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Design, Siting, and Construction of Low-Cost Housing and Community Buildings to Better Withstand Earthquakes and Windstorms

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Bureau
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Standards

Effects of earthquake in Huaraz, Peru. Thousands of people were buried under collapsed houses. (Courtesy of United States Geological Survey.)

Design, Siting, and Construction of Low-Cost Housing and Community Buildings to Better Withstand Earthquakes and Windstorms

A Report Prepared for

The U.S. Agency for International Development
Washington, D.C. 20523

by

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PREFACE

Earthquakes and windstorms are responsible for great loss of life and property throughout the world. In the period 1926-1972, for example, earthquakes alone caused almost one million deaths, as well as damages to buildings and public works totaling an estimated fifteen billion dollars[1/]. Windstorms may be even more destructive than earthquakes. For example, a typhoon-generated flood killed an estimated half million people in East Pakistan in 1970.

Improved design, siting and construction procedures can contribute significantly to the reduction of such losses. In developing countries, however, cultural patterns, severe socio-economic constraints, and inadequate technical expertise make the adoption and implementation of such procedures particularly difficult and are thus an indirect cause of continued losses on a massive scale.

In recognition of the need for achieving low cost housing and community buildings with better resistance to earthquake and windstorms, the Agency for International Development (AID) requested the National Bureau of Standards (NBS) to conduct a study on the potentials of applying housing technology to mitigate earthquake and windstorm disasters in developing countries and on relevant socio-economic and cultural constraints.

The AID Office of Science and Technology of the Technical Assistance Bureau monitored the project for AID. The Institute for Applied Technology, Center for Building Technology, NBS, was responsible for conducting the study. An interagency steering committee served as an advisory group to the NBS in the execution of the project.

The specified goals of the project were as follows:

- Examine existing knowledge relevant to the design, siting and construction of earthquake and windstorm resistant buildings, including recent American technological innovations applicable within the framework of socio-economic and cultural requirements in developing countries.

- Suggest promising technological innovations applicable within this context.

- Evaluate the potential of these innovations through consultations and on-site "case study" investigations in Peru, Turkey and the Philippines.

- Identify technical and socio-economic constraints concerning construction in earthquake and windstorm areas of developing countries.

- Describe alternative approaches to overcome technological and socio-economic barriers against more effective building practices in each of the selected countries.

In order to assess the current state of the art as it relates to low-cost housing technology and to define typical socio-economic constraints in developing countries, field trips were made to Peru, Turkey and the Philippines, countries that suffer frequent devastation from natural disasters such as earthquakes and typhoons.

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1 "Report on Seismology and Earthquake Engineering," Department of Advancement of Science, UNESCO (United Nations Education, Scientific and Cultural Organization), Paris, 1965.

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A Project Steering Committee comprised of representatives from the National Bureau of Standards, Department of Housing and Urban Development, United States Geological Survey, and Agency for International Development provided valuable assistance and guidance in the overall investigation.

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SUMMARY

The extensive loss of life and property caused by earthquakes and windstorms in developing countries may be reduced to a considerable degree by the use of improved design, siting and construction procedures. In attempting to establish and implement such procedures, the technical constraints which govern earthquake and windstorm resistant construction, as well as the severe cultural and socio-economic constraints which prevail in developing countries, must be taken into account. The purpose of this report is to identify such constraints, to study the potentials of housing and building technology for mitigating earthquake and windstorm disasters in developing countries, and to propose practical solutions toward achieving this end.

To provide the background required for assessing structural systems and materials used in earthquake and windstorm resistant construction, the structural characteristics of buildings and building materials are discussed. The structural performance of buildings under earthquake and windstorm conditions is then described, and the factors responsible for the occurrence of structural damage or collapse are identified and explained in detail. Specific reference is made to actual structures typical of developing countries. Suggestions for improvements to mitigate earthquake and windstorm effects on buildings are classified according to whether the cause of the destruction is related to the structural configuration or aerodynamic features of the building, or to its foundations, walls, frames, upper floors or roofs. It is shown by means of illustrative examples that considerable improvement of the earthquake or windstorm resistance of structures widely used in developing countries may be achieved by relatively simple measures. These include, for example, horizontal bracing of certain types of roofs over adobe masonry houses, rational distribution of openings in shear walls, provision of adequate walls or frames to withstand concentrated seismic load action, reinforcement of critical areas susceptible to being over-stressed, and strengthening of connections at critical joints. It is also pointed out that in order to achieve safe and rational typhoon resistant construction in such areas as the Philippines, special studies on the distribution of extreme wind speeds and on the aerodynamics of full-scale buildings and of reduced scale models are required.

A review of siting considerations to reduce the effects of earthquakes and windstorms is presented, with specific application to Turkey and Peru. Recommendations related to siting in earthquake and windstorm zones include: development and improvement of seismic, tsunami and extreme wind risk maps; preparation of geologic site plans and site evaluations to be used in both short- and long-range community planning; preparation from the former of microzoning maps to be used by engineers responsible for construction; and siting of new structures at reasonably safe locations, in accordance with indications furnished by geologic maps and studies. For example, depending upon the risk category to which they belong, new structures should not be located within 50-200 m* from main faults or branches.

Traditional and industrialized methods of housing construction are described in an attempt to provide information on existing construction technology capabilities in developing countries. The possibility of upgrading these methods is discussed with reference to specific cases, for which suggestions are made aiming at improved structural behavior under earthquake and windstorm conditions.

The role of building codes and regulations in preventing the design and construction of unsafe structures is also discussed. It is pointed out that most of the countries affected by earthquakes do not have building

* See Conversion Table on Page 132.

code provisions for aseismic design or construction. In the countries in which building codes exist, the code provisions are in many cases inadequate. In Iran, for example, it appears that the disastrous consequences of the Fars earthquake are attributable in a large measure to the use of an inadequate building code. In the Philippines, more stringent provisions on items associated with typhoon-caused damage (such as anchorages of roof trusses, purlins, roofing materials) are required. Deficiencies are also noted in the Peruvian and Turkish codes. Among these is the absence of provisions regarding local types of structures. The promulgation of codes applicable to specific types of non-engineered structures would significantly contribute to achieving better resistant structures built in accordance with local needs and capabilities.

Code enforcement is in many cases unsatisfactory, mostly because qualified personnel are not available. It is suggested that local credit-granting institutions be responsible for inspecting the building construction they finance and make loans conditional upon compliance with building codes. The enforcement of provisions applicable to local non-engineered construction could be entrusted to properly trained inspectors with limited formal education. Finally, it is stated that building codes should not inhibit technological innovation.

Social and economic factors affecting housing construction in developing countries include: shortage of funds, heavy migration of rural population to urban centers, population growth, markets of insufficient size to insure economies of scale in prefabricated construction, insufficiently developed transportation and distribution systems, shortage of skilled labor, generally low standards of workmanship. An additional negative factor is users' resistance to certain construction materials and systems. Such resistance can in many cases be overcome. For example, user acceptance of adobe blocks (which are still considered in Peru and Turkey less "noble" than bricks) will be considerably improved by the quite satisfactory appearance of adobe upgraded through stabilization and improved manufacturing techniques.

Feasible technical improvements include the upgrading of materials such as, for example, adobe or bamboo. Stabilized adobe can be produced in vast quantities at low prices, and exhibits superior structural, architectural, thermal and acoustical properties. Deterioration of bamboo can be prevented by chemical preservatives which can be manufactured in developing countries. Building techniques that can be improved include masonry construction which, if properly designed (particularly with reinforcement), exhibits superior aseismic properties, and to which a considerable body of knowledge, available particularly on the West Coast of the United States, may be successfully adapted; building prefabrication to which techniques used in various European countries or in the United States may be applied; production of industrialized dwellings such as the CARE, Inc. units developed in Bangladesh.

New construction materials such as jute fiber, reinforced concrete with vegetable or plastic reinforcement, stabilized adobe, and lightweight structural sandwich systems which are now being utilized in the United States, could be employed for low-cost housing in developing countries. Improved production methods and equipment could result in lowered costs and better quality of these new materials. National research institutions can play a significant role in developing technical improvements.

To stimulate such improvements, institutional action at various levels is required. Operations related to housing construction of various institutions, governmental, international, and to a limited extent, private, are described in this context. Effective communication and transfer of technology can be achieved within the process of interaction between experts of both the assisting agencies and the developing countries involved in specific cooperation programs. An important role is also played by training, educational and fellowship programs and by seminars. Building information centers serving professionals as well as laymen building their own houses can provide information on material selection, and technical guidance and advice on building know-how. Production units serving as models or pilot plants can contribute to the diffusion of advanced technologica methods. Prototype buildings can be built for the purpose of acquainting the public with innovative systems designed to provide better resistance to earthquakes and windstorms.

A considerable potential for technical improvements leading to structures better resistant to earthquakes and windstorms exists. Decisions as to which areas should be accorded priority depend on the specific needs of the developing countries involved.

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DESIGN, SITING AND CONSTRUCTION OF LOW-COST HOUSING AND COMMUNITY BUILDINGS TO BETTER WITHSTAND EARTHQUAKES AND WINDSTORMS

Edited by

William F. Reps and Emil Simiu

The extensive loss of life and property caused in developing countries by earthquakes and windstorms (hurricanes, typhoons and tropical cyclones) may be reduced to a considerable degree by the adoption and implementation of improved design, siting and construction procedures practicable within the context of the cultural and socio-economic constraints prevailing in these countries.

The report provides technical information regarding characteristics of materials and building systems, and discusses the structural performance of buildings subjected to the action of earthquakes and wind forces with specific reference to structures typical of developing countries. Potential ways are described in which structures can be made more resistant to such action. Siting considerations are discussed from a geological, seismic and climatological viewpoint, and recommendations relating to siting problems are made. Techniques of housing construction, both traditional and industrialized, are described and improvements resulting in better earthquake or windstorm resistance are suggested. Building codes, their improvement and their enforcement are also discussed.

The report discusses cultural and socio-economic constraints influencing the adoption of improved practices, describes various feasible technical improvements of construction materials, composite systems and building systems, identifies mechanisms for stimulating technical improvements and discusses the role of institutions in this regard. Throughout the report, specific references are made to Peru, the Philippines and Turkey, countries which suffer from frequent devastation from natural disasters such as earthquakes and typhoons and which were selected as case studies for the purpose of this report.

Key words: Buildings; construction; design; developing countries; earthquakes; low-cost housing; natural disasters; structures; windstorms.

Chapter 1. Introduction

William F. Reps
National Bureau of Standards

The extensive loss of life and property caused in developing countries by earthquakes and windstorms (hurricanes, typhoons and tropical cyclones) may be reduced to a considerable degree by the adoption and implementation of improved design, siting and construction procedures practicable within the context of the cultural and socio-economic constraints prevailing in these countries.

As a first step toward establishing and implementing such procedures, it is necessary that the relevant technical, cultural and socio-economic constraints be identified and that solutions compatible with these constraints be proposed. This report examines the technical problems related to the destruction of structures in developing countries under the action of earthquakes and windstorms. It describes potential ways in which structures can be made more resistant to such action, either by upgrading local materials and procedures or by transferring and adapting, in a practical and effective manner, technology from developed countries. Cultural and socio-economic constraints influencing the adoption and implementation of improved practices are identified and discussed.

Technical information regarding general characteristics of buildings, building materials and structural performance of buildings subjected to earthquakes and wind forces is provided in Chapters 2, 3, and 4. The importance of siting considerations from the geological, seismic and climatological viewpoint is outlined in Chapter 5. Chapters 6 and 7 review methods of housing construction, building codes and regulations. Chapters 8 and 9 summarize the major social and economic factors that influence the advancement of housing technology in developing countries. These chapters drew extensively from the consultants' reports. Chapter 10 presents feasible technical improvements in construction materials, composite systems, and building systems. Chapter 11 describes mechanisms for stimulating technical improvements and the role of institutions in this regard.

Chapter 2. General Structural Characteristics of Buildings and Building Materials

S. G. Fattal
National Bureau of Standards*

2.1 Introduction

This chapter provides background information for the discussions in Chapters 3 and 4 regarding structural performance of buildings subjected to wind and earthquakes. In Section 2.2 buildings are described according to structural type and the manner with which they transfer lateral and gravity forces. Section 2.3 describes and classifies building elements according to shape and composition whereas construction materials and their mechanical properties are discussed in section 2.4. Special attention is given to types of construction and materials identified with low-cost housing development.

2.2 Structural Types

2.2.1 Bearing Wall Buildings

In buildings of bearing wall construction, the walls are designed to transmit gravity and lateral loads to the foundation by functioning as structural elements in compression, shear, tension, and bending. Gravity forces consist of the dead load of the structure and vertical live loads from human occupancy, furnishings, snow, ice, or other transient loads. Vertical forces are also induced by wind suction, uplift and direct pressure on the roof (see Chapter 4), and by vertical movements of the ground in an earthquake (see Chapter 3). Lateral forces are produced by winds, floods, tidal waves, debris loading and horizontal earthquake movements of the ground.

Figure 2.1 offers a simple illustration of the force transfer mechanism. Vertical loads from the roof assembly produce the compressive forces shown acting on the walls below. Resistance to lateral forces is provided primarily by walls of the same orientation. For instance, in the figure, shearing resistance of walls A and C is mobilized against horizontal forces indicated by solid arrows. Similarly, walls B and D are mobilized against transverse forces indicated by the broken arrows. In addition, walls provide direct tensile resistance against overturning or uplift forces and bending resistance against out-of-plane normal loads induced by lateral forces.

2.2.2 Frame Buildings

The main identifying feature of a framed building is the presence of a substantially complete vertical load-carrying frame consisting of beam and column elements. Where the frame is also called upon to participate in resisting lateral forces, the design usually provides for bracing or for rigid connections so that the rotations at any joint are collectively resisted by the interconnected framing elements in proportion to their bending stiffnesses. For example, in the single-cell space frame of Figure 2.2, beams A to D are rigidly attached to columns E to H at the top four joints. The deformed shape of the frame under the simultaneous action of vertical and lateral loads is shown exaggerated by the broken lines for the sake of clarity. Resistance

* Complete addresses for all contributors to this report are given on page iv.

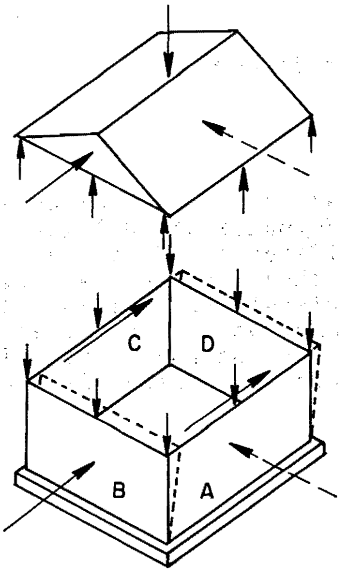

Figure 2.1 Illustration of Force Transfer Mechanism

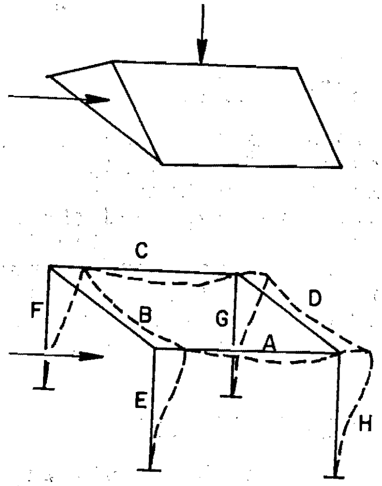

Figure 2.2 Illustration of Bending Under the Effect of Horizontal Loads

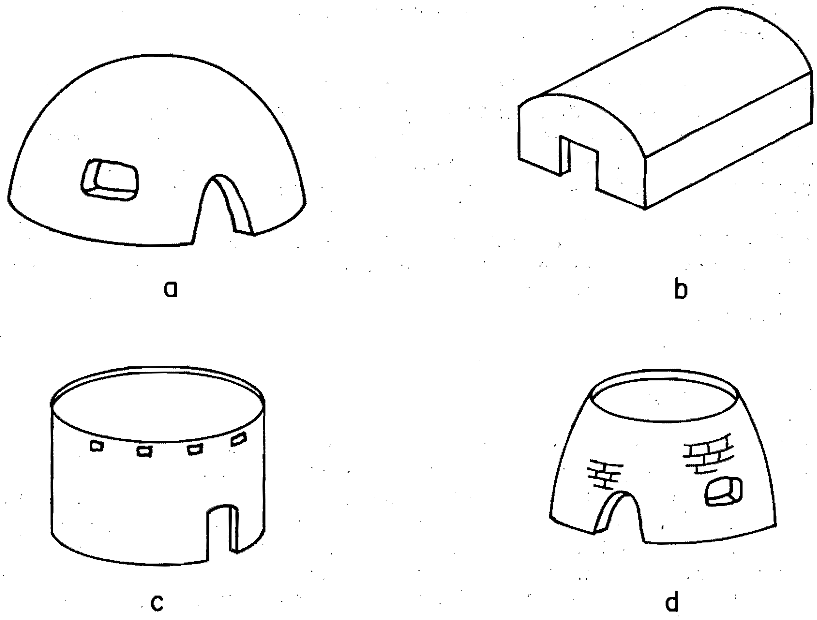

Figure 2.3 Examples of Shell Structures

to lateral forces is primarily contributed by bending and shearing of columns and bending of beams. In addition, beams provide bending and shear resistance against vertical loads transmitted from the roof through floor joists and other attachments, with columns offering resistance against axial loads and any bending moments induced by continuity of joints.

Walls of frame buildings are generally constructed for the non-structural purpose of providing enclosure. However, when they are attached to, or built integrally with the rest of the structure, as in the case of infilled frames, most of the lateral forces are carried by the walls in shear since their in-plane stiffness is significantly larger than the combined lateral stiffness of the frame columns.

2.2.3 Shell and Membrane Buildings

Shell type buildings consist primarily of single or double curvature elements as illustrated in Figure 2.3. The dome shape in (a) provides continuity of roof and wall. The truncated dome in (d) consists of a flat roof bearing on walls of double curvature (i.e., vertical and horizontal). The structure in (b) uses a cylindrical roof with flat vertical walls and (c) depicts a "silo" shaped structure with flat roof bearing on cylindrical wall enclosure.

The shell is a highly efficient structural form deriving its ability to withstand loads from curvature which, when properly exploited by the designer, gives it the ability to transmit loads through membrane action (i.e., in-plane compression, shear and tension) with a minimal amount of bending.

2.3 Structural Elements

2.3.1 Foundations

Building foundations are designed to transmit superstructure loads to the ground below. The type of design is dictated by the bearing capacity of ground material, intensity of loads to be transmitted and allowable levels of tolerance to settlements. These factors become less critical for low-rise dwellings of one to two stories than in high-rise buildings. Certain foundation types, such as piles, are seldom utilized for small buildings except in frequently flooded areas where houses may be built on bamboo stilts driven into the ground to a length sufficient to develop the required load capacity by friction with the surrounding soil. Where flooding is not a major factor, rectangular footings of plain or reinforced concrete or gravel with soil-cement mortar are quite commonly utilized. Wall footings are usually laid under the entire length of the wall with widths varying from twice the wall thickness for load-bearing walls to slightly larger than the wall thickness for nonload-bearing walls and partitions. Depths of footings commonly vary between 30 to 60 cm. For small dwellings rectangular spread footings, similar to wall footings in composition, are used to support individual column loads of frame buildings on rocks or high-quality compact soil. Combined footings or mat foundations are used with less favorable soil conditions.

2.3.2 Frame Elements (Figure 2.2)

A frame is an assembly of beam, column, and bracing elements of small sectional dimensions relative to length. The structural behavior of each element identifies it from the other types.

A beam transmits vertical loads horizontally to columns and walls through the combined mechanism of shear and bending. Shearing may be visualized as the tendency of two surfaces, formed by the splitting of a section, to slide across one another in opposite directions. The mechanism is actuated by opposite internal forces developed in the plane of a section. Bending produces curvature in an element causing compression at the concave side and tension at the convex side. For this reason, beams made of materials of low tensile strength, such as concrete, require reinforcing bars near tensile regions for effective action against bending. Beam cross sections of reinforced concrete or wood construction are usually rectangular whereas the I-shape is the more common shape of steel beams.

Columns transmit vertical loads and beam reactions to the foundation. Their structural effectiveness is in compression although in most instances they are also designed to transmit bending induced by continuity of joints or eccentricities of axial loads. Square, circular, rectangular or I-shaped sectional profiles are quite common. Columns are made chiefly of reinforced concrete, masonry, wood, or metal.

Bracing elements in frames inhibit lateral deflections and provide resistance against horizontal forces. A common application is the diagonal cross bracing in which the tensile resistance of bracing elements is mobilized against the lateral forces. Bracing is also used to increase the resistance of columns against lateral buckling. Materials strong in tension are well suited for bracing. Steel, wire, wood, bamboo or even rope are typical examples.

2.3.3 Walls

Structurally, a bearing wall is the counterpart of a column in that both are designed to support primarily vertical loads in compression. In addition, bearing walls develop substantial shear forces from lateral loads which also produce some bending in these elements.

The assembly of a filler wall with a confining frame around it, is known as an infilled frame. Under lateral loads, such as seismic or wind loads, filler walls alter the basic behavior of the frame by inhibiting lateral deflections and absorbing most of the shear. Axial loads in filler walls are nominal.

The main function of nonstructural walls such as parapets and interior partitions is to provide enclosure in buildings. Therefore, the contribution of these walls to the overall structural resistance should be minimal.

Structural walls of wood, concrete, burnt clay or soil-cement composition are quite common in low-cost housing construction. The walls may be monolithic or of masonry type construction where staggered courses of basic units are laid in beds of mortar. Clay brick and tile, adobe brick and concrete block are conventional masonry units. Masonry mortar of a desired consistency and strength is prepared by using certain proportions of cement-lime-sand or soil-cement mixtures.

2.3.4 Roofs and Upper Floors

Floors above the ground level are designed to develop sufficient capacity in shear and bending to transmit direct gravity loads to floor joists, frame elements or bearing walls below. They also function as diaphragms distributing lateral forces to supporting elements. Typical examples of floor systems are reinforced concrete slabs supported by joists or at the edges of the building, and joist-supported wood floors.

Diverse types of materials and shapes are utilized in roof construction. Pitched roofs are often attached to a wood supporting frame or a truss. Flat roofs are similar to floor slabs in structural behavior although the nature of loads is somewhat different mainly due to the presence of suction and uplift forces. A traditional type of roof construction used in Peru consists of wood joists or logs spanning across opposite walls, overlain first by bamboo, straw or asphalt-impregnated burlap, and then adobe.

2.4 Materials and Their Mechanical Properties

2.4.1 Concrete

At the construction site, concrete is placed in preassembled wood forms which are removed after setting. Near full strength is usually attained in about a month. Standard cylinder control specimens may be taken from different batches during construction for testing to determine the compressive strength of the concrete used. This practice is desirable in view of the dependence of concrete compressive strength upon the proportioning and quality of its ingredients, rate of curing and many other factors. Compressive strengths ranging from 1,400 to 3,500 N*/cm^2 are typical.

Concrete is weak in tension and therefore, seldom used without reinforcement. The use of steel, fiberglass, bamboo and other materials capable of withstanding tension for reinforcement, coupled with properties such as durability, fire resistance and suitability for molding into different shapes, makes concrete a most versatile construction material.

Ferrocement is a material consisting of concrete reinforced with wire mesh. Ferrocement construction can be successfully achieved with local labor under minimal supervision. The materials needed are cheap and readily available in developing countries. Its earthquake- and wind-resistant properties, if used for such elements as slabs or silos, are very good [1].1/

2.4.2 Masonry

The compressive strength of masonry with a specified type of mortar is equal to the test strength of a standard size prism of the same composition modified by a factor. Alternately, the strength is sometimes expressed as a fraction of the strength of its unit for a specified type of mortar. The ranges of compressive strengths of brick and concrete block masonry used in construction are as follows:

Type	(N/cm^2) Compressive Strength of Masonry Units	(N/cm^2) Compressive Strength of Masonry
Brick	1,400-10,000	400-3,200
Block (Concrete)	350-2,000	100-6,500

Because of its low tensile strength, in the order of 5% or less of its compressive strength, masonry requires the use of reinforcement to develop

* N = 1 Newton = 1/9.81 kg.

1/ Figures in brackets indicate figure references at end of each chapter.

any structurally significant bending resistance in the absence of axial compression.

2.4.3 Soil

In many parts of the world, particularly in developing countries, natural earth is probably the most common material used in building construction. Sun-dried adobe bricks containing sand, silt and clay, often untreated against water penetration, have been the basic masonry units for traditional low-cost housing construction. The more recently introduced asphalt-stabilized adobe brick of high durability and water-repellent properties marks a significant breakthrough in improved low-cost construction. With good workmanship, stabilized adobe bricks with compressive strengths of 350 to 500 N/cm^2 may be obtained. Mortars used with adobe units are mixtures of soil and cement, with asphalt added to give it the desired stability.

Several attempts have been made in Turkey to provide stabilization with asphalt. A study recently conducted by the General Directorate of Building Materials of the Ministry of Reconstruction and Resettlement (Ankara) concluded that laboratory analyses of the adobe were necessary to determine the kind and optimum amount of asphalt to be used for stabilizing it. The analyses should include a sieve test (gradation) and a determination of silt and/or clay amount. Liquid limit and plastic limit should be determined to know the plasticity index (PI) of the soil. In general, soils with a clay and/or silt content of more than 45% are not suitable for asphalt stabilization. The kind of asphalt to be used is determined by the type of soil, as follows:

Cut-back asphalts of RC (Rapid Cure) type and emulsion asphalts, are very suitable for sandy soils, with a small silt and/or clay content. Soils of low plasticity index are of this kind. As nonplastic soils are cohesionless, the stability of the mixture is a function of the binding power of the asphalt used.

Cut-back asphalts of MC (Medium Cure) type provide a more homogenous mixture in case they are used with soils of medium plasticity index. As the plasticity becomes higher, cohesion increases. Consequently, the stability of the mixture is determined by both the binding power of asphalt and the cohesion effect of clay. This kind of soil gives satisfactory results with emulsion asphalts.

Asphalts of SC (Slow Cure) type are good for clayey soils as they are highly penetrative. They can be used with soils of high plasticity index, and silt and/or clay content higher than 30%. The stability of the mixture does not depend much on the binding property of the asphalt, as the soil itself is highly cohesive.

Soil should contain approximately half of the optimum water content for cut-back asphalts. In other words, the asphalt will substitute the remaining half. When emulsified asphalts are used, the water content should be 10% or slightly more. This amount of water facilitates the mixing of asphalt.

The following table shows the average results for two sets of tests (one with 4% and the other with 7% asphalt ratio, with 85-100 penetration rate, in form of an emulsion containing 60% water):

	With 4% Asphalt	With 7% Asphalt
Unit Weight	1.879 kg/m^3	1.902 kg/m^3
Pressure Strength		
(a) Normal in dry air		
Average	848 N/cm^2	1,100 N/cm^2
Minimum	69.5 N/cm^2	1,020 N/cm^2
(b) Absorbed with water		
Average	-	86.5 N/cm^2
Minimum	-	70.5 N/cm^2
(c) After frost	-	Collapsed after 15th repetition.
Capillary water rise		
(a) cm/hour (23 hours)	7 cm	
(b) gr/hour (27 hours)	160 gr	19 gr
Water absorption	Collapsed	3.64
Cost per adobe block		
(29 x 14 x 9.5 cm)	0.387 T. ($0.027)*	0.738 TL. (0.0515)

Availability of Asphalts Used for Adobe Stabilization in Turkey

(a) MC (Medium Cure) Cut-back Asphalt: A mixture of asphalt cement (AC) and kerosene. Grades 0, 1, 2 of this kind can be produced by Batman Refinery. The current (1972) price from Batman is about 750 TL. ($52.50) per ton.

(b) RC (Rapid Cure) Cut-Back Asphalt: A mixture of asphalt cement (AC) and gasoline. Grades 0-5 of this kind of asphalt can be produced by Batman Refinery. Unit price is about the same as MC type. It is highly flammable and the Turkish General Directorate of Highways prefers to produce it locally.

(c) SC (Slow Cure) Cut-Back Asphalt: A mixture of asphalt cement (AC) and light oils. Crude oil and fuel oil are of this kind. It is not produced nor used in large amounts but can be produced by Batman Refinery. Current price from Batman is about 600 TL. ($42.00) per ton.

2.4.4 Wood

The structural uses of lumber in building construction are diverse and extensive. Wood joists and plywood panels are used for roof and floor systems. Sandwich panels with wood studs and plywood skins are utilized for exterior walls and partitions. However, lumber is not everywhere available or economically feasible for low-cost housing construction.

* 1 TL = $0.07 (November 1972).

In such cases, nondimensional lumber, raw timber, cane, bamboo, palm or thatch are used as alternates depending on their local availability.

Generally, wood exhibits good strength in both tension and compression in the direction of its longitudinal fibers. This property makes it adaptable to construction of bending resistant elements in a building. Cane, bamboo or split wood may also be utilized to reinforce adobe masonry walls and elements of poured stabilized soil. Exposed wood generally requires special protection against moisture, fire and insect infestation.

2.4.5 Metals

Steel in the form of reinforcing bars for concrete and masonry elements is used extensively in housing construction. Individual reinforcing bars of different diameter sizes are generally fabricated with deformed surfaces for better bond. Wire mesh reinforcement is fabricated by welding together two layers of spaced thin bars (usually 1 mm. or less in diameter) in a grid pattern. Poultry netting or similar steel mesh of hexagonal or triangular pattern is a relatively-inexpensive manufactured product which merits exploitation as a reinforcing material for low-cost houses, particularly in ferro-cement, as it may be more readily available locally than other types of reinforcement.

Steel exhibits high strength, stiffness and ductile properties. Stiffness is a measure of resistance against deformation, whereas ductility is the ability to sustain substantial deformation without rupture. Both strength and ductility provide a measure of the capacity of a material to absorb energy without rupture. Tensile strength of steel reinforcement usually falls within the range of 25,000 to 45,000 N/cm^2. Mechanical properties of steel change rapidly at temperatures above 400°C, and surfaces exposed to moisture are subject to corrosion. In construction, steel is protected by painting and by coating with fire proofing materials.

Other applications of metals in low-cost housing construction includes the use of corrugated sheet metal of galvanized steel or aluminum for roofing and wall siding, use of steel connectors for bolting and anchoring various elements, and use of rods and cables for bracing purposes.

2.4.6 Plastics

Knowledge about weathering characteristics of plastics in outdoor use and durability in relation to the traditional materials is still incomplete, particularly in regard to their use in tropical areas such as the Philippine Islands. However, plastics are finding increasing use in housing construction in many developing countries, including the Philippine Islands, South Korea and Taiwan, which are among the chief plastics-producing countries in the Far East. A range of plastic products, using indigenous and imported raw materials and processing machinery, are manufactured in these and some other developing countries, with certain plastic products proving of interest to the building industry. In contrast, the Peruvian and Turkish plastics industries are only in the very early stages of development, and plastics are little used by the building industry.

Some advantages of plastics which have been considered by the building industry are their adaptability to mass-production techniques, their lightness, corrosion-resistance, and ease of manipulation in manufacturing any specified design of building components. These characteristics of plastics are currently enhancing their acceptance in building applications.

Cellular plastics [2] exhibit excellent thermal insulation and thus reduce temperature fluctuations in hot, arid regions with a wide range of temperature cycling. On the other hand, in hot, humid regions less thermal advantage is to be gained by the use of plastics, except as part of a lightweight system of construction or as a substitute for the thermally-inadequate corrugated steel.

Plastics have yet to find full acceptance in the building industry, which generally tends to be conservative in its approach to innovative building materials and techniques. As a tradition in Turkey for example, solid and durable materials are generally preferred for building construction. However, a variety of plastic materials are recently emerging in the market and some of them are being used in the newly constructed modern buildings in urban centers. Greater acceptance of plastics as a construction material is likely to occur in the near future.

Replacement of the traditional materials used in the manufacture of various goods and articles by plastics has resulted in rapid development of the plastic industry in Turkey. Whereas certain polymers and plasticizers began to be produced in recent years, industry depended mostly on imports for raw and auxiliary materials until the end of 1969.

Of the plastics now produced in Turkey [3] (about 300,000 tons in 1972), only the items listed below are used in buildings (all reflect recent developments in Turkey):

(a) Vinyl-asbestos floor tiles have recently become popular in cities and towns, and are substituted for cement and mosaic tiles. Production is growing rapidly, and the rate of acceptance shows that this material may well be adopted in villages in the near future.

(b) Clean and/or waste water plastic installation pipe: Plastic pipes are already used widely for irrigation and other agricultural purposes. It should be acceptable for plumbing in rural dwellings, for it has advantages such as lightness, workability, and durability.

(c) Kitchen and bathroom fixtures, water reservoirs, washbasins, handrails, plinths: Use of plastic for such items is constantly increasing in cities, and undoubtedly will increase in rural areas.

(d) Flat or corrugated plastic sheets: Although corrugated plastic sheets are widely used as roofing material in temporary structures (partly for decoration purposes), they have not yet been widely accepted as a general material in permanent structures.

(e) Sheets or bags of polyethylene films: Recently, thin plastic sheets (films) are widely used on roofs (especially on earth roofs, which provide a good thermal insulation but are poorly resistant to water penetration), for waterproofing, or in hollow gables of roofs for windproofing. Plastic bags are used to hold glass wool in place for heat insulation.

(f) Plastic foam for heat and acoustic insulation: Although several kinds of plastic form insulation materials exist on the market, they are not yet used in dwellings, but are popular for industrial use (refrigeration, industrial insulation) and for thermal and acoustic insulation of large modern buildings.

(g) Styrofoam beads and panels are used to provide light-weight insulation in prefabricated houses.

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Chapter 3. Structural Performance of Low-Cost Housing and Community Buildings Under Earthquake Conditions

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3.1 Nature of Earthquakes

Major earthquakes are generally believed to be of tectonic origin associated with large strains in the crust of the earth. Severe earthquakes may affect large geographic areas, releasing large amounts of energy, creating fissures, cracking and causing sudden relative changes in ground elevation which results in damage and destruction to surface structures.

The point from which the first seismic waves propagate is known as the focus or hypocenter of an earthquake. The epicenter is the point on the earth's surface directly above the focus. The severity of an earthquake can be measured by the modified Mercalli scale and the Richter scale. The Mercalli scale measures the intensity or degree of destruction and is dependent on several factors including intensity of shaking, condition of geologic foundation material, and distance from the hypocenter. It is an arithmetic scale of 12 divisions, indicated by Roman Numerals, wherein intensity I is barely felt by people and XII reflects total destruction of well-built earthquake resistant structures. The Richter scale measures the magnitude or energy released by an earthquake as estimated from seismograms. It is a logarithmic scale in which destructive earthquakes generally have magnitudes greater than 6, and the great historical earthquakes greater than 8. Post-earthquake experience is utilized to develop seismic risk maps which are adopted by various codes and building regulatory agencies in prescribing specifications for earthquake resistant design of structures (see Chapter 7).

3.2 Seismic Effects on Buildings

3.2.1 Influence of Structural Configuration

The distribution and relative intensities of seismic forces within a structure are influenced, to a large extent, by the type of construction, geometry, mass distribution and stiffness properties. In general, heavier elements in a building develop greater "direct" forces while stiffer elements receive a larger share of the forces transmitted between elements. Peak lateral forces tend to concentrate at massive roof and floor levels and propagate to other levels through vertical elements. For example, in the structure of Figure 3.1a, the lateral force acting on the roof is transmitted through connections to relatively lightweight columns below, producing critical shear and bending forces in these elements. Additional column bending occurs as a result of gravity load eccentricities created by the lateral drifting of the roof. The introduction of lateral stiffening elements such as cross bracing (shown dotted on the sketch) or walls in faces parallel to the direction of ground excitation reduces drift and its effects on columns, and alters drastically the force distribution pattern (i.e., the bracing acting in tension, or the walls acting in plane shear, assume most of the lateral forces transmitted from the roof).

The geometry of a building may have a marked effect in distributing seismic forces and influence the type and degree of failure. For example,

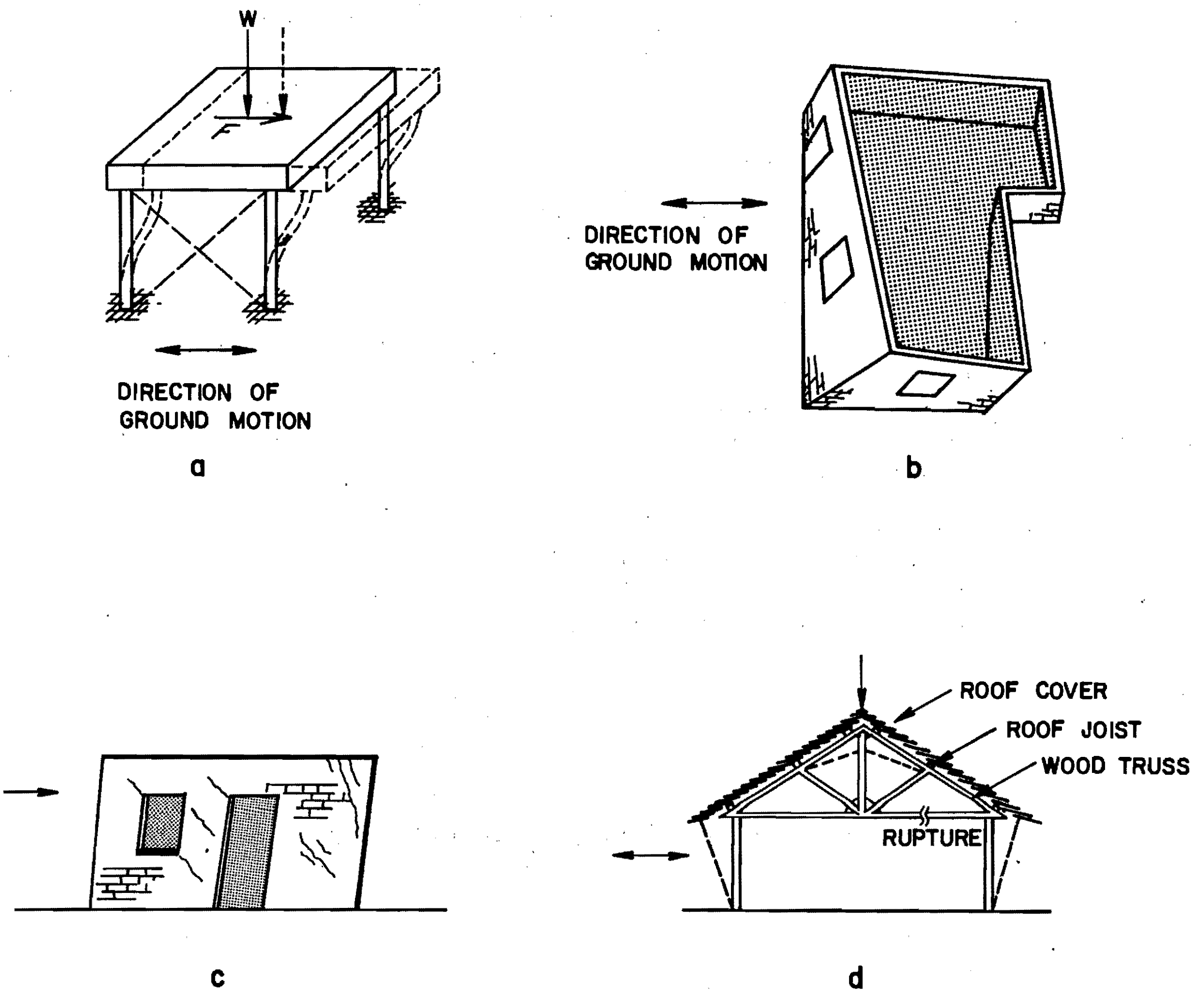

Figure 3.1 Effects of Ground Motion on Structures

twisting and warping are more likely to occur in buildings of irregular shape (Figure 3.1b) or in buildings having nonuniform arrangement of walls and openings. Failure commonly occurs at corners of openings (Figures 3.1c and 3.2), at the top junctions of abutting walls, near attachments of projecting elements, or, as a result of "hammering" between adjacent walls of detached buildings. In general, buildings marked with sharp transitions in mass and/or geometry tend to develop structurally unfavorable force distribution patterns.

3.2.2 Foundations

Frequently, structures designed to withstand earthquakes fail due to inadequate foundation design. Cracking and failure of superstructures may result from differential settlement of footings. Such settlement may be due to differential compaction of ground, to liquefaction of water-saturated soil, or to incipient slumping and sliding on slopes.

Certain types of foundations are more susceptible to earthquake damage than others. For example, foundations of shallow, individual spread footings are likely to be subjected to high differential settlements and "rocking," particularly where the supporting ground consists of different types of soils. Unfavorable conditions may also develop when mixed types of foundations are used for the same structure.

Many houses in coastal areas are built on poles or foundations of treated piles (see Chapter 4). In such cases the house must be properly fastened to the poles to give it sufficient stability against lateral earthquake forces.

Shallow foundations deteriorate with age as a result of exposure to freezing and thawing of the surface ground in regions of cold climate, and to frequent flooding in tropical regions. In seismic areas, some degradation of foundation material occurs as a result of the cumulative effect of past earthquakes even though they may not create any visible damage to the above-ground structure.

3.2.3 Walls, Frames and Shells

Unreinforced bearing walls of masonry, or concrete construction, commonly used throughout the world, are highly susceptible to earthquake damage as a result of their relatively low in-plane shearing capacity. Further reduction in strength of such walls results from window and door openings (Figure 3.1 c).

Walls commonly fail in racking shear, out-of-plane bending or a combination of both. Racking shear failures are recognized by the cross-diagonal cracking pattern commonly observed in building walls damaged by earthquakes. This type of failure is initiated by cracks at points of high stress concentration (corners of openings, centers of wall segments, or piers flanking adjacent openings) which then may quickly propagate outward causing complete rupture (Figure 3.2).

Out-of-plane bending failure is due chiefly to direct seismic forces acting in a direction transverse to the wall. In general, bending and shearing effects occur simultaneously in an earthquake since the direction of seismic excitation is often inclined with respect to the orientation of the walls.

Bearing wall failures are characterized by sudden, partial or complete collapse of wall segments accompanied by collapse of roofs and upper floors (Figures 3.6, 3.7). Such collapse may be widespread and is a

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Figure 3.2 Damages sustained by residential units at Chimbote, Peru. Causes of damage: excessive size of openings in relation to area of walls (note the absence of cracks at the corners of the small openings); inadequate reinforcement at opening corners. Damage could have been prevented by reducing size of openigns, providing adequate tie-beams and lintels sufficiently longer than the opening; strengthening the connections between roof to walls and floor to walls.

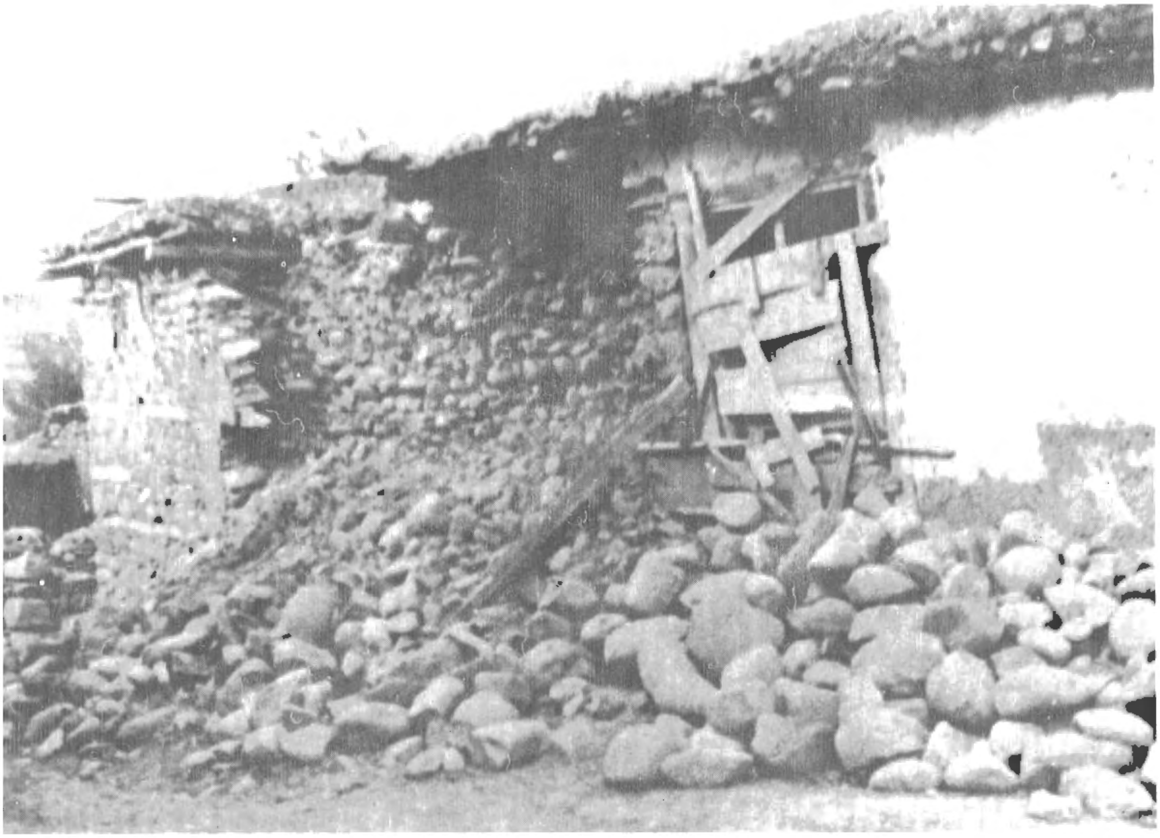

Figure 3.3 Field stone masonry house set in mud mortar, Turkey. Such construction is highly undesirable in earthquake-prone regions. Note, however, that wood ties have preserved the integrity of the wall at the corner. Field stone may be used in earthquake resistant construction provided that adequate tie-beams are used and that the mortar is of acceptable quality (see Figure 3.4).

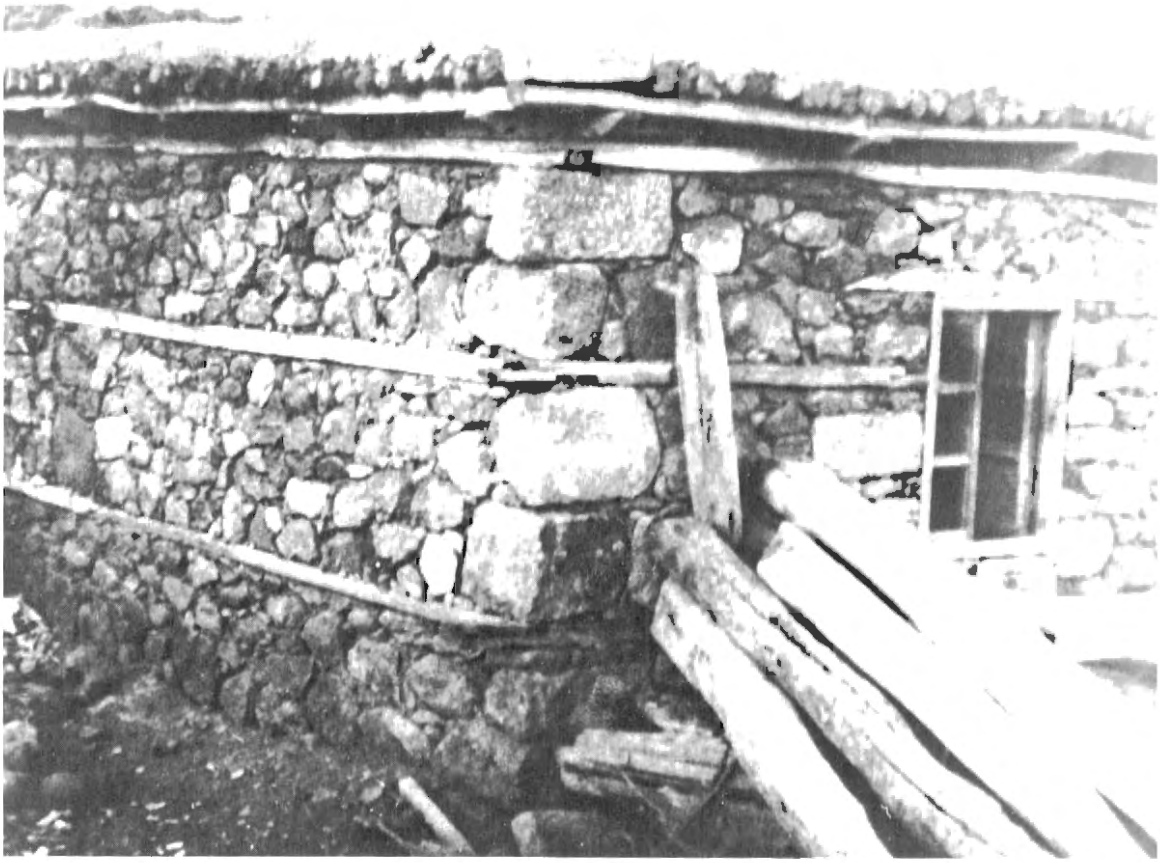

Figure 3.4 Stone dwelling with wood ties near Bingol, Turkey. The ability to withstand earthquakes is markedly improved in the case of this dwelling by the good quality of the workmanship and materials used (see Figure 3.6).

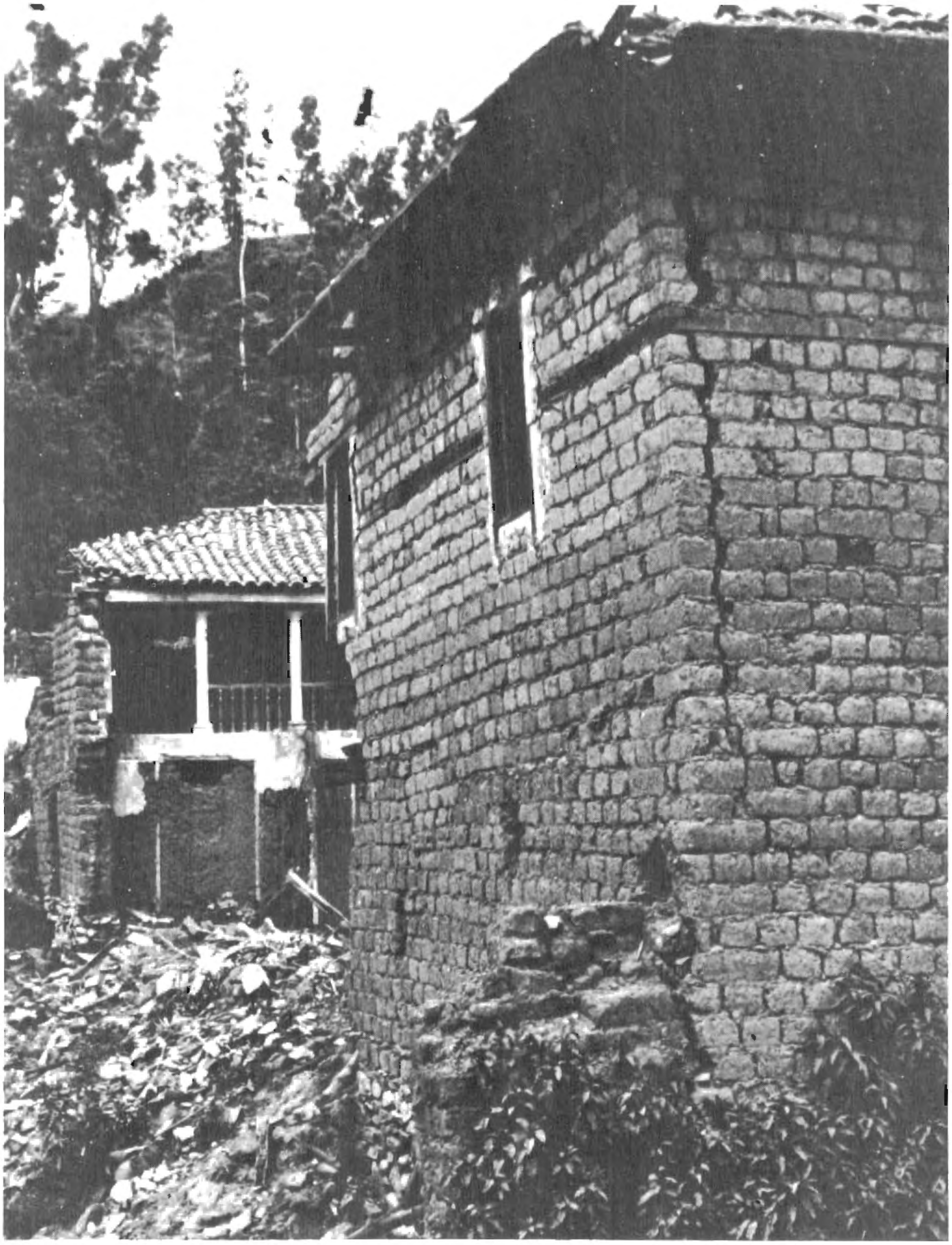

Figure 3.5 Corner failure of a two-story adobe wall with wood tie-beams (Peru). In this type of building, the roof does not act as a unit and thus does not transfer loads to the lateral walls (which would act in shear and thus easily sustain the loads). Instead, during the earthquake the roof exerts a thrust upon the frontal wall (the wall with openings in this picture) and detaches it from the lateral walls.

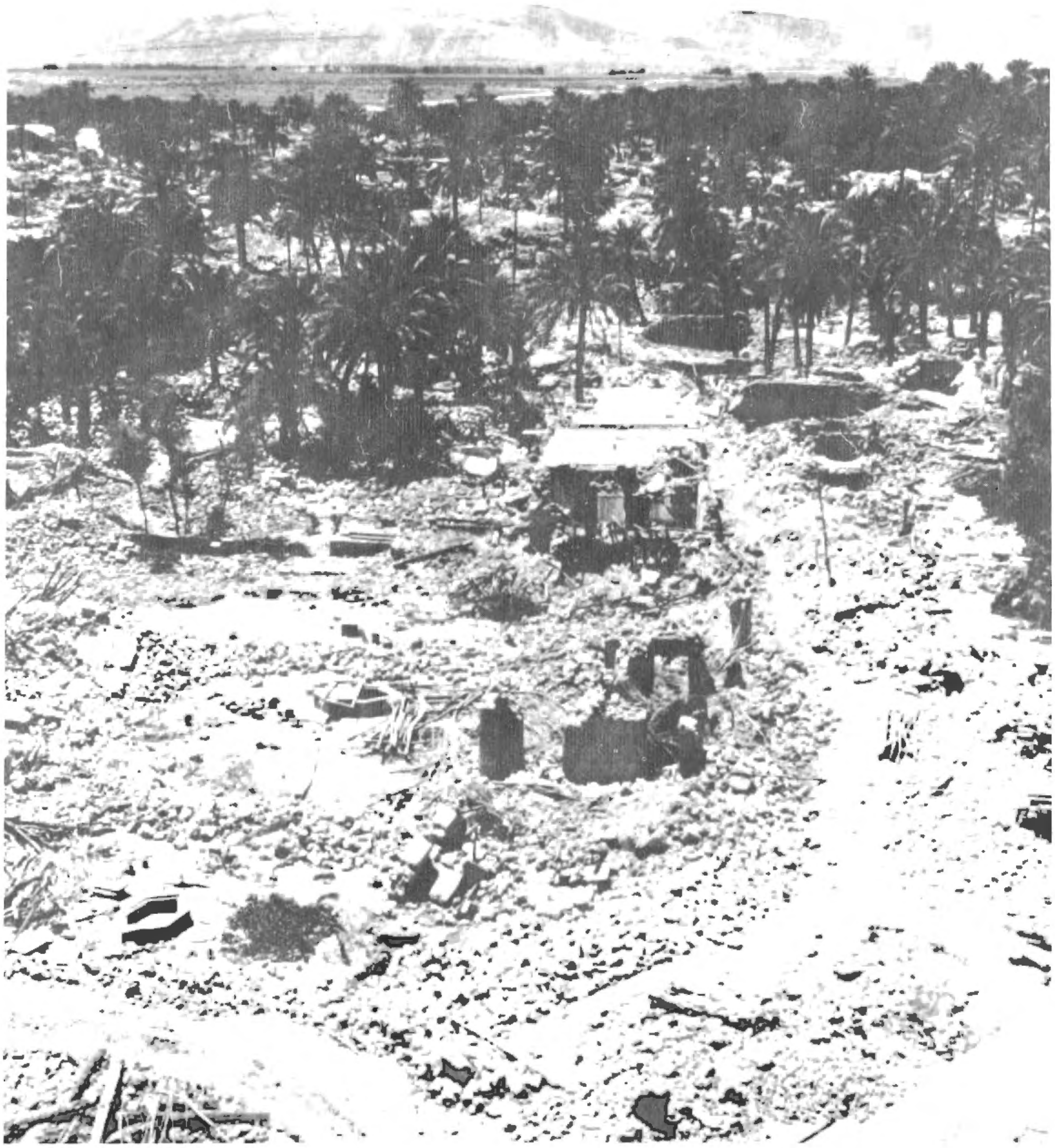

Figure 3.6 The town of Qir (Iran) after the 1972 earthquake. Most houses in Qir were built with sun-dried adobe blocks or rock rubble and adobe mortar, and had heavy roofs of logs first overlain by straw or burlap and then covered by adobe. Two-thirds of the people in Qir perished in the debris of their homes. Contributing factors to the magnitude of the disaster were the poor quality of the building blocks and of the mortar, the heavy roofs and the absence of adequate horizontal and vertical reinforcement and ties (courtesy of U.S.G.S.).

Figure 3.7 Collapsed two-story adobe building, Burdur, Turkey. The poor quality of the adobe blocks and mortar was a contributing factor in the collapse of this dwelling. Note the careful brickwork of the building standing in the background. Improved adobe block and mortar quality as well ad the provision of adequate ties and connections substantially decreases the risk of failure under earthquake loads.

major cause of injury and death in developing countries as shown by destruction of adobe wall dwellings during the 1970 Peru earthquake and the 1972 Fars earthquake in Iran.

Bearing wall collapse also may be due to failure of connections between roofs and walls (Figure 3.2) and between walls and foundations. As a result the building lacks the necessary structural integrity to act as a unit against earthquake shock (Figure 3.8). Tension cracks between abutting walls propagating from the roof downward (Figures 3.1c and 3.5) are indicative of inadequate wall-to-wall connections.

The structural weakness of bearing walls is also inherent in filler walls confined within load-bearing frames. Due to the effect of frame enclosure, however, filler walls tend to develop increased shear and bending capacity although this is partially offset by the absence of compressive loads, which up to a certain level, increase the capacity of a wall to resist in-plane shear forces.

Rectangular frames of the type shown in Figures 2.2 and 3.1a resist lateral forces through the combined bending and shear action of their elements. Collapse of frames under lateral forces may be caused by excessive column bending or by failure of rigid joints of frame elements.

Certain types of shell enclosures such as cylindrical or spherical shapes (Figure 2.3), have found their use in low-cost housing construction in the past. These dwellings are commonly built with traditional materials such as adobe block, without any reinforcement. Under seismic loading, failure is likely to be initiated by cracking at corners of openings or near ground or roof attachments where localized bending stresses are greatest.

3.2.4 Roofs and Upper Floors

One of the major concerns in the mitigation of earthquake disasters is to prevent collapse of roofs and floors which cause great loss of human lives. The use of heavy nonstructural roofing materials account for the high incidence of roof failures in low-cost houses in past earthquakes. Generally, roof failures may be attributed to insufficient strength or to lack of adequate connections. Roof collapse may also occur as a result of the rupture of supporting walls, columns and other load-bearing elements. The different modes of roof failures are dependent on the structural configuration of the system. For example, the rupture of the bottom chord of a roof truss (Figure 3.1d) may trigger a complete structural collapse by forcing the supporting walls outward as indicated by the broken lines. On the other hand, under a horizontal seismic movement, the roof transmits transverse forces to the supporting walls causing the formation of tension cracks and separation of abutting walls. This mode of failure is also characteristic of massive flat roofs (or floors) supported by beam joists that in turn are supported only by opposite bearing walls (Figure 3.5).

3.3 Building Improvements to Mitigate Earthquake Effects

3.3.1 Structural Configuration

The following is a list of recommendations regarding structural configurations that result in improved behavior under seismic loads:

Figure 3.8 Collapse of a dwelling in Casma, Peru during 1970 earthquake. The collapse was due to inadequate arrangement of walls, leading to unbalanced stress distribution in building, poor connections between vertical and horizontal elements, and the absence of sound horizontal tie-beams

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 manner 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. (Figures 3.2 and 3.4).

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.

3.3.2 Foundations

For low-cost single-story housing construction the only type of foundation of reasonable cost in relation to the cost of the structure is the superficial foundation. Where soil conditions require the use of deep or piled foundation, or where the possibility of soil liquefaction exists, an alternate construction site should be selected if possible.

The following requirements should be met in order 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 ground.

2. Continuous wall footings 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 integral 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.

3.3.3 Walls, Frames and Shells

The seismic resistance of walls constructed out of stabilized adobe block may be improved considerably by utilizing locally available reinforcing materials. Results of preliminary tests (Improved Adobe Construction Program at the National University of Engineering in Lima, Peru) of several wall sections constructed by traditional methods but utilizing split cane for reinforcement and oil-stabilized adobe block show an increase of over 100% in resistance to static lateral force.

Asphalt and soap emulsification provides a means of increasing the compressive strength of adobe blocks. 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. The extension of reinforcement into neighboring walls and foundations provides an effective means of achieving continuity and improved seismic-resistant construction.

An effective method of improving the strength of walls is to provide a ring beam at their top. The purpose of a ring beam is to tie the top of the walls together and to prevent tensile cracking from developing at the upper corners. In order to function in this capacity a ring beam should be reinforced with materials of high tensile strength such as bamboo, wire or steel rods.

The structural resistance of walls is significantly impaired by the location and size of openings. To a certain extent, it is possible to strengthen walls by using smaller openings and by providing equalized space between openings or between an opening and the vertical edge of the wall. Nevertheless, the danger of brittle collapse initiated by the failure of piers adjacent to openings can be reduced by providing effective reinforcement around these openings.

Tests on frames with properly tied-in infilled walls have indicated a considerable increase in strength of the frame-wall assembly as compared to the individual strengths of frame or wall [1]. The observation was made on reinforced concrete frames with brick masonry filler walls. Whether this increased capacity can be realized if the infilled frame were made of rammed earth, adobe, or other materials of low tensile strength, with cane or other reinforcement, should be determined by future research. Filler walls may also be designed in such a way as to permit most of the energy released in a severe seismic disturbance to be dissipated through the process of cracking of the walls leaving the main load-bearing frame relatively undamaged.

3.3.4 Roofs and Upper Floors

An effective way to improve the seismic performance of a building is to reduce the weight of its roof. To a certain extent, this may be achieved without loss of strength by substituting lighter-weight materials for roof covering in lieu of heavy materials such as mud or tile which have had widespread use in traditional low-cost dwellings in the past. Reduction of weight can also be achieved by using shorter spans which require the use of load-bearing interior partitions. This practice may be justified because (a) the addition of load-bearing partitions will increase the lateral resistance of the system, and (b) the reduction of weight is greater than the reduction of the span, often by significant amounts. Lightweight panel systems, which are highly efficient in bending may also be a substitute for traditional heavy roofs as discussed in Chapter 10.

3.4 Needed Research

As noted in Section 3.3.3, tests made on assemblies consisting of reinforced concrete frames with brick masonry filler walls have indicated a considerable increase in strength compared to the individual strengths of frame walls. Whether this increased capacity can be achieved if the infilled frame were made of rammed earth, adobe or other materials of low tensile strength, with cane or other reinforcement, should be determined by future research.

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Chapter 4. Structural Performance of Low-Cost Housing and Community Buildings Under Windstorm Conditions

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4.1 Characteristics of Windstorms

Windstorms of sufficient intensity to cause damage to buildings include tropical cyclones, extratropical cyclones, orographic winds, and severe local storms.

Tropical cyclones, of which the most destructive are called hurricanes in the North American area and typhoons in Asia, are most frequent during the summer and autumn of the hemisphere in which they occur. Upon moving to higher latitudes, they tend to assume the characteristics of extratropical storms, i.e., become less symmetrical and are accompanied by lighter rainfall. The damage caused by tropical cyclones is due to the direct action of winds, which may reach surface velocities of 150 mph or more, to rainfall, and to storm surges, i.e. violent piling up of water by the wind. The damage caused by storm surges is restricted to coastal areas and depends upon the distance from the shore and upon the elevation above mean tide level. The intensity of storm surge is measured in terms of the surge height which depends upon wind speed and direction, atmospheric pressure, coastline geometry, and bottom topography offshore.

The approximate average number of tropical cyclones and hurricanes per year for various geographical areas is given in table 4.1 [1].

TABLE 4.1. AVERAGE NUMBER OF TROPICAL CYCLONES AND HURRICANES PER YEAR

	Tropical Cyclones	Hurricanes (typhoons)
Eastern North Pacific Ocean	8	3
North Atlantic Ocean	8	5
Indian Ocean	15	
South Pacific Ocean	5	
Central & Western North Pacific Ocean	28	20

Extratropical cyclones occur in the middle latitudes and are usually more intense in winter and spring.

Orographic winds are winds intensified by the mechanical action of hills or mountains. Damage from such winds has been reported frequently on the eastern slope of the Rocky Mountains, and has occurred on a considerable scale in Sheffield, England [2].

Severe local storms include thunderstorms and tornadoes.

Thunderstorms are characterized by violent winds of relatively short duration (sometimes on the order of minutes). In certain areas of the world as much as 50% of maximum winds occur in thunderstorms [3].

Tornadoes (tatsumakis in Japan) are funnel-shaped windstorms attaining speeds estimated at 200 mph or more. The damage they cause is due to the direct action of their high wind speeds as well as to the very rapid drop in ambient pressure as the vortex of the tornado moves over an area. Buildings literally explode because of the intense pressure differentials imposed on them.

4.2 Effects of Windstorms on Buildings

4.2.1 Influence of Building Shape on Magnitude of Wind Loading

The magnitude of the critical wind pressure is dependent, to a large extent, upon the geometric characteristics of a building. A few examples of this dependence are shown in Figure 4.1, in which coefficients proportional to the pressure intensities for given wind speeds are shown for various height to width ratios and for various roof slopes. Pressures may also depend upon the relative position of buildings in a group. It follows that the wind resistance of buildings may be improved, sometimes considerably, by avoiding shapes or configurations which cause undesirable aerodynamic effects.

The aerodynamic behavior of a given building or its parts may be determined on the basis of available theoretical and experimental data, or by performing a wind tunnel model study.

4.2.2 Foundations

The mechanical action of wind forces may cause sliding or overturning of a building, and storm surges and heavy rainfall characteristic of hurricanes and typhoons may result in floods that damage the foundation soil or the foundation itself. Other potential ground effects are scouring, landslides, and loss of bearing capacity of the foundation material.

4.2.3 Walls, Frames and Shells

Wind-induced stresses in walls may be classified as either out-of-plane bending or in-plane stresses. Out-of-plane bending is produced by the direct action of wind pressures or suctions on a wall and become more critical as the wall thickness decreases. Damage caused by tornadoes is largely due to the high bending produced by the explosive action of suctions due to pressure drop in the tornado. In-plane stresses develop in walls as a result of their action as shear resisting elements within the building (see Chapter 2).

For wind acting in the direction indicated by the arrows in Figure 4.2, the frontal wall (ABCD) will be subjected to bending stresses. The lateral walls (CDEF and ABGH), which prevent the building from racking under the wind action, will be subjected to in-plane stresses. The effect of wind on wall ABCD is illustrated in Figure 4.3.

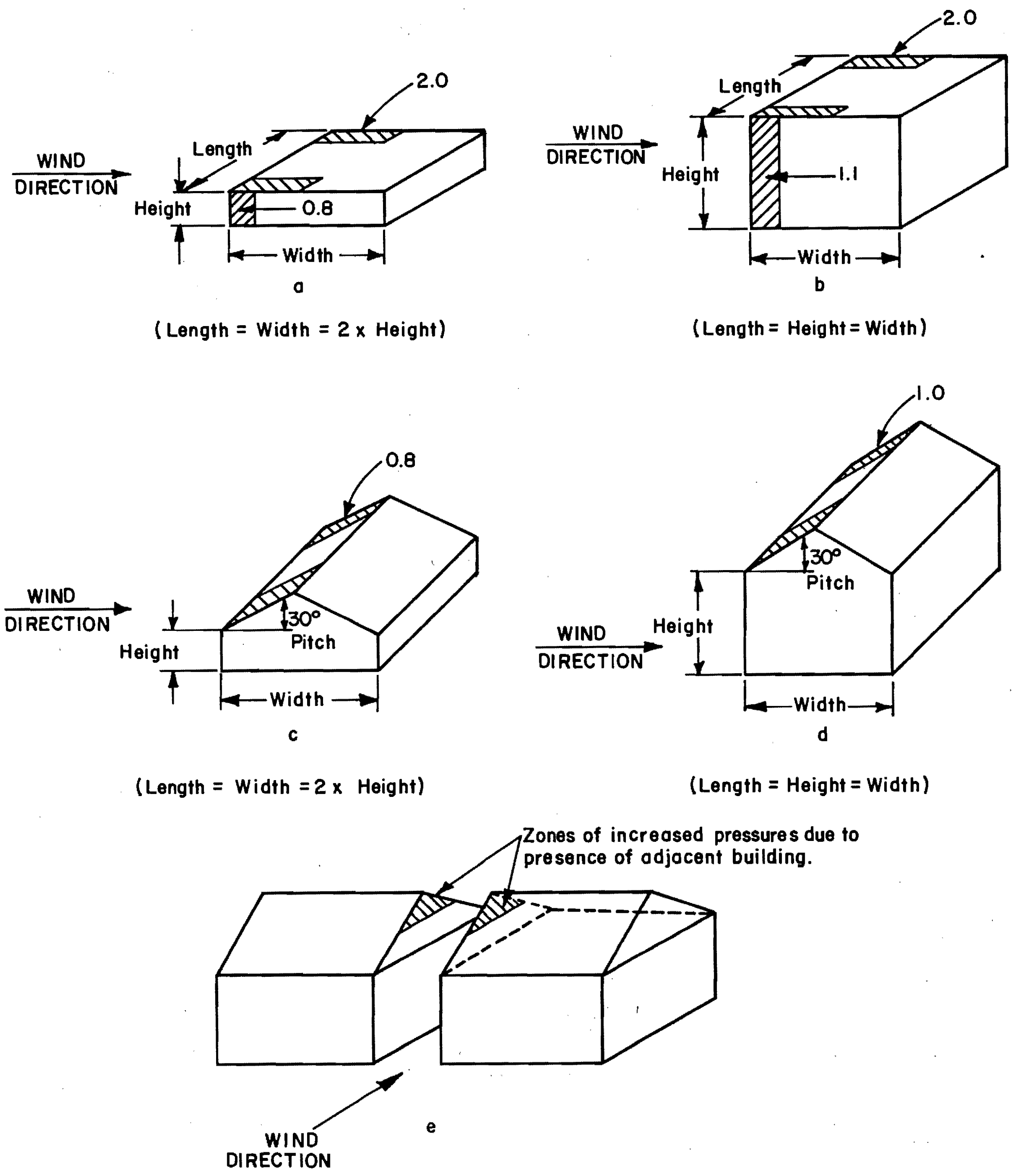

Figure 4.1 Wind pressures on buildings. (Shaded areas are areas of maximum wind pressure; numbers shown are a measure of the wind pressure intensity. For example, the pressures on the side areas of horizontal roofs (a, b) are twice as high as in the case of the 30° pitched roof (d)).

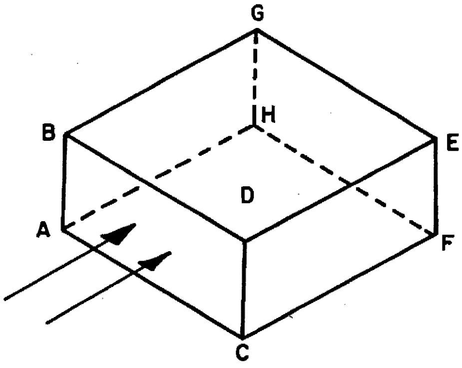

Figure 4.2 Bending stresses

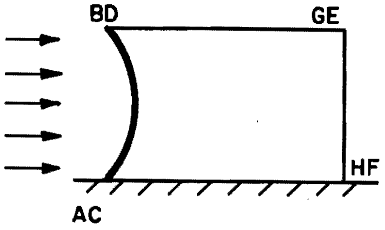

Figure 4.3 In-plane stresses

Openings in walls create stress concentrations which may be critical, particularly at the opening corners (Figure 3.2). Connections at the intersection of two walls, or between walls and foundations, floors, and roofs, are subject to exceptionally high stress, and if not properly designed or built may fail under the action of wind.

The structural function of lateral walls may be performed by frames, either prefabricated or built on the site. Frame joints are particularly vulnerable to effects of wind. The attachment of cladding or sheathing to walls or frames also requires special care (Figure 4.4), especially in areas of high suctions near the corners of the building and near the eaves.

Relatively rigid shells have been used in cylindrical-type construction and may present considerable advantages over boxlike construction, both structurally and aerodynamically.

4.2.4 Roofs and Upper Floors

The magnitude of wind pressures or suctions on roof surfaces is a function of the roof pitch, as illustrated in Figure 4.1.

The effects of wind on roofs may be direct or indirect. Direct effects may be local or extend over the entire roof. Direct local effects consist of high pressures or suctions over localized areas of the roof and may result in damage to roofing (shingles, tiles, sheets) or to parts of the roof structure. Overhangs are particularly susceptible to wind damage, as they are subjected to a positive pressure from below and suction from above (Figure 4.5). Indirect effects are associated with the transfer to lateral walls of wind loads acting on the frontal walls (Figure 4.2).

Figure 4.4 'Marcos" school destroyed by Typhoon Sening (Joan), October 1970, the Philippines. The inability of this structure to withstand wind loads was due to inadequate strength of the frame joints (particularly at the foundation level), of the roof connections, of cladding to building framing, of the end walls. Measures to improve behavior under wind loads would include provision of interior vertical bracing parallel to the short direction of the building (or a substantial increase of the bending capactiy of the frames), improvement of roof and cladding connections, reinforcement of the end wall (or provision of in-plane bracing in end wall).

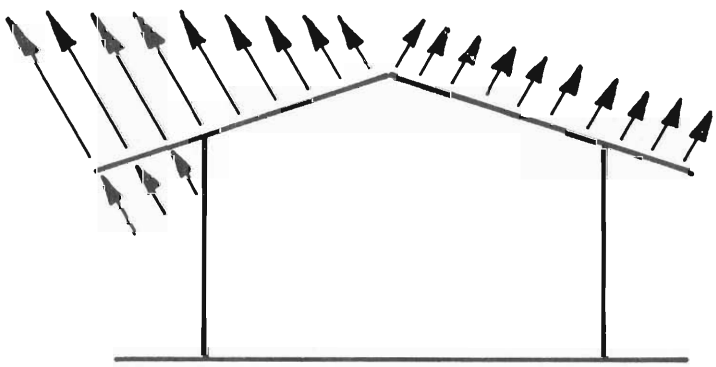

Figure 4.5 Wind damage to roof overhangs

If the positive pressures on the overhangs and the suctions on the roof become strong enough, the capacity of the connections will be exceeded and the roof lifted (Figures 4.4, 4.6, 4.7, 4.8). Since the roof performs a structural function in the building, in that it acts as a horizontal diaphragm for the transmission of wind loads from the frontal to the lateral shear walls, serious damage to roofs may result in loss of support at the upper part and consequent collapse of frontal or lateral walls (Figure 4.9).

4.3 Building Improvements to Mitigate Windstorm Effects

4.3.1 Aerodynamic and Structural Considerations

Critical pressures resulting from the action of wind may be reduced considerably by proper aerodynamic design. Sharp edges, low roof pitches, large overhangs, and aerodynamically unfavorable shapes or grouping of buildings (see Section 4.2.1) should be avoided wherever possible. Improvements in the aerodynamic behavior of buildings or of parts of buildings may be achieved in certain situations by providing rough surfaces or ribs at the exterior side of walls [4]. Grass roofs have been noted to have pressure relieving characteristics. Aerodynamically smooth transitions between planes may also be effective in decreasing pressures or suctions induced by wind.

The shape of the building affects its behavior not only from an aerodynamic, but also from a structural standpoint. Therefore, the selection of a shape which permits as direct a stress path as possible is recommended when the expected wind loads are high. Experience has shown, for example, that cylindrically shaped buildings are particularly well suited for resisting direct tornado action.

4.3.2 Foundations

The structural integrity of a building subjected to wind forces depends largely upon the strength of the connections and anchorages to the foundations. Such strength should be consistent with that of the building structural elements. Undesirable stress concentrations, or stresses, should be avoided. For example, anchorage lengths should not be less than determined by tests performed on the materials used.

The damaging effects of storm surges or floods on the foundation itself may be avoided by providing adequate foundation materials whose properties do not deteriorate under the prolonged action of water. If the foundation is constructed of soil, mortar and stone, a stabilizing ingredient can be added which will improve its resistance to water damage. Inexpensive protective banks or pole-type foundations [5] may serve to protect the building from severe storm surges.

4.3.3 Walls, Frames and Shells

Adequate connections must be provided between walls and between walls and foundations, floors, and roofs. Horizontal or vertical reinforcement may be required for the strengthening of certain types of walls, including adobe walls. Such reinforcement may be provided by inexpensive, locally available materials (for example, split cane, bamboo). Where vertical reinforcement is used, adequate grouting should be provided, using methods and mortars appropriate to the type of material available for wall construction. Buttressing of walls, bond beams for lateral support, and vertical or horizontal bracing may be required for the purpose of improving the structural capacity of walls, including walls built with

Figure 4.6 A church at Catanduanes, the Philippines, stripped of its roof by Typhoon Sening (Joan), October 1970.

Figure 4.7 Roofing blown off by typhoon winds, the Philippines, October 1970. Sound attachment of roofing to roof members would have prevented damage to roof of buildings in the foreground and background of the picture.

Figure 4.8 Destroyed homes and institutional building in the Bicol Region, the Philippines, October 1970. Cause of roof collapse: inadequate connections between roof members, inadequate anchorage of roof to walls.

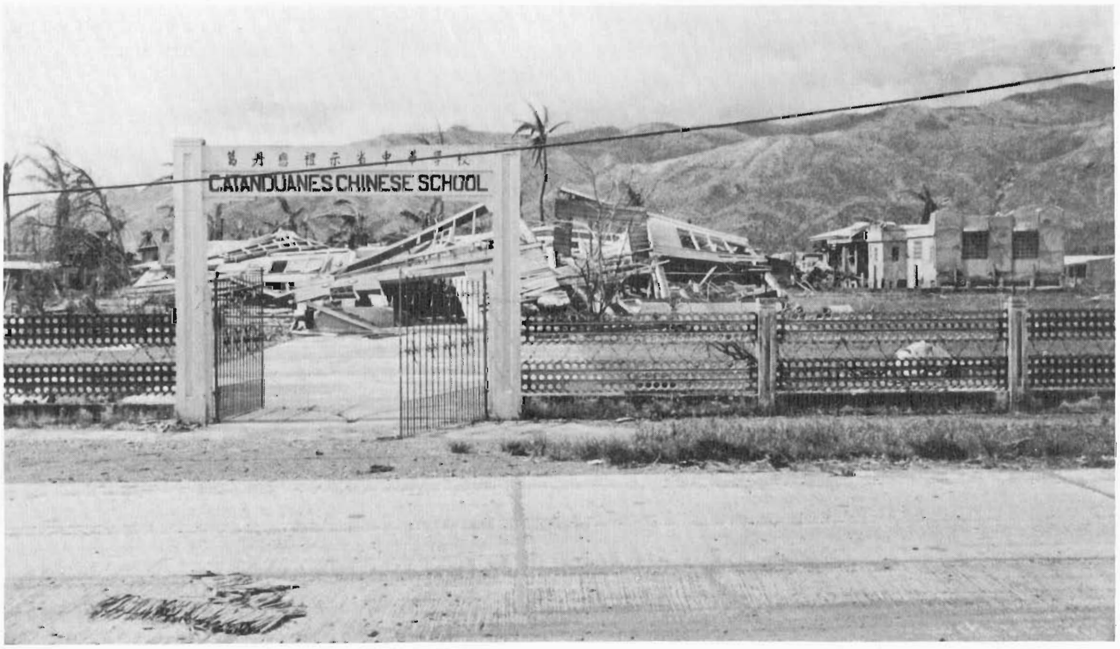

Figure 4.9 The Catanduanes school levelled to ground by Typhoon Sening (Joan). Poor vertical bracing was possibly responsible for the failure of this building.

such materials as adobe and/or bamboo. Adequate design of corners and openings should result in decreased stress concentrations through elimination of sharp transitions between planes. Wind resistant types of sheathing and appropriate fasteners should be used. Protruding elements (such as parapets) are particularly vulnerable to the action of wind (see masonry building in the background of Figure 4.4) and should be provided with adequate anchorage.

4.3.4 Roofs and Upper Floors

In the areas of high suction of roofs of various types, connections consistent with the magnitude of the expected loads should be designed. Roofs known to be vulnerable and which for various reasons cannot otherwise be improved should be anchored against a predicted storm, for example, by using wind-storm anchorage kits [6] consisting of coconut fiber nets in 0.6 m. squares thrown over the building and anchored to the ground, or using anchorage ropes or cables. Large overhangs and parapets should be designed so that localized damage due to overstress is kept from extending to the entire roof. This could be accomplished, for example, by the provision of specially designed pinned connections. It is also possible to design overhangs which allow easy removal and storage of the overhanging roofing sheets. The removal would follow a storm warning and considerably reduce the vulnerability of the roof if the storm actually occurs [6].

Appropriate thicknesses of roofing and sizes of washers should be used in metal sheet roofs to avoid tearing of the roof sheeting.

4.4 Needed Research.

1. Data on tropical and cyclone wind structures and speeds, applicable for structural engineering purposes, are scarce. Full scale field studies of tropical cyclones, designed to provide the data required for such purposes, are therefore needed in the future.

2. Most theoretical and wind tunnel studies performed so far are applicable to high-rise buildings only. Aerodynamic studies of low-rise buildings, especially those in tropical regions, are needed as a basis for better design and construction of wind-resistant structures. These studies should be carried out on both full-scale buildings and wind-tunnel models.

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Chapter 5. Siting Considerations to Reduce the Effects of Earthquakes and Windstorms

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5.1 Introduction

This chapter consists chiefly of two studies, one by Arthur Grantz (section 5.4), which discusses seismic and related hazards to low-cost housing in Turkey, and the other by George Ericksen, George Plafker, and Juan La Cruz, which is a case study of engineering geology and siting problems related to the Peru Earthquake of May 31, 1970. These reports are preceded by a brief summary of earthquake and windstorm hazards and their identification.

Seismological data collected during the past 70 years have shown that earthquakes generally take place within two principal seismic belts: the Circum-Pacific belt, extending from New Zealand north to Japan and Alaska, then south along western North and South America to Chile; and the Mediterranean-Alpine belt, extending from Morocco, through the Mediterranean and Middle East into central and southeastern Asia. Other belts of activity are associated with large rift systems, such as the Mid-Atlantic Ridge and the East African Rift Valley.

An earthquake as a geophysical event is measured in magnitude of energy release and in duration and intensity of ground shaking. An earthquake as a human event is measured in loss of life and property. The scale of the human event is not always proportional to that of the seismic event, for casualties and property damage depend on population density, type of structures, stability of geologic foundations, and time of occurrence, as well as on the magnitude, duration and focal distance of the earthquake.

Destructive windstorms include tropical storms, hurricanes of the Caribbean region and typhoons of the western Pacific, and cyclones, which occur most frequently in rather well-defined belts in the temperate climatic zone. On the whole, windstorms cause far greater destruction and loss of life than do earthquakes. Damage may be directly due to galeforce winds, to wave action or wind-generated tides at the sea coast, or to inland floods caused by heavy rainfall.

Considerations of siting to lessen the hazard of destruction are different for earthquakes than for windstorms. In the case of earthquakes, the total geologic environment must be taken into account--the danger from failure of geologic foundations and from landslides is of paramount importance. Damage during windstorms is generally restricted to that caused directly by force of wind or indirectly by flooding. As a consequence, site evaluations for earthquake-resistant construction are complex, time consuming, and costly, whereas those concerned with construction to resist windstorms are relatively simple and deal largely with the topographic configuration of the site and surrounding region.

5.2 Earthquake Hazards

Estimates of seismic risk may be presented in the form of seismic-risk maps, which show the maximum intensity of earthquakes likely to occur within the area covered by the map. Such maps are based mainly on a statistical analysis of the number and intensity of earthquakes actually recorded in the area since observations began. Map reliability is a function of the length of the period of observation and of the volume and quality of data collected, and therefore is greatest for areas of high seismicity for which much data exist.

A seismic-risk map does not indicate the probable future frequency of earthquakes of a given intensity but permits one to extrapolate the maximum intensity to be expected, knowledge that is essential in determining structural design. As such an extrapolation is based on the observed relation between magnitude and frequency of previous earthquakes in the area, the probability of occurrence of a large earthquake may be predicted from the observed frequency of smaller ones.

Unfortunately, instrumental records, which are available only for about 70 years, are still an inadequate base for a statistical analysis of probable earthquake frequence. In many areas, however, instrumental data can be supplemented by information obtained from historical records. Geologic and tectonic data furnish additional information for preparation of seismic-risk maps of some areas, as has been done in Turkey and Iran.

A good seismic-risk map will contain reliable information on the relative level of risk from damaging earthquakes in an area, but it will not tell when such earthquakes will occur. The problem of predicting the time and location of earthquakes, which is of considerable importance, has only recently become the subject of intensive study, chiefly in Japan, the Soviet Union, and the United States. The need for extending such studies to other regions is critical. Success in this research would be a major scientific achievement.

At any specific site, earthquake hazard is governed by seismic probability, foundation conditions, topography, local and regional geology, proximity to surface-water bodies (lakes, bays, and streams), occupancy, and structural design. All these variables can be shown on maps from which one may interpret level of risk at each point on the ground surface. Such maps may be of great aid in determining appropriate land use. They also may be used to identify specific or potential hazards and thus serve as a guide to engineering design as well as site planning. These types of maps, however, are still in the development stage, and it may be many years before standards are established, and still longer before such maps become generally available.

When an earthquake occurs at sea, a segment of the ocean floor may be elevated or depressed, owing to faulting or warping of the floor, causing a complex high-velocity sea wave, or tsunami. When such a wave approaches land, it loses velocity but gains amplitude, and depending upon the local bathymetry, it may produce a high wave that devastates low-lying coastal regions in its path. To evaluate potential disaster from such waves, special tsunami-hazard maps should be prepared for coastal areas, such as those of the Pacific Basin, which are subject to seismic sea waves.

Although the intrinsic value of geologic site plans and their use in community development are widely recognized, such plans have not been widely used, even in the so-called developed nations. Meaningful site plans could greatly reduce future earthquake destruction of new communities. Detailed site evaluations by qualified earth scientists are particularly important as a preliminary phase in construction of large buildings such as schools, hospitals, high-rise apartments and offices, and other public buildings.

A good site plan will accommodate both short- and long-range expansion needs and take account of potential hazards, such as low-lying ground liable to flooding, landslides, tsunamis, and active faults, and water-saturated ground subject to compaction and lateral spreading. As a part of site planning, it is desirable to determine soil behavior in response to seismic shaking, especially under load, and at various degrees of saturation. Laboratory study of behavior of both dry and wet soil under vibrational loading is essential to site planning and for predicting the potential of different soil types for compaction or liquefaction during an earthquake. The behavior of soils under conditions of load and vibration also may be determined by measuring micro-seismal characteristics and by in situ soil study.

A microzoning map prepared from such data may greatly aid site planning. Microzoning maps should give the natural period of the foundation material and portray potential hazards in a manner that is readily understandable to engineers and others who are responsible for construction. A report on seismic microzoning of the Chimbote area in Peru [1] provides an excellent example of site evaluation. The report provides information about the geologic foundation conditions that will permit reconstruction of Chimbote as an "antiseismic" city.

In seismic areas, the public needs to be better informed on the nature of earthquakes as well as on potential local hazards and means of dealing with them. Such information might be introduced into school curricula. In such areas, officials dealing with environmental hazards and the professional community of earthquake engineers and scientists would share the responsibility of keeping community decision makers informed of new knowledge of earthquake hazards and of assessing these hazards as a basis for action to minimize destruction and loss of life during an earthquake.

5.3 Windstorm Hazards

Good site location or orientation in terms of local topography and natural cover can be determined to some degree from historical wind data that give the frequency, velocity, and direction of the prevailing or predominant wind. This information can be utilized to locate building sites and position individual dwelling units to minimize the hazard from wind. Windstorm damage may be minimized by placing buildings so that they are protected by hills or by stands of trees. How effective wind planning and aerodynamic positioning will be in improving the resistance of structures to tropical windstorms remains to be determined. In the future, effective designs that consider shape, size, and type of building as well as position and orientation, may be developed that minimize wind damage from tropical storms.

5.4 Siting Considerations for Low-Cost Housing in Turkey*

5.4.1 Geologic and Seismic Setting

The geologic, seismic, and hydrologic hazards that pose a threat to low-cost housing in Turkey have their roots in the unusual degree

* Publication authorized by the Director, U.S. Geological Survey.

of mobility of the earth's crust in the Mediterranean region, and particularly in Turkey. This mobility has persisted, with pauses, for perhaps the last 200 million years of earth history. Although geologic hazards in Turkey are serious and widespread, they can to a considerable degree be anticipated and either avoided or provided for in site preparation. This chapter first reviews the origin and nature of these hazards and then proposes ways of coping with them at sites of low-cost housing. The work in Turkey, on which this report is based, was undertaken by the author during parts of February and March 1972.

Turkey is astride the Alpine earthquake belt, one of Earth's two major zones of strong and frequent earthquakes. This belt is thought to owe its seismicity to continued differential motion between the Eurasian and Afro-Arabian crustal plates.

Turkey is almost wholly within a belt of strongly deformed sedimentary rocks that were deposited in a seaway separating Eurasia and Afro-Arabia in pre-early Tertiary time. Intense compression of the rocks laid down in this seaway was caused by the progressive drift of Eurasia and Afro-Arabia toward each other during the last 200 million years. This compression produced a generally east-trending belt of strongly folded, faulted, and locally intensely sheared and broken rocks, to which the name Alpine Orogenic Belt has been applied. In many places, large volumes of submarine volcanic and intrusive igneous rocks were added to (and churned into) the sedimentary rocks of the Alpine belt. The collision of Eurasia and Afro-Arabia in early Tertiary (50-60 million years ago) closed the intervening seaway and what is now Turkey became an area of mountains separated by narrow seaways and lowlands. The seaways and lowlands received locally thick accumulations of marine, lagoonal, and continental sediments (some of which are still poorly consolidated) and volcanic rocks.

Subsequent uplift and local deformation during Tertiary time contributed further to the folding, dismemberment, and crushing of the pre-Tertiary rocks and locally produced complex structures in the Tertiary rocks themselves. Such movement has continued into modern times, producing the mountainous terrain that dominates much of the present Turkish landscape. Other manifestations of this young crustal mobility are repeated fault displacements, earthquakes, and volcanic activity.

5.4.2 Seismic Zones of Turkey

Some 40 percent of Turkey is subject to severe earthquakes. Since the advent of modern instrumental seismology some 70 years ago, Turkey has suffered the largest shocks, in terms of Richter scale magnitude, of any country in the Mediterranean region. Records dating from late Roman times indicate that, on the average, catastrophic earthquakes have occurred in Turkey every 60 to 80 years. The distribution and character of these shocks, and the location and activity of the four main seismic zones of Turkey (Figure 5.1), are directly related to the location and type of the geosuture zones that traverse the country. These seismic zones are: 1) Aegean-Marmara zone, 2) Northern Anatolian zone, 3) Central Anatolian zone, and 4) Southeastern Anatolian zone [2].

Aegean-Marmara Zone--The Aegean-Marmara zone is the most complex seismic zone in Turkey and the only one having a significant number of deep earthquakes. Deep earthquakes in Turkey are those having focal depths greater than 60 km [3]. Many earthquakes of both shallow and deep origin in the Aegean-Marmara zone have exceeded magnitude 7 on the Richter scale. Thirty-five major earthquakes per hundred years, as judged by reports of heavy damage to cities, have shaken this roughly

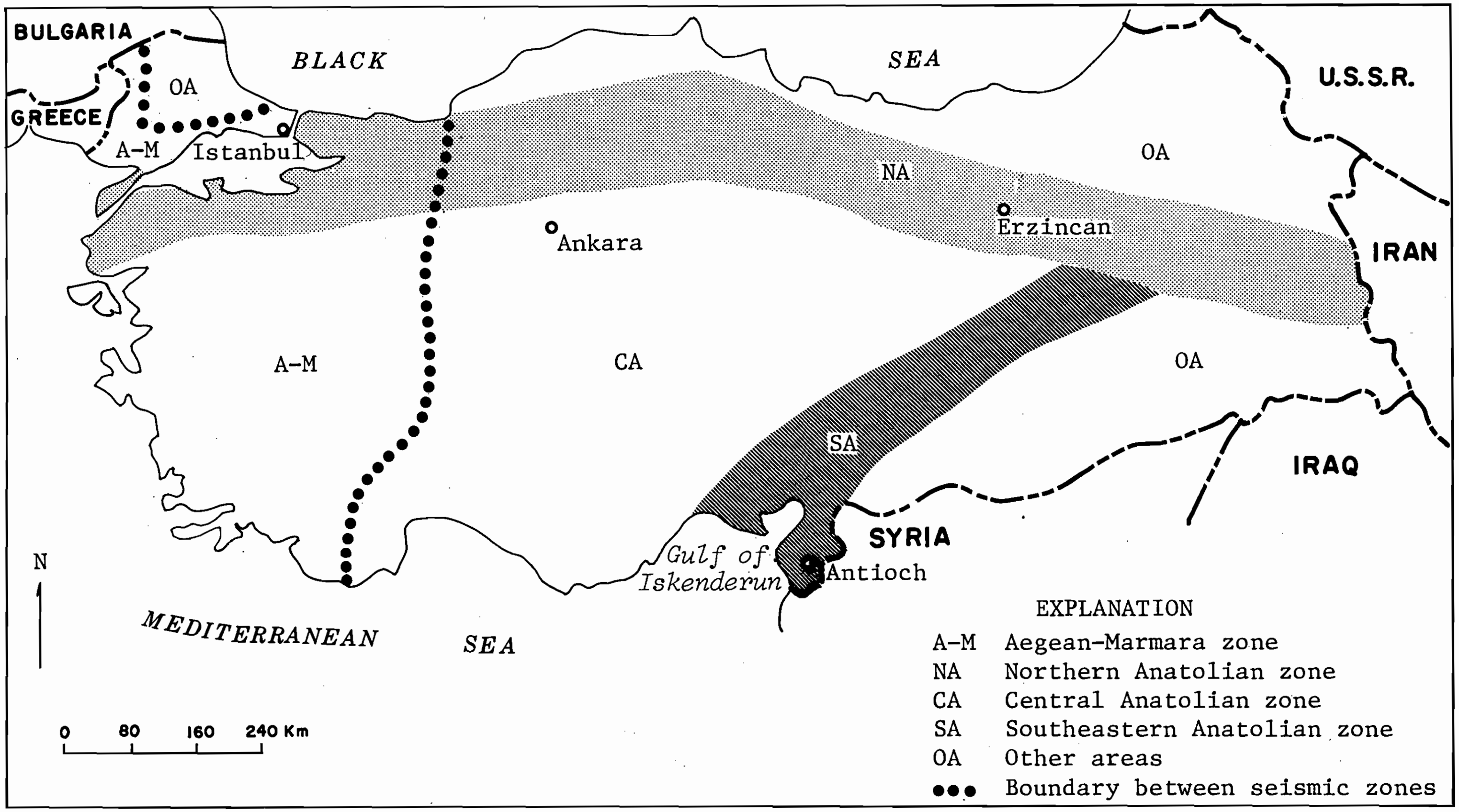

Figure 5.1 Seismic zones of Turkey

200,000 km^2 seismic zone since the 11th century A.D. [2].

The earthquakes of the Aegean-Marmara zone are of two types: 1) deeper shocks, which become progressively deeper from west to east, are due to westward movement of the Anatolian crustal plate over the Aegean plate, and 2) shallower shocks, commonly accompanied by fault displacements that extend to the earth's surface, which seem to be related to subsiding linear fault-bounded troughs, called grabens, that extend east-west across the Aegean-Marmara zone. Surface faulting and shallow earthquakes in the Anatolian plate in the Aegean-Marmara zone are especially damaging because settlements of the area tend to be localized in the long, narrow east-trending valleys that have been formed in part by these same seismically active faults and grabens.

When vertical displacements occur beneath large bodies of water, as they commonly do in the Aegean-Marmara zone, tsunamis may accompany earthquakes of moderate to large magnitude.

Northern Anatolian zone--Destructive shallow earthquakes are caused by horizontal fault displacement, or slip, between the Eruasian and Afro-Arabian crustal plates along the steeply to vertically dipping Northern Anatolian fault zone. Along this fault zone, which is a major geosuture, Eurasia is moving eastward relative to Afro-Arabia. In Turkey, the zone can be traced for about 1,100 km; seismic evidence indicates it to be an additional 400 km long. Although the Northern Anatolian zone is relatively narrow, reflecting the linearity and relative simplicity of the fault zone and its branches, it accounts for fully half the major destructive earthquakes in Turkey. The western part of the Northern Anatolian fault zone trends into the northern part of the Aegean-Marmara seismic zone, where it appears to split into several branch faults. In this area, the seismicity associated with the North Anatolian fault zone cannot be distinguished in all cases from that associated with faults of the Aegean-Marmara zone.

Earthquakes in the Northern Anatolian fault zone are typically related to large fault displacements that reach and rupture the earth's surface. These features thus pose a direct hazard to structures. Individual episodes of rupture along faults of this zone have, in historic times, displaced the earth's surface as much as 4.3 m horizontally and 1.5 m vertically. The surface displacement, which accompanied the earthquake of December 26, 1939, was traced for a distance of 340 km along the fault zone.

Long, linear valleys have been eroded by streams along the crushed rocks of the Northern Anatolian fault zone, creating some of the larger areas of arable ground in the mountainous region traversed by the fault. These valleys have served to concentrate settlement along the fault zone, thereby making a larger proportion of the population of the area vulnerable to damage from both earthquake vibration and sudden fault displacements than might otherwise be the case.

Reports of heavy damage to cities indicate 10 or 11 major earthquakes per 100 years since the second century A.D. From 1939 to 1967, eight or nine earthquakes along the zone were accompanied by fault displacement of the earth's surface. One of these, the earthquake that struck the Erzincan region on December 26, 1939, killed 40,000 persons.

Central Anatolian zone.--The earthquakes of the Central Anatolian zone, which is less active seismically than the Aegean-Marmara zone, are related to block faulting. Some of the block faults extend into this zone from the Aegean-Marmara zone, but are included in the Central Anatolian zone because: 1) associated earthquakes occur less frequently than in the Aegean-Marmara zone, and 2) earthquakes of deep focus such as characterize the Aegean-Marmara zone are rare or absent.

With the exception of two strong earthquakes at the border with the Aegean-Marmara zone, recorded earthquakes in the Central Anatolian zone have had Richter magnitudes of less than 7. Since the year 1205 A.D., about six major earthquakes per hundred years have occurred in the zone.

Southeastern Anatolian zone.--A relatively narrow zone of earthquakes, called the Southeastern Anatolian zone, trends northeast from the Gulf of Iskenderun to the Northern Anatolian zone near Lake Van, a distance of about 600 km. These earthquakes are related to horizontal movement on a fault zone along which the Arabian Peninsula is being displaced relatively northwestward with respect to the eastern Mediterranean sea and Central Anatolia. The nature of the intersection of this fault zone and the Northern Anatolian fault is presently unknown. They may merge, or one may cut the other.

Since A.D. 110, there have been seven or eight major earthquakes per hundred years along the Southeastern Anatolian zone. Although recent earthquakes in this zone have been of small or moderate magnitude, the historically important city of Antioch, at the southwest end of the zone in Turkey, never recovered its classical splendor after it was demolished by a great earthquake in 527 or 528 A.D.

5.4.3 Seismic and Related Hazards to Low-Cost Housing in Turkey

Building sites in the seismic zones of Turkey are subject to four types of seismic and related hazards as shown in table 5.1. The seismic-risk categories used in the table are analogous to those adopted by Algermissen [4] for the Seismic Risk Map of the United States. They are based, however, on judgments derived from a comparison of recent faulting and seismicity of Turkey and the United States, rather than on a detailed analysis of Turkish seismicity. These relative ratings are presented only as a guide to the application of the lateral-force requirements of the 1970 Uniform Building Code [5] to the design of low-cost housing in Turkey, and not as a substitute for a carefully considered seismic-risk map of that country. The UBC uses the Seismic Risk Map of the United States as the basis for its lateral-force requirements.

The risk categories for tsunamis (table 5.1) cannot, of course, be applied to building design in terms of lateral-force requirements, nor is it feasible to design buildings to resist tsunamis. The categories of foundation failures include numerous or widespread failures such as compaction and liquefaction of soil and slumping or sliding of rock and soil. Efforts to alleviate the danger of such foundation failures are costly, and may be unsuccessful. Fortunately, such risks are local and it is generally possible to select a safer nearby site.

Future multistory-multifamily low-cost housing plans, if designed for Turkey, should strive for lateral-force requirements at least as stringent as those specified by the U.B.C. These requirements should be supported by a modern seismic risk map of Turkey. Such a map does not now exist, although one is being prepared by the Earthquake Research Institute of the Ministry of Reconstruction and Resettlement of Turkey. To be realistic, this map should be based on geologic and tectonic criteria of recent and anticipated future seismicity, on the long historic record of Turkish earthquakes, and on modern seismographic records and field investigations of earthquake intensity.

TABLE 5.1. SEISMIC-RISK CATEGORIES

[1]Risk categories for direct effects of seismic shaking and tsunamis:	[2]Risk categories for foundation failures during earthquakes:
0 - Negligible risk of damage	0 - Negligible risk
1 - Significant risk of minor damage; small risk of moderate or major damage	A - Small risk
2 - Significant risk of moderate damage; small risk of major damage	B - Moderate risk
3 - Significant risk of major damage	C - High risk

It may not be economically and culturally feasible to design traditional single-family housing for Turkey that will meet the lateral force requirements of the U.B.C. Nevertheless, efforts should be made to improve such housing and perhaps approach U.B.C. requirements.

With respect to siting of low-cost housing near active faults, it is recommended that: (1) New single-family low-cost housing in Turkey be sited at least 50 and preferably 100 meters from main faults, fault strands, and branches that can be observed or inferred to have displaced geologic formations or deposits of Holocene age (the last 10,000 years), (2) all high-population-density (multistory-multifamily) low-cost housing be sited at least 100 meters, and preferably 150 meters from faults, fault strands, and branches that can be observed or inferred to have displaced geologic formations or deposits of Holocene age, and at least 50 meters from faults that can be observed or inferred to have displaced deposits of pre-Holocene Quaternary age (the last 2 or 2 1/2 million years); (3) all critical structures (those with many people per unit area, such as schools, auditoriums, and hospitals, and those that provide essential services, such as power plants or water-treatment plants) should, in addition to the requirements in category 2, be sited at least 50 meters from any fault not proven to have been inactive (i.e., has not undergone displacement) since the beginning of Quaternary time. The difference between categories 2 and 3 is in the character of the evidence required for judgment. In category 3, definite evidence of lack of Quaternary activity is required; in category 2, lack of evidence for Quaternary activity is accepted in lieu of definite evidence of lack of such activity. The distinction is necessary because bedrock in Turkey is broken by so many faults that application of Category 3 to all multistory buildings would be unrealistically restrictive.

The width of the proposed setback zones along faults of Holocene or Quaternary displacement is adequate for most, although not all, faults or fault zones. It is rather conservative, however, for faults that show repeated surface rupture in the same location. Consequently, setbacks could be reduced where detailed site studies, which should include the excavation of trenches across the fault zones, showed that smaller setbacks would be safe. In no case, however, should the setbacks be less than 20 meters. Detailed investigations undoubtedly will also show that in some places setbacks should be even larger than those specified above.

The relative hazard from tsunamis given in the tabulation applies only to the most susceptible parts of the coastal areas categorized.

Tsunami hazard is not uniform along a given coast because the severity of impinging tsunami wave trains varies markedly with the local configuration of the shoreline and nearshore bathymetry. Bold headlands and coasts having deep water near shore are generally little affected by tsunamis, whereas low-lying coastal areas bordering a shallow moving platform or narrowing or shoaling inlets are subject to large and destructive wave trains. Thus, some sites on low ground at the head of narrow, shoaling inlets in the Aegean-Marmara zone are in danger of destruction by tsunamis.

During some earthquakes around the world, large rockfalls or landslides falling into deep water have created surge waves that have devastated adjacent shorelines to recorded heights of at least 565 m. Subaqueous slides in deep water have also set in motion local surges that have destroyed entire communities on adjacent shores. In Turkey, such surge waves are a potential hazard in a few areas where bold topography underlain by poorly consolidated or intensely sheared rocks abuts deep tidal inlets, reservoirs, or lakes.

5.4.4 Ground Failures

Landslides (slumps, mudflows, and rockfalls), landspreading, and differential compaction of weakly or irregularly consolidated alluvium and other surficial deposits locally pose serious siting problems for structures of all sizes in Turkey, even in the absence of earthquakes. Such ground failures are especially common, however, under the dynamic stresses induced by strong earthquakes. The physiography and climate of Turkey and the character of many of its geologic formations make large areas of the country susceptible to landslides, and it is not surprising that field reports of the effects of strong earthquakes in Turkey commonly mention landslides, soil slumps, and lurching (cracking of soft ground induced by lateral movement) as important, and often damaging, secondary geologic effects. The hazard from landslides, mudflows, and rockfalls is not, of course, limited to site disruption, but includes both slow and extremely rapid modes of site inundation.

5.4.4.1 Landslides

The distribution and relative abundance of landslides is controlled chiefly by slope, precipitation, character of underlying soils and rocks, and cuts and fills or other perturbations created by the activities of man. Studies in California and elsewhere [6] show that most landslides form on slopes of 15° to 35°; a lesser, but appreciable percentage form on slopes of 5° to 15° and greater than 35°. Very few landslides form on slopes of less than 5°, and these are commonly caused by liquefaction or landspreading during earthquakes. In California, landslides are also rare in areas receiving less than 250 mm of mean annual precipitation. The absolute amount of precipitation above 250 mm per year does not, however, seem to be as important as the character of the underlying soil and rock which is the dominant control on the distribution and abundance of landslides in areas having slopes greater than 5° and more than 250 mm of mean annual precipitation. Soft, water-saturated, poorly consolidated formations and intensely sheared or fractured rocks, especially when water-saturated, and rocks containing minerals that swell or decay readily in the presence of ground water, are especially susceptible to sliding and slumping. The activities of man in undermining slopes by cuts and excavations, or in overloading slopes by excessive or inappropriately placed fills, commonly induce sliding and slumping on otherwise stable slopes. The addition of water to certain slopes by irrigation and by seepage from pipes, septic systems, springs, or other sources is a common cause of sliding, because the water increases the weight of the ground while simultaneously decreasing its resistance to shearing stresses.

Landsliding is a significant problem in Turkey because large areas of the country have slopes that exceed 5°, and slopes of 15° to 35° are common; mean annual precipitation in almost all of Turkey exceeds 250 mm per year; many of the rocks that underlie Turkey are poorly consolidated or intensely sheared; and swelling clays are probably widespread and abundant in the rocks and soils. The extensive steep tracts that are underlain by 1) soft sedimentary rocks of Tertiary, and especially late Tertiary age; 2) crushed and sheared rocks along many of the fault zones; and 3) ophiolite melanges (chaotic mixtures of diverse rock types that are characterized by widespread intensely sheared rocks and by serpentine), are all especially susceptible to sliding. The stability of potential building sites on these landslide-prone terrains, particularly where slopes exceed 15°, should be examined with special care. The relatively small proportion of lowlands in Turkey will inevitably lead to more construction of houses, roads, and a variety of other engineered works on hills and mountainsides where the risk of damage from landsliding is especially high, particularly during strong earthquakes.

5.4.4.2 Unconsolidated Deposits

The distribution and intensity of damage due to shaking during a given earthquake has been observed by many workers to be strongly influenced by the local character, geometry, and thickness of the underlying soils and unconsolidated deposits, and by the position of the water table. The relationship between these properties of the substrata at a site, and the nature and intensity of damage is complex, however, and one that is strongly influenced by the amplitude, frequency, content, and duration of the seismic wave train at the site. Thus, the predominantly short-period shaking from nearby shocks may produce very different amplitudes and periods of shaking and adversely affect very different kinds of structures from the long-period shaking that dominates the wave trains from more distant earthquakes. Study of the relation of the local distribution of earthquake damage to local soil and rock conditions should be made as a basis for selecting sites for low-cost housing developments.

Patterns of damage from strong earthquakes, particularly to multistory buildings sited on unconsolidated deposits, are closely related to lateral variations in the thickness, composition, and water saturation of the underlying soils and shallow geologic formations. Variations in these factors can, for example, cause the horizontal velocity of ground motion from a moderate earthquake to vary by a factor of 2 to 10 with respect to nearby sites on bedrock [7], and the response of given types of structures to vary by factors ranging from 3 to 6 [8]. Liquefaction, differential settlement and landspreading of unconsolidated deposits, and block glides and slumps on gentle to steep slopes are also common geologic foundation failures that have created extensive damage during moderate and large earthquakes.

Methods of predicting the dominant period and relative amplitude of earthquake-induced shaking at a particular building site are currently under study by many workers, and steady progress is being made toward widely applicable analytical procedures [8,9]. Such predictions, however, require fairly detailed knowledge of the thickness and physical properties of the soils and poorly consolidated rocks of the site, and a realistic assessment of the seismicity of the area [10]. Some of the analytical procedures are moderately sophisticated, but estimates can be made from relatively simple formulas. Modern practice requires that, in areas of significant seismic risk, large buildings should be designed to have a different fundamental period of vibration from that of the natural ground at the site.

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Unconsolidated deposits containing liquefiable (noncohesive) materials and having abrupt lateral variations in density and compactibility are susceptible to flowage, differential compaction, lurching, and landspreading during earthquakes; these deposits can be recognized by sufficiently detailed surface and subsurface site examination. Examples of geologic foundation materials in Turkey that are especially susceptible to failure, particularly where the water table is shallow, are fine-grained, noncohesive, or very soft cohesive alluvial, pluvial, estuarine, bog, and delta deposits. Failures in such materials have caused damage in past earthquakes in Turkey, and will be subject to failure during future earthquakes. Although deep piles will sometimes protect a structure resting on such material, such site preparation is costly. Consequently, it is generally best to select an alternate site with more stable foundation material.

5.4.5 Floods

The high mountains and narrow alluvial valleys that characterize much of Turkey have created a significant hazard from local, but sometimes large floods. In some years, heavy snow accumulations on the higher mountains may melt at rates that exceed the capacity of the river channels, resulting in overflow and flood damage to settlements. The magnitude of the problem is difficult to gauge from the literature available to the writer, but the Menderes and Seyhan River systems, for example, which drain high mountains in southern Turkey have periodically been the scene of destructive floods. Accordingly, dikes and other floor-control structures have been built on some rivers in Turkey, and have reduced flood hazards. Additional flood-control structures on these and other rivers in Turkey would further reduce the danger of floods. However, to completely eliminate the danger of floods, particularly flash floods in mountainous areas, would not be feasible. The danger can best be eliminated by selection of sites away from potential floods.

5.4.6 Recommended Site Investigations for Earthquake-Resistant Low-Cost Housing in Turkey

In Turkey, the significant risk to low-cost housing from the seismic and other geologic hazards outlined above can be substantially reduced by using geologic, hydrologic, and soils engineering principles in selecting and preparing building sites. Furthermore, it is certain that rapid advances now being made in these disciplines will increase their effectiveness for guiding the selection of building sites. Accordingly, it is recommended that any large-scale program to construct low-cost housing in Turkey include such investigations in the selection and preparation of building sites. The program of such investigations proposed below envisions more than a pilot study, because the usefulness and practicability of such investigations have been demonstrated in comparable studies elsewhere. On the other hand, it is not offered as a national program of land-use analysis, although it contains elements that would be included in a national program.

5.4.7 Methods of Guiding and Controlling Site Selection and Preparation

Two methods exist for applying scientific and engineering knowledge to the selection and preparation of building sites to reduce seismic and other hazards. One uses regional geologic, soils engineering, hydrologic, and other studies to guide the initial selection of sites. The second consists of inspection and approval of site preparation and building plans by a building official or inspector after a builder (private or governmental) has selected a site and prepared plans for its development. The two methods are quite compatible, and can be used in sequence.

The first method, which emphasizes regional studies, serves to help find the best building sites in an area in advance of costly site and building plan preparation. It requires fewer well-trained professionals than the second method, which is based on individual inspection of all sites or projects. The principal disadvantages of siting control at the planning stage are that it is too expensive for isolated single houses or small developments and insufficiently detailed to control site selection and preparation for large buildings.

The second method typically relies upon a building code administered by local offices of national or regional agencies, and generally requires intensive site investigations of problem areas. If based upon a well-prepared building code, this method has the advantages of uniformity and clarity in its requirements. It has the drawbacks, however, of being costly and time-consuming, of exercising review and control only after a considerable effort has been expended on site selection, planning, and design, and of requiring greater numbers of technical people to review site selection and planning than will likely be available in Turkey for many years.

The building-code approach to assuring the safety of foundations is exemplified by Chapters 29 and 70 of the 1970 edition of the Uniform Building Code [5]. Chapter 70 deals with grading practices and makes specific recommendations on the dimensions, slope, drainage, and erosion control of cuts and fills. Chapter 29 relates building foundation requirements to the character of the soils and geologic formations beneath a building site. These chapters serve as general guides to site preparation. Adherence to at least these minimum recommended grading practices is especially desirable for earthquakeresistant construction because geologic foundation failures are a common cause of building damage and loss during earthquakes. However, the U.B.C. does not provide specific guidelines for treating such seismic and related hazards as active faults, offsite landslides, mudflows, and liquefaction. Nor can a general code provide adequate guidance to the influences that local geology, soils, ground and surface water, macro- and micro-climate, and topography may have on the safety or suitability of a site. As is true of all general-purpose codes, the grading requirements specified by the U.B.C. are too restrictive for some sites and insufficiently restrictive for others. Recognizing this, the U.B.C. specifies that soils engineering and engineering geologic investigations for cuts and fills be made at the option of the responsible building official. Of necessity, the code neglects local customs and local technical and administrative capacity for adequate inspection and control of building sites. Indeed, such inspection and control are rarely available for single-family and small multifamily dwellings in smaller cities, villages, and the countryside anywhere in the world.

5.4.8 Proposed Site Investigations

It is recommended that planning-stage studies be the basis for selecting and preparing sites for all earthquake-resistant housing for which more than one or two alternative sites are available. Site-intensive investigations (detailed studies of foundation conditions at a building site and its environs) should be made of all sites proposed for large engineered buildings, whether or not the sites were selected on the basis of planning-stage studies.

A practical program to guide site selection and preparation for low-cost housing in Turkey must deal realistically with the following conditions:

1) Recognition of many siting problems is difficult, and the assessment of the risk presented by these problems, even after they are recognized, requires a high level of technical competence.

2) Level of risk varies widely, even between adjacent sites.

3) Several disciplines (principally geology, soil engineering, and hydrology) are required to recognize and evaluate even the most common siting problems and hazards.

4) The number of competent professionals in these disciplines is in short supply in Turkey and in most developing countries.

Accordingly, a program of site investigations in Turkey should: 1) rely more on active site investigations by multidisciplinary teams of professionals than on the enforcement of detailed codes by local or regional building officials; 2) concentrate on housing units or projects that are large enough or extensive enough to warrant the application of necessarily expensive site investigations; 3) utilize regional reconnaissance studies as an alternative to site-intensive studies for some types of low-cost housing projects; and 4) incorporate a review board to provide for continuing review and updating of site evaluation and selection procedures and criteria, and to guide continuing training of the site-evaluation and selection teams.

5.4.8.1 Planning-Stage Investigations

Effective planning-stage studies require that the entire region under consideration for low-cost earthquake-resistant housing be evaluated for suitable building sites. Experience in California and elsewhere has shown that specialists who are able to extend or detail existing soil, geologic, and hydrologic data by use of aerial photographs in conjunction with field investigation can evaluate areas of a few square kilometers or more at much less cost than by standard field methods alone. Mapping scales for planning-stage investigations ordinarily range from 1:10,000 to 1:250,000.

5.4.8.2 Site-Intensive Investigations

Site-intensive investigations consist of field and laboratory study of geology and soils of selected sites and their relevant environs. "Relevant environs" refers to the minimum area surrounding a site that must be studied to evaluate its seismic and related hazards. This area most commonly ranges from one or two hectares to a few tens of hectares in extent, but in special cases it may be much larger. Study of an area much larger than the building site may be necessary because the critical evidence for many siting hazards, such as landslides, is commonly difficult to find within a small site. Subsurface investigation by drilling, trenching, and geophysical surveys would ordinarily be conducted at and near the site, particularly for large structures. Mapping scales will ordinarily range from 1:100 to 1:1,000. Evaluation of the engineering data about geologic features and soils must take into account the nature of the seismic risk zone in which the site occurs. For sites on flood plains, or those having shallow ground water, poor drainage, or other water-related problems, hydrologic studies may be required.

5.4.8.3 Scope of Investigations

Both planning-stage and site-intensive investigations should include consideration of the following possible foundation problems and siting hazards, but a complete list for any site will require study of the site itself by qualified experts.

Geologic: 1) Active faults at and near the site; 2) landslides or other slope failures beneath or upslope from the site; 3) liquefiable or easily compactable materials beneath the site; 4) lateral inhomogenities in compactable materials beneath the site; and 5) expansive and/or creeping soils.

Hydrologic: 1) Anomalous drainage or foundation conditions due to permanent or seasonally shallow ground water, springs, or seeps; 2) eroding shorelines of seas, lakes, reservoirs, and rivers; 3) floods and mudflows; 4) tsunamis and surge waves.

Seismic: 1) Estimation of magnitude, epicentral distance, duration, and frequency of damaging earthquakes; and 2) estimation of the base motion at the building site due to the most damaging earthquake that might be expected.

Soil engineering: 1) Natural period of vibration of building sites; 2) bearing strengths of the surface and substrata; 3) estimate of the effect that soils and poorly consolidated geologic materials beneath a site will have on the character of shaking caused by an earthquake; 4) slope stability; and 5) liquefaction potential.

Economic and cultural factors: Rural and village populations apply a variety of economic and cultural factors in siting their houses, factors that will commonly be equivalent or greater in importance than the seismic, geologic, and hydrologic considerations. Serious conflicts and economic hardship may befall the occupants of low-cost housing that is sited without regard to such economic and cultural factors. Accordingly, the planning-stage site-selection teams should include a person or persons knowledgeable about the life style and economic pursuits of the relevant populations. Interviews with the people to determine their needs and wishes are important in order that the technical studies can concentrate on finding safe sites that are also economically and culturally acceptable and satisfying to the people.

5.4.8.4 Single-Family and Small Multifamily Houses

Site control for single-family and small multifamily housing is practical only by planning-stage investigations; the cost of site-intensive studies generally is too great for such buildings. Even planning-stage investigations, however, are practical only for large projects of such housing. Siting control for isolated individual units (or small groups of units) of low-cost earthquake-resistant housing will have to be limited to existing procedures, if any, until suitable regional studies are made on behalf of larger housing projects, or for other purposes.

5.4.8.5 Multifamily Houses

Site investigations for large, engineered multifamily-multistory low-cost housing should follow two patterns. Where the choice of sites is limited or predetermined, site-intensive investigations of the geologic, soil engineering, and hydrologic conditions at the site and the relevant contiguous terrain should be made. Where there are alternative sites, selection should be based on a regional environmental (planning-stage) study followed by site-intensive investigations of the most suitable site or sites. The cost of many of the site-intensive investigations will be significantly reduced if the site is selected through a regional study.

5.4.8.6 Improvement of Existing Houses

Site studies can be of assistance in preparing proposals to improve the earthquake resistance of existing housing by structural or foundation modifications. Where extensive housing tracts or large buildings are involved, regional planning-stage and site-intensive studies can be used to guide expenditures for modification of those houses that are at suitable sites. Unsuitable sites might then be designated for eventual conversion to parks or other low-risk uses.

5.4.9 Technical Supervision

The site-selection program should strive for technical excellence through the establishment of an independent review board composed of scientists and engineers from university faculties, private consulting firms, and governments at home and perhaps abroad. International financial assistance for obtaining foreign technical participation might be obtained. The most important task of the review board would be the establishment and continual improvement of a set of recommended investigations and site standards that are realistic to the specific area or region of the country at each stage in its development, and commensurate with available budgets and professional staff. The board should also provide guidance for the site-selection teams in difficult or special problems, assist in the recruitment and selection of personnel for study teams, and administer a program of continuing training of team members in the newest technical developments in their various disciplines.

5.5 Case Study: Engineering Geology and Siting Problems Related to the Peru Earthquake of May 31, 1970*.

5.5.1 Introduction

The Peru earthquake of May 31, 1970, offers a model for examining the effects of the geologic environment on destruction, because it caused a wide variety of geologic foundation and slope failures that were major contributors to the extensive destruction and death toll. In the affected region (Figure 5.2), the rugged topography, extreme variation in relief, proximity to the sea, and great range of climatic conditions have given rise to most of the geologic hazards that might be found in any earthquake-prone region, all within a relatively small area. This earthquake was probably the most catastrophic natural disaster in the history of the Western Hemisphere and ranks high among the world's greatest natural

* Publication authorized by the Director, U.S. Geological Survey.

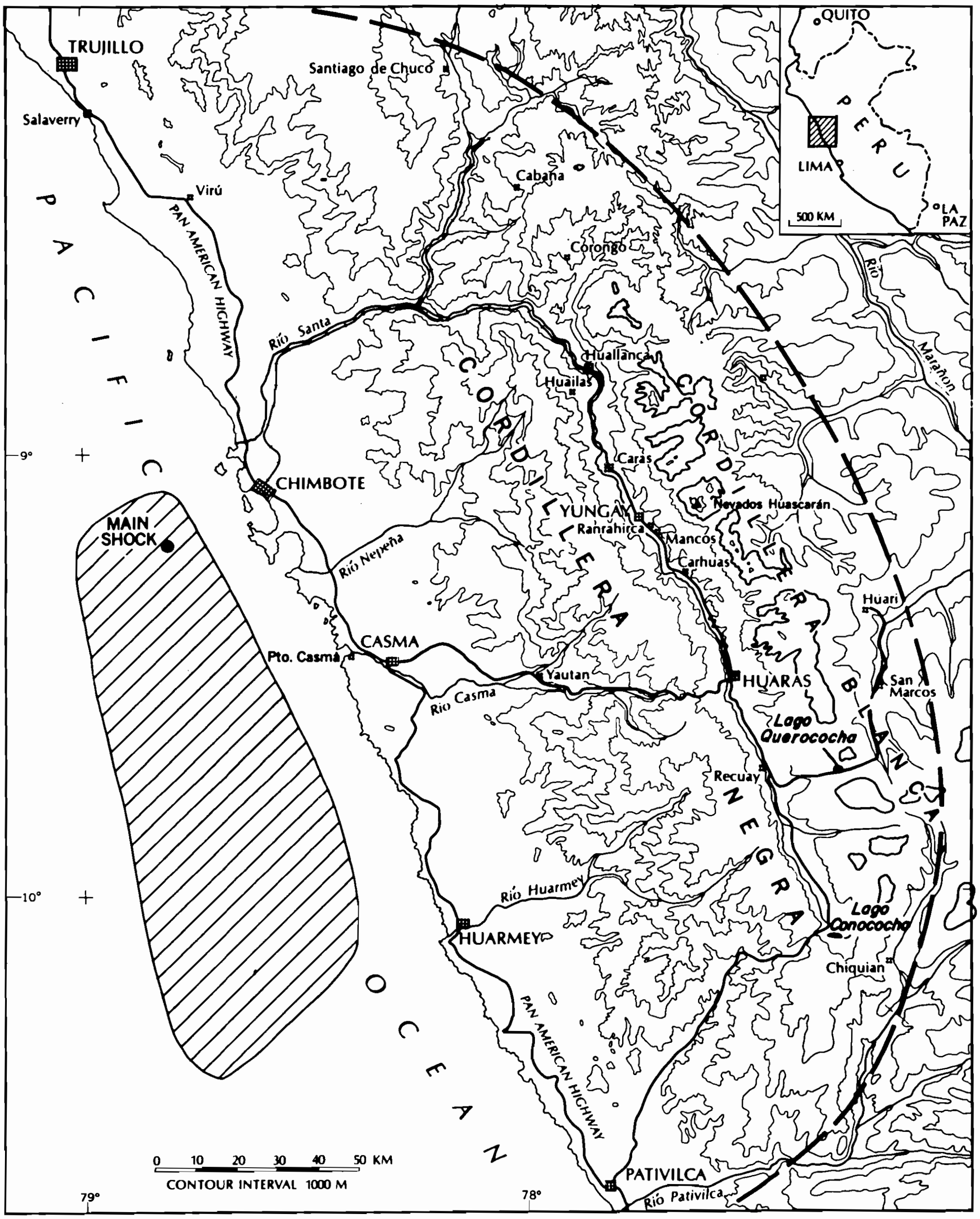

Figure 5.2 Region of northern Peru affected by the May 31, 1970, earthquake showing the epicenter of the main shock and the region of principal aftershocks (diagonal line pattern). Heavey dashed line shows the approximate limit of compaction and fissuring of unconsolidated sediments, of landslides, and of widespread damage of buildings (from Ref [11]).

disasters. The extent of destruction--roughly 49,000 people killed and 184,000 buildings destroyed--was largely due to unstable terrain and to failure of classical adobe construction that had little resistance to seismic shaking. Destruction was far out of proportion to the magnitude of the earthquake (Richter Scale 7.7), which in terms of seismic energy release does not place it among the truly great earthquakes of historical times.

The initial shock occurred on May 31, 1970, at 3:23 p.m., Peruvian time, according to the U.S. Coast and Geodetic Survey (P.D.E. card, June 1, 1970). The epicenter was at lat 9.2° S., long 78.8° W., at sea 25 km west of the port city of Chimbote in the northwestern part of the Department of Ancash. The hypocenter, or focus, was determined by the Coast and Geodetic Survey to be at a depth of 56 km. Most of the after-shocks having magnitudes between 4 and 6.25 and hypocentral depths of 44-66 km, occurred in a well-defined zone 25-50 km wide that extends about 140 km southward from the main shock epicenter (Figure 5.2).

The area of moderate to severe structural damage and pronounced ground effects extends along the coast from near Trujillo to Pativilca, and inland for a maximum distance of about 135 km (Figure 5.2). A maximum intensity of shaking of VIII on the Modified Mercalli scale is indicated in the coastal region between Casma and Chimbote, and at Huaraz in the Andean region.

This report is based on information in earlier reports on fieldwork carried out by Juan La Cruz and other geologists of CRYRZA, and on fieldwork by Ericksen and Plafker during June and July 1971 [11], [12].

5.5.2 Geologic Environment

The Andean region of Ancash has extremely rugged topography and great relief; oversteepened slopes tend to be extremely unstable and subject to destructive landslides and rockfalls during earthquakes. In the high glacier-covered Cordillera Blanca (Figure 5.2), rock and ice avalanches are an extreme hazard, as are the more than 200 glacial lakes, which may burst during an earthquake to cause devastating floods and debris flows. Volcanic and granitic rocks on steep slopes of the Cordillera Negra (Figure 5.2) are locally deeply weathered or strongly fractured and consequently are subject to sliding during the rainy season, or during a seismic event. Many thousands of landslides in both these ranges during the 1970 earthquake caused extensive damage to farm lands and rural communities. Fortunately, none of the glacial lakes ruptured during the earthquake.

The valley of the Rio Santa is partly filled with unconsolidated deposits of streams, debris avalanches, debris flows, and moraines. The behavior of these sediments, which are the principal foundation materials of the communities in the valley, varied greatly in response to seismic shaking. The oldest sediments, constituting the earliest valley fill, are well-cemented and relatively stable, whereas younger terrace gravels, glacial moraines, and alluvium are poorly-cemented and subject to landslide failure. Fine-grained water-saturated sediments and soil tended to fail by differential compaction, liquefaction, and lateral spreading during the earthquake.

Most of the coastal communities are built on the alluvial deposits of flood plains of the major streams draining westward from the Cordillera Negra. Stream valleys for distances of 5-10 km inland from the coast are generally flat bottomed and have valuable agricultural land and many rural settlements. Towns and cities along the coast, Chimbote, for example, have extensive areas underlain by lagoonal and beach deposits, commonly with a shallow water table. These fine-grained water-saturated deposits, which tend to be very unstable under seismic shaking, underlie most areas where geologic foundation failure contributed to extensive structural damage.

No detectable vertical coastal uplift was associated with the earthquake, nor does there appear to have been a significant seismic sea wave (tsunami or maremoto) of the type that has accompanied some great coastal earthquakes in Peru and elsewhere around the Pacific margin. This suggests a probable absence of shallow dip-slip faulting on the sea floor during the earthquake and is compatible with the seismologic data, indicating that the earthquake was of subcrustal origin.

Surface faulting was not observed anywhere in the earthquake-affected region, and, to judge from the location of the epicenter and major aftershocks offshore from the coast, major faulting would not be expected onshore. Nevertheless, recent faults are widespread in the region; the most prominent constitute a system of en echelon normal faults along the west flank of the Cordillera Blanca. The faults are marked by well-defined scarps as much as 20 m high that displace Holocene glacial moraines and beds of streams cutting these moraines. Undoubtedly, movement has taken place on some of these faults during the past few hundred years, but evidently not during the 1970 earthquake.

5.5.3 Regional Siting Problems

Throughout the area affected by the Peru earthquake of May 31, 1970, the degree of destruction in any one community was determined largely by the type and age of buildings, by the type of geologic foundation material, and by relative stability of slopes of nearby hills. In general, old two- and three-story adobe buildings, such as those of Huaraz (many having supporting timbers weakened by age and termites), or buildings constructed of very poor quality adobe, such as those of Casma (Figure 5.3), were more heavily damaged than well-constructed adobe buildings. Other types of buildings showed various degrees of damage, but most of the modern reinforced-concrete buildings, or buildings with reinforced-concrete frames and brick filler walls, sustained little or no damage.

Extensive damage due to failure of geologic foundations resulted from differential compaction, slumping, and lateral spreading of water-saturated fine-grained sediments such as lagoonal and beach deposits and manmade fill. The most notable example of foundation failure in deposits of these types was in Chimbote. To a far lesser degree, similar foundation failures took place in several other communities on the coast and in the Andes. Furthermore, buildings constructed on dry dune sand and on mudflow material associated with piedmont aprons and slope-debris accumulations in the extremely arid coastal region, showed greater damage than buildings of similar construction on compact stream gravels and bedrock.

There seems to be no obvious correlation between the intensity of structural damage and foundation materials in many areas where foundation failure did not occur. Adobe structures failed on foundations as diverse as granodiorite and saturated alluvium or thick soils. Some villages were almost totally destroyed, whereas nearby villages of apparently similar construction and geologic foundation were only moderately damaged. Similarly, in the towns, one could find adobe houses that had collapsed next to houses of similar age and construction that were either moderately damaged or undamaged. The reasons for these striking variations in degree of damage are uncertain: subtle differences in composition and

Figure 5.3 Residential street in Casma, Peru, where all adobe-block houses collapsed during the earthquake of May 31, 1970. Adobe used in construction here was of extremely poor quality, containing a high-percentage of silt and sand, with little or no straw binder. It crumbles easily in the hand. Casma, a town of about 15,000 inhabitantas before the earthquake was almost totally destroyed during the earthquake.

(or) water content of the foundation material could be an important factor, but slight differences in construction and the pattern of seismic-wave propagation may be equally important.

The most widespread damage due to earthquake shaking was to residences made of adobe blocks, which constitute the overwhelming majority of smaller buildings. Significantly, good adobe construction, such as the 3-story Hotel Chimu in Chimbote, survived the earthquake with little or no structural damage. Unreinforced brick or concrete-block buildings generally withstood shaking better than adobe, but in some areas, buildings of this type were extensively damaged (Figure 5.4). Well-constructed houses and most small buildings of reinforced concrete generally showed little or no damage in most towns, even where they were entirely surrounded by demolished adobe-block structures. Damage to large reinforced concrete and brick structures ranged from negligible to total collapse, depending upon design, quality of construction, and stability of the geologic foundation.

5.5.4 Behavior of Unconsolidated Sediments in Flat-Lying Areas

Failure of unconsolidated sediments in flat-lying areas caused extensive damage to structures during the May 31, 1970, earthquake. The most serious damage was due to compaction and spreading of fine-grained water-saturated sediments. Coarse unconsolidated sediments, such as stream gravel and glacial moraine, were subjected to little or no compaction during the earthquake and consequently caused little damage. Dry unconsolidated sediments were comparatively stable, but some dry sediments, such as coastal desert soils containing highly porous mudflow material or manmade fill, failed by differential compaction and slumping. Such failure, which was commonly accompanied by fissuring at the surface, caused damage to roads and buildings. Differential compaction of dry slope debris containing mudflow material and manmade fill caused widespread damage to the steel plant in Chimbote, chiefly by breaking of heavy concrete floors and misalignment of heavy equipment. The observed settlement at the steel plant ranged from a few centimeters to about 30 cm.

Although compaction of unconsolidated sediments probably occurred to some degree throughout the earthquake-affected region, its effects were most noticeable in the Chimbote and Casma areas and along those segments of the coastal transportation routes that cross alluvium-filled valleys. Compaction of water-saturated materials was locally accompanied by ejection of water or water-sediment mixtures and the formation of sand boils. Near-horizontal movement or landspreading of water-saturated sandy, silty, and clayey deposits toward free faces occurred at several coastal localities. This process has been termed "landspreading" [13] to differentiate it from landsliding, which connotes downslope movement.

The most spectacular examples of compaction and landspreading of water-saturated sediments in Chimbote include: 1) settling and flooding of a residential area in the southern part of the city (Figure 5.5), where there was almost total destruction of unreinforced buildings; 2) differential compaction in the downtown business district (Figure 5.6); 3) compaction and landspreading near the steel plant dock, which caused subsidence of about a meter (Figure 5.7) and damaged roads and buildings; and 4) spreading of liquefied sand on a beach berm that resulted in opening of a fracture more than a block long, along which masonry houses were ripped apart (Figure 5.8).

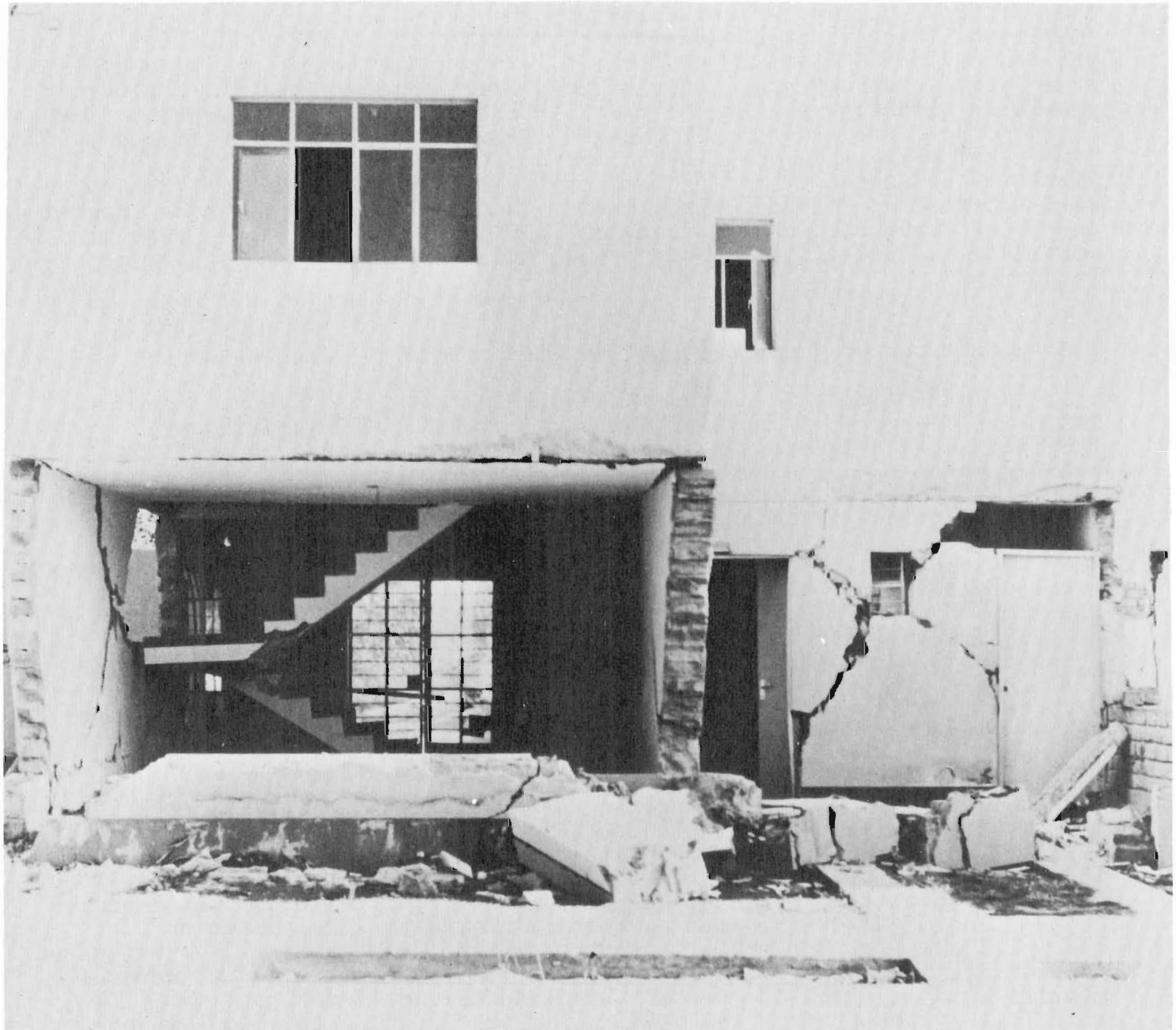

Figure 5.4 Destruction of new home of unreinforced brick construction in the Buenos Aires suburb of Chimbote, Peru; all buildings in this suburb were damaged beyond repair. None of the homes collapsed, probably because of the reinforced concrete stairway that connected concrete floor slabs.

Figure 5.5 Compaction of foundation material and destruction of adobe, brick, and concrete block houses in low-lying area near the coast in southern Chimbote. Before the earthquake, the ground surface was dry, and the water table was reportedly at a depth of about 50 cm.

Figure 5.6 Street in downtown Chimbote where differential compaction of water-saturated beach deposits and manmade fill caused settling of buildings and cracking of concrete sidewalks. Here, 2-, 3-, and 4-story buildings settled 20-30 cm into the foundation material.

Figure 5.7 Subsidence of roadway fill at side of steel plant dock in northwestern Chimbote, resulting from compaction and seaward spreading of underlying water-saturated sediments. Roadway settled about 1.2 m here. The dock, which is on deep concrete piles, did not subside.

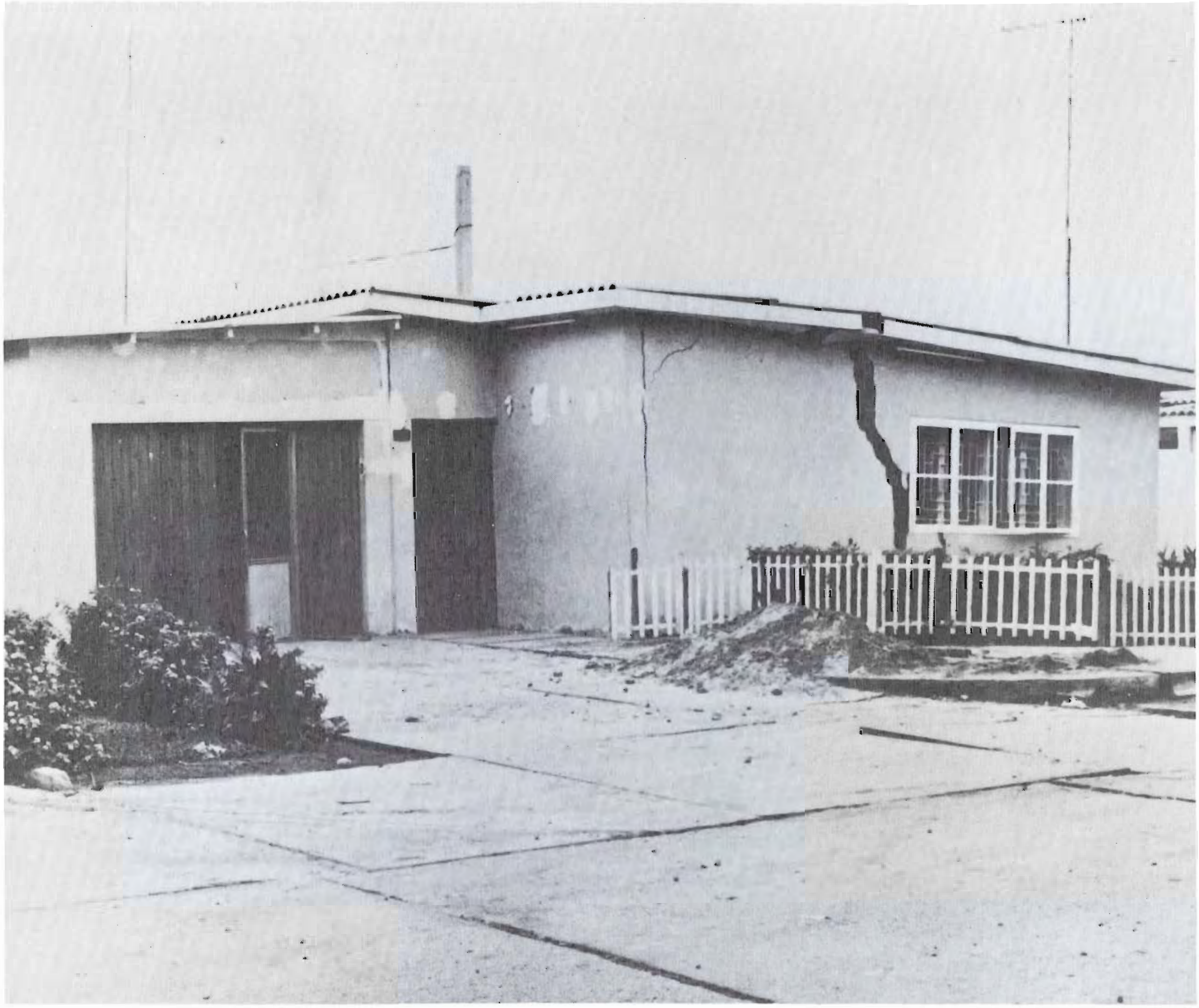

Figure 5.8 Concrete block house at the Corporacion Peruana del Santa housing development, northwestern Chimbote, torn apart by seaward spreading of the underlying beach sands that became liquefied during the earthquake.

The near-total destruction of central Huaraz (Figure 5.9) was the result of collapse of old relatively-unstable adobe buildings owing to a combination of shaking and probable incipient compaction and landspreading of water-saturated foundation material. This geologic foundation consists of a layer of silty and clayey sediment, at least 2 m thick, resting on gravelly material of an alluvial fan.

Compaction of water-saturated sediments, fissuring, and landspreading at many other localities in the Santa Valley, particularly in fields along old terraces or flood plains of the Rio Santa, caused local damage to roads and buildings. Notable slumping and landspreading occurred in a gently sloping field just south of Caraz. Here, slump material in an area 50-75 meters in diameter spread downslope, with formation of fissures and tilted blocks in the soil at the head of the slump area and a surficial flow of liquified soil at the toe.

Many earth flows were formed by liquefaction of water-saturated silt and sand associated with extensive glacial outwash and morainal deposits in the southern part of the Santa Valley. This is a grassy area of subdued topography, and the flows took place on gentle to moderately steep slopes. Because these flows formed in a sparsely populated area, the only damage they caused was to roads and trails.

5.5.5 Landslides, Rockfalls, and Soil Slips

The earthquake triggered thousands of landslides and avalanches throughout the area of about 65,000 km^2 outlined on Figure 5.2. The landslides included a wide variety of falls, slides, and flows involving bedrock, unconsolidated sediments, and snow and ice, in varying proportions. The overwhelming majority of the slides occurred on the steeper slopes of the Cordillera Blanca and Cordillera Negra, within the area outlined in Figure 5.10, and in the region of deeply incised drainage along the western flank of the Cordillera Negra, just west of the outlined area. The largest and most destructive slide was the Huascaran debris avalanche. At least six of the slides blocked stream drainage, forming landslide-dammed lakes. Many small rockfalls occurred along the steeper natural slopes and in roadcuts in the relatively low-lying arid coastal region, but none is known to have resulted in noteworthy damage. The total volume of material moved downslope during the earthquake is conservatively estimated to be between 100 million and 200 million m^3 -- perhaps a quarter to half of which was in the great Huascaran debris avalanche.

Most landslides involved falls or slides of rock and slides of poorly consolidated debris and soil along steep valley walls, streambanks, and roadcuts. The largest slides, which could be discerned on vertical airphotos, are plotted on Figure 5.10. Some of these are so closely spaced that a single symbol on the figure may represent many slides. In general, the large slides were mainly in the Cordillera Blanca, whereas most of the smaller ones occurred in the Cordillera Negra, particularly near the north end of the range and in deeply incised canyons elsewhere. Most of the individual landslides are rockfalls and rockslides that involve at least a few thousand cubic meters of material. Rockfalls and slides are so numerous in and near the Canon del Pato downstream from Caraz that it is virtually impossible to delineate individual slides.

Shallow soil slips of unconsolidated materials were observed throughout the area but were especially common on slopes mantled with water-saturated glacial till, volcanic ash, and colluvium. Soil slips are characterized by a series of irregular transverse open fissures, as shown in Figure 5.11, and by areas where thin slablike soil masses have broken away

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Figure 5.9 Typical street scene in a 100-block area of central Huaraz where nearly all adobe block buildings were destroyed. Most buildings were 2 or 3 stories high and had heavy tile roofs. Thousands of people were buried here in the narrow streets as well as in collapsed houses.

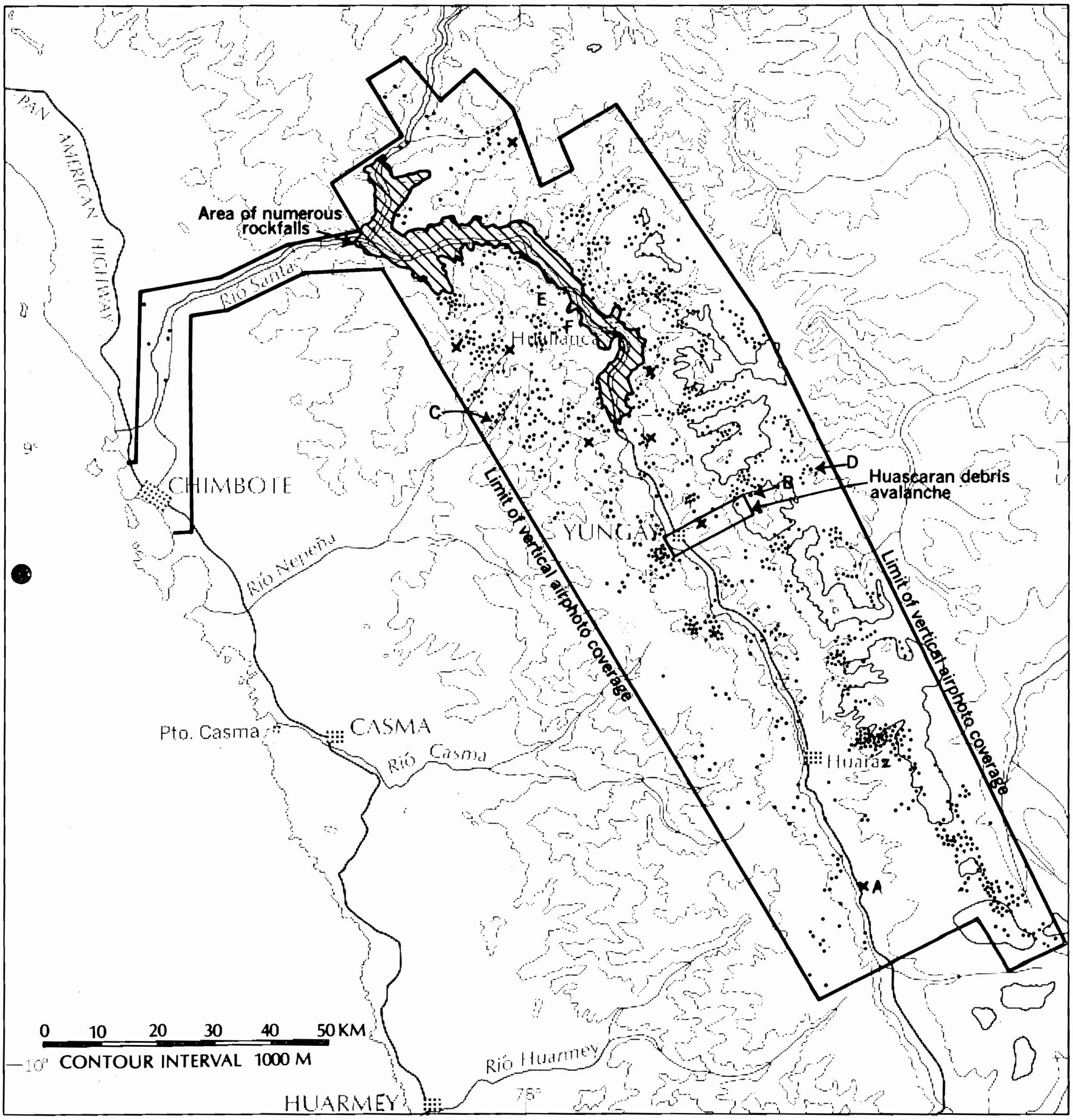

Figure 5.10 Map showing distribution of landslides triggered by the earthquake of May 31, 1970. Dots--rockfalls, rockslides, and debris slides; crosses--block slumps and rotational slides; letters--landslides-dammed lakes.

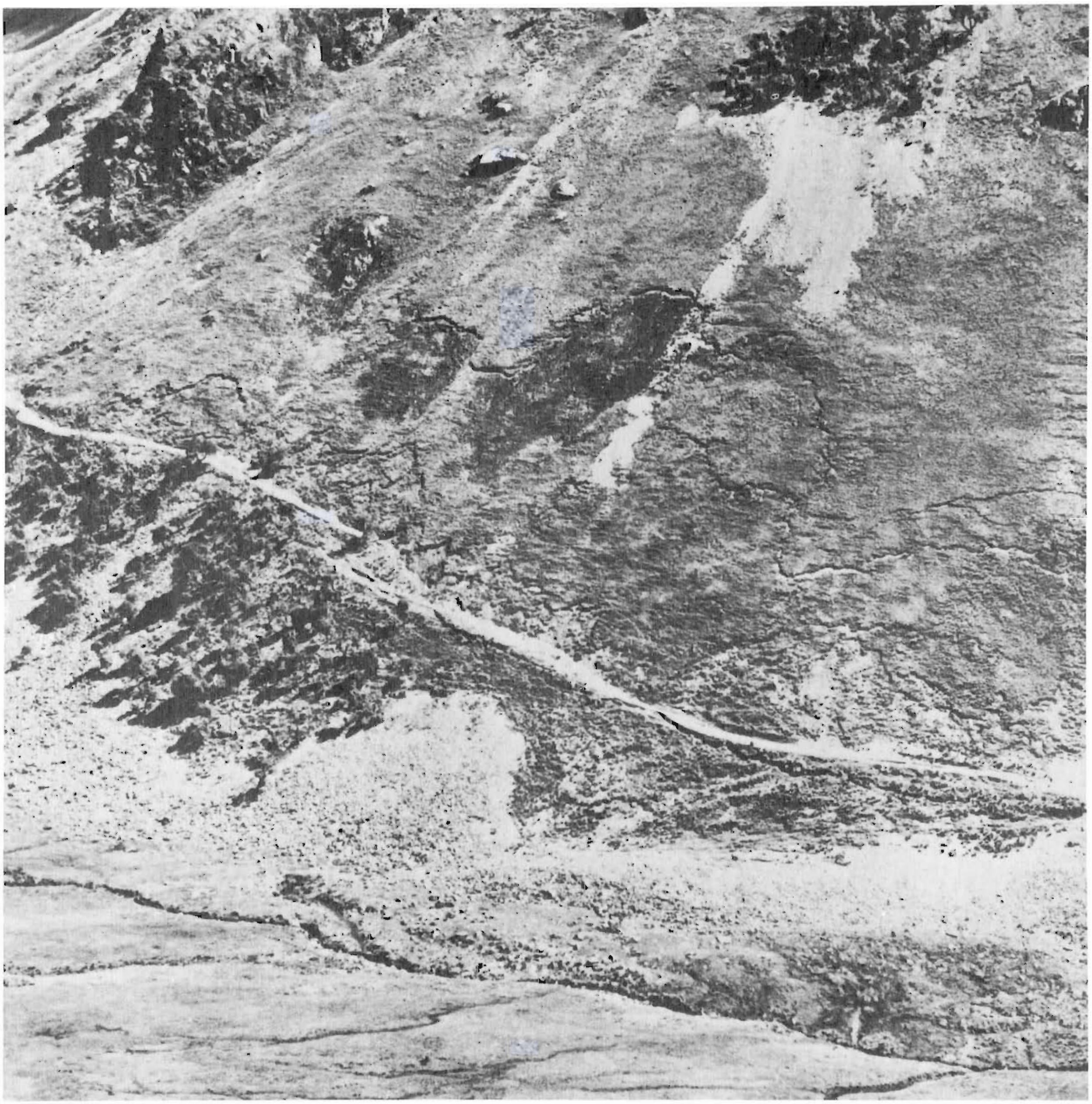

Figure 5.11 Surficial slips in thin grass-covered soil and slope debris along trail on east side of Cordillera Blanca, from Catac-San Marcos road about 2 km north of pass across range.

and slid or tumbled downslope. Although they are subtle features, soil slips caused extensive damage because they commonly formed on cultivated hillsides where they disrupted irrigation canals, trails, and fences, and destroyed fields and buildings. In some very steep areas on the west side of the Cordillera Negra, the thin soil of steeply-inclined fields (many having slope angles of 30° or more) slipped away, leaving bare rock. In this same area, soil slips destroyed trails that were the only access to many fields. Many of these fields still were not accessible a year or more after the earthquake because of the difficulty and expense of blasting trails across newly exposed steep rocky slopes.

Eleven landslides involving slumps and rotational slumps of large masses of coherent materials were identified within the area outlined in Figure 5.10, the area for which post-earthquake aerial photographs were available. Each of these slides is estimated to contain more than a million cubic meters of material, chiefly poorly-consolidated fluvial-glacial deposits, pyroclastic volcanic rocks, and thin-bedded shaly sedimentary rocks. The largest rotational slide block, at Recuay (Figure 5.12), involved at least 8 million cubic meters of material, and perhaps as much as 20 million cubic meters, depending upon curvature and depth of the failure surface. The upthrust toe formed a dam across the Rio Santa. At least five of the other rotational slides temporarily blocked streams.

5.5.6 Debris Avalanches

By far the most destructive and geologically-fascinating aspect of the earthquake was the cataclysmic avalanche of rock and ice from the glacier-covered north peak of Nevados Huascaran (Figure 5.13). This avalanche appears to be an event that, in terms of destructiveness, height of fall, velocity, and probably volume, far exceeds any avalanche known to have occurred during historic time.

The debris avalanche originated as a rock and icefall from the sheer west face of the north peak of Huascaran, between the altitudes of 5,500 and 6,400 meters. The original slide mass, in which the amount of rock apparently far exceeded the amount of ice, probably involved a volume of at least 50 million cubic meters. This mass gained velocity as it slid over Glacier 511 (Figure 5.14) for a slope distance of 2.4 km and vertical drop of nearly 1 km. Below this glacier, part of the debris was funnelled along the valley of Quebrada Armapampa; the remainder broke out of the valley and sped across major topographic irregularities on a more direct course toward Quebrada Incayoc. Below the confluence of Quebradas Armapampa and Incayoc, the main tongue of the avalanche was channelled down the Rio Shacsha valley to the Rio Santa. Within a few minutes after the first tremors of the earthquake were felt, the avalanche had sped 16 kilometers from Huascaran to the Rio Santa. The debris blocked the Rio Santa, temporarily causing it to back upstream for a distance of about 1 kilometer; it also lapped up onto the west bank of the river, reaching and destroying part of the town of Matacoto, and flowed downstream. Yungay was buried by a relatively small tongue of debris that swept over the ridge between the city and the valley of Rio Shacsha. In overtopping this ridge, the avalanche climbed as much as 230 m above the adjacent valley floor.

According to eyewitnesses, the Huascaran debris avalanche was triggered within a few seconds after strong earthquake tremors were first felt. It moved downslope at high velocity with a deafening noise, and was accompanied by a strong turbulent blast of air. An eyewitness account indicates that the debris avalanche travelled the 14.5 km distance from its source to the vicinity of the cemetery at Yungay in less than 3

Figure 5.12 Rotational slide in glacial outwash and underlying thin-bedded sedimentary rocks at Recuay. Maximum height of headwall (arrows) is about 7 meters. The toe (arrows) is a 5-meter high ridge that blocked the Rio Santa and formed the small lake in foreground of photograph.

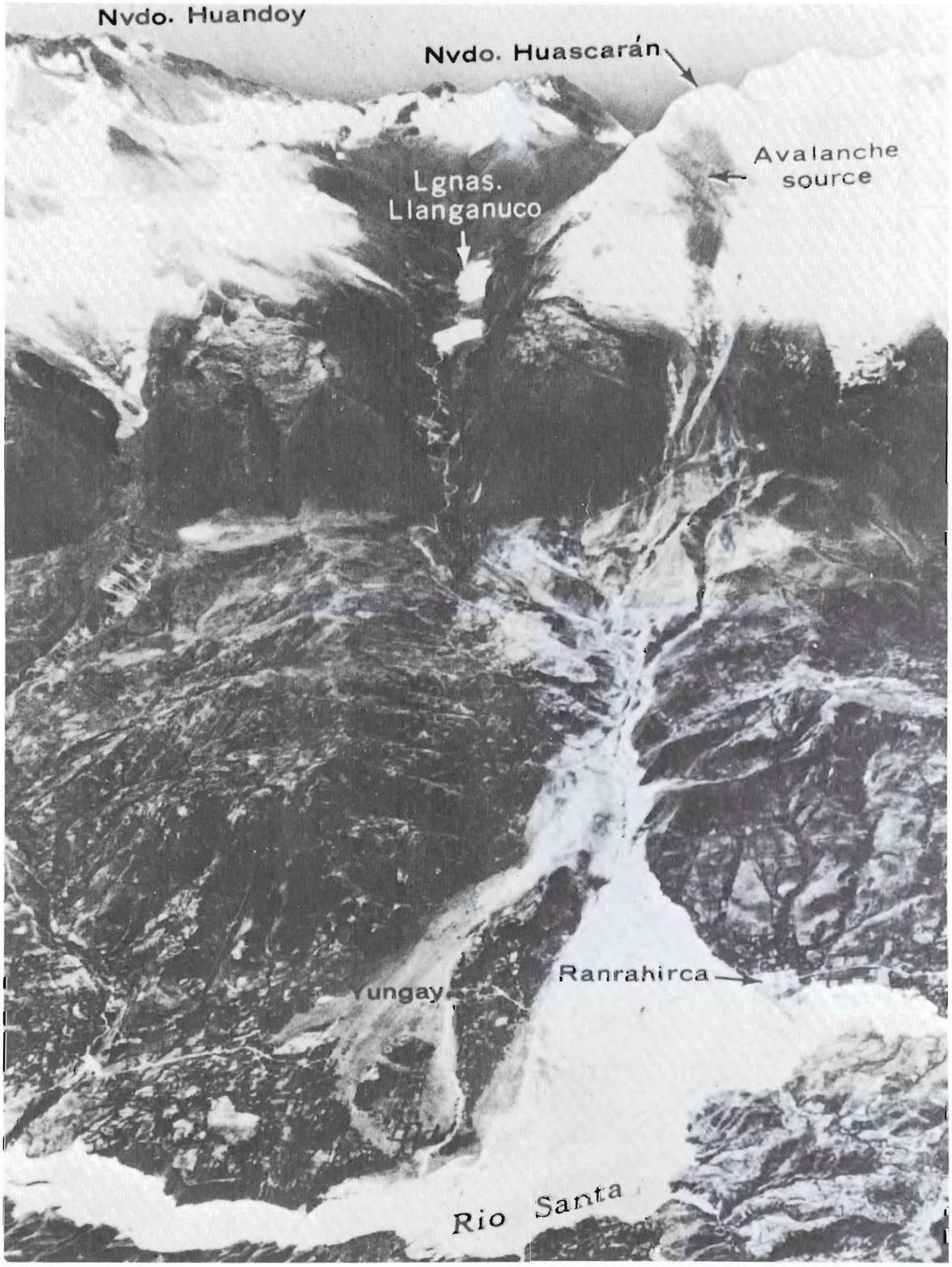

Figure 5.13 Oblique aerial view of Nevados Huascaran and the Huascaran debris avalanche that destroyed Yungay, part of Ranrahirca, and other nearby communities. Vertical relief between the avalanche source and the Rio Santa averages 3,500 m (11,500 ft.). (Courtesy of the Servicio Aerofotografico Nacional de Peru).

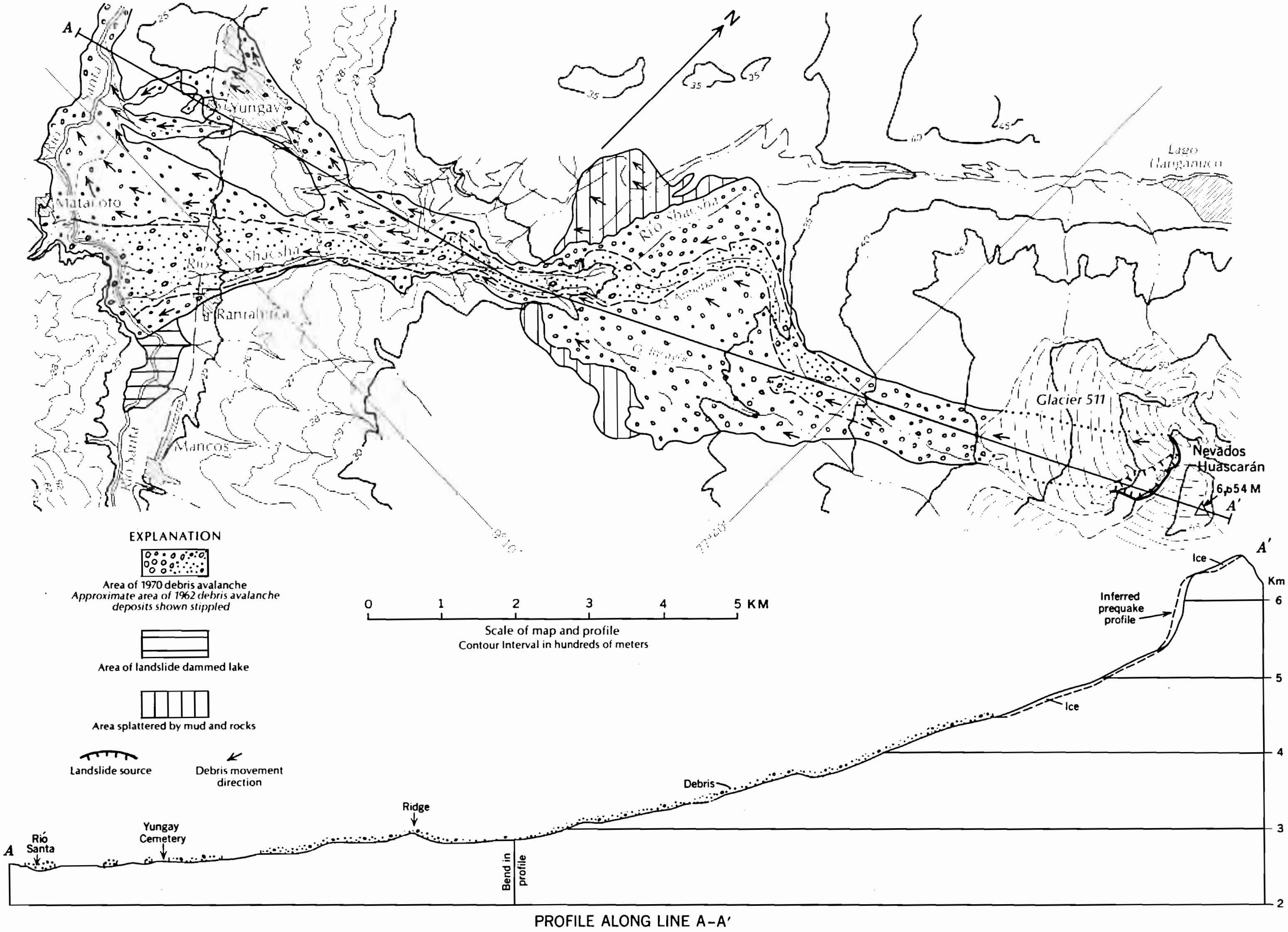

Figure 5.14 Sketch map and profile of the Huascaran debris avalanche. Plotted from aerial photographs on a base map of the Austrian Alpine Club (scale 1:15,000), which also shows the 1962 debris avalanche.

minutes and possibly as little as 2-1/2 minutes--an average velocity of between 280 and 335 km/hr (Mateo Casaverde, oral communication, July 3, 1970). Extremely high instantaneous velocities are indicated by the distances that boulders were hurled across the Rio Shacsha valley. For a vacuum ballistic range of 1,600 m, the estimated maximum horizontal distance that boulders were thrown, the initial projectile velocity had to be at least 450 km/hr. The effects of air drag would increase this initial velocity by some 25-50 percent, suggesting an initial velocity of as much as 600 km/hr.

5.5.7 Conclusions

The extensive destruction and loss of life in the Peru earthquake of May 31, 1970, was due largely to 1) poor construction of buildings, chiefly adobe, which had little resistance to lateral forces imposed by earthquake shock, and 2) the Huascaran debris avalanche that buried Yungay and parts or all of several smaller communities, and destroyed extensive areas of farm lands. To a lesser, but significant degree, destruction was caused by the widespread landslides and by differential compaction, landspreading, and fissuring in unconsolidated geologic foundation materials. Geologic conditions influenced the distribution of the landslides and foundation failures during this earthquake, and will undoubtedly do so in future earthquakes in Peru. Although neither lake breakouts, surface faults, nor a destructive tsunami accompanied the earthquake, they remain potential earthquake hazards in this part of Peru.

Large landslides and debris avalanches and flows constitute the major geologic hazard in the mountainous regions of Peru. Steep slopes are extremely unstable and are periodically subject to sliding, particularly when the ground becomes water saturated during the annual rainy season. Earthquakes often cause widespread downslope movement of unconsolidated material and may trigger some larger slides than those that would normally be expected to occur sporadically in mountainous regions. Failure of unstable dams of moraine, alluvium, and landslide debris that impound lakes in steep-walled glacial valleys may result in disastrous floods and debris flows during earthquakes. Such a debris flow, triggered by the January 6, 1725, earthquake, buried the colonial town of Ancash, which is in the Santa valley about 3 km downstream from Yungay (Figure 5.2).

Differential compaction, landspreading, and fissuring may cause extensive destruction during large earthquakes, particularly to structures that are built on water-saturated fine-grained unconsolidated deposits or on poorly compacted natural or artificial dry materials. In Peru, these materials are generally most widespread in valleys of coastal regions, which commonly are also areas of highest population density.

Surface faulting was associated only with the 1946 Ancash and 1969 Pariahuanca earthquakes in Peru (Ernesto M. Deza and Daniel Huaco, oral communication, June 1970 [14]). Because most known active faults in Peru are in remote, sparsely populated areas, damage by direct fault displacement does not appear to be a major hazard. However, active faults are serious hazards in most other earthquake-prone regions, and movement of them can cause extensive destruction to works of man.

A major earthquake-related hazard in coastal regions of Peru is from destructive sea waves or tsunamis that could be generated by sudden large-scale vertical displacement of the sea floor at the continental shelf or slope. No such waves were generated during the 1970 Peru earthquake, presumably because the causative fault displacement was relatively deep seated. Nevertheless, many large destructive tsunamis have accompanied previous major earthquakes along the Peruvian coast (Berninghausen, unpub. data, 1962 [14]) and will undoubtedly occur in the future. Both distant and near-source tsunamis could cause widespread inundation of low-lying parts of Peru, as well as of other coastal settlements of the Pacific basin.

5.5.8 Recommendations

The investigation of the Peru earthquake of May 31, 1970, has shown the need for systematic geologic and seismologic studies in Peru in order to better select sites for construction that will avoid potential geological hazards. The following systematic seismologic and geologic studies should be carried out in Peru to identify hazards and to undertake corrective measures to minimize destruction and loss of life in future earthquakes: a) Preparation of a seismic-risk map of Peru; b) preparation of a tsunami-hazard map of the Peruvian coast; c) preparation of geologic foundation maps of the principal cities of Peru (investigations should include borehole and trenching tests and study of microtremor characteristics); d) monitoring of glacial lakes of Peru in order to evaluate the potential for breaking of morainal dams that could result in disastrous floods and debris flows; and e) identification of areas or regions that are particularly susceptible to major landslides and rockfalls.

A single agency of the Peruvian Government should be designated to undertake the above-mentioned investigations as well as continuing studies of seismicity in Peru, and engineering geology and seismology of individual earthquakes. In addition to carrying out investigations, this agency could act as coordinator for earthquake studies carried out by other institutions in Peru, particularly the intensive studies that immediately follow each major earthquake and involve international as well as national institutions. Among the agencies in Peru that have been most active in seismological and/or geological studies related to earthquakes are: the Instituto Geofisico del Peru (IGP), the Comision de Reconstruccion y Rehabilitacion de la Zona Afectada por el Terramoto del 31 Mayo de 1970 (CRYRZA); the Escuela de Ingeneria del Peru, the Servicio de Geologia y Mineria, and the Centro Regional de Sismologia para America del Sur (CERESIS). Of these institutions, the IGP, which has been most deeply involved in seismological studies on a long-term basis, would probably best qualify as the prime agency responsible for earthquake studies.

The staff for earthquake-related investigations, as outlined above, need not be large, perhaps not more than ten scientists, and should include soils scientists and hydrologists as well as engineering geologists and seismologists. Equipment will be needed in addition to that now in Peru. Of particular importance are portable seismographs, strong-motion seismographs, and portable seismometers of high sensitivity for microtremor observations.

CRYRZA, which was formed specifically as the agency to undertake diverse studies and reconstruction of the area affected by the 1970 earthquake, represents an innovative type of institutional development. It has a wide variety of specialists, from geologists to structural engineers and economists, that allows a multidiscipline approach to the problems of reconstruction of an earthquake-devastated area. Such an institution is potentially the most effective means of organizing relief after an earthquake and bringing about the efficient reconstruction of the affected area and revitalizing local industry and the overall economy.

5.6 Summary of Recommendations

1. Minimize wind damage by placing buildings so that they are protected by hills or by stands of trees.

2. Design future housing for adequate lateral-force requirements. In Turkey, these requirements should be at least as stringent as those specified by the Uniform Building Code [5] and be supported by a modern seismic-risk map of Turkey.

3. New housing be sited at adequate distances from faults or fault strands. In Turkey, siting with respect to faults or fault strands and branches should meet the requirements set forth in Section 5.4.3.

4. Planning-stage studies should be the basis for selecting sites for all earthquake-resistant housing for which more than one or two alternative sites are available. Site-intensive investigations should be made of all sites proposed for large engineered buildings (see Section 5.4.8).

5. Prepare seismic-risk maps in Peru.

6. Prepare a tsunami-hazard map of the Peruvian Coast.

7. Prepare geologic foundation maps of the principal cities of Peru.

8. Monitor glacial lakes of Peru in order to evaluate potential for disastrous floods and debris flows.

9. Identify areas or regions in Peru that are particularly susceptible to major landslides and rockfalls.

10. Designate a single agency of the Peruvian Government to undertake investigations and studies of seismicity in Peru.

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Chapter 6. Methods of Housing Construction

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6.1 Introduction

Viable technologies capable of responding to the urgent need for large numbers of inexpensive earthquake and storm resistant dwellings in developing countries can only be achieved if the resources available in the area of housing construction are properly utilized. One such resource, often overlooked, comprises traditional methods and skills, which may be changed and improved by the application of innovative technologies requiring only limited investments and training programs. The resulting improved methods could achieve considerably higher standards of quality and productivity while being compatible with local conditions and needs.

In recent years, industrialized methods of construction have been introduced and used in various developing countries, often with encouraging results. Such methods represent an extremely promising technical solution to the problem of providing safe, inexpensive construction on a large scale. Progressive technologies compatible with local capabilities and needs should therefore be used in an effort to develop and improve industrialized methods of construction.

This chapter contains a brief review and discussion of traditional and industrialized methods of construction in three developing countries selected as case studies: Peru, Turkey and the Philippines.

6.2 Traditional Construction Methods

Peru. Stone masonry was used in Peru by the Incas for fortifications which are still standing today.

On the north coast rural houses are commonly built on stilts with walls made of woven mats and with roofs made of reeds and banana leaves. Pegs or thongs of leather are used as binding elements.

Various types of cane are used for housing throughout the Coast. A common type of dwelling consists of a framework of thick cane or wood uprights imbedded in the earth to a depth of 15 cm. Walls are made of cane mats fastened to bamboo or wooden stringers with rails or thin rope and lined with earth mortar or with wrapping paper. Roof mats have a light covering of earth.

In urban areas of the Coast, quincha construction is widely used because it is earthquake resistant, inexpensive and easy to build. This system consists of a framework of wood uprights placed at 80 cm to 100 cm intervals between a floor and a roof beam and braced with diagonals and an intermediate stringer. Cane is placed vertically and tied to the framework with cord or leather strips. The wall is then plastered with mud and finished with a coat of whitewash. In spite of its advantage, quincha construction is now less favored by potential users mainly due to shifts in social and cultural acceptance.

Adobon is the most common construction type in the Sierra and consists of mud mixed with straw, manure and pebbles molded in place between wood planks. The width of the wall is 60-80 cm. Adobon houses generally have two stories of about 2.80 meters height each and are built with no windows. Tiny openings are left in the walls for ventilation. Roofs are made with eucalyptus poles covered with wild straw.

Adobe construction is prevalent throughout the Coast. Adobe is generally considered by potential users to be inferior and undesirable. This attitude can probably be changed by upgrading the quality of adobe bricks. Modern techniques applied to adobe construction have great potential in so far as achieving inexpensive, socially acceptable, good quality earthquake resistant structures (see Chapters 2 and 10). An example of a typical adobe construction is shown in Figure 3.5.

Turkey. Wood is widely used in Northern Anatolia where log houses are built in the forest regions.

Stone masonry construction is used in almost 50 percent of the rural dwellings in Turkey and are especially frequent in eastern, southeastern, south and southeastern Anatolia (see Figure 3.4). Walls are generally 40-60 cm thick and stones are usually bound with mortar. Horizontal wood, metal or reinforced concrete ties are placed at about one meter intervals.

Almost 30 percent of existing rural dwellings are built with adobe which is the most common material around Marmara and in western, central and eastern Anatolia. Adobe is used in blocks, or poured in place with or without tree branches as reinforcement. Its social acceptability is at present low. As in Peru, upgraded adobe construction is a promising technological development.

Brick construction is mainly used near Marmara and in northern and northeastern Anatolia.

Timber is used for framing and is filled with mud, tree branches, adobe, stone or bricks. Adobe, stone or brick filled construction is dangerous in earthquake zones if the timber members and their connections are not sufficiently strong (Figure 6.1).

Thick earth roofs are frequently used, especially in adobe construction (Figure 6.2). Unless the roofs are adequately braced horizontally while diagonal bracing is provided in the walls, they may constitute a hazard in earthquake regions. Their use should therefore be limited by building codes (see Chapter 7).

6.3 Industrialized Construction Methods

6.3.1 Labor-Intensive Industrialization

In order to promote more efficient use of scarce resources of capital and skills in a community having an abundant labor supply, it is natural to develop labor-intensive industrialization, as the first phase of a transitional technology that will evolve with and stimulate the economy. Labor-intensive methods are not incompatible with the use of new techniques. For example, foam plastics appear to offer significant promise for light-weight roof insulation and wall in-fill. Honeycomb and corrugated cardboards show potential in sandwich panel configurations using gypsum, jute fabrics and foam insulation. The production of adobe blocks or bricks also lends itself to labor-intensive industrialization.

Before the actual initiation of a local production setup, a determination of economic feasibility is necessary. While quality and quantity are important, costs of production and revenue possibilities are clearly the most critical factors in evaluating the feasibility of such a program.

Figure 6.1 Two-story adobe-filled timber-framed structure in Turkey. Damage is due to poor quality of framing and connections.

Figure 6.2 Traditional Turkish adobe building. Damage at top of first floor wall is due to poor quality of masonry. Damage underneath roof is caused by horizontal thrust of roof beams on frontal walls. To prevent such damage, the roof should be braced horizontally in order that horizontal loads produced by earthquake motion be transmitted to the lateral walls which are capable of absorbing them. The seismic resistance of this type of building would be further increased by a better distribution of the openings in the end walls and by providing at least one interior bearing wall parallel to the short dimension of the building.

In marketing the product, in addition to considerations of design, construction and site planning, the individual user's demand for such attributes as choice and control of dwelling environment must be taken into account.

6.3.2 Prefabricated Housing in Turkey

Prefabricated housing in Turkey was first introduced in 1957 when a Turkish construction firm built a housing complex consisting of one, two and three-story units in the Eregli region, using the Danish Larsen-Nielsen procedure. However, until a few years ago when the Turkish Government became involved in this field, only a few prefabricated houses had been built.

Prefabricated housing efforts have increased considerably since 1967, mainly due to successive natural disasters (earthquakes, floods, other) occurring in Turkey since this date which produced an urgent need for housing. The government awarded initial contracts to private firms for the construction of partially-precast dwellings. Later the fabrication of construction components was started in the workhouses of the MKE (State Mechanical and Chemical Industry Institution) and in the plants of the Land Resettlement Directorate.

The following prefabricated frame and wall units are now being manufactured in Turkey for housing construction:

- (i) Steel skeleton and timber partition walls
- (ii) Reinforced concrete panels
- (iii) Lightweight, reinforced concrete panels (Figure 6.3)
- (iv) Plastered panels
- (v) Steel frames and walls filled with lightweight concrete
- (vi) Timber panels (Figure 6.4)
- (vii) Prestressed concrete units
- (viii) Plastic dome elements

These prefabricated units now are produced mainly by three plants, the Lodumnu and Etlih plants, which belong to the Ministry of Reconstruction in Ankara, and a plant owned by the Swedish "Ytong" firm in Istanbul.

The "Lodumnu plant" in Ankara was founded in 1968 and prepares timber components which are used primarily for housing but are also used in the construction of mosques. Initially, the plant produced six dwellings a day for the regions of Kigi, Igdir, Amasra and Bartin. After the Gediz earthquake in 1970, the production capacity was increased to sixteen dwellings a day. At present, seven dwellings are produced in a normal shift and sixteen a day in emergencies.

The plant manufactures several types of timber panels including both outside panels and inside panels on a modular size of 1.20 m. Outside panels are 10 cm thick. Half of this thickness is insulating glass-wool. They are covered by 19 mm thick hard board on the inner face and by 8 mm thick asbestos on the outer face. Inside panels are 6.0 cm thick and are doubly faced with thin hardboard. Some panels have window and door openings. The panels are mostly used in construction of one-story, single family dwelling units of 48 m^2 clear surface for urban units and 43 m^2 for rural units, in accordance with prototype

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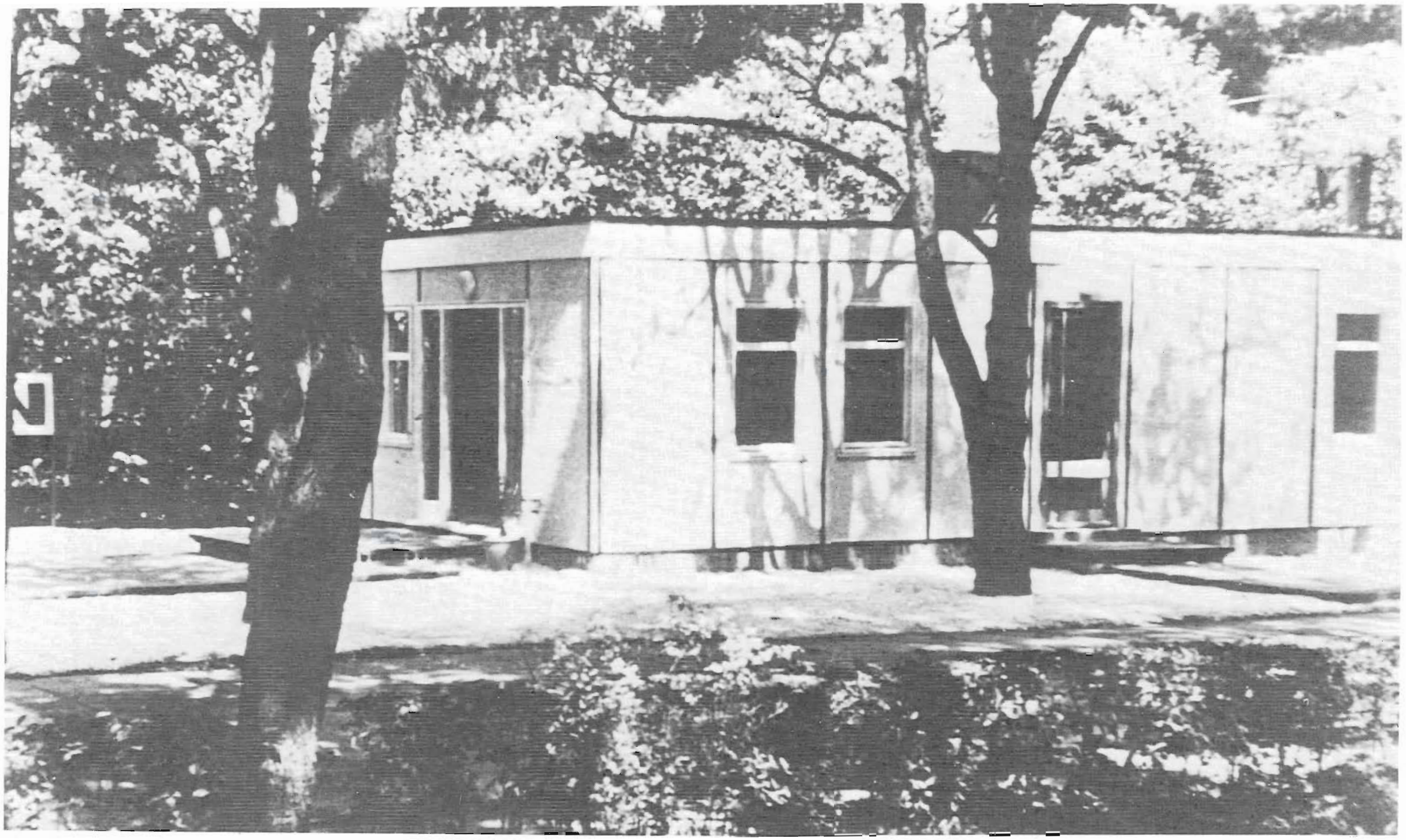

Figure 6.3 Precast lightweight reinforced concrete panel building, Turkey. Lightweight concrete panel construction is capable of adequately withstanding earthquake loads if properly designed and built. In the case of this building interior shear walls of adequate strength would be required in addition to the end walls, as the strength of the latter is impaired by the presence of large openings. Cast-in-place reinforced concrete beams, ties and columns contribute substantially to improving the aseismic behavior of such buildings.

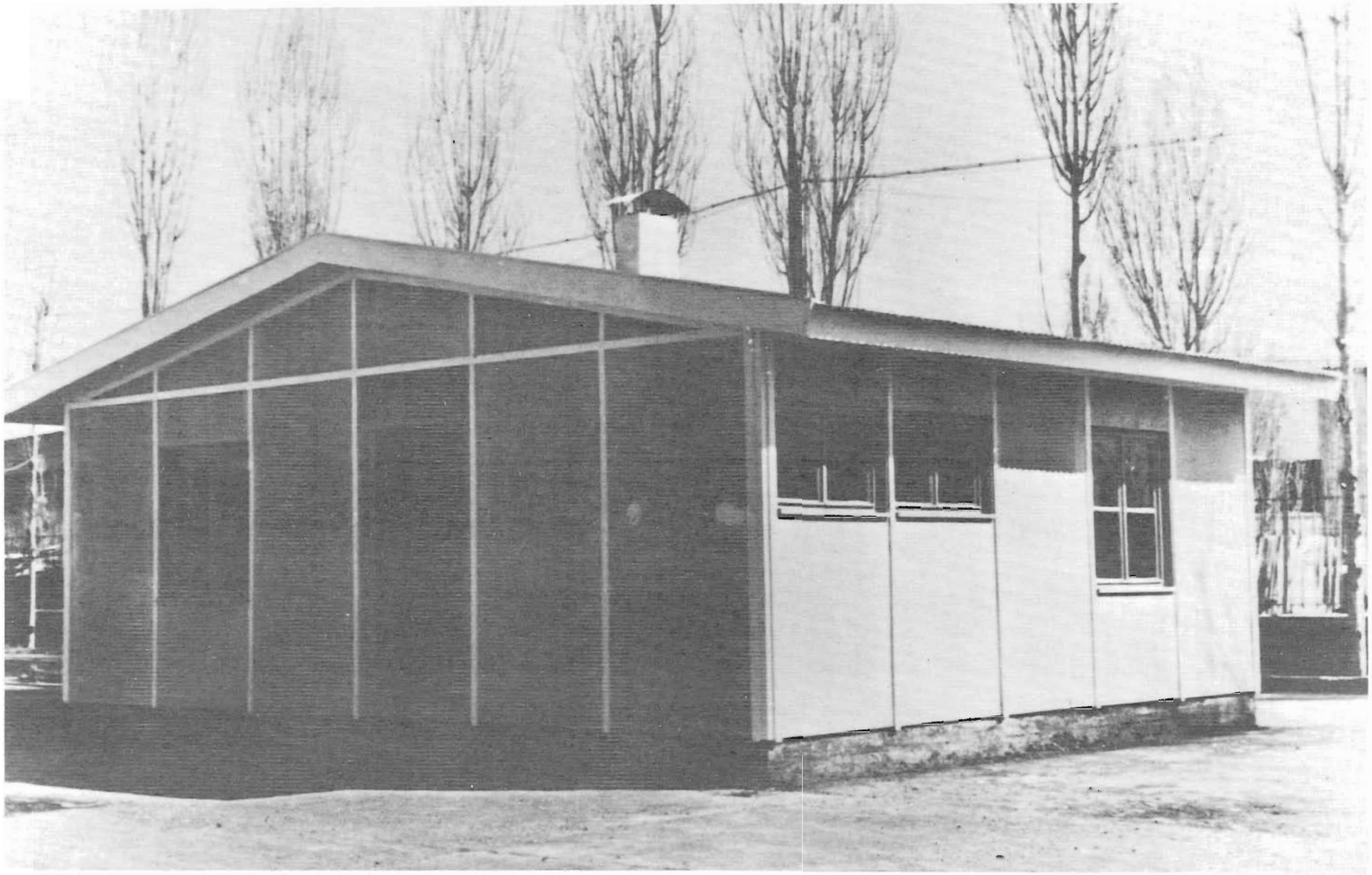

Figure 6.4 Timber-panel prefabricated house, Turkey. The principal materials used in this dwelling are plywood, asbestos, cement, wood (for frame and floor), corrugated metal. Excellent aseismic behavior of such units can be achieved through use of light materials, rational design of framing and of connections.

architectural plans. In addition, the plant also manufactures and delivers the timber roof system which consists of 37 panels, 7 roof trusses, and additional miscellaneous items.

The thermal insulation provided by the glass-wool is satisfactory. Laboratory tests show that the heat transfer from 10-cm-thick external panels is equivalent to a 60-cm-thick brick wall. The earthquake resistance of the panels has not been tested in the laboratory, but the earthquake hazard risk of house of this type of construction is far less than for brick masonry dwellings of the same size.

The prices of these panel units vary between 140 and 167 TL.* (1972 prices) for inside panels and between 194 TL. and 233 TL. for outside panels. The components and miscellaneous items required for the construction of a dwelling are sold by the plant at a price of 13,000 TL. With foundation, erection, and installation of sanitary and electrical equipment, the price rises to 21,000 TL. For a total construction area of 51.8 m^2 (a clear surface of 48m^2) this corresponds to a unit price of approximately 400 TL./m^2, or 2.5 times less than for similar dwellings made by private firms.

The Etlik plant, near Ankara, was founded in 1970 and produces prefabricated light-weight concrete panels. The aggregate used in the lightweight concrete is imported Styropor, a product of the German BASF firm. Styropor will soon be produced in Turkey in the PETKIM (State Petrochemical Industry) plants. Concrete with this light-weight aggregate has a compressive rupture cube strength of not less than 40 kg/cm^2.

The panel components also are based on a 1.20 m modular size, with a typical panel size of 1.20 m x 2.40 m. Panel thickness is 6 cm for inside walls and 8 cm for outside walls. The panels are covered by 1.5 cm-thick concrete on outer faces and by 0.2 cm-thick concrete on inner faces. Typical dwellings built with these panels in earthquake regions have a prototype plan of 6.08 m x 7.28 m. Prices in 1972 of these panels range from 136 TL. to 179 TL.

A typical dwelling is constructed using 39 panels and 47 additional elements, including timber roofing elements. The price of all the items was 11,500 TL. Including erection costs, the total price of one dwelling is 17,200 TL. or 400 TL./m^2.

The heat insulation capacity of these panels is equivalent to that of a 50 cm-thick brick wall. The earthquake resistance is estimated to be good, although no tests have been conducted.

The two plants of the Ministry of Reconstruction are now producing components for the construction of school buildings and for dormitory buildings used by the Turkish Army, in addition to use in dwellings and other structures.

The "Ytong" firm of Turkey, founded in 1966, utilizes a Swedish process which utilizes a mixture of ground limestone, alumina powder, and portland cement. Hydrogen is released in the chemical reaction which takes place after the contact of the dry mixture with water. Within two hours after the chemical reaction, the material reaches a sufficient degree of strength to be cut into blocks which are then placed in autoclaves with steam circulating under pressure. This forced curing and drying process takes about 10 hours. The resultant material can be cut into desired shapes and sizes, such as bricks, panel wall units, panel slab units, etc.

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* 1 U.S. \$ ≈ 14.30 TL (Turkish Lira) in 1972.

The "Ytong" standard products used in the partial prefabricating are:

(i) Panel Slab Units are the rectangular prismatic blocks with standard width of 50 cm. Their length ranges from 1.0 m to 6.0 m, in increments of 0.25 m. Their thicknesses range from 7.5 cm to 25 cm, in increments of 2.5 cm.

The slab panels are also used as precast concrete joists. Empty spaces left between the panels are filled with reinforced concrete joist beams.

(ii) Panel Wall Units have a width of 50 cm and lengths ranging from 0.50 m to 3.00 m, in increments of 25 cm, thicknesses range from 15 to 25 cm.

6.3.3 Prefabricated Housing in the Philippines

Only two companies are presently involved in the manufacture of prefabricated components in the Philippines, a private firm producing wall panels and roof trusses and a government firm producing light-weight concrete panels. The government firm, as the result of reported technical difficulties, has not yet produced the porous concrete wall panels for which it was designed.

Filipino builders are aware of the savings intrinsic in prefabrication and are confident of their capacity to undertake prefabricated construction work. However, the volume of such work is small at present, most likely because of lack of adequate financing to develop a viable industry.

6.3.4 Prefabricated Housing in Peru

Wood Construction

According to the official registers of the Ministry of Industry and Commerce, there are two plants for the production of prefabricated wood houses, one located in Lima and the other in Pucallpa in the jungle region. In 1955 these companies produced 123 units at a total value of S/6,912,000,* i.e. an average value of S/56,195 per unit, whereas in 1968 they produced 190 units at a total value of S/25,075,785 and an average unit value of S/131,978. The available statistics include as units not only houses but also temporary sheds erected at the beginning of civil construction projects. An estimate of the construction capacity for prefabricated wood houses shows that between 1965 and 1968 only 30% of the installed capacity was used.

In the city of Lima about fifty carpentry shops produce wood houses, of which less than ten account for about 70% of the production. It is estimated that the present installed capacity, working two shifts, can deliver between 500,000 and 600,000 units a year, provided there is a sufficient supply of the appropriate wood.

It is noted that the consumption of lumber and plywood was only 8.5 bd ft per capita in 1970, lower than in most Latin American countries. It was estimated that resources available in the natural forests of the eastern slopes of the Andes and of the upper Amazon basin amount to approximately 500 bd ft per capita yearly. The present under-utilization is due to rudimentary exploitation techniques, to transportation

* 1 U.S. $ ≈ 43.4 Soles (S/) in 1972.

difficulties, and to the difficulty of harvesting selected trees in a mixed forest, where more than 1,500 species are estimated to exist (only 300 species exist in Europe) of which only 25 are exploited commercially in Peru.

Concrete Construction

At Chimbote, where cement is readily available from the plant at Pacasmayo, large concrete panel and modular systems are competing with conventional permanent construction (Figure 6.5).

The Unicreto plant, located south of the city, produces a variety of "U" shaped modules, or units, averaging 3 m wide, 2-1/2 m high and 1-3/4 m deep. The units are placed on 7-1/2-cm-thick concrete slabs in an inverted position forming walls and roof. In this fashion three inverted "U's" shipped to the site with trimmed window and floor openings form a space of approximately 15m^2. The present output of this plant is approximately sixty modules per day. An average house consists of nine basic units. The concrete used has a strength of 210 kg./cm.^{2}

Presently the Unicreto plant is producing 328 complete houses and 872 basic units under a contract which will probably be extended to include an additional 2,000 units. In addition, the national plan of Peru calls for an additional 6,000 units by the end of 1973. The cost of units currently being built average S/70,000 for a 46 m^2 complete home. Land and utilities are an additional S/50,000. Total cost thus averages S/2600 per m^2 of floor space ($6.10 per ft^2.). For a basic unit of 29 m^2 the cost is S/31,000 and S/32,000 for the site and utilities, an average of S/2,200 per m^2 of floor space. Lot sizes average 150 m^2.

The plant as it now exists is an efficient operation occupying 40,000 square meters and employing 150 persons, of whom four are skilled. Delivery problems cause difficulties because the number of special vehicles available to deliver modules to the site presently is inadequate. Inasmuch as production is on schedule, a large number of units are accumulating at the plant awaiting delivery. Additional delivery vehicles are being adapted from conventional dump trucks.

At the Listos plant, also located south of Chimbote, columns and panels are manufactured under a process patented in Peru. Four basic units are produced: a hollow wall panel of 3 m x 3 m x 20 cm, a solid wall panel of 3 m x 30 cm x 12 cm, a 15 cm^2 column notched to receive the solid wall panels, and a narrow hollow roof panel similar to the hollow wall panels. It is estimated that at least two crews of seven men each and three to four days' time is needed to produce the components for a single housing unit.

The Listos plant has its own large clientele in the private sector, and also has won the public bidding for the construction of 200 dwellings in Chimbote (in an area devastated by the 1970 earthquake). Plant owners also are negotiating to build a similar plant in Mexico, where they have apparently won a public bidding. The plant is being enlarged in order to reach a production of between 50 and 100 dwellings per month.

The cost of construction of houses of this type is as much as S/1,600 per square meter for low-cost types of housing. Although relatively expensive, this system has the advantage of a short construction time, with resistance to earthquake approximately equal to Unicreto.

Figure 6.5 Unicreto precast concrete buildings, Chimbote, Peru. Very careful technical supervision of the erection of such buildings is necessary in regions subjected to earthquakes. Particular attention should be given to connection of components, both in design and in construction.

Miscellaneous Systems

Other systems use wood or steel frames, and panels made of asbestos-cement, fiber-cement, plywood, "maderita," "mapresa," reinforced expanded polyurethane, etc. Extensive studies of special roof panels, first developed in India, using thick cloth as both forms and reinforcement for light air-entrained concrete with pumice stone aggregate, were carried out at the National University of Engineering between 1957 and 1972. Such panels, if successfully developed, may be used to advantage in earthquake resistant construction.

A prototype house made from jute core laminated with fiberglass was designed, developed and constructed by CARE, Inc. in Bangladesh (Figures 6.6, 6.7). The reaction to the full size model in Dacca was highly favorable as the construction uses a high proportion of locally-available materials and appears to be of superior resistance and durability. The house is still in the experimental stage, both from the structural and the social acceptance standpoints.

Figure 6.6 Plastic prototype house of CARE, Inc., Bangladesh. (1971). Interior view of three segments in place. Note variation in segments, one at extreme left does not use jute husk laminate but pure fiberglass with the necessary gusseting for this type of configuration. The other two sections are jute husk laminate each with some experimental variations.

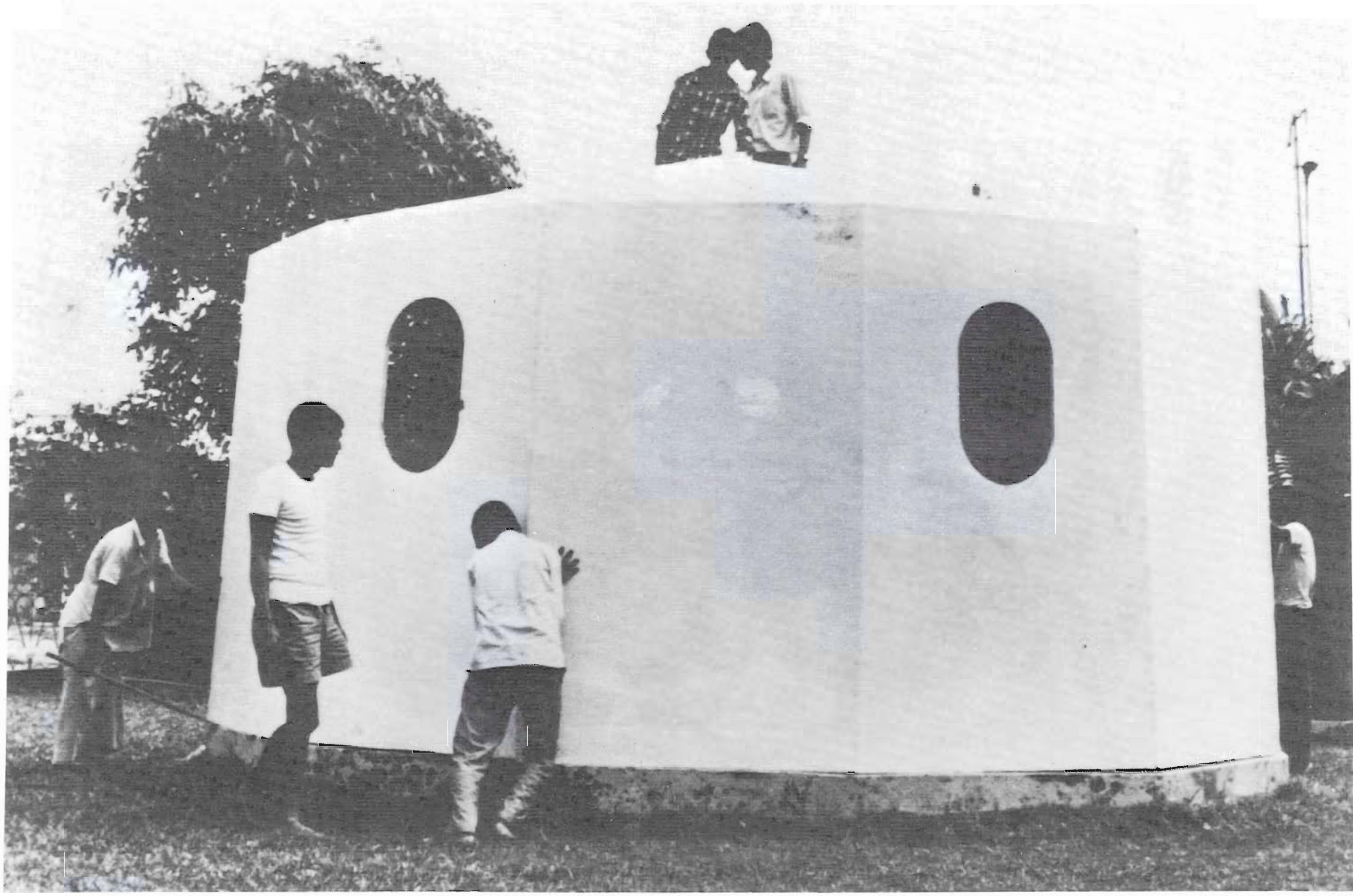

Figure 6.7 Aligning the individual sections of the CARE, Inc. dwelling in Bangladesh, 1971.

Chapter 7. Building Codes and Regulations

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7.1 Introduction

Building Codes and Regulations contain mandatory requirements, one of the main purposes of which is to prevent the design and construction of structures deemed to be unsafe. In a seismic region, for example, building codes should specify the magnitude of the minimum seismic loads that structures must sustain, the quality of materials and workmanship consistent with an adequate aseismic behavior of structures, and positioning of structures in relation to potential site hazards.

In order that effective building programs be undertaken, it is necessary that building codes be developed which take into account local conditions and needs. The compilation of national seismic codes published in 1960 by the Organizing Committee of the Second World Congress on Earthquake Engineering reveals that more than half of the 70 countries which lie within the main seismic zones of the world, do not have building code provisions for aseismic design or construction. The absence of adequate building codes may have serious, and sometimes disastrous technical, economic, and social consequences. Improvement of existing building codes is therefore a required phase of any effort to provide safe, low-cost housing on a major scale.

In this chapter a brief discussion will be presented of problems related to building codes that are typical of developing countries. The questions of whether codes exist, of the scope of existing codes, of whether they would be effective if enforced and of whether they are enforced will be examined with reference to the case studies of Peru, the Philippines and Turkey.

7.2 Difficulties Encountered in the Promulgation and Enforcement of Codes and Regulations

The promulgation and enforcement of building codes and seismic-resistant structures presents problems of particular difficulty in developing countries. For example:

(a) Many local materials or construction systems have not yet been studied scientifically. Their technical design parameters are therefore not known.

(b) In many regions, local geology and soil conditions have not been investigated.

(c) In many regions, seismic or extreme wind records are not available.

(d) In many areas, a reliable system of inspection and enforcement does not exist and is difficult to establish.

The promulgation of conservative, i.e., safe, building codes may meet with resistance motivated by short-term economic factors. For example, in Nicaragua the promulgation of a code similar to that used in California was advocated by various experts long before the Managua earthquake of December 1972. It is only after this disaster that the decision to adopt such a code appears to have been made.

For housing built with funds borrowed by the owner from a local savings institution, improved enforcement of codes may be achieved by making the granting of credits contingent upon satisfactory compliance with building code requirements. The inspection of the building site to insure enforcement of the codes could in this case be performed by qualified agents of the savings institution.

7.3 Building Codes, Local Conditions, and Innovative Technology

In order to effectively perform their function, building codes must be compatible with local conditions. Codes in developing countries cannot be based on conditions prevailing in countries with a highly-developed technical base. It is, in addition, necessary that, within the same country, local conditions that may vary from region to region or even within the same region, be properly taken into account. For example, modern buildings located in the Fars region of Iran were designed by Tehran engineers using criteria which did not take into account the geologic characteristics of that region. In the recent earthquake which devastated southern Fars, over 60 percent of the victims perished as a result of the collapse of such buildings.

Building codes also must be compatible with local capabilities. If this is not the case, systematic evasion of unrealistic requirements occurs, and the protection offered by the codes becomes illusory.

The relationship between codes and the development of new technologies must also be considered. Innovative technical solutions, compatible with local conditions, must be sought in order that the protection to the public provided by properly-enforced building codes not be achieved at the expense of prohibitively-high construction costs. Rigid formulation of the codes may have the effect of hindering the development and use of progressive technologies. Properly-formulated codes should therefore exhibit sufficient flexibility to allow the adoption of new techniques.

7.4 Building Codes in Peru

Since the creation in 1962 of the College of Engineers of Peru, only engineers and architects graduated from or associated with the College can present construction plans. Until recently, the regulations utilized were, depending upon the type of construction or the judgement of the engineer, selected from German, North American, French, or Japanese sources.

In 1967, the government named a commission to formulate a unified construction code. After the 1970 earthquake the commission accelerated its work and in that same year approved the National Construction Regulations which are now in force in all parts of the country. The National Construction Regulations of Peru is a detailed document that represents a significant technical advance. It is believed, however, that further progress is possible in the area of aseismic design. Indeed, while the present aseismic regulations prepared by the National Technical University contain provisions applicable to construction, they do not include provisions for design. With regard to adobe construction, the Regulations do not include limitations on the height of adobe buildings [1]. In addition, progress can be made in standardizing manufacture and construction of adobe blocks and of other materials and construction elements.

With respect to the application of the codes, it should be kept in mind that few municipalities have the staffs of professional experts required to monitor construction to assure compliance with the established regulations and to interpret the code requirements in the light of local conditions.

Requirements specifically applicable to local conditions may substantially increase the effectiveness of building codes. For example, in addition to the general code requirements that adequate bracing be provided to insure structural integrity, specific requirements for structures of the type shown in Figure 3.5 may be added to local codes of regions where such structures are frequently built. These requirements would refer in sufficient detail to the horizontal bracing of the roofs needed to achieve satisfactory aseismic behavior. Detailed requirements applicable to structural types widely used locally would greatly enhance the ability of properly-trained local officials with modest formal education to enforce the codes.

7.5 Building Codes in the Philippines

Regulations governing building construction exist in the Greater Manila area and in a few other urban centers such as Baguio, Cagayan de Oro, Cebu, Bacolod, Iloilo and Davao City. Enforcement of these codes is reported to be generally satisfactory. Most areas and particularly rural areas do not have such regulations at this time. A bill is pending in Congress ("An Act to Ordain and Institute a National Building Code of the Philippines"), the purpose of which is to meet the need for a nationally applicable set of building regulations [2]. The proposed code, prepared by a committee of technical experts and assisted by United Nations consultants, would provide for normal structural safety and, within the limits of the state of the art, for safety under fire, earthquake or typhoon action. A Joint Building and Environmental Planning Research and Standards Commission would be entrusted with enforcing the code, but the City or District Engineer would be charged with implementing the code at the local level.

Code improvements which would contribute to solving some of the problems of providing safe and inexpensive typhoon-resistant housing on a massive scale include:

(a) more strict provisions governing structural elements most frequently associated with typhoon-caused damage. Such elements include anchorages of roof trusses, purlins and roofing materials, and are described in Chapter 4.

(b) greater flexibility in the introduction and use of appropriate innovative designs, especially those related to prefabricated structures.

(c) wind-loading provisions based on climatological studies using modern methods of wind speed records analysis and on full-scale aerodynamic studies.

7.6 Building Codes in Turkey

The Turkish Association for Bridge and Structural Engineering is an unofficial professional organization established to supply technical assistance for Turkish engineers working in the fields of bridge and structural engineering. One of the main tasks of the association has been to publish recommendations for construction and design. Such recommendations have proven of great assistance to Turkish engineers until the early 1960's, when they were superseded by the comprehensive specifications published by the Ministry of Public Works, and construction and materials standards were prepared by the Turkish Standards Institution.

A building code now specifies requirements for construction and design in various seismic zones in Turkey. The code is limited to structures other than dams, bridges, minarets, mosques, stacks, transmission towers, etc, for which special design criteria are determined by the government ministry concerned with the structure in question. The code contains provisions regarding earthquake-resistant construction, and gives specifications for five different types of construction: reinforced concrete, masonry, semi-masonry, wood-frame, and adobe [3].

(a) Reinforced Concrete Building Structures. Specific requirements are given for the aseismic design of structural elements of reinforced concrete buildings, such as foundations, foundation connections, columns, beams, slabs, and walls. Recommendations on the design of a structure considered as a whole are also made. The code also indicates the dependence of earthquake loads upon the building stiffness.

(b) Masonry. The maximum number of stories (excluding basement) that masonry buildings can have is three in seismic Zone I, and four in Zones II and III (zones are shown in Figure 5.1). Regulations for foundations and footings are given according to the seismic zones. Minimum wall thicknesses are also given according to seismic zones, number of stories and type of material. Three types of material are specified for walls; these are stone or concrete, brick and solid concrete brick.

(c) Semi-masonry. These structures can have a maximum of two stories, excluding the basement. Foundation design is the same as for masonry. Minimum thicknesses are specified as a function of the number of stories and of the material used.

(d) Wood Frames. The code requires that wooden frame structures have a maximum of two stories excluding the basement and that each story have a maximum height of three meters. Foundations are to be designed using the regulations for masonry structures.

(e) Adobe. For foundation and basement, uncut stones (moloz tasi) may be used. It is required that bearing walls be made of clay soil. Organic soil cannot be used for walls. In seismic Zone I, the building may not have a flat earth roof.

The control of construction of buildings in the cities and towns is governed by the Municipal Construction Offices. The architectural design and construction project of each private building are examined in accordance with the master city plan and also with the current building codes. If the projects are found to be adequate, a construction license is issued by the Municipal Construction Office. During the construction period and after the completion of the building, municipal engineers check the building for compliance with the approved projects. If the building is found to be adequate, a license for occupancy is issued.

The above mentioned system for controlling construction does not appear to always work efficiently in practice because of shortcomings existing in the current Municipal Regulation. For this reason, a more strict Municipal Regulation for controlling private construction is being prepared by the Government.

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Chapter 8. Social Factors Which Influence the Advancement of Housing Technology

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8.1 Introduction

Socio-Economic Studies. Innovative technologies capable of responding to the need for low-cost earthquake and storm-resistant housing can be successful only if compatible with local social and economic conditions. So that existing and future constraints or barriers to the successful implementation of this project could be determined, socio-economic studies were undertaken by consulting organizations in Peru, the Philippines, and Turkey [2, 3, 4].

The objective of this chapter is to discuss the social factors which affect decision making on housing projects. The following items will be discussed: social framework for low-cost housing, user requirements, and acceptance of innovative designs and of new materials. The analysis of user requirements for basic housing in Peru is based on References [2], [12], [14] and on observations made on a field trip by the writer.

8.2 Social Framework in Low-Cost Housing

8.2.1 Population Growth and Family Planning

It has become increasingly difficult to raise housing standards and to maintain even the present quality of life in the face of the world's population growth, especially in the developing countries.

The high rates of population growth being experienced by most developing countries result from their traditional high birth rates and declining mortality rates. Improved health services and medical technology will cause mortality to decline further, which will require fertility rates to be reduced from present levels simply to avoid further increases in population growth rates.

The three countries included in this study: the Philippines, Turkey and Peru have experienced a process of rapid demographic growth during the last two decades. In the Philippines, growth of the national population is expected to average at around 3.0% annually, with the urban population increasing at a higher rate of 3.7% compared to the rural populace's 2.6% rate of increase. Despite the present efforts of the Philippine government to promote family planning, household size has increased from 5.7 in 1969 to 6.0 in 1970 and is expected to further increase to around 6.2 by 1980 [4].

In Turkey the death rate decreased since 1940 from 27.2% to 12.6%. At the same time the birth rate increased from 37.1% to 44.0%. To slow down the rate of increase, a population policy based on family planning was put into effect in 1965 [3]. In Peru the yearly demographic growth until 1970 was 3.12%, the birth rate being 4.2% and the death rate 1.1% [2].

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* This study was made while Mrs. Cronberg was a Guest Worker in the Center for Building Technology, National Bureau of Standards, (1972-1973).

8.2.2 Urban Growth

From 1920 to 1960 the urban population of the developing world grew by 255 million, i.e., from 73 to 328 million. The projected increase in the urban population of the developing countries in the 40 years from 1960 to 2000 is over one billion, more than four times the increase in the previous 40 years and about three times the total urban population of the developed countries in 1960 [1].

In the Philippines the annual population increase is 3.7% in urban areas and 2.6% in rural areas. The primary contributory factor to the high growth-rate of the urban population is the net in-migration flows to those regions with large metropolitan centers such as the Southern Tagalog region, specifically the Greater Manila area, and the two Mindanao regions [4].

In Peru the growth in urban areas has been 4.3% compared to 1.93% in rural areas. Migration is directed mainly from the rural areas in the Sierra towards the coastal region, especially towards Metropolitan Lima [2].

Of all the problems of urbanization, that of providing shelter for the expanding city populations and of improving housing conditions of a majority of existing inhabitants appears in many respects the most difficult. In the developed countries, the basic issues concern primarily social and institutional rigidities rather than a basic lack of national resources. In the developing countries, national resources including skills are generally grossly inadequate for investment of the magnitudes required while maintaining economically-productive investment. Progress in solving the housing problem in the cities of the developing world has been, with few exceptions, conspicuously slow. The housing situation is deteriorating progressively each year.

8.2.3 Slums and Squatter Settlements

Squatter settlements and slums are typically the fastest-growing areas of cities and already frequently cover one-quarter, sometimes over a half of the city area. They can be constructed quickly and in a variety of forms to meet rapid population growth, providing accommodation at rents, if any, that can be afforded. The squatters are themselves providing a housing solution and community development, rudimentary but effective. In their expansion, they are shaping the fundamental structure and character of the urban areas.

Rather than attempt their demolition, attention should therefore be directed to improving squatter settlements and slums. Self-help and community action are typical of squatter settlements. More permanent structures and facilities are constructed as the settlement becomes more established. High morale of the inhabitants is evident in most squatter settlements. This provides hope for dealing more effectively with the housing problem than has been possible so far.

Also provision should be made for such settlements on a more organized basis. It is suggested that new development areas with minimum services be provided for self-help housing. In the site and services concept, for example, in the World Bank's pilot scheme in Dakar, Africa, attention is centered on provision of the barest housing infrastructure and the stimulation of self-help measures in actual construction work.

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8.2.4 The Role of Social Workers

The role of social workers is central in preventing any program from being too mechanical and losing sight of the human dimension.

The social worker should enter into the community long before any program or project is undertaken. Many future projects can be successful if there is someone who really feels the pulse of the community.

The social worker should be trained and prepared in the best professional manner, with an in-depth knowledge of the project envisioned for the community.

The social worker must, at the same time, have access to those doing technical planning, conveying to them the real sentiments and aspirations of the community. Subsequent collaboration depends greatly upon this communication.

In the Philippines, the Department of Social Welfare has decentralized and expanded in social services by setting up eight regional offices. These offices are authorized to make all necessary decisions to suit national programs to local needs. Evicted squatters are given special attention with financial and material aid, counselling services, training in vocational skills, self-help projects and relocation to designated sites for rehabilitation.

8.3 User Requirements on Basic Housing

8.3.1 Outline of Requirements

Access to decent housing and community services is defined in the U.N. Declaration of Human Rights as a basic right for all. However, in spite of the recognition of the role played by housing in man's development, the world housing situation is claimed to be worsening during the Second U.N. Development Decade. Words like "crisis" and "critical state" have been used on occasion to describe the situation.

User needs and their relations to elements in the physical environment are complex and not well understood even in the most developed countries. The methodological problems encountered when identifying individual user needs and relating these to user requirements on the physical environment are often considered to account for this situation. However, a systematic analysis of the user and his requirements on the basis of information and methods available today will increase our knowledge of the user's preferences and contribute to the elimination of some of the main causes for the deterioration of human settlements.

8.3.1.1 Sources of Information

To study the user requirements in developing countries, in geographic areas where the need for earthquake and storm resistant housing is most urgent, several problems arise:

- When housing, built by traditional methods and using conventional building materials, does not exhibit the necessary characteristics of earthquake and storm resistant housing, new designs and non-traditional building materials will most likely be recommended. No past experience data on the user acceptance and reaction to these designs and materials will thus be available.

- Earthquake- and storm-resistant housing is sometimes provided in an emergency situation. No time will be available for extensive studies on local user requirements.

- The techniques usually employed for gathering data on user requirements, surveys of users or observations in the existing building environment will have to be modified due to the occupant's limited experience of various built environments, his illiteracy and unfamiliarity with strangers and the interviewer/observer's lack of understanding of the user's way of life.

Because of these anomalies three main sources of information are recommended when gathering data on user requirements in these areas:

1. Statistical sources of information. Information is usually provided in each country concerning: birth rate, age of marriage, size of families, average income, type of employment, average family income, expenditure on housing, etc.

2. Interviews with local builders, architects or construction workers. These persons are probably the best source of information concerning the user's way of life, and preferences in relation to the built environment.

3. Observations of existing built environment.

8.3.1.2 Type of Information Needed

Independently of the sources used, certain types of data should be provided in order to enable conclusions on user requirements and their consequences for design and choice of technical solutions. The information needed is divided into two categories and discussed below [8].

- user characteristics

- user activities

<u>User Characteristics</u>

<u>Physiological</u> characteristics of the user, of interest for design, are:

- Physical development: size and proportions

- Motor development: the ability to move and manipulate features in the environment.

- Sensory development: sight, hearing, smell, taste and tactile sensitivity.

<u>Psychological</u> characteristics such as the occupant's attitude, values, his intellectual and emotional development determine his identification with the community and the dwelling, his desire to maintain or modify his physical environment and his acceptance of available technical solutions and materials.

Socio-economic characteristics of the user include family size and structure, mobility, group identification (ethnic, religious, geographic), as well as educational background and past and present employment and income level.

User Activities

The design of a house may stimulate certain activities or make them easier whereas others will be excluded. Knowledge of activities is not only important when studying the spatial attributes of the physical environment but also for the requirements of safety and comfort as well as the need for privacy and social interaction.

8.3.2 Case Study; User Requirements for Basic Housing in Peru

User requirements, outlined in general terms in the above section, will in here be related to the specific information available on Peru, one of the earthquake-prone areas to be dealt with in this report. Since the information available is not related to any specific housing project and/or any specific occupants, no detailed list of user requirements can be provided. The considerations presented will thus only provide a broader framework for the formulation of the individual user requirements within a specific design process.

8.3.2.1 User Characteristics in Peru

The following general user characteristics for the whole population are abstracted [2]

- ethnic origin:	46% indians, 43% mestizos, 11% caucasians
- language:	Spanish, for the mountain indians Quenchua or Aymara
- religion:	Roman Catholic
- age distribution:	45% under 15 years, 32% over 64 years, life expectancy 59 years
- education:	55% of adult population illiterate
- rural/urban communities:	53% of population lives in communities of less than 1000 (68% of the above in communities of less than 50), migration from rural to urban areas, from mountains to coastal area (especially to metropolitan Lima)
- size of family:	average about 5 persons (mostly 4-7)
- economic situation:	yearly GNP growth 4.7%. 53% of all families are estimated to have a minimum monthly income of S/4000* of which 16-22% is spent on housing.

* 1 U.S. \$ ≈ 43.4 Soles (S/) in 1972.

- occupation/ employment: mainly agriculture, cattle breeding in the Sierra (only 73% of total agricultural labor force is estimated to be employed)

According to an estimate, about 300,000 persons or about to 25% of the population in Lima in 1969 were living in the "pueblos jovenes" or young towns - urban communities, where the great majority have built their dwellings without having title to the land or access to community services [14]. In 1968 the Junta Nacional de la Vivienda published a survey on the occupations of the family heads in such communities with the following results: 49% workers and artesans, 15% merchants, 12% office and service employees, 18% other occupations [14]. Thirty percent of the potential labor force was estimated to be unemployed. No statistics are provided on the income level, which is likely to be considerably lower than the national average.

- physiological characteristics: No detailed data provided. Only 4.2% of the dwellings in the young towns have potable water connections in the dwelling and only 6.7% have sewage [12].

- psychological characteristics: One of the main factors which creates a successful low income housing project is the user's acceptance of the project and the technical solutions provided. A positive reaction will lead to pride and identification with the community and to participation in local activities aimed at the improvement of the physical environment. Through the participation of residents of several young towns, roads and schools have been built and the original straw houses there have been replaced by brick constructions.

Several factors contribute to identification:

- Satisfaction with location: availability and proximity of employment being one of the main determinants. This question must be dealt with individually in each housing project.

- Ownership and control: Title to land and the dwelling.* Autonomous housing projects built and later improved by the occupant/owner are more advantageous than identical projects where the occupant has no influence on the location, design, financing and construction and where the control of the settlement is maintained by investment interests even after occupancy.

- Acceptance of technical solutions and materials. The residents of the young towns have a strong interest in building a house of "noble material" - in Lima of brick and cement ("adobe is shunned as a weak material, perhaps because it is less prestigious than brick") [14]. This factor will be dealt with in more detail in another section of this chapter.

A psychological factor of importance when considering the earthquake and storm resistance of housing is the attitude which the people exhibit towards these catastrophies. When they are viewed with concern, the occupants will be more motivated to spend more on housing of this type and to take precautions, than when the attitude is one of indifference.

-Socio-economic characteristics: The overall growth of GNP gives only a very inadequate measure of these changes in the low-income group.

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* (Information on land ownership not provided)

Even within the latter group the pace of social change will vary greatly and should therefore be individually studied within each housing project. Factors determining the socio-economic characteristics of the occupants in a housing project are: employment opportunities, participation in community activities, social interaction and the psychological factors mentioned above. Social interaction is supposed to be very limited for newly-arrived immigrant families without relatives in the city. Neighborhood kinship is developed only after several years. In the squatter settlements the relationships are also impeded by cultural differences between the "criollo" - usually a coastal mestizo speaking Spanish and the "serrano" - an indian from the Sierra speaking Quenchua or Aymaro. Class lines between these groups are maintained in the settlement until the "serrano" becomes a "criollo", for which he usually needs 3-4 years. Differences between these groups have been discussed by Patch [13].

In order to study the economic requirements of the users, more detailed information on the income distribution and trends should be provided.

8.3.2.2 User Activities in Peru

Information of user characteristics should be supplemented with information on user activities in order to get a comprehensive picture of the user requirements to be satisfied by housing.

In the information sources used, very little data is provided on user activities. Some conclusions may, however, be drawn on the basis of the information provided on existing housing conditions in Peru. The available data is summarized below:

- 68% of the units have one or two rooms; 85% of the households living in these units have more than four members;

- 16% of the households in the country are estimated to have both potable water and sewage service in the units, 70% are estimated to lack potable water and 50% are estimated to lack sewage facilities;

- 38% of the households have electricity, 45% use kerosene for lighting (remaining 17% use various other means for lighting;)

- 75% of the houses have floors of stamped earth, 54% have adobe walls and 53% have flammable roofs.

Corresponding figures for the residents of the young towns are [14]:

42% have potable water service in the home;

- only 6.7% of these households have sewage facilities, 11.8% use irrigation ditches and 81.5% have no service at all;

- 7.6% have electrical lighting, 23% partial electrical service and 68.7% lack all forms of electrical service.

No data is available on the size of the houses or the number of family members but the percentage of households living in overcrowded conditions in these communities is no doubt higher than the overall percentage for the whole country. Because of this, most of the basic activities of the household must be either staggered in time or performed partly outside the house. Because of this, the question of semiprivate open space - where, depending on the climate, laundry, drying, receiving visitors, recreational activities and in some cases even cooking can take place - should be considered together with the space inside the house (possibility of tradeoffs).

When listing activities which the design should support and which are to be performed in the dwelling, attention should be paid to the family size and structure, the activities of a one-person household being essentially different from those of a family of five. In Peru special attention should be given to the fact that over 47% of the population is under 15 years of age, indicating that activities such as recreation and play, learning and education, child care and supervision should be provided for accordingly.

Below, some basic activities are discussed in relation to the following attributes: health & safety, comfort, functional characteristics and acceptability. The solutions to these problems in existing housing are presented where relevant information is available. The list is by no means exhaustive, its objective being to clarify the proposed way of identifying user requirements. The discussion is confined to the low income group of users, whose characteristics have been considered above.

Activity Attribute	Design Parameters	Present Solutions
<u>Sleeping</u>		
Health and Safety:	- intrusion (people/ animals)	- urban: iron gratings in windows
Comfort:	- ventilation	- rural/coast: provided through holes in the structure
		- rural/sierra: minimum ventilation to avoid heat loss; windows and other openings often blocked by adobe blocks
		- urban: windows
	- heating	- coast: not needed
		- sierra: small space (1 room), insulation by use of adobe, blocking of openings, additional heat provided by all family members sleeping in the same room, and cooking inside in the evening
Functional Characteristics	- space and spatial arrangements	- average space provided 5-7m^2/person, majority of homes have 1-2 rooms
		- coast: usually two rooms, one of which is used for sleeping

		- sierra: usually only one room, providing space for all inside activities including sleeping
Acceptability:	- privacy	- family members sleep in one room, no privacy provided
<u>Food Preparation</u>		
Health and Safety	- fire	- open fire or kerosene stove used. Since roofs are of flammable materials, fire protection is probably provided through caution and experience (learning)
	- storage of food	- see storage
	- disposal of wastes	- see personal sanitation
Comfort:	- ventilation	- when cooking inside see above
	- lighting	- coast: windows, holes
		- sierra: only limited daylight, windows blocked to avoid heat losses, kerosene lamps
Functional Characteristics:	- space	- coast: cooking often done on a patio or semi-private courtyard
		- sierra: indoors, in the only room provided, (heating)
	- equipment	- kerosene stove or open fire
<u>Storage</u>		
Health and Safety:	- fire safety: storage of fuel (kerosene, wood)	
	- security: storage of personal belongings	

	- contamination: storage of garbage	- when no garbage collection is provided (rural/ some urban areas) this is either burned or dumped outside (road nearby field)
Functional Characteristics	- storage space and location: food (human/ animal)	- depends on size of family, the access to stores/markets and whether the family produces its own food (agriculture/cattle), in the latter case storage space is necessary for the whole season.
	water	- when no connection in the home, water is provided by public storage tanks or trucks, and stored in 50 gallon tanks outside the house
	fuel	- see health and safety
	personal belongings	
	sleeping equipment (during daytime to allow for space for other activities)	
	utilities for work (artisans, farmers)	
<u>Personal Sanitation</u>		
Health and Safety	- access to water	- washing of body/clothes usually takes place rural: on a river or irrigation ditch, drying of clothes on the ground urban: semiprivate courtyard
	- access to sewage/disposal of body waste	- since majority of the low income housing lacks any kind of sewage facilities, open air latrines in backyards, nearby vacant lots (urban) or fields (rural) are used to excrete.

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Acceptability:	- need for privacy	- Most activities performed without provision for privacy
<u>Work</u>		
Functional Characteristics:	- need for space when work done at home or in close vicinity (artisans, shopkeepers, etc.)	
	- storage of utilities (farmers, etc.)	
Acceptability:	- location of house in relation to employment opportunities for the family members	- urban: only 21% of the employed work in the vicinity of their residences [12]
	- possibility for childcare and supervision while away at work	- small children are known to be locked inside the home when parents are working
<u>Recreation/Play</u>		
Functional Characteristics:	- access to space	- most activities performed in the streets, football fields provided in few areas
Acceptability:	- possibility to creative and joint activities for parents and children	- urban: robberies, thefts because of lack of organized activities and amount of time spent away from home by the parents - rural: participation together with parents in work (guarding cattle)
<u>Receiving of Guests, Social Interaction</u>		
Functional Characteristics:	- access to space	- because of the lack of private space, streets, shops and markets function as places of social contact
	- access to TV, radio, etc.	- the homes of families with TV are meeting points of the neighborhood

Acceptability:	- access of social interaction related to ethnic groups, religion, etc.	- criollo/serrano
<u>Identification/ Participation</u>		
	- design parameters affected should be established	
<u>Learning</u>		
Acceptability:	- location in relation to schools	- urban: most "young towns" have elementary schools, no childcare centers are provided by community - urban: exposure to different physical and social environments is limited, children exposed to delinquency in several of the "young towns"
<u>Orientation</u>		
Functional Characteristics	- location/ orientation of home	
	- roads, alleys	
	- special characteristics: monuments, squares etc.	
	- inside of home: view of the outside world	- in the sierra openings blocked by adobe for better insulation

8.3.3 Summary and Recommendations

<u>Summary</u>

It is generally recognized that the provision of a physical shelter is not a sufficient goal for housing. Its acceptability from the point of view of the user; to allow for his personal development and fulfillment of social needs, is considered to be at least equally important. To achieve this latter goal two main constraints are set on the designer:

- inadequate knowledge of user requirements

- costs

Analysis of user requirements is discussed from two aspects:

- how to find the necessary information
- which type of information one should look for

The methods used to generate this information based on surveys and observations have been developed in the industrialized countries and may not be feasible in the geographic areas to be studied. Therefore, other sources of information are suggested, including statistical data in the country in question, interviews and discussions with local people involved in the building trade, and observations of existing built environments.

It is evident that no single solution exists to fulfill the social needs of various low-income groups in different geographic areas. At all times, therefore, housing should be looked upon as a process corresponding to the user's social and economic situation. The process will be defined both by the level of social development as well as by the trends of development, thus enabling us to better understand why similar physical environments in certain conditions decay and others upgrade. By studying the user's characteristics - physiological, psychological and socio-economic - and his activities, which housing is to support, the parameters of this process can be established. The combined information on user characteristics and user activities will implicitly state the user requirements to be considered in each design process.

To demonstrate the approach proposed for the identification of user requirements, examples are discussed both for basic housing in general and for basic housing in Peru.

Recommendations

1. In order to avoid future deterioration or abandonment of the physical environment to be provided, identification of user requirements for individual housing projects is essential.

2. This should be done in cooperation with local experts familiar with the existing conditions and the user's way of life, combined with actual observations of existing built environments.

3. The information provided should include data both on the user's physiological, psychological and socio-economic characteristics and on the user's activities (all family members) for which the home is to provide a framework.

4. In order to establish priorities for the satisfaction of user requirements, more information is generally needed on

- health standards in existing physical environments (urgency for community services)
- need for personal space and privacy (in the generally overcrowded housing conditions)
- contact patterns for social interaction within the neighborhood and community
- activities of specific user groups such as children and the effect of the provided physical environment on them.

5. Because of its vital importance for the development trends for the physical environment more basic knowledge should be provided

on the factors affecting the user's identification with his community and dwelling and his interest in participating in community activities.

8.4 Acceptance of Innovative Designs and of New Materials

The Philippines (4)

The economic advantages of standardized designs have resulted in their relatively-widespread acceptance by most low- and middle-income homeowners, especially when, as is often the case, small individual modifications in the housing units are possible during occupancy.

Most practicing architects and engineers readily accept new construction materials which exhibit desirable technical properties and are economically advantageous.

Peru (2)

The introduction of new construction materials in Peru has always resulted in an initial period of strong rejection, and there are very few products which have survived this reaction and maintained a place in the market.

In 1957 an attempt was made to introduce the product "Durisol," manufactured under a Swiss patent, which consists of mineralized vegetable fibers encased in cement and used for the manufacture of hollow blocks for walls, thick panels for partitions, and thin panels for facings. These products had been widely accepted in Switzerland and Germany. A "Durisol" operation was set up in 1959 with a capital of S/20 million (about $1.25 million) but had to close down at the end of 1960 after losing its capital.

In 1965 a factory was built for the production of products of expanded (or cellular) gypsum, under the "Belroc" patent. The principal product consisted of 2.40 x 1.20 x 0.10 meter panels for building partitions. The product had good structural characteristics and was easy to handle and install; however, the manufacturer was never able to expand the initial market, and the demand lessened gradually until production was stopped recently.

Innovative construction materials produced in Peru include reconstituted wood, asbestos-cement products, glass-fiber plastics and fiber-cement sheets.

"Mapresa" or reconstituted wood, is made of shavings or fragments of soft wood mixed with synthetic resins and then pressed. It is offered on the market as sheets of various thicknesses (0.6 cm to 5 cm) and in sections of 1.2m x 2.4m and 1.2m x 3m. This product enjoys broad use in furniture manufacture, generally in veneered or duco-painted pieces, but its application to the construction of houses has been limited to temporary camps. As a construction material it possesses the disadvantage of absorbing moisture.

"Maderita" is a product similar to the above, based on sawdust. Its use in construction of housing is even more limited than that of Mapresa, as it is very fragile and brittle.

Corrugated sheets of plastic (PVC) and glass fiber for roofs, which had considerable initial acceptance, are losing their market because of high price and poor mechanical properties.

Sanitary fixtures of glass fiber, such as bathtubs and basins, were relatively expensive and have not had any better acceptance. Their production recently ceased. However, the manufacture of plastic tubing for water supply and sewerage (rigid PVC) has had success and its market continues to grow.

Fiber-cement is a product extensively used in industrial construction. It consists of wood (shavings) or cane fiber held together by cement. It is made in sheets 1.2 cm to 5 cm in thickness, 0.50 m wide and 1.00 to 2.00 m long. Its mechanical and physical properties are poor, however.

The introduction of "sandwich" panels based on wood has not had much success in Peru, even in building construction, because masonry walls and partitions are preferred despite their dead weight. Because brick and concrete are more economical to use and adobe and quincha dwellings are cheaper to construct, the above mentioned products have had little success in the field of housing construction.

The only construction materials which have had broad acceptance are "calamina" (corrugated sheets of galvanized steel) and corrugated sheeting of asbestos-cement. Although calamina is widely used both on the coast and in the sierra, its physical properties, especially those of thermal and acoustic insulation, are very poor. Nevertheless, due to its relative light weight per sheet and resistance to fracture, it can be easily and inexpensively transported, even on the backs of beasts of burden, and this makes it much prized in the Sierra region.

Corrugated sheets of asbestos-cement have better thermal and acoustic properties than calamina. Due to their fragility, they are mainly used on the coast as there is a high percentage of breakage during transport on second-class or inferior roads and in handling. The high number of sheets lost by breakage during transport and delivery in the sierra (which can reach 30% of the cargo) makes it an expensive product. Asbestos-cement is also used in the manufacture of flat sheets, tubing for water and sewerage, posts for electric wires, and other preformed products, such as water tanks.

After the May 31, 1971 earthquake, emergency shelters consisting of sprayed polyurethane domes, or igloos, developed by Farbenfabriken Bayer, Leverkusen, Federal Republic of Germany, have been provided in Caraz (see Figure 8.1). The igloos were soon abandoned by their occupants, for the following reasons:

1. The lack of corner areas became a source of family strife as, in the opinion of the inhabitants, one could never put anything "out of the way."

2. The interior acoustics were such that the sound of two or more people speaking simultaneously proved unnerving.

3. The lack of conventionally defined property lines made it impossible to fence in animals raised for consumption.

It is noted that igloos provided by the German Red Cross near Gediz, Turkey, after the March 28, 1970 earthquake were also abandoned.

In a Peruvian survey done in 1962 by students of the Architecture Department of the National University of Engineering with the purpose of finding out the attitude of the public toward prefabricated housing, the following conclusions were reached:

Figure 8.1 Polyurethane "igloo" homes at Caraz, Peru, built by the German firm Bayer, A. G. These homes failed to gain acceptance on the part of their users, who abandoned them after being adversely affected by
1) the lack of corner areas in the homes
2) the poor interior acoustics
3) the lack of private plots.

1. The lack of consumer interest in this type of housing is due to the following reasons:

   a. Prefabricated houses represent only a small margin of economy compared to brick and concrete houses.

   b. Prefabricated houses are more expensive than adobe and quincha dwellings.

   c. Prefabricated houses built enmasse have the disadvantage of being of uniform architecture.

   d. The public did not truly appreciate the savings caused by the shorter construction time required for this type of housing.

2. The lack of interest of builders in this type of housing is due to the following reasons:

   a. The market was very restricted, and this resulted in high sales costs.

   b. Because of limited acceptance of prefabricated housing, there was no system of financing prefabricated housing projects in Lima.

   c. Prefabricated housing projects in the provinces outside the area of Lima turned out to have very high construction costs because of the difficulty and high cost of freight transportation.

Housing constructed by so-called conventional procedures has greater acceptance than any new procedures that have been proposed, and at present most approved projects involve conventional construction types.

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Chapter 9. Economic Factors Which Influence the Advancement of Housing Technology

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9.1 Introduction

The economic conditions and policies in developing countries have direct bearing upon theri capactiy for undertaking large-scale safe low-cost earthquake and windstorm resistant housing construction. In developing countries, relatively small amounts of capital combined with properly-utilized large supplies of unskilled low-cost labor may result in significant increases of both output and employment. Given the considerable weight of the construction sector in the national economy, particularly in the case of developing countries, such increases in turn produce important beneficial effects on the development of the economy as a whole.

The housing construction sector is directly affected by such economic factors as labor rates and productivity, availability and cost of construction materials, land prices and credit mechanisms. Additional information and details on the economic aspects of housing construction in Peru, the Philippines and Turkey may be found in References [1], [2] and [3] of Chapter 7. The reader is also referred to Section 7.2 of this report for a brief discussion of the possible contribution of credit-granting institutions to improved building code enforcement.

9.2 Housing Programs in Developing Countries

The Inter-American Development Bank (IDB) [1] distinguishes two basic approaches to the housing problem in Latin American countries.

The first approach envisages the problem as one of insufficient quantities of standard modern housing units, coupled with inadequate financial resources to remedy the situation. In the second approach, housing is not evaluated on an arbitrary standard which may be unrelated to the social, cultural and economic levels of the residents, but on the basis of how well it facilitates access to areas where family activities occur daily, how adequately it provides protection from a hostile environment, and to what degree it assures security of tenure. In other words, "traditionalists" are more aware of the appearance of the housing, whereas "environmentalists" are concerned with the way in which the housing accommodates the residents in relation to their life situations.

The traditional approach which is frequently used for planning housing programs has been criticized for the following reasons. First, housing deficits are calculated arbitrarily without taking into consideration the values or preferences of the persons to be housed. Secondly, some calculations of housing deficits show the traditional solution to be well beyond current capital investment rates. In the case of Latin America, for example, the traditionally conceived housing deficit in 1967 was estimated to be about 22 million units, projected to be at least 100 million by the year 2000. It was estimated that it would be necessary to build more than 3 million units per annum in order to eliminate the deficit over the period to that time. If each unit of land cost only $US 1,800, the annual investment in housing would be $US 5.4 billion, or 6.6 percent of the regional gross domestic product of Latin America at 1967 levels.

Even in developing countries in which the expected rates of growth are relatively high, the competing demands of development programs in agriculture and industry leave funds available for housing construction in amounts far inferior to actual needs. It is therefore necessary that self-help be encouraged for the partial fulfillment of these needs. For example, in Peru the Organismo Nacional de Desarrollo de los Pueblos Jovenes has the responsibility of studying, planning, proposing, and co-ordinating programs to intensify efforts at incorporating slum-dwellers into the development process. More than 20 percent of the urban population (over 1.3 million) live in squatter settlements; some 78 percent are entirely without services, 10 percent have only electricity, and just 12 percent enjoy water and sewage facilities. Under such conditions, "site-and-services" type schemes warrant emphasis. Several laws were passed in 1968-69 for the purpose of facilitating improvement of these conditions; the progress achieved has been so far relatively slow. In Turkey, where the urban and rural housing requirements for the period 1968-1972 have been estimated at 900,000 and 300,000 respectively, the second five-year national development plan aims specifically at encouraging self-help for squatter house dwellers, by providing roads, basic and other services, and allocating plots and making long-term loans in order that houses be built by their future dwellers themselves.

For the period 1960-1980, it is estimated that 5,790,000 additional new houses will be needed in the Philippines, plus another 3,640,000 owing to replacement, obsolescence, disuse, disrepair, and natural disasters. This would call for twelve new dwellings per 1,000 population, requiring about 5.7 percent of the gross national product. Whereas in 1965 only 1.5 percent of the gross national product was invested in housing, 2.8 percent was invested in 1967. In either case, the small investment did not create conditions benefiting the low-income groups. As a result, slum and squatter conditions accelerated; and 10 percent of the total population of Manila and 30 percent of the population of Jolo City, Luzan, Visayas and Mindanao currently live in slums.

In the Philippines, self-help (known as "Bayanikan") is used extensively for the construction of dwellings and buildings.

The magnitude of the task of providing low-cost housing has led to government involvement in the housing construction sector in a large number of developing nations, including Peru, Turkey, the Philippines, and Iran.

9.3 Economic Factors Affecting Housing Construction

9.3.1 Land Use

Land use is regulated by building codes, by legislation on zoning, pollution, and public purchase of land, and by taxation of land and property. Proper planning for land use should include zoning for industry and housing, consolidation and acquisition of land for specific other purposes such as parks and recreation, and regulatory laws to prevent land speculation. Ineffective land use regulation and inadequate policies of public acquisition of land present a serious obstacle to rational urban development.

To the extent that provision of subsidized housing is not feasible, "site-and-services" type schemes (wherein land and utilities are provided for self-help housing) may offer an interim solution.

9.3.2 Availability and Cost of Labor and Construction Materials.

Peru. Salaries paid in civil construction in Peru are fixed by the government. Generally, salary changes are a consequence of long-standing demands by labor unions and are retroactive, at times up to 6 months, so they may cause difficulties in the construction industry. Average salaries in 1970 were approximately S/90-S/125* daily, depending on skill. Foremen and specialized operators generally are not available outside the Lima area so that it is necessary to import managers and skilled labor from Lima for major projects in the provinces. On projects in isolated areas, which have their own construction camps, personnel are given food and lodging at an estimated cost of S/50.00 daily per person. In cases involving minor projects, without such camps, an additional amount of approximately S/180.00 is paid per person per day for food and lodging.

By official decree the Ministry of Labor has fixed minimum output standards for labor in civil construction for the area of Metropolitan Lima. These standards, which are a measure of the productivity of labor at the present time, are summarized in Table 2, Section 13 of the Peruvian socio-economic study. In practice, to obtain a higher output it is necessary to offer some program of economic incentives. Even if these do not decrease construction costs, they often reduce the time needed for the completion of the project. Minimum output standards have not been established for areas outside Metropolitan Lima, but as a general rule productivity is about 10 percent less.

Construction materials are generally available. In particular, adobe is abundant and inexpensive. Adobe construction upgraded using stabilization techniques and adequate aseismic designs (see Chapters 2 and 10) should therefore be extensively used.

Turkey. The salaries of craftsmen vary considerably according to specialities (from 40 TL* to nearly 100 TL daily). Plasterers have the lowest salaries, masons earn slightly more, but less than carpenters, and those in mechanical trades get the highest salaries. No statistical data regarding the differences in salaries between rural areas and cities and between regions are available.

For unskilled workers who constitute 70 percent of the manpower employed in the construction sector, the labor law of 1969 had fixed the minimum gross salaries between 15.50 TL. and 19.50 TL daily. Unskilled workers in the construction sector are paid at most 20 TL. per day, based on minimum rates in Eastern Anatolia (East of the Samsun-Gaziantep line), whereas salaries in the Western region are slightly higher and may reach 30 TL. per day in July and August.

Construction materials are generally available with adobe being the most abundant and least expensive.

The Philippines. Average daily wage rates in the Greater Manila area in 1971 ranged from 9.34 Pesos* for common laborers to 17.50 Pesos for foremen.

Construction materials in the Philippines as well as skilled labor needed for conventional methods of construction are readily available. Delivered prices of materials are reasonable because production is dispersed throughout the country. The potential for cost reduction exists notably

* 1 U.S. $ ≈ 43.4 Soles (S/) in 1972.

* 1 U.S. $ ≈ 14.30 Turkish Lira (T.L.) in 1972.

* 1 U.S. $ ≈ 6.80 Pesos in 1972.

in the area of bulk handling and of delivery. Prefabricated construction components are relatively expensive because the current size of Philippine markets is not large enough to achieve economies of scale, and because transportation and distribution costs are high.

The chemical process industry for plastic products is small, protected by high tariffs and generally produces simple types of household construction materials.

Under the recent Investment Incentives Programs, the 1970's will witness the development of larger and more complex chemical process plants and of an integrated petro-chemical complex base. Judging from experiences of countries which do possess such a base now, it is doubtful that the capability to produce plastic materials will have a strong impact on the construction industry until the 1990's.

9.3.3 Credit Mechanisms for Housing

In order to illustrate conditions and procedures for granting dwelling credits, a description of credit mechanisms for housing in Turkey, where most dwelling credits are provided by the Social Insurance Institution and by the Real Estate and Credit Bank, is presented below.

The Social Insurance Institution. The Social Insurance Institution is a large governmental organization that provides medical and social care for workers and helps them to finance cost of construction of homes. The conditions and the procedures of dwelling credits may be summarized as follows:

(a) The insured individuals who want dwelling credits must form a cooperative.

(b) To be entitled to a dwelling credit, the insured, his wife or husband or children should possess no dwelling and have received no credit from the Institution.

(c) The insured or his relatives should not be members of any cooperatives formed for similar purposes.

(d) The insured should have paid a certain minimum amount in premiums to the Institution.

(e) The dwellings to be built should meet minimum social dwelling standards.

(f) No credit is provided for dwellings outside the municipal areas of cities or towns, or in settlements with a population less than 10,000. However, the Institution may approve exceptions after conducting a survey.

(g) No credit is given for dwellings with a gross area larger than 100 square meters.

(h) The maximum amount of dwelling credit is TL. 60,000, regardless of the income of the insured.

(i) The term of credit is 20 years and the rate of interest is 4%. The term starts from the date that a housing permit is given.

(j) The payment is done according to a payment plan, based on equal monthly payments.

(k) The dwellings may not be sold to another person for a 10-year period.

The credits provided by the Institution in the years 1969 and 1970 were as follows:

Year	No. of Dwelling Units	Value (TL.)
1969	1,449	45,527,129.00
1970	1,649	55,000,495.00

<u>The Real Estate and Credit Bank.</u> The Real Estate and Credit Bank, which is connected to the Ministry of Reconstruction and Resettlement, is the main bank that provides credit for dwellings. The requirements and procedures are as follows:

(a) The bank opens a "Dwelling Saving Blocked Account" upon the request of the individual.

(b) This money is not subject to interest or to any kind of lottery for encouraging savings.

(c) The quality of the dwelling should conform to the specified regulations.

(d) The person, his wife or husband or children should not possess a dwelling and should have received no loans from the bank.

(e) The nominal value of the saving account, called the contract amount, may be between 10,000 TL. and 50,000 TL. Included is 25% of the total amount that was deposited by the individual.

(f) The contract amount can be increased or decreased, provided that it remains between the upper and lower limits, and the approval of the bank is obtained.

(g) No money can be drawn from this account. Only under obligatory conditions the bank may approve a partial payment. In this case, the priority points of the person are reduced accordingly.

(h) The individual may cancel the contract at any time with a written application.

(i) The individuals who can preserve the account in the bank for at least two years, who deposit 25% of the contract amount in cash, are deemed as qualified to receive dwelling credit.

(j) These rights can be transferred to children, father, mother, wife or husband, provided that the bank approves. A second transfer is not accepted.

(k) The term is 15 years and the annual interest is 6%. The interest rate may be, however, subject to change if new rates are stipulated by the State.

(l) The money can only be used within the boundaries of the municipalities and the urban reconstruction areas.

The impact of the Real Estate and Credit Bank program is relatively small to date. The numbers of credits provided under this scheme in the years 1969, 1970, 1971 are respectively 632, 492, 757.

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Chapter 10. Feasible Technical Improvements

William F. Reps
National Bureau of Standards

10.1 Introduction

The preceding chapters have defined, in broad terms, the various factors to be considered in determining the feasibility of improving the dwelling environment. In this chapter, a discussion will be presented of some technical improvements that are feasible in the context of the social, economic and technical constraints typical of developing countries. The improvements discussed offer substantial advantages in so far as the achievement of inexpensive construction better resistant to earthquakes and windstorms is concerned.

The potential of oil stabilization for the manufacture of the basic building block component is discussed in the next section. Polymer and other chemical stabilization procedures appear worthy of further investigation, particularly in those countries where there is an abundance of lateritic soil.

Bamboo-reinforced concrete is presently in the development stage and appears to offer promise as a material to be used in secondary members of which the bamboo would appreciably increase the resistance in tension and flexure.

The structural sandwich panel as an innovative building system merits serious consideration for application in developing countries where labor-intensive production and local materials are used to create new methods of building technology appropriate to the region.

A technical development which can greatly contribute to the production of inexpensive earthquake and windstorm resistant dwellings is the development of building systems utilizing modular components in various schemes. The provision in the future of complete prefabricated mechanical cores would further contribute to reducing costs and construction time. Mechanical cores have in certain schemes the additional advantage of eliminating the need for various non-architectural openings in the structure, thereby improving its ability to withstand earthquakes and windstorms.

10.2 Stabilized-Soil Building Blocks

Among the numerous and varied methods of soil stabilization currently in use, the following methods appear to offer the highest potential for innovation and improved performance in low cost housing.

10.2.1 Oil-Stabilized Adobe Blocks

As a result of mixing certain types of asphalts--which contain a curing agent--with water and a clayey soil, the surface of the clay particles is covered by an oil film which remains after the water and curing agent evaporate. The oil film repels moisture thus eliminating the expansive characteristic of the clayey soil.

Adobe blocks or bricks stabilized with rapid-curing road-oil, or emulsified asphalt, exhibit desirable characteristics of good insulation, impermeability, erosion resistance, vermin and termite resistance and durability. The blocks or bricks are relatively maintenance-free and need not be plastered or painted which significantly reduces construction time and labor costs.

The manufacture of modular stabilized adobe block or brick would lend itself to the design and construction of low-cost, earthquake-resistant buildings or building systems, utilizing labor-intensive techniques.

Generally speaking, sun-dried adobe block or bricks are less expensive than common fired-clay bricks or concrete blocks. The cost of manufacturing the adobe block or brick varies with the method of manufacture, the characteristics of the soil, and the cost of delivery if the block or bricks are not made in the immediate vicinity of the construction site. The price of adobe block manufactured by hand in Cuzco, Peru was about .05¢ per block in 1971 at the plant site.

10.2.2 Polymer-Stabilized Adobe Blocks

Chemical soil stabilization techniques for unstable excavations or lining of deep cavities are also well known and frequently utilized. Polymer stabilization techniques were suggested as a result of preliminary experiments and research into the potential uses of plastic resins in low-cost housing schemes. An applied research project should determine the feasibility of using polymer chemicals and soil mixed with various organic fillers such as bagasse, rice hulls, and jute, or mineral fillers such as vermiculite and expanded shale for the production of inexpensive building materials.

10.2.3 Lateritic Stabilization

An example of a recent breakthrough in technology is the production of blocks or bricks from lateritic soils. Laterite is the common reddish soil that can be found in large land areas of the earth's surface, particularly in tropical and subtropical areas of South America, Africa, South-East Asia and India. Laterite is the residual product of rock decay with a high content of iron oxides. Lateritic soil is usually considered unsuitable for production of building blocks such as burnt brick or tile because it generally lacks sufficient silicates and also has an excess of aluminates. However, the use of a chemical additive can alter the characteristic reaction of a mixture of lateritic soil and water to produce a sun-cured brick or block that should compare favorably with a baked product [3]. The lateritic soil block is handmade in the same manner as the classic adobe block, using a wooden mold and rudimentary mixing techniques. The manufacturing process can be adapted for labor intensive production.

10.3 Bamboo-Reinforced Concrete

Results of recent studies of the feasibility of using bamboo as reinforcement for temporary reinforced concrete structures indicate that bamboo reinforcement can develop from two to four times the ultimate flexural load-carrying capacity of unreinforced members of equal dimensions. The study is based on results obtained from small cane and is believed to be conservative when other species of bamboo are used. The principal problems associated with bamboo reinforcement are swelling and shrinking due to moisture changes and low bond strength. Pre-soaking split bamboo for 72 hours and applications of surface coatings are effective in mitigating these problems [4].

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10.4 Composite Systems

10.4.1 Structural Sandwich Panels

10.4.1.1 Characteristics and Uses of Structural Sandwich Panels

One of the most efficient structural systems is the structural sandwich. Basically a structural sandwich has a relatively thick, low strength core bonded to thin, relatively high strength facings. The structural sandwich system when used as a flexural member in a roof system would consist of three components; the upper, exterior facing, a core material, and the lower, interior facing.

The exterior facing material must have reliable compressive properties and must either be water resistant or be waterproofed by an applied coating.

The interior facing material must have reliable tensile properties and be fire resistant. An alternative to the fire resistance requirement for the facing would be application of an auxilary fire resistant layer to protect the interior facing.

The core material must have reliable shear properties and should be of relatively low unit weight, and should provide the required thermal insulation.

The bonding medium used in sandwiches must have sufficient strength and durability against moisture and under temperature extremes of the exterior environment, and resistance against insect attack.

The strength required in this bond depends on the sandwich design, on the materials used and on the loads expected in service. For example, the tensile strength of the bond between the core and the interior facing must be sufficient to support the dead weight of the facing. In addition, the shear strength of the bond must be sufficient to transfer all shear stresses to the facings without excessive creep. The magnitude of the shear stresses is a function of the thickness and span length of the panels as well as the intensity of applied loads.

Roof systems for structures utilizing low flexural strength wall constructions should be of relatively low mass in earthquake zones. To achieve low mass in the roof there are but two alternatives: 1) either use small amounts of high-strength materials, or 2) use lower-strength materials in a highly efficient manner. High strength materials are usually relatively expensive and their use is often not possible in many areas. As a result the only method available in many developing areas for construction of a suitable roof system is to use locally available materials as efficiently as possible. Structural sandwich panels, which are both light and structurally effective, are therefore suitable for use in roof systems.

Structural sandwich panels may also be successfully used for interior and exterior walls.

10.4.1.2 Performance of Structural Sandwich Panels

Tests recently conducted on an experimental unit constructed in 1947 by the U.S. Department of Agriculture -Forest Service, Forest Products Laboratory, Madison, Wisconsin, using structural sandwich panels showed that their performance was quite satisfactory.

The sandwich panels in the experimental unit were constructed of paper honeycomb cores with plywood or other wood-base facings, and other materials. The paper honeycomb cores were produced by assembling sheets of Kraft paper weighing about 22 kilograms (45 pounds) per ream, impregnated with phenolic resin. The plywood facings were treated with phenolic resin. The walls, floor and roof of the experimental unit was constructed of sandwich panels. The Forest Products Laboratory of the U.S. Forest Service issued the following summary of observations in publishing the results of the tests carried out in Wisconsin, U.S.A.:

> "Performance of sandwich panels in the experimental unit over 21 years indicates that panels of nominal thickness and construction can be satisfactorily used for housing construction. Minimum stiffness and strength requirements are easily achieved, and most constructions retain their stiffness and strength properties even after long-time service. Adhesive bonding techniques proved to be adequate with good bonds even after as much as 21 years of service. No moisture problems at the bond were observed. Synthetic resins in the honeycomb material also afford a degree of moisture resistance that insures adequate strength and stability even if the material is immersed. Plywood-faced panels have demonstrated excellent performance during 21 years of service. They had a minimum of movement due to temperature and moisture changes, and retained stiffness and strength. Mechanical fasteners used in assembling a house might govern the thickness of facings. In some cases, thinner prefinished plywood with a non-marring plastic surface might be used for the interior facing.
>
> Although plywood was relatively stable, the other wood-base facings were more affected by moisture and temperature changes. In normal construction, much of the bowing would be eliminated by fastenings; however, restricting the panel edges might result in cross bowing or cupping. Therefore, facings that are highly sensitive to temperature and moisture changes are undesirable. . .
>
> Minimum insulation requirements for many areas of the United States are satisfied by the corrugated core. . . The panels with styrofoam core or urethane foamed into expanded core both have insulating properties comparable to conventional wood-frame house construction with two inches (5 cm) of blanket insulation. The long-term durability test with panels exposed for periods as long as 21 years has shown the feasibility of using this type of construction in housing. The requirements for satisfactory sandwich panels are selection of proper combinations of facings, core, and adhesives; careful fabrication techniques; and good quality control."

10.4.1.3 Materials Used in Structural Sandwich Panels

One commonly used core material is paper honeycomb which is made from a phenolic-resin-impregnated kraft paper. The phenolic-resin impregnation stiffens the paper, increases the wet strength, and provides fungus resistance. Paper honeycomb is manufactured in both a hexagonal configuration and a corrugated configuration similar to that in cardboard used in making paper cartons.

Sheet metals are often used as facing material, but other materials that are available in large flat shapes such as plywood, hardboard, gypsum board, plastic laminates, cement-asbestos board are also used.

In evaluating the possible materials for use in the roof system, paper honeycomb as the core material is considered feasible in most countries, particularly in systems designed to utilize modular prefabricated building components. Alternative core materials would be a low-density pressed-fiber board or even bundled reeds, although the density would not be as low as paper honeycomb. Most countries have corrugated paper plants in which corrugated honeycomb could be made. These products would have to be impregnated with either phenolic resin, an inexpensive polymer product that may be produced locally, or some other material which would provide the required properties.

A possible facing material is gypsum plaster which would have to be reinforced for the interior facing because of its poor tensile strength. The use of emulsified asphalt and other additives in the exterior facing should be studied in connection with the effect of weathering on the mechanical properties of the facing material. Also needed are tests on the durability of the panel materials in highly humid climates.

The use of locally available core material such as bundled reeds and split bamboo has also been considered. Polyurethane-foam sandwich panels using bamboo cane reinforcement have been experimentally tested at Washington University in St. Louis, Missouri. Also being evaluated is an application of polyurethane foam on a woven-thatch wall panel. The results of the experiments indicate that one may anticipate difficulties in the production and control of the polymer and thus the finished panel. The high comparative cost of the basic resin appears prohibitive at this time.

10.5 Prefabricated Housing

Technical improvements which may contribute substantially to the capability of producing inexpensive dwellings better resistant to natural disasters include the use of prefabricated systems compatible with local conditions and lending themselves to large scale industrial production [5].

Among innovations that may be introduced is the pre-assembled utility core package, housing appropriate mechanical, electrical and sanitary systems. These units may contain the kitchen, the toilet or bathroom area and the utility complex. All wiring, plumbing, heating and cooling lines and ducts are pre-assembled, and may include a heating unit, plumbing fixtures, lights, storage units, and sinks. They eliminate from the building site the most difficult and costly portion of the entire construction process. Typically, one may erect the utility core on the building site, usually over a foundation or sub-core with the remaining units or components of the house then built around it. The core may be stacked like a sectional box, with all connections between sections of the core made in the field. Solar energy may be used in mechanical cores for the heating of water and possibly for other purposes (water treatment, heating and cooling)[6].

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Chapter 11. Mechanisms for Stimulating Technical Improvements

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11.1 Introduction

The development, adoption and implementation of improved earthquake- and windstorm-resistant housing technologies in developing countries can be effectively stimulated by appropriate action in the areas of financing, design, construction and education. Financing institutions can contribute to improving such technologies by requiring that the projects they finance be designed and built in accordance with building code requirements (see Chapter 7). Cooperative programs involving specialized agencies provide the opportunity for interaction between workers and experts at all levels, during which communication and transfer of technology can be effectively achieved. In addition to developing new or improved building materials and systems, research institutes such as exist in Indonesia [1] can be active in transferring existing technology through building information centers serving professionals as well as laymen who build their own houses. The centers can provide information on proper selection of materials, and technical guidance and advice on building know-how. Production units serving as models or pilot plants can contribute to the diffusion of advanced technological methods. Prototype buildings can be built for the purpose of acquainting the public with innovative systems designed to provide better resistance to earthquakes and windstorms.

In order to illustrate various ways in which such interaction can occur, the programs and goals of several agencies involved in housing development programs are briefly described in the following.

11.2 The Inter-American Bank

The Inter-American Development Bank (IDB) has played a significant role in the last ten years with regard to urban development activities by financing two types of projects: 1) basic infrastructure and 2) construction of housing (not including land). The bank is now interested in integrated or total community development wherein all appropriate infrastructure is provided, including surface access and potential transportation networks.

As of December 30, 1970, the IDB had twelve on-going projects in Latin America. These projects range from infrastructure to integrated community development.

The IDB offers technical services along with financing of projects. Transfer of technology is achieved mainly in the process of providing these services.

11.3 The World Bank

The World Bank does not contemplate direct lending for house construction at this time. It considers, however, lending for seed capital to develop housing finance institutions. The emphasis here is on the leverage effect in prompting savings and developing capital markets in a form which will lead to amelioration of the overall housing and employment situation. Particular attention will be paid to the income groups for which housing is proposed, the mobilization of small savings and the possibilities for supporting improvements to substandard housing.

In line with these considerations, the urban project program in this field is concentrated on "site and services" and similar projects to provide urbanized land on which the occupants can build their own dwellings using self-help methods. One project is already being appraised in Senegal and several others are envisaged. The first project is illustrative. The land provided by the Government will be equipped with roads, water, sewage and power facilities. Most water and sewage facilities will be provided on a community basis. Education and health facilities are included in the project as well as sites for industrial, commercial, recreational and other developments. Exclusive of the social facilities and power grid, charges to occupants are expected to cover costs which will be only a small fraction of those of minimal housing schemes in the city. A new institutional organization will be built up with technical assistance to form the basis of a national program on similar lines. The emphasis on use of local labor and employment will result in a somewhat higher proportion of local costs than has been customary in bank lending.

11.4 United Nations

11.4.1 U.N. Center for Housing, Building and Planning

The United Nations Center for Housing, Building and Planning (UNCHBP) is performing most valuable work in devising housing programs compatible with technical and financial resources, and on the social organization of sites and services schemes. The World Bank is assisting the UNCHBP in instituting regular inter-agency exchanges of information on activities with a view to sharing information and completing necessary studies by the most appropriate agency, avoiding duplication of effort, and reducing the burden on developing country administrations resulting from numerous uncoordinated missions. An area of Latin America has been selected for trial exchange of information. In the field of water supply and sewage, a joint program has been established with the World Health Organization, and in education with UNESCO.

11.4.2 U.N. Industrial Development Organization (UNIDO)

A UNIDO sponsored Expert Working Group Meeting on the "Use of Plastics in the Building Industry" was held at UNIDO headquarters, Vienna, Austria, September 20-24, 1971. The meeting covered the following areas of interest: building systems using plastics, plastics deterioration in building in tropical areas, prefabrication trends with plastics in buildings, user requirements and performance specifications, and research and development needs. The basic thrust of the meeting was focused on developing mass produced low-cost housing schemes for the developing countries in Africa and the Middle East.

The information and practical experiences exchanged during the conference indicated a significant potential for plastics in low-cost housing schemes. As a result of this meeting, experts are currently participating in a practical development program of a plastic dwelling for emergency use in Bangladesh. Also under way is an applied research effort to investigate the potential of urea-formaldehyde (U-F) foam for insulation in a lightweight roof sandwich panel composed of a cardboard honeycomb core, U-F foam, and an outer skin of gypsum reinforced with a jute fabric. Ultraviolet ray protection is provided by a surface coating of a special water soluble plastic paint.

As a result of the discussions, the technical experts group formulated certain recommendations for action that might be initiated by developing countries and by UNIDO in cooperation with developed countries with a view to encourage development, introduction and promotion of the use of plastics in the building industry. Significant recommendations are summarized below:

1) Keeping in view the varied climatic and socio-economic conditions in the developing countries, the development and introduction of plastics building products should be gradually and systematically organized.

2) It would be essential to educate architects, engineers and building contractors in the proper selection and use of plastics building components. This would necessitate organizing appropriate education/training programs.

3) Relevant performance specifications in respect of plastics building components should be formulated to facilitate their ready acceptance by the local building industry.

4) Assist the developing countries to encourage mass-production techniques for housing.

5) Take part in specific projects to encourage dissemination of information about plastics for building applications. This could include the provision of non-commercially oriented literature and specialist advisers and the provision of models and full-size samples of buildings put up with systems suitable for use in developing countries, to be displayed at seminars and building exhibitions.

6) Participate, as far as possible, in setting up industrialized housing systems to use present and potential local resources.

The following recommendations pertain to action by United Nations and other international organizations and agencies:

1) Provide inter-disciplinary teams of experts to developing countries to examine user requirements and relate this information to the possibility of local industrial production of housing using plastics with emphasis on present and potential local resources.

2) Initiate fellowship programs for experts from developing countries and organize, as early as possible, interregional seminars in developing countries on the use of plastics as building materials.

3) In order to expedite the organization of necessary meetings, consider the joint participation with outside professional organizations in provision of facilities and funds for such meetings.

4) Establish criteria for evaluating housing systems, which incorporate the use of plastics, make available this information at the request of developing countries and assist them in evaluating the cost, performance and adaptability of any proposed system to local climatic and socio-economic conditions.

In view of the capacity of properly designed building systems using plastics to withstand earthquakes or windstorms, the recommendations of the UNIDO meeting are of particular interest in the context of the present study and report.

11.4.3 U.N. Development Program

The U.N. Development Program (UNDP) is the world's largest program of multilateral technical assistance. Typical of the type of project that the UNDP has initiated in the past is the Experimental Housing Project in Peru which was to assist the Government of Peru in establishing a long-term housing policy through the planning, construction and initial management of an experimental housing project with particular emphasis on the needs of low-income sectors of the population. It consists of four pilot projects the first three of which are located in Lima. The fourth was added after the earthquake of May 31, 1970, to assist the Government in reconstruction and is located in the affected region in northern Peru. The Experimental Housing Project espoused methods and techniques which might be applied on a larger scale as part of Peru's housing policy.

The following is a brief outline of the project:

Pilot Project I (New Community)

The first pilot project is for the design and construction of a new community of approximately 1,500 low-cost houses complete with all community buildings. The design of the community is based upon the concept of high-density, low-rise houses with internal patios which can expand and adjust to accommodate the changing requirements of low-income families. Special emphasis is placed upon improved design, rationalized building methods and materials, dimensional standardization, and use of suitable building plant and equipment. In the first stage approximately 500 houses will be built. These consist of prototypes of thirteen Peruvian and thirteen foreign designs and also include community sub-center with kindergarten and school. The first stage has been carefully planned to compare and evaluate the various building methods, house types and groupings. The favorably evaluated house types will be repeated in larger numbers in the second stage which will complete the neighborhood with all facilities and appropriate infrastructure.

Pilot Project II (Housing Rehabilitation)

The second pilot project is to develop procedures and techniques to extend the functional life of existing sub-standard housing stock by rehabilitating older dwellings and urban areas to meet contemporary environmental standards. By applying these techniques on a larger scale in urban areas a substantial contribution to the reduction of housing deficits could be made at considerably less cost than through the alternative of new houses. In the selected location a comprehensive social and economic survey on all families and condition-of-structure survey on all houses has been carried out and this data forms the basis for the rehabilitation planning. The rehabilitation program provides for structural improvements and additions to sub-standard dwellings, new sanitary and electrical installations and general upgrading of groups of houses and their urban environment. In the rehabilitation of the individual dwelling, self-help methods will be widely employed for occupant families. A community-action program will aim at maintaining social homogeneity and obtaining maximum participation from the 300 families in the area of the project.

Pilot Project III (Sites and Services)

The third pilot project is for families whose low incomes are not sufficient to amortize a loan to purchase a contractor-built dwelling unit. Self-help building methods, which can reduce the cost of a house by 40%, will be fully employed. Families will be organized and trained for building their own houses with new construction methods using small building elements and improved traditional methods. Technical supervision will be provided to the families. A social plan runs parallel with the training, construction and management aspects of the project. The main work phases of the project are: a) defining socio-economic characteristics of the families, b) development of community plan, houses designs and building methods, c) community development and housing management.

Pilot Project IV (Earthquake Resistant Housing)

The fourth pilot project is for low-cost, earthquake-resistant and fast-to-erect permanent housing and includes the development of basic building materials industries. Two groups of dwellings are planned. One group of approximately 60 houses is to be located at Casma on the coast and one group of approximately 60 units at Catac in the Sierra.

Small workshops are located on each building site for the production of building components and the training of families in self-help building methods by technical experts. Manuals of practical building methods have been prepared as instruction aids and for widespread circulation in the region for use by self-help builders. Social workers are collaborating in the training of families and the organization of the groups of families for participation in the project. The project also includes technical assistance to small local industries to improve and expand the productivity of building materials and components.

A workshop has been constructed on the site of Pilot Project I, fully equipped with tools, machinery and plant provided by the United Nations, for the development and testing of building materials and methods to be employed in all four pilot projects.

The Project is directed by a project manager in cooperation with a national director appointed by the Government. A Coordinating Commission of representatives of national housing and planning agencies coordinates the Project with related development agencies of the Government. The planning and implementation of each pilot project is carried out by a separate development group consisting of Peruvian and United Nations personnel. An inter-development group and specialized personnel assist each pilot project as required in technical areas including engineering, productivity, costing and finance, training and housing management.

11.5 CARE, Incorporated

The Cooperative for American Relief Everywhere, Inc. is currently employed in a major relief operation in Bangladesh where, in addition to the many and diverse needs, housing has become critically essential. The CARE, Inc. organization contacted the National Bureau of Standards as a result of preliminary conversations with members of the Building Research Advisory Board of the National Academy of Sciences in Washington, D.C. CARE, Inc. requested an informal evaluation of a new composite building material made of pulp from the core of the jute plant, jute cloth and a plastic resin for binder and facing material. From this combination, other variations of plastic resin and jute materials have been formulated for laboratory testing, prototype construction and wind testing of a full scale unit. With properly designed details, dwelling units of the type developed by CARE, Inc. can successfully withstand extreme environmental loads.

11.6 National Institutions

The initial phase or information gathering stage on this project included the establishment of appropriate communication and exchange of information with a number of national institutions. The opportunity to develop potential areas of collaboration in the transfer and utilization of innovative technology was evident in each country visited during this phase of the project.

11.6.1 Peru

A program to develop improved methods for adobe construction was recently set up. The program will help fulfill one of the principal objectives of a current technical assistance project initiated by the U. S. Agency for International Development mission in Lima, Peru, in collaboration with the following national institutions: Ministerio de la Vivienda (Ministry of Housing); Banco de la Vivienda (Housing Bank); Universided Nactional De Ingenieria (National University of Engineering); the International Institute of Housing Technology of Fresno State College, California, and the National Bureau of Standards, Center for Building Technology. The specific objectives of the program are:

1. Production of a low-cost, high quality stabilized adobe block.
2. Development of adequate structural designs and building techniques for anti-seismic adobe construction.
3. Construction of a number of prototype houses and training and technical assistance to families on the new construction methods and promotion of these new methods.
4. After the technical and economic feasibility of constructing houses with stabilized adobe have been determined, large-scale projects would be developed and implemented throughout Peru, with different sources of finance.

11.6.2 Turkey

Meetings were held in 1971 between N.B.S. personnel visiting Istanbul and Ankara and representatives of the Istanbul Technical University, the Bosphorus University (Roberts College), the Middle East Technical University and the Ministry of Reconstruction and Resettlement (Earthquake Research Institute and General Directorate of Natural Disaster Affairs). In the course of these meetings the approach to the Turkish socio-economic study was discussed. The study provided an opportune mechanism to join together, for the first time, many of the leading engineers, architects, and scientists in Turkey for a common goal. The National Committee of Earthquake Engineering in Turkey was thus formed, headed by the Dean of Turkish Engineers, Professor Dr. Rifat Yarar. Also, a Board of Research Associates and Consultants were formed as contributory experts for the socio-economic study, under the guidance of the National Committee.

The Minister of Reconstruction and Resettlement, the Director of the Earthquake Research Institute and the General Director of Natural Disaster Affairs supported and contributed to the socio-economic study.

The National Committee of Earthquake Engineering in Turkey is planning future projects related to seismology, geology and innovative technology transfer. An Earthquake Engineering and Training Center is envisaged in conjunction with symposiums, seminars and other academic gatherings for purposes of teaching and information exchange.

The Ministry of Reconstruction, Department of Building Materials, Research and Testing Laboratories in Anakra has expressed interest in construction and testing of prototype dwelling units in their facilities. Interest was noted in applied research of low-cost housing constructed of honeycomb cardboard cores, gypsum and stabilized adobe.

The General Directorate of Natural Disaster Affairs expressed interest in a field mission to develop and teach improved methods and materials for adobe construction and other innovative techniques that might be appropriate.

11.6.3 The Philippines

The Philippine Weather Bureau has proposed a five-year integrated research project entitled "Typhoon Research" to the National Science Development Board. The objectives of the project are to: 1. Assess the prospects of artificial modification of typhoons; 2. Achieve a better understanding of the structure of typhoons, their development and motion, and improve their prediction; 3. Obtain adequate climatological and hydrological data for the Philippines to support economic development planning. The Typhoon Research Project may be managed by representatives of a number of National Institutions including but not limited to: The Department of Foreign Affairs, Office of the Executive Secretary, Department of Agriculture and Natural Resources, National Science Development Board, Weather Bureau and the Philippine Air Force.

Considerable interest was also expressed in an applied research program to develop the design criteria and methodology for wind-resistant, low-cost houses, and to construct one or more prototype units at selected weather observation stations, and to instrument and measure the prototype units under actual typhoon conditions. The National Science Development Board is considering allocating some funds for such a project if additional funding from other sources was made available. The Weather Bureau has stated its readiness to provide the sites for the prototypes. The University of the Philippines, Department of Engineering, is interested in technical collaboration to develop and test a prototype in the University's Building Research Institute-Civil Engineering Laboratory. The National Bureau of Standards has subsequently proposed to the Agency for International Development a research project along these lines, and the proposal has been accepted and funded.

11.6.4 Iran

Adobe brick was developed in Iran almost 5,000 years B.C. and as today, it was formed by hand using a primitive mold and a clay soil mixture. It is estimated that almost 80% of all houses in Iran are constructed with adobe brick, wood, straw and stone.

Under Iran's Third Development Plan (1963-1968) approximately 17,000 government-assisted housing units were built. About 200,000 units were built by the private sector, and private sector investment in urban construction projects is increasing at a rate of about 12% per year. The Fourth Development Plan (1968-1973) calls for a total of 275,000 new housing units, 25,000 of these governmentally assisted, not including industrially oriented housing development or rural housing.

Most of the government-assisted units will be replacements for slum housing, and efforts are being made to provide more living space per unit. Most of the new housing is built of brick walls approximately 40 centimeters thick. The average size of the brick is about 5 x 11 x 22 centimeters.

Earthquake damage is virtually continual in several areas of Iran. Many dwellings are destroyed by earthquakes and many people are killed by collapsing of roofs and walls.

The Ministry of Housing and Development in Tehran has completed a program of construction of prototype houses in an experimental village located in Narmak, a suburb of Tehran. The houses are each of a different design, with the majority constructed of adobe brick and adobe plaster. Several prototypes are scheduled for static testing.

The Ministry of Housing and Development expressed a strong interest in several areas of technical assistance, including an exchange of technical information, a training program for qualified engineers and an extensive field mission to develop and teach improved methods and materials for adobe construction.

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CONVERSION UNITS

Length

1 in = 0.0254* meter
1 ft = 0.3048* meter

Area

1 in^2 = 6.4516* x 10^{-4} $meter^2$
1 ft^2 = 0.09290 $meter^2$

Force

1 lb (lbf) = 4.448 newton
1 kip = 4448 newton

Pressure, Stress

1 psi = 6895 $newton/meter^2$
1 ksi = 6.895 x 10^6 $newton/meter^2$

Mass/Volume

1 lb/ft^3 (lbm/ft^3) = 16.02 $kilogram/meter^3$

Moment

1 kip-in = 113.0 newton-meter

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* Exactly

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

The extensive loss of life and property caused in developing countries by earthquakes and windstorms (hurricanes, typhoons and tropical cyclones) may be reduced to a considerable degree by the adoption and implementation of improved design, siting and construction procedures practicable within the context of the cultural and socio-economic constraints prevailing in these countries.

The report provides technical information regarding characteristics of materials and building systems, and discusses the structural performance of buildings subjected to the action of earthquakes and wind forces with specific reference to structures typical of developing countries. Potential ways are described in which structures can be made more resistant to such action. Siting considerations are discussed from a geological, seismic and climatological viewpoint, and recommendations relating to siting problems are made. Techniques of housing construction, both traditional and industrialized, are described and improvements resulting in better earthquake or windstorm resistance are suggested. Building codes, their improvement and their enforcement are also discussed.

The report discusses cultural and socio-economic constraints influencing the adoption of improved practices, describes various feasible technical improvements of construction materials, composite systems and building systems, identifies mechanisms for stimulating technical improvements and discusses the role of institutions in this regard. Throughout the report, specific references are made to Peru, the Philippines and Turkey, countries which suffer from frequent devastation from natural disasters such as earthquakes and typhoons and which were selected as case studies for the purpose of this report.

17. KEY WORDS (Alphabetical order, separated by semicolons)

Buildings; construction; design; developing countries; earthquakes; low-cost housing; natural disasters; structures; windstorms.

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