# 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
# Confined masonry houses

| | |
|---|---|
| **Report #** | 51 |
| **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 |
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| **Reviewer(s)** | Sergio Alcocer |



**Summary**

This is the most common single-family housing construction practice followed both in urban and rural areas of Peru in the last 45 years. Confined masonry buildings consist of load-bearing unreinforced masonry walls made of clay brick units, confined by cast-in-place reinforced concrete tie columns and beams. These buildings do not have a complete load path in both

horizontal directions required for adequate lateral load resistance. However, in spite of that, typical houses may show a good seismic performance.

# 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 both rural and urban areas. This construction type has been in practice for less than 50 years.

Currently, this type of construction is being built. This construction type is followed in the last 45 years.

Figure 1: Typical Building

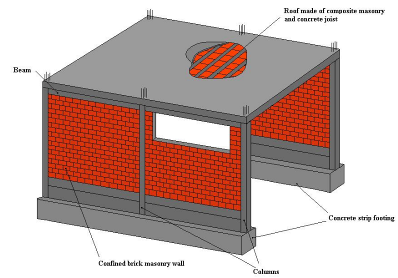


Figure 2: Key Load-Bearing Elements

# 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 0.01 meters.

## 2.2 Building Configuration

Rectangular shape or L-shape. A typical house has 6 to 10 windows per floor, with a total average size of 3.0 $m^2$. The position of these openings is variable, but usually is approximately 0.8 to 1.0 m from the floor level in rooms and from 1.8 to 2.0 m in bathrooms.

## 2.3 Functional Planning

The main function of this building typology is single-family house. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. A typical house has only one main stair used in case of an emergency.

## 2.4 Modification to Building

Commonly, owners build interior walls or additional floors for new rooms.

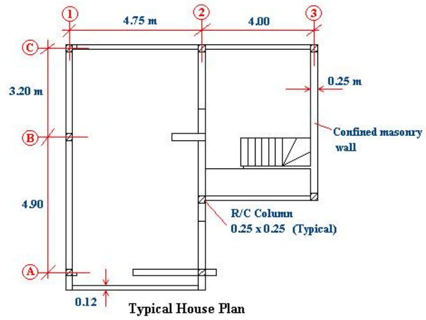

Figure 3: Plan of a Typical Building

# 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 | ☐ |
| | | 22 | Moment frame with in-situ shear walls | ☐ |

| | | | | |
|---|---|---|---|---|
| | Structural wall | 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) | ☐ |

In some cases, rubble stone and massive stone walls have been used.

## 3.2 Gravity Load-Resisting System

The vertical load-resisting system is confined masonry wall system. In general, the same system as describe above. Floors/roofs transmits gravity loads to the structural walls.

## 3.3 Lateral Load-Resisting System

The lateral load-resisting system is confined masonry wall system. Masonry shear walls give stiffness to the structure and control lateral drifts. Tie columns and bond beams provide adequate confinement and ductility to the masonry walls. Typical houses have a good wall density in one horizontal direction, but a lower wall density in the other. This makes the house particularly vulnerable in the horizontal direction where the density is lowest. Tie columns have enough longitudinal reinforcement to resist overturning moments. Closely spaced transverse reinforcement at beam-column joints provides adequate ductility to resist seismic forces. Floors/roofs can consider to be rigid diaphragms in the analysis. Typical wall thickness is 150 mm or 250 mm.

## 3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 10 and 15 meters, and widths between 5 and 10 meters. The building has 2 to 3 storey(s). The typical span of the roofing/flooring system is 3-4 meters. The typical storey height in such buildings is 2.60 - 2.80 meters. The typical structural wall density is up to 10 %. Typical wall densities for each horizontal direction are 2% and 7%, respectively.

## 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 | ☑ | ☑ |

## 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 | ☐ |

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

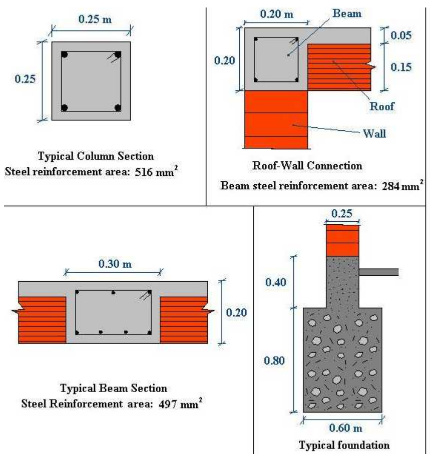


Figure 4: Critical Structural Details

Figure 5A: Key Seismic Features-Slender Walls

Figure 5B: Seismic Deficiencies - Short Column

# 4. Socio-Economic Aspects

## 4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit(s). 1 units in each building. In some cases, two families may occupy one house. The number of inhabitants in a building during the day or business hours is less than 5. The number of inhabitants during the evening and night is 5-10.

## 4.2 Patterns of Occupancy

Typically, one family occupies one house.

## 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 Middle Class the Housing Unit Price is 80,000 and the Annual Income is 12,000. For Rich Class the Housing Unit Price is 120,000 and the Annual Income is 60,000.

| 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 3 bathroom(s) without toilet(s), 1 toilet(s) only and 3 bathroom(s) including toilet(s).

Typically 3 or 4 bathrooms per house. .

### 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 | Statement | Most appropriate type | | |
|---|---|---|---|---|

| Feature | | 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. | ☐ | ☐ | ☑ |
| 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:<br><br>Less than 25 (concrete walls);<br><br>Less than 30 (reinforced masonry walls);<br><br>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:<br><br>For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls;<br><br>For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls;<br><br>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 | -Inadequate thickness to resist gravity and seismic loads (slender walls). -Inadequate wall density in one direction. | Good seismic force transfer | Shear cracking in the walls (cracks propagate 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 (MM) |
| 1974 | Lima | 7.7 | VIII (MM) |
| 1996 | Nazca | 7.3 | VII (MM) |

Figure 6: A Photograph Illustrating Typical Earthquake Damage (1996 Nazca earthfquake)

# 6. Construction

## 6.1 Building Materials

| **Structural** | **Building** | **Characteristic strength** | **Mix** | |
|---|---|---|---|---|

| element | material | | proportions/dimensions | Comments |
|---|---|---|---|---|
| Walls | Brick masonry | Compressive strength (masonry prisms): 13 - 16 MN/m² Shear strength: 0.6 - 0.8 MN/m² | 1:4 / 90 mm X 120 mm X 240 mm | Compressive strengths depend on the quality of brick units. |
| Foundation | Concrete | Compression strength: 10-14 MN/m² | | |
| Frames (beams & columns) | Concrete | Compression strength: 18 - 21 MN/m² Steel yield strength: 410 MN/m² | 1:2:3 | |
| Roof and floor(s) | Concrete | Compression strength: 21- 35 MN/m² Steel yield strength: 10 MN/m² | 1:2:3 | |

## 6.2 Builder

It is typically built by developers.

## 6.3 Construction Process, Problems and Phasing

Masonry walls are built with serrated edges, and then the tie-columns are cast against them. After that, bond beams, lintels and floors are built simultaneously. Concrete is mixed in machine mixers and taken with wheelbarrows to fill the wood formwork. Tools and equipment used are: hammers, spatulas, wheelbarrows, concrete vibrator and concrete mixers. The construction of this type of housing takes place in a single phase. Typically, the building is originally not designed for its final constructed size. Buildings are originally designed for a specific number of stories. However, it is common that owners decide to build additional floors some years later.

## 6.4 Design and Construction Expertise

Both, the structural and the construction engineer will have five years of study and minimum work experience of two years. Engineers are in charge of the structural design and construction process. Architects are in charge of the architectural design and could be 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 a common practice that owners retain a building supervisor to oversee 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) , Tenant(s) and No one.

## 6.8 Construction Economics

Unit construction cost may vary from 200 to 250 $US/m². This price includes the entire construction cost and could change depending on the quality of finishing materials. In order to start the construction, it is necessary to get a building permit. Municipal authorities are in charge of giving this permit to builder companies. Each project must have four types of technical drawings: structural drawings, architectural drawings, hydraulic installation drawings, and power installation drawings. Municipal authorities need to approve this technical information to issue a building permit. A typical 2-story house will need approximately 90 days (3 months) to complete the construction.

# 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. It is not common that owners purchase earthquake insurance. It is a total coverage, which includes the price of a new house.

# 8. Strengthening

## 8.1 Description of Seismic Strengthening Provisions

**Strengthening of New Construction :**

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

## 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 nonstructural 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 in the strengthening efforts.

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.

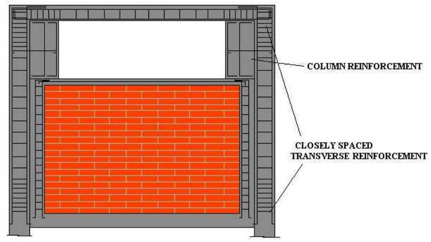


Figure 7: Illustration of Seismic Strengthening Techniques

# Reference(s)

1. Diseno de Estructuras de Concreto Armado
   Harmsen T. y mayorca
   Pontificia Universidad 1997

2. Norma Peruana de Albanileria E-070
   Norma Peruana de Albanileria E-070
   Capitulo Peruana del ACL. 1998

3. Norma Peruana de Diseno Sismorresistente E-070
   Capitulo Peruan0 del Peru. 1998

4. El Terremoto de Nasca del 12 de Noviembre de 1996
   Quiun,San Bartolome,Torrealva, Zegarra
   Pontificia Universidad Catolica del Peru 1997

5. Construcciones en Albanileria
   San Bartolome
   Pontificia Universidad Catolica del Peru 1994

6. Fuerzas Sismicas de Diseno para Edificaciones de..
   San Bartolome, Munoz, Rodriguez
   Pontificia Universidad Catolica del Peru 2001

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