World Housing Encyclopedia

an Encyclopedia of Housing Construction in
Seismically Active Areas of the World

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HOUSING REPORT
Vivienda de Adobe (adobe brick houses)

Report #	144
Report Date	11-06-2007
Country	GUATEMALA
Housing Type	Adobe / Earthen House
Housing Sub-Type	Adobe / Earthen House : Adobe block walls
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Summary

Buildings made of adobe brick masonry can still be found in all parts of Guatemala both in rural and urban areas. Generally adobe houses are characterized by only one story, no basement, and sometimes an irregular plan shape. The main use is residential or small commercial (retail trade) purposes. In the 1970's adobe buildings represented the prevalent construction type in the Republic of Guatemala with a share of more than 39 %. More than

half of these buildings (54.3 %) were located in rural settlements, while the rest (45.7 %) was located in urban areas, e.g. Guatemala City (Marroquin and Gándara, 1976). Surprisingly, the percentage of adobe buildings at that time was higher in urban areas than in rural regions. Today, circumstances have changed and adobe structures prevail in rural areas while only remainders of this traditional construction technique can be found in the cities. Based on a more recent statistical survey in the municipality of Guatemala City conducted by ASIES (2003), around 4 % of the building stock is either adobe or bahareque buildings. The latter not being covered in the present report. Throughout the report, a distinction is made between adobe buildings in rural (Figure 1) and urban (Figure 2) areas. This distinction affects some of the building parameters and features herein.

1. General Information

Buildings of this construction type can be found in all parts of the country, however, their percentage of the total building stock strongly depends on the region of Guatemala. Higher percentages of adobe buildings can be found in mountainous regions with altitudes greater than 1000 m above sea level (i.e. Región Central, Región del Altiplano Occidental, and Región del Altiplano Oriental). In contrast, few adobe houses are located in coastal and low mountain regions below 1000 m, i.e. Región Costera del Pacifico, Región Seca Oriental, and Región Norte (Marroquin and Gándara, 1976; Figure 3). This type of housing construction is commonly found in both rural and urban areas.

Adobe buildings can even be found in larger cities, e.g., the capital Guatemala City where a considerable percentage of the building stock still consists of adobe houses. In 1973 more than 52 % of the buildings in Guatemala City were of adobe type. Nowadays, this percentage is of course lower since the building stock has changed since then and many of the old adobe houses have been demolished in the meantime.

This construction type has been in practice for more than 200 years.

Currently, this type of construction is being built. New buildings made out of adobe walls are mainly found in rural areas. No restrictions for the use or construction of this building type exist. (At present Guatemala has no national seismic building code.).

Figure 1. Typical adobe building for rural areas (San Juan La Laguna). [Click to enlarge figures]

Figure 2. Typical adobe building for urban areas (Guatemala City, Zona 11).

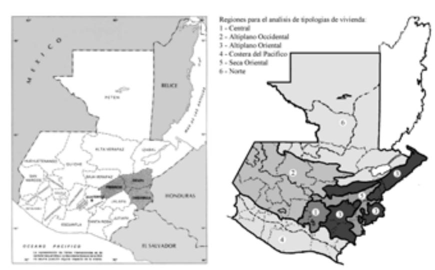

Figure 3. Maps of Guatemala illustrating (left) the different counties (

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat, sloped and hilly terrain. They share common walls with adjacent buildings. Urban: It is very common that buildings have common walls with adjacent buildings, on one or both sides. Rural: Buildings standing alone, and buildings in a row with adjacent walls to neighboring buildings are common When separated from adjacent buildings, the typical distance from a neighboring building is a range of meters.

2.2 Building Configuration

All different plan shapes can be found. The most common are rectangular shapes, followed by L- and U-shapes. In urban areas, L- or U-shaped buildings with an inner courtyard (patio) are very prevalent (Figure 4). In rural areas, residential premises often consist of smaller separated single buildings with a rectangular plan shape. Here the kitchen, storage room, or lavatory is sometimes separated by open ground from the main building which consists of the dormitories and living rooms (e.g. Figure 5c). The number, size, and position of openings is dependent on the location of the building (rural, urban) and moreover on the number of adjacent neighboring buildings and should not be quantified by a single number. Judging from the front facade, buildings in urban areas often have much larger openings than those in rural areas (compare Figures 1 and 2). In buildings being used for small shops, large openings often serve as showcases or sales counters with opening widths of more than 2 m (supported by reinforced-concrete lintels presumably assembled at a later date). In rural areas, lintels consist of wooden trusses which in most cases are visible and not covered by the plaster (Figure 6). It is reported that the lintels' depths of anchorage (i.e. the support width at either side) are often insufficient. In Guatemala, we observed the contrary, with the lintels' depth of anchorage being more or less oversized (up to 50 cm).

2.3 Functional Planning

The main function of this building typology is single-family house. Besides residential use by one single family, adobe houses often accommodate small shops (retail trade) or handicraft businesses especially in urban areas. In a typical building of this type, there are no elevators and no fire-protected exit staircases. The buildings have at least one entrance door on the front facade and one at the back entering a patio. In urban areas it is also common for these structures to have two doors located on the front facade (Figures 2 and 15). In urban areas where the crime rate is higher, the doors and windows (means of escape) are heavily locked by bars, rendering a quick escape from the building in case of an earthquake impossible (Figure 7).

2.4 Modification to Building

Repair of walls or changes to the building are in most cases constructed with day bricks or concrete blocks since the acquisition of these materials is much easier (and cheaper). However, the bad quality of the applied concrete blocks with compression strength values mostly below 25 kg/cm^2 makes these modifications not really a good remedy.

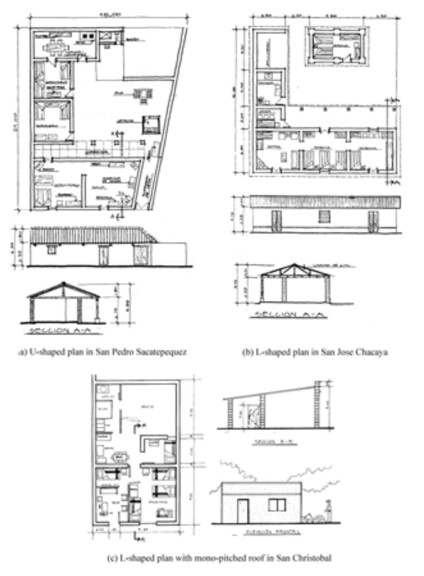

Figure 4. Plan shapes, cross-sections and views of typical adobe houses in urban areas (taken from Marroquin and G

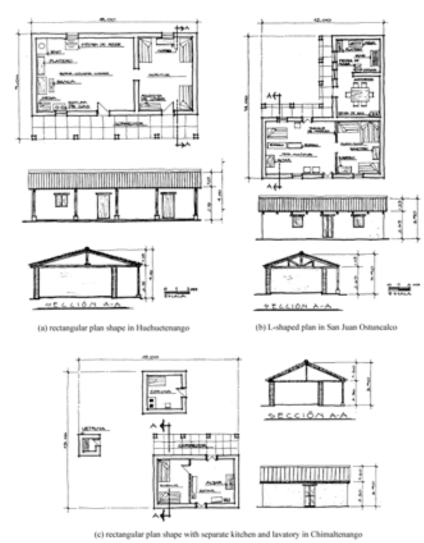

Figure 5. Plan shapes, cross-sections and views of typical adobe houses in rural areas (taken from Marroquin and G

Figure 6. Window lintels consisting of wooden trusses.

Figure 7. Heavily locked doors and windows by lattices in Guatemala City.

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	☐
		2	Dressed stone masonry (in lime/cement mortar)	☐
	Adobe/ Earthen Walls	3	Mud walls	☐
		4	Mud walls with horizontal wood elements	☐
		5	Adobe block walls	☑
		6	Rammed earth/Pise construction	☐
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	☐
		8	Brick masonry in mud/lime mortar with vertical posts	☐
		9	Brick masonry in lime/cement mortar	☐
		10	Concrete block masonry in cement mortar	☐
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	☐
		12	Clay brick masonry, with concrete posts/tie columns and beams	☐
		13	Concrete blocks, tie columns and beams	☐
	Reinforced masonry	14	Stone masonry in cement mortar	☐
		15	Clay brick masonry in cement mortar	☐
		16	Concrete block masonry in cement mortar	☐
Structural concrete	Moment resisting frame	17	Flat slab structure	☐
		18	Designed for gravity loads only, with URM infill walls	☐
		19	Designed for seismic effects, with URM infill walls	☐
		20	Designed for seismic effects, with structural infill walls	☐
		21	Dual system – Frame with shear wall	☐
		22	Moment frame with in-situ shear walls	☐

	Structural wall	23	Moment frame with precast shear walls	☐
	Precast concrete	24	Moment frame	☐
		25	Prestressed moment frame with shear walls	☐
		26	Large panel precast walls	☐
		27	Shear wall structure with walls cast-in-situ	☐
		28	Shear wall structure with precast wall panel structure	☐
Steel	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐
	Braced frame	32	Concentric connections in all panels	☐
		33	Eccentric connections in a few panels	☐
	Structural wall	34	Bolted plate	☐
		35	Welded plate	☐
Timber	Load-bearing timber frame	36	Thatch	☐
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	☐
		38	Masonry with horizontal beams/planks at intermediate levels	☐
		39	Post and beam frame (no special connections)	☐
		40	Wood frame (with special connections)	☐
		41	Stud-wall frame with plywood/gypsum board sheathing	☐
		42	Wooden panel walls	☐
Other	Seismic protection systems	43	Building protected with base-isolation systems	☐
		44	Building protected with seismic dampers	☐
	Hybrid systems	45	other (described below)	☐

3.2 Gravity Load-Resisting System

The vertical load-resisting system is earthen walls. Gravity loads from the roof construction itself (dead loads), live loads, wind or snow loads are transferred directly from the roof construction to the walls and then to the foundation. In most cases the largest gravity loads are produced by heavy clay roof tiles (mission-tiling; self-weight ~ 1 kN/sqm).

3.3 Lateral Load-Resisting System

The lateral load-resisting system is earthen walls. The lateral stiffness is provided by the massive adobe shear walls which have thicknesses up to several tens of centimeters. Generally, wall thickness is between 40 and 60 cm, sometimes even up to 80 cm. According to Minke (2001) and Morales M. et al. the common dimensions of adobe bricks in Central America are 38 × 38 × 8 cm or 40 × 20 × 10 cm. The roof is usually constructed of wood (both square-shaped and round timber) in a gabled or mono-pitched shape and can be considered a flexible diaphragm not able to support any lateral loading. The wooden trusses and beams of the roof rest directly on the adobe walls without any friction-locking connection.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 0 and 0 meters, and widths between 0 and 0 meters. The building has 1 to 0 storey(s). The typical span of the roofing/flooring system is 4 to 5 meters. Because of the large variety of adobe buildings it is impossible to identify distinct values of plan dimensions (Figures 5 and 6). The typical storey height in such buildings is 2.5 meters. The typical structural wall density is more than 20 %. Story heights vary between 2.20 and 3.50 m. Also, due to the large variety of adobe buildings, it is difficult to define parameters with a single number.

3.5 Floor and Roof System

Material	Description of floor/roof system	Most appropriate floor	Most appropriate roof
Masonry	Vaulted	☐	☐
	Composite system of concrete joists and masonry panels	☐	☐
Structural concrete	Solid slabs (cast-in-place)	☐	☐
	Waffle slabs (cast-in-place)	☐	☐
	Flat slabs (cast-in-place)	☐	☐
	Precast joist system	☐	☐
	Hollow core slab (precast)	☐	☐
	Solid slabs (precast)	☐	☐
	Beams and planks (precast) with concrete topping (cast-in-situ)	☐	☐
	Slabs (post-tensioned)	☐	☐
Steel	Composite steel deck with concrete slab (cast-in-situ)	☐	☐
Timber	Rammed earth with ballast and concrete or plaster finishing	☐	☐
	Wood planks or beams with ballast and concrete or plaster finishing	☐	☐
	Thatched roof supported on wood purlins	☐	☑
	Wood shingle roof	☐	☐
	Wood planks or beams that support clay tiles	☐	
	Wood planks or beams supporting natural stones slates	☐	☐
	Wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles	☐	☑
	Wood plank, plywood or manufactured wood panels on joists supported by beams or walls	☐	☐
Other	Described below	☑	☑

The floors generally consist of compacted earthen materials or cast plaster floor (screed). The roofing system either is made of wood purlins supported thatched roof or wood planks or beams supporting clay tiles, metal asbestos cement or plastic corrugated sheets.

3.6 Foundation

Type	Description	Most appropriate type
Shallow foundation	Wall or column embedded in soil, without footing	☐
	Rubble stone, fieldstone isolated footing	☐
	Rubble stone, fieldstone strip footing	☑
	Reinforced-concrete isolated footing	☐

	Reinforced-concrete strip footing	☐
	Mat foundation	☐
	No foundation	☐
Deep foundation	Reinforced-concrete bearing piles	☐
	Reinforced-concrete skin friction piles	☐
	Steel bearing piles	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

It is estimated that the foundations consist of field stone strip footings. However, a specific identification of the footing type is in most cases impossible. In case of new construction, the strip foundations are made out of low-strength concrete as suggested by a number of available construction manuals for Central America (e.g. GTZ COPASA, 2002).

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). Typically only one family occupies one house. The number of inhabitants in a building during the day or business hours is less than 5. The number of inhabitants during the evening and night is 5-10. The number of occupants varies. In some cases an extended family with several generations occupies the building and in other cases a single person resides in the building alone. According to ASIES (2003), 77 % of all single-family buildings in Guatemala contain 6 persons or less.

4.2 Patterns of Occupancy

4.3 Economic Level of Inhabitants

Income class	Most appropriate type
a) very low-income class (very poor)	☑
b) low-income class (poor)	☑
c) middle-income class	☑
d) high-income class (rich)	☐

The majority of occupants of adobe houses are people of a lower income level (poor). Additionally, the percentage of very poor or middle-class people living in adobe buildings is low. However, in some areas designated as cultural heritage (e.g. Antigua) well-maintained adobe buildings are used by middle-class people as their residence and also their commercial space for retail trade, hotel accommodation or other tourist industries.

Ratio of housing unit price to annual income	Most appropriate type
5:1 or worse	☐
4:1	☐
3:1	☐

1:1 or better	☑

What is a typical source of financing for buildings of this type?	Most appropriate type
Owner financed	☑
Personal savings	☑
Informal network: friends and relatives	☑
Small lending institutions / micro-finance institutions	☐
Commercial banks/mortgages	☐
Employers	☐
Investment pools	☐
Government-owned housing	☐
Combination (explain below)	☐
other (explain below)	☐

Adobe houses are mainly built with own resources of the people. There are no small lending institutions which do supply money for such investments. In the past, there might have been some ONG's doing this. In each housing unit, there are 1 bathroom(s) without toilet(s), 1 toilet(s) only and no bathroom(s) including toilet(s).

In rural areas, the bathroom or latrine is often separated from the main building (Figure 5c; all information based on interviews with local inhabitants.) .

4.4 Ownership

The type of ownership or occupancy is renting, outright ownership and ownership with debt (mortgage or other).

Type of ownership or occupancy?	Most appropriate type
Renting	☑
outright ownership	☑
Ownership with debt (mortgage or other)	☑
Individual ownership	☐
Ownership by a group or pool of persons	☐
Long-term lease	☐
other (explain below)	☐

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		Yes	No	N/A
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the	☐	☑	☐

	foundation.			
Building Configuration	The building is regular with regards to both the plan and the elevation.	☑	☐	☐
Roof construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	☐	☑	☐
Floor construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	☐	☐	☑
Foundation performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	☑	☐	☐
Wall and frame structures- redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	☑	☐	☐
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	☑	☐	☐
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	☐	☑	☐
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps	☐	☑	☐
Wall openings	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.	☑	☐	☐
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	☐	☑	☐
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).	☐	☑	☐
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)	☐	☑	☐
Additional Comments				

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	- large openings producing instabilities- missing ring beam at the top of the walls- brittle wall material deteriorated due to climatic effects (Figure 8)	- small height-to-thickness ratios lead to higher stability and reduces the susceptibility of out-of-plane failures of wall parts	- partial failure and collapse of single walls due to shear and out-of plane effects

Roof and floors	- missing friction-locked connection to the walls- large dead loads due to heavy roof tiles (inverted pendulum)- missing diaphragm- material deterioration of wooden (or metal) trusses due to weathering effects (Figure 9)	NA	- total and partial collapse of roof construction

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is A: HIGH VULNERABILITY (i.e., very poor seismic performance), the lower bound (i.e., the worst possible) is A: HIGH VULNERABILITY (i.e., very poor seismic performance), and the upper bound (i.e., the best possible) is B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance).

Vulnerability	high	medium-high	medium	medium-low	low	very low
	very poor	poor	moderate	good	very good	excellent
Vulnerability Class	A	B	C	D	E	F
	☑	☑	☐	☐	☐	☐

5.4 History of Past Earthquakes

Date	Epicenter, region	Magnitude	Max. Intensity
1902	Guatemala City	7.5	
1968	Figueroa	6.0	
1976	160 km NE of Guatemala City	75.	I = IX (MMI)
1988	Uspantán Alta Verapaz	6.0	I = VI
1991	Pochuta, Chimaltenango	6.2	I = VI

The traditional construction type of adobe bricks is also covered by the vulnerability table of the European Macroseismic Scale EMS-1998 (Grünthal (ed.) et al., 1998) where a classification into class A is suggested. Even though "methods of adobe construction vary widely" (..) which "introduces some variations in the strength of adobe houses against earthquake shaking" a general classification of adobe houses into class A with exceptions into class B is suggested. Regardless the fact that adobe buildings with wooden frames "possess added strength and perform significantly better", the brick walls suffer damage or completely fail relatively easily and thus overall not reducing the vulnerability. [NO ROOM FOR THIS COMMENT ABOVE] 1976 February 04 (09:01 UTC): A magnitude 7.5 earthquake struck about 160 km northeast of Guatemala City. It caused more than 23,000 deaths and extensive structural damage. Most adobe type buildings in the outlying areas of Guatemala City were completely destroyed (USGS Earthquake Information Bulletin, July-August 1976, Vol. 8, No. 4).

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments

Walls	The walls are built from adobe bricks w. adobe mortar	See Lopez et al. (2006):0.25 kg/cm2 (shear)Morales et al. for 'simple' adobe bricks:0.55 kg/cm2 (shear)10.3 kg/cm2 (compression)	The mix proportion is 13:4:3 (sand:lime:clay). See Lopez et al. (2006).	
Foundation	The foundation is built from rubble/field stones and/or concrete		As suggested by Morales et al., the mix of materials is 1:4:6:10 (cement:sand:gravel:field stones)	
Frames (beams & columns)				
Roof and floor(s)	The roof consists of a wood construction with clayey tiles or metal sheeting. The roof supporting structure mainly consists of wooden purlins. The floor is made of earthen materials or cast plaster (screed)			

6.2 Builder

Generally the residents erect the building himself.

6.3 Construction Process, Problems and Phasing

The construction process of adobe houses is described in a number of available manuals (e.g., GTZ COPASA, 2002) or reports (e.g. Morales M. et al.). Therein, the production of the adobe bricks, the selection criteria and preparation of the building site, as well as the single steps of construction are described. In principal this covers: 1. Selection of a building site, which is of solid ground and 'safe' (e.g. in terms of landslides). 2. Leveling of the site and the building. 3. Production of the adobe bricks using steel or wooden molds. Storing and drying of the bricks for approximately 4 weeks. 4. Excavation of the strip foundation with a depth > 40 cm and a width ~ 50% larger (20 cm broader) than the foreseen width of the adobe walls and concreting of the foundation as well as the wall base (height > 25 cm) by a mix of mortar and field stones. 5. Erection of the walls (made of the adobe bricks and adobe grout). 6. Mounting of the timber beams and purlins of the roof construction and tiling with the roofing material. 7. Furnishing of walls with plaster. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size.

6.4 Design and Construction Expertise

A considerable number of non-profit organizations and NGO's have initiated projects to strengthen, retrofit, and reconstruct traditional building types in Guatemala. This expertise is spread through training and the distribution of manuals. However, generally an architect or civil engineer is not directly involved in the construction process. Generally engineers or architects are not involved in the design or construction of this housing type. The construction process of adobe houses is described in a number of available manuals (e.g., GTZ COPASA, 2002) or reports (e.g. Morales M. et al.). Therein, the production of the adobe bricks, the selection criteria and preparation of the building site, as well as the single steps of construction are described. In principal this covers: 1. Selection of a building site, which is of solid ground and 'safe' (e.g. in terms of landslides). 2. Leveling of the site and the building. 3. Production of the adobe bricks using steel or wooden molds. Storing and drying of the bricks for approximately 4 weeks. 4. Excavation of the strip foundation with a depth > 40 cm and a width ~ 50% larger (20 cm broader) than the foreseen width of the adobe walls and concreting of the foundation as well as the wall base (height > 25 cm) by a mix of mortar and field stones. 5. Erection of the walls (made of the adobe bricks and adobe grout). 6. Mounting of the timber beams and purlins of the roof construction and tiling with the roofing material. 7. Furnishing of walls with plaster In addition to the already addressed deficits and structural features of adobe buildings with regard to their seismic resistance, a large percentage of these traditional buildings possess some further disadvantages which influence their general condition as well as their vulnerability. Earthen materials such as adobe are very susceptible to water and moisture. The (sub-)tropical climatic conditions in many parts of Guatemala, with heavy rainfall and moderate to high humidity, are a major threat to adobe housing. Rain water causes heavy material deterioration over time (Figure 9). This occurs by way of leaks in the roof or ascending moisture from the ground. Additionally, insects or rodents are more attracted by these organic materials and can contribute to the deterioration of the structural elements. In the case of those houses having no appropriate foundation or founded on unfavorable soil conditions, ground subsidence or rainwater undercutting may lead to settlements or tilting of the walls.

6.5 Building Codes and Standards

This construction type is not addressed by the codes/standards of the country.

6.6 Building Permits and Development Control Rules

This type of construction is a non-engineered, and not authorized as per development control rules. Building permits are not required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Builder and Owner(s).

6.8 Construction Economics

The unit construction cost is approximately US-$ 35 /m2. It typically takes 2 months to construct such housing.

7. Insurance

Earthquake insurance for this construction type is typically unavailable. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
insufficient wall strength	strengthening of the walls and corners by superimposed meshes or geotextiles (superficial reinforcement)
humidity in walls (Figure 08)	assembly of water barrier at the wall base
weak roof construction (Figure 09)	friction-locked connection to the walls (ring beam); increase of strength by replacing rotten wood elements
heavy roof	substitution of heavy roof tiles by (corrugated) iron sheeting

Strengthening of New Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
insufficient wall strength	internal horizontal and/or vertical reinforcement, e.g. bamboo, steel bars (Figure 10)
insufficient wall strength	addition of a ring beam made of logs, lumber or reinforced concrete (Figure 11)
insufficient wall strength	addition of corner posts or wooden diagonal corner bracings (Figure 12)
insufficient wall strength	strengthening of wall corners by wall buttresses (Figure 13)
humidity in walls	water barrier at the wall base
heavy roof	use of (corrugated) iron sheeting

weak roof construction	friction-locked connection to the walls (ring beam)

8.2 Seismic Strengthening Adopted

Has seismic strengthening described in the above table been performed in design and construction practice, and if so, to what extent?
All of the above described methods are part of design practice in different Central and South American countries. However, in Guatemala the addressed strengthening techniques are only rarely applied. One strengthening measure which was often applied is the assembly of single concrete elements (e.g. as lintels). After the 1976 earthquake, there were some efforts at the universities in Guatemala in order to improve the different construction techniques, and also to promote the use of earth-cement blocks (ferrocement) for simple houses (ref.: pers. comm. with people at the Univ. de San Carlos, Guatemala City).

8.3 Construction and Performance of Seismic Strengthening

Was the construction inspected in the same manner as the new construction?

No.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?

The owner or a contractor.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?

There is no experience in Guatemala.

Figure 8. Spalling of plaster due to ascending moisture in the adobe walls(Guatemala City, Zona 7). [Click to enlarge figures]

Figure 9. Rotten beams of the wooden roof construction.

Figure 10. Principle of internal wall reinforcement with bamboo (Universidad de El Salvador UES, 2007).

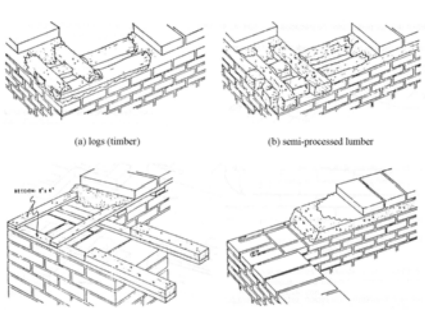

Figure 11. Different ways of strengthening adobe walls by the arrangement of ring beams (taken from Morales et al.).

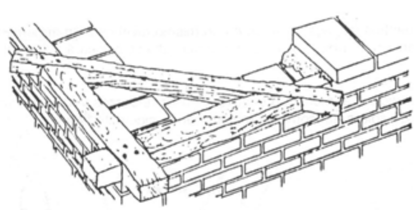

Figure 12. Strengthening of wall corners by diagonal wooden bracings (taken from Morales et al.).

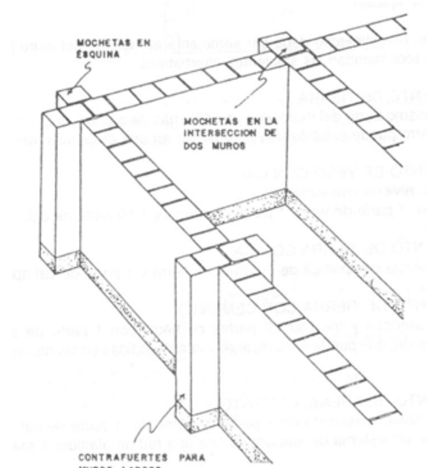

Figure 13. Strengthening of adobe walls by buttresses (taken from Morales et al.).

Figure 14. Well-maintained adobe buildings in Antigua.

Figure 15. Typical adobe buildings of residential and commercial use in Guatemala City.

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