World Housing Encyclopedia

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

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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
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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 (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.

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

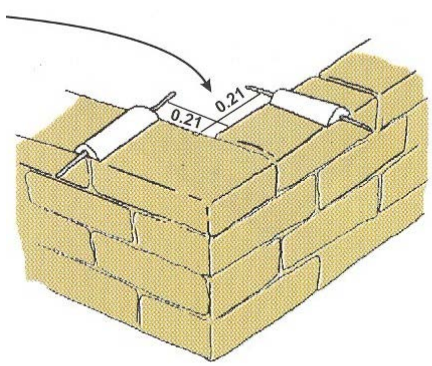

Figure 5: Wires embedded in joints for connecting the interior and exterior meshes.

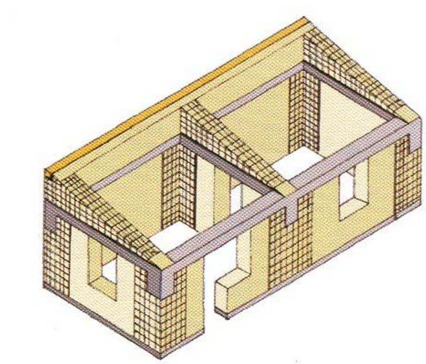

Figure 6: Roof slope and wire mesh on adobes over collar beam

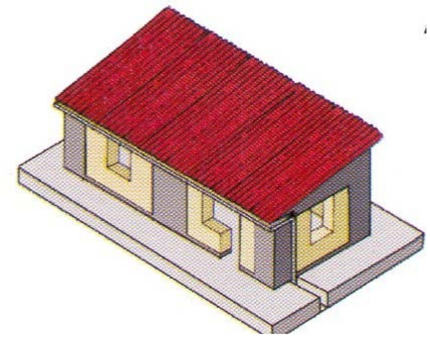

Figure 7: Roof with tiles and mortar covering the wire mesh on the walls

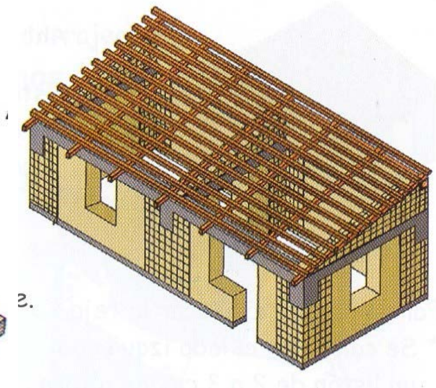

Figure 8: Wood beams for the roof

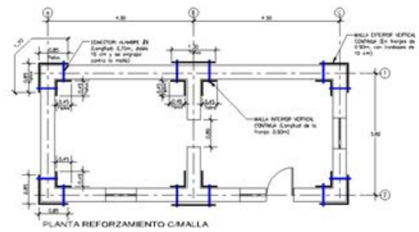

Figure 9: Plan view of reinforced adobe house

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)	☐
		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	☐
	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	☐
	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐

Steel	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)	☐

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	☐	☐
	Composite system of concrete joists and masonry panels	☐	☐
	Solid slabs (cast-in-place)	☐	☐
	Waffle slabs (cast-in-place)	☐	☐
	Flat slabs (cast-in-place)		

Structural concrete		☐	☐
	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	☑	☑

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	☐
	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	☐

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)	☑
b) low-income class (poor)	☐
c) middle-income class	☐
d) high-income class (rich)	☐

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	☑
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)	☐

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	☐
outright ownership	☐
Ownership with debt (mortgage or other)	☐
Individual ownership	☑
Ownership by a group or pool of persons	☐
Long-term lease	☐
other (explain below)	☐

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.	☐	☐	☑
Building Configuration	The building is regular with regards to both the plan and the elevation.	☑	☐	☐
	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.	☐	☑	☐
Floor construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	☐	☐	☑
Foundation performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	☑	☐	☐
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	☐	☑	☐
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	☐	☐	☑
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	☑	☐	☐
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps	☐	☑	☐
Wall openings	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.	☑	☐	☐
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	☑	☐	☐
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).	☑	☐	☐
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber)	☐	☑	☐
Additional Comments				

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	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
	☐	☐	☑	☐	☑	☐

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 diapraghm	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 conector 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.

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