World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

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HOUSING REPORT

Adobe / Earthen House : Adobe block walls

Report#	144
Last Updated	
Country	Guatemala
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Important

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General Information

Building Type:	Adobe / Earthen House : Adobe block walls
Country:	Guatemala
Author(s):	Dominik Lang Lisa Holliday Omar G. Flores Beleton
Last Updated:	
Regions Where Found:	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. Region Central, Region del Altiplano Occidental, and Region del Altiplano Oriental). In contrast, few adobe houses are located in coastal and low mountain regions below 1000 m, i.e. Region Costera del Pacifico, Region Seca Oriental, and Region Norte (Marroquin and Gandara, 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.
	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 thanhalf 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 Gandara, 1976). Surprisingly, the

Summary:	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.
Length of time practiced:	More than 200 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Mixed residential/commercial
Typical number of stories:	1
Terrain-Flat:	Typically
Terrain-Sloped:	Typically
Comments:	Currently, this type of construction is being built. New buildings made out of adobe walls are mainly found in rural areas. No r

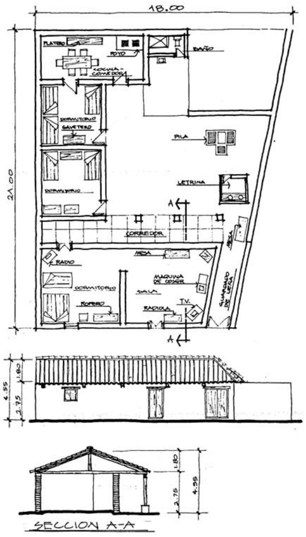
Features

Plan Shape	Rectangular, solidL-shapeU- or C-shapeOther
Additional comments on plan shape	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).
Typical plan length (meters)	
Typical plan width (meters)	

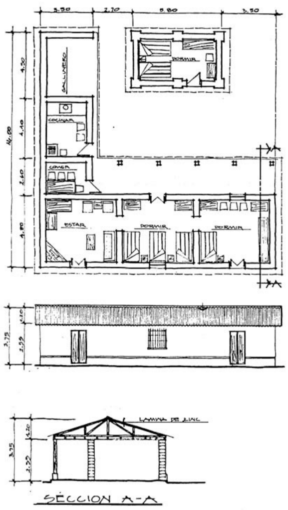
Typical story height (meters)	2.5
Type of Structural System	Masonry: Earthen/Mud/Adobe/Rammed Earth Walls: Adobe block walls
Additional comments on structural system	Lateral load-resisting system: The lateral load-resisting system is earthen walls. The lateral stiffness is provided by the massive adobe 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 and Morales M. et al.(2001) 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. Gravity load-bearing 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).
Gravity load-bearing & lateral load-resisting systems	
Typical wall densities in direction 1	>20%
Typical wall densities in direction 2	>20%
Additional comments on typical wall densities	
Wall Openings	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).
Is it typical for buildings of this type to have common walls with adjacent buildings?	Yes
Modifications of buildings	Repair of walls or changes to the building are in most cases constructed with clay 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/sq. cm. makes these modifications not really a good remedy.
Type of Foundation	Shallow Foundation: Rubble stone, fieldstone strip footing
Additional comments on foundation	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).
Type of Floor System	Other floor system
Additional comments on floor system	The floors generally consist of compacted earthen materials or cast plaster floor (screed).
Type of Roof System	Roof system, other
Additional comments on roof system	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.
Additional comments section 2	Story heights vary between 2.20 and 3.50 m. Because of the large variety of adobe buildings it is impossible to identify distinct values of plan dimensions (Figures 5 and 6). 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

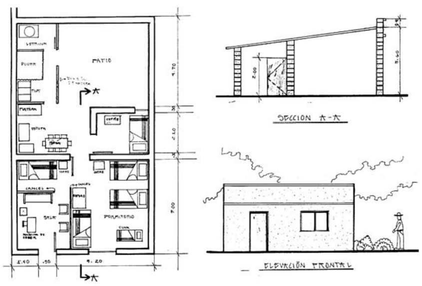
adjacent walls to neighboring buildings are common. When separated from adjacent buildings, the typical distance from a neighboring building is a range of meters.



(a) U-shaped plan in San Pedro Sacatepequez

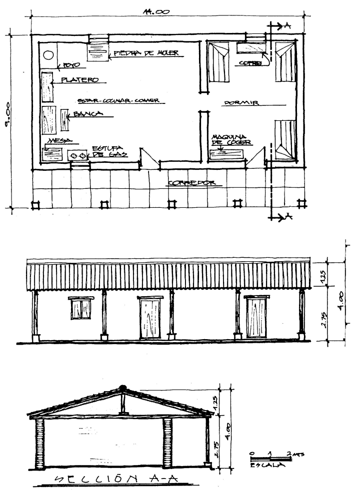


(b) L-shaped plan in San Jose Chacaya

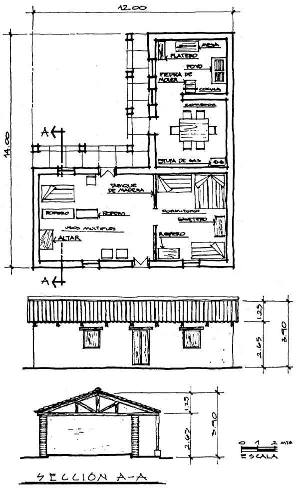


(c) L-shaped plan with mono-pitched roof in San Christobal

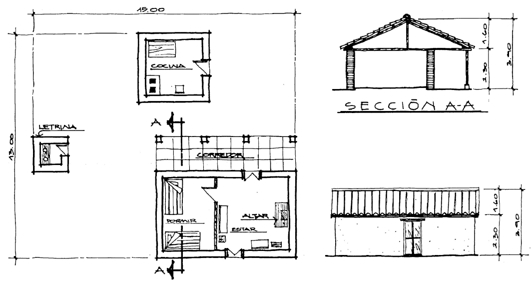
Plan shapes, cross-sections and views of typical adobe houses in urban areas



(a) rectangular plan shape in Huehuetenango



(b) L-shaped plan in San Juan Ostuncalco



(c) rectangular plan shape with separate kitchen and lavatory in Chimaltenango

Plan shapes, cross-sections and views of typical adobe houses in rural areas

Window lintels consisting of wooden trusses.

Heavily locked doors and windows by lattices in Guatemala City.

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	The walls are built from adobe bricks w. adobe mortar	Characteristic Strength- 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) Mix Proportion/Dimensions- The mix proportion is 13:4:3 (sand:lime:clay). See Lopez et al. (2006).
Foundations	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)
Floors	The floor is made of earthen materials or cast plaster (screed)	
Roof	The roof consists of a wood construction with clayey tiles or metal sheeting. The roof supporting structure mainly consists of wooden purlins.	
Other		

Design Process

Who is involved with the design process?	Other
Roles of those involved in the design process	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.
Expertise of those involved in the design process	Generally engineers or architects are not involved in the design or construction of this housing type.

Construction Process

Who typically builds this construction type?	Owner
Roles of those involved in the building process	Generally the residents erect the building himself.
Expertise of those involved in building process	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.).
Construction process 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.
	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

Construction issues	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.

Building Codes and Standards

Is this construction type address by codes/standards?	No
Applicable codes or standards	
Process for building code enforcement	

Building Permits and Development Control Rules

Are building permits required?	No
Is this typically informal construction?	Yes
Is this construction typically authorized as per development control rules?	No
Additional comments on building permits and development control rules	

Building Maintenance and Condition

Typical problems associated with this type of construction	
Who typically maintains buildings of this type?	BuilderOwner(s)
Additional comments on maintenance and building	

condition	

Construction Economics

Unit construction cost	The unit construction cost is approximately US-$ 35 /m2.
Labor requirements	It typically takes 2 months to construct such housing.
Additional comments section 3	

Socio-Economic Issues

Patterns of occupancy	Each building typically has 1 housing unit(s). Typically only one family occupies one house.
Number of inhabitants in a typical building of this construction type during the day	<5
Number of inhabitants in a typical building of this construction type during the evening/night	5-10
Additional comments on number of inhabitants	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.
Economic level of inhabitants	Very low-income class (very poor)Low-income class (poor)Middle-income class
Additional comments on economic level of inhabitants	House Price/Annual Income (Ratio) 1:1 or better. 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.
Typical Source of Financing	Owner financedPersonal savingsInformal network: friends or relatives

Additional comments on financing	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.
Type of Ownership	RentOwn outrightOwn with debt (mortgage or other)
Additional comments on ownership	
Is earthquake insurance for this construction type typically available?	No
What does earthquake insurance typically cover/cost	
Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?	No
Additional comments on premium discounts	
Additional comments section 4	

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
1902	Guatemala City
1968	Figueroa
1976	160 km NE of Guatemala City
1988	Uspantan Alta Verapaz
1991	Pochuta, Chimaltenango

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	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).
Additional comments on earthquake damage patterns	Walls: partial failure and collapse of single walls due to shear and out-of plane effects Roof/Floor: total and partial collapse of roof construction

Structural and Architectural Features for Seismic Resistance

The main reference publication used in developing the statements used in this table is FEMA 310 “Handbook for the Seismic Evaluation of Buildings-A Pre-standard”, Federal Emergency Management Agency, Washington, D.C., 1998.

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.

Structural/Architectural Feature	Statement	Seismic Resistance
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.	FALSE
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	TRUE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	TRUE
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	FALSE

	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.	N/A
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.	TRUE
Wall and Frame Structures-Redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	TRUE
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);	TRUE
Foundation-Wall Connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	FALSE
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	FALSE
Wall Openings		TRUE
Quality of Building Materials	Quality of building	FALSE

	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 a few typical buildings) is considered to be good (per local construction standards).	FALSE
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	FALSE

Building Irregularities

Additional comments on structural and architectural features for seismic resistance	
Vertical irregularities typically found in this construction type	Other
Horizontal irregularities typically found in this construction type	Other
Seismic deficiency in walls	Large openings producing instabilities- missing ring beam at the top of the walls- brittle wall material deteriorated due to climatic effects (Figure 8)
Earthquake-resilient features in walls	small height-to-thickness ratios lead to higher stability and reduces the susceptibility of out-of-plane failures of wall parts
Seismic deficiency in frames	
Earthquake-resilient features in frame	
Seismic deficiency in roof and floors	missing friction-locked connection to the walls- large dead loads due to heavy roof tiles (inverted pendulum)- missing diaphragm- material

and floors	deterioration of wooden (or metal) trusses due to weathering effects (Figure 9)
Earthquake resilient features in roof and floors	
Seismic deficiency in foundation	
Earthquake-resilient features in foundation	

Seismic Vulnerability Rating

For information about how seismic vulnerability ratings were selected see the Seismic Vulnerability Guidelines

	High vulnerability		**Medium vulnerability**		**Low vulnerability**	
	A	B	C	D	E	F
Seismic vulnerability class	o	-|				

Retrofit Information

Description of Seismic Strengthening Provisions

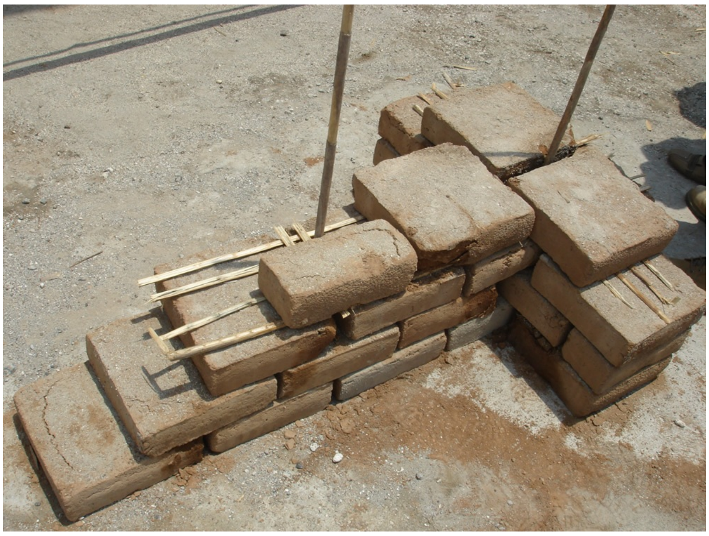
Structural Deficiency	**Seismic Strengthening**
insufficient wall strength	strengthening of the walls and corners by superimposed meshes or geotextiles (superficial reinforcement)
humidity in walls (Figure 08)	assembly of water barrier at the wall base
weak roof construction (Figure 09)	friction-locked 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

Additional comments on seismic strengthening provisions	Strengthening of New Construction: insufficient wall strength- internal horizontal and/or vertical reinforcement, e.g. bamboo, steel bars (Figure 10) addition of a ring beam made of logs, lumber or reinforced concrete (Figure 11) addition of corner posts or wooden diagonal corner bracing (Figure 12) strengthening of wall corners by wall buttresses

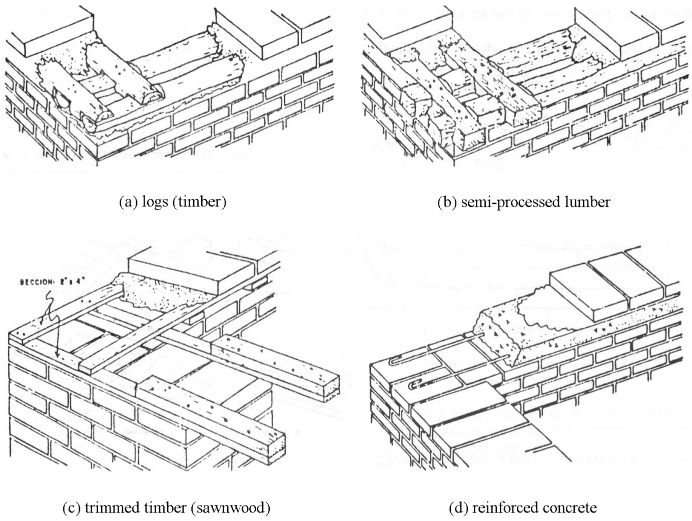
	(Figure 13) humidity in walls- water barrier at the wall base heavy roof- use of (corrugated) iron sheeting weak roof construction- friction-locked connection to the walls (ring beam)
Has seismic strengthening described in the above table been performed?	All of the above described methods are part of 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).
Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?	
Was the construction inspected in the same manner as new construction?	No
Who performed the construction: a contractor or owner/user? Was an architect or engineer involved?	The owner or a contractor.
What has been the performance of retrofitted buildings of this type in subsequent earthquakes?	There is no experience in Guatemala.
Additional comments section 6	

Spalling of plaster due to ascending moisture in the adobe walls (Guatemala City, Zona 7).

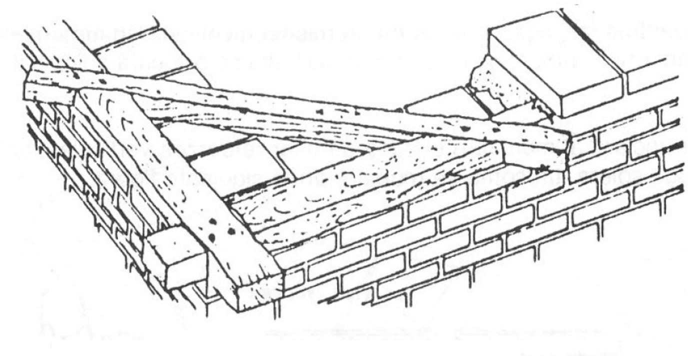
Rotten beams of the wooden roof construction.



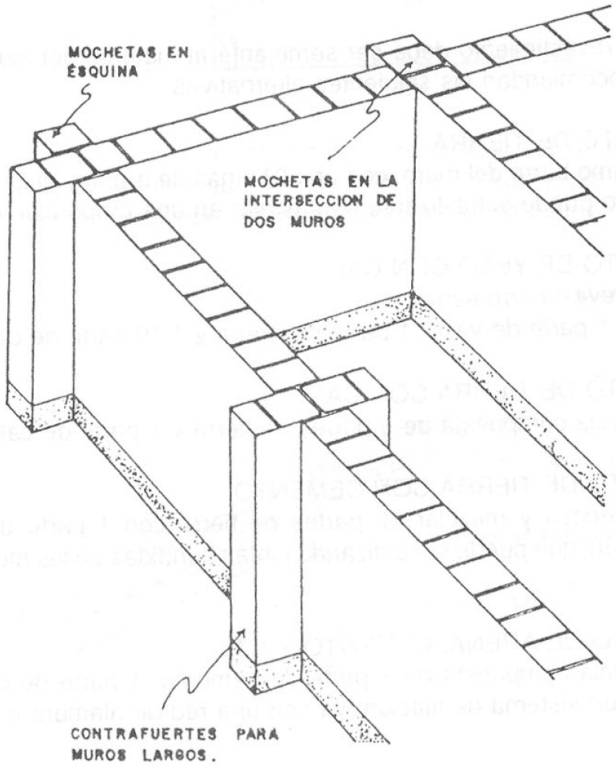
Principle of internal wall reinforcement with bamboo (Universidad de El Salvador UES, 2007).



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



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



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

Well-maintained adobe buildings in Antigua.

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

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