World Housing Encyclopedia

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

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HOUSING REPORT
Confined masonry building

Report #	50
Report Date	05-06-2002
Country	PERU
Housing Type	Confined Masonry Building
Housing Sub-Type	Confined Masonry Building : Clay brick masonry, with concrete tie-columns and beams
Author(s)	Cesar Loaiza F., Marcial Blondet
Reviewer(s)	Sergio Alcocer

Important
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Summary

This multifamily housing construction type has been the most commonly used in the urban areas of Peru during the last 35 years. Confined masonry buildings consist of load-bearing unreinforced clay masonry walls confined by cast-in-place reinforced concrete tie columns and beams. Tie columns are cast after the construction of the masonry walls is complete and they

are connected to the tie beams. Confined masonry walls have limited shear strength and ductility; however, buildings of this type typically have a good seismic resistance.

1. General Information

Buildings of this construction type can be found in all parts of Peru, particularly in the coastal region. This type of housing construction is commonly found in urban areas. This construction type has been in practice for less than 50 years.

Currently, this type of construction is being built. This construction practice has been followed in the last 35 years.

Figure 1: Typical Building

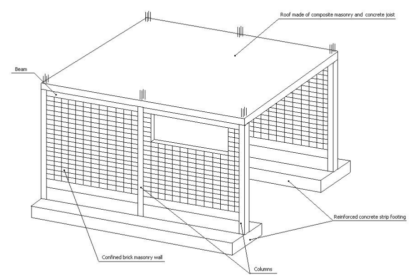

Figure 2: Key Load-Bearing Elements

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. When separated from adjacent buildings, the typical distance from a neighboring building is 0.5-1.0 meters.

2.2 Building Configuration

Rectangular shape. A typical building has 3 to 4 windows (typically 1 to 2 m wide) in each in the longitudinal direction. In the transverse direction there may be one or two openings per facade.

2.3 Functional Planning

The main function of this building typology is mixed use (both commercial and residential use). In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. Typically, there is only one stair and emergency stair does not exist. A few confined masonry buildings have emergency stairs.

2.4 Modification to Building

In some cases owners build additional interior walls as a part of the building extension (new rooms or bathrooms).

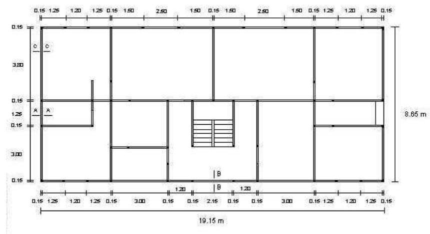

Figure 3: Plan of a Typical Building

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	☐

	Precast concrete	24	Moment frame	☐
		25	Prestressed moment frame with shear walls	☐
		26	Large panel precast walls	☐
		27	Shear wall structure with walls cast-in-situ	☐
		28	Shear wall structure with precast wall panel structure	☐
Steel	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐
	Braced frame	32	Concentric connections in all panels	☐
		33	Eccentric connections in a few panels	☐
	Structural wall	34	Bolted plate	☐
		35	Welded plate	☐
Timber	Load-bearing timber frame	36	Thatch	☐
		37	Walls with bamboo/reed mesh and post (Wattle and Daub)	☐
		38	Masonry with horizontal beams/planks at intermediate levels	☐
		39	Post and beam frame (no special connections)	☐
		40	Wood frame (with special connections)	☐
		41	Stud-wall frame with plywood/gypsum board sheathing	☐
		42	Wooden panel walls	☐
Other	Seismic protection systems	43	Building protected with base-isolation systems	☐
		44	Building protected with seismic dampers	☐
	Hybrid systems	45	other (described below)	☐

3.2 Gravity Load-Resisting System

The vertical load-resisting system is confined masonry wall system. Generally, the same system as described above. Floor and roof structures are composite structures, made of masonry units and concrete joists that transfer the gravity loads to the walls.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is confined masonry wall system. Confined masonry walls give stiffness to the structure and control lateral drift. Tie columns and post beams prevent damage due to out-of-plane bending effects and improve wall ductility. Tie columns have the longitudinal reinforcement necessary to resist overturning moments. In some cases, reinforced concrete walls are required to avoid cracking of reinforced concrete elements.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 20 and 20 meters, and widths between 12 and 12 meters. The building has 4 to 6 storey(s). The typical span of the roofing/flooring system is 4 meters. Typical Plan Dimensions: Average plan area is 260 m². Length varies from 15 to 30 m, and the width varies from 5 to 15 m. Typical Story Height: Story height varies from 2.5 meters to 2.8 meters. Typical Span: Typical span varies from 3.5-5

m. The typical storey height in such buildings is 2.70 meters. The typical structural wall density is up to 5 %. Total wall area/plan area (for each floor) is 3-5%.

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	☑	☑

In the analysis, the floors are considered to be rigid diaphragms.

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	☐
	Reinforced-concrete bearing piles	☐
	Reinforced-concrete skin	☐

	friction piles	
Deep foundation	Steel bearing piles	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

Usually the foundation is of plain (unreinforced) concrete unless the soil is clay or silt.

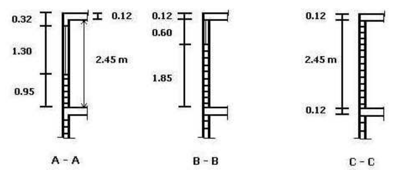

Figure 4: Critical Structural Details - Wall Sections

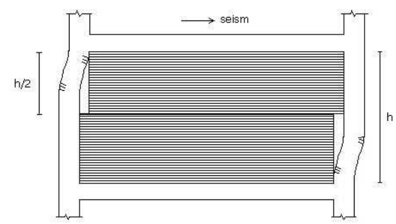

Figure 5: An Illustration of Key Seismic Deficiencies

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 5-10 housing unit(s). 6 units in each building. Usually there are from 4 to 8 units in each building. The number of inhabitants in a building during the day or business hours is 5-10. The number of inhabitants during the evening and night is 11-20.

4.2 Patterns of Occupancy

Typically, one family occupies one housing unit. However, in low social classes, two or three families share one housing unit.

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 Poor Class the Housing Unit Price is 15,000 and the Annual Income is 3,500. For Middle Class the Housing Unit Price is 40,000 and the Annual Income is 12,000. For Rich Class the Housing Unit Price is 100,000 and the Annual Income is 50,000.

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 type?	Most appropriate type
Owner financed	☑
Personal savings	☑
Informal network: friends and relatives	☐
Small lending institutions / micro-finance institutions	☑
Commercial banks/mortgages	☑
Employers	☐
Investment pools	☐
Government-owned housing	☑
Combination (explain below)	☐
other (explain below)	☐

In each housing unit, there are 1 bathroom(s) without toilet(s), 1 toilet(s) only and 1 bathroom(s) including toilet(s).

4.4 Ownership

The type of ownership or occupancy is renting, outright ownership and ownership with debt (mortgage or other).

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			

Floor construction	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	Limited ductility and the absence of tie columns diminishes shear strength.	Good transfer of seismic forces.	Wall shear cracking that propagates through tie columns.
Frame (columns, beams)			
Roof and floors			

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

Figure 6: A Photograph Illustrating Typical Earthquake Damage

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Clay masonry	Compression strength: 12 -16 MPa Shear strength: 0.5 - 0.8 MPa.	1:4 / 90 mm X 12 mm X 24 mm	Compression strength depends on the quality of bricks.
Foundation	Concrete.	Compression strength: 14 - 18 MPa.		
Frames (beams & columns)	Concrete Steel	Compression strength: 21-35 MPa Steel yield stress: 410 MPa		
Roof and floor(s)	Concrete Steel.	Compression strength: 21- 35 MPa Steel yield stress: 410 MPa		

6.2 Builder

Construction companies build the buildings of this type and sell them.

6.3 Construction Process, Problems and Phasing

Masonry walls are built with serrated endings, then tie columns are cast against them. After that tie beams, lintels and floors are built simultaneously. The equipment commonly used is: concrete mixer, traveling crane, winch, trucks. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size.

6.4 Design and Construction Expertise

Both the structural and the construction engineer should have 5 years of study and minimum work experience of 2 years. Commonly, the construction process is inspected. The designer may visit the construction process once or twice during the construction. Engineers are in charge of the structural design and construction process. Architects are in charge of the architectural design and in some cases in charge of the construction process.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Seismic Design Standards E-030. The year the first code/standard addressing this type of construction issued was 1977. National Construction Standards, Masonry Standards E-070. The most recent code/standard addressing this construction type issued was 1998. Title of the code or standard: Seismic Design Standards E-030 Year the first code/standard addressing this type of construction issued: 1977 National building code, material codes and seismic codes/standards: National Construction Standards, Masonry Standards E-070 When was the most recent code/standard addressing this construction type issued? 1998.

Municipal authorities approve the structural and architectural design for the building. It is common that the owner hires a private inspector for supervise the construction process.

6.6 Building Permits and Development Control Rules

This type of construction is an engineered, and authorized as per development control rules. Building permits are required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Builder, Owner(s) and Tenant(s).

6.8 Construction Economics

Unit construction cost may vary from 200 to 300 US$/m². Depending on the technology used, the construction of a typical building may take 2-3 stories per month.

7. Insurance

Earthquake insurance for this construction type is typically available. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is available. Despite earthquake insurance being available, people living in these buildings do not have enough money to pay it. Cover all costs of damages or the construction of a new building.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Columns	Installation of additional shear reinforcement in tie columns (Figure 7)

Strengthening of New Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Parapets and nonstructural walls	Parapets are confined with tie-columns and bond-beams. When parapets are located between tie-columns, walls are isolated through construction joints.

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, parapets are confined and non structural walls are isolated from the structure.

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

The seismic strengthening was done in a new construction.

8.3 Construction and Performance of Seismic Strengthening

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

N/A.

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

Usually engineers are involved.

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

Good seismic performance: parapets resist overturning forces and cracking effects were reduced in non structural walls.

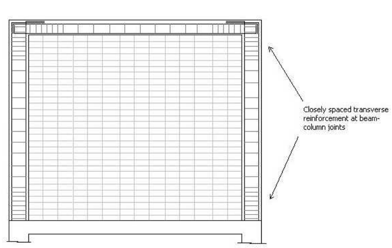

Figure 7: Illustration of Seismic Strengthening Techniques

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Author(s)

1. Cesar Loaiza F.
   Professor, Civil Engineering Dept., Catholic University of Peru
   Av. Universitaria cuadra 18 San Miguel 32, Lima 100, PERU
   Email:cloaiza@pucp.edu.pe FAX: 51-1-463-6181

2. Marcial Blondet
   Professor, Civil Engineering Dept., Catholic University of Peru
   POB 1761, Lima 32 , PERU
   Email:mblondet@pucp.edu.pe FAX: 51-1-463-6181

Reviewer(s)

1. Sergio Alcocer
   Director of Research
   Circuito Escolar Cuidad Universitaria, Institute of Engineering, UNAM
   Mexico DF 4510, MEXICO
   Email:salcocerm@iingen.unam.mx FAX: +52 (55) 56162894

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