
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

Reinforced Adobe

Report #	107
Report Date	30-12-2009
Country	PERU
Housing Type	Adobe / Earthen House
Housing Sub-Type	Adobe / Earthen House : Mud walls
Author(s)	Daniel Quiun
Reviewer(s)	Andrew W. Charleson

Important

This encyclopedia contains information contributed by various earthquake engineering professionals around the world. All opinions, findings, conclusions & recommendations expressed herein are those of the various participants, and do not necessarily reflect the views of the Earthquake Engineering Research Institute, the International Association for Earthquake Engineering, the Engineering Information Foundation, John A. Martin & Associates, Inc. or the participants' organizations.

Summary

This is a reinforcement system for existing adobe houses, as well as an adaptation for new adobe houses, with the objective to prevent their collapse under severe earthquakes. An extensive experimental research project was developed between 1994 and 1999, with the financial support of GTZ of Germany, the administration of CERESIS, and the execution of the Catholic University of Peru (PUCP). Several reinforcement techniques were studied, and it

was concluded that the most appropriate was to reinforce the walls with horizontal and vertical strips of wire mesh electrically welded, covered with mortar. The technique was applied in 1998 as pilot projects in 20 houses in 6 cities in Peru. Later in 1999-2000 it was extended to Chile, Bolivia, Ecuador and Venezuela. We had to wait for an earthquake to assess the effectiveness of the reinforcement. In the earthquake of June 23, 2001 ($M_w=8.4$), that affected the south of Peru, six reinforced adobe houses had no damage. Neighboring dwellings of unreinforced adobe suffered heavy damage or collapsed. This success motivated several reconstruction programs of new reinforced adobe houses in the Andean zone, in which the technique was improved and applied in more than 500 houses, which are described herein. Shaking table tests on the system used in the new houses at the Structures Laboratory of PUCP demonstrated that the reinforcement provided is effective for resisting severe earthquakes without collapse. The August 15, 2007 Pisco earthquake ($M_w8.0$), 200 km south of Lima, also provoked the collapse of many traditional adobe houses. In Ica province, 5 houses were reinforced in 1998 using the wire mesh strips, and all withstand the earthquake undamaged.

1. General Information

Buildings of this construction type can be found in the following areas of Peru: Arequipa, Moquegua, Tacna, Ica, Trujillo, Huaraz and Cuzco. This type of housing construction is commonly found in rural, sub-urban and urban areas.

Some small towns may be considered as urban areas.

This construction type has been in practice for less than 25 years.

Currently, this type of construction is being built. Several reconstruction programs in southern Peru after the 2001 earthquake are using this method of reinforcing adobe.



Figure 1: Typical small Andean town in Arequipa



Figure 2: Typical street in an Andean town



Figure 3: Main door with window centered in the wall



Figure 4: Windows and door centered in the walls

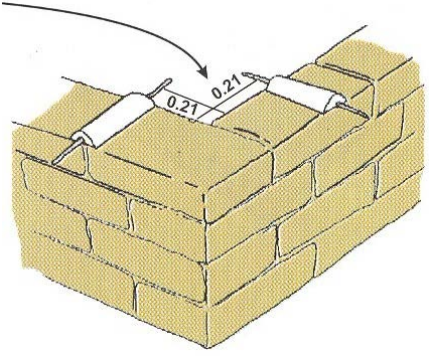


Figure 5: Wires embedded in joints for connecting the interior and exterior meshes.

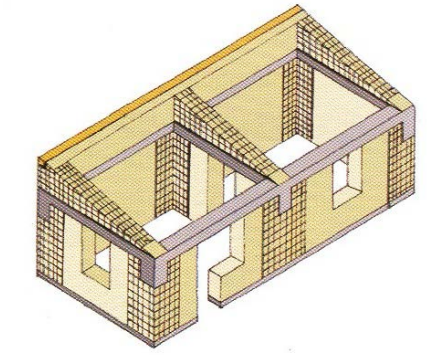


Figure 6: Roof slope and wire mesh on adobes over collar beam

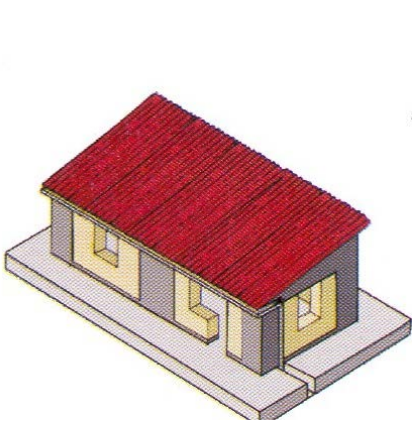


Figure 7: Roof with tiles and mortar covering the wire mesh on the walls

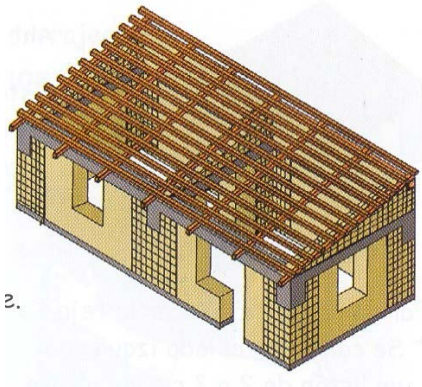


Figure 8: Wood beams for the roof

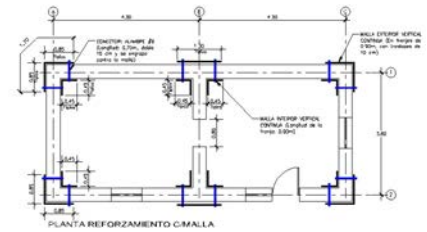


Figure 9: Plan view of reinforced adobe house

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. When separated from adjacent buildings, the typical distance from a neighboring building is 0.8 meters.

2.2 Building Configuration

A typical house has two rooms, with 36 square meters of plan area. Each room has 3.2m sides, and 2.2m height at the lowest part to 3.0m at the highest part. The thickness of the wall is 0.4m and the roof has a small slope. There is one main door with a window, and central windows in other walls.

2.3 Functional Planning

The main function of this building typology is single-family house. These types of house were repaired and reconstructed after the 2001 earthquake in southern Peru. In a typical building of this type, there are no elevators and no fire-protected exit staircases. The only means of escape is one main door, the same through which inhabitants enter.

2.4 Modification to Building

The idea is that the 36 m² module can be replicated in the remainder free area of the property.



Figure 10: A typical rural street



Figure 11: Adobe house facade with colorful tiles in Machaguay



Figure 12: Adobe house facade with Peruvian style drawings

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)	<input type="checkbox"/>
		2	Dressed stone masonry (in lime/cement mortar)	<input type="checkbox"/>
	Adobe/ Earthen Walls	3	Mud walls	<input checked="" type="checkbox"/>
		4	Mud walls with horizontal wood elements	<input type="checkbox"/>
		5	Adobe block walls	<input type="checkbox"/>
		6	Rammed earth/Pise construction	<input type="checkbox"/>
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	<input type="checkbox"/>
		8	Brick masonry in mud/lime mortar with vertical posts	<input type="checkbox"/>
		9	Brick masonry in lime/cement mortar	<input type="checkbox"/>
		10	Concrete block masonry in cement mortar	<input type="checkbox"/>
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	<input type="checkbox"/>
		12	Clay brick masonry, with concrete posts/tie columns and beams	<input type="checkbox"/>
		13	Concrete blocks, tie columns and beams	<input type="checkbox"/>
	Reinforced masonry	14	Stone masonry in cement mortar	<input type="checkbox"/>
		15	Clay brick masonry in cement mortar	<input type="checkbox"/>
		16	Concrete block masonry in cement mortar	<input type="checkbox"/>
Structural concrete	Moment resisting frame	17	Flat slab structure	<input type="checkbox"/>
		18	Designed for gravity loads only, with URM infill walls	<input type="checkbox"/>
		19	Designed for seismic effects, with URM infill walls	<input type="checkbox"/>
		20	Designed for seismic effects, with structural infill walls	<input type="checkbox"/>
		21	Dual system – Frame with shear wall	<input type="checkbox"/>
	Structural wall	22	Moment frame with in-situ shear walls	<input type="checkbox"/>
		23	Moment frame with precast shear walls	<input type="checkbox"/>
	Precast concrete	24	Moment frame	<input type="checkbox"/>
		25	Prestressed moment frame with shear walls	<input type="checkbox"/>
		26	Large panel precast walls	<input type="checkbox"/>
		27	Shear wall structure with walls cast-in-situ	<input type="checkbox"/>
		28	Shear wall structure with precast wall panel structure	<input type="checkbox"/>
Moment-resisting frame	29	With brick masonry partitions	<input type="checkbox"/>	
	30	With cast in-situ concrete walls	<input type="checkbox"/>	
	31	With lightweight partitions	<input type="checkbox"/>	

Steel	Braced frame	32	Concentric connections in all panels	<input type="checkbox"/>
		33	Eccentric connections in a few panels	<input type="checkbox"/>
	Structural wall	34	Bolted plate	<input type="checkbox"/>
		35	Welded plate	<input type="checkbox"/>
Timber	Load-bearing timber frame	36	Hatch	<input type="checkbox"/>
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	<input type="checkbox"/>
		38	Masonry with horizontal beams/planks at intermediate levels	<input type="checkbox"/>
		39	Post and beam frame (no special connections)	<input type="checkbox"/>
		40	Wood frame (with special connections)	<input type="checkbox"/>
		41	Stud-wall frame with plywood/gypsum board sheathing	<input type="checkbox"/>
Other	Seismic protection systems	42	Wooden panel walls	<input type="checkbox"/>
		43	Building protected with base-isolation systems	<input type="checkbox"/>
	Hybrid systems	44	Building protected with seismic dampers	<input type="checkbox"/>
		45	other (described below)	<input type="checkbox"/>

The structural system simulates a confined masonry system with vertical strips of cement plastered welded steel mesh as columns and identical horizontal strips as beams. The purpose of those strips is to resist the forces produced by the earthquake.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is earthen walls. Gravity loads are resisted by reinforced adobe walls. In fact, the technique of reinforcement does not improve the gravity load-resisting system substantially.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is earthen walls. Adobe walls are reinforced with strips of electrically welded wire mesh attached to the adobe wall by nails, and covered with cement mortar. A reinforced concrete collar beam is used on top of all walls.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 9 and 9.6 meters, and widths between 6 and 6.4 meters. The building is 1 storey high. The typical span of the roofing/flooring system is 3.6 meters. Typical Plan Dimensions: The roof extends 0.30 m beyond the walls. The typical storey height in such buildings is 3 meters. The typical structural wall density is up to 20%. Usually it is in the range of 10% - 14%.

3.5 Floor and Roof System

Material	Description of floor/roof system	Most appropriate floor	Most appropriate roof
Masonry	Vaulted	<input type="checkbox"/>	<input type="checkbox"/>
	Composite system of concrete joists and masonry panels	<input type="checkbox"/>	<input type="checkbox"/>
	Solid slabs (cast-in-place)	<input type="checkbox"/>	<input type="checkbox"/>
	Waffle slabs (cast-in-place)	<input type="checkbox"/>	<input type="checkbox"/>
	Flat slabs (cast-in-place)		

		<input type="checkbox"/>	<input type="checkbox"/>
Structural concrete	Precast joist system	<input type="checkbox"/>	<input type="checkbox"/>
	Hollow core slab (precast)	<input type="checkbox"/>	<input type="checkbox"/>
	Solid slabs (precast)	<input type="checkbox"/>	<input type="checkbox"/>
	Beams and planks (precast) with concrete topping (cast-in-situ)	<input type="checkbox"/>	<input type="checkbox"/>
	Slabs (post-tensioned)	<input type="checkbox"/>	<input type="checkbox"/>
Steel	Composite steel deck with concrete slab (cast-in-situ)	<input type="checkbox"/>	<input type="checkbox"/>
Timber	Rammed earth with ballast and concrete or plaster finishing	<input type="checkbox"/>	<input type="checkbox"/>
	Wood planks or beams with ballast and concrete or plaster finishing	<input type="checkbox"/>	<input type="checkbox"/>
	Thatched roof supported on wood purlins	<input type="checkbox"/>	<input type="checkbox"/>
	Wood shingle roof	<input type="checkbox"/>	<input type="checkbox"/>
	Wood planks or beams that support clay tiles	<input type="checkbox"/>	<input type="checkbox"/>
	Wood planks or beams supporting natural stones slates	<input type="checkbox"/>	<input type="checkbox"/>
	Wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles	<input type="checkbox"/>	<input checked="" type="checkbox"/>
	Wood plank, plywood or manufactured wood panels on joists supported by beams or walls	<input type="checkbox"/>	<input type="checkbox"/>
Other	Described below	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>

a floor on the ground. These are single storey houses with no suspended floors. Photos are included. Adobe houses described here are single storey.

3.6 Foundation

Type	Description	Most appropriate type
Shallow foundation	Wall or column embedded in soil, without footing	<input type="checkbox"/>
	Rubble stone, fieldstone isolated footing	<input type="checkbox"/>
	Rubble stone, fieldstone strip footing	<input checked="" type="checkbox"/>
	Reinforced-concrete isolated footing	<input type="checkbox"/>
	Reinforced-concrete strip footing	<input type="checkbox"/>
	Mat foundation	<input type="checkbox"/>
	No foundation	<input type="checkbox"/>
Deep foundation	Reinforced-concrete bearing piles	<input type="checkbox"/>
	Reinforced-concrete skin friction piles	<input type="checkbox"/>
	Steel bearing piles	<input type="checkbox"/>
	Steel skin friction piles	<input type="checkbox"/>
	Wood piles	<input type="checkbox"/>
	Cast-in-place concrete piers	<input type="checkbox"/>
	Caissons	<input type="checkbox"/>
Other	Described below	<input type="checkbox"/>

Rubble concrete strip footings are also used. The stones are up to 8 inches size. Some 4 inch stones should be attached on the upper base of the foundation for providing connectivity with the walls.



Figure 13: Plain concrete foundation



Figure 14: Bearing adobe walls are also the seismic resistant elements



Figure 15: Interior wall strips and roof wood beams

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 house is used for housework activities during the day. The number of inhabitants during the evening and night is less than 5. The house is used like a normal home.

4.2 Patterns of Occupancy

The houses are used for housework activities.

4.3 Economic Level of Inhabitants

Income class	Most appropriate type
a) very low -income class (very poor)	<input checked="" type="checkbox"/>
b) low -income class (poor)	<input type="checkbox"/>
c) middle-income class	<input type="checkbox"/>
d) high-income class (rich)	<input type="checkbox"/>

The majority of houses have precarious electricity and water mains system.

Ratio of housing unit price to annual income	Most appropriate type
5:1 or worse	<input checked="" type="checkbox"/>
4:1	<input type="checkbox"/>
3:1	<input type="checkbox"/>
1:1 or better	<input type="checkbox"/>

What is a typical source of financing for buildings of this	Most appropriate type

type?	
Owner financed	<input type="checkbox"/>
Personal savings	<input type="checkbox"/>
Informal network: friends and relatives	<input type="checkbox"/>
Small lending institutions / micro-finance institutions	<input type="checkbox"/>
Commercial banks/mortgages	<input type="checkbox"/>
Employers	<input type="checkbox"/>
Investment pools	<input type="checkbox"/>
Government-owned housing	<input type="checkbox"/>
Combination (explain below)	<input checked="" type="checkbox"/>
other (explain below)	<input type="checkbox"/>

The reconstruction programs were mainly financed by foreign government agencies. About 400 houses were constructed in the first program and around 100 houses were done in the second program. The German government through GTZ and COPASA (Peruvian institution of the Arequipa Region local government) financed 67% of the construction materials, qualified labor and technical direction. The family contributed the remainder; 33% in non-qualified labor, local materials and transportation. In each housing unit, there are no bathroom(s) without toilet(s), no toilet(s) only and no bathroom(s) including toilet(s).

Inhabitants use latrines rather than common toilets, which are located outside the house. .

4.4 Ownership

The type of ownership or occupancy is individual ownership.

Type of ownership or occupancy?	Most appropriate type
Renting	<input type="checkbox"/>
outright ownership	<input type="checkbox"/>
Ownership with debt (mortgage or other)	<input type="checkbox"/>
Individual ownership	<input checked="" type="checkbox"/>
Ownership by a group or pool of persons	<input type="checkbox"/>
Long-term lease	<input type="checkbox"/>
other (explain below)	<input type="checkbox"/>

The family contributes a certain percentage of the total price of the house (33%).

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.	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Building Configuration	The building is regular with regards to both the plan and the elevation.	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	The roof diaphragm is considered to be rigid and it is			

Roof construction	expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
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.	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
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.	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
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);	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Wall openings	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than 1/2 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.	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Additional Comments				

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	Adobe has low shear strength	Wire and mortar provide walls with higher lateral stiffness. The mortared mesh ties the walls of the building together to reduce the likelihood of collapse.	Diagonal shear cracks and shear friction cracks.
Frame (Columns, beams)	No frame action.		
Roof and floors	The roof is not a rigid diaphragm.		

Other	Humidity may erode lower parts of the walls.		
-------	----------------------------------------------	--	--

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is D: MEDIUM-LOW VULNERABILITY (i.e., good seismic performance), the lower bound (i.e., the worst possible) is C: MEDIUM VULNERABILITY (i.e., moderate seismic performance), and the upper bound (i.e., the best possible) is E: LOW VULNERABILITY (i.e., very good 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
	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>

5.4 History of Past Earthquakes

Date	Epicenter, region	Magnitude	Max. Intensity
2001	Atico, Arequipa	8.4	MMI VIII
2007	Pisco, Ica	8.0	MMI IX

Existing adobe houses were reinforced by adding wire mesh nailed to the walls and covered with mortar in 1998. The June 23, 2001 Mw=8.4 Atico earthquake produced no damage to the reinforced adobe houses, while neighboring houses had severe cracks or collapsed. The 2007 August 15 earthquake in Pisco also affected many adobe houses, but five reinforced adobe houses in Ica province remained undamaged.



Fig. 16: Inspection after 2001 Earthquake in Moquegua: reinforced house without damage and neighboring unreinforced house with severe damage,



Fig. 17: Interior of adobe house of Fig 16, with the owner, Mr. Fanegas.



Fig. 18: Adobe house reinforced with strips of wire mesh, undamaged after 2001 earthquake in Moquegua.



Fig. 19: House in Ica after the 2007 earthquake, reinforced walls undamaged.



Fig. 20: Collapsed houses in the same block as the reinforced house of Fig. 19, after the 2007 earthquake in Ica.



Figure 21: Demonstration house with partial reinforcement in Parcona, Ica. This is the station of the Peruvian Geophysical Institute, in which a peak acceleration of 0.49g was recorded.



Figure 22: House reinforced in 1998 in Ica; after the 2007 earthquake. Owner Mr. Legua receives visitors showing undamaged adobe walls.



Fig. 23: Houses next to the one shown in Fig. 22, with heavy damage, Ica, 2007.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/ dimensions	Comments
Walls	Houses are made of Adobe.	The axial compressive strength is 0.8 MPa or less. The material has a poor shear strength, which is the reason why it needs to be reinforced	Adobe is a mixing among soil, water and straw. The proportion between mud and straw is 5 :1. The purpose of straw is to prevent the adobe from cracking. Adobe units size: 400mmx400mmx100 mm	In some parts of the country, additional materials are added for making adobe.
Foundation	Rubble concrete	Rubble concrete has a moderate strength for axial loads.	Cement:coarse sand 1:10 plus 40% of stones (6" maximum size).	The coarse sand and stones must be carefully chosen to avoid premature failures.
Frames (beams & columns)				
Roof and floor(s)	The house has roof beams made of wooden logs.			

6.2 Builder

These houses are built by trained masons with the aid of the owners.

6.3 Construction Process, Problems and Phasing

The procedure is similar to plain masonry houses, from foundations until roof. First, a rubble strip foundation is done following the former specifications. Then, stem walls are built over the foundation. Adobe units are placed with mud mortar to build the walls, according to former described procedures. Connector wires are left inside the mortar

joints (these ones with cement mortar). Then, the corners are reinforced with welded mesh strips, which are nailed to the adobe walls. Hereafter, a collar concrete reinforced beam is built around the top of all walls. Finally it is time to make the sloped roof. For this purpose, wood beams are used and finally the roof is made of metal sheets or day looking sheets. 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 the case of existing adobe construction of the reinforcement is designed. The places to put the mesh strips are carefully determined.

6.4 Design and Construction Expertise

A mason with experience of mixing and placing mortar is required. Engineers have developed the reinforcing system.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. The Peruvian National Building Code, has a section for Adobe, called "Norma E.080".

The Code is prepared by a technical committee in SENCICO, a governmental agency. Later it is approved by the Ministry of Housing and becomes mandatory for all the country.

6.6 Building Permits and Development Control Rules

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

A. 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 Tenant(s).

6.8 Construction Economics

The average cost of each of 400 houses was US \$1714, of which 33% was provided by the family and 67% by the COPASA-GTZ project. The family provided low quality hand labor and local materials. The project provided the cement, wire mesh and steel bars and the technical guidance.



Fig. 24: Reinforcement of existing house of Fig. 19 in Ica, in 1998. Workers mark position for horizontal strip.



Fig. 25: Placement of vertical strip of mesh at a corner



Fig. 26: Conector wires for confining the wall between vertical strips.

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. The new houses built after the 2001 earthquake received financial support from GTZ (67% on average).

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Fragile material	Reinforced by wire mesh covered with cement mortar
Lack of reinforcement	Vertical strips of wire mesh attached externally to both sides of the walls at corners
Lack of collar beams	Horizontal strips of wire mesh attached externally to both sides of the walls

Strengthening of New Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Bad soil conditions	Plain concrete strip foundations
Lack of rigid diaphragm	A RC collar beam upon all the walls.

National Building Code in Peru issued in 2006 includes a special chapter on adobe (called Norma E.080 in Spanish).

Among the recommended reinforcement systems, the use of wire meshes are specified.

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, in rural areas of Arequipa and Moquegua regions after the 2001 earthquake (more than 500 house units).

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

New housing units were constructed after the destruction caused by the 2001 earthquake.

8.3 Construction and Performance of Seismic Strengthening

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

Yes, 2 PUCP professors visited the rural areas in 2003 for one week.

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

The project by GTZ-COPASA-SENCICO provided technical assistance and the owner/user provided low quality handwork.

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

In 1998, six similar existing adobe houses were retrofitted (in Moquegua and Tacna regions), and withstood the M8.4 2001 earthquake undamaged. Later, five similar existing adobe houses were retrofitted in Ica region, and withstood the M8.0 2007 Pisco earthquake undamaged.



Fig. 27: For new houses, check the width of joints and use connector wires in the joint



Fig.28: Form used for units and mud mortar mix



Figure 29: Adobe units under construction



Fig. 30: Adobe walls under construction



Fig. 31: Strips of wire mesh nailed to the corners, and wood collar beam.



Fig. 32: Model tested in PUCP shaking table, with some damage under severe earthquake.

Reference(s)

1. EFFECTIVE SYSTEM FOR SEISMIC REINFORCEMENT OF ADOBE
Angel SAN BARTOLOME, Daniel QUIUN and Luis ZEGARRA
13th World Conference on Earthquake Engineering 2004
2. PERFORMANCE OF REINFORCED ADOBE HOUSES IN PISCO, PERU
Angel SAN BARTOLOME, Daniel QUIUN, Luis ZEGARRA
14th World Conference on Earthquake Engineering 2008
3. Norma Tecnica de Edificacion NTE E.080 ADOBE
SENCICO
SENCICO 2000
4. Manual de Construcciones Sismo Resistentes en Adobe
GTZ-COPASA
Editorial Regentus 2005

Author(s)

1. Daniel Quiun, Catholic University of Peru
Av. Universitaria cdra. 1801, San Miguel Lima 32, PERU
Email:dquiun@pucp.edu.pe FAX: 51-1-6262813

Reviewer(s)

1. Andrew W. Charleson
Associate Professor
School of Architecture, Victoria University of Wellington
Wellington 6001, NEW ZEALAND
Email:andrew.charleson@vuw.ac.nz

Save page as

