Inspection of Vocational Education Centers Built Under BEST II

SEPTEMBER 2000

Prepared by

Claudio D. Fortunato, P.E.
Fred Webster, PhD, P.E.

For

DEVTECH SYSTEMS, INC.

1629 K Street, NW, Suite 1000
Washington, DC 20006 USA
Tel: 202/296-8849
Fax: 202/296-4884
devtech@devtechsys.com

Contract No. 522-C-00-00-00243-00
USAID/Honduras

Inspection of Vocational Education Centers Built Under BEST II

Scope of Work

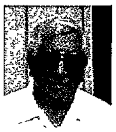
The Client requested that during the days of 06 to 16 September 2000, we inspect nine *Vocational Education Centers* (**VTCs**) built under a USAID/Tegucigalpa financed project known as *BEST II.*

People Met

Chronologically, we met with:

Ronald Saunders
DevTech Chief of Party – Tegucigalpa, Honduras

Rolando Chavarria
USAID/Honduras TCN, Engineer



Padre Guerrino Giacomel
Administrator of the San Giovanni Bosco VTC in Tegucigalpa

Noel Girón
Director of the VTC in San Marco de Colón

Mario Midence	*Superintendent of Construction in the VTC Stephen Youngberg in Peña Blanca*
Marcelino Montoya	*Director of the VTC in El Mochito*
Mario Mendoza	*Director of the VTC Ernesto Ponce in Guaymas*

Marcel Sanchez	*Director of the VTC Centro Tecnológico Prof. Nestor Danilo Amaya in Villanueva*
Miguel Barahona	*Director of the VTC* Mario Ugarte in Choloma Cortes
Esteban Romero	*Caretaker of VTC Hogares Manantial in San Pedro Sula*
Aristides Assencio	*Administrator for the VTC of Eusebio Castillo in La Entrada*
Diane Leach	*Education Officer USAID/Honduras HRD/ET*

Documents Examined

During this period we examined no documents

Activities and Observations

Wednesday, 06 September 2000

The two-legged Fortunato's flight from Orlando to Tegucigalpa suffered delays due to bad weather in both Miami, where the flight could not depart until 2 hours later than scheduled, and Honduras, where the captain decided that a storm and low laying clouds made it unsafe to land in Tegucigalpa. A second attempt, after having diverted the aircraft to San Pedro Sula for refueling and waiting out the storm over the capital city, proved successful. The alternative, the captain explained over the public address, would have been a return to the Miami airport and try again for Tegucigalpa the following day.

After checking in Hotel Princess, Chief of Party Saunders presented an overview of the upcoming activities thus:

Fortunato will inspect a concrete frame brick building in Tegucigalpa with the USAID Third Country National Engineer Chavarria and, with both Chavarria and Webster, travel with a vehicle provided by USAID to inspect

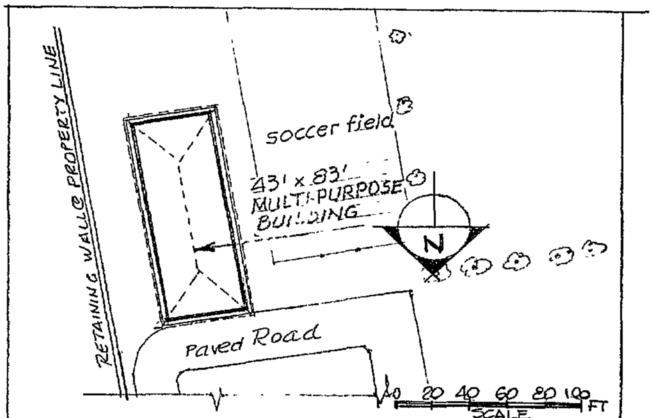
- A concrete frame adobe center in San Marco de Colón
- Two VTCs on the way to San Pedro Sula
- Four more VTCs near San Pedro Sula
- The last center on the way back to Tegucigalpa

- Report to USAID and
- Prepare a site visit report with pertinent recommendations

Since these VTCs were designed prior to the American Disability Act of 1998, none of them were conceived with nor do they provide proper access for and use by individuals who may be physically challenged.

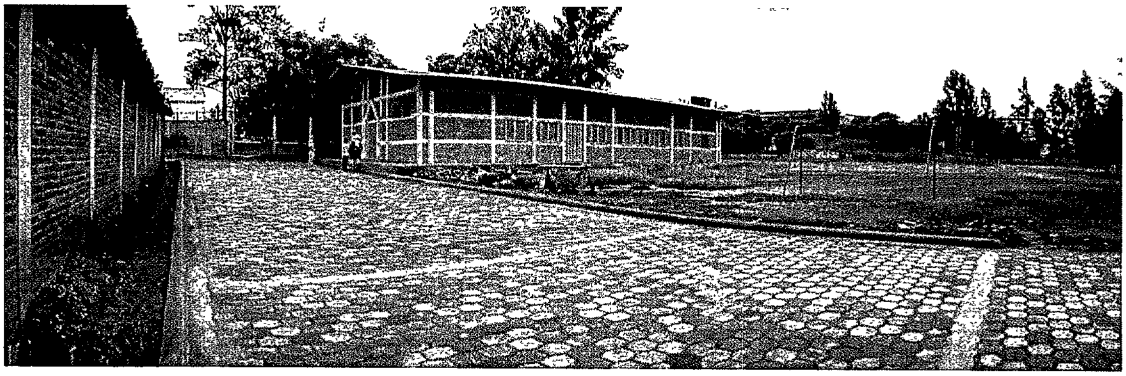
The Client has authorized additional time to complete this report including all pertinent recommendations after the consultants return to their respective home–offices in the United States. In fact, additional time will be required to coordinate and unify two reports independently written in Tegucigalpa.

Thursday, 07 September 2000



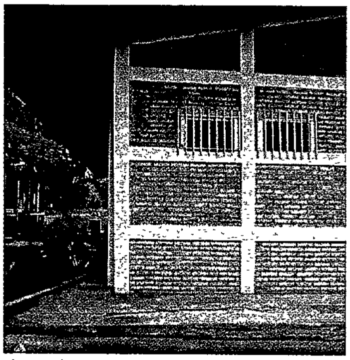
BEST II AT S.GIOVANNI BOSCO IN TEGUCIGALPA

During the mid-morning hours, Mr. Chavarria leads Fortunato to the VTC San Giovanni Bosco in **Tegucigalpa**. The center was built over the years with funds provided by several donors, Padre Giacomel explains. BEST II, on the other hand, provided funds to construct the latest addition: a multipurpose 3,600 square foot (**s.f**) concrete frame and brick building under a light weight steel roof system that cannot be inspected because it is hidden by a fixed suspended ceiling.



This structure lies next to a soccer field and is surrounded by a 6'-6" walkway elevated 6" to 18" above grade. The steel roof deck extends beyond the walkway's footprint providing shelter from torrential rains.

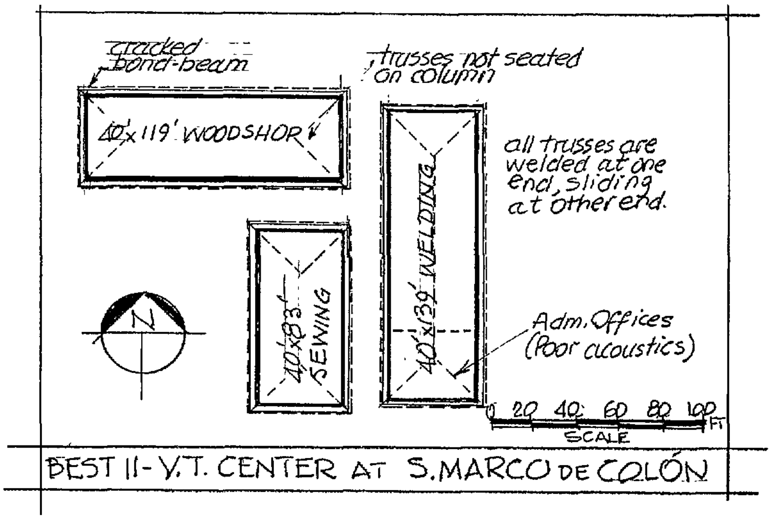
…The steel deck extends beyond a 2-meter wide walkway's footprint providing shelter from frequent torrential rains. This feature is typical for all buildings constructed under BEST II



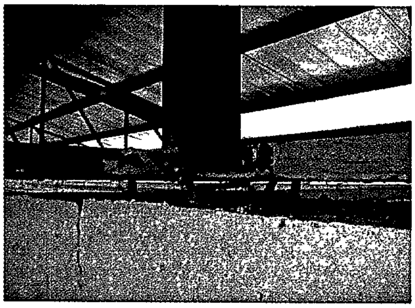
Except for cracks at the walkway, caused by poorly executed shallow control joints, and some *chipping away* (**spalling**) of plaster from the base of the NW corner column, the fairly new concrete frame and brick structure is in sound structural condition and needs no structural retrofitting.

Even the NE column that was erected out of plumb causes no serious structural concern being tied by the three ring beams placed all around the building.

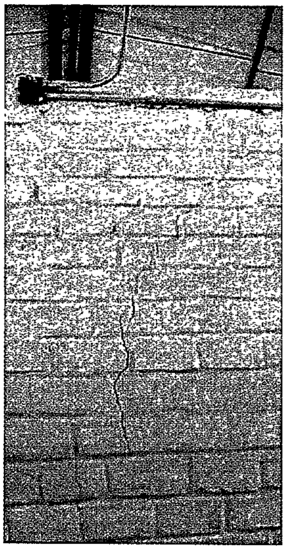
Friday, 08 September 2000

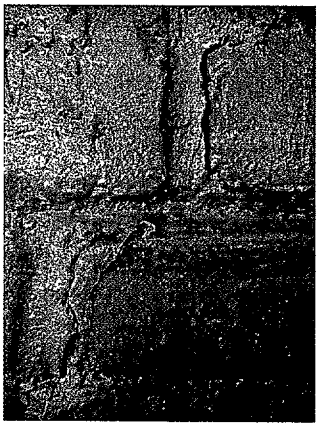


We spend most of the day traveling to and returning from **San Marcos de Colón**, well over 250 km SSE of Tegucigalpa, crossing populated and spectacular mountain ranges covered by plush vegetation. The rainy season has covered Honduras with beautiful shades of green.

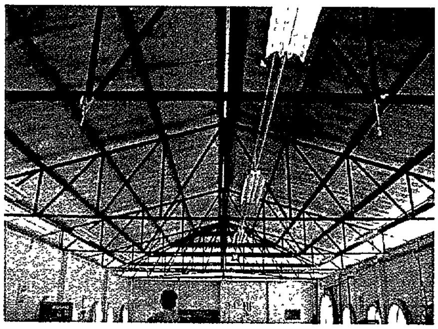


The three buildings that constitute the VTC in San Marcos are a 1,800s.f sewing training center (left foreground), a 5,600s.f administration section and welding training center (at right), and a 4,800s.f woodwork-training center (in the background). When asked what complaints he may have about the recently completed center (February, 2000), Director Girón said: "Bad acoustics, units at vaults over doors becoming loose, and numerous cracks, more or less severe, throughout the buildings."





We also observe several shrinkage cracks at floors for insufficient control or construction joints, badly executed bearing connections of trusses to top of columns, lack of continuity of an undersized bond beam (missing on some walls), and shrinkage cracks so severe that daylight is visible through some of them as they continue to grow...



The director informs that he observed adobe walls being erected rapidly as blocks were produced, indicating that the contractor used non-cured adobe to build walls that exhibited severe early shrinkage. This explains the randomly widespread cracks and the working loose of some vault units...

Despite the numerous more-or-less severe cracks, these non-bearing adobe walls would be safe only as long as no dynamic loads, such as those caused during an earthquake and/or hurricane winds, are excluded. They would certainly crumble, however, should any such calamity ever strike!

With some minor exceptions, what is true for the VTC in San Marco is applicable to the next seven VTCs inspected during this site visit...

The questionable connections of weak steel roof systems to the top of walls and the doubtful integrity of bond-beams, in addition to walls that are much too slender, add to the urgency for retrofitting all VTCs to avoid life-threatening catastrophes!

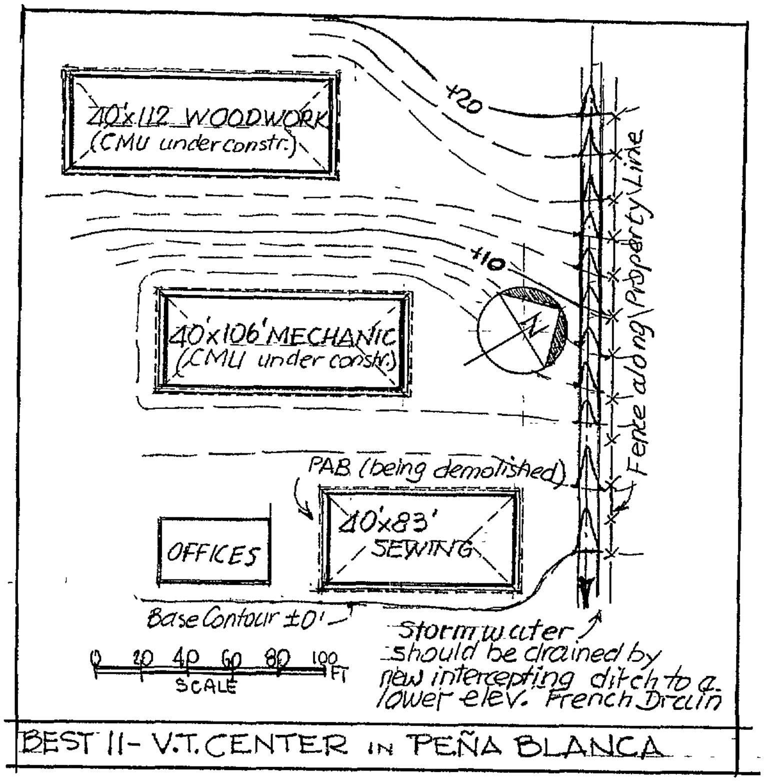
Saturday, 09 September 2000

No activities for this assignment.

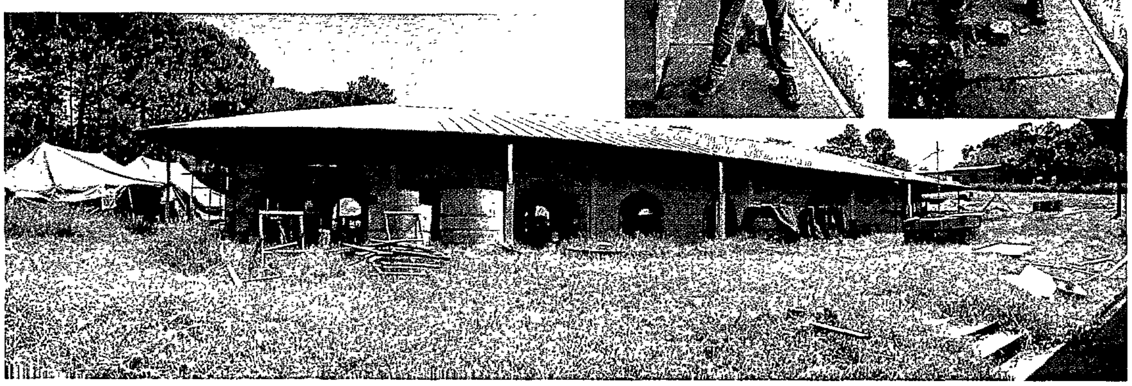
Sunday, 10 September 2000

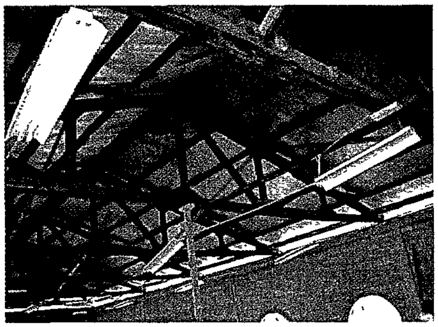
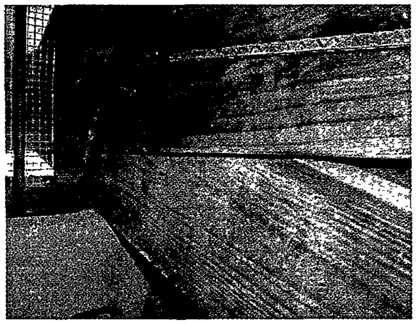
We spend a good part of the day writing this report and preparing for the oncoming trip to and from San Pedro Sula when we shall visit the remaining seven VTCs.

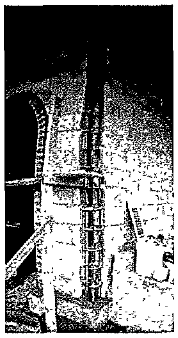
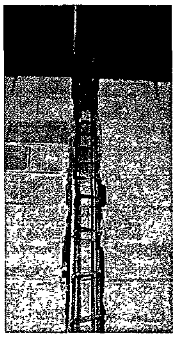
Monday, 11 September 2000



Along the northern route to San Pedro Sula, we stop to visit the VTCs in Pena Blanca and El Mochito. In **Peña Blanca**, the last of the three buildings of the Stephen Youngberg VTC, completed in 1997, is being demolished. We ask why and the work superintendent tells us that the adobe bearing walls were too soft and absorbed moisture and the administration feared a possible collapse. In fact, when subject to a drop test, two of the randomly selected units shattered. *(We would also learn from Ms. Leach that the structures developed cracks during an earthquake.)* The contractor has already demolished the other two buildings, which are being rebuilt with hallow concrete blocks.



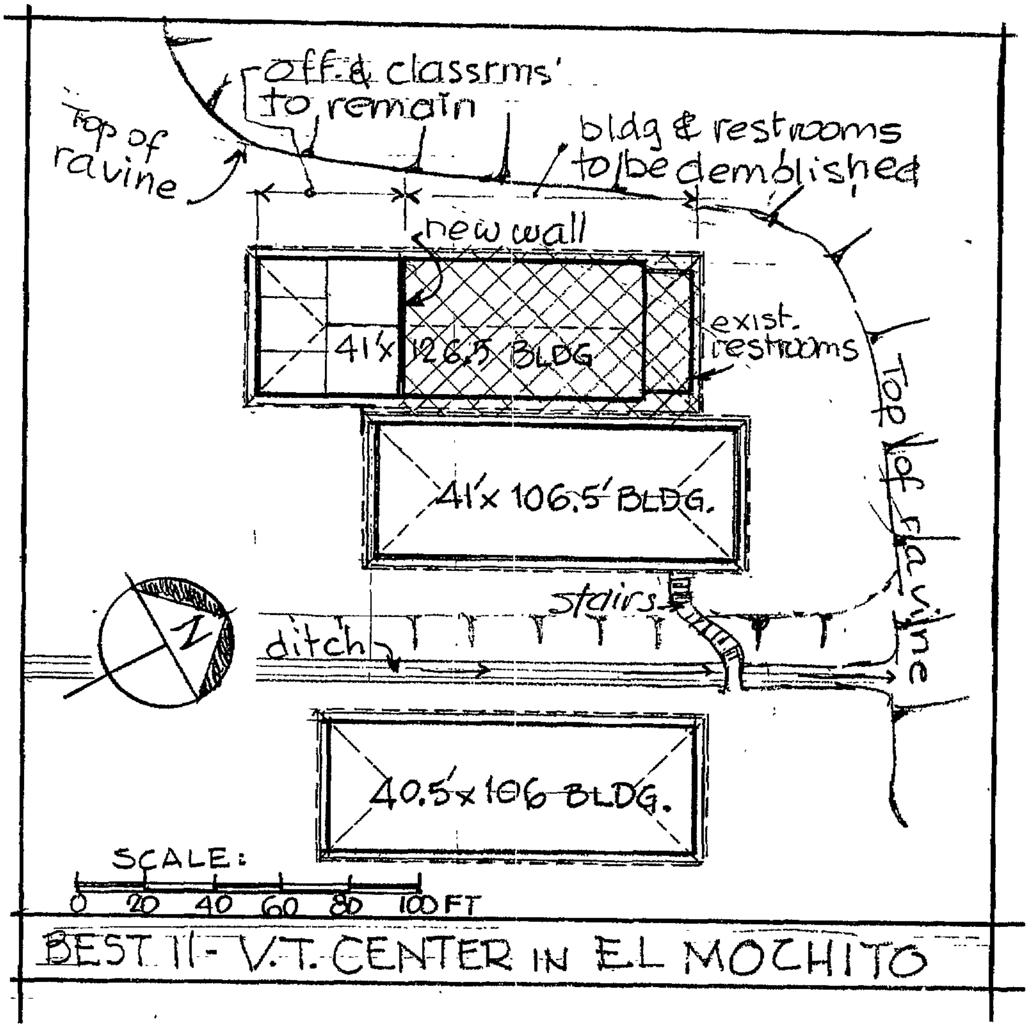



The reconstruction is not well conceived, however. The structural system of pouring columns after erecting the wall on either side, despite being widespread in developing countries because it saves formwork, has no known tested behavior whose resistance to vertical and overturning loads could be properly designed and analyzed for safety. Practical experience in building construction leads to believe that the 6" thick bearing walls and columns combination, standing about 12', is unsafe. The *Uniform Building Code* (**UBC**) recommends minimum thickness of a hollow concrete-block bearing wall, in low seismic zones (0 - 1), to be 1/18 its height (but no less than 8") and 1/20 for a non-bearing wall.

The VTC roof structure in Peña Blanca, made out of timber obtained from the U. S. Department of Defense surplus, is not properly connected to the walls below.

Although giving the appearance of being larger, the effective size of concrete columns poured after the walls are erected are only 6"x6". Columns expected to sustain both vertical loads, transmitted by the roof, and horizontal loads, conveyed by high wind and/or earthquake, need to resist relatively high stresses… In the case of the VTC in Peña Blanca, hardly any reinforcement (only one 3/8"Ø rebar) is used to transmit column loads to the walls that could otherwise help in absorbing some of the forces acting upon the building.

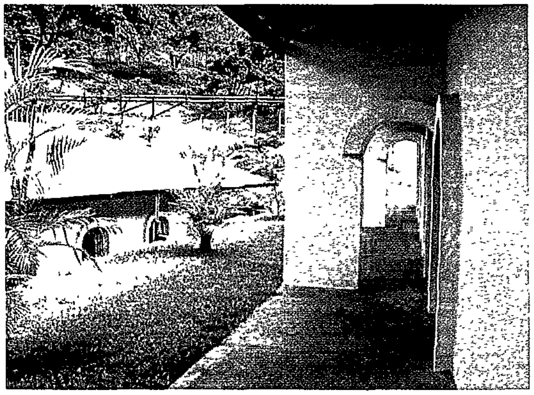


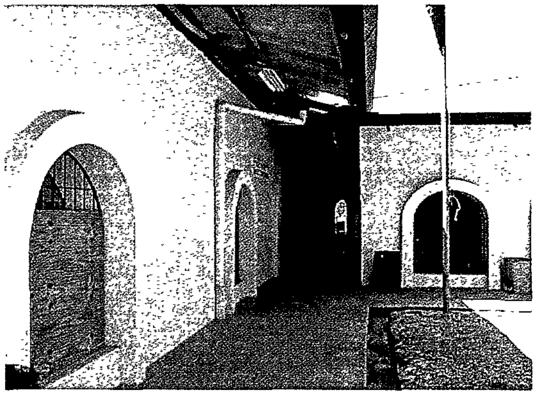
The VTC in **El Mochito**, on the other hand, was completed in 1998 with plastered bearing adobe walls reinforced by buttresses and without the use of concrete col-

umns. The center consists of three 4,275s.f, 12' high structures and a 530s.f toilet facility attached to the western building.

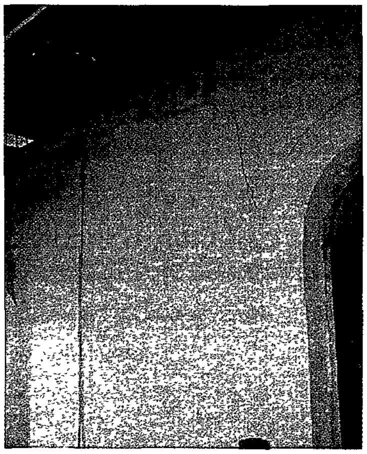
Except for major cracks and impending structural failure due to settlement of filled earth material at the western end of the site, the absence of severe shrinkage cracks in the other two buildings proves that it is best to use the adobe as it should be: a gravity-bearing wall. However, the 12" thickness is substandard.

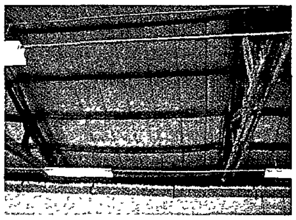
With regards to the western building, it is best to remove the portion that is in danger of being absorbed by the some 40' deep ravine a very short distance away.





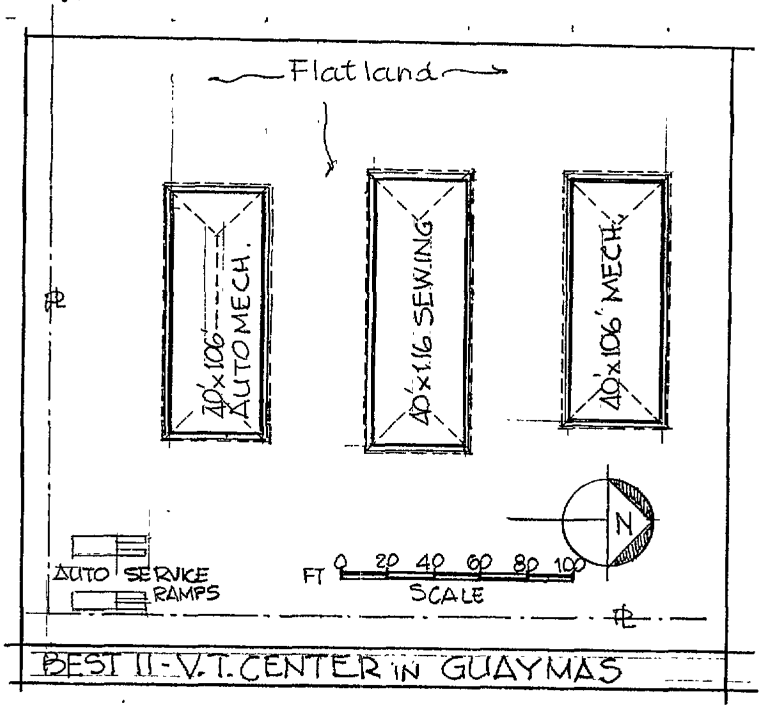
As in San Marco de Colón, the roof trusses in El Mochito, made out of timber obtained from the U. S. Department of Defense surplus, rest on adobe walls but are not anchored to them, as they should be. Both VTCs exhibit weakly designed and built roof decks that will offer negligible resistance to overturning should high winds and/or earthquake ever strike. The only advantage of timber trusses is their greater weight, compared to steel trusses, that helps a little in stabilizing the supporting walls against tipping over.



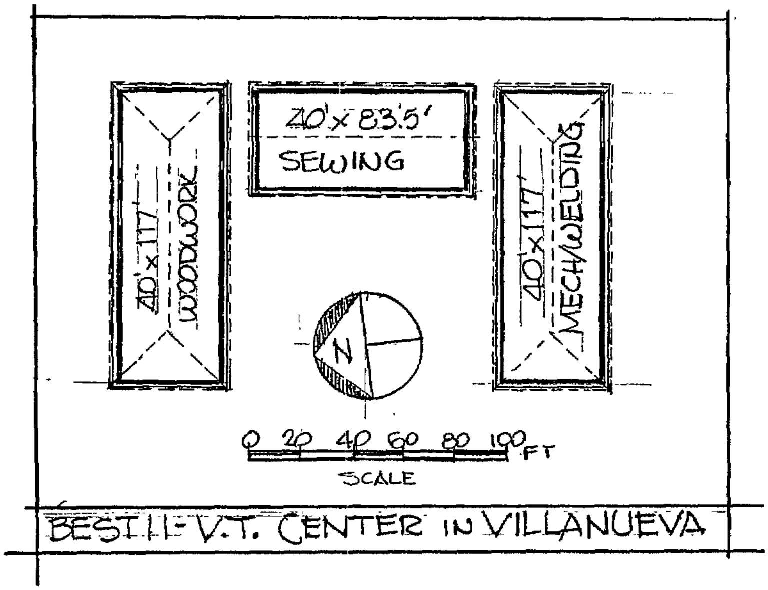


Tuesday, 12 September 2000

Today, we visit four more VTC's:

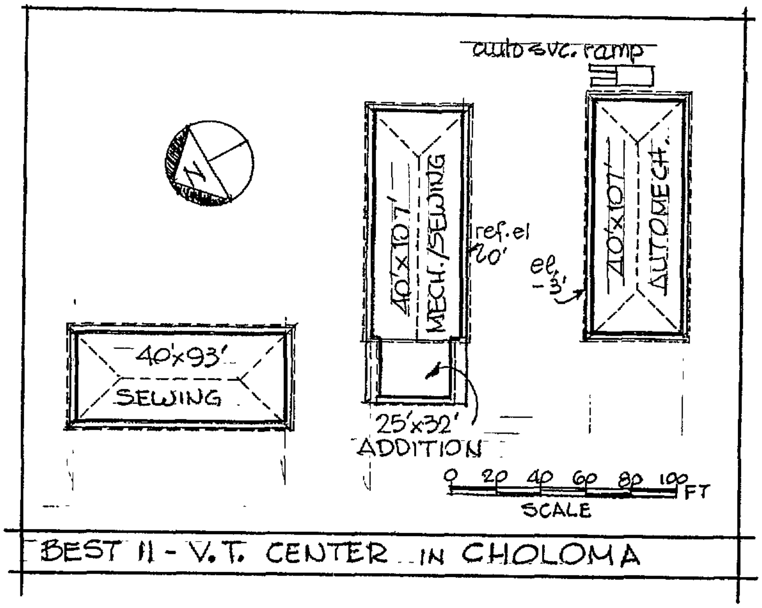


The Ernesto Ponce VTC in **Guaymas**, completed in December 1999 and which, in addition to a 550s.f toilet facility and two auto service ramps, consists of three 12' high concrete-frame and adobe with steel-hip-roof buildings, two of which measure 4,275s.f for the auto- and industrial-mechanics respectively, and one 4,700s.f for the industrial cut and sewing training. Severe cracks at walls, a bond beam that is more rigid than those previously observed in other sites but causing additional horizontal cracks, *poorly-poured unbound aggregate-exposed concrete* (**honey-combing**), less than desirable down-spout design, contributing to weakening and potentially flooding the interior of the adobe walls, characterize this center.

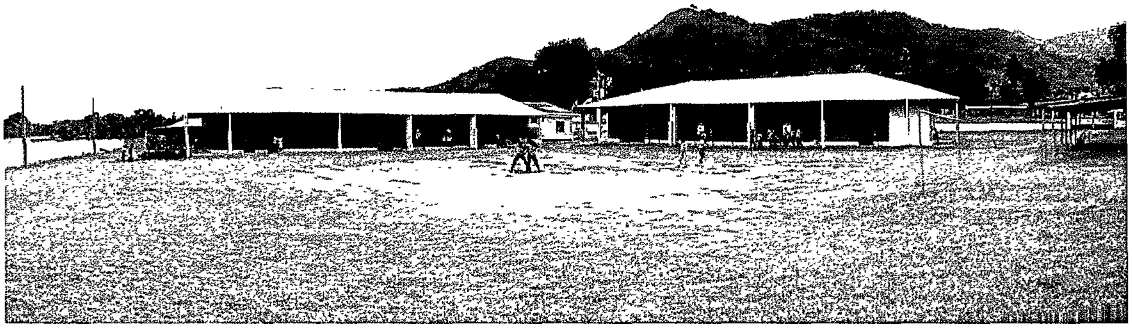


The Centro Technólogico Prof. Nestor Danilo Amaya VTC in **Villanueva**, also completed in 1999, exhibits two 12' high buttressed adobe-wall-bearing with steel-hip-roof buildings for industrial woodwork and welding training, respectively, and one similar building, except for a gable roof at the south end, dedicated to industrial cutting and sewing training.

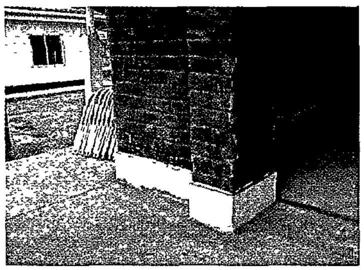
A 450s.f toilet facility abuts the west end of the welding training building, where some foundation settlement has occurred creating minor cracks at the walls. Although the material used for the adobe is less than optimal, we are informed that the blocks used in this center were cured before construction began. Lack of severe cracks, a stiff bond beam at the top of longitudinal walls supporting the non-connected trusses characterizes this center erected on flat land.

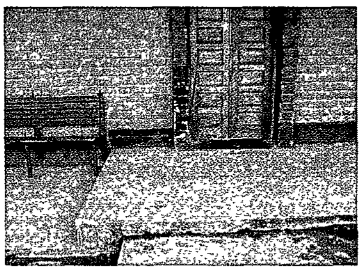


The Mario Ugarte VTC in **Choloma**, completed in 1999 and which, in addition to a 800s.f abutting the north end of the middle building and one auto service ramp next to the east end of the south building, consists of three 12' high buttressed adobe-wall-bearing and timber-roof-truss buildings. The northern building has a hip roof and measures 3,200s.f; it is dedicated

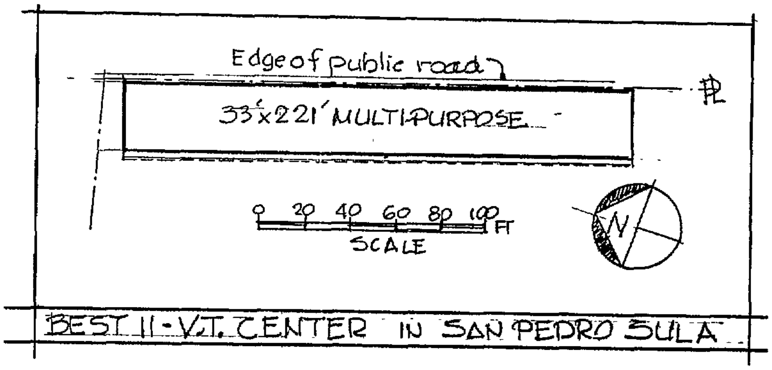


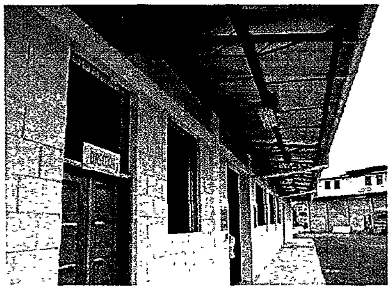
to industrial cut and sewing training. The middle building measures 4,275s.f and is shared by both industrial mechanics and sewing training; the additional concrete block structure was added at the western end of this building where the roof structure is gabled. The third and southernmost building, to train students in auto me-

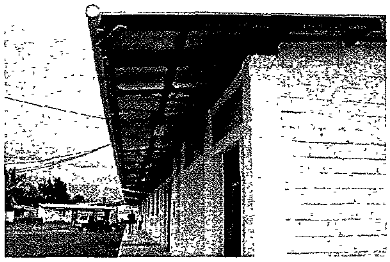




chanics, has a hip roof and measures 4,275s.f Poor workmanship, less than optimal material used for adobe (causing the walls to crumble easily), moderate cracking of the walls and vaults, small 8" x 8" pilasters at the end walls, roof trusses tied at their seats against wind uplift with field-bent rebars (the only site observed with tied down wood trusses) characterize this center.



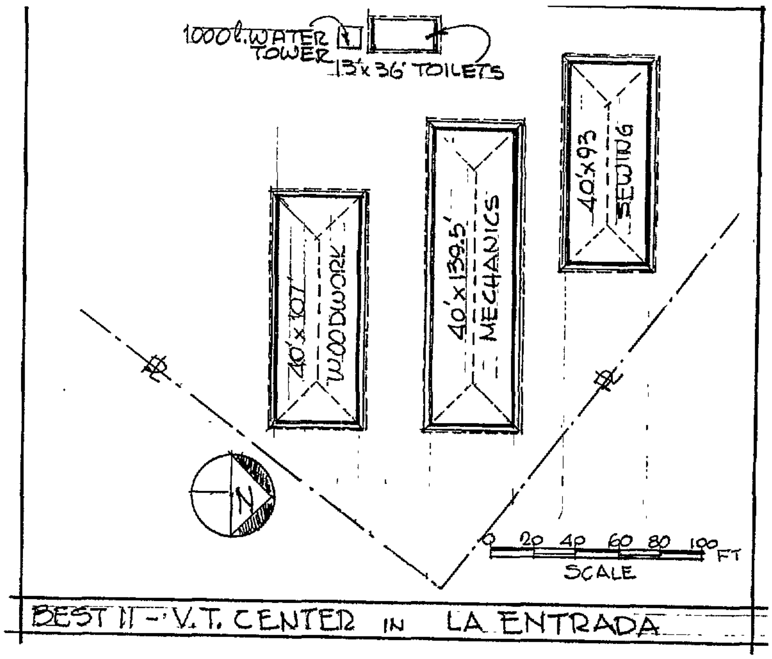




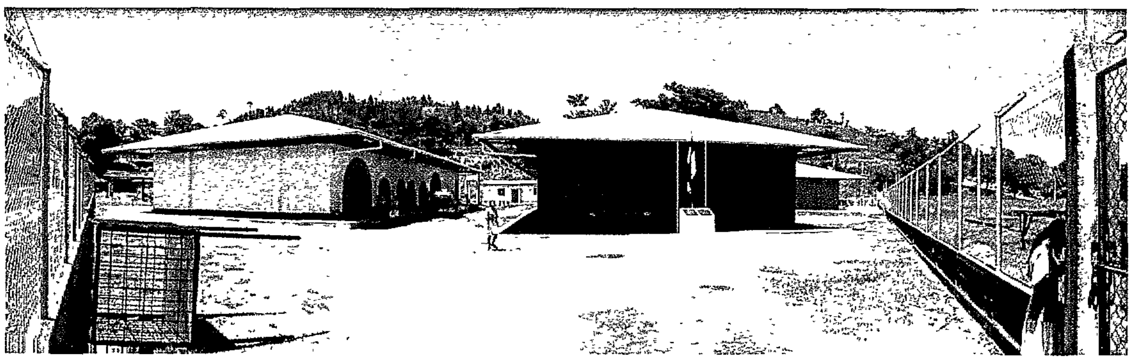
The VTC Hogares Manantial in **San Pedro Sula** was recently completed (August 2000) and consists of only one 221' x 33', or 7,300s.f building laid on a north-south direction. It is a reconstruction of and an addition to a pre-existing structure demolished by the contractor who left standing, next to a road, only one 8" thick and 15'-7" high concrete block wall, portions of the top few courses of which were removed to allow for air circulation and daylight. The floor slab and the foundations belong to the old structure, but the contractor added the lower 8" and 11'-4" high hollow concrete block wall along the western front elevation. He also utilized the old roof joists that sagged excessively, and added an equal number of new deeper joists–minus one, that had to be cut at the supports to allow for erection. The roof is precariously unsafe as are the walls that lack dependable columns/pilasters or a bond beam that could assist in lateral stability.

With the exception of the multi-purpose brick building in Tegucigalpa, all roof decks, columns, and walls are weak and slender; but the ones in San Pedro Sula are excessively under-designed...

Wednesday, 13 September 2000

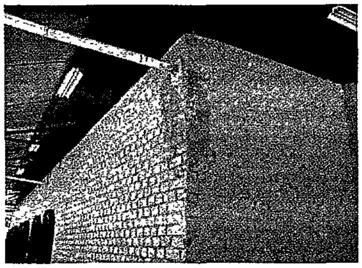
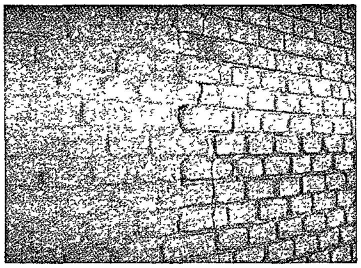


On the treacherous and long way back to Tegucigalpa (at one point Fortunato observes Mario, the driver, silently making the sign of the cross), we inspect the last center: the six-month old Eusebio Castillo VTC in **La Entrada**. In addition to three concrete-column, adobe-wall, and hip-steel-truss buildings, each capped with a 6" bond beam, this center is composed of a 475s.f toilet facility and a 1000-liter water tower. Administrator Assencio informs us that the walls were erected using fresh adobe as the extensive severe cracks in these six-month-old buildings witness!



From south to north, we inspect the three buildings: a white painted 2,900s.f for industrial woodwork, a red 6,600s.f for mechanics, and one yellow 3,750s.f for cutting/sewing training.

Despite being the only center where the contractor braced vertically and longitudinally the middle of all trusses, these buildings show the poorest workmanship in adobe construction responsible for some of the worse cracks we observed during this assignment. Moreover, the electrical distribution system, with wires lying directly on the ground from one building to the next, is utterly unacceptable.


Thursday, 14 September 2000

We spend most of the day writing this report independently, knowing that we will finalize it after our return to our respective home offices. In the afternoon, Chief of Party Saunders drives us to the USAID/Honduras office, where we meet with RDO Leach and Engineer Chavarria for debriefing. We orally present the following

Executive Summary

Considering the governing seismic zones in Honduras and with the exception of the San Giovanni Bosco multi-purpose building located in Tegucigalpa, none of the buildings inspected during this assignment meet U.S. standards for educational facilities or any other category. Although the former building exhibits poor workmanship and its roof deck could not be inspected because of a suspended ceiling nailed to the bottom chords of trusses, it is deemed safe for occupancy.

All other buildings, including those constructed with concrete blocks, exhibit major weaknesses. They are:

- Insufficient wall thickness
- Widespread and more or less severe cracking of adobe walls
- Poor selection of adobe material
- Poor workmanship
- Undersized and questionably poured reinforced concrete columns and bond-beams (where used)
- Questionable capacity of foundations to resist overturning due to seismic and/or high wind loads, and
- Weak roof system and poor or missing connection between each roof system and its bearing structures.

Two buildings need immediate attention. They are:

> *Interrupt immediately all activities in each of the inspected VTC's, with the exception of the multi-purpose building in San Giovanni Bosco in Tegucigalpa.*
> *Resume teaching at each VTC as the recommended retrofitting is completed.*

- The western building in El Mochito, a good section of which has separated from its remaining and relatively stable portion, due to an embankment that is failing. The contractor created this steep embankment to obtain additional area for construction. Since the toilet facilities will be demolished, new ones must be built elsewhere on this VTC.

- The center in San Pedro Sula, the roof structure of which needs to be dismantled, the top two courses of concrete block walls removed, a continuous bond beam poured, and a new roof deck erected.

All the buildings, including those in El Mochito and San Pedro Sula, need retrofitting. The following measures are applicable to all buildings, whether their walls are of adobe or hollow concrete blocks:

- Brace roof trusses longitudinally, transversally, vertically, and horizontally by adding angle steel cross bracing, where these are missing, and improve the existing bracing where needed
- Fabricate in place steel bond beams
- Connect bottom of roof trusses to the newly fabricated steel bond beams
- Apply galvanized stucco wire mesh, thru-tied at 24" on center each way, to both faces of all walls
- Plaster each side of all walls

> *Depending on the intensity of an eventual earthquake and/or a hurricane, the above measures may save lives but do not guarantee further use of any retrofitted building.*

Findings, Conclusions, and Recommendations

MULTI-PURPOSE BUILDING AT THE S. GIOVANNI BOSCO V.T. CENTER
located in
TEGUCIGALPA

Chipping away of plaster at the base of the NW column	*Patch with cement plaster and finish to match adjacent area*

Before continuing with specific findings, conclusions, and recommendations on the next eight VTCs, we recommend the readers to peruse the following commentary. It will help them understand why the proposed *retrofitting methods* (**fixes**) are indeed necessary before all buildings constructed under BEST II may be made safe for occupancy.

Structural Safety Matrix

LOCATION	01. Seismic Zone	02. Building Material	03. Material Condition	04. Construction Quality	05. Structural Wall System	06. Wall H/t (slenderness ratio)	07. Condition of Walls	08. Concrete Columns/Pilasters	09. Buttresses	10. Bond-beam Depth (inches)	11. Bond-beam Continuity	12. Roof Structure	13. Truss/Joist Adequacy	14. Purlin Adequacy	15. Anchorage Adequacy	16. Bearing Plate	17. Foundation Problems	18. Seismically Safe	19. Wind Storm Safe	20. Site Drainage Problem	21. U.S. Standards
San Marcos	C	PAB	OK	P	NB	11	SC	Y	N	4	N	ST	N	Y	N	Y	N	N	N	N	N
Peña Blanca	B	CMU	OK	P	B	22	OK	Y	N	8	Y	W	N	N	N	N	N	N	N	Y	N
El Mochito	B	PAB	OK	OK	B	11	SC	N	Y	6	Y	W	N	N	N	N	SF	N	N	Y	N
Guaymas	B	PAB	OK	P	NB	11	SC	Y	N	6	N	ST	N	Y	Y	Y	N	N	Y	Y	N
Villanueva	B	PAB	P	OK	B	11	LC	N	Y	8	Y	ST	N	Y	N	Y	N	N	N	Y	N
Choloma	C	PAB	P	P	B	11	LC	N	Y	4	Y	W	N	Y	P	N	N	N	Y	Y	N
San Pedro Sula	C	CMU	OK	P	B	23	OK	Y	N	8	N	SJ	N	N	N	N	N	N	N	N	N
La Entrada	C	PAB	P	P	NB	11	SC	Y	N	6	N	ST	N	Y	N	Y	N	N	Y	Y	N

01. Seismic Zone:

Honduras (UBC) Seismic zones A (UBC zone 2)
B (UBC zone 3)
C (UBC zone 4)

The recommended seismic zones in Honduras are based on the work of D. Caceres and O. Kulhanek–*Seismic Hazard of Honduras*, as simplified by Fred Webster for the purposes of designing new and evaluating existing buildings in Honduras. Honduras has three seismic zones: A, B, and C, which are comparable with the *Uniform Building Code* (**UBC**) seismic zones 2, 3, and 4, respectively; 4 being the zone of greatest seismic risk. Most of Honduras is in seismic zone B (UBC zone 3), while there are two strips of seismic zone C (UBC zone 4): one along the northwest border with Guatemala and the other along the southwest border with El Salvador and the Pacific Ocean.

02. Building Material:

hollow concrete block	**(CMU)**
pressed adobe block	**(PAB)**

The building materials used for BEST II consist of either *concrete masonry units* (**CMU**) or *stabilized pressed adobe block* (**PAB**). All but two of the nine sites visited were originally built using PAB. During our visit to Peña Blanca, however, we observe the last of three buildings being demolished to be replaced with CMU construction. The building material has much to do with performance of the type of structural system at the site. For example, it is much more appropriate to use PAB in load bearing wall systems than in concrete column/beam systems. CMU, on the other hand, is more appropriate in the concrete column/beam system.

03. Material Condition:

poor quality	**(P)**
good	**(OK)**
superior	**(S)**

As we may safely assume that the condition of the CMU is governed by Honduran industry standards, we recognize the condition of the PAB to be a serious issue because it was not manufactured using any known standard or quality control. The condition of PAB depends on the raw materials, the mixing techniques, and the operation of the machinery. Poorly mixed materials, poorly graded materials, and inappropriate use of the machinery result in a PAB with shrinkage cracks or containing too much or not enough clay...sand...cement, et cetera. Those we observed throughout the BEST II construction, in fact, crumble, break or chip away easily, and are generally very weak. It is apparent that a program of quality control did not exist or, if it did, was inappropriate.

04. Construction Quality:

poor	**(P)**
adequate	**(OK)**
superior	**(S)**

Construction quality includes suitable PAB laying techniques, adequate mixing and placing of mortar, placement of *reinforcement bars* (**rebars**) in both columns and bond beams, correct overlaps at the ends of the rebars, standard bends and anchorage of the ends of rebars into columns and around corners. Continuity of rebars placed in bond beams around corners and wall intersections, through columns, and consolidation of concrete assure integrity of reinforced concrete frame construction, from which the safety of the building relies.

Some of the buildings show a lack of regard for the above construction characteristics. The adobe, more often then not, was laid up rapidly in wall sections between columns, building several *horizontal layers* (**courses**) at once in a given section without regard to consistency with other sections. Some buildings have wall sections with vertical mortar joints missing between blocks. We observe several cracks through the bond beam intersecting columns or at building corners revealing lack of rebar continuity or structural failure.

Bearing plates for trusses, when provided, are often welded to rebars projecting from the top of the column: a practice that is not recommended by the American Concrete and the Concrete Reinforcing Steel Institutes. In no case was grout ever placed under these bearing plates. In some buildings, the bond beam concrete shows *gravel at the surface unbound by cement* (**honeycombing**), indicating poor consolidation and lack of structural integrity. All of the above are basic examples of attributes considered when judging the quality and safety of construction.

05. Structural Wall System:

bearing (B)
non-bearing (NB)

The wall system of a one-story building can be designed and constructed either to *carry the gravity loads of the roof* (**load bearing**) or not (**non-load bearing**). Load bearing walls require no columns. Non-load bearing walls, however, require columns/pilasters to carry the roof loads. Adobe walls are best suited for load bearing, and, unless special care is taken, will crack when used as non-load bearing in conjunction with concrete columns/pilasters because of the materials' different stiffnes.

06. Wall Height/Thickness

slenderness ratio = H/t

As blocks piled higher and higher contribute to the instability of a structure, so does the *height of a wall or column compared to its thickness*: the higher the number (**slenderness ratio**) the weaker the wall or column.

The slenderness ratio is, therefore, an indication of potential for damage to walls during earthquakes and/or high winds. In the U.S. lower seismic risk zones, the maximum H/t is 10/1 for non-reinforced PAB, and 18/1 for non-reinforced hollow blocks walls, whose thickness shall not be less than 8". For buildings in seismic risk zones 3 and 4, walls should be shorter, thicker, and reinforced with adequately anchored and sized steel reinforcement bars. After observing the buildings erected under BEST II, including those made of CMU, we conclude that they must all be retrofitted with wire mesh to contain the wall material during earthquake shaking or hurricane winds to protect the occupants from harm or even death.

07. Condition of Walls:

severely cracked (SC)
moderately cracked (MC)
lightly cracked (LC)
no cracks (OK)

The condition of the walls refers to whether the walls are cracked or not, and the extent of cracking. Only one building at El Mochito clearly suffered crack damage because of soil failure during and after Hurricane Mitch. Most other observed crack damages are the result of shrinkage of the PAB and mortar, primarily in conjunction with hard, rigid concrete columns/pilasters and bond beams.

When PAB is not dried and cured completely before laying up the wall, shrinkage cracks will result. If mortar is not the right mix and/or is laid too thickly, shrinkage cracks will also result in the wall. Once shrinkage of the PAB and mortar has subsided, however, they may be repaired. Further cracking will only be the result of building movement, such as during an earthquake, high winds, or foundation movement.

08. Concrete Columns/Pilasters:

yes (Y)
no (N)

The structural as well as the non-structural performance depends on whether or not the wall system includes concrete columns/pilasters. The buildings with concrete columns/pilasters have significantly more crack damage in the PAB walls than the load bearing walls without columns/pilasters. Concrete columns represent hard and rigid locations in the wall. As the PAB construction dries and shrinks, it pulls away from the rigid concrete elements that also exert some bonding to the adobe.

09. Buttresses:

yes (Y)
no (N)

The buildings without column/pilasters must have buttresses along longitudinal walls to transversally brace them. The earlier construction under the BEST II project exhibits buttresses extending exteriorly and across a two-meter concrete walkway. Each has an arched opening to allow pedestrian's crossing without leaving the walkway.

10. Bond-beam Depth:

inches

To better absorb horizontal forces induced by earthquakes and/or high winds, a bond beam needs to be strong but flexible, not rigid. This means a relatively thin beam but not at the expense of inadequate rebar embedment in its concrete matrix. Bond beam depth is an indication of the amount of concrete cover over the rebars placed in them. The cover is important because it provides protection for rebars and allows these to bond with the concrete, thereby allowing the bond-beam to perform as a reinforced concrete beam.

11. Bond-beam Continuity:

yes (Y)
no (N)

One of the most important contributors to structural safety in adobe buildings is to have a continuous bond-beam on the tops of all walls. This means continuous at the corners and wall intersections, over exterior and interior walls, as well as through columns, when these are used. Stopping a bond-beam and its rebars at building corners, or at columns, essentially isolates one wall section from another and can make a wall section extremely vulnerable during earthquake ground shaking and/or high hurricane winds.

12. Roof Structure:

wood truss/purlins	**(W)**
steel truss/purlins	**(ST)**
steel joists	**(SJ)**

The roof-structure for seven of these buildings consist of either wood or steel trusses spanning in the transverse direction, with wood or steel purlins spanning between the trusses that are supported at each concrete column, where present, or on PAB walls at approximately 20 feet *on center* (**O.C**). In the case of the CMU building at San Pedro Sula, steel joists at uneven spacing are used instead of trusses.

The wood trusses are constructed of double 2" x 6" chords and braces, bolted and nailed together. The steel trusses consist of double 1½" x 1½" welded steel angles, used as both chords and braces, and 1" x 1" tubing diagonals. 2" x 4" wood or lightweight steel channels, spaced at 4 to 5 feet O.C, make up the *members supporting the galvanized steel roof deck* (**purlins**). In Choloma, 2" x 6" wood purlins are spaced at 4 feet O.C.

13. Purlin Adequacy:

yes (Y)
no (N)

Purlins are beams that span between trusses or roof joists to carry the weights of the roof deck and of workers or maintenance personnel to the trusses. They need to be sized and spaced to carry these loads without overstressing and without over-deflecting. Under-sizing and/or excessive spacing between them generate sagging and weak roof structures. (*See the next section for design loads and deflections.*)

14. Trusses/Joists Adequacy:

yes (Y)
no (N)

Trusses and joists carry the roof weight to the walls and/or columns/pilasters. They also resist the uplift effects of wind forces and aid in withstanding earthquake forces by tying parallel walls together across the building. The trusses used in the BEST II construction, along with any other roof deck component, should have been designed to safely carry the following loads: the roof dead weight and a temporary live loads of 20 pounds per square foot (98kg/m^2) or 250 pounds (114kg) concentrated weight at any point.

The above loads should also induce no objectionable sagging, which must be limited to 1/360, for trusses carrying suspended ceiling, or 1/240 of the span, for those that do not. In no case should other members (deck, purlins, and braces) sag more than 1/180 of the span. To help the building act as a unit that resists lateral loads induced by earthquakes and/or high winds, roof trusses should also be braced continuously longitudinally and at the bottoms in both directions, to provide a diaphragm that braces the structure.

Although the observed trusses are capable of supporting the roof weight, the span between them is too great and/or the space between the purlins is too large, resulting in noticeable sagging. Some of the steel trusses also sag, indicating integral weakness and negligible resistance against transverse forces that may be induced by earthquake and/or high winds. In fact, many of the diagonal braces between the steel trusses also sag and there is no continuity of the diagonal bracing across the buildings in the longitudinal direction. The inadequately shallow steel joists used in San Pedro Sula are also incorrectly placed.

15. Anchorage Adequacy:

yes (Y)
no (N)
partial (P)

To resist uplift due to wind and to act as an integral part of the building structural system, roof trusses must be adequately anchored to the tops of the walls or columns. Normally, such anchorage consists of a welded or bolted connection to a bearing plate, which in turn is anchored to the top of the wall bond-beam or the column/pilaster. In Choloma, the contractor has achieved partial anchorage by bending and nailing, around the top of each truss, two #3 ($^{3}/_{8}$" Ø-diameter) rebars that project out of the bond beam.

16. Bearing plate:

yes (Y)
no (N)

The truss bearing plate is a means of anchoring the truss to the tops of the walls or columns/pilasters. Ideally, a steel bearing plate has bent flat- or round-bars (no rebars) welded to it, is set level and flush with the top of the bond-beam or column before pouring, while the bars become embedded in concrete. Alternatively, anchor bolts should project out of the top of the bond-beam or column and a loose steel plate, or one that has been shop welded or otherwise connected to the truss, would be set on grout and welded or bolted to the anchors.

None of the observed truss bearing plates conforms to either type described above. At Villanueva a bearing plate at the corner of one of the buildings has slightly tilted and applied a concentrated roof load on the bond-beam. The result is a crack through the bond-beam at this location.

17. Foundation Problems:

severe (SF)
moderate (MF)
none (N)

Foundation problems include differential settlement of the building, in which part of the building – often at a corner – settles more than the rest. This condition may create cracks in the floor slab, grade-beam, and wall. Other foundation problems result from cut-and-fill sites where a portion of a hillside is cut away and the soil is used to build up the down slope section in order to create a flat surface for constructing a building. If the fill portion is not properly compacted, retained and/or stabilized it will slip over time, causing the building foundation and walls to crack and fail.

18. Seismically Safe:

yes (Y)
no (N)

It is obvious that none of the buildings were designed to resist seismic forces of any significance, even though they are all located within one of the two highest seismic zones in Honduras. It should be understood that while it is not feasible to bring these buildings into compliance with U.S. standards for seismic design, they could be made seismically safe for occupancy with retrofitting and crack repairs.

19. Wind Storm Safe:

yes (Y)
no (N)

The design wind speed in Honduras, according to local engineers, is 100 km/hr (63 mph). This does not take into consideration higher velocity winds generated by hurricanes. Nor does it take into account the effects of geographical characteristics of the site. Wind generates pressure on the walls and roof structure of a building, both inward (positive) and outward (negative). When a roof structure and/or roofing material is not adequately fastened or anchored to the walls, the roof, or a portion of it, can be lifted off by negative pressure. Buildings with large roof overhangs or eaves are particularly vulnerable to wind damage.

Adequately anchoring the roof trusses to the tops of the walls may hold the trusses onto the building, but may not prevent the roof deck from being ripped off for lack of sufficient attachment and support. The buildings inspected during this site visit exhibit questionable and generally weak fastening techniques.

20. Site Drainage Problems:

yes (Y)
no (N)

Sites with drainage problems can result in damage to the adobe walls, in the form of flooding and soaking the base of the walls, and/or causing the soil beneath the structure to settle unevenly, thereby resulting in cracked slabs, foundations, and walls.

21. Meets U.S. Standards:

yes (Y)
no (N)

Not only the types and qualities of building materials available in the United States are hard to find in Honduras, but also the country apparently trains its engineers and architects differently. Since Honduras either has not adopted a building code or does not enforce one, engineers and architects use their own judgment and, without sufficient resources and reference standards, may not be able to meet U.S. standards of design and construction. In addition, without proper inspection and oversight, no construction projects could ever meet U.S. standards. Many problems arise on site and need the involvement of both the engineer and the architect to resolve them. Without this basic approach, even the simplest design could not be implemented properly.

Conclusions

The general conclusion regarding the condition of the buildings constructed under BEST II is that they suffer from the following deficiencies:

- Lack of training for engineers and architects in U.S. standards and building codes;
- Lack of an appropriate design for the material and the natural load environment, including earthquake and high winds;
- Lack of input by qualified soil engineers;
- Lack of appropriate design and construction documents, including drawings and technical specifications;
- Lack of an appropriate quality control program for the production of adobe block, the fabrication of steel trusses and bearing plates, and the placement of concrete;
- Lack of understanding of how adobe structures should be designed and built;
- Lack of continuous inspections and oversight by personnel adequately trained in construction quality standards and construction document interpretation.

Because of the above deficiencies, we face severe cracking of adobe and concrete, soil problems, and fragile building structures that are inadequate to resist the natural forces of earthquakes and hurricanes.

Recommendations

Recommended Fixes

	A	B	C	D	E	F	G	H	I	J
San Marcos	●	●	●	●	●	●				
Peña Blanca	●		●	●		●	●		●	
El Mochito	●	●	●	●		●	●	●	●	
Guaymas	●	●	●		●	●			●	
Villanueva	●	●	●	●	●	●			●	
Choloma	●	●	●			●			●	
San Pedro Sula			●				●			●
La Entrada	●	●	●		●	●			●	

A. Apply new continuous steel channel tie beam at bond beam level, both faces of wall similar to DETAIL 1.

B. Repair cracks and under-filled bed or head joints in adobe walls. Do this by
   - Removing paint on both sides of crack
   - Clean out debris, paint, and loose mortar from crack

- o Inject mortar slurry made of soil, sand, fly ash, and lime. By weight, the proportions shall be 60, 20, 18, and 2 respectively, with sufficient water to produce the required consistency
- o Repeat injection as necessary after slurry has had a chance to dry.

C. Contain all exterior and interior walls within 1½" x 17 gauge galvanized stucco wire mesh applied to both faces of walls, including buttresses, from top to bottom. When doing this work,

- o Attach galvanized wire mesh
  at top, to new steel channel tie-beam as in DETAIL 2 and
  at bottom, to new steel angle bolted to grade beam
- o Wrap corners 2 feet by overlapping the galvanized wire mesh
- o Drill holes through wall, without use of impact tools
- o Thru-tie with nylon cable ties or 18 gauge galvanized wire the stucco mesh at 24 inches O.C throughout and in both directions, as in DETAIL 2
- o Plaster both faces of all walls.

D. Anchor roof trusses to tops of walls or columns by field welding bottom chords to newly placed steel bond beams or using steel brackets as appropriate for wood trusses (see DETAIL 1).

E. Clean debris from under bearing plates and inject dry-pack grout between bearing plate and concrete.

F. In order to obtain a stronger roof system that would act as a diaphragm to engage and work together with the vertical bearing structure, add bracing members as follows:

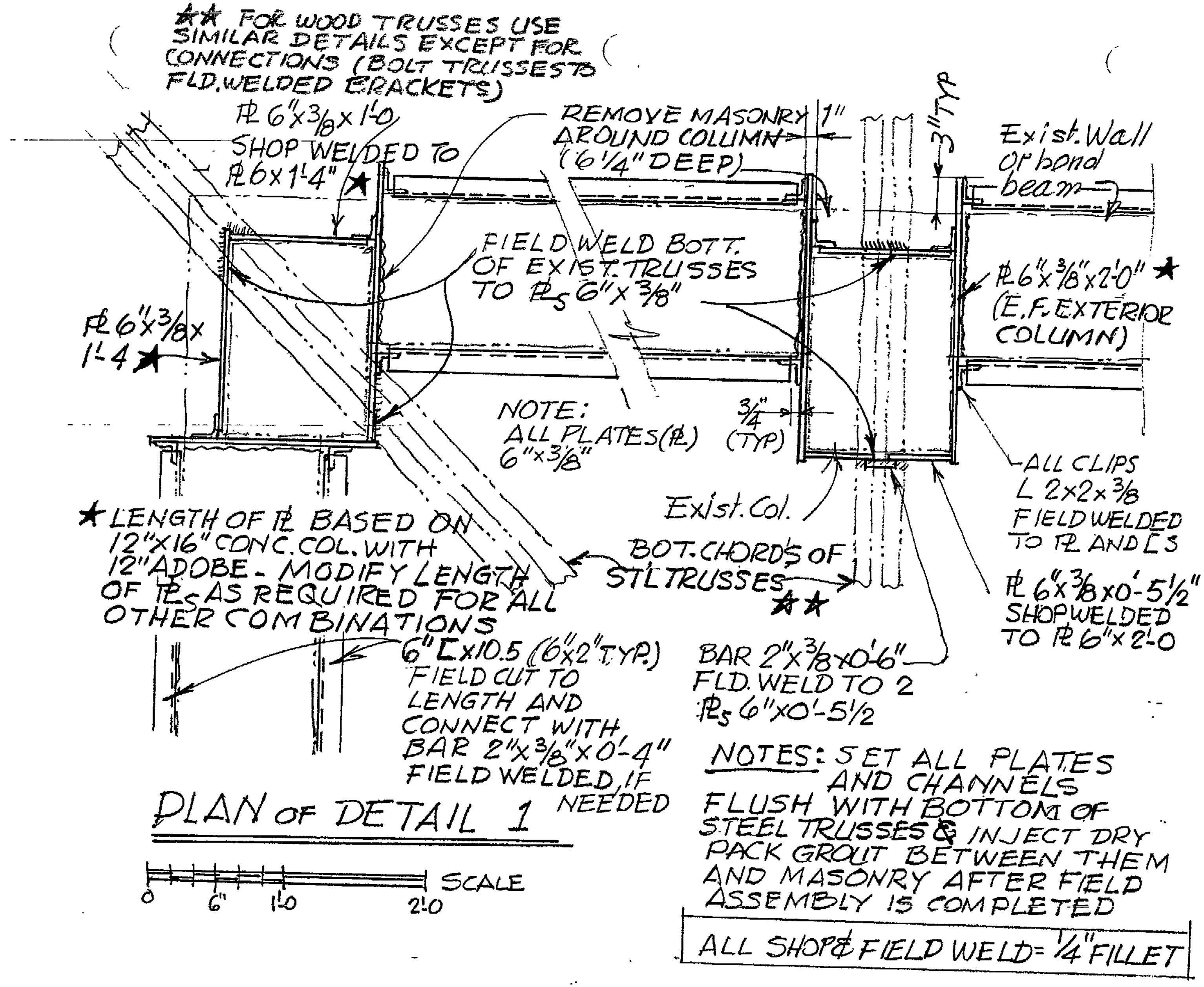
- o Install new double-angle steel bottom chord longitudinally to connect both end-walls' newly placed steel bond beams at centerline.
- o Install diagonal braces between trusses where needed to include all trusses.
- o Stiffen existing sagging diagonal braces by adding additional angle or steel gusset, cutting, straightening, and reattaching to truss
- o Add new diagonal braces, in the horizontal plane of all trusses' bottom chords.

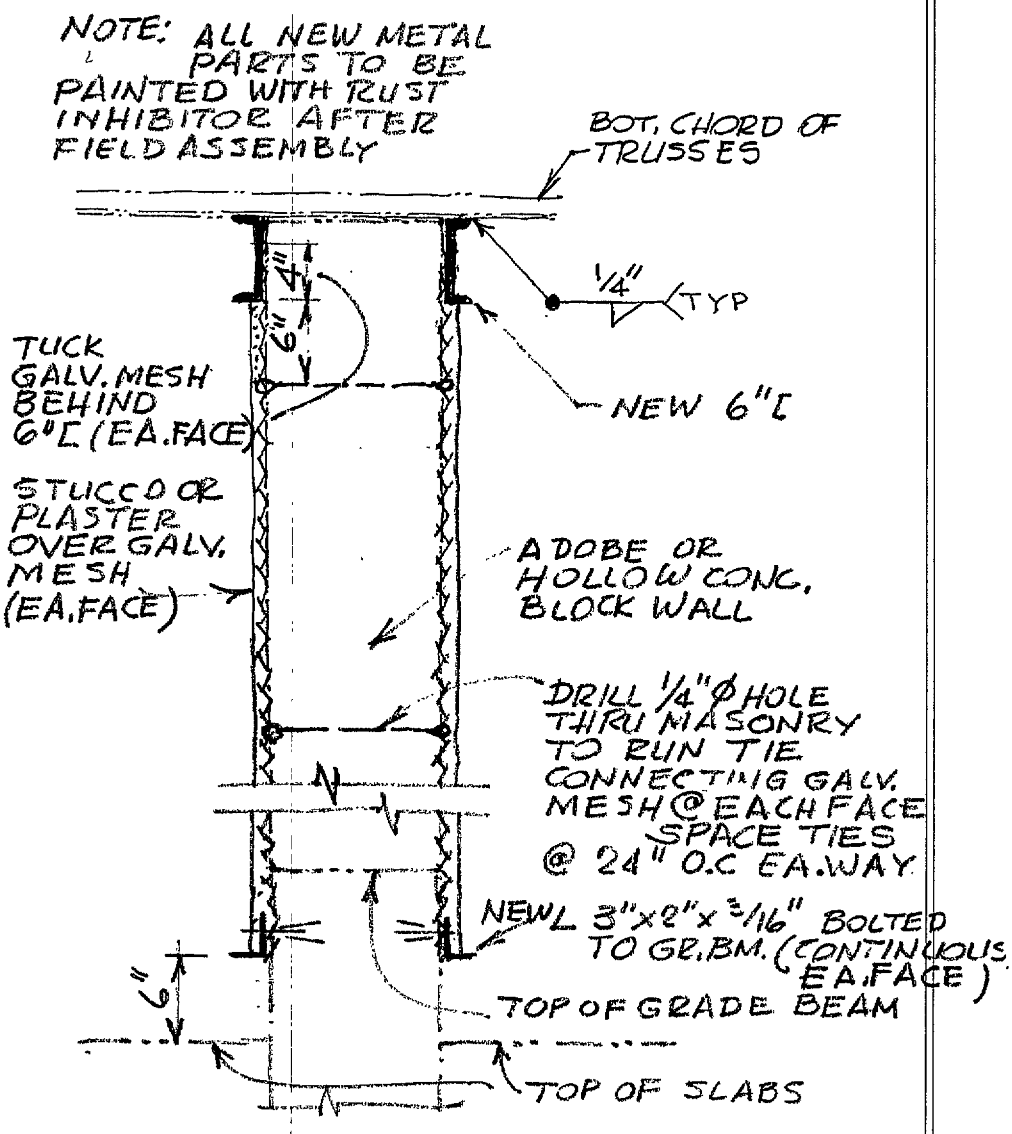
G. Replace purlins with stronger, stiffer elements and reattach roof sheathing.

H. Demolish section of building affected by embankment failure. Construct new end wall as necessary and rebuild toilet facilities elsewhere on the site.

I. Provide appropriate site drainage.

J. Remove existing roof, add new continuous bond beam, and reconstruct a correctly designed roof.


★★ FOR WOOD TRUSSES USE SIMILAR DETAILS EXCEPT FOR CONNECTIONS (BOLT TRUSSES TO FLD. WELDED BRACKETS)
PL 6"x3/8x1'-0 SHOP WELDED TO PL 6x1'-4" ★
REMOVE MASONRY AROUND COLUMN (6 1/4" DEEP)
1"
3" TYP
Exist. Wall or bond beam
FIELD WELD BOTT. OF EXIST. TRUSSES TO PLS 6"x3/8"
PL 6"x3/8"x2'-0" ★ (E.F. EXTERIOR COLUMN)
PL 6"x3/8x 1'-4 ★
NOTE: ALL PLATES (PL) 6"x3/8"
3/4" (TYP)
Exist. Col.
ALL CLIPS L 2x2x3/8 FIELD WELDED TO PL AND [S
★ LENGTH OF PL BASED ON 12"x16" CONC. COL. WITH 12" ADOBE - MODIFY LENGTH OF PLS AS REQUIRED FOR ALL OTHER COMBINATIONS
BOT. CHORDS OF STL TRUSSES ★★
PL 6"x3/8x0'-5 1/2" SHOP WELDED TO PL 6"x2'-0
6" [x10.5 (6"x2" TYP.) FIELD CUT TO LENGTH AND CONNECT WITH BAR 2"x3/8"x0'-4" FIELD WELDED, IF NEEDED
BAR 2"x3/8x0'-6" FLD. WELD TO 2 PLS 6"x0'-5 1/2
PLAN OF DETAIL 1
SCALE
0 6" 1'-0 2'-0
NOTES: SET ALL PLATES AND CHANNELS FLUSH WITH BOTTOM OF STEEL TRUSSES & INJECT DRY PACK GROUT BETWEEN THEM AND MASONRY AFTER FIELD ASSEMBLY IS COMPLETED
ALL SHOP & FIELD WELD = 1/4" FILLET



SECTION OF DETAIL 2