World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

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

HOUSING REPORT
Reinforced Adobe

Report#	107
Last Updated	
Country	Peru
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Important

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General Information

Building Type:	Reinforced Adobe
Country:	Peru
Author(s):	Daniel Quiun
Last Updated:	
Regions Where Found:	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.
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 itwas 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 (Mw=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 (Mw8.0), 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.
Length of time practiced:	Less than 25 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Single dwelling
Typical number of stories:	1
Terrain-Flat:	Typically
Terrain-Sloped:	Typically
Comments:	Several reconstruction programs in southern Peru after the 2001 earthquake are using this method of reinforcing adobe.

Features

Plan Shape	Rectangular, solid
Additional comments on plan shape	
Typical plan length (meters)	9-9.6
Typical plan width (meters)	6-6.4
Typical story height (meters)	3
Type of Structural System	Masonry: Earthen/Mud/Adobe/Rammed Earth Walls: Mud walls
Additional comments on structural 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. 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
	The structural system simulates a confined masonry

Gravity load-bearing & lateral load-resisting systems	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.
Typical wall densities in direction 1	10-15%
Typical wall densities in direction 2	10-15%
Additional comments on typical wall densities	The typical structural wall density is up to 20 %. Usually it is in the range of 10% - 14%.
Wall Openings	There is one main door with a window, and central windows in other walls.
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	The idea is that the 36 m2 module can be replicated in the remainder free area of the property.
Type of Foundation	Shallow Foundation: Rubble stone, fieldstone strip footing
Additional comments on foundation	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.
Type of Floor System	Other floor system
Additional comments on floor system	A floor on the ground. These are single storey houses with no suspended floors. Photos are included. Adobe houses described here are single storey.
Type of Roof System	Roof system, other
Additional comments on roof system	Wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles
Additional comments section 2	When separated from adjacent buildings, the typical distance from a neighboring building is 0.8 meters. 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.

A typical rural street

Adobe house facade with colorful tiles in Machaguay

Adobe house facade with Peruvian style drawings

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	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.
Foundations	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.
Floors		
Roof	The house has roof beams made of wooden logs.	
Other		

Design Process

Who is involved with the design process?	EngineerBuilder
Roles of those involved in the design process	Engineers have developed the reinforcing system.
Expertise of those involved in the design process	

Construction Process

Who typically builds this construction type?	OwnerMason
Roles of those involved in the building process	These houses are built by trained masons with the aid of the owners.
Expertise of those involved in building process	A mason with experience of mixing and placing mortar is required.
	The procedure is similar to plain masonry houses, from foundations until roof. First, a rubble strip

Construction process and phasing	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 clay 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.
Construction issues	

Building Codes and Standards

Is this construction type address by codes/standards?	Yes
Applicable codes or 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.
Process for building code enforcement	

Building Permits and Development Control Rules

Are building permits required?	Yes
Is this typically informal construction?	Yes
Is this construction typically authorized as per development control rules?	Yes

Additional comments on building permits and development control rules	

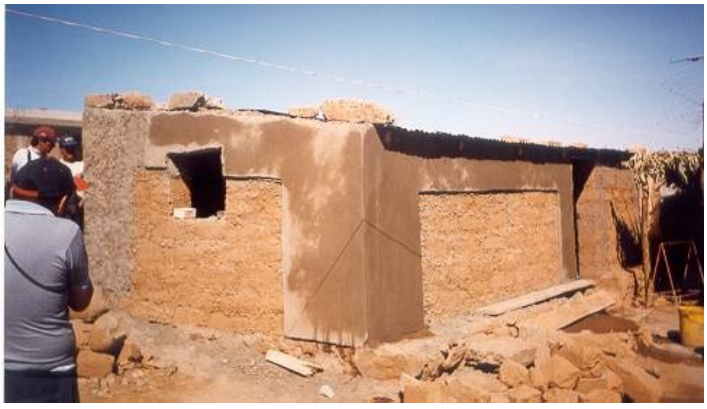
Building Maintenance and Condition

Typical problems associated with this type of construction	
Who typically maintains buildings of this type?	Owner(s)Renter(s)
Additional comments on maintenance and building condition	

Construction Economics

Unit construction cost	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.
Labor requirements	
Additional comments section 3	

Plain concrete foundation



Bearing adobe walls are also the seismic resistant elements

Interior wall strips and roof wood beams

Socio-Economic Issues

Patterns of occupancy	The houses are used for housework activities.
Number of inhabitants in a typical building of this construction type during the day	<5
Number of inhabitants in a typical building of this construction type during the evening/night	<5
Additional comments on number of inhabitants	
Economic level of inhabitants	Very low-income class (very poor)
Additional comments on economic level of inhabitants	Ratio of housing unit price to annual income: 5:1 or worse The majority of houses have precarious electricity and water mains system.

Typical Source of Financing	Combination
Additional comments on financing	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.
Type of Ownership	Units owned individually (condominium)
Additional comments on ownership	The family contributes a certain percentage of the total price of the house (33%).
Is earthquake insurance for this construction type typically available?	No
What does earthquake insurance typically cover/cost	
Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?	No
Additional comments on premium discounts	
Additional comments section 4	The new houses built after the 2001 earthquake received financial support from GTZ (67% on average).

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
2001	Atico, Arequipa
2007	Pisco, Ica

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	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.
Additional comments on earthquake damage patterns	Diagonal shear cracks and shear friction cracks. (Walls)

Structural and Architectural Features for Seismic Resistance

The main reference publication used in developing the statements used in this table is FEMA 310 “Handbook for the Seismic Evaluation of Buildings-A Pre-standard”, Federal Emergency Management Agency, Washington, D.C., 1998.

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.

Structural/Architectural Feature	Statement	Seismic Resistance
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.	N/A
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	TRUE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	TRUE

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.	FALSE
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.	N/A
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.	TRUE
Wall and Frame Structures-Redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	FALSE
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);	N/A
Foundation-Wall Connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	TRUE
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at	FALSE

	each diaphragm level with metal anchors or straps.	
Wall Openings		TRUE
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	TRUE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	TRUE
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	FALSE

Building Irregularities

Additional comments on structural and architectural features for seismic resistance	
Vertical irregularities typically found in this construction type	Other
Horizontal irregularities typically found in this construction type	Other
Seismic deficiency in walls	Adobe has low shear strength
Earthquake-resilient features in walls	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.
Seismic deficiency in frames	No frame action.

Earthquake-resilient features in frame	
Seismic deficiency in roof and floors	The roof is not a rigid diaphragm
Earthquake resilient features in roof and floors	
Seismic deficiency in foundation	
Earthquake-resilient features in foundation	

Seismic Vulnerability Rating

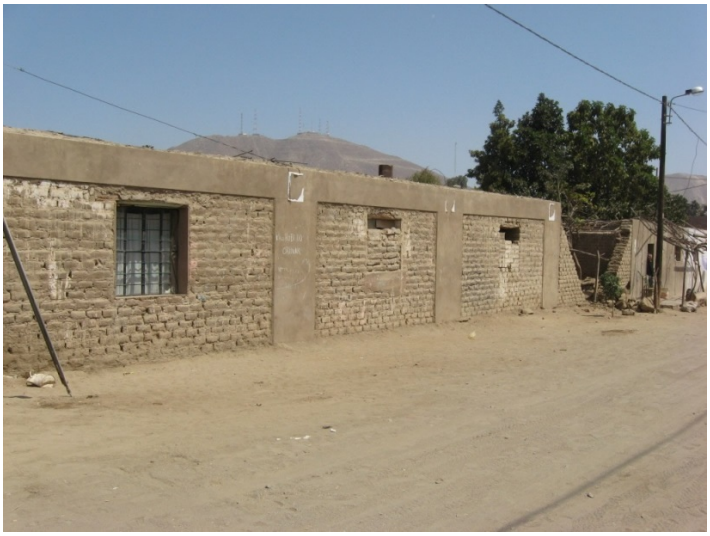
For information about how seismic vulnerability ratings were selected see the Seismic Vulnerability Guidelines

	High vulnerability		**Medium vulnerability**		**Low vulnerability**	
	A	B	C	D	E	F
Seismic vulnerability class			|-	o	-|	

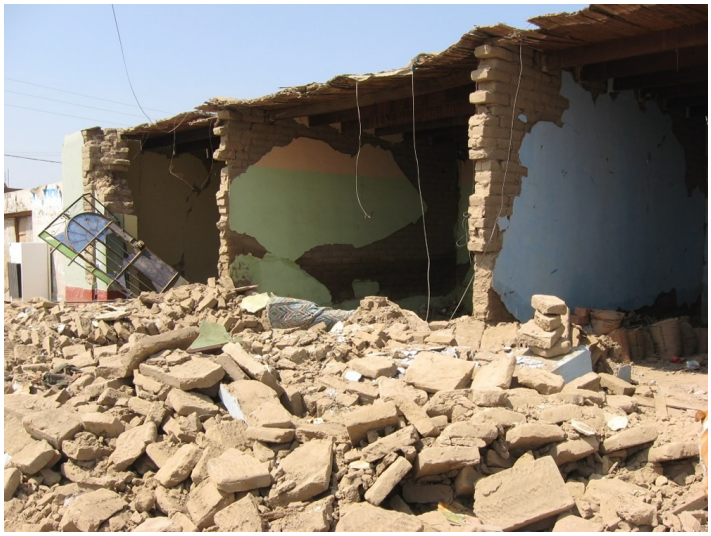
Inspection after 2001 Earthquake in Moquegua: reinforced house without damage and neighboring unreinforced house with severe damage

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

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

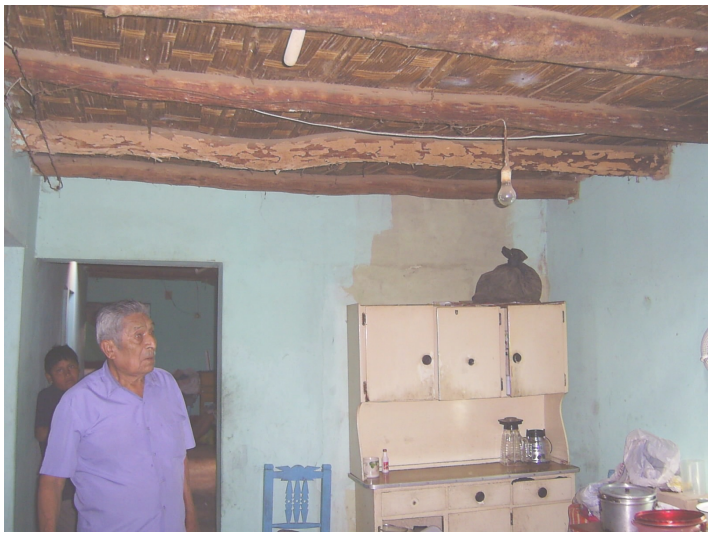


House in Ica after the 2007 earthquake, reinforced walls undamaged



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

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.



House reinforced in 1998 in Ica;

Houses next to the one shown in

after the 2007 earthquake. Owner Mr. Legua receives visitors showing undamaged adobe walls

Fig.22, with heavy damage, Ica, 2007

Retrofit Information

Description of Seismic Strengthening Provisions

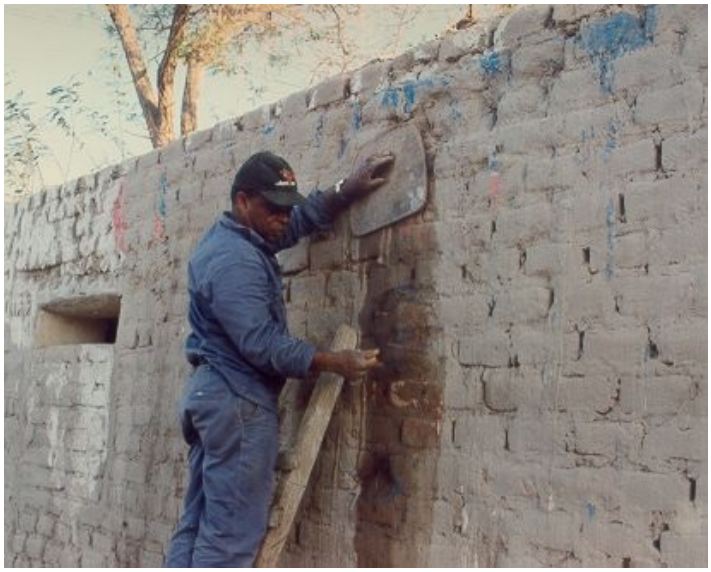
Structural Deficiency	Seismic Strengthening
Fragile materia	Reinforced by wire mesh covered with cement mortar
Lack of reinforcement	Vertical strips of wire mesh attached externally to both sides of the walls at corners
Lack of collar beams	Horizontal strips of wire mesh attached externally to both sides of the walls
Bad soil conditions	Strengthening of New Construction : concrete strip foundations
Lack of rigid diaphragm	Strengthening of New Construction : A RC collar beam upon all the walls.

Additional comments on seismic strengthening provisions	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.
Has seismic strengthening described in the above table been performed?	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 a repair following earthquake damages?	New housing units were constructed after the destruction caused by the 2001 earthquake.
Was the construction inspected in the same manner as new construction?	Yes, 2 PUCP professors visited the rural areas in 2003 for one week.
Who performed the construction: a contractor or owner/user? Was an	The project by GTZ-COPASA-SENCICO provided technical assistance and the owner/user provided

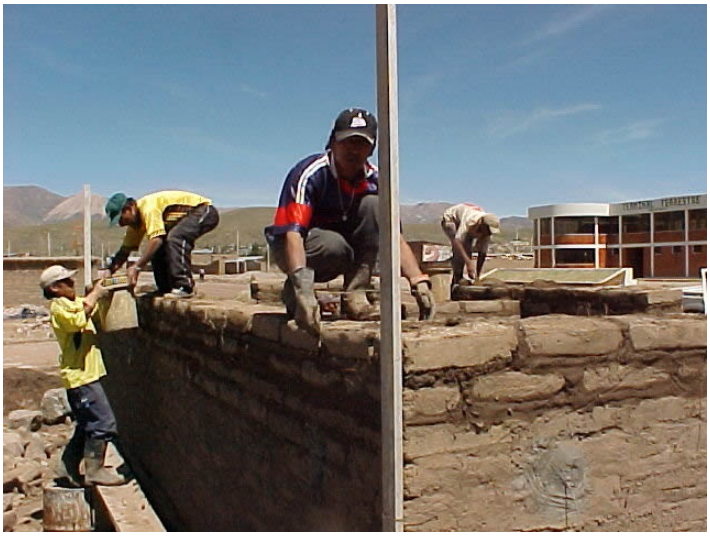
architect or engineer involved?	low quality handwork.
What has been the performance of retrofitted buildings of this type in subsequent earthquakes?	In 1998, six similar existing adobe houses were retrofitted (in Moquegua and Tacna regions), and withstood the M8.4 2001 earthquake undamaged. Later, five similar existing adobe houses were retrofitted in Ica region, and withstood the M8.0 2007 Pisco earthquake undamaged.
Additional comments section 6	

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

Placement of vertical strip of mesh at a corner



Connector wires for confining the wall between vertical strips.



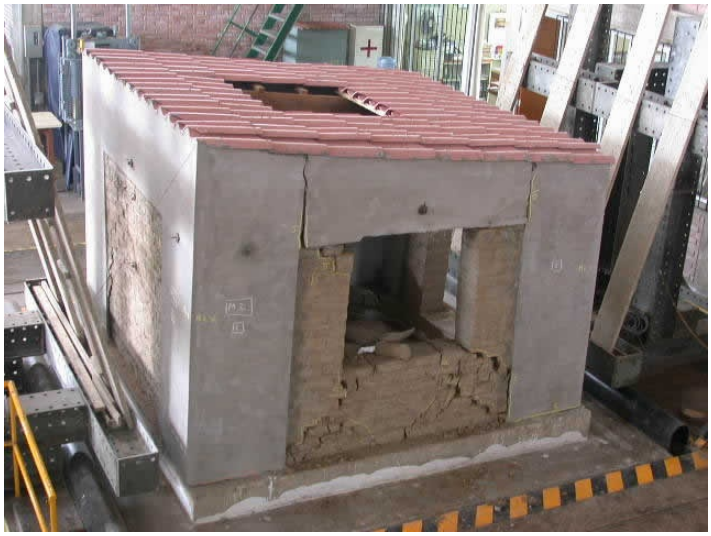
For new houses, check the width of joints and use connector wires in the joint

Form used for units and mud mortar mix

Adobe units under construction

Adobe walls under construction

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



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

References

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