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 house

Report #	52
Report Date	05-06-2002
Country	PERU
Housing Type	Adobe / Earthen House
Housing Sub-Type	Adobe / Earthen House : Mud walls with horizontal wood elements
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Summary

This is a traditional construction practice followed for over 200 years. Houses of this type can be found both in urban and rural areas in the coastal and highlands regions of Peru. Walls are made of adobe blocks laid in mud mortar. The roof structure is made of wood; it usually consists of timber beams with timber planks covered with a mud mortar overlay or with clay tiles or metal sheets. Houses of this type are mainly occupied by poor people. This

construction is considered to be very vulnerable to earthquake effects.

1. General Information

Buildings of this construction type can be found in the Peruvian coastal and highland regions. This type of housing construction is commonly found in both rural and urban areas. This construction type has been in practice for more than 200 years.

Currently, this type of construction is being built. This is a traditional construction practice followed for over 200 years.

Figure 1: Typical Building

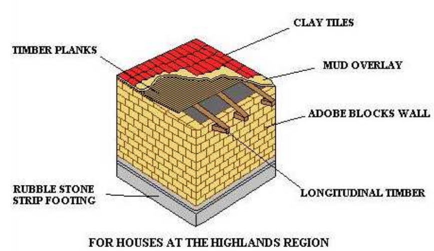

Figure 2B: Key Load-Bearing Elements for Houses in the Coastal Region

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat, sloped and hilly terrain. They do not share common walls with adjacent buildings. There is no separation between houses When separated from adjacent buildings, the typical distance from a neighboring building is 0 meters.

2.2 Building Configuration

Building plan is typically of a regular shape, usually rectangular or square. Typically one door or window opening per wall. It is estimated that the window and door widths constitute approximately 30 - 40% of the total wall length.

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 1-2 fire-protected exit staircases. Usually there is one main door at the house façade and one auxiliary door at the rear part. Both doors can be used in case of emergency.

2.4 Modification to Building

In the coastal region it is common that owners build an additional floor with quincha. This material consists of wood planks filled with bamboo and covered with mud or gypsum.

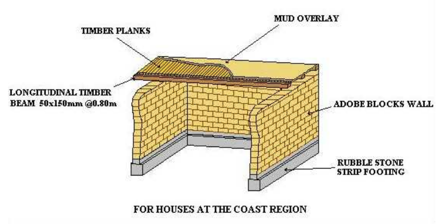

Figure 3: Plan of a Typical Building

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	☐
		24	Moment frame	☐

	Precast concrete	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). Adobe block walls carry gravity loads due to roof self-weight and transmit them to the foundations. Wood lintels assist in resisting the gravity loads at wall openings.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is others (described below). Adobe block walls provide resistance to lateral loads. The wood roof structure is considered to be a flexible diaphragm in the analysis. Wall corners (junctions) are very vulnerable parts of the structure. Typical wall thickness varies from 300 to 800 mm.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 9 and 9 meters, and widths between 8 and 8 meters. The building is 1 storey high. The typical span of the roofing/flooring system is 6 meters. Typical Plan Dimensions: Length varies from 8 to 10 m. Width varies from 5 to 10 m. Typical Story Height: In the coastal region, the typical story height is 4.0 m; in the highland region the height is 3.0 m. Typical Span: Span varies from 3 to 6 m. The typical storey height in such buildings is 4.0 meters. The typical structural wall density is more than 20 %. 20% - 40%.

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	☐	☑

Floor/roof is not considered to be a rigid diaphragm in the analysis.

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	☐

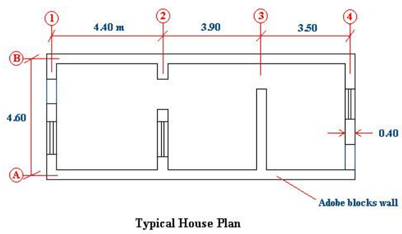

Figure 4: Critical Structural Details

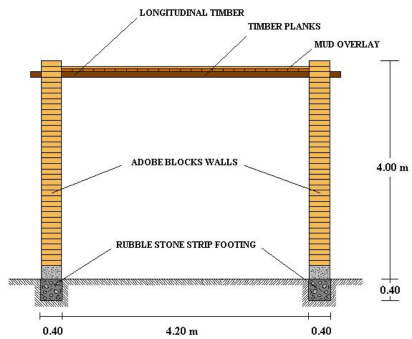

Figure 5A: Key Seismic Deficiencies - Adobe Wall Failure Due to Out-of-Plane Seismic Forces


Figure 5B: Key Seismic Deficiencies - Wall Damage Due to Inadequate In-Plane Seismic Resistance

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

Typically occupied by extended families.

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)	☐

Economic Level: For Very Poor Class the Housing Unit Price is 1,500 and the Annual Income is 700. For Poor Class the Housing Unit Price is 5,000 and the Annual Income is 1,000.

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	Most appropriate type

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).

Typically one bathroom per house. .

4.4 Ownership

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

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.	☐	☑	☐
	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its			

Floor construction	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	-Adobe block walls have poor tensile and shear resistance. -Wall corners are rather vulnerable. -Walls have low resistance to out-of- plane seismic forces.	-Steel mesh keeps walls working as a unit. -Wooden beams act as lintels	Wall shear cracking
Frame (columns, beams)			
Roof and floors	Roof behaves as a flexible diaphragm.		

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
1970	Chimbote	7.8	VI (MMI)
1974	Lima	7.7	VIII (MMI)
1996	Nazca	7.3	VII (MMI)

Figure 6A: A Photograph Illustrating Typical Earthquake Damage (November 1996 Nasca Earthquake)

Figure 6B: A Photograph Illustrating Typical Earthquake Damage (November 1996 Nasca Earthquake)

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Adobe piles	- Compression 1.20 MPa - Shear 25 kPa	Masonry mortar mix 1:5 cement/sand mortar Masonry brick dimensions: 400mm	Mortar mix proportion changes significantly the resistance of a pile

			X 18mm X 10 mm	of adobe blocks
Foundation	Adobe piles	- Compression 1.20 MPa - Shear 25 kPa	Masonry mortar mix 1:5 cement/sand mortar Masonry brick dimensions: 400mm X 18mm X 10 mm	
Frames (beams & columns)				
Roof and floor(s)	Wood	- Tension (parallel with the grain): 41 MPa - Compression (perpendicular to the grain): 4 MPa - Shear: 1.5 MPa		

6.2 Builder

Builders typically live in these houses, however there are few houses built by professional construction companies.

6.3 Construction Process, Problems and Phasing

Typically constructed by village artisans. Process starts with the selection of a good soil to make the adobe blocks. The soil needs to have an adequate proportion of day. Subsequently, adobe blocks are prepared using wood molds and left to dry for minimum 15 days. A rubble stone strip footing is made, with a minimum depth of 0.40 m. After the wall height is reached, a wood beam is laid atop the adobe block wall with transverse timber planks laid over them. Finally, walls are covered with a cape of mud mortar. The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size.

6.4 Design and Construction Expertise

Professional engineers do not have too much design experience related to this housing type. It is typically built by village artisans. It is not common that engineers and architects participate in the construction process, as this is typically an informal construction. However in big projects financed by the Peruvian Government or other institutions, engineers would be in charge of the construction process and the structural design, and architects would be in charge of the architectural design.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Peruvian Adobe Structures Code. The year the first code/standard addressing this type of construction issued was 1977. The most recent code/standard addressing this construction type issued was 1998. Title of the code or standard: Peruvian Adobe Structures Code Year the first code/standard addressing this type of construction issued: 1977 When was the most recent code/standard addressing this construction type issued? 1998.

There is no process for building code enforcement in rural areas. However, for construction in urban areas and for big projects it is necessary to obtain the approval of municipal authorities. .

6.6 Building Permits and Development Control Rules

This type of construction is a non-engineered, and authorized as per development control rules.

In urban areas, building permits are required for this construction type, however in rural areas this construction is typically informal and consequently building permits are not required. 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

This cost is variable, but an average value could be around $US 20/m². The unit cost can be lower than the value provided if the owners contribute with their own labor. It will take approximately 1 month to complete the construction of a typical one-storey house.

7. Insurance

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

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Adobe walls- Lack of confinement	Adobe walls are confined with reinforced concrete tie columns and beams. Concrete columns are cast against the serrated endings of adobe walls. This is a very good seismic strengthening system, however it could be expensive for owners.
Lack of integrity- adobe walls	A wood beam is cast atop the walls, keeping them united during an earthquake. It is an inexpensive system (see FIGURE 7C).
Adobe walls-poor in-plane and out-of-plane resistance	A steel mesh fixed with metal plates is installed to strengthen the adobe walls. The mesh is applied on both wall surfaces and at the wall corners. This is a very effective and inexpensive strengthening system, developed at the Catholic University of Lima

Strengthening of New Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Improved integrity of adobe walls	A wooden beam is cast atop the walls, keeping them united during an earthquake. Rectangular wood beams are used as lintels (see FIGURE 7C).
Reinforcing of walls with bamboo cane reinforcement	Bamboo cane is used in adobe walls to provide ductility and improve tensile resistance. This is a very effective and inexpensive strengthening system. Cane does not increase significantly the lateral resistance, however lateral drifts are reduced (see FIGURE 7B).

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, all of them had been performed.

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

The work was done in both cases.

8.3 Construction and Performance of Seismic Strengthening

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

Yes.

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

Owners perform the construction, supervised by a structural engineer.

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

Very good performance; house collapse was avoided.

Figure 7A: Illustration of Seismic Strengthening Techniques

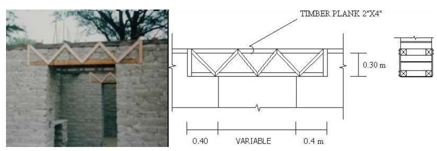

Figure 7B: Seismic Strengthening - Cane Reinforcement of Adobe Walls


Figure 7C: Seismic Strengthening - Construction of Wooden Beams atop the Adobe Walls

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