World Housing Encyclopedia

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

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HOUSING REPORT
Adobe with sawn timber roof framing and corrugated iron sheeting

Report #	136
Report Date	26-05-2007
Country	GUATEMALA
Housing Type	Adobe / Earthen House
Housing Sub-Type	Adobe / Earthen House : Rammed earth/Pise construction
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Summary

This very small building doubles as a home and workplace. The homeowner weaves products such as hats, clothes and mats for a living. The building functions as a showroom for her products by the day and as her house for rest at night. Three months before the site visit, the

house was washed away by Hurricane Stan that hit the Central American region. Massive rainfall led to landslides in the Lago Antilian area, where the site is located. Her house was destroyed and this is the new one constructed. This case study is characteristic of new adobe construction in the Guatemala today. Timber dowels at the top brick course help to secure the ring beam or timber roof framing to the walls. For economic reasons, the roof is corrugated iron, but the long-term plan is to place clay tiles directly over top for their thermal and aesthetic properties. This case study is testament to the trying and tenuous living conditions which the occupants face. It demonstrates that even though un-reinforced adobe fails, many have no option but to replace it with structurally fragile adobe once more.

1. General Information

Buildings of this construction type can be found in Guatemala, mostly in the highlands. The traditional construction is bajareque, which is similar to Wattle and Daube. Vertical and horizontal timber poles hold a core of stone and/or mud, and the outside is plastered with mud mix. Adobe use in urban areas is less prevalent than it has been historically. There are some historic towns, such as Antigua, which are almost completely composed of adobe dwellings relying on this romanticised past of adobe architecture to draw tourists. This type of housing construction is commonly found in both rural and urban areas.

As noted, there is a large existing building stock of adobe in urban centres, but few new buildings. The exception to this is in Guatemala city, where 'satellite settlements' on the urban fringe use adobe for economic reasons. Thin reinforced concrete frames with red fired brick infill walls is the emerging preferred method in these urban centres.

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

Currently, this type of construction is being built. In the Solola district, adobe is commonly used still, because the transport networks do not easily deliver fired brick or concrete.

Figure 1: Connection of roof framing to wall incorporating a timber ring beam.

Figure 2: Rear view of building.

Figure 3: Front view of building from road.

Figure 4: Side view of building.

Figure 5: Interior view of building

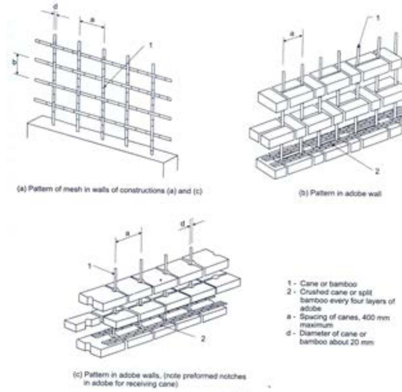

Figure 6: Bamboo reinforcing system. IAEE Guidelines, 2004, p.73.

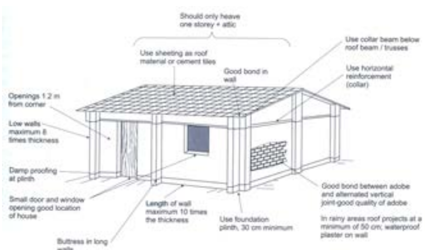

Figure 7: 'Improved Adobe' principles. IAEE Guidelines, 2004, p.75.

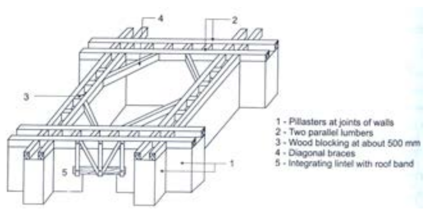

Figure 8: Timber ring beam and lintel connection. IAEE Guidelines, 2004, p.72.

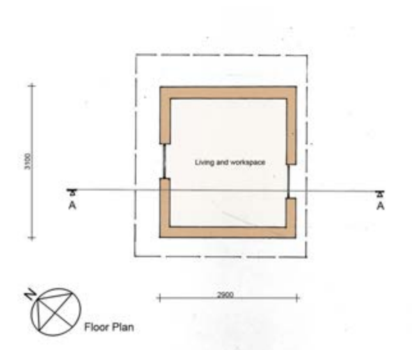

Figure 9: Floor Plan

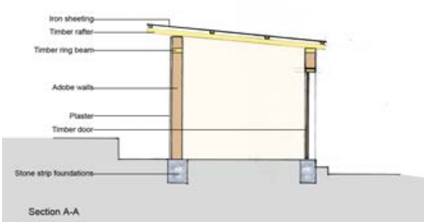

Figure 10: Section A-A

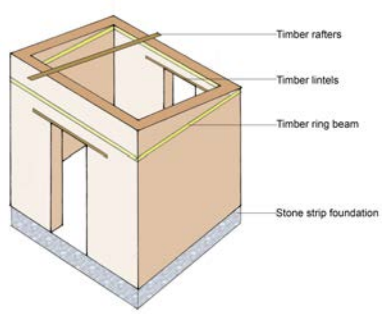

Figure 11: Load bearing structure

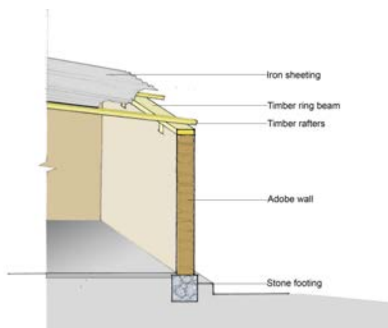

Figure 12: Elements of the building.

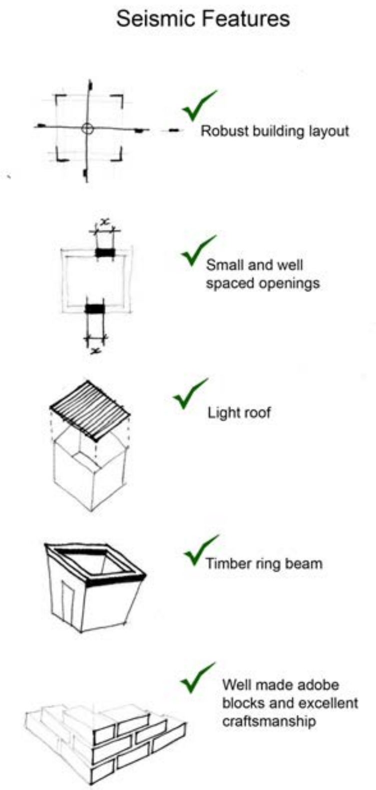

Figure 13: Seismic features of this building.

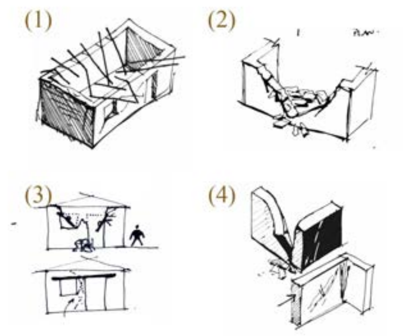

Figure 14: (1) Typically the roof collapses inwards due to reduced wall support and poor connections. The probability of this damage pattern occurring is increased when heavy roofing materials such as earth are used. (2) Wall collapse under face loads is a common earthquake damage pattern with adobe. This is especially true for long walls without mid-span buttresses. (3) Timber lintels above windows and doors typically fall due to insufficient wall support. When openings are too close together wall strength is compromised which increases the structures vulnerability to collapse by shear cracking. (4) Earthquake damage commonly occurs when building elements are not connected together adequately. Walls can separate at the corners due to poor bonding of the block courses in this area. Walls are also increasing vulnerable under seismic loads when rising moisture has eroded their base.

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. Due to the limited availability of flat land in the area, the houses are constructed very dose together When separated from adjacent buildings, the typical distance from a neighboring building is 0.5 meters.

2.2 Building Configuration

The building is well configured with respect to its plan geometry and symmetry; it is simply one square room. The building has two doors, 700mmx1800mm. There are no windows.

2.3 Functional Planning

The main function of this building typology is mixed use (both commercial and residential use). The other functions such as kitchen and bathing area are located at the rear of the site, in a separate building, 4m from this building. The interior of the building is plain and has no fixtures. In a typical building of this type, there are no elevators and no fire-protected exit staircases. There are two timber slatted doors opening inwards on opposing walls.

2.4 Modification to Building

There are no structural modifications. The exterior plaster and day roof tiles are added incrementally as funds permit. This will provide increased thermal comfort and aesthetic value. There are plans to build a timber addition on the east side.

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	☐
	Structural wall	22	Moment frame with in-situ shear walls	☐
		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	☐
		29	With brick masonry partitions	☐

Steel	Moment-resisting frame	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 others (described below). The adobe walls also act as the gravity load bearing structure. Gravity loads are transferred from the roof to the ring beam then to the wall and through to the ground.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is others (described below). Adobe shear walls act as the lateral resisting structure in both directions. The blocks measure 200mm wide, 400mm long and 100mm deep. The timber framed roof is a flexible diaphragm, and hence will play minimal role in resisting or transferring lateral loads.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 3.1 and 6 meters, and widths between 2.9 and 6 meters. The building is 1 storey high. The typical span of the roofing/flooring system is 3 meters. The typical storey height in such buildings is 2.2 meters. The typical structural wall density is none. Wall density is unknown.

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	☐	☐
	Solid slabs (cast-in-place)	☐	☐
	Waffle slabs (cast-in-place)	☐	☐
	Flat slabs (cast-in-place)		

Structural concrete		☐	☐
	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	☑	☑

Compacted earth and cement mix.

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	☐

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). 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 less than 5.

4.2 Patterns of Occupancy

The building is occupied by a mother and two children. It functions as a home and workshop.

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 owner relies on sales of woven products to tourists, hence is economimcally very vulnerable to fluctuations in the tourist market.

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)	☐

In each housing unit, there are no bathroom(s) without toilet(s), no toilet(s) only and no bathroom(s) including toilet(s).

These functions are located in another building on site. .

4.4 Ownership

The type of ownership or occupancy is 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)	☐

Non-Governmental Organisations (NGOs) played a large role in providing relief to this community after Hurricane Stan struck. The actual figures are not known, but micro-finance and small loans along with volunteer help have enabled rebuilding to occur.

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	☐	☑	☐
	The total width of door and window openings in a wall is:			

Wall openings	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	This building is well maintained as it is new, but many others are not. The workmanship is very good. The blocks and mortar joints are even, course heights level and block mix consistent. This is to be commended.			

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	The adobe walls are too thin and brittle to resist lateral in plane and face loads. Adobe is strong in compression, but very weak in tension.	Lintels have suitable anchorage back into the walls.	45° shear cracking under in-plane lateral loads occurs. This cracking increases vulnerability for wall collapse under face loads.
Frame (columns, beams)			
Roof and floors	The roof is too flexible and insufficiently connected to the walls to enable it to work as a rigid diaphragm.	The roof is light-weight minimising risk of injury.	The roof fails to hold the top of the walls in place. Wall displacement becomes too large and dislodges roof support, which in turn leads to roof collapse.
Other			

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 A: HIGH VULNERABILITY (i.e., very 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
1976	15.320N, 89.100W	7.5	9 (MMI)
1988	13.881N, 90.450W	6	6 (MMI)
1991	14.646N, 90.986W	6.2	6 (MMI)

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Adobe blocks	3-4 MPa standard block strength. Stabilised blocks up to 8 MPa. Strength depends on mix consistency when forming blocks.	Clay 30%-50% Silt 0%-20% Sand 50%-70% Straw to bind.	Mix changes with site conditions, material availability and builder.
Foundation	Stone and cement strip footing.			
Frames (beams & columns)				
Roof and floor(s)	Roof: Timber with corrugated iron Floor: Compacted earth and concrete topping		Roof: Sawn 80mm X 40mm rafters Floor: 10% concrete, 90% earth. Straw to bind.	Floor: It is not a 'concrete slab' floor, but around 10% cement was added to a earth mix.

6.2 Builder

Yes.

6.3 Construction Process, Problems and Phasing

The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size. With adobe construction a 'base' house is built as one complete project and over time other rooms (not always of adobe) are added as needed.

6.4 Design and Construction Expertise

The NGO's working in the area and help that has come to 'clean up' may have had some trained building staff. The likelihood is that no practising architect or engineer was involved in this building. Traditional knowledge and methods generated the design and construction. These people are not involved.

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

US $ 35/ m2. The house took two people two months to build.

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 New Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Walls: Adobe as a material has limited tension strength. Inadequate connections to return walls and lack of face load strength for long walls reduces strength	1. Bamboo: Several researchers have been involved with using internal horizontal and vertical bamboo, in a similar fashion to reinforced concrete masonry walls. 2. Timber ring beam: This helps to hold the walls together and facilitate transfer of loads from the roof to the walls. 3. 'Improved Adobe' has long been promoted to make adobe buildings more robust under seismic activity. The 'system' does not utilise another material, but focuses on the design and planning of adobe buildings by limiting opening sizes, plan dimensions, wall lengths and heights, and roof weight.
Roof: The roof will not work as a diaphragm to help transfer lateral loads to the ground.	A timber ring beam helps to hold the walls together and prevent them falling inwards. Galvanised sheet metal as is used here reduced roof loads, which minimises injury, if collapse occurs.

The bamboo strengthening scheme is not used in Guatemala, but is presented in this report as an option for making adobe buildings safer generally.

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?
Bamboo: Yes, it has been implemented in Peru with successful structural results but unsuccessful local adoption of the concept. The system is not used in Guatemala. Timber ring beam: These are common now, but often limited finances ensure they are out of reach for many in Guatemala. 'Improved Adobe': Some of the principles, such as small openings and walls, are used but others such as buttresses are not evident.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
All work was done as part of mitigation efforts.

8.3 Construction and Performance of Seismic Strengthening

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
Bamboo: The performance of buildings has been successful with only slight cracking and full collapse averted. Timber ring beams: These have been successful in reducing full collapse of the structure.

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