World Housing Encyclopedia

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

an initiative of
Earthquake Engineering Research Institute (EERI) and
International Association for Earthquake Engineering (IAEE)

HOUSING REPORT
Adobe walls supporting rough timber framed roof with corrugated iron sheeting.

Report #	137
Report Date	26-05-2007
Country	NICARAGUA
Housing Type	Adobe / Earthen House
Housing Sub-Type	Adobe / Earthen House : Adobe block walls
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Summary

The plan of this adobe building is a simple rectangle with three rooms. Adobe as a material is very weak under seismic loads, which is the main issue which concerns this building type. Also, the roof does not have sufficent eaves to protect the adobe walls, which has resulted in

the dislodging of the exterior plaster. This has erroded the walls, further reducing their structural strength. Adobe is commonly used in Nicaragua, as it is both affordable and accessible, but it is being replaced by more 'modern' materials, such as concrete block and red fired brick.

1. General Information

Buildings of this construction type can be found in Nicaragua, predominantly used near the Honduras border. Towns dose to Costa Rica and the Mosquito Coast area have few adobe dwellings due to their geographic location. This type of housing construction is commonly found in rural areas.

Sometimes, adobe is used in urban centres, but not extensively.

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

Currently, this type of construction is being built. Influence from its overdeveloped far northern neighbours has led to a wider adoption of newer methods of construction, such as reinforced concrete and red fired brick, minimising in the use of adobe in Nicaragua.

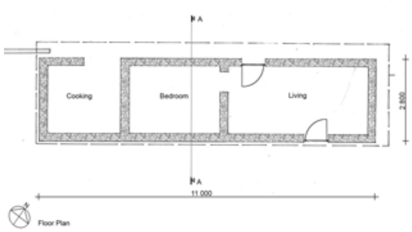

Figure 1: Plan of building

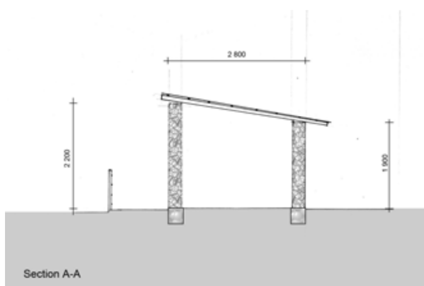

Figure 2: Section A-A

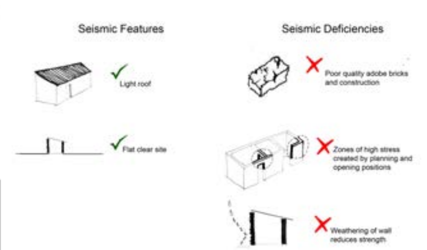

Figure 3: Seismic features and deficiencies in this building.

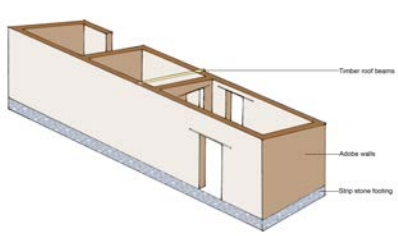

Figure 4: Load bearing structure.

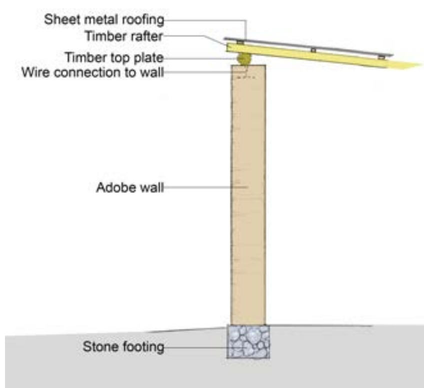

Figure 5: Wall section of loadbearing elements

Figure 6: View from the road. The exterior plaster on the left side has fallen off due to the lack of eaves.

Figure 7: Roof and wall connection.

Figure 8: Timber roof framing and plastered wall.

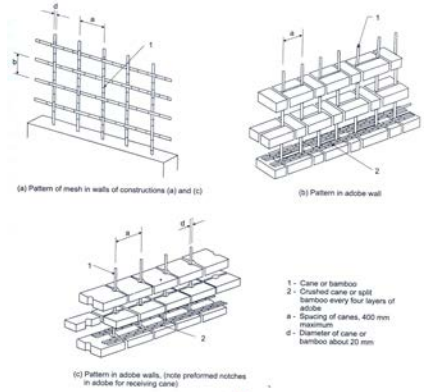

Figure 9: Bamboo reinforcing system for adobe buildings. IAEE Guidelines, 2004, p73.

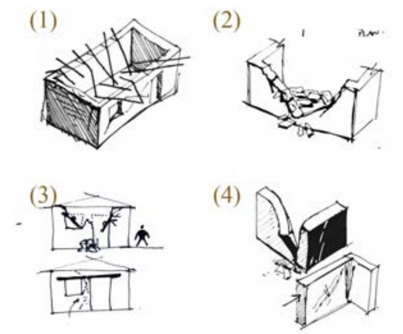

Figure 12: (1) Typically the roof collapses inwards due to reduced wall support and poor connections. The probability of this damage pattern occurring is increased when heavy roofing materials such as earth are used. (2) Wall collapse under face loads is a common earthquake damage pattern with adobe. 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.

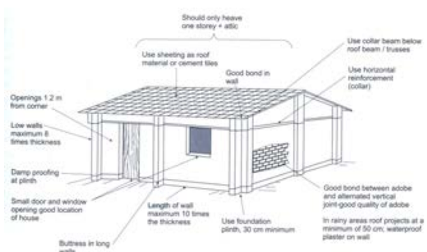

Figure 10: 'Improved adobe' suggestions. IAEE Guidelines 2004, p.75.

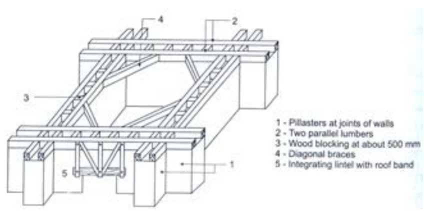

Figure 11: Timber ring beam and lintel support. IAEE Guidelines 2004, p.72.

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. When separated from adjacent buildings, the typical distance from a neighboring building is 4 meters.

2.2 Building Configuration

The building is a rectangle, composed of three rooms; two are 'weather-proof' spaces, and the third a semi indoor-outdoor kitchen. The wall facing the road is higher to account for roof pitch. The building has only one door opening on the road elevation due to the need to screen off the dust and noise. The opposing wall has one doorway and one larger break in the wall to allow access to the cooking area. The internal wall to the bedroom has one door opening. There are no windows.

2.3 Functional Planning

The main function of this building typology is single-family house. In a typical building of this type, there are no elevators and no fire-protected exit staircases. The two external doors are the exits for the building. From the 'internal' bedroom, one has to go through these two doors to exit.

2.4 Modification to Building

A work area has been added at the rear of the building, but this plays no structural part in the main dwelling being reported on here. This area is merely a roof with one wall on the road 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	☐
			Moment frame with precast	

		23	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 others (described below). The adobe walls resist gravity loads and rest on stone rubble foundations.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is others (described below). Adobe walls are relied on to resist lateral loads. The blocks measure 250mm wide, 300mm long and 100mm deep. Mortar joints average 40mm. It is unlikely the roof will work as a diaphragm due to its flexible nature and lack of connection to the walls.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 4 and 9 meters, and widths between 2.7999 and 4 meters. The building is 1 storey high. The typical span of the roofing/flooring system is 3.5 meters. The typical storey height in such buildings is 2.2 meters. The typical structural wall density is none. .

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	☑	☑

Compacted earth.

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 house is occupied by one family. It is used as a base from which the mother and daughter make food to sell on local buses as their source of income. During the evening, the whole family is present.

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)	☐

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) induding toilet(s).

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	The adobe walls have limited tension resistance under seismic loads.		The walls will crack in shear from lateral in-plane loads, or will fall in or out due to face-loads. In both cases, roof collapse may follow due to loss of wall support.
Frame (columns, beams)	Not applicable.		
Roof and floors	The roof is poorly connected to the walls, and these poor connections ensure that it can not be counted on to act as a rigid diaphragm for the transfer of loads.	The roofing material is lightwight, so the risk of injury from roof collapse is minimised.	The roof collapses due to lack of wall support and poor connections.
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
1972	12.400N	6.2	6 (MMI)
1985	11.725N	6	6 (MMI)
2004	11.424N	6.9	6 (MMI)
2005	11.198N	6.6	6 (MMI)

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Adobe	3-4 MPa standard block strength. Stabilised blocks up to 8 MPa. Final block strength depends on mixture consistency when pouring blocks.	Clay 10%-30%, Silt 0%-20%, Sand 50%-70%, Straw to bind	The mix changes with site conditions, material availability and builder preference.
Foundation	Stone and mortar		Field stones and mud	Foundation types vary widely.
Frames (beams & columns)				
Roof and floor(s)	Roof: Timber with iron sheeting Floor: Compacted earth		Roof: 100mm X 40mm sawn timber rafters laid on unsawn timber top plate. Floor: 5-10% chopped straw to bind earth	Floor: Relaid/ relevelled as required

6.2 Builder

Yes.

6.3 Construction Process, Problems and Phasing

The site is cleared. The mud block ingredients are mixed and placed in a wet mould. This is compacted and turned out to dry. While the blocks are drying, the site is further prepared. After four weeks, and several rotations of the drying block, the block is ready for final placement. The wall is constructed by simply laying one block on another with mud mortar between until the desired height is reached. The timber roof framing is laid and the corrugated iron material nailed in place. 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

Only local traditional knowledge is used in these constructions. The role of architects is minimal to none.

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 Owner(s) and No one.

6.8 Construction Economics

US $ 20/m2. Typically, adobe dwellings of this size take between 1-3 months to construct. The bricks alone must be left to dry for 3-4 weeks in the sun. As there several people on site - family, friends, and community helpers - adobe is a relatively quick and informal construction method for Nicaragua.

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 has limited tension strength. Inadequate connections to return walls, poor lintel	1. Bamboo: Several researchers have been involved with using internal horizontal and vertical bamboo, in a fashion similar 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: There is a lack of connection between roof and walls. Heavy clay tile roofs increase vulnerability.	Adequate connections to a top timber or concrete ring beam and stronger connections in the framing itself will help the roof act as a diaghrapm. Galvanised sheet metal is now common and helps reduces high loads. For thermal and aesthetic reasons, however, clay tile continues to be used.

The bamboo strengthening scheme is not used in Nicaragua, but is presented here as an option for making Nicaragua buildings safer.

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 has not been used in Nicaragua. Timber ring beam: These are common now but often limited finances ensure they are out of reach for many in Nicaragua. 'Improved Adobe': Some principles are used, such as small openings and walls, but others are not evident, such as buttresses.

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

8.3 Construction and Performance of Seismic Strengthening

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
Technical assistance was used in the Bamboo implementation. Timber ring beams are often incorporated in new constructions by the occupants.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
The bamboo system and timber ring beams have proven structurally successful in earthquakes.

Reference(s)

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