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
Vivienda de Adobe (Adobe house)

Report #	14
Report Date	06-05-2002
Country	EL SALVADOR
Housing Type	Adobe / Earthen House
Housing Sub-Type	Adobe / Earthen House : Adobe block walls
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Reviewer(s)	Sergio Alcocer

Summary

This housing type can be found in rural and urban areas. Rural: Adobe houses are generally small structures, 5 x 6 m in the plan, having load-resistant walls made of adobe bricks between 0.3 and 0.5 m thick. Usually, they are single-family (5-person) houses. Wood planks that support metal sheets covered by tiles sometimes constitute the roof. In some cases, the roof can be a thatched roof supported on wood purlins. Urban: Adobe houses are much bigger in

urban areas than in rural areas. They are one-floor structures and their plans are 15 x 30 m or larger. The wall thickness can easily reach 1 m and wall height can reach 3 m or more. In both the cases mentioned above, the adobe housing type has performed badly in earthquakes. Its heavy roof sometimes can be its biggest weakness and its unreinforced walls make this house vulnerable to earthquake effects.

1. General Information

Buildings of this construction type can be found in the entire country. San Salvador, the capital of El Salvador, is perhaps the only area where this construction type does not exist. The San Salvador Metropolitan building and planning agency (OPAMSS) and the Vice Secretary of Housing (ViceMinisterio de Vivienda) have prohibited the construction of adobe housing due to its poor seismic performance. The Vice Secretary allows adobe houses only in regions declared as ecological areas. This type of housing construction is commonly found in both rural and urban areas.

This housing type is no longer permitted in urban areas.

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

Currently, this type of construction is being built. This construction practice was, and still is, widely used in El Salvador although this region is highly seismic. El Salvador's earthquakes of 2001, and their aftershocks, mainly destroyed dwellings built with adobe; unfortunately, however, people are still using this construction type to rebuild their shelters.

Figure 1: Typical Building

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. Adobe houses have independent walls between each other, however spacing between those walls is scarce in most of the cases When separated from adjacent buildings, the typical distance from a neighboring building is 0 meters.

2.2 Building Configuration

The typical shape of a building plan for this housing type is rectangular. Rural: Houses have four walls, two of which have openings. Openings are less than or equal to 30% of the wall area. The other two walls generally do not have openings. Urban: There is a number of openings in these houses. The amount of openings can be as high as 50%.

2.3 Functional Planning

The main function of this building typology is single-family house. Some houses also include commercial space, especially in towns in urban areas. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. Houses have a main entrance and have exits to an internal patio in urban areas. In rural areas, houses have two doors, each of which is located at opposite walls of the structure.

2.4 Modification to Building

There is no modification from the original structure.

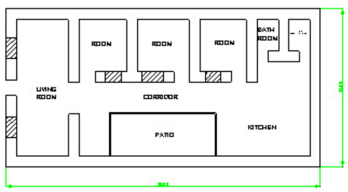

Figure 2A: Plan of a Typical Building

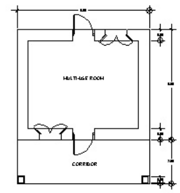

Figure 2B: Plan of a typical rural dwelling

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	☐
	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	☐

Structural concrete		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	☐
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. Roof loads are directly transmitted to the shear walls by wood purlins or beams. The beams directly rest on the top of the walls. Walls take the entire gravity load. Walls transfer the load to the foundation.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is earthen walls. The adobe walls that act as shear walls providing the lateral stiffness. In urban areas, the thickness of the walls can be as much as 1 m. In rural areas, the thickness can be between 0.3 and 0.5 m. The roof can be considered as a flexible diaphragm and is supported directly on the walls.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 30 and 30 meters, and widths between 15 and 15 meters. The building is 1 storey high. The typical span of the roofing/flooring system is 5 meters. Typical Plan Dimensions: It is for urban. For rural length is usually 6 and width 5. Typical Story Height: Height variation is 2.5 - 3 m. The typical storey height in such buildings is 3 meters. The typical structural wall density is more than 20 %. Urban: 35%. Rural: 20%.

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	☑	☑

Earth. Roof system can be considered as flexible diaphragm.

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	☐

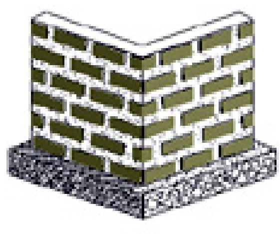
Figure 3: Key Load-bearing Elements


Figure 4A: Critical Structural Details: An illustration of wood beams supporting clay tiles and roof-walls connections


Figure 4B: Wall connections

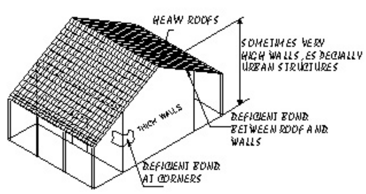

Figure 5A: An illustration of Key Seismic Features and/or Deficiencies

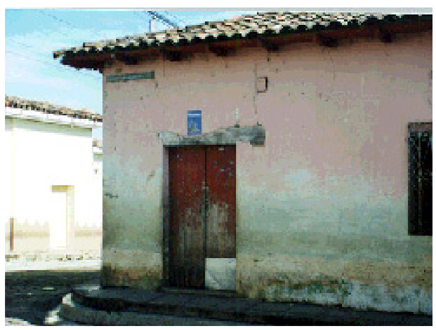
Figure 5B: Deficient bedding of lintels

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). 1 units in each building. 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.

4.2 Patterns of Occupancy

One family typically occupies one house.

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 prices are expressed in US$. Ecomomic Level: For Very Poor Class the Housing Unit Price unit is 350 and the Annual Income is 1000. For Poor Class the Housing Unit Price unit is 700 and the Annual Income is 2500. For Middle Class the Housing Unit Price unit is 12000 and the Annual Income is 20000.

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 1 bathroom(s) without toilet(s), 1 toilet(s) only and 1 bathroom(s) including toilet(s).

1 in urban areas; 1 or 0 in rural areas .

4.4 Ownership

The type of ownership or occupancy is renting, outright ownership and others.

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)	☑

Urban: Typically own outright. Rural: The landowners give a space to peasants to build their houses and to work the land. The peasants give part of their harvest to the landowner as rent.

5. Seismic Vulnerability

5.1 Structural and Architectural Features

Structural/ Architectural Feature	Statement	Most appropriate type		
		True	False	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	Wall openings are most true in the rural and may be false in urban.			

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	There is a lack of dependable joints among walls, especially at the top of walls. This causes adjacent walls to open up during an earthquake.		Damages due flexural and shear effects.
Frame (columns, beams)			
Roof and floors	There is inadequate vertical and horizontal load transfer mechanism from roof to walls.		Total and partial collapse of the roof due to material degradation and loss of support from walls.

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
1936	San Vicente	6.1	VII-VIII (SIEBERG)
1951	Jucuapa/ Chinameca	6	(MSK) VIII
1965	San Salvador	6	(MMI) VIII
1982	Pacific Ocean	7.2	(MMI) VII

1986, San Salvador, 5.4 (MMI), VIII El Salvador had two big earthquakes at the beginning of 2001. The first one was on 13 January 2001 with its epicenter located in the Pacific Ocean and with magnitude Mw= 7.7, with a maximum estimated intensity of VIII (MMI). The second one happened on 13 February 2001 with epicenter at San Juan Tepezontes and Mw= 6.5; the estimated intensity was VIII in some places, however in many of the affected areas its intensity was VII (MMI). One of the most important features of these two EQ is that they destroyed adobe housing in many places throughout El Salvador.

Figure 6A: Damage to an adobe house in the 1936 San Vincente earthquake

Figure 6B: Damage to adobe houses in the 1936 San Vincente earthquake

Figure 6C: Damage to an adobe church in the 1999 Apastepeque earthquake

Figure 6D: Wall damage (corner separation) in the 1999 Apastepeque earthquake

Figure 6E: Damage in the town of Juayua due to the January 13, 2001 earthquake

Figure 6F: Damage in the city of Cojutepeque due to the February 13, 2001 earthquake

Figure 6G: The San Jose church, Cojutepeque, damaged in the 13 February 2001 earthquake

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Adobe Brick	0.25 kg/cm^2 (Shear)	13:4:3 (sand:lime:clay) 400 mm X 200 mm X 150mm	
Foundation	Mortar		1:2 (soil: straw)	
Frames (beams & columns)				
Roof and floor(s)	Wood Tiles			

6.2 Builder

The builder typically lives in this construction type.

6.3 Construction Process, Problems and Phasing

First of all, the builder hydrates the adobe mixture, composed of 65% sand, 20% lime and 15% clay. The water volume could be 1/3 of the whole mixture volume. Bricks are made by placing this mixture into molds measuring 40 cm X 20 cm X 15 cm. After 3 days, the bricks are removed from the molds and dried for four weeks. Meanwhile, the site where the structure will be erected is leveled. Once this step is complete, excavation for the foundation begins. The width of the excavation is one and a half times the width of the wall. Both stone and mortar are placed into the hole; this will be the foundation. After the foundation is finished, the walls begin to be erected up to 2.5 m. It has to be noted that maximum height per construction day must be 1 m to avoid crushing of the walls due to its own weight. When walls reach 2.5 m, approximately, the roof is built. Wood purlins are place on top of walls spaced 20 cm between purlins. Later tiles or steel sheets are placed. 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

There is some experience to build this construction type; however, the work force is not trained. Generally, neither engineers nor architects have a role in the design, or construction of this housing type.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Norma para la Contrucción de Viviendas. An additional comment: Adobe housing is addressed by El Salvador's 1994 Building Code in an appendix; however, it gives recommendations about building better adobe housing without imposing enforcement. The year the first code/standard addressing this type of construction issued was 1994. The most recent code/standard addressing this construction type issued was 1994. Title of the code or standard: Norma para la Contrucción de Viviendas. An additional comment: Adobe housing is addressed by El Salvador's 1994 Building Code in an appendix; however, it gives recommendations about building better adobe housing without imposing enforcement. Year the first code/standard addressing this type of construction issued: 1994 When was the most recent code/standard addressing this construction type issued? 1994.

N/A.

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 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

Rural: US$ 15 /m² Urban: US$ 30 /m². Rural: 1.5 months using two people (including time for the mixture to be hydrated).

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. N/A.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Walls: There is lack of dependable joints among walls, especially at the top of walls. This causes adjacent walls to open up during an earthquake.	Collar Beam or Lintel Band: This feature ties the walls together. Buttresses: This feature helps to retain the integral action of walls and facilitate the connection of collar beams with each other. Vertical and Horizontal Reinforcement using bamboo: This features tries to provide reinforcement similar to that for concrete structures. Adobe bricks have to be molded appropriately to use this kind of strengthening technique.
Roof: Very heavy elements.	Sheets of metal: Use this feature instead of clay tiles

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?

Yes, it has. However, It is not widely used. It has been done as a test in some rural communities.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?

It was done as a test.

8.3 Construction and Performance of Seismic Strengthening

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

No, it was not. These houses did have supervision.

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

An ONG.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
Very good, nothing happened to them. However, they are located in an area that was not as affected by the recent earthquakes.

Figure 7A: Illustration of Seismic Strengthening Techniques

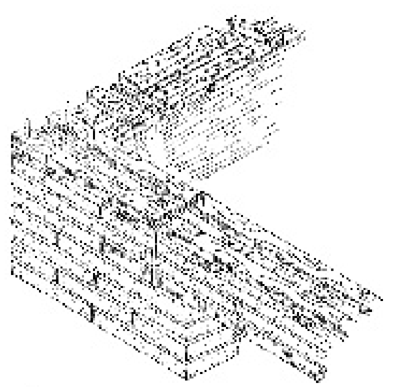

Figure 7B: Seismic Strengthening: Vertical and Horizontal Reinforcement

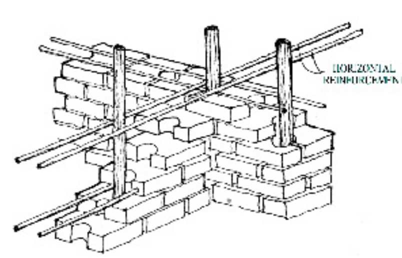

Figure 7C: Seismic Strengthening: Wall Buttresses

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