$$R_o^* = 0.4\ R_o$$

When tests are carried out using prismatic specimens:

$$R_o = R_\lambda \sqrt{\lambda}$$

where: λ = slenderness (largest/smallest dimension)

$1 \leq \lambda \leq 6$

R_o = compressive strength for $\lambda = 1$.

The size effect for cubical specimens can be considered to be negligible.

If no experimental data is available, values indicated in Table N° 1 can be used (*).

2. Mortars

Mortars can be classified into two groups:

- Type I (Sand and agglomerates based)
- Type II (Soil with or without agglomerates)

a) Type I. Mortar

- Its compressive strength (ASTM C109) should not be lower than 25 Kg/cm^2.
- For cement + sand mortars, the volumetric ratio should be within 1:3 and 1:12.
- For cement + lime or gypsum + sand mortars, the volumetric ratio between agglomerates and inert constituents should be between 1:2.5 and 1:8.
- The amount of water to be used is the minimum allowing full joints within the masonry.

NOTE: The mortar quality is associated to its bond with the units. The use of the compressive strength as an indicator has been adopted for practical reasons only (8).

The above mentioned limits have been established in relation with the bond because of the behavior observed during the tests performed.

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* Data obtained from tests performed on ordinary adobe at the Pontificia Universidad Católica del Perú Laboratory.

b) Type II. Mortar

- This type of mortar is to be used only in rural dwellings or temporary buildings.

- Mortars with compressive strength lower than 25 Kg/cm^2 will be considered in this category.

- The mortar composition must meet the same requirements as the adobe units.

- The water quantity must be the minimum required to obtain a workable mixture.

Masonry joints are to be considered the critical zones, consequently, utmost care should be taken with them.

3. Reinforcement

Due to the adobe constructions fragility, use of reinforcement is recommended to ensure ductility, monolithism and eventually, resistance.

The use of the following materials is suggested:

a) Rural Construction (Mortar Type II)

Cane Arundo Phragmites type, in plain stripes every certain number of rows (from 2 to 4), tied at their ends and placed in every wall. Joints at the top and bottom levels of each span will be reinforced, trying to keep these levels at a uniform height.

Additionally, it is possible to include vertical canes, tied to the horizontal reinforcement, placed in a central plane between the adobe units and surrounded by mortar, greatly increasing the ductility of the construction. The cane employed should be subjected to some preservation treatment before being used as reinforcement.

Wood Placed in span lintels and collar beams above the walls. In both cases, this reinforcement will be tied with wire to the wall foundations. The lintel can be tied to the collar beam.

Wire Placed vertically or in a St. Andrew cross arrangement, fixing the collar beam or lintels to the foundations giving ductiltiy to the structure. It is recommended to stress the wire when placing it.

b) Urban construction (Mortar Type I)

Steel Reinforcing steel bars, forming vertical or horizontal elements of reinforced concrete, avoiding contact with mortars containing gypsum.

Steel mesh embedded in mortar plaster and joining collar beams with foundations can also be used.

Agglomerates
Cement, gypsum or other agglomerates forming enriched mortars.

4. Masonry

a) Thickness of joints

The thickness of the joints will be 20 mm for mortars type II, and 15 mm for mortars type I, with 50% allowance for both.

b) Compressive strength

The masonry compressive strength (R^*_m) can be determined experimentally; alternatively, reference values given in Table N° 2 can be used.

- Pile tests using materials to be employed in the building:

  If possible, piles should be formed by the number of bricks required to obtain a slenderness coefficient of 4. However, 4 unit piles can be used, since it has been observed that for adobe, results show very small variations when the number of joints is above 3 and they are practically independent of the slenderness of the pile being tested. Special care should be taken to maintain the verticality of the specimen. The drying period of the mortar of the pile should be at least one month, the strength of the piles increasing with the drying period (+ 50% during the first year).

  The nominal strength (R^*_m) will be considered to be 40% of the value exceeded by 90% of the piles tested. ($R^*_m = 0.4\ R_m$).

  The minimum number of piles to be tested will be 6, and under no circumstance a value of $R^*_m > R^*_o$ should be considered.

- If no adobe pile tests are available, the reference values of Table N° 2 can be used.

c) Shear Strength

The masonry shear strength (C_m^*) can be determined experimentally, or the reference values given in Table N° 2 can be employed.

- Shear test with materials to be used in construction.

  Specimens will be small walls having a length/height ratio of about 1.7, loaded laterally at 2/3 of its height, with or without simultaneous compression load. Length by height product of specimen should be around 1 m^2. Drying period for the test pieces should be around one month.

  The nominal shear strength (C_m^*) should be considered to be 40% of the specimen strength (C_m) the latter being the value exceeded by 90% of the specimens tested. ($C_m^* = 0.4\ C_m$).

  The minimum number of pieces to be tested will be 12, using three different levels of simultaneous compressive load (4 specimens/load level).

  The shear strength (C_m), will always be calculated as a lineal function of the acting compressive stress:

$$C_m = a + b\ \sigma_m$$

  Experimental results have shown that this value should be multiplied by a scale factor (in order to take into account full scale walls) $\alpha = 2$. C_m will be calculated multiplying a and b by this value of α.

  Only 70% of the gravitational forces will be considered when calculating σ_m, due to the eventual simultaneous action of the inertia forces associated to vertical accelerations present during an earthquake. Additionally, only half of the wall weight will be considered to determine the average height of the critical section.

- If no shear tests are performed, reference values shown in Table N° 2 can be used for design purposes.

d) Tensile Strength

For design purposes, tensile strength across the joints will be considered to be negligible.

e) Modulus of Elasticity

The modulus of elasticity of the masonry can be determined experimentally, but if this is not possible, the following values can be used:

Mortar Type I : $E = 5000\ Kg/cm^2$ or $1000\ R^*_m$

Mortar Type II: $E = 1700\ Kg/cm^2$ or $680\ R^*_m$

The modulus of elasticity increase with the drying period of the test piece.

For short loading periods a 50% increase in the value of E is recommended.

f) Modulus of Rigidity

A value of $G = 0.4\ E$ is suggested.

5. Design and Construction guidelines

Stresses on different elements can be determined using elastic analysis, considering that no tensile stresses are present across the masonry joints.

Due to the complex distribution of stresses within the assemblage of walls with or without spans, the possibility of a detailed elastic analysis is discarded for practical reasons. On the other hand, the elastic behavior of material is only accomplished at a very low level of stresses, producing early and unpredictable redistributions of stresses in the structural element joints as well as around the spans.

6. Structural System

Adobe houses should be compact, with a high density of walls sharing the support of the roof weight; rooms should tend to be square shaped, with very small spans centered in the middle of the walls. The architectural distribution must be in accordance with this scheme.

7. Forces Distribution

Usually, wood or cane is used for the roof of these buildings and the possibility of obtaining rigid diaphragms with these materials can be a difficult and expensive task. In order to overcome this difficulty and guarantee an acceptable behavior of the structure as a whole when subjected to seismic forces, walls aligned along the direction of the seismic action should resist the shear stresses and those normal to it should be capable of resisting the seismic forces by flexure.

The distribution of shear forces will be made according to the zones of influence on each longitudinal wall, considering its mass plus the corresponding fractions of the transverse walls and roof masses. If rigid roofs are present, seismic forces will be distributed according to the relative stiffness of the different walls. In all cases, roofs should be made as light as possible.

The effects of the gravitational loads will be distributed by areas of influence on each wall, according to the structural scheme of the roof.

8. Dynamic Analysis

An adequate aproximation level is considered to be obtained if a quasi-static analysis is carried out, using the recommendations given by the National Building Code.

For the purpose of using the spectrum, the fundamental period (T), can be calculated considering the building as an assemblage of two subsystems: one formed by the transverse walls (which is dominant) and the other formed by the longitudinal walls, so that:

$$T = (T_e^2 + T_s^2)\ 1/2$$

T_e and T_s periods for the longitudinal and transverse walls can be obtained using the static deflection method.

The rapid degradation of the material will provide flexibility to the system, thus decreasing the value of the inertial forces initially assumed.

The ductility reduction factor (R_a) given by the National Building Code will be 1.5, 2.0 or 2.5 depending on the type of reinforcement used (horizontal cane, steel wire or cane mesh respectively).

9. Design of Longitudinal Walls

The strength C_A will be used over the critical cross section of each wall (subtracting the spans if that is the case). Part of the transverse walls cross section can be included (only if they are present at both ends), this extra area being equal to 25% of the length of the shortest wall or five times the thickness of the longitudinal wall multiplied by their respective thickness (whichever is smaller).

10. Transverse Wall Design

The method of yield lines is recommended, based on the permanent action of a (gravitational) flexure resistant moment through the wall cracks or using the expressions obtained by that method, modified by empirical evidence.

The study of these walls defines the spacing of the bracing walls, the length of which must not be shorter than:

$$l_o = \frac{chl}{2}$$

where: l_0 = bracing wall length

c = seismic coefficient employed

h = wall height

l = length of the main wall

The thickness of the bracing wall will be the same or larger than the main wall

For pre-dimensioning purposes, the maximum distance between bracings can be considered to be:

$$d = 2.5 \frac{b}{ch}$$

11. Foundations

To minimize the seismic effects, the adobe constructions should only be founded on solid soils. (σ admissible ≥ 3 Kg/cm^2).

ACKNOWLEDGEMENTS

The Author wishes to express his gratitude to all those persons involved in the different research programs from which the information for this paper has been taken.

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NOTATION

γ = Safety factor for admissible stresses.

R_o = Nominal value of the compressive str th for cubical test pieces (value exceeded by the 80% of the specimens tested).

R_o^* = Value of reduced compressive strength (γ = 2.5), to be used in design for admissible stresses.

R_λ = Value of compressive strength for slender test pieces.

λ = Slenderness coefficient of test pieces (largest/shortest dimension $\geq$ 1).

R_m^* = Value of reduced compressive strength for masonry, to be used in design for admissible stresses.

R_m = Value of compressive strength for masonry piles with 1:4 slenderness, (minimum 4 adobes) exceeded by 90% of the specimens tested.

T_f^* = Value of reduced tensile strength by flexure for the units (γ = 2.5).

T^* = Value of reduced tensile strength (Brazilian test) in cylindrical specimens of 15 x 30 cm (γ = 2.5).

C_m = Value of shear strength for the masonry wall, exceeded by 90% of the specimens tested.

C_m^* = Value of shear strength for the masonry, to be used in design for admissible stresses.

σ_m = Compressive stress acting on the masonry ($\sigma_m < R_m$) (Kg/cm^2)

E = Modulus of Elasticity (Kg/cm^2)

G = Modulus of Rigidity (Kg/cm^2)

TABLE N^{O} 1

Admissible Resistance of Units

Reference values of results obtained on ube tests:

Compression (cubes)	$R_o^* = 0.4\ R_o = 5\ Kg/cm^2$
Tension by flexure (units)	$T_f^* = 1.3\ Kg/cm^2$
Tension (Brazilian Test)	$T^* = 0.3\ Kg/cm^2$

NOTE: These values may be increased by 20%, if the mixture contains 25% or more cement or gypsum (on a dry volumetric basis).

TABLE N^{O} 2

Admissible Resistance of Masonry

Reference values of results obtained on adobe pile tests:

Compression

Mortar Type I :	$R_m^* = R_o^*$
Mortar Type II:	$R_m^* = 0.5\ R_o^*$

Shear

Mortar Type I :	$C_m^* = 0.08 + .48\sigma_m\ (Kg/cm^2)$
Mortar Type II:	$C_m^* = .040 + .24\sigma_m\ (Kg/cm^2)$

ENSAYOS DE ELEMENTOS DE ADOBE.
BASES PARA UN CODIGO SISMO RESISTENTE

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RESUMEN:

Se presenta en forma abreviada los estudios, ensayos y conclusiones sobre construcciones de adobe, realizados en la Pontificia Universidad Católica del Perú desde 19.3 a 1980.

Estos resultados fueron la base para la propuesta modificatoria del Código Sismo Resistente peruano, que se incluye como apéndice.

ADOBE TESTING. BASIS FOR A SEISMIC RESISTANT CODE

SUMMARY:

A brief outline of tests, studies and conclusions on adobe constructions are given based on the work carried out at the Catholic University of Peru between 1973 and 1980.

These results were used as a basis for the enclosed modified propose for the Peruvian Seismic Resistant Code.

ENSAYOS DE ELEMENTOS DE ADOBE. BASES PARA UN CODIGO SISMO RESISTENTE

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I. Introducción

Las primeras ciudades construídas por el hombre, de las que se tiene noticia, surgieron en la Baja Mesopotamia y fueron hechas de tierra sin cocer. Desde varios siglos antes de Cristo hasta nuestros días se ha seguido empleando sus dos principales tipos, el Adobe y el Tapial. Con este material se han levantado viviendas, templos, fortalezas y en el presente siglo, inclusive, edificios de varios pisos (1).

Se debe reconocer una tradición en la construcción de adobe o tapial, pero desafortunadamente muy pocos han intentado adaptar la tecnología de la Ingeniería Sismo Resistente a obras realizadas con este material.

Sin embargo, la mayor parte de las víctimas y daños que los sismos ocasionan ocurren en viviendas rústicas, rurales y pobres que se elaboran en base a tierra sin cocer o a piedra asentada con barro (Foro 1). Es indudable que un serio esfuerzo de la investigación mundial en el campo de la Ingeniería Antisísmica debiera ser urgentemente orientado hacia este grave problema.

Este trabajo que pretende dar un punto de vista latinoamericano del estado del conocimiento existente, incursionará también en el bosquejo de lo que necesitaríamos conocer para resolver los problemas prioritarios.

En la técnica de construir con adobe, se acentúan una serie de problemas que la Ingeniería Sismo Resistente ya ha detectado y está en proceso de resolver, para obras con otros materiales. Todo ello debido a la gran fragilidad y, en general, pobreza de la albañilería de adobe. Este hecho conduce a la necesidad de guiarse mas por la opinión o intuición antes que desarrollar análisis numéricos profundos.

Indudablemente es conveniente enriquecer las decisiones con la mayor información que hoy es posible obtener: la que proviene de la observación de daños producidos por los terremotos y la que se deriva de la realización de ensayos de laboratorio.

Países tercer mundistas como Perú, México, Irán, Turquía, India, etc., han iniciado programas de investigación que ojalá tengan eco en otras latitudes y países con mayores posibilidades de investigación. Ello significa poner al alcance de los investigadores, mejores herramientas para la profundización del conocimiento, tales como los más modernos avances tecnológicos en términos de computación, equipos de laboratorio, etc., acrecentados por el contacto con los mas altos niveles de formación.

También destaca en la tecnología del adobe la relativamente mayor importancia de los aspectos constructivos y de selección de los materiales. Detalles en la constitución del material de las juntas de asentado de los bloques, son piezas fundamentales en la resistencia de la albañilería de adobe como veremos posteriormente.

En las construcciones de adobe dañadas por terremotos es más palpable, que en otros materiales, el hecho de que los métodos actuales para definir ingenierilmente el movimiento del suelo son poco acertados. La acelera-

ción instrumental máxima registrada tiene baja relación con el nivel de daños observado. En países como Chile y Perú se estudia la utilización de otros parámetros para distribuir espacialmente la actividad sísmica o más aún, la destructividad sísmica. Un último estudio probabilístico de Riesgo Sísmico para zonificar el Perú, que se viene realizando en la Pontificia Universidad Católica del Perú, indica que hay mayor relación entre la destructividad y la distribución del algoritmo $\frac{ad}{v^2}$ (valores máximos esperados para un mismo período de retorno), que con la distribución de aceleraciones máximas, o velocidades máximas, o desplazamientos máximos tomados separadamente (2). De esta manera se remedia parcialmente , a través de la inclusión de una relación de "frecuencias dominantes", la ausencia de la dimensión del tiempo.

Lo anterior ha sido corroborado por observaciones de destrucción en viviendas rurales de adobe, la que empieza a producirse desde muy bajos niveles de severidad de los movimientos, en razón de su fragilidad. La distribución de destructividad , "filtró" la consideración de los efectos locales a causa del subsuelo que en el caso de las construcciones de adobe, resulta crítica. Las características dinámicas de este tipo de construcción, la flexibilidad creciente durante el proceso de degradación de los muros, la desconexión de los diferentes elementos desde bajos niveles de daño, son tales que se concluye en la necesidad de ubicar este tipo de obras exclusivamente en suelos firmes y estables frente a las vibraciones.

La observación de los daños en construcciones de tierra también revela la notable influencia de la simultaneidad de las diferentes componentes del movimiento sísmico. El fenómeno ha sido posible reproducirlo parcialmente en laboratorio con promisor éxito para investigaciones futuras. Este conocimiento conduce al diseño de importantes detalles de refuerzo, especialmente en las conexiones de los diferentes elementos. La distribución simétrica y uniforme de muros, la tendencia a habitaciones cuadradas y vanos pequeños, la adecuada rigidez torsional, cobran especial importancia y darán rígidas pautas al proyecto arquitectónico. Pautas mucho más exigentes que para otros materiales con mejores propiedades mecánicas.

La complejidad de los modelos estructurales, que puedan representar con éxito a las masivas construcciones de adobe, es bastante grande. Hasta el momento se ha intentado solucionar este problema con modelos fuertemente simplificados, comprobados empíricamente y en forma aproximada por ensayos estáticos de laboratorio (3). Se ha realizado también en México, ensayos en mesa vibratoria que abren el camino para establecer modelos de comportamiento dinámico (4 y 5). Las opiniones coinciden en señalar la necesidad de realizar ensayos a escala natural sobre mesa vibradora, para corroborar los resultados hasta ahora obtenidos por medio de ensayos estáticos a escala natural o vibratorios pero con modelos a escala reducida.

Finalmente, toda esta experiencia adquirida de la observación de daños y ensayos de laboratorio, debe canalizarse para su uso por los usuarios urbanos y rurales. Ya se incluye en algunos países, códigos sismo resistentes para construcciones de adobe (6) y en la realidad latinoamericana ello significa tan solo la difusión de estos conocimientos a nivel urbano. Queda por solucionar la difícil misión de difundir los conocimientos adquiridos en el esparcido y accidentado medio rural.

2. Ensayos para definir las propiedades mecánicas del adobe

Empezaremos por distinguir las propiedades mecánicas del bloque o unidad, de las propias a la albañilería. Esto debido a la fuerte variación de resultados según el tipo de material de junta, que llamaremos mortero. La experiencia demuestra que aún utilizando únicamente morteros de barro, de las mismas características del bloque de adobe, es posible observar enormes diferencias en la resistencia de la albañilería, sin que existan mayores diferencias en las propiedades de los bloques.

En otras palabras, el estado del conocimiento del comportamiento mecánico del adobe no permite, como en el caso de la albañilería de ladrillo, deducir una resistencia de la albañilería, conociendo las características del bloque y el mortero.

En el caso del adobe asentado con el mismo barro, las pruebas que se realizan sobre el mortero, vienen a ser las mismas que se pueden realizar sobre el bloque. Las probetas de mortero no tienen mayores diferencias con los bloques mismos. Por ello, se ha tratado de normalizar únicamente un juego de ensayos que dan información sobre ambos.

Mas bien si se utilizan morteros enriquecidos con materiales aglomerantes (cemento, cal, yeso, etc.) sin que la mezcla contenga tierra como elemento inerte, es posible utilizar las mismas pruebas que se usan para el mortero de la albañilería de ladrillo, para conocer las propiedades mecánicas del mortero.

Una idea básica debe quedar clara en la evaluación de estos morteros: la práctica de clasificarlos según su resistencia a compresión obedece a razones de simplicidad, pero poco tiene que ver dicha resistencia con la buscada adherencia que los morteros deben tener con los bloques y de la cual depende grandemente la resistencia de la albañilería. Recordemos que en el comportamiento sísmico de una obra de tierra, la resistencia a compresión de la albañilería no parece ser crítica.

2.1. Ensayos sobre el bloque o unidad

2.1.1. Compresión axial

Los ensayos sobre el bloque o medio bloque no han dado buenos resultados por el confinamiento que se produce en la probeta, especialmente en los bloques cuya menor dimensión es de 8 a 10 cms.

Por esta razón se prefirió normalizar este ensayo sobre cubos cuya arista sea la menor dimensión del bloque, siempre que ésta no sea mayor de 15 cms. Caso contrario deberá tallarse cubos de 10 cms. Estudios sobre la influencia del tamaño de la arista, revelan la conveniencia de esta limitación.

Se ha analizado la influencia de la esbeltez de prismas (tallados de bloque o adobe), en la resistencia a compresión. También se

ha realizado ensayos dinámicos, con variaciones de la frecuencia en señales armónicas y a distintos niveles de carga con relación a la carga última de los ensayos estáticos.

Las principales variables que influyen en la resistencia a la compresión son: la composición del suelo, su densidad, tiempo de secado y contenido de humedad.

El orden de magnitud de la resistencia a compresión puede apreciarse con los siguientes resultados:

Perú (PUCP) cubos de 8 cms.	$\sigma_{prom.} = 1.5\ N/cm^2$	(3)
México (UNAM) cubos	$\sigma_{máx.}$ varía de 0.52 a 1.6 N/cm^2 según la procedencia del suelo (5)	
U.S.A.	$\sigma_{máx.}$ varía de 0.41 a 5.4 N/cm^2 según la composición del suelo (7,8,9 y 10).	

2.1.2. Tracción

Se ha logrado buenos resultados confeccionando probetas cilíndricas con moldes semejantes a los utilizados para el concreto (6" x 12"). El secado en dichos moldes requiere de un tiempo varias veces mayor que el necesario para los bloques. Este ensayo tipo brasilero demostró, en el caso del adobe peruano, que la resistencia a tracción es del orden del 8% de la de los cubos a compresión de 10 cms. de arista.

2.1.3. Tracción por Flexión .- (Módulo de Ruptura)

Se ha discutido sobre los detalles del ensayo del bloque a flexión, por ejemplo, distancia entre apoyos en relación a su mayor dimensión, material de apoyo, etc., pero en general pareciera que la heterogeneidad propia del material, no permite precisar los resultados diferenciados de esas sutiles variaciones. En principio las normas ASTM para bloques de ladrillo son aplicables al caso del adobe, siempre que se fije el ancho del bloque que sí es un factor determinante, pues a mayor ancho se obtendrá mayor resistencia. Se sugiere normalizar un ancho de 30 cms. con una tolerancia de ± 5 cms.

Es importante destacar que las variables que influían en la resistencia a compresión de los cubos, influyen también en la resistencia a tracción, pero no necesariamente en el mismo sentido ;

y lo mismo ocurrirá para la resistencia frente a otras solicitaciones (corte, cizallamiento, etc.). Así, mientras el contenido de arcilla, por poner un caso, influye positivamente en la compresión, lo hace negativamente en la tracción. También ocurre que la influencia del tiempo de secado o contenido de humedad, son más influyentes en la resistencia a tracción que en la de compresión.

Se reporta en general resistencias a tracción por flexión del orden de entre la cuarta y la sexta parte de la resistencia a compresión (3,9).

2.1.4. Corte o Cizallamiento

Utilizando técnicas que normalmente emplean los especialistas de Mecánica de Suelos (ensayos triaxiales) o de Mecánica de Rocas (ensayos de cizallamiento) se ha intentado evaluar algún tipo de resistencia al corte. Sin embargo los resultados no son halagadores, al menos como para normalizar el ensayo. Por otro lado, la utilidad de conocer la resistencia del bloque no aparece tan clara, como si ocurre más bien en la albañilería de adobe.

2.2. Ensayos sobre pequeños elementos de albañilería de adobe

2.2.1. Compresión axial

El ensayo más típico resulta ser el de la pila de adobes asentados horizontalmente (la menor dimensión vertical). Estudios experimentales acerca de la influencia de la esbeltez de dichas pilas y del número de juntas rellenas de mortero, revelan que la relación 1:4 entre la menor y mayor dimensión de la pila da resultados estables con dimensiones todavía muy manejables para el transporte (5,11).

Sin embargo, si las pilas son confeccionadas con adobes mas bien verticales (menor dimensión horizontal), se obtienen importantes variaciones no solo en la resistencia que disminuye, sino en el módulo de rigidez que aumenta aún en mayor proporción. Esto demuestra la no isotropía de la albañilería de adobe para cargas aplicadas en su plano (3).

Variaciones en la dimensión de los bloques no producen efectos significativos, pero si influye fuertemente (50%) el tiempo de secado. Ello se ha comprobado que la composición del mortero influya mayormente para este tipo de solicitación.

La inclusión en el mortero de barro de aglomerantes como la cal o el yeso, mejoran la resistencia en un 20 ó 25% (12). Si en cambio los morteros son de aglomerantes con arena en vez de tierra (cemento-arena, cemento-yeso o cal-arena, etc.), los incrementos de resistencia pueden ser del orden del 250 ó 300%. Asimismo, este tipo de morteros aumenta considerablemente el módulo de elasticidad (mayor rigidez).

Se ha concluido también en la importancia del espesor de las juntas. Si éstas son muy gruesas, disminuye la resistencia y transportabilidad de las pilas.

Respecto al ensayo mismo, es conveniente tomar providencias especiales para garantizar una carga axial sin mayores excentricidades. Las medidas de la deformabilidad de la pila deben ser tomadas a través de deformómetros laterales y no ubicados en los extremos de la pila.

Si el tiempo de secado es grande, ensayos bien elaborados producen resistencias iguales a las de los cubos de 10 cms. de arista en pilas con mortero de barro y juntas horizontales. Experiencias reportadas en la referencia (11) dieron estos resultados con un 14% de coeficiente de variación.

2.2.2. Compresión Diagonal

Este ensayo realizado primero en México y luego en Perú, sirve para evaluar la resistencia al corte de la albañilería, parámetro básico en el comportamiento sísmico de los muros de adobe. La deducción teórica de la distribución de esfuerzos se encuentra en las referencias 13 y 14. El tamaño de las probetas cuadradas es del orden de un bloque y medio por lado. El ancho es el de la menor dimensión del bloque.

Estos ensayos pueden realizarse con la probeta en posición horizontal con la carga paralela al suelo o en posición vertical con la carga perpendicular al suelo. Las mediciones de deformaciones son efectuadas sobre las 2 diagonales del especimen.

Una investigación conjunta realizada entre la UNAM de México y la PUCP del Perú, para corroborar las fuertes diferencias reportadas en este tipo de ensayos, reveló que la resistencia al corte puede variar de 1 a 5 dependiendo de las propiedades del barro de la junta de asentado. Esta investigación si bien descartó algunas variables que pudieron haber explicado las diferencias, no planeaba profundizar en el porqué y el cómo la composición del suelo influía tan fuertemente. Resulta imprescindible ahondar este tipo de investigaciones y llegar a resultados que junto con los incrementos de resistencia y ductilidad que se describirán posteriormente, transformarían las construcciones de adobe en edificaciones seguras y económicas.

Mientras que el promedio de los resultados peruanos es de τ_o 0.026 N/cm^2 con un coeficiente de variación del 61%, los resultados mexicanos arrojan valores del orden de 0.13 N/cm^2.

2.2.3. Ensayos de Corte Directo

Este ensayo propuesto en la norma peruana (6), sirve para defi-

nir los esfuerzos admisibles en los muros que absorben la fuerza sísmica de una construcción. Como es conocido, la resistencia al esfuerzo cortante es función del nivel de esfuerzo de compresión (σ) que actúa simultáneamente en el plano del especimen. En la foto 2 se aprecia la realización del ensayo cuyo especimen consta de un ensamble de 2 bloques completos (arriba y abajo) y dos medios bloques separados 1 cm. (al medio). Los resultados se ajustan a una expresión del tipo de $\tau = \alpha + \beta\sigma$ donde α sería una cierta medida de la cohesión y β del coeficiente de fricción aparente.

Numerosos ensayos realizados en el Perú (11), han permitido ajustar esta expresión, corrigiendo la recogida en la norma vigente. Los ensayos se realizaron con variaciones de σ entre 0.02 y 0.2 N/cm^2 y con variaciones en el espesor de la junta. No resulta fácil relacionar estos resultados con los de muros a escala natural y ésto constituye un inconveniente para normalizar el ensayo.

2.2.4. Ensayos de Corte en Muretes

Intentando una mejor relación entre muretes pequeños (alrededor de 1 m^2) y los muros a escala natural, se han realizado gran número de ensayos con variación de dimensiones, espesores de junta y calidad de morteros. Estos ensayos consisten en la aplicación de una carga concentrada horizontalmente en el mismo plano de los muretes ubicados verticalmente. Otra variable de estudio fue la altura del punto de aplicación de la carga en relación a las dimensiones de la probeta, intentando incluir estas variables en la expresión de la resistencia al corte, lo cual no resulta sencillo. De los ensayos sobre estos pequeños muretes se ha logrado establecer un factor de escala respecto a los muros de tamaño natural, pero es necesario ampliar el número de ensayos para terminar de dominar este problema. Sin embargo, el ensayo en sí resulta muy simple y adecuado para normalizarlo.

Utilizando este ensayo se ha realizado estudios de albañilería de adobe con morteros de junta de distintos materiales, permitiendo una primera clasificación de morteros para efectos de definición de normas técnicas (ver clasificación el apéndice). El ensayo es muy eficiente para optimizar morteros de cualquier material.

2.2.5. Ensayo de Flexión

En el caso de muretes pequeños, el ensayo que mejores resultados ha proporcionado es el de flexión de muretes en posición horizontal apoyados en dos o cuatro lados. Desafortunadamente sólo es posible realizar este ensayo con albañilería de adobe de muy buena calidad. Los especímenes se elaboran verticales y luego se relaten. Esta operación obliga a un mínimo de calidad para evitar fisuras previas al ensayo mismo. Se ha intentado tam

bién confeccionar los especímenes horizontalmente y luego retirar parte del molde, pero aún así se requiere de buena mampostería para soportar tan solo el peso propio y posteriormente cierta carga vertical (concentrada y aplicada al centro cuando hay 2 apoyos y uniforme cuando hay 4 apoyos).

Por lo expuesto, no es muy conveniente normalizar este ensayo pues serviría solo para ciertos tipos de albañilería de adobe.

2.3. Ensayos con elementos a escala natural

2.3.1. Ensayos de corte en muros

Estos ensayos consisten en la aplicación de una carga concentrada en el plano del muro. Los tamaños de los especímenes varían entre cuadrados de 2m. de lado a rectángulos de 2.4 x 4.0 m. (3,15).

Fundamentalmente se utilizan dos tipos de ensayos dependiendo de la calidad de la albañilería.

El primer tipo es el ensayo en voladizo, que es apropiado para albañilería de poca resistencia, si es que se desea obtener una medida de esta resistencia al corte con un tipo de falla semejante al que ocurre en las construcciones por efecto de los sismos. Este ensayo somete a la probeta a tracciones en la parte inferior de la cara que recibe la carga y ésto de alguna manera disminuye la resistencia al corte, lo cual no deja de ser un inconveniente. Normalmente la fuerza se aplica a través de un elemento de repartición. La falla empieza donde termina ese elemento de repartición. La altura "efectiva" del muro a efecto de comparaciones con cálculos analíticos debe considerarse desde el suelo hasta el inicio de la fisura.

El segundo tipo utiliza dos tirantes verticales a los lados del especimen que bajo una leve tensión unen dos vigas de concreto. La viga superior recibe la carga lateral y la inferior actúa como cimiento y está fija a la base. Este ensayo logra una buena falla de corte, pero tiene el inconveniente de ir tensando un tirante y aflojando el otro, a medida que aumenta la carga lateral, introduciendo una distribución de tensiones muy desuniforme y variable entre fase y fase de carga. Este ensayo o una variación del mismo con un solo tirante, es conveniente para albañilerías de mejor calidad (Ver fotos 3 y 4).

Estos ensayos conducen a la evaluación de la resistencia cortante y a expresiones empíricas aplicables al diseño o comprobación de muros de adobe. Así en Perú se definen expresiones lineales en función del esfuerzo unitario de compresión ($\tau = a + b\sigma$), que tienen validez solo dentro de un cierto rango de σ. Para valores mayores de σ se puede utilizar una expresión cuadráti

ca ($\zeta = c + d\sigma$), como la definida en México $\zeta = \gamma_0 \left[1 + \zeta/\gamma_0 \right]$, donde γ_0 es la resistencia a tracción que se supone constante.

También se ha ejecutado ensayos sobre muros en L o en T para apreciar la distribución de esfuerzos en la conexión, el tipo de falla y principalmente para definir criterios prácticos de diseño, que involucren en el cálculo de la resistencia al corte de los muros longitudinales, parte del área correspondiente a los muros transversales (3).

2.3.2. Ensayos de Flexión en muros

Dos tipos de falla muy comunes por acción de los sismos, ocurren debidos básicamente a la flexión: la falla vertical en los encuentros de muros y la falla vertical al centro de los muros largos. Por supuesto estas fallas muchas veces se complican por la actuación de otras solicitaciones o por la presencia de vanos.

Para estudiar la resistencia a flexión se han ejecutado ensayos con cargas perpendiculares al plano del muro, apoyado este en uno, dos, tres y cuatro lados. Gracias a este tipo de ensayos se pudo establecer la aplicabilidad de la teoría de líneas de rotura para el diseño o comprobación de muros (16). Por supuesto también son aplicables los conceptos de la teoría elástica en base a los parámetros establecidos a través de los ensayos sobre especímenes pequeños de albañilería (ya descritos en 2.2) y corroborar por los ensayos a escala natural.

Estos mismos ensayos de cargas perpendiculares al plano del muro han sido ejecutados sobre ensambles de muros en "U" para estudiar el comportamiento de las esquinas (3). (Ver Foto 5)

3. Refuerzos y Ductilidad

Por un lado se han realizado esfuerzos por mejorar la calidad del adobe y su albañilería, en base a estudios sobre su composición y que, como ya se ha mencionado, puede variar la resistencia de la albañilería de 1 á 5 veces según el tipo de mortero de junta. Pero por otro lado es también indispensable conceder ductilidad a las construcciones y tratándose de un material muy frágil, es necesario para ello recurrir a la utilización de algún tipo de refuerzo. Para estudiar y optimizar este reforzamiento se han desarrollado ensayos a escala natural de "módulos" de cuatro paredes, que pueda ser representativo del comportamiento de las construcciones reales de adobe.

3.1. Ensayos estáticos de bajo costo

Uno de los procedimientos utilizados para estudiar el reforzamiento adecuado de construcciones de adobe, consiste en la inclinación paulatina, mediante gatos, de una mesa de concreto sobre la que se ha construído los "módulos" o especímenes. De esta manera una componente de la fuer

za gravitacional actúa paralela a la base, tal como ocurre con las componentes horizontales de un sismo real. Con estos ensayos se consiguen fisuras del tipo de las que se presentan en los sismos reales y es posible evaluar los incrementos de resistencia de corte flexionante que confieren los diferentes acomodos de refuerzo. Es posible efectuar ensayos cíclicos y también ensayos que simulen la actuación simultánea de las dos componentes horizontales de un sismo (en relación variable de sus valores, con diferentes giros en planta del "módulo" respecto a los ejes de la mesa inclinable). (Ver Foto 6)

Con este tipo de ensayos se realizó en la PUCP el estudio de refuerzos para viviendas rurales en base a caña, alambre y madera (3, 17).

El reforzamiento que resultó más eficiente en base a caña, se muestra en la fig. 1 y la foto 7 muestra una fase del ensayo de un módulo con ese tipo de refuerzo. Para dar una mejor idea de la ductilidad lograda con esta disposición de refuerzo, en la fig. 2 se comparan los resultados de los ensayos de corte sobre muros en voladizo, realizados sobre un especimen sin refuerzo y otro reforzado.

Los resultados de estos ensayos estáticos debieran ser ratificados por ensayos con equipo más sofisticado que induzca algún tipo de solicitación dinámica (mesa vibradora).

3.2. Ensayos en mesa vibradora

Los únicos ensayos dinámicos, utilizando una mesa vibradora, han sido efectuados en la Universidad Nacional Autónoma de México con modelos reducidos a escala 1:25 bajo un programa de refuerzo de vivienda rural (1977-78). Ellos relacionaron los resultados teóricos y experimentales, así como evaluaron la eficiencia de ciertos refuerzos (viga cadena superior de concreto armado, tensores metálicos, etc.). Las conclusiones de este programa se encuentran en la referencia (4).

Las dificultades para elegir un modelo dimensional son importantes y ésto hace difícil la cuantificación de los esfuerzos críticos durante el ensayo, así como también su distribución. A la fecha no se han realizado ensayos sobre mesa vibradora con modelos a escala natural.

La línea de reforzamiento que se recomienda en México para ductilizar las construcciones, en base a sus experiencias, difiere totalmente de la recomendada en Perú, pues esta última limita previamente los materiales de refuerzo a los obtenibles en las áreas rurales relativamente incomunicadas. De esta forma las experiencias se complementan, ampliando la gama de soluciones posibles de reforzamiento.

No debe olvidarse la acción simultánea de las aceleraciones verticales que conlleva un sismo, especialmente para definir ciertos detalles constructivos tales como las cadenas superiores de rigidización de madera o concreto, y que probablemente no se puedan observar en los ensayos en mesa vibradora unidireccional, como los que existen en México y Perú. En otras palabras, si bien es cierto que estos ensayos permiten acercarnos

al estudio del comportamiento de las construcciones de adobe durante los sismos, hay que completar esta información con intuición y observación sobre edificaciones que han soportado terremotos.

4. Líneas futuras de Investigación

El estado del conocimiento de las construcciones de adobe es tal, que se vislumbra prontas soluciones económicas y seguras realizando investigaciones en dos sentidos:

- Influencia de la composición del mortero de junta y unidad de adobe. Optimización de la composición. Influencia de las propiedades físico-químicas del suelo.

- Perfeccionamiento de los sistemas de refuerzo, incorporación de nuevos materiales. Rigidización de techos ligeros.

Respecto a la primera ya se ha manifestado que es posible incrementar la resistencia del orden de 5 veces, variando adecuadamente los componentes del adobe (especialmente del mortero en relación al adobe). Si a ésto le añadimos la mejora en resistencia debida a los refuerzos, que según se ha reportado es del orden 2.5 a 3 veces respecto a las construcciones sin reforzar, ya podemos afirmar que se cumplirá pronto aquel deseo de John Blume que escribió para los lectores de Newsletter-EERI, en el sentido de que le agradaría promover cualquier programa de investigación sobre viviendas pobres, si es que se pudiera obtener incrementos de 10 veces su resistencia con muy bajo incremento del costo.

En base a las dos principales líneas de investigación mencionadas, se concluye que es imperativo el apoyo al desarrollo de nuevas investigaciones sobre construcciones de adobe. El esfuerzo e interés desplegados para poder apreciar las posibilidades y logros con dicho material, requieren ahora del concurso de mayores medios y mejores especialistas para lograr los objetivos bosquejados.

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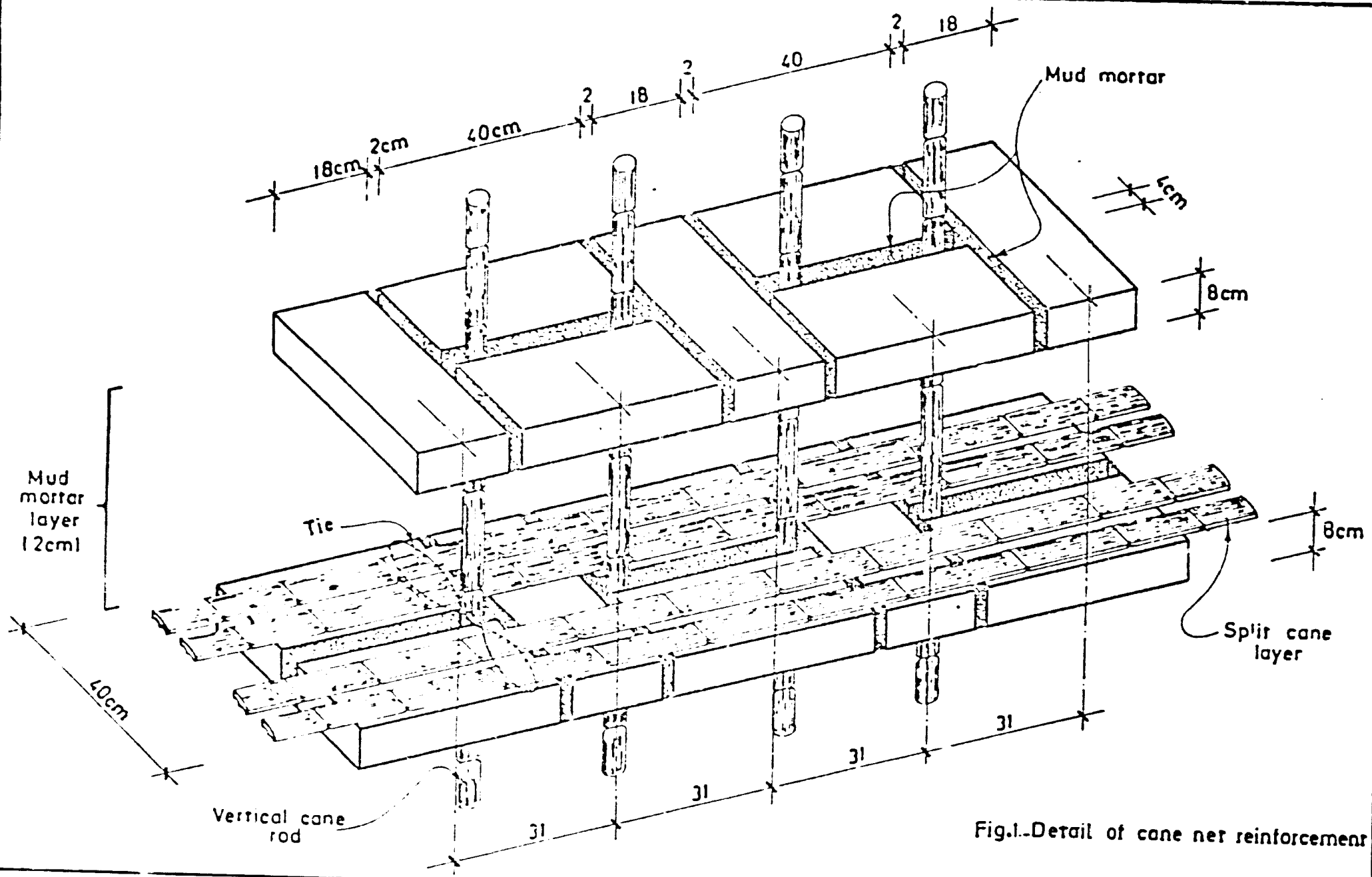

Fig.1.-Detail of cane net reinforcement

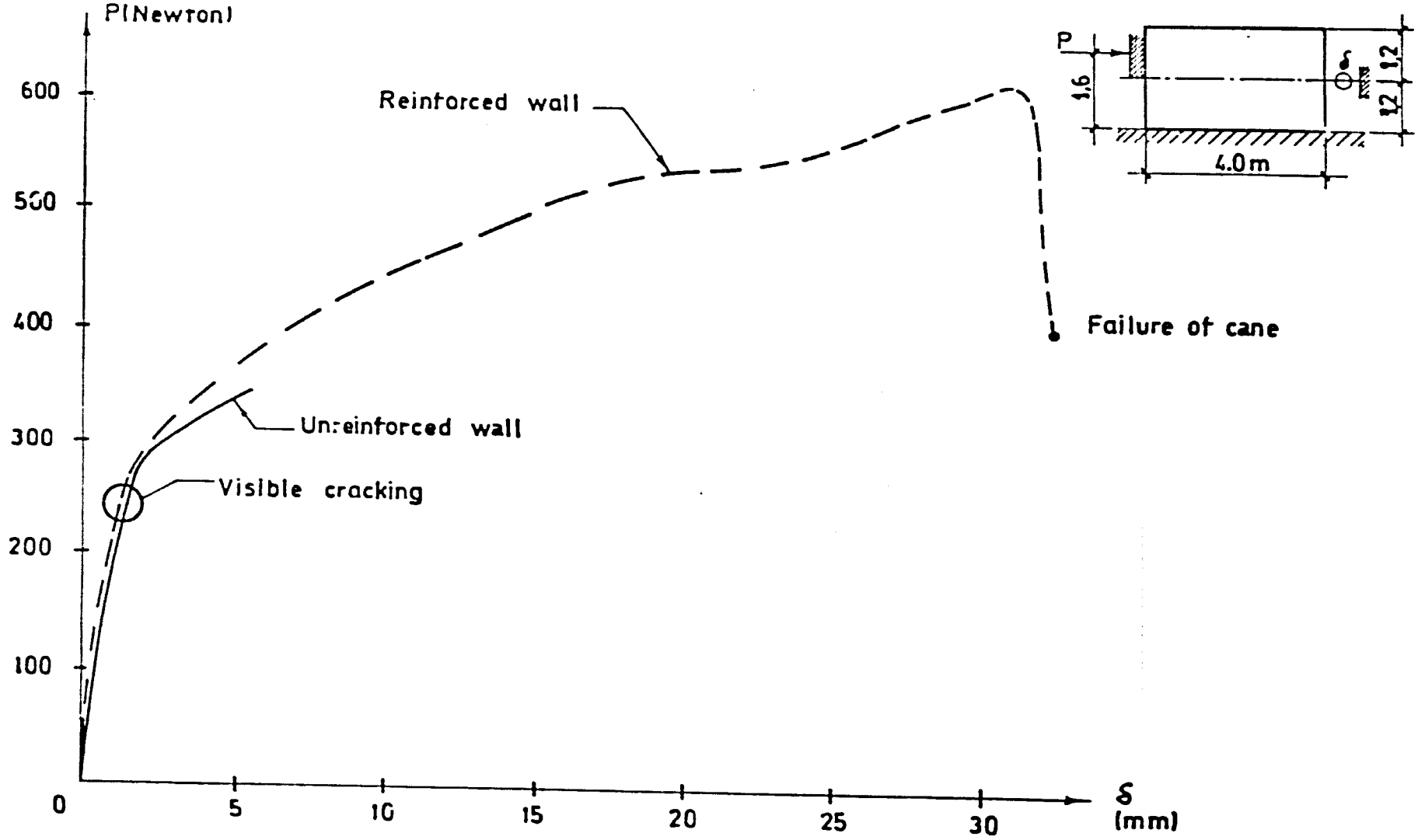

Fig. 2.- Ductility in reinforced wall (net of cane)
Monotonic load

A P E N D I C E

CONSTRUCCIONES DE ADOBE. BASES PARA UN CODIGO SISMO RESISTENTE

1.- ANTECEDENTES

Muchos países se han cuestionado acerca de la conveniencia de reglamentar la construcción con adobe. En el Perú, de acuerdo a su realidad, optó por la implementación de un código antisísmico que posee un capítulo para dichas construcciones (1). En Abril de 1977 se aprobó el Reglamento Nacional de Construcciones con esta singularidad, sin embargo, no alcanzó a recoger los resultados de las investigaciones que antes de esa fecha se realizaron y continúan aún realizándose (2, 3, 4, 5 y 6).

2.- ALCANCE

Las disposiciones de este proyecto, pueden aplicarse al diseño y construcción de muros constituídos por adobe y tapial, así como servir de referencia para mampostería de piezas de ladrillo, piedra artificial o natural, suelo-cemento, etc. con mortero de barro.

Se contempla construcciones de adobe con y sin refuerzo , diferenciando los materiales utilizados según se trate de obras rurales o urbanas. Esto incluye la utilización de morteros enriquecidos.

3.- MATERIALES

3.1. UNIDADES

3.1.1. TIPOS DE UNIDADES

Las unidades usadas en elementos estructurales de mampostería no tendrán restricción alguna en sus dimensiones, pero se recomienda que éstas sean paralelepípedos de proporciones enmarcadas entre 1:1:3 y 1:4:8 para el caso del adobe y tapial. Las unidades serán macizas y se utilizarán solo después de un mes de secado.

En cuanto a la composición de la mezcla para fabricar las unidades, se recomienda bs siguientes lineamientos:

- Los componentes mínimos serán agua, arcilla, limo y arena. Se considerará como partículas de arcilla las menores de 0.002 mm., de limo las comprendidas entre 0.002 y 0.02 mm.y de arena las comprendidas entre 0.2 y 2 mm.
- Podrá tolerarse un pequeño porcentaje (hasta 5% en peso) de partículas de grava.

- El contenido de arcilla deberá estar comprendido entre 10 y 20%, para asegurar la plasticidad sin tener problema de fisuras por el secado.

- La cantidad de limo deber se semejante a la de la arcilla, pero ambas no debieran sobre pasar el 30%. El saldo deberá ser arena con o sin ingredientes adicionales, tales como paja, gravilla, estiércol, etc.

- Debe utilizarse la menor cantidad de agua que permita una adecuada trabajabilidad.

- Se recomienda el uso de paja siempre que no exceda de 1.0% en peso.

- Es recomendable utilizar adicionalmente aglomerantes como el yeso o cemento en proporciones de alrededor de 1:4 con barro, para incrementar la calidad de las unidades.

- Es recomendable utilizar emulsiones asfálticas (adobe estabilizado asfalto RC-250, 1.5 á 2%), para preservar la construcción frente a la humedad, erosión, etc. (7).

3.1.2. RESISTENCIA A LA COMPRESION

La resistencia a la compresión se determinará ensayando cubos labrados cuya arista sea la menor dimensión de la unidad de adobe o cubos de alrededor de 10 cms. de arista para el caso del tapial. Se empleará un valor de la resistencia (R_o), calculada en base al área de la sección transversal. Este valor será el sobrepasado por el 80% de las piezas ensayadas.

A efectos de diseño se considerará un coeficiente de seguridad de 2.5 ($R^*_o = 0.4\ R_o$).

Se podrá homologar resultados de probetas prismáticas de esbeltez λ = mayor/menor dimensión, utilizando la expresión $R\lambda = R_o / \sqrt{\lambda}$ (para $\lambda \leq 6$). No se considerará significativa la variación del tamaño de la arista de la probeta cúbica. El valor de R_o corresponde a $\lambda = 1$.

De no contarse con resultados experimentales, podrá considerarse el valor consignado en la tabla 1 (*).

El valor de R^*_o ha sido calculado como $0.4\ R_o$.

(*) Datos obtenidos con adobe corriente, en la Pontificia Universidad Católica del Perú.

3.2. MORTEROS

Los morteros podrán clasificarse en dos grupos:

a) Tipo I (En base a arena y aglomerantes).

b) Tipo II (En base a tierra con o sin aglomerantes).

3.2.1. MORTEROS TIPO I

- Su resistencia a compresión (ASTM C109), no será menor de 25 kg./cm^2.

- Si se trata de morteros de cemento arena, la relación volumétrica estará comprendida entre 1:3 y 1:12. Debe utilizarse arena gruesa.

- Si se trata de morteros de cemento cal o yeso arena, la relación volumétrica entre aglomerante y agregado inerte estará comprendida entre 1:25 y 1:8.

- Deberá emplearse la mínima cantidad de agua que permita juntas planas en la albañilería.

NOTA.-

La calidad del mortero está asociada a la adherencia con las unidades. El uso de la resistencia a compresión como indicador, obedece solo a razones prácticas (8).

Los límites señalados han sido fijados en relación con dicha adhrencia, dado el comportamiento durante los ensayos efectuados.

3.2.2. MORTEROS TIPO II

- Serán utilizados únicamente en viviendas rurales o construcciones provisionales.

- Se considerará dentro de esta categoría a los morteros con resistencias a compresión menores que 25 kg./cm^2.

- La composición del mortero debe cumplir los mismos lineamientos que las unidades.

- Deberá emplearse la menor cantidad de agua que sea necesaria para una mezcla trabajable.

Se considera que las juntas de la albañilería constituyen las zonas críticas, en consecuencia ellas deberán recibir el mayor cuidado.

3.3. REFUERZOS

Dada la fragilidad de las construcciones de adobe, es indispensable la utilización de refuerzos, tendientes a proporcionarles ductilidad, monolitismo y eventualmente resistencia.

Se sugiere la utilización de los siguientes materiales y funciones:

3.3.1. OBRAS RURALES.- (MORTERO TIPO II)

Caña : (Tipo carrizo)

En tiras planas cada cierto número de juntas (de 2 ó 4), cocidas en los encuentros y en todos los muros. Se reforzará la junta que coincida con el nivel superior o inferior de cada vano, tratándose de que estos niveles coincidan de un vano a otro.

Adicionalmente es posible colocar cañas verticales atadas a las horizontales y colocadas en un plano central entre unidades de adobe y rodeadas de mortero. Esta disposición proporciona gran ductilidad a la construcción. La caña deberá ser tratada para efectos de conservación.

Madera:

En dinteles de vanos y en vigas "collar" sobre los muros. En ambos casos se sujetará con alambre dicho refuerzo al cimiento de los muros. El dintel puede sujetarse a la viga "collar".

Alambre:

Vertical o en cruz de San Andrés, para fijar la viga "collar" o los dinteles a la cimentación. Proporciona ductilidad al conjunto. Se recomienda tensar el alambre al colocarlo.

3.3.2. OBRAS URBANAS.- (MORTERO TIPO I)

Acero :

Varillas corrugadas de construcción, formando elementos verticales u horizontales de concreto armado. Evitar contacto con morteros que contengan yeso.

Mallas de acero embutidas en enlucidos de mortero, uniendo viga collar con cimentación.

3.4. MAMPOSTERIA

3.4.1. ESPESOR DE JUNTAS

El espesor de las juntas será de 2 cms. para morteros tipo II, y de 1.5 cm. para morteros tipo I, con una tolerancia del 50%.

3.4.2. RESISTENCIA A COMPRESION

La resistencia a compresión de la mampostería, R^*_m, podrá determinarse experimentalmente o por los valores referenciales de la tabla 2.

a) Ensayo de pilas, con materiales a usar en obra.

De preferencia las pilas estarán compuestas por el número de ladrillo necesaria para obtener un coeficiente de esbeltez de 4. Sin embargo, podrá usarse pilas desde 4 unidades, en vista de que ha quedado demostrado que para el adobe, luego de 3 juntas, la variación de resultados es mínima y prácticamente independiente del coeficiente de esbeltez. Se tendrá especial cuidado en mantener la verticalidad del especimen. El tiempo de secado del mortero de las pilas será de alrededor de un mes. La resistencia de las pilas aumenta significativamente con el tiempo de secado (± 50% en el primer año).

La resistencia nominal R^*_m se considerará como el 40% del valor sobrepasado por el 90% de las pilas ensayadas.
$R^*_m = 0.4\ R_m$. El número mínimo de pilas a ensayar será de 6. En ningún caso se considerará $R^*_m > R^*_o$

b) Si no se realiza ensayos de pilas de adobe, se podrá utilizar los valores referenciales de la tabla 2.

3.4.3. RESISTENCIA A CORTE

La resistencia a corte de la mampostería, C^*_m podrá determinarse experimentalmente o por los valores referenciales de la tabla 2.

a) Ensayo de corte, con materiales a usar en obra.

Los especímenes serán muretes de relación largo-altura de alrededor de 1.7, cargados lateralmente a 2/3 de su altura, con o sin carga de compresión simultánea. El producto del largo por la altura será de alrededor de 1 $m.^2$

El tiempo del secado de las probetas será de aproximadamente un mes.

La resistencia nominal, C^*_m se considerará como el 40% de la resistencia del murete, C_m considerada como el valor sobrepasado por el 90% de los ensayos $C^*_m = 0.4\ C_m$.

El número mínimo de probetas a ensayar será de 12, utilizando tres niveles distintos de esfuerzo de compresión simultánea (4 probetas por nivel).

La resistencia a corte, C_m se calculará siempre como una función lineal del esfuerzo de compresión actuante.

$C_m = a + b\ \sigma_m$

Resultados experimentales demuestran que este valor debe ser afectado de un factor de escala (para considerar muros a escala natural) $\alpha = 2$, de modo que los valores de a y b deberán ser multiplicados por este factor α, antes de calcular C_m.

En el cálculo de m se considerará solamente el 70% de las fuerzas gravitacionales, debido a la eventual actuación simultánea de fuerzas de inercia asociadas a aceleraciones verticales propias a un sismo. Adicionalmente solo se considerará el peso propio de medio muro para fijar una altura promedio del área crítica.

b) Si no se realiza ensayos de corte, se podrá realizar los valores diferenciales de la tabla 2.

3.4.4. RESISTENCIA A TRACCION

Para fines de diseño se considerará nula la resistencia a tracción de la mampostería. (Esfuerzos perpendiculares a las juntas).

3.4.5. MODULO DE ELASTICIDAD

El módulo de elasticidad de la mampostería podrá evaluarse experimentalmente, o en su defecto considerar:

Mortero tipo I : $E = 5000\ kg./cm^2$ ó $1000\ R^*_m$

Mortero tipo II : $E = 1700\ kg./cm^2$ ó $680\ R^*_m$

El módulo de elasticidad se incrementa con el tiempo de secado de la probeta.

Para cargas de corta duración se utilizará un valor de E incrementado en un 50%.

3.4.6. MODULO DE RIGIDEZ

Se considerará como $G = 0.4\ E$.

4. GUIAS DE DISEÑO Y CONSTRUCCION

La determinación de los esfuerzos actuantes en los diferentes elementos, en general se harán a través de un análisis elástico, teniendo en cuenta que la mampostería no resiste tracciones normales a las juntas. Dada la compleja distribución de esfuerzos en las paredes con o sin vanos, ensambladas ortogonalmente, se descarta la posibilidad de un análisis elástico muy prolijo para fines prácticos. Por otro lado, el comportamiento elástico del material solo se cumple a un nivel muy bajo de esfuerzos, produciéndose tempranamente redistribuciones impredecibles de esfuerzos, ya sea en las uniones de elementos como alrededor de los vanos.

4.1. SISTEMA ESTRUCTURAL

Las casas de adobe deben ser compactas, con una gran densidad de muros, de ser posible todos colaborantes (portando el peso del techo), de habitaciones cuya planta tienda a ser cuadrada, con vanos muy pequeños y centrados al medio de las paredes. La distribución arquitectónica debe obedecer a este esquema.

4.2. DISTRIBUCION DE FUERZAS

Usualmente los techos de este tipo de viviendas es de madera o caña. Con estos materiales resulta costoso y difícil lograr diafragmas rígidos como para conseguir un comportamiento conjunto de los muros frente a acciones sísmicas. Por tanto, para este tipo de efectos se considerará que las paredes paralelas a la acción sísmica en estudio, resisten el corte y las transversales resisten por flexión las fuerzas perpendiculares a su plano.

La distribución de las fuerzas de corte se hará por zonas de influencia sobre cada puro longitudinal, considerando la propia masa y las fracciones pertinentes de la masa de muros transversales y la del techo.

En el caso de contar con techos rígidos en su plano, se distribuirá las fuerzas sísmicas según la rigidez relativa de los diferentes muros.

Los techos deberán ser lo más ligeros posibles.

El efecto de las cargas gravitacionales se distribuirá por áreas de influencia sobre cada muro, según el esquema estructural del techo.

4.3. ANALISIS DINAMICO

Se considera que el nivel de aproximación adecuado se logra con un análisis cuasi-estático, utilizando las indicaciones del Reglamento Nacional de Construcciones.

A efectos de utilización del espectro, el período fundamental (T), se puede calcular considerando a la vivienda como un ensamble de dos subsistemas: el de los muros transversales (que es dominante) y el de los muros longitudinales, de tal forma que:

$$T = (T_e^2 + T_s^2)\ 1/2$$

Los períodos T_e y T_s de los muros longitudinales y transversales se pueden obtener utilizando el método de la deflexión estática.

La rápida degradación del material originará una flexibilización del sistema, que disminuirá el valor de las fuerzas de inercia inicial - mente supuestas.

El factor de reducción por ductilidad Rd., que el Reglamento Nacional indica, será de 1.5, 2.5 según se haya considerado refuerzos de cañas horizontales cocidas, alambre vertical o diagonal o malla de caña, respectivamente.

4.4. DISEÑO DE MUROS LONGITUDINALES

La aplicación de la resistencia C^*_m, se efectuará sobre el área transversal crítica de cada muro (descontando vanos si fuera el caso). Se podrá incluir el área de una fracción de los muros transversales (solo si los hay en los dos extremos), igual al 25% de la longitud del menor de ellos, pero nunca mayor de cinco veces el espesor del muro longitudinal.

4.5. DISEÑO DE MUROS TRANSVERSALES

Se recomienda utilizar el método de líneas de rotura, basado en la actuación permanente de un momento flector resistente (gravitacional) a través de las fisuras del muro o bien utilizando las expresiones ajustadas empíricamente a partir de dicha teoría.

El estudio de estos muros define la separación de los muros de arriostre transversales, cuya longitud no deberá ser menor que:

$$l_o = \frac{c\ h\ l}{2}$$

donde: l_o = longitud del muro de arriostre

c = coeficiente sísmico empleado

h = altura de los muros

l = longitud del muro principal

El espesor del muro de arriostre será igual o mayor que el del muro principal.

Para efectos de predimensionamiento podrá considerarse que la distancia máxima entre arriostres será:

$$d = 2.5 \frac{b}{c\,h}$$ donde b es el espesor del muro principal.

$$d \leq \frac{4}{3} h$$

4.6. SUELO DE CIMENTACION

Para minimizar los efectos sísmicos, las construcciones de adobe solo podrán cimentarse sobre suelos firmes (σ admisible ≥ 3 kg/cm^2).

NOTACION

γ = Coeficiente de seguridad para esfuerzos admisibles.

R_o = Valor nominal de la resistencia a compresión en probetas cúbicas, sobrepasado por el 80% de los especímenes.

R_o^* = Valor de la resistencia minorada ($\gamma = 2.5$) a compresión, para uso en diseño por esfuerzos admisibles.

R_λ = Valor de la resistencia a compresión en probetas de esbeltez λ.

λ = Coeficiente de esbeltez de la probeta, cociente entre mayor y menor dimensión de la misma ($\lambda \geq 1$).

R_m^* = Valor de la resistencia minorada ($\gamma = 2.5$) a compresión de la mampostería, para uso en diseño por esfuerzos admisibles.

R_m = Valor de la resistencia a compresión de pilas de mampostería con esbeltez 1:4, (mínimo 4 adobes), sobrepasado por el 90% de las probetas ensayadas.

T_f^* = Valor de la resistencia minorada de tracción por flexión de unidades ($\gamma = 2.5$).

T^* = Valor de la resistencia minorada de tracción (Ensayo brasilero) en probetas cilíndricas de 15 x 30 cm. ($\gamma = 2.5$)

C_m = Valor de la resistencia a corte de muretes de mampostería, sobrepasado por el 90% de las probetas ensayadas.

C_m^* = Valor de la resistencia minorada ($\gamma = 2.5$) a corte de la mampostería, para uso en diseño por esfuerzos admisibles.

σ_m = Esfuerzo de compresión actuante en la mampostería ($\sigma_m \leq R_m$) (kg/cm^2)

E = Módulo de Elasticidad (kg/cm^2)

G = Módulo de Rigidez (kg/cm^2)

TABLA Nº1

RESISTENCIAS ADMISIBLES DE UNIDADES

- **Valores referenciales de resultados de ensayos en adobe.**

Compresión (cubos) :	R^*_o	$= 0.4\ R_o = 4.5\ kg./cm^2$
Tracción por flexión (Unidades):	T^*_f	$= 1.3\ kg./cm^2$
Tracción (Ensayo brasilero):	T^*	$= 0.3\ kg./cm^2$

NOTA.- Estos valores podrán incrementarse en un 20% , si la mezcla contiene cemento o yeso en proporción volumétrico igual o mayor al 25% respecto al resto de los componentes secos.

TABLA Nº2

RESISTENCIAS ADMISIBLES DE MAMPOSTERIA

- **Valores referenciales de resultados de ensayos de pilas de adobe.**

COMPRESION :

Mortero tipo I : $R^*_m = R^*_o$

Mortero tipo II : $R^*_m = 0.5\ R^*_o$

CORTE :

Mortero tipo I : $C^*_m\ .08 + .48\ \sigma_m\ (kg./cm^2)$

Mortero tipo II : $C^*_m\ .04 + .24\ \sigma_m\ (kg./cm^2)$

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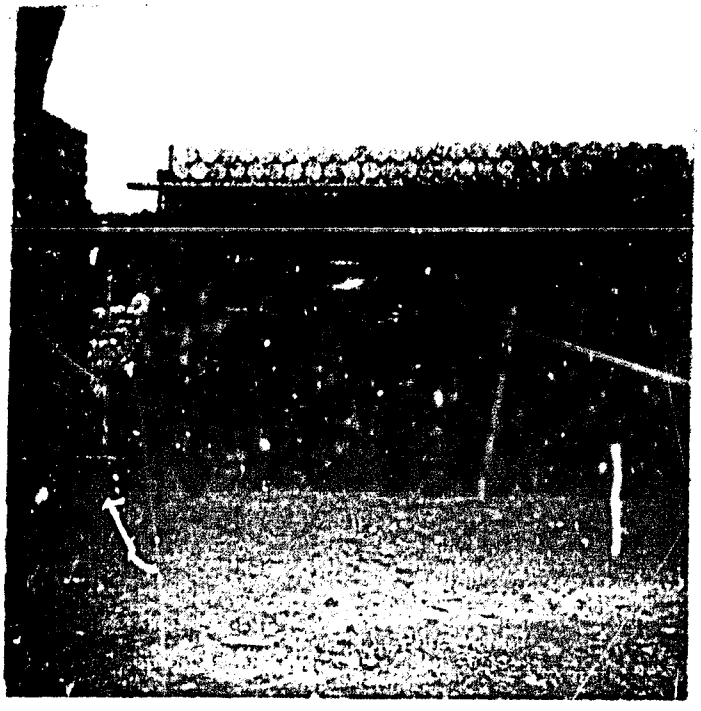
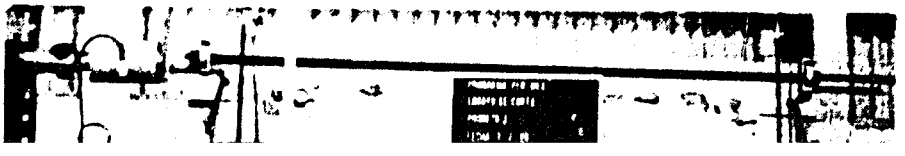


3. Ensayo de corte de muro en voladizo.



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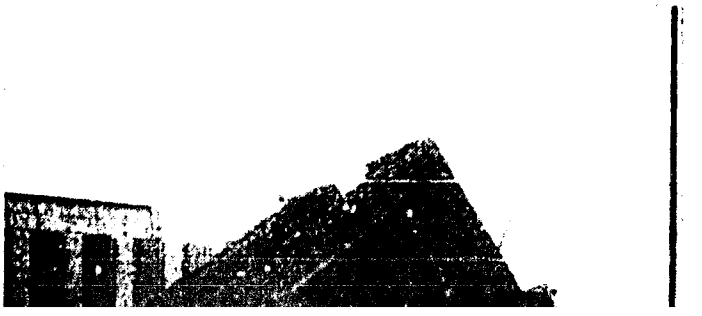
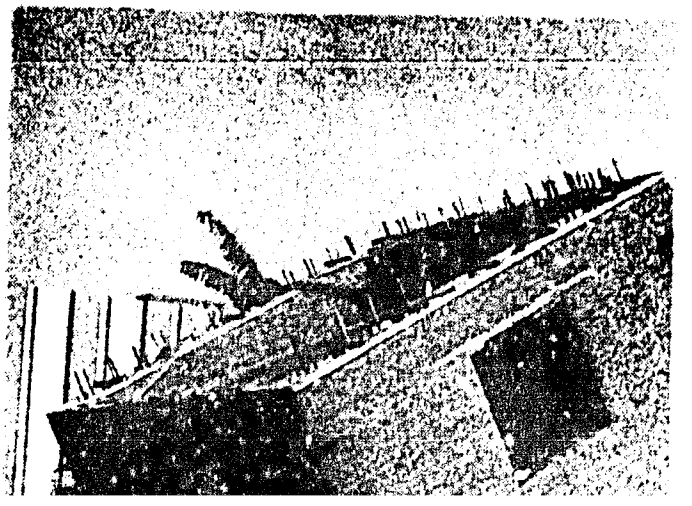




TURKISH STANDARDS AND CODES ON ADOBE AND ADOBE CONSTRUCTIONS

Müfit Yorulmaz
Technical University of Istanbul,Turkey.

ABSTRACT Standards on adobe, cement treated adobe blocks, adobe buildings and their construction methods are presented.

Adobe buildings section of Turkish Earthquake Code is also presented and compared with the above mentioned standards; the conformability of Standards and the Code is discussed by taking into consideration the ideas which were effected the preparation of these regulations.

1. Introduction

In Turkey adobe buildings, though decreasing sharply in number in cities, they are still widespread in rural areas and hold a percentage of approximately 20 %, of all buildings which have been built as masonry structures. Apart being used structurally, adobe blocks are also used as a filling material for timber framed constructions. (1)

Adobe is most popular, particularly in the regions where farming is the main occupation. Climate is another factor effecting to its usage, e.g., regions with land climate seem more favourable for this material.

People living in rural areas who have to build their own houses, stables and straw ricks prefer adobe for the following reasons :

a. Raw material of adobe, i.e. clayey earth, is available nearly everywhere and in most cases free of charge,
b. They have a wrong impression that these houses could be built without feeling necessity for some technical knowledge or advice,
c. Workmanship is simple,
d. These houses provide high degree of thermal and noise insulation,
e. Farmers could build their houses by utilizing their seasonally available free time.

On the other hand, in some cases, adobe houses have some significant disadvantages. These buildings are vulnerable to water. Adobe blocks may lose most of their strength and shape

adobe blocks as a building material and to establish a set of rules for designing adobe buildings and their construction methods.

Turkish Standards Institute and Ministry of Reconstruction and Resettlement to achieve the above mentioned objectives issued three standards and a code respectively, under the following titles :

a.1. Cement treated adobe bricks, (2)
2. Adobe blocks and production methods, (3)
on adobe as a building material,
b.1. A specific section in Turkish earthquake resistant building design code related with adobe buildings, (4)
2. Adobe buildings and construction methods, (5)
on adobe buildings.

The purpose of this paper is to introduce, discuss and compare the contents of the standards and the code mentioned above.

Initially, rules of standard and/or code will be presented, then the applications made by people who are unaware of these rules and build according to their traditional methods.

2. Adobe Blocks

2.1. Dimensions :

Standard defines two groups of adobe blocks each having two types :

		Dimensions (cm)	Volume (dm3)	Weight (kp)	
Group I	a.	12x19x40	9.12	10-12	(cub)
	b.	12x30x40	14.40	15-25	(mother)
Group II	a.	12x18x30	6.48	7-11	(cub)
	b.	12x25x30	9.00	10-15	(mother)

Dimensional tolerances are ±5 %

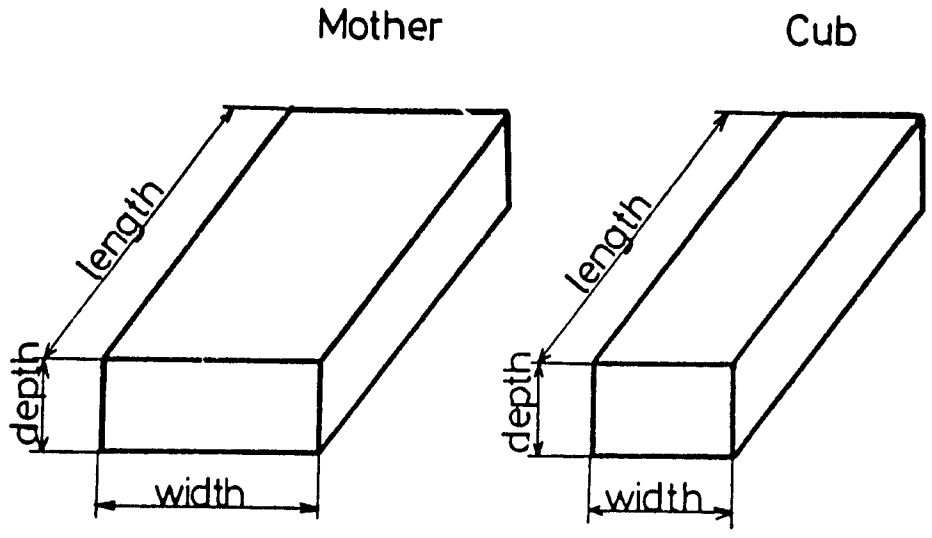


FIG. 1
Adobe block dimensions

for mother blocks (27 to 30) x (30 to 40) cm. (6).

This shows that standard aimed to obtain an average value of usual dimensions and generalize it as a rule.

2.2. Compressive Strength :

Standardly, compressive strength of adobe blocks should have a minimum of 8 kp/cm2, and the average of three specimens tested should be 10 kp/cm2 at minimum.

Compression tests on specimens sampled through 62 localities have given an average value of 9.55 kp/cm2 for compressive strength, 3.12 kp/cm2 for standard deviation. (6). This shows that standard values are viable and can be realized with little effort.

2.3. Water resistance :

When they are tested, as described in the standard, it is expected that the blocks should not disintegrate before 45 minutes.

2.4. Materials for adobe blocks :

Standard describes the raw materials of adobe blocks as follows :

Adobe blocks are made of clayey earth. The most suitable

stones bigger than 3 cm. If earth contain more clay than it is recommended, then sand, crushed brick or stone, slag is advised to be added. Hay, which is used as an additive, should be dry, not-rotten and their fibre lengths should be 10 - 12 cm. Mixing water should be clean.

In practice, earth usually obtained from excavated earth at building site or in the neighbourhood, however, in some cases special pits provide earth for adobe construction. Roots, gravel and in most cases hay are additives used in practice, though in some regions additives are not used at all.

2.5. Preparation of materials :

Standard describes the production method as follows :
A pit is excavated 3-5 m in diameter and one meter in depth and an amount of earth, which will be treated in one day is deposited into it. 500 lt water and additives are added for each m3 of earth and they are mixed and pressed thoroughly. Depending on the clay ratio within the earth, for each m3 of earth, hay is added with the following amounts :

20 % clayey earth	5 - 7 kp
35 % clayey earth	7 - 10 kp
50 % clayey earth	10 - 15 kp
70 % clayey earth	15 - 20 kp

This mixture left at rest for 12 hours.

In case earth has a high clay ratio, 70 - 340 lt sand,stone or brick crushings or slag should also be added for each m3 of earth.

In practice, however much more hay is added as compared to

life applications throughout the country. However, standard puts them forward in a systematic manner and emphasizes the important points.

2.7. Tests on adobe blocks :

Standard describes the tests which should be done on raw material and the adobe blocks and explains the preparation of test specimens, test procedures and how the test results should be interpreted. These tests are on the determination of :

a. Tension and compression strength, shrinkage, softening properties of the mud material,
b. Dimensional accuracy, compression strength and water absorption properties of adobe blocks.

It is inconceivable for a villager, who builds his own house to carry out these tests. Therefore, the purposes of defining these tests, as I understand, to help government offices responsible for building habitations at rural areas by standardizing the tests and to provide common basis for different laboratories working on adobe constructions.

2.8. Works on improving the qualities of adobe blocks :

Several researchers have been working to improve the properties of adobe blocks. Cement treated adobe blocks with their established standard are some of results of these works.

2.8.1. Treating with cement :

Standard gives the dimensions of cement treated adobe blocks as :

7x11.5x24 cm
11x11.5x24 cm
11x17.3x36.5 cm

Their density should be 1.70 - 1.95 kp/dm3. Dimensional tolerances are 5%.

Then, preparing of the earth-cement mixture and casting into moulds are explained.

Finally, tests for dimensional accuracy, density and compression strength are described.

Tests carried out by researchers have shown that applying pressure on the mixture causes increase on the compressive strength of the cement treated blocks. (7). With 5% and 10% cement contents compressive strengths are increased to 20 and 35 kp/cm2 respectively. After water absorption and freeze-thaw tests these strengths are only decreased by 10 - 15%.

2.8.2. Treating with gypsum or other stabilizers :

Since Turkey has big deposits of gypsum, gypsum treating of adobe blocks is also investigated with successful results. 10 - 15 % gypsum addition to earth has increased compressive strength of gypsum treated blocks to 40 - 50 kp/cm2. (8, 9, 10).

3. Adobe Buildings

Under this title standard and the earthquake code are presented and compared.

3.1. Materials :

Adobe blocks should conform to their standards. Stone and timber should conform usual building standards and material specifications. Mortar is the same material which is used to produce adobe blocks. Apart from conventional roof covers, timber planks, reed, hay, clay and earth are mentioned as

3.2. Number of storeys :

Standard mentions one and two storey buildings.

Earthquake code gives permission only single storey adobe houses, with at most, a stone walled basement. As 95 % of population of Turkey lives in earthquake zones, that means nearly all adobe constructions in Turkey should required to be single storey buildings.

3.3. Foundations :

Standard gives a minimum of 70 cm for the foundation depth with a provision that it may change depending on the soil conditions.

Earthquake code increases this depth to 80 cm and below to the freezing level of the site.

For the width of foundations, standard gives 50 cm for single storey, 60 cm for double storey buildings and instructs to revise these widths for poor soil conditions. Earthquake code also gives 50 cm width and calls for the stone foundation wall to raise at least 50 cm above ground and specifies the mortar qualities for stone foundation walls. These matters have been explained in the standard in more detail. Furthermore, specific information is given on the arrangement of steps of foundation levels at the sloping building sites. Earthquake code calls for 60 cm stone wall for basement walls.

Surveys made on 76 localities have shown that average foundation depth is 76 cm and standard deviation is 34 cm. (12).

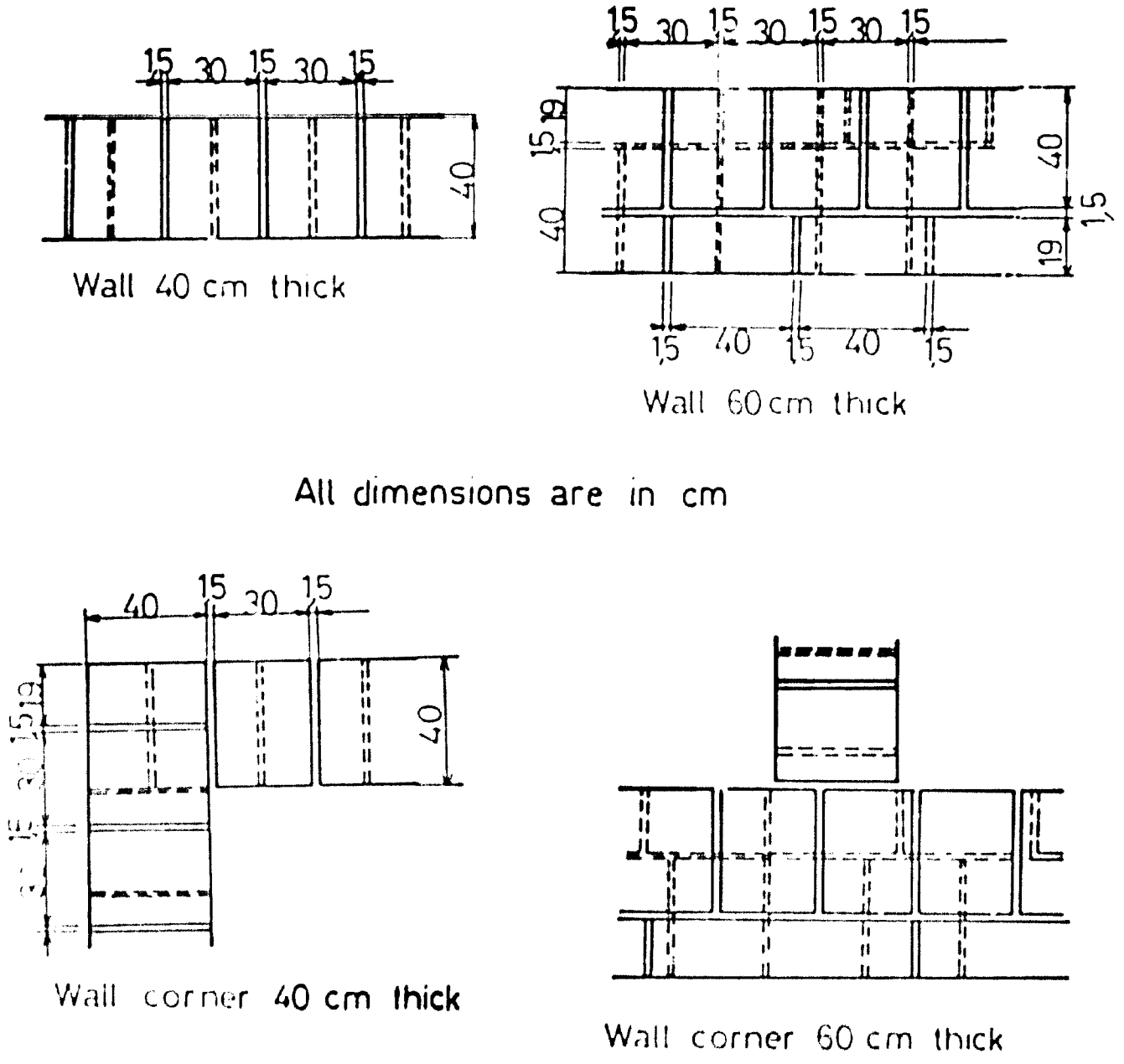


FIG. 2

Wall thicknesses

Earthquake code assumes the length of adobe block 30 cm, which differs from standard's block dimensions and instructs 45 cm wall thickness for external walls and 30 cm wall thickness

Standard allows 18 cm wall thickness for non-structural walls.

Measurements made on 82 localities give an average wall thickness of 57 cm for external walls with a standard deviation of 10 cm. (12). For internal walls 63 measurements were made and average thickness is found as 50 cm with a 13 cm standard deviation.

The wall thicknesses given both in standard and earthquake code are smaller than the applications in practice. Apparently, the standard and the code assume blocks which were produced properly according to their own standards. As a matter of fact, the maximum compression stress is calculated as 2.18 kp/cm2 for a single storey adobe house which is designed against seismic effects. (13). This value, compared with the compressive strength of, 10 kp/cm2, given in the standard, represent an ample safety factor of 4.6.

3.4.2. Wall heights :

Standard has given maximum wall heigths as :

for 40 cm thickness 2.50 m ,

for 50 cm thickness 3.00 m ,

for 60 cm thickness 3.50 m .

Earthquake code restricts this height to 2.70 m for all cases.

Then standard gives information on constructing of the wall. On the other hand earthquake code instructs buildings to be rectangular in plan and symmetrical in both directions.

3.4.3. Free longitudinal length of walls :

Standard fixes the free space between the transverse walls at 4.00 m maximum. This distance may be increased to 6.00 m at independent stables and straw ricks.

Earthquake code gives this distance as 4.50 m between the axis of transverse walls, which conforms with standard's value.

3.4.4. Wall openings :

Earthquake code gives more detail on this subject and standard differs slightly from the code.

Minimum distance between the building corner and the opening should be 1.00 m and the opening should be at least 50 cm from the crossing point of walls. Maximum dimensions for doors are, 1.00x2.10 m , for windows are 0.90x1.40 m. Wall portions between openings should be minimum 60 cm ; if this distance is shorter, then two 10x10 cm timber posts should be provided on both sides of the opening and these posts should be connected to tie beams and/or lintels.

These limitations on openings could provide a good thermal insulation and enough load carrying capacity to absorb the lateral forces due to earthquake action.

Insulation against humidity should be provied under all adobe walls.

3.5. Chimneys :

Chimneys should be so arranged that they should not coincide with the cross-section of structural walls. Preferably they should not made of adobe blocks. Cross-sections of chimney space should be minimum 4.15 cm or 15x15 cm

said 4 levels on both surfaces of the wall. They should be tied with each other horizontally at every 1.00 m according to standard and every 0.50 m according to code with cross tie-beams.

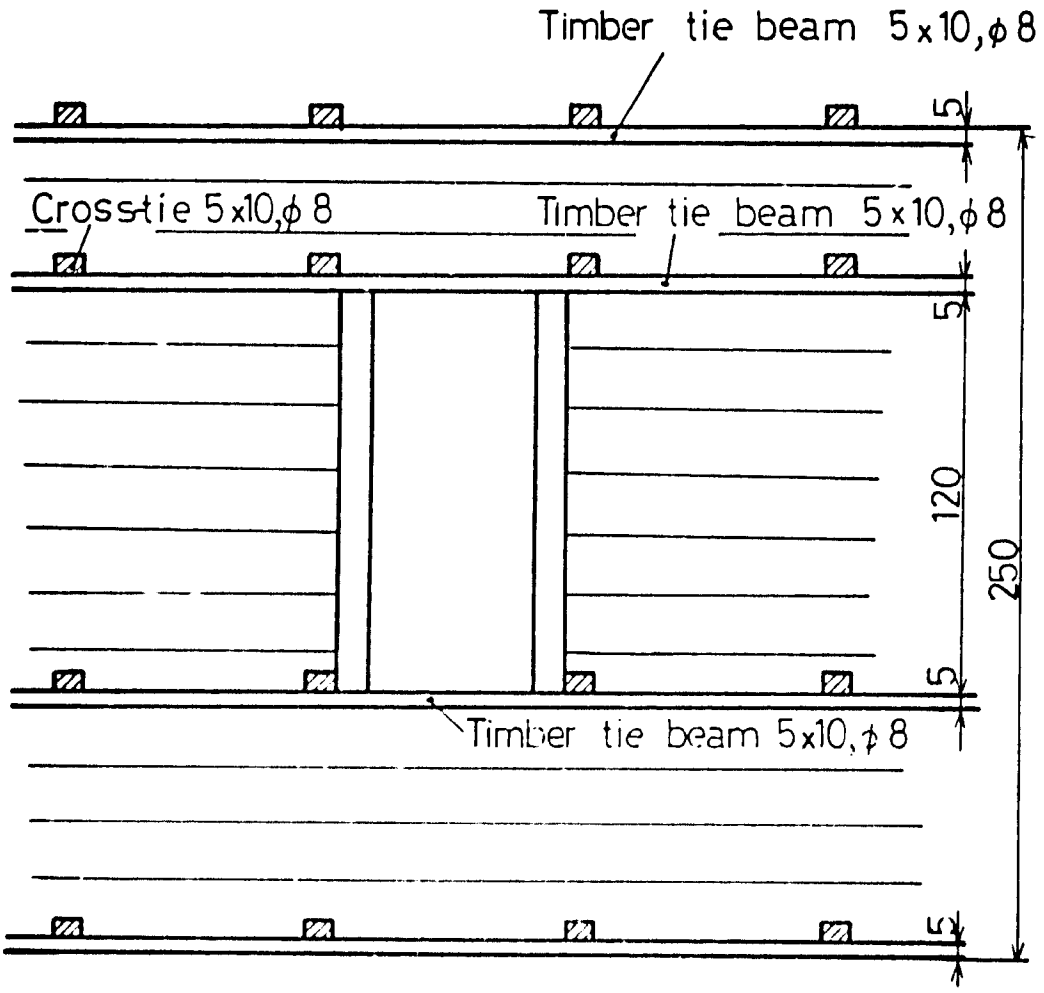
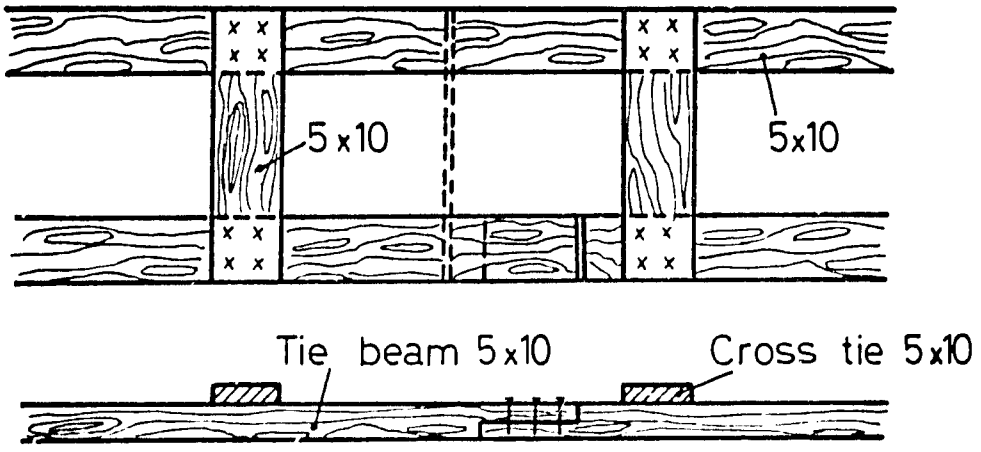


FIG. 4
Timber tie-beams

3.6.2. Reinforced concrete tie-beams :

These ties should have the width of the wall, a depth of 15 cm and 4 times Ø 10 mm bars reinforcement. Standard calls for stirrups at 40 cm, code at 25 cm. In both cases diameter of bars is 6 mm.

Standard also gives information on the construction of these tie-beams of which importance in earthquake behaviour of buildings is undisputable.



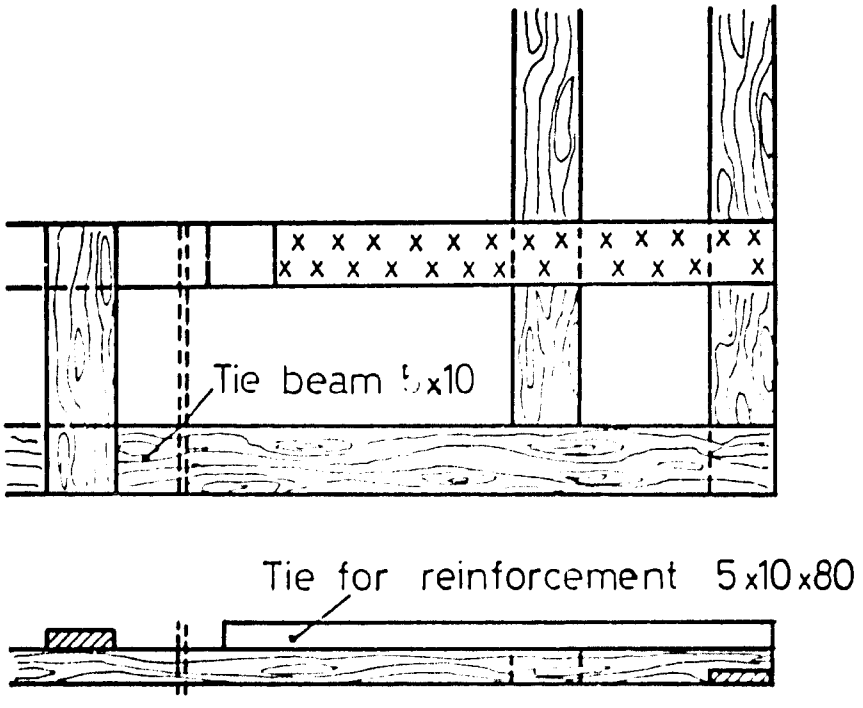


FIG. 5

Timber tie-beams

22 of 86 buildings taken under survey have no tie-beams at all. 19 buildings have one, 15 buildings have two, 29 buildings have three and only one building has four tie-beams. This shows that builders of traditional houses in rural areas do not give

3.7. Floors :

Earthquake code offers little information on floors as it assumes the buildings to have single storey.

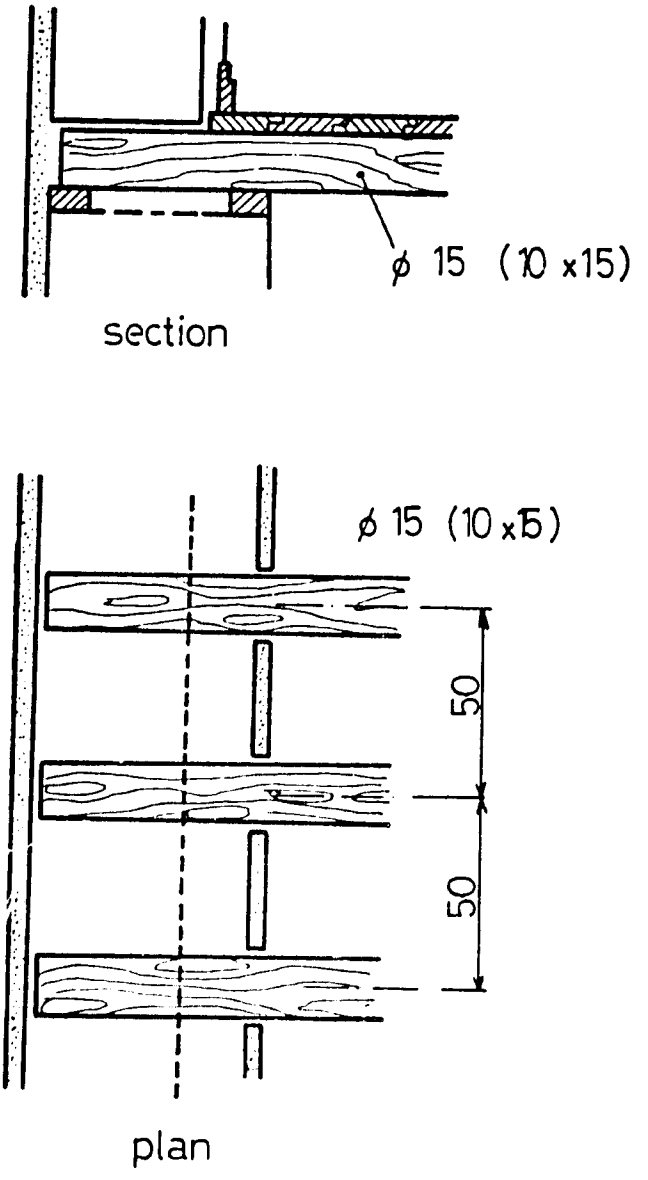


FIG. 6
Floor detail

Standard recommends beams at 50 cm from center to center for floors and at 40 cm from center to center for roofs. Their cross-sections should be Ø 15 cm or 10x15 cm. The maximum span for these beams is 4.00 m. This shows conformity with free wall length.

3.8. Roofs :

Earthquake code calls for a roof as light as possible and 50 cm eaves out of the building. Earth covered roof is prohibited in Earthquake Zone I and II and it is only permitted in Earthquake Zone III and IV, provided that, the earth cover is not thicker than 15 cm. Standard also emphasizes on light roofs, gives constructional details for several types of roofs and roofings, including earth.

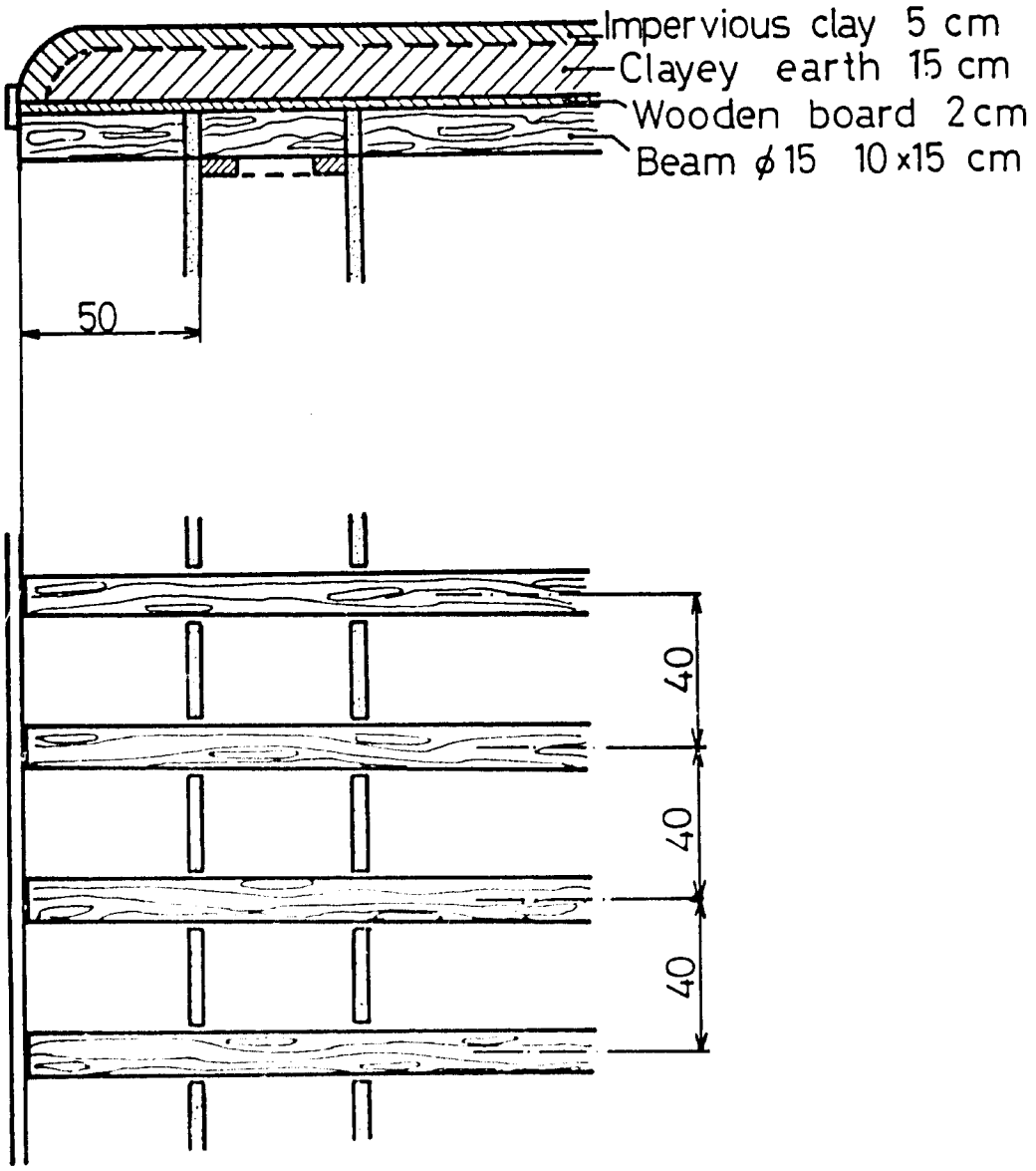


FIG. 7
Roof detail

46 out of 86 buildings which were investigated have earth covered roofs. The average thickness of the earth is 25 cm and its standard deviation is 11 cm.

Some of the recent earthquakes in Turkey though their magnitudes were moderate, regretfully resulted in with high numbers of casualties. One of the main reasons of failures of these rural houses is their heavy roofs which cause big inertia forces at roof levels which in turn cause the failure of the walls and the collapse of the heavy roof over the inhabitants to crush them like a press. This is the most important disadvantage of adobe buildings, which are indispensable to villagers as long as they are cheap to build and provide good insulation.

3.9. Other building elements :

Standard puts forward some rules and recommedations for doors, windows and plastering. Earthquake code does not mention about these aspects as it assumes these elements non-structural.

4. Conclusions

Earthquake code which essentially aims to limit even prohibit the adobe buildings in earthquake zones brought forward discouragingly strict rules and limitations for this type of buildings.

On the other hand, standard assumes that this type of construction will continue and therefore gives detailed

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International Workshop Earthen Buildings in Seismic Areas

Conference Report
Research Needs and Priorities
Volume III

The University of New Mexico

Intertect

Prepared for
The National Science Foundation

INTERNATIONAL WORKSHOP

EARTHEN BUILDINGS IN SEISMIC AREAS

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INTERNATIONAL WORKSHOP ON EARTHEN BUILDINGS IN SEISMIC AREAS

CONFERENCE REPORT

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e International Workshop.

INTERNATIONAL WORKSHOP ON EARTHEN BUILDINGS IN SEISMIC AREAS

CONFERENCE REPORT

I. INTRODUCTION

A. Description of The Conference

1. Background

Although adobe is used as a building material in areas of high seismic risk in the United States and is the predominant building material in many seismically active regions of the developing countries, very little effort has been expended in formulating a systematic body of knowledge of seismic behavior and design of such structures. During this century alone nearly one million people have died in earthquakes, with more than 80% of these deaths occurring in collapsed unreinforced masonry and adobe buildings. Most of the research conducted to date has been applied to engineered structures, typically of reinforced concrete or steel construction. Little has been written about ways of applying existing earthquake engineering knowledge to buildings using traditional materials and methods. Recognizing this problem, the University of New Mexico and INTERTECT jointly hosted a conference to bring together researchers and implementers in order to compile the work to date, so that an international effort could be directed toward reducing one of the major seismic hazards.

2. Goals and Objectives

In May 1981, an International Workshop on Earthen Buildings in Seismic Areas was convened in Albuquerque at the University of New Mexico. The workshop, jointly hosted by the Engineering College of the University and INTERTECT (a Dallas-

International. The emphasis of the workshop was on non-engineered adobe houses in seismic areas, although information about related forms of earthen and unreinforced masonry structures was also presented and discussed.

The workshop brought together a select invited group of domestic and foreign researchers and implementers to achieve the following objectives:

a. To develop a clear statement of the problems associated with earthen low-rise buildings in seismic areas;

b. To define the existing state of the art in regard to earthen building materials, design and construction methods in seismic regions;

c. To identify and categorize existing national and international research findings in related areas and seek to establish their applicability to the seismic design and construction of earthen buildings;

d. To identify appropriate channels for technology transfer across international boundaries and to explore social and economic barriers to such transfer;

e. To identify opportunities for cooperative international research;

f. To identify and describe the gaps in the present body of knowledge and to define research needs.

3. Workshop Organization

The primary responsibility for planning and implementing the workshop rested with an executive committee composed of four individuals:

a. Dr. Gerald W. May
Professor of Civil Engineering
Dean of the College of Engineering
University of New Mexico

c. Mr. Frederick C. Cuny
Executive Chairman
INTERTECT
Dallas, Texas

d. Ms. Jinx Parker
Program Manager
INTERTECT
Dallas, Texas

Working with the Executive committee was an advisory board consisting of leading researchers in the field. The functions of the advisory board were:

a. To help in identifying participants;

b. To help in identifying topic areas and discussion agendas for the work groups;

c. To recommend resource people for discussion groups;

d. To help develop a list of topics for presentations or to identify other contributors; and

e. To comment on the proceedings drawn up by the discussion groups.

The individuals who served on the advisory board were:

a. Dr. John A. Blume
Past President, Earthquake Engineering Research Institute
President, URS/J.A. Blume & Associates

b. Dr. Aybars Gurpinar
Principal Research Associate
D'Appolonia, Inc.
Brussels, Belgium

c. Dr. Julio Vargas Neumann
Department of Engineering
Pontificia Universidad Catolica
Lima, Peru

d. Mr. Roberto Meli
Institute of Engineering
Universidad Autonoma de Mexico
Mexico, D.F.

e. Dr. Mete Sozen
Professor of Civil Engineering
University of Illinois
Urbana, Illinois

f. Dr. Eric Carlson
Deputy, Director, Appraisal
U.N. Centre for Human Settlements (HABITAT)
Nairobi, Kenya

g. Dr. Nicholas Ambrayses
Imperial College of Science and Technology
University of London
London, U.K.

h. Dr. Jai Krishna
Past President, International Association of Earthquake Engineering
Professor Emeritus, University of Roorkee
Roorkee, India

The Executive Committee met with members of the Advisory Board in Istanbul in September 1980 at the 7th World Conference on Earthquake Engineering. During this meeting, the Advisory Board reviewed the plans, suggested a number of topics for discussion and identified a number of candidates to receive invitations to the conference.

4. Inter-disciplinary Participation

It was decided that not only outstanding earthquake engineers and researchers would be invited to participate in the conference, but also building officials and staff from housing agencies and other practitioners involved with the actual implementation of housing improvement. In all, five particular types of candidates were sought. They included:

a. Engineers and architects involved in earthquake engineering research, both in structures and materials;

b. Personnel from governments, voluntary agencies and foreign aid organizations involved in the implementation of modification programs;

c. Experts on social, economic and cultural aspects of the overall problem;

d. Officials experienced with building codes involving earthen buildings and persons from lending institutions familiar with the problem of financing improvements to earthen buidings in seismic areas.

Participants from each of these groups were identified and letters were sent to them. If they indicated interest, and their interests were compatible with the Workshop scope, letters of invitation to participante in the conference were sent. The list of actual participants present at the conference is ircluded in Section B of this chapter. In all, 16 countries were represented by the 87 participants.

5. Topic Areas

The conference scope was organized into five primary topic areas:

a. Subject Area 1: Structures
b. Subject Area 2: Materials
c. Subject Area 3: Social, Economic and Cultural Aspects
d. Subject Area 4: Program Implementation
e. Subject Area 5: Codes, Specifications and Standards

6. Workshop Structure

a. Format of the Workshop

The Workshop was structured so that a maximum of interaction occurred in small discussion groups. It spanned a period of 4 days, with 2-1/2 days of intensive work sessions.

and structure for the work sessions that followed in the afternoon. Each participant received a schedule with assignments to a particular session at a specific time (based on pre-workshop selection of preferred topic areas by the participants) and was able to attend three of the five work sessions during the course of the Workshop. At each group session, the participants were asked to review the state-of-the-art, identify research needs, and identify the resource persons actively engaged in the field. Each group was chaired by a respected researcher or practitioner who guided the discussions and, with the assistance of a recorder, prepared a summary of each session. Three of the 15 discussion sessions were conducted in Spanish expecially for the Spanish-speaking participants from Latin America. At the end of the Workshop, the session leaders and recorders from each subject area met to prepare a brief report on the findings of the different groups on that subject area and summarized the findings to the final full plenary session.

b. Briefing Papers

In order to provide the participants with an overview of each subject area and to identify some of the key issues and topics for the work sessions, the Executive Committee elected to prepare a set of briefing papers for conference participants. These briefing papers, which are included in the Appendix, identified areas of concern, described existing research, and provided a list of bibliographic sources for each of the topics.

d. Conference Library

Each of the participants was asked to bring copies of relevant publications on the topic of earthen buildings in seismic areas which could be displayed at the conference and used as a temporary reference library. At the end of the conference, many of the participants elected to leave the publications with the University of New Mexico to form a basis for a library which could be used to facilitate further exchange of information.

e. Field Trips

Two field trips were conducted during the conference. These included a visit to a large adobe brick production yard which produces stabilized adobe for use in the Albuquerque region, and a visit to the construction sites of several modern homes of stabilized adobe in the Albuquerque area. The following day the participants visited the historic Indian Pueblo of Tesuque, New Mexico, about 80 miles north of Albuquerque to observe adobe buildings several centuries old. They also inspected the test site of the Thermal Mass Study, a project sponsored by the Department of Housing and Urban Development and the Department of Energy, which is exploring the thermal properties of adobe buildings.

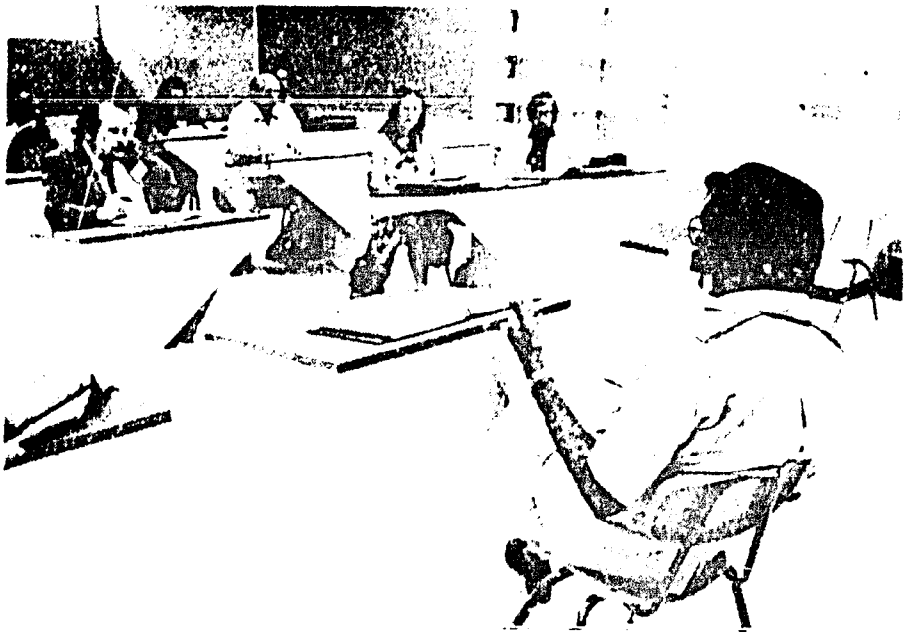

Figure 2. Discussion Group in Session.

Figure 4. The central atrium, gathering place between sessions.

Figure 6. Teddy Boen and Frederick Cuny in discussion.

B. List of Conference Participants

INTERNATIONAL WORKSHOP

ON

EARTHEN BUILDINGS IN SEISMIC AREAS

List of Participants

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C. Conference Schedule and Workshop Session Assignments

DATE	TIME/PLACE	
Sunday, May 24	7:30-9:30 p.m. Cabaret Room Hilton Inn	Reception and Registration
Monday, May 25	7:15 and 8:15 a.m. Hilton, AMF, Holiday Inn, Dollar Inn	Buses from Hotels to Campus
	8:00-9:00 a.m.	Late Registration (ME Bldg)
	9:00-9:15 a.m. Plenary Rm. 218 ME Bldg	Welcome: Gerald W. May Dean, College of Engineering University of New Mexico
	9:15-9:45 a.m. Plenary Rm. 218 ME Bldg	Opening Address: John A. Blume President, URS/J.A. Blume & Associates Past Pres. Earthquake Engineering Research Institute (EERI)
	9:45-10:15 a.m. Plenary Rm. 218 ME Bldg	Keynote Paper: W. O. Keightley Professor, Dept. of Civil Engineering Montana State University
	10:15-10:45 a.m. Plenary Rm. 218 ME Bldg	Keynote Paper: Ian Davis Disasters & Settlements Unit Dept. of Architecture Oxford Polytechnic
	10:45-11:00 a.m. Lobby, ME Bldg	Break
	11:00-11:45 a.m. Plenary Rm. 218 ME Bldg	Keynote Paper: Aybars Gurpinar Staff Consultant, D'Appolonia S.A.
	12:00-1:15 p.m. Patio, ME Bldg	Lunch
	1:30-2:00 p.m. Plenary Rm. 218 ME Bldg	NSF Programmatic Perspectives Frederick Krimgold Earthquake Hazard Mitigation Program Robert W. Lawson

DATE	TIME/PLACE	
Monday, May 25	1:30-4:30 p.m. Rms. 206, 208, 210, 214, 220, ME Bldg	Work Sessions: I, II, IV, V (English) III (Spanish)
	4:45 p.m.	Buses to Hotels
	Evening Open	
Tuesday, May 26	8:00 and 8:35 a.m. Hilton, AMF, Holiday Inn, Dollar Inn	Buses from Hotels to Campus
	9:00-9:15 a.m. Plenary Rm. 218 ME Bldg	Introduction: Frederick C. Cuny Executive Director, INTERTECT
	9:15-9:45 a.m. Plenary Rm. 218 ME Bldg	Keynote Paper: Eric Carlson U.N. Centre for Human Settlements (HABITAT)
	9:45-10:15 a.m. Plenary Rm. 218 ME Bldg.	Keynote Paper: Haresh Shah Prof. of Structural Engineering Stanford University
	10:15-10:30 a.m. Lobby, ME Bldg.	Break
	10:30-11:00 a.m. Plenary Rm. 218 ME Bldg	Keynote Paper: Roberto Meli Instituto de Ingenieria Universidad Autonoma de Mexico
	11:00-11:30 a.m. Plenary Rm. 218 ME Bldg	Keynote Paper: P. G. McHenry McHenry and Company, Albuquerque
	11:30-12:00 Noon Plenary Rm. 218 ME Bldg	Keynote Paper: Julio Vargas Neumann Director de Investigacion Departamento de Ingenieria Pontificia Universidad Catolica del Peru
	12:00-1:15 p.m. Patio, ME Bldg	Lunch
	1:30-4:30 p.m. Rms. 206, 208, 210, 214, 220, ME Bldg	Work Sessions: I, III, IV, V (English) II (Spanish)

DATE	TIME/PLACE	
Tuesday, May 26	4:45 p.m.	Buses to Hotels
	7:30 p.m. Hilton Inn	International Case Studies
Wednesday, May 27	8:00 and 8:35 a.m. Hilton, AMF, Holiday Inn, Dollar Inn	Buses from Hotels to Campus
	9:00-12:00 Noon Rms. 206, 208, 210, 214, 220, ME Bldg	Work Sessions: II, III (English) I, IV, V (Spanish)
	12:00-1:15 p.m. Patio, ME Bldg	Lunch
	1:30-4:30 p.m. Buses leave from ME Bldg; return to hotels	Corrales Tour Adobe yard, construction site
	6:00 p.m. Hilton, AMF, Holiday Inn, Dollar Inn	Buses to Old Town
	7:30 p.m. La Placita Restaurant Old Town, Albuquerque	Banquet Speaker: P. G. McHenry Buses return to hotels after Banquet.
Thursday, May 28	9:30 a.m. Hilton Inn only	Bus for Santa Fe Tour (Optional)
	5:00 p.m. Hilton Inn only	Bus returns from Santa Fe

SUGGESTED WORKSHOP ASSIGNMENTS

TUESDAY, May 26, 1981

SUBJECT AREA 1: SOCIAL, ECONOMIC & CULTURAL ASPECTS (English)

Bates
Bender
Cash
Davis
Gerbrandt (P)
Huden
Krimgold
Mathur (P)
McHenry
McKay
Murtz
Oakley
Scawthorn
Snarr (P)
Ural
Vargas

SUBJECT AREA 2: MATERIALS (Spanish)

Acosta
Crisosto
Giuliana
Ordonez
Penalba
Perdomo
Razani
Samanez Argumedo
Tejado (P)
*Torres

SUBJECT AREA 3: STRUCTURES (English)

Abrams (P)
Aytun
Barash
Bosl
Butler
Crosby
Kalevras (P)
*Keightly
Luther (P)
Maiola
Mostaghel (P)
K. K. Mumtaz
R. Parker
Rihal (P)
Shaw
Ural
Webster (P)
White
Yorulmaz

SUBJECT AREA 4: IMPLEMENTATION (English)

Agarwal
Arya
Asturias
Boen
Burk
Carlson
Haney
Hartkopf
*B. Mumtaz (P)
Oakley (P)
Oliver
K. Parker
Rockwell
Spence
Webster

SUBJECT AREA 5: CODES, SPECIFICATIONS AND STANDARDS (English)

Abrams
Agarwal
Aytun (P)
Barnes (P)
Burk
Erdik
Gurpinar
*Haney (P)
Jain
Kalevras
Meehan (P)
Webster
Yorulmaz (P)

* Session Leader

(P) Presenting a Paper

SUGGESTED WORKSHOP ASSIGNMENTS

MONDAY, May 25, 1981

SUBJECT AREA 1: SOCIAL, ECONOMIC & CULTURAL ASPECTS (English)

Agarwal
Asturias
Barash (P)
Butler
Carlson
Crosby
Harthopf
Jain
Luther
Maiola
B. Mumtaz
K. K. Mumtaz (P)
Oakley
*Oliver (P)
K. Parker

SUBJECT AREA 2: MATERIALS (English)

Bender
Boen
Burk
Kalevras
Meehan
Mostaghel
K. K. Mumtaz
Murty
*Plecnic (P)
Scawthorn
Spence
Yorulmaz

SUBJECT AREA 3: STRUCTURES (Spanish)

Acosta
Bejarano
Crisosto (P)
Giuliani (P)
Herrera
Meli
Ordonez
R. Parker
Penalba (P)
Perez
Tejada
Torres (P)
Vargas

SUBJECT AREA 4: IMPLEMENTATION (English)

Abrams
Aytun
Barnes
Bates (P)
Butler (P)
Davis
Erdik (P)
Gurpinar
Huden
*McKay
Snarr
White

SUBJECT AREA 5: CODES, SPECIFICATIONS AND STANDARDS (English)

Arya
Boen
Bosl
Cash
Krimgold
*McHenry
Razani
Rihal
Rockwell
Ural
Webster

*Session Leader

(P) Presenting a Paper

SUGGESTED WORKSHOP ASSIGNMENTS

WEDNESDAY, May 27, 1981

SUBJECT AREA 1: SOCIAL, ECONOMIC & CULTURAL ASPECTS (Spanish)

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Peradomo
Perez
Samanez Argumedo (P)

SUBJECT AREA 2: MATERIALS (English)

Abrams
Crosby
Hartkopf
Huden
Keightley
Maiola
B. Mumtaz
Rihal
Rockwell (P)
Shaw
Webster
White

SUBJECT AREA 3: STRUCTURES (English)

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Aytun
Barnes
*Boen (P)
Burk
Cash
Davis
Erdik
Gurpinar
Jain
Krimgold
McHenry
McKay
Mostaghel
Murtz
Oakley
Oliver
Plecnic
Meehan
Rezani
Rihal
Scawthorn (P)
Snarr
Spence (P)
Webster

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Bejarano
R. Parker
Perdomo
Perez
Samanez Argumedo
Tejada

SUBJECT AREA 5: CODES, SPECIFICATIONS AND STANDARDS (Spanish)

Bates
Barash
Carlson
Crisosto
Giuliani
Herrera
Torres
*Vargas

*Session Leader

(P) Presenting a Paper

D. Products of the Conference

1. Documents

There are three documents which describe the work of the conference and present the papers prepared as a result of the conference. They are:

a. The Proceedings of the conference (papers submitted by invited participants as well as others who could not attend)

b. The Research Needs and Priorities

c. An annotated bibliography on earthen buildings in seismic areas and related topics.

The Proceedings will be published as two separate volumes, and the Research Agenda and Bibliography will be combined in a third volume.

2. Establishment of An International Working Group

During the last plenary session of the workshop, the participants elected to hold a meeting to discuss follow-up activities, to continue the work and spirit of the workshop. At a meeting on the final day, a group composed of more than one third of the participants voted to formally establish an international working group to work towards the goal of reducing vulnerability of earthen buildings in seismic areas. The group asked the conference organizers to serve as a focal point for the working group and to carry out the following activities:

a. To prepare a draft declaration describing the scope of the problem as established by the conference and citing the need for further research in order to reduce the problem.

serve as a vehicle for information exchange among researchers and practitioners, and to sponsor follow-up activities to the conference.

c. To establish an information center. The participants asked the conference organizers to establish a center for the compilation and dissemination of information on earthen buildings in seismic areas and to provide a focal point for the exchange and translation of key documents in the subject area.

d. To prepare and publish a newsletter.

e. To organize immediate follow-up activities to facilitate coordination of research and standardization of reconnaissance, research and implementation activities.

II. STATE-OF-THE-ART AND RESEARCH NEEDS AND PRIORITIES

The research agenda is divided into five topic areas which coincide with the work groups that were established during the conference. They are:

A. Structures

B. Materials

C. Social, Economic and Cultural Aspects

D. Program Implementation

E. Building Codes, Specifications and Standards

The research agenda for each topic area is preceded by a description of the state-of-the-art as identified by the participants. The research topics are then identified and organized according to either priority or a logical progression of activity.

Each research need is presented with a descriptive statement, a description of the specific tasks and action required,

Figure 10. Field trip: a visit to an adobe manufacturing yard.

Figure 12. In discussion with the owner of the adobe yard.

SUBJECT AREA 1: STRUCTURES

A. State of The Art

While structural testing and research on earthen buildings in seismic areas has not been extensive in the United States, major research projects and activities have been conducted overseas, especially in Latin America. It was felt that U.S. participation in this area could benefit both the developing countries and the United States. By committing American research facilities and equipment to the effort, testing procedures and data could be developed which could aid not only research on earthen buildings in seismic areas, but also parallel research on related structural types such as low-quality masonry buildings.

Coordination of research efforts to date has been on an informal basis with the most coordination occurring among researchers in Latin America. A wide variety of testing methods and procedures have been developed to simulate earthquake loading conditions ranging from high technology shake tables to low technology tilt tables. To date, however, there has been no attempt to standardize testing procedures or to develop comparisons or establish the relationship between different testing methods.

No standardized classification of earthen buildings, materials or structures exists. This, combined with language difficulties, was seen as a major obstacle to coordination of research efforts.

The participants noted that post-disaster reconnais-

the various laboratory facilities that are currently engaged in this work.

Before international cooperative efforts can be established, however, it was felt that certain activities to standardize testing practice sould be initiated. Among the activities listed were:

1. Development of testing standards.
2. Defining the intent of testing.
3. Establishing valid scaling laws for experimental tests.
4. Establishing the relationship of different testing procedures and methods.

It was noted that more research to date has concentrated on adobe buildings. While it was recommended that adobe should retain a high priority, other types of earthen buildings are also found in large numbers in the seismic regions. Participants noted the need to especially examine rammed earth and wattle-and-daub construction commonly found throughout Latin America.

Participants also noted a need for closer liaison with related earthquake engineering research, especially in low-quality, unreinforced masonry construction. It was felt that much of the work on earthen buildings could be related to research on low-quality masonry, especially the development of testing procedures, terminologies, etc.

The difficulties of instrumentation of earthen buidings under actual seismic loading conditions were also noted. Instrumentation is difficult due to the nature of the materials and

B. Research Agenda

The structures research agenda is divided into four parts: Standardization and coordination of research, documentation, testing, and priorities.

1. Standardization and Coordination

a. Coordination of Research Efforts

(1) Statement

Due to the limited number of researchers and institutions involved in research on earthen buildings in seismic areas, research efforts sould be more coordinated and cooperative research programs should be instigated.

(2) Action

To provide cordination and stimulacion of cooperative research, an international network of researchers and institutions engaged in the field should be established. To be effective, this network should have a central information clearing house and should publish periodic newsletters and organize periodic meetings, both in the regions and at an international level, to encourage further exchange of information among researchers.

(3) Implementation

As a result of the workshop, a group of the participants agreed to formally establish an International Working Group on the Improvement of Earthen Buildings in Seismic Areas. The objectives of this group are to promote continued research into all aspects of the problems of earthen building in seismic areas to stimulate cooperative research; to provide a focal point for the exchange of information; and to work with the existing earthquake engineering research organizations to

b. Standardization

(1) Statement

In order to facilitate coordination and to encourage cooperative research, standard classification and nomenclature must be established.

(2) Action

It is recommended that an international committee of researchers be convened to establish common classifications and nomenclature required for international research. Standardization should cover:

(a) Materials

(b) Building systems

(c) Building forms

(d) Damage descriptions

It is recommended that the classifications be in both English and Spanish.

(3) Implementation

It is the intent of the newly formed International Working Group to convene within one year an international meeting of experts to define common terminology and classifications. It is hoped that the sponsors of the workshop will continue to support this activity and provide assistance to enable members of the committee to attend the meeting.

2. Documentation

a. Reconnaissance

(1) Statement

Increased post-disaster reconnaissance efforts are required in order to develop a base of data for structural research.

(2) Action

In order to improve the quality of the data developed by reconnaissance surveys, the adoption of standard evaluation procedures and forms is required.

In order to provide the needed data, increased reconnaissance missions should be supported. Reconnaissance teams now responding to earthquakes should be expanded to include specialists in earthen construction. Regional researchers in this field should be supported to participate in international efforts.

Reconnaissance should not only examine buildings which failed but also those that survived. The surveys should also seek to identify traditional forms of architecture and construction which are effective against earthquakes but which have fallen into disuse.

(3) Implementation

The international committee established to develop standards (mentioned above) should develop and adopt standard reconnaissance procedures and formats.

It is recommended that NSF encourage the Earthquake Engineering Research Institute and other organizations engaged in reconnaissance activities to include specialists on earthen buildings in the reconnaissance teams where applicable.

It is recommended that the International Working Group identify a number of researchers in various regions who could participate in reconnaissance efforts. This list should be provided to EERI and other organizations engaged in reconnaissance activities.

b. Defining the Scope of the Structural Research Agenda

(1) Statement

Research to date has concentrated on the

buildings in seismic areas and to identify the various structural systems now in use.

(2) Action

Coordinated research efforts to identify the principal and most critical structural aspects of earthen buildings should be undertaken on both macro and micro levels. Using the standard classification recommended earlier, efforts should be supported to identify the various structural systems in use and to determine the prevalence of various non-structural components and features (such as partitions, stairs, parapets and ornamental features).

(3) Implementation

The collection of the data at a macro level will require support from numerous organizations. Some of the data may in fact, already exist from other sources. Efforts, therefore, should be focused on supporting research, compiling existing data, and supporting efforts to identify and classify structures where data is not now available.

c. Compilation of Data

(1) Statement

The compilation and dissemination of data concerning structural aspects of traditional housing should be centralized.

(2) Implementation

This activity sould be a function of the International Working Group established as a result of the workshop.

3. Testing

a. Standardization of Testing Procedures

(1) Statement

Various methods have been developed to

conditions. The relationship between the various methods utilized however, has not been established. Comparative data needs to be developed in order to be able to equate the different systems.

(2) Action

Four activities are required in order to establish the relationship between various testing methods:

(a) Identical structures should be tested dynamically at full scale and at several smaller scales to establish reliable scaling laws.

(b) Tests on the large scale test platforms (tilt table, and rolling stock test bed) should be conducted to determine the relationship between the various testing methods.

(c) Blast tests on full scale buildings should be conducted and equated with both the large-scale and small-scale tests.

(d) The relationship between the full-scale tests and small-scale tests should be established.

(3) Implementation

Establishment of the relationship between the various testing procedures and methods will require an international cooperative effort. Unique testing facilities have been developed in India (the rolling stock test facility) and Peru (tilt table) which could be equated and compared to various-sized shake tables in the United States.

Cooperative research could be supported under a number of funding programs within the National Science Foundation and through monies from other interested organizations

due to the nature of the materials and variations in construction techniques and workmanship. New methods for instrumenting and/or observing earthen buildings under various seismic conditions is required.

(2) Action

New methods and equipment for instrumenting and observing earthen buildings should be developed. Instrumentation techniques developed for research on unreinforced, low-quaiity masonry may be applicable for use in earthen buildings.

c. Implementation

NSF is encouraged to support research on new methods of instrumenting and observing earthen buildings during seismic events.

4. Repair and Strengthening of Earthen Buildings

a. Statement

To date, little research on the repair and strengthening of earthen buildings in seismic areas has been conducted.

b. Action

Increased research on repair and strengthening of earthen buildings should be conducted. Especially important is research on surface coating which would increase seismic resistance, epoxy injection, and retrofitting strategies.

c. Implementation

It is recommended that current research on the use of surface coatings and epoxies be broadened to include the potential for the application of these materials to earthen buildings.

5. Research Priorities

The following is a list of research priorities identified by the workshop participants:

a. Architectual forms and structural systems which will result in more uniform stress distribution to minimize reinforcement requirements should be identified.

b. Research on different types of reinforcing systems including wood and steel should be expanded.

c. Research on alternative lightweight roofing systems that are culturally acceptable should be conducted.

d. Studies on reinforced concrete or other frames using adobe as an infill material should be conducted.

e. Research on the effects of non-structural components on the earthquake resistance of adobe structures should be conducted. Research should include:

(1) Interior partitions

(2) Stairs

(3) Parapets

(4) Ornamental features

(5) Verandas and porches

f. Research to determine the behavior of poured adobe should be initiated.

g. Research on the behavior of rammed each structure should be expanded.

h. Research on the causes of understress should be conducted.

i. In situ testing of full size structures should be conducted.

j. Blast tests to determine the dynamic resistance and response of earthen structures should be conducted.

k. Research on strengthening and repair of earthen buildings should be initiated.

l. Simple analytical methods for design application should be developed.

m. The effect of soil/foundation interaction should be investigated.

n. Simple methods of field testing for use by building officials and local builders should be developed.

SUBJECT AREA 2: MATERIALS

A. State of The Art

Most research on earthen materials used in houses in seismic areas has concentrated on examinations of various types of adobe buildings. Extensive research on adobe was conducted at three different periods. At the turn of the century, extensive research on adobe was carried out by the Department of Agriculture and several universities in the Land Grant system. The research focused on means of improving individual adobe blocks. Little of this research addressed seismic issues.

In the 1930's and 1940's, earthen building materials were again examined in some detail. During this time, asphalt was introduced and promoted as a stabilizer for adobe. Some limited research was conducted on the properties of adobe buildings and their seismic resistance.

In the 1970's, an extensive international research effort was begun in response to the widespread damage that was observed in the 1970 Peruvian earthquake. Research efforts to develop low-cost, stabilized adobe were conducted under a joint effort of the National Bureau of Standards, Fresno State University and several private companies in conjunction with several Latin American counterparts. In Peru, a major program of research on earthen buildings and adobe was conducted by the government of Peru and several participating universities.

Until the late 1970's , the majority of efforts focused

reached. It was felt by the participants that alternative means of stabilizing earthen materials need to be examined and newer low-cost methods, especially those which utilize local materials which can be obtained at little or no cost, should be explored. The types of materials which should be examined include natural resins and fibers found in the plants of many developing countries, as well as low-cost industrial products.

The participants also identified the need to conduct research on other types of earthen construction methods found in seismic areas. While it was agreed that adobe should continue to receive a high priority, more work should be directed toward rammed earth structures and other types of earthen buildings.

Alternative means of providing protection for earthen buildings was also felt to be a high priority. It was noted that there has been some research on the use of exterior coatings for prolonging the life of earthen materials as well as limited research on surface bonding. It was felt that both areas required further research and that priorities should be given first to developing surface treatment for low-cost housing in areas of high rainfall and second, to developing treatments for preserving historic buildings.

While participants noted that there were a number of notable research efforts and recent publications on material-related topics, international exchange of information has been relatively limited due to both linguistic barriers and lack of a

B. Research Agenda

1. Establishment of a Data Bank

a. Statement

A considerable amount of both experimental and performance data about various types of earthen buildings in seismic areas has already been developed. Hence, the first priority should be the creation of a data bank on all existing information available on earthen materials and earthen construction.

b. Action

As an outgrowth of this workshop, a number of the participants voted to formally establish an international network of researchers and practicioners to coordinate and exchange information on activities related to earthen buildings in seismic areas. As a part of th effort, the participants asked the conference organizers to establish a center for the collection and dissemination of information related to this effort.

c. Implementation

The conference organizers are currently working to establish the network and information center as recommended by the conference participants. It is hoped that the sponsors of the conference and other interested organizations can help provide resources and support for these activities.

2. Standardization of Terminology and Testing Procedures

a. Statement

It was found that variations in the terminology relating to earthen buildings and the non-standardization of tests often hamper international exchanges of information on

committee of the principal researchers in the field should be established to define common terminology and to establish common testing procedures.

c. Implementation

The international committee recommended above should accomplish its tasks through regional meetings of experts coordinated under the direction of the International Working Group established at this workshop. The first meetings of the committee should coincide with other international meetings which numbers of the committee would normally attend, thereby reducing costs.

It is recommended that American participation in these committees be supported by NSF and that foreign participation in these standardization efforts be supported by A.I.D., HABITAT, Appropriate Technology International and UNESCO.

3. Material Properties

a. Statement

Further research on the key factors and properties of adobe blocks and their influence on seismic resistance of earthen buildings is required.

b. Action

It was recommended that further research should be conducted to determine the effect of material properties of adobe blocks on seismic resistance of structures. The following research topics were identified:

(1) The effect of soil gradation and type.

(2) The effect of water impurities (such as salinity).

(3) The effect of water content on fabrication and strength

(5) The relative effectiveness of various types of stabilizers commonly used (example: straw, cement, lime, asphalt, etc.) and their relative effectiveness in increasing strength and durability.

(6) Research on the optimum size and shape of adobe blocks for purposes of seismic resistance in different sizes of structures.

c. Implementation

It was recognized that substantial progress in this research has already been made in several foreign laboratories. Thus, it was recommended that the majority of the research effort be continued in these locations and that American researchers be supported to participate in these efforts.

It is recommended that NSF continue to support American participation in these activities through programs such as Science in the Developing Countries and through cooperative U.S. and foreign projects.

It is recommended that U.S. institutions which have extensive experience or recent work in stabilization and materials research be encouraged to expand these efforts and that their work be supported by NSF.

It is recommended that A.I.D continue to support international research efforts and foreign national research in this field.

It was felt that both A.I.D. and NSF could play a central role in coordinating research efforts and the exchange of information simply through the use of their good offices and awareness of activities in both the foreign and domestic sectors. Thus, the participants urged that NSF and A.I.D. establish

4. Mortar Joints

a. Statement

Analyses of adobe structures following recent earthquakes suggest that the majority of failures occur at the brick-mortar interface.

b. Action

Research studies on the development of greater bond strength between the adobe block and mortar joints should be conducted.

c. Implementation

It was felt that the international organizations and institutions which have already conducted extensive research on earthen material should be supported for research on bonding. It is recognized however, that recent developments and research from related fields (such as unreinforced, low-quality masonry) may play a significant role in this task. A study should be made to determine the applicability of this information to adobe masonry. Therefore, increased interchange between U.S. and foreign research institutions is encouraged, and support for joint U.S. and foreign cooperative research should be supported by a variety of institutions including NSF, A.I.D., UNESCO and HABITAT.

5. Field Test Procedures

a. Statement

Standardized experimental tests which can be readily performed, even in remote locations, to determine the properties of earthen materials and what is needed to effectively prepare and strengthen the materials for use in construction should be developed.

b. Action

(1) Assist local builders in determining the best soils for use in preparing earthen materials.

(2) Provide guidance on the best types of stabilizing materials to use with the soils.

(3) Provide guidance on the best types of mortar to use with the blocks.

(4) Provide information on the related construction aspects such as recommended reinforcing systems, maximum size and width of walls, and general data relating to the configuration of the building.

This data should be standardized to the greatest extens possible and should include only those tests which can be readily performed with minimum scientific knowledge.

c. Implementation

It is recommended that Appropriate Technology International and other appropriate technology groups support the development of these construction aids.

Since construction aids of this type would be beneficial in any locale where earthen buildings are used, cooperative research and development should be encouraged.

6. Research on Non-Earthen Materials Commonly Used in Conjunction With Earthen Buildings

a. Statement

Research on non-earthen materials commonly used in construction of earthen buildings (such as wood, cane, straw, etc.) and their properties and performance when used in earthen buildings under seismic loading conditions is not presently adequate.

b. Action

First, research is needed to define the dura-

interaction between earthen materials and reinforcement under seismic loading conditions. Both full-scale and small-scale testing is required.

Second, research is needed on durability of wood and other structural elements commonly used. Priority should be given to simple, lowcost methods of prolonging the life of wood in earthen buildings.

c. Implementation

It is recommended that NSF support research in this area. Bracing systems of wood, concrete, etc., using earthen materials as an infill, were seen as a research objective which could benefit from U.S. testing facilities.

7. Effect of Climatic Conditions on Earthen Buildings

a. Statement

Little information exists concerning the effects of extreme climatic conditions on the seismic performance of earthen buildings.

b. Action

Research should be carried out to improve earthen materials under varying climatic conditions, including rain, freeze/thaw cycles and various wind and erosion conditions. Research should include:

(1) Development of information on the changes to the material properties under various climatic conditions.

(2) Development of recommendations for reducing adverse climatic effects (such as the use of coatings and sealants).

c. Implementation

It is recommended that research in this field be carried out in two parallel programs. First, foreign research institutions with extensive earthen materials research capabili-

the changes in material properties due to climatic exposure. Second, it is recommended that NSF support domestic research related to development of coatings, sealants, and stabilizing materials which could strengthen the materials under varying conditions.

The overall research should be coordinated through periodic meetings of the researchers involved and an exchange of researchers during parts of the program.

It is recommended that NSF support the domestic research component under a joint U.S. and foreign cooperative research program.

8. Effect of Material Properties on Structural Behavior

a. Statement

The interaction betwen structural design and material characteristics of earthen buildings under seismic loading conditions is not fully known.

b. Action

The interaction between structural design and material characteristics should be investigated by means of both full-scale and small-scale tests.

c. Implementation

Joint U.S. and foreign cooperative research should be supported on this topic with full-scale tests being conducted internationally and small-scale tets being conducted at U.S. facilities. It is recommended that NSF support the small-scale testing components as part of a comprehensive U.S. and foreign research program and that A.I.D. participate in the support of the foreign research institutions.

SUBJECT AREA 3: SOCIAL, ECONOMIC, AND CULTURAL ASPECTS

A. State of The Art

The participants noted that there is a need for more information about the inter-relationship of the social, economic and cultural aspects of indigeneous buildings in seismic areas. The failure to develop this data was cited as the principal reason why vulnerability reduction efforts have not been more successful. The participants felt that researchers and engineers have not been sensitive to this complex balance and thus many structural modifications have not been accepted by the people they were designed to help.

A number of both engineers and social scientists present felt that the technology for safe construction of earthen housing in seismic areas has been growing faster than the actual application of the various techniques. The reasons cited for this were summarized as follows:

1. A lack of understanding of the social, economic and cultural aspects of the problem.

2. A lack of cumulative and comprehensive collection of information existing about the topic.

3. A lack of interaction between social scientists and earthquake engineers.

4. Insufficient communication between all levels of a program, from the engineer/designer to the occupant.

5. A lack of understanding of the techniques of successful technology transfer and the cultural and economic obstacles which must be overcome.

It was noted that actual vulnerability reduction efforts to date have been fairly limited; thus, the existing

B. Research Agenda

1. Standardized Terminology

a. Statement

In order to facilitate coordination, research and implementation, standardized terminologies, definitions, and classifications are required.

b. Action

An international committee of the principal researchers in the field should be established to define the common terms, etc. This committee should:

(1) Establish the nature and variety of earthen buildings in worldwide use. This should be presentd as a taxonomy of building forms, types and materials.

(2) Establish the cultural context in which earthen buildings are used.

(3) Establish the social and economic relationship between earthen buildings and disaster vulnerability.

c. Implementation

These objectives should be accomplished through regional meetings of experts coordinated by a central project manager. Terminologies should be in English and Spanish.

2. Cultural Mapping

a. Statement

Detailed cultural mapping on both a macro and micro scale is required in order to further identify and define the scope of the problem.

b. Action

Research projects on a regional and country-by-country basis should be supported. Mapping should include:

(1) Popular building features which affect seismic resistance of a building.

(2) Traditional forms and their influence on

(3) Cultural influences, preferences, customs, etc., which affect building construction.

(4) Legal or governmental regulations which affect building construction.

Specific topics which should be examined are:

(a) Urban building patterns

(b) Rural building patterns

(c) Local building skills

(d) Perceptions of risk and vulnerability and how they affect design and construction of housing.

c. Implementation

These objectives should be carried out in two ways. First, U.S.A.I.D., HABITAT Center and the World Bank should be encouraged to support local research and mapping efforts in countries with a high number of earthen buildings. To facilitate this work, a standardized format for such efforts should be adopted (this should be a task of the committee described in paragraph 1(b) above).

Second, NSF, U.S.A.I.D, HABITAT and the World Bank should support regional mapping efforts, compiling the work accomplished at the country level into regional and worldwide atlases.

3. Economic Factors

a. Statement

Research is required to collect data related to the economic factors involving earthen building systems.

b. Action

Research is required to determine the economic aspects and implications of earthen buildings, focusing on:

(1) An evaluation of construction costs/maintenance costs correlated to the anticipated life of buildings in both existing and proposed earthen building types.

(2) An analysis of the relative cost benefits of improvements to earthen buildings in comparison to complete relocation of alternative methods of construction.

(3) The development of a comprehensive data base describing construction techniques which provide maximum earthquake tolerance at minimum costs.

c. Implementation

It is recommended that NSF support further research on economic factors related to housing modification and vulnerability reduction.

It is recognized that much of the needed data also pertains to other types of structures both in the U.S. and abroad. Therefore, portions of the necessary research can be non-specific to earthen buildings and earthquakes. Thus, NSF is encouraged to support a broad range of research on societal and economic factors to develop the required data. It is recommended that existing societal research be expanded to include those issues specific to earthen buildings in seismic areas.

Such studies as A.I.D., A.T.I., and HABITAT can assist in these efforts by supporting in-country efforts to develop social-economic data relating to program implementation.

It is recommended that NSF, A.I.D. and A.T.I. establish an informal liaison group to encourage broader interchange between U.S. and foreign scientists and researchers engaged in these efforts. Programs such as NSF's Science in Developing Countries (SDC), A.I.D's Invitational Travel Funds, and various foreign currency programs can provide much needed support for international interchange.

4. Defining the Urban Versus Rural Context

b. Action

Research is required to determine the essential social, cultural and economic differences and similarities when earthen buildings are used in urban and rural areas. Specifically, comparative research is required on:

(1) Investment levels

(2) Differences in building costs

(3) Differences in construction and maintenance practices.

(4) Changes in the building process dictated by a change from rural to urban settings.

(5) Changes in site selection and development necessitated by changing from a rural to an urban context.

c. Implementation

It is recommended that research on these topics should be supported by the National Science Foundation, the World Bank, and HABITAT Center.

5. Psychological and Social Aspects of Intervention

a. Statement

The impetus to modify earthen buildings is normally a result of planned housing improvement programs. Little information exists concerning the psychological and social factors related to this type of intervention and the impact of such interventions on both families and the society in which they occur.

b. Action

New research on the psychological and social aspects of intervention should be conducted. In particular, research should be directed towards:

(1) Identification of the psychological and

(3) The impact of the introduction of new materials and/or new or adapted technologies. This should also be viewed in terms of the impact on rising aspirations for social and economic development.

(4) The social implications and factors affecting acceptance or rejection of building codes.

c. Implementation

The impact of intervention and various intervention strategies is a vital concern not only to U.S. hazard mitigation efforts but also to foreign aid programs. Thus, research in this area should be supported by many different types of institutions. NSF can support these efforts through research on societal aspects of earthquake hazard mitigation.

Implementing agencies such as U.S.A.I.D., the World Bank and various non-governmental organizations involved in housing mitigation and vulnerability reduction efforts should be encouraged to support these efforts through evaluations and assessments of past intervention programs.

6. Longitudinal studies

a. Statement

Often a project's post-documentation and evaluation are conducted immediately after implementation. Therefore, the long-range effects of a program are not fully known.

b. Action

Longitudinal studies should be conducted to document and evaluate various implementation approaches over extended periods of time following implementation. Studies should especially identify the specific aspects of a program which are continued without support at the end of the intervention.

of modification efforts rather than on comprehensive assessments of all aspects of a particular disaster.

7. Cost-Benefit of Various Hazard Mitigation Strategies

a. Statement

Little information is known about the comparative cost-benefit relationship between various alternative strategies to reduce vulnerability of earthen buildings in seismic areas.

b. Action

Research should be conducted to define the trade-offs between risk reduction strategies including an examination of the potential social and economic consequences of the various alternatives. In particular, a comparative analysis should be made of:

(1) Relocation from vulnerable sites versus structural modification to reduce vulnerability.

(2) The comparative advantages and disadvantages of changing from earthen buildings to other types of materials and the social and economic consequences of such changes.

c. Implementation

Relocation is a strategy often proposed as a vulnerability reduction alternative. Several relocation programs have been attempted in the developing countries. Thus, NSF is encouraged to support research on these programs. The information can be useful to U.S. program planners for comparative purposes, and to Third World program officials for immediate application in post-earthquake reconstruction programs.

8. Social Input in Structural Research

a. Statement

Many of the techniques which have been devel-

is believed that much of this reserch could have resulted in more practical applications had adequate social-science inputs been made early in the research and development process.

b. Action

When dealing with low-cost, non-engineered buildings normally built without the influence of building codes or specifications, it is imperative that social factors be considered from the very beginning of any structural or material research program. Increased interaction between social scientists, housing program implementers and structural and material researchers is required.

c. Implementation

Increased interaction between social scientists, program implementers and earthquake engineers can be effected in two ways:

(1) NSF should encourage increased participation by social scientists in earthquake engineering research programs directed at non-engineered buildings.

(2) The inter-disciplinary network which has been formed as a result of this workshop should be further supported by the sponsors of the workshop. A preliminary activity that should be encouraged is the development of a roster of qualified and experienced social scientists and program implementation personnel who can assist earthquake engineering research.

9. Perceptions of Risk

a. Statement

Information concerning people's perception of risk and the relative priority that risk and vulnerability reduc-

of vulnerability reduction efforts. Research sould be directed towards:

(1) Developing definitions of risk and vulnerability in both real and relative terms.

(2) Determining how perceptions of risk and vulnerability affect community lives.

(3) Identifying cultural adaptations to vulnerability in the local, indigineous architecture.

(4) Identifying societal and organization coping mechanisms which have developed in response to risk and vulnerability.

c. Implementation

Research on perceptions of risk and societal adaptations to risk and vulnerability should be carried out in both the United States and overseas. International efforts should be supported as lessons and information developed from abroad may provide information useful to hazard mitigation programs in this country.

SUBJECT AREA 4: PROGRAM IMPLEMENTATION

A. State of The Art

Much of the discussion about efforts to reduce vulnerability and improve earthen buildings in seismic areas focused on the lack of information about past experience and highlighted the fact that extensive program implementation activities have not yet been conducted on a large scale. With a few notable exceptions (such as efforts in Turkey and recent efforts in Guatemala by OXFAM, World Neighbors, Save the Children, and U.S.A.I.D.), few programs have been evaluated or observed over any length of time. The participants recognized that the techniques for modifying and improving earthen buildings have only been developed in the last decade; thus, information necessarily will be fragmented and minimal. However, the general lack of data and research on approaches and implementation strategies further frustrates the development of workable implementation programs in this field.

The overall scarcity of information was attributed to a lack of comprehensive research on program implementation; a failure of the operating agencies to evaluate existing projects; and a lack of long-operating agencies to evaluate existing projects; and a lack of longitudinal studies on the long-term impact and results of programs which have been carried out. Where information is available, it has tended to be compartmentalized and not disseminated widely to other practitioners.

The participants also noted that there has been little interaction between researchers and program implementers. There-

The participants noted that most research on improving earthen buildings has concentrated on engineering solutions, and the social and cultural aspects and constraints have often been overlooked and are not fully understood by the research community. To overcome these problems, increased involvement of the engineering researchers in field level activities was urged.

Each of the work sessions on implementation noted the need for increased emphasis on developing local solutions to the problems. Several methods were proposed to bring research and implementation closer to the grassroots level. Several groups recommended that efforts should be initiated to train an intermediate group of technicians (somewhat along the "barefoot doctor" concept employed successfully in public health in China). These intermediate technician groups would serve as problem-solvers at the local level and would aid families in developing acceptable local solutions to specific vulnerability problems.

Several of the experienced practitioners noted the problems of quality control in vulnerability reduction programs. It was noted that as soon as a formal housing program ended, the application of the structural modification techniques often became irregular, and improper construction methods became widespread. To overcome this problem, participants suggested the need for increased emphasis on the trainin of local building technicians and cited quality control as an appropriate role for the "intermediate engineering group" mentioned above.

The participants discussed a number of obstacles to vulnerability reduction. It was noted that most vulnerability reduction efforts have occurred after an earthquake and had been directed towards improving the design and construction of new housing, not reduction of vulnerability of existing housing. The difficulty of intervention, except in disasters, was discussed at some length. The participants agreed that in order to carry out disaster mitigation efforts, local governments' capacities to conduct mitigation programs must be strengthened. It was also felt that research on different kinds of incentives which could be used to encourage home owners to utilize earthquake resistant construction techniques should be carried out. Among the incentives that should be explored are: financial incentives (such as loans, subsidies, etc.); material incentives (example: lightweight roofing, bracing, cement, etc.); and legal incentives (such as codes, tax reductions, etc.).

It was found that most research on reduction of vulnerability to earthen buildings has focused on the modification and strengthening of new construction. For overall vulnerability efforts to be successful, new methods for modification and strengthening of existing buildings need to be explored.

B. Research Agenda

The following topics were identified as the highest priority for future research related to program implementation and vulnerability reduction.

1. Implementation Approaches

a. Statement

More data on program implementation is needed

research and evaluation of projects. The criteria for such studies should be established and methodologies developed for general use.

c. Implementation

Research on strategies and approaches for vulnerability reduction programs should be funded by the National Science Foundation as a part of its overall hazards mitigation program. In support of this research NSF should also fund longitudinal studies of current and past programs to develop data upon which program models can be developed.

It is recognized that the majority of information on program implementation strategies may be found in the developing countries. In order to assist U.S. vulnerability reduction efforts, increased linkages between foreign and domestic researchers and program implementation personnel should be encouraged. It is recommended that joint U.S. and foreign research projects be encouraged and that U.S.A.I.D. and NSF establish a joint working group to explore ways in which research and evaluations can be complementary.

U.S.A.I.D. can support this effort by promoting evaluation and assessment of operational programs that receive support from the agency.

2. Techniques for Improving Low-Cost Housing

a. Statement

Often the techniques for anti-seismic modification of low-cost, non-engineered buildings are too costly and complicated for home builders to implement without extensive technical assistance. Recognizing cost as a major obstacle to housing

b. Action

In order to implement this approach, several activities must be carried out simultaneously. First, research is needed to develop simplified procedures for assessing a particular building and determining what the most cost-effective methods would be to strengthen that particular building. The procedure should enable the assessor to recommend a plan for modification or retrofitting taking into account the various trade-offs of time, labor, materials, etc.

The actions which are available for strengthening a house should be prioritized according to which method most reduces the relative vulnerability.

The results of this research must be presented in a non-technical form for use by implementing agencies and builders.

c. Implementation

It is recommended that the National Science Foundation should support research on:

(1) The priorization of modification techniques.

(2) The determination of which modification methods and which building features most affect or reduce vulnerability in a non-engineered structure.

(3) The development of a simple assessment procedure for field use.

(4) The development of step-by-step approaches to modification of housing which will allow homeowners/builders an opportunity to progressively upgrade housing.

It is further recommended that the National Science Foundation and the Agency for International Development

It is recognized that research in related fields (such as unreinforced, low-quality masonry) could also benefit from these procedures; therefore, it is recommended that this research be carried out in conjunction with other on-going efforts.

3. Communication and Education

a. Statement

Little information exists on the process of technology transfer or means of encouraging homeowners to utilize earthquake resistant building techniques.

b. Action

Research is required to develop more information on the overall process of technology transfer, especially communication techniques and housing education. Research topics include:

(1) Identification of th most critical concepts and techniques which need to be transferred and methods for presenting the information in such a manner as not to overwhelm or confuse the audience. Especially needed is theidentification of the critical and priority structural detail, to be presented and methods for presenting these ideas in a non-technical manner.

(2) Information about the techniques of teaching and communicating, especially methods of presenting technical issues as well as methods for encouraging cultural acceptance of the methods being presented.

(3) Research is needed to identify what materials should be presented to each different audience, i.e., the best points of intervention for successful program

4. Special Problems of the Urban Environment

a. Statement

It is recognized that dense urban development creates unique aspects and problems for the reduction of seismic vulnerability. Most research to date has been on detached buildings which are most likely to be found in a rural environment. The special aspects of earthen buildings in urban areas and the problems in implementation of vulnerability reduction require new study.

b. Action

Research on non-structural methods of reducing vulnerability during program implementation is required. Of special concern is research on appropriate methods of siting and sub-division development in urban settings.

Structural methods of providing safety in urban settings are also required. Methods which should be explored are: in-house shelters, safe cores, and other methods of realistically addressing the problem on a cost-effective basis.

c. Implementation

It is recommended that the National Science Foundation encourage and support research on non-structural methods of reducing vulnerability in urban areas.

It is further recommended that NSF and A.I.D. place increased emphasis on research to develop methods of providing basic, minimal safety to urban dwellers living in non-engineered structures. Research in related fields (such as high wind engineering) and on related types of structures (such as low quality, unreinforced masonry buildings) can provide useful

b. Action

Increased research is required in order to determine the conditions under which modification of earthen buildings will be accepted. It is recognized that in the developing countries many of the people living in earthen buildings are those most resistant to change. In addition, these people may be the most difficult to reach due to illiteracy and unfamiliarity with related technical aspects. Research should be supported to identify the conditions under which change or modification would be accepted.

c. Implementation

This information is needed not only for modification of earthen buildings in seismic areas but for modification of all types of non-engineered structures vulnerable to earthquakes and/or windstorms. Thus, it is recommended that NSF encourage comprehensive research on societal and cultural attitudes towards housing modification as part of the current research efforts on societal response to earthquakes.

It is recommended that A.I.D. be encouraged to support parallel research on this topic by local researchers in countries with large numbers of non-engineered structures, vulnerable to either earthquakes or windstorms.

It is recommended that both NSF and A.I.D. and other organizations involved in disaster mitigation encourage further international interchange between social scientists and