

World Housing Encyclopedia

A Resource on Construction in Earthquake Regions



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

HOUSING REPORT

Non-engineered unreinforced brick masonry building

Report#	10
Last Updated	
Country	Colombia
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Reviewers	Sergio Alcocer,

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

General Information

Building Type:	Non-engineered unreinforced brick masonry building
Country:	Colombia
Author(s):	Luis Gonzalo Mejia
Last Updated:	
Regions Where Found:	This type of construction is found especially in the following provinces of the Andean region of Colombia: Antioquia, Caldas, Risaralda, Quindio, Tolima and Valle, where it is used in approximately 60% of the housing stock.
Summary:	This type of housing is typically constructed in urban and rural areas in the interior of Colombia. This type of construction is especially widespread in the following provinces of the Andean region of Colombia: Antioquia, Caldas, Risaralda, Quindio, Tolima and Valle, where it constitutes approximately 60% of the housing stock. It is used exclusively as residential housing. This construction is very vulnerable to earthquake effects due to its brittle behavior. It has demonstrated poor seismic performance in several Colombian earthquakes.
Length of time practiced:	25-60 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Residential, 3-4 units
Typical number of stories:	2
Terrain-Flat:	Never
Terrain-Sloped:	Typically
Comments:	Traditional construction practice for low-rise buildings (1- to 4- story high) followed in the last 50 years.

Features

Plan Shape	Rectangular, solid
Additional comments on plan shape	
Typical plan length (meters)	15
Typical plan width (meters)	6
Typical story height (meters)	2.5
Type of Structural System	Masonry: Unreinforced Masonry Walls: Brick masonry in lime/cement mortar
Additional comments on structural system	The vertical load-resisting system is un-reinforced masonry walls. Besides carrying the lateral load, these walls also carry all the gravity loads down to the foundation, which is made of plain concrete and rubble stone. The lateral load-resisting system is un-reinforced masonry walls. This is a bearing wall system. The walls and partitions supply in-plane, lateral stiffness and stability to resist lateral loads (wind and seismic). The slabs are generally made of tile block floor construction. The roof is composed either from rafters, with sheathing, roofing felt and Spanish tile, or RC slab. Often, additional stories are added subsequently, leading to buildings that are eventually 3 or 4 stories high. The RC slab behaves as a rigid diaphragm, however the wood roof behaves as a flexible diaphragm. A continuous R.C. beam over the walls is quite often missing.
Gravity load-bearing & lateral load-resisting systems	
Typical wall densities in direction 1	0-1%
Typical wall densities in direction 2	0-1%
Additional comments on typical wall densities	The typical structural wall density is none. 0.1.
Wall Openings	Information about the openings in a typical 2-story house with an average plan area of 35.0 sq m is summarized below: [Number of openings, Size (sq m), Opening area/wall area, Position of opening] - Doors Windows: Median 3 2.0 1.50 30% Between 0.5 and 1.0 m from corners building 8 1.8 1.0 25% Corner 6 2.0 1.50 40% building 8 1.8 1.0 25%.

Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	Typical modification is vertical expansion (construction of new stories).
Type of Foundation	Other Foundation
Additional comments on foundation	Unreinforced #ciclopeus# concrete. This is a type of strip footing
Type of Floor System	Other floor system
Additional comments on floor system	The floor can be considered as a rigid diaphragm and the roof as a flexible one.
Type of Roof System	Roof system, other
Additional comments on roof system	The floor can be considered as a rigid diaphragm and the roof as a flexible one.
Additional comments section 2	This construction is normally found on the sloped terrain in the Andean region, and in the areas of transition to flat terrain. When separated from adjacent buildings, the typical distance from a neighboring building is several meters.



Plan of a Typical Building

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	Brick with cement mortar	3.0 MPa , 9.0 MPa Characteristic strength w /h/l : 150x200x400mm 100x200x400mmm Cement: Sand 1:8 Typical dimensions: variable compression determined based on the gross area. Compression strength determined using 50 mm cubes
Foundations	Plain rubble stone	f'c = 10.0-15.0 MPa The concrete by itself (without stones) has f'c #15.0 Mpa.
Floors	Concrete (Hollow tile floor)	f'c= 10.0-15.0 MPa 1:2:4- >1:3:5 Cement/sand/aggregates
Roof	Concrete (Hollow tile floor)	f'c= 10.0-15.0 MPa 1:2:4- >1:3:5 Cement/sand/aggregates
Other		

Design Process

Who is involved with the design process?	Builder
Roles of those involved in the design process	
Expertise of those involved in the design process	Engineers and architects do not participate in this type of building construction.

Construction Process

Who typically builds this construction type?	Builder
Roles of those involved in the building process	

Expertise of those involved in building process	The construction labour is semi-skilled.
Construction process and phasing	The construction process begins by clearing the site, followed by the construction of the foundations, basement (retaining) walls, masonry walls at the first floor level, first storey floor-slab, etc. The masons are semi-skilled and the concrete is prepared and mixed directly at the site. Simple tools are used for the construction (no special equipment). The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size. No concern is given to structural aspects.
Construction issues	

Building Codes and Standards

Is this construction type address by codes/standards?	Yes
Applicable codes or standards	1984: Colombian code for earthquake resistant buildings CCCSR-84. 1998: Colombian code for earthquake resistant design and construction of buildings NSR-98 Prior to 1984, the ACI and UBC codes were widely used.
Process for building code enforcement	So far, there are no established procedures related to the building code enforcement for this type of construction.

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?	No
Additional comments on building permits and development control rules	At the present time there are strict building regulations for the construction of new buildings. Nevertheless, poor people, who build this informal construction, ignore the building regulations, thus making worse the general earthquake hazard

situation in Colombia.

Building Maintenance and Condition

Typical problems associated with this type of construction

This construction shows a sudden, brittle and catastrophic failure in earthquakes. The main causes of such behaviour are: the cracks in the walls grow rapidly due to the absence of wall reinforcement, the weak materials, the openings, the interaction with other buildings, and the adverse soil amplification in the hilly areas.

Who typically maintains buildings of this type?

Owner(s)

Additional comments on maintenance and building condition

Due to the difficult economic situation of inhabitants of this construction type, these buildings are seldom maintained.

Construction Economics

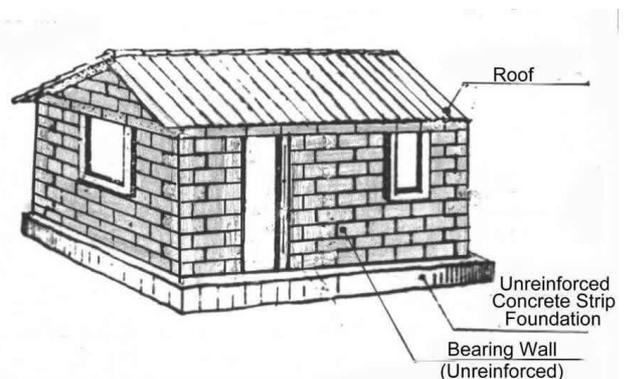
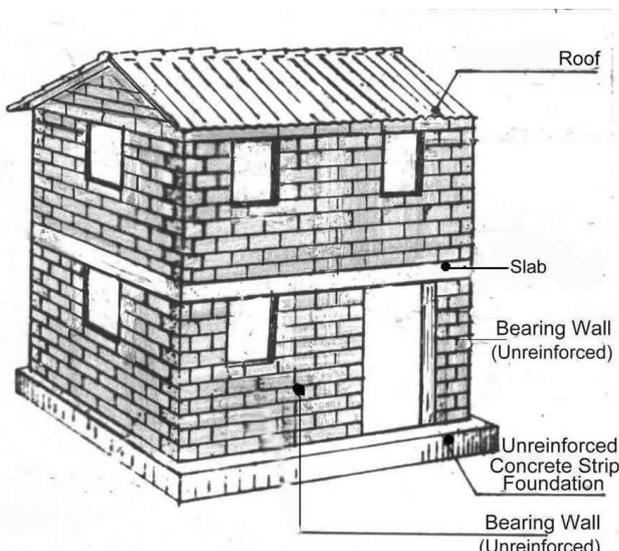
Unit construction cost

Although the labour costs in rural areas are less than in urban areas, the materials are more expensive because they have been transported from the urban areas. The average construction cost is 250,000 Col.pesos/m.sq. (125 \$US /m.sq.)

Labor requirements

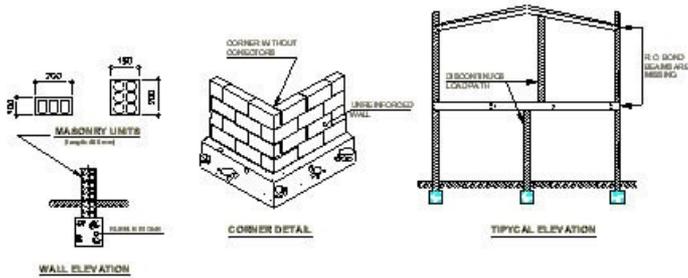
Typically, it takes two months per storey for a team of 20 people; this includes structural part only - rough brick work. Additional time is required to complete the finishings etc.

Additional comments section 3



Key Load-bearing Elements

Key Load-bearing Elements



Wall Elevation

Socio-Economic Issues

Patterns of occupancy	One family per dwelling, with the exception of the houses of poor people in urban areas, where there are 3 or 4 families per dwelling.
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	5-10
Additional comments on number of inhabitants	In rural areas, one housing unit/building; in urban environments, two or three housing units in a building.
Economic level of inhabitants	Low-income class (poor) Middle-income class
Additional comments on economic level of inhabitants	Ratio of housing unit price to annual income: 5:1 or worse The economic distribution of the population in Colombia is as follows: [Economic Status % Annual Income (US Dollars)] Very Poor: 35 <1000, Poor: 35 1000-2000, Middle Class: 25 2000-10000, High Middle Class: 4 10000-40000, Rich: 1 >40000 Economic Status is as follows: For Poor Class the Housing Price Unit is 7500 and the Annual Income is 1400. For Middle Class the Housing Price Unit is 30000 and the Annual Income is 6000.
Typical Source of Financing	Combination

The main source of financing for the poor people is

Additional comments on financing	informal network (friends and relatives) and (sometimes) small lending institutions. For the middle class population, the main sources of financing are personal savings and commercial banks.
Type of Ownership	RentOwn outrightOwn with debt (mortgage or other)
Additional comments on ownership	
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	

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
1979	4.8N, 76.2W, depth: 108 km (Mistrato)
1983	2.46N, 76.69W, depth: 22 km (Popayan)
1985	4.1N, 76.62W, depth: 73 km(Pereira)
1999	4.46N, 75.72W, depth: 17 km (Armenia)

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type

Majority of buildings of this type suddenly collapsed, killing inhabitants, particularly in the areas with pronounced soil amplification effects.

Additional comments on earthquake damage patterns

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 $\frac{1}{2}$ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than $\frac{1}{3}$ of the distance between the adjacent cross walls; For precast concrete wall structures: less than $\frac{3}{4}$ 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.	FALSE
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	FALSE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	FALSE
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.	TRUE
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.	TRUE
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);	FALSE
Foundation-Wall Connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doveled into the foundation.	FALSE
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	FALSE
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	FALSE

estimate).

Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	FALSE
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	#NAME?
Earthquake-resilient features in walls	
Seismic deficiency in frames	
Earthquake-resilient features in frame	
Seismic deficiency in roof and floors	#NAME?
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	-			



Key Seismic Deficiencies: Wall Weakness due to Electrical and Water Conduits



Key Seismic Deficiencies: Poor Quality of Materials



Key Seismic Deficiencies: Very Slender Walls



Key Seismic Deficiencies: Poor Quality of Materials



Key Seismic Deficiencies: Discontinuous Boundary Members



Typical Earthquake Damage: Partial Collapse



**Typical Earthquake Damage:
Structural Collapse**

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic Strengthening
WALLS: -Unreinforced walls - No clear earthquake load path (discontinuous path); - Unequal stiffness distribution; - Sometimes very slender (drift and instability problems); -Stepped construction	See Additional Comments
ROOFS AND FLOORS: -Absence of continuous boundary members (chords and collectors); - weak roof-wall and floor-wall connections	See Additional Comments

Additional comments on seismic strengthening provisions

Although improbable for economic reasons, this construction could be strengthened as follows: 1. New boundary members (chords and collectors) are added to floor and roof to ensure the integrity and diaphragm action. Roof and slabs are anchored to the walls to ensure the inertia force transfer to the walls, as illustrated in Figure 14. 2. Whenever possible, end elements (columns-posts) are added in the selected earthquake resistant walls, as illustrated in Figures 13 and 17. Wall cracks are stitched with reinforcement and grouted with mortar to restore the wall integrity. 3. A continuous RC beam is built atop the strengthened walls in order to improve the diaphragm action at the floor level, as illustrated in Figures 12, 13, and 16. It is considered that the implementation of the above described techniques would result a significant enhancement of seismic stability in buildings of this

	type.
Has seismic strengthening described in the above table been performed?	Yes. Seismic strengthening has been used in practice by the author of this contribution, as illustrated in Figures 13 through 18.
Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?	The work was done as a mitigation effort.
Was the construction inspected in the same manner as new construction?	Yes
Who performed the construction: a contractor or owner/user? Was an architect or engineer involved?	The work was performed by a contractor and an engineer was involved.
What has been the performance of retrofitted buildings of this type in subsequent earthquakes?	There were no major earthquake after the strengthening was performed, however the performance in moderate earthquakes was very good.
Additional comments section 6	



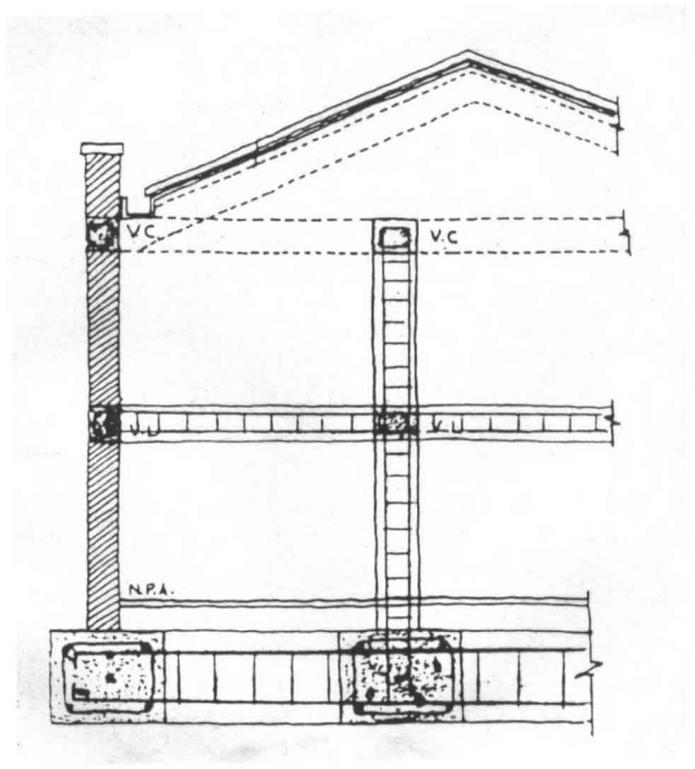
***Seismic-strengthening Techniques:
Construction of New Columns and
Bond Beams***



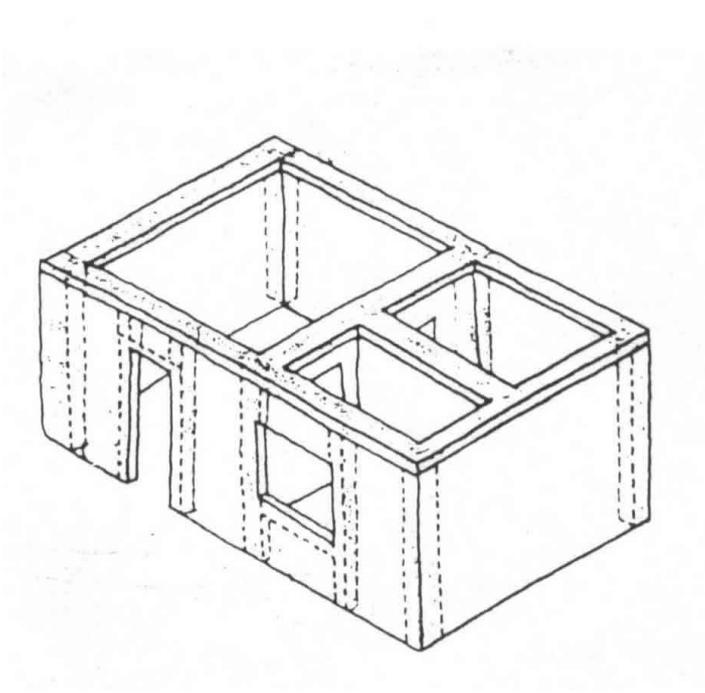
***Seismic-strengthening Techniques:
Construction of New Bond Beams***



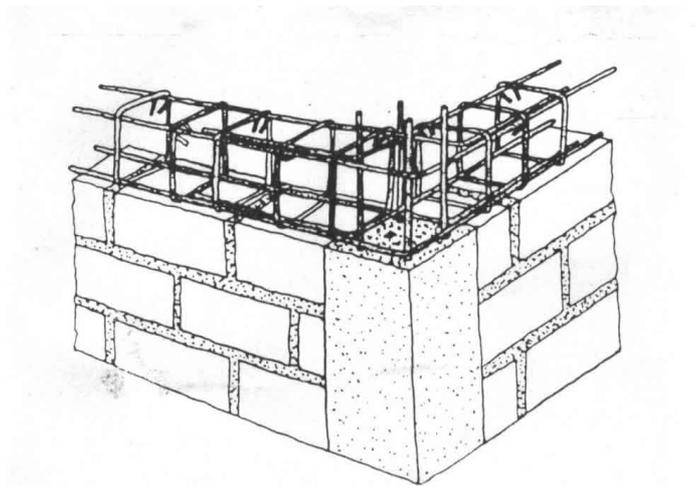
***Seismic-strengthening Techniques:
Construction of the Wall-Roof
Connection***



Seismic-strengthening Elements



***Seismic-strengthening Techniques:
Construction of New RC Ring Beam***



***Seismic-strengthening Techniques:
Construction of New RC Tie-
Columns***

References

1. Colombian Code for Earthquake-Resistant Design and Construction of Buildings (CCCSR-84 and NSR-98).
2. Mejia, Luis Gonzalo #Basic Aspects for the Design and Construction of Earthquake-Resistant 1- or 2-story Buildings# (in Spanish)
3. Mejia, Luis Gonzalo #Specifications for the Earthquake-Resistant Design of 1- or 2-story Houses Per the Colombian Code NSR-98# (in Spanish)

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