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

Clay brick/concrete block masonry walls with concrete floors (predating seismic codes or with a few seismic features)

Report#	12
Last Updated	
Country	Colombia
Author(s)	Luis Gonzalo Mejia,
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 A, Martin & Associates, Inc. or the participant’s organizations.

General Information

Building Type:	Clay brick/concrete block masonry walls with concrete floors (predating seismic codes or with a few seismic features)
Country:	Colombia
Author(s):	Luis Gonzalo Mejia
Last Updated:	
Regions Where Found:	Buildings of this construction type can be found in Colombia. It represents approximately 50% of the existing housing stock of medium rise buildings (4- to 6-story high). This type of housing construction is commonly found in urban areas. Majority of buildings of this type found in rural areas are 1- and 2-story high.
Summary:	Typical multi-family housing construction found in urban areas of Colombia. It is a modern construction practice and represents approximately 50% of the housing stock for medium-rise (4- to 6-story high) buildings constructed in the last 25 years. This type of construction generally predates seismic codes, however some buildings of this type were constructed after the first edition of the Colombian Seismic Code was issued in 1984. This type of construction can be found either on flat or on sloped terrain; vertical stiffness irregularity in the sloped terrain conditions may introduce additional unfavorable effects. Due to poor construction practices and poor detailing of reinforcement, this construction is considered to be very vulnerable to earthquake effects.
Length of time practiced:	Less than 25 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Residential, 5-9 units
Typical number of stories:	5
Terrain-Flat:	Typically

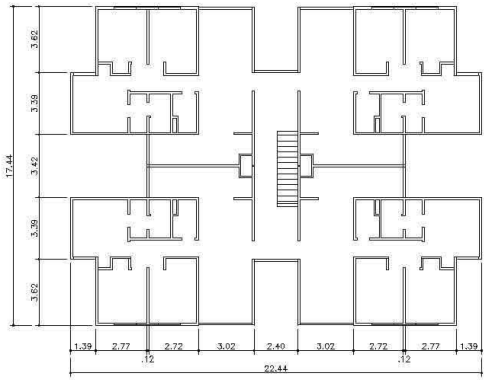
Terrain-Sloped:	Typically
Comments:	

Features

Plan Shape	Square, solidRectangular, solid
Additional comments on plan shape	Typically, a square plan (4 flats per floor) or a rectangular plan (2 flats per floor).
Typical plan length (meters)	17
Typical plan width (meters)	17
Typical story height (meters)	2.6
Type of Structural System	Masonry: Unreinforced Masonry Walls: Brick masonry in lime/cement mortarMasonry: Unreinforced Masonry Walls: Concrete block masonry in cement mortar
Additional comments on structural system	The walls carry both lateral and gravity loads down to the R.C. strip foundation. In poor soil conditions, pile foundations are used because of the great susceptibility to settlement of the bearing walls. It is important to mention that the slabs span normally in one direction so the walls in one direction sustain gravity and lateral loads and the walls in the cross direction carry lateral loads only. This is a bearing wall system, wherein the walls provide stiffness for in-plane lateral loading and stability to resist lateral loads (wind and seismic effects). Floor slabs are either 100 mm thick R.C. slabs or different types of slab and joist floors; in some cases, slabs with concrete joists and tile blocks are used. The roof is normally made from rafters, sheathing roofing felt and asbestos-cement tile or R.C. slab. Floor slab can act as a rigid diaphragm; the same is not true for the wooden roof because a continuous R.C. beam (bond beam) atop the walls is often absent.
Gravity load-bearing & lateral load-resisting systems	Most buildings of this construction are brick masonry in lime/cement mortar or clay brick/tile masonry, with wooden posts and beams; however, some buildings are concrete block masonry in cement mortar or clay brick masonry, with concrete posts/tie columns and beams.
Typical wall densities in	5-10%

direction 1	5-10%
Typical wall densities in direction 2	5-10%
Additional comments on typical wall densities	The typical structural wall density is 6% to 8.5%.
Wall Openings	Information about the openings in a typical median building is summarized below: Number of openings Size (sq m): Doors Windows Facade 5 0 1.80 Opening area/wall area: Between 0.5 and 1.0m from corners Position of opening: Interior 7 2.0 0. Total 30%.
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	There are no many modifications in this building type. The most typical modification pattern observed is demolition of interior walls.
Type of Foundation	Shallow Foundation: Reinforced concrete strip footingDeep Foundation: Reinforced concrete bearing pilesDeep Foundation: Reinforced concrete skin friction piles
Additional comments on foundation	It consists of reinforced concrete end-bearing piles and reinforced concrete skin-friction piles. In some Colombian cities e.g. Bogota, deep foundations are mandatory in a typical case. However, in other cities e.g. Medelin, R.C. strip footings are normally used.
Type of Floor System	Cast-in-place beamless reinforced concrete floorOther floor system
Additional comments on floor system	Other: Structural concrete cast-in-place flat slabs, precast solid slabs The floor is considered to be a rigid diaphragm that transfers the loads to the wall, although in many instances the floor-to-wall connections are deficient.
Type of Roof System	Roof system, other
Additional comments on roof system	Other: Timber wood planks or beams that support slate, metal, asbestos-cement or plastic corrugated sheets or tiles; wood planks or beams supporting natural stones slates The roof is considered to be a flexible structure.
	This type of construction is found on flat terrain (in the coastal areas) and in the continental region (the

Additional comments section 2	Andean) on the sloped and occasionally very steep terrain When separated from adjacent buildings, the typical distance from a neighboring building is 10 meters.



Plan of a Typical Building

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	Concrete block masonry walls Clay Brick masonry wall Cement Mortar Cement grout	f'm = 10.0 MPa w/h/l 150x200x400 mm120x200x400 mm f'm = 3 - 10.0 MPa w/h/l 200 x 100 x 400200 x 150 x 400 3MPa for unreinforced or confined masonry and 10MPa for masonry with interior reinforcement f'm = 5 - 10.0 MPa Cement : Sand1:6 to 1:4 Better strengths for buildings with vertical reinforcement, because they have some seismic features. 10.0 MPa 1:4 For walls with vertical reinforcement
Foundations	Reinforced concrete	f'c = 20.0 MPa 1 : 2 : 3 Cement/sand/aggregates
Floors	R.C. slabs or hollow tile	10.0 # 20.0 MPa 1:3:5 - >1:2:3 Cement/sand/aggregates

Roof	Abarco (Cariniane piriformis)	9.0 MPa 50 x 100 mm Whenever the roof is in R.C. properties are the same as floors.
Other		

Design Process

Who is involved with the design process?	EngineerArchitectOther
Roles of those involved in the design process	Whenever engineered, this construction type is built for speculation purposes.
Expertise of those involved in the design process	Architects and engineers participate in the design of buildings of this type built for inhabitants belonging to the middle economic class. However, architects and engineers are not involved in the informal construction developed in areas inhabited by poorer sections of the society. If engineers and architects are involved in the construction, there is a "resident" (architect or engineer) on the site during the construction. Unfortunately, he/she is concerned mainly with the project cost aspects (rather than with the construction quality). Engineers and architects do not play any role in informal projects developed for poor people.

Construction Process

Who typically builds this construction type?	Other
Roles of those involved in the building process	
Expertise of those involved in building process	The masons involved in the construction are usually skilled and semi-skilled.
Construction process and phasing	This is a typical construction process: firstly, the terrace is formed, followed by the construction of strip foundation. Subsequently, walls, slabs and roof are built, and the masons are skilled or semi-skilled. No equipment is used except for the simple tools. Normally, buildings of this type are built by a developer (in some cases by the owner). The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size. The above statements are true, except for the case of informal construction.

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	After an earthquake, the authorities enforce the use of building codes, however shortly thereafter these regulations are not enforced with an adequate effort.

Building Permits and Development Control Rules

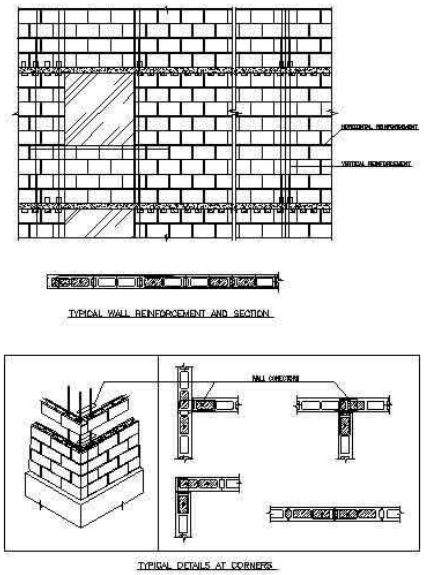
Are building permits required?	Yes
Is this typically informal construction?	No
Is this construction typically authorized as per development control rules?	Yes
Additional comments on building permits and development control rules	Some of these buildings, especially those of unreinforced masonry construction or confined masonry are informal construction.

Building Maintenance and Condition

Typical problems associated with this type of construction	As the amount of reinforcement is it rather limited (and in some cases does not exist at all), and the quality of materials and workmanship is generally poor, this construction type is very susceptible to earthquake effects.
Who typically maintains buildings of this type?	Owner(s)
Additional comments on maintenance and building condition	

Construction Economics

Unit construction cost	On the average $300,000 Colombian pesos/ sq m ($US 150 /sq m)
Labor requirements	It is possible to construct one floor per month on the average (when the building is designed for its final size and engineers/architects participate in the construction).
Additional comments section 3	



Critical Structural Details - Typical Wall Reinforcement in New Buildings

Critical Structural Details - Modern buildings Built with Continuous R/C Bond Beams

Key Seismic Deficiencies - Inadequate Reinforcement and Poor Grouting (note the reinforcement bar slippage)

Seismic Deficiencies - Discontinuous R/C Bond Beams

Poor construction practice - unreinforced masonry walls and the absence of cross walls (note that both clay bricks and concrete blocks were used for the wall construction)

Vertical Stiffness Discontinuity - Walls Interrupted at the First Story and Replaced with Columns

Seismic Deficiencies - An Example of a Building Collapse Caused by Gravity Loads Only (buildings with such weaknesses have very little chance to survive earthquake effects)

Seismic Deficiencies - Poor Quality of Materials (mortar and grout); Inadequate Vertical and Horizontal Reinfocement

A building weakened due to tilting induced by a pre-earthquake foundation settlement (separation between the two buildings was 100 mm at ground level but 0 mm at the top). Such buildings are likely to suffer more extensive earthquake damage

A building weakened due to tilting induced by a pre-earthquake foundation settlement (separation between the two buildings was 100 mm at ground level but 0 mm at the top). Such buildings are likely to suffer more extensively earthquake damage

Typical Earthquake Damage - Lateral Movement of the Collapsed Building Relative to the Foundations

Socio-Economic Issues

Patterns of occupancy	Normally one family occupies one housing unit. On the average, 5 floors per building; consequently, there are 20 units in buildings of a square plan (four apartments per floor), and 10 units in buildings of a rectangular plan (two apartments per floor).
Number of inhabitants in a typical building of this construction type during the day	5-10
Number of inhabitants in a typical building of this construction type during the evening/night	>20
Additional comments on number of inhabitants	

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 above are average values. House price for middle class section ranges from US$ 30,000 to 50,000. The approximate economic distribution of population in Colombia is as follows: Economic status % Annual Income Very poor 35 <1000 Poor 35 1000 - 2000 Middle Class 25 2000 -10000 High Middle Class 4 10000 - 40000 Rich 1 >40000 Economic Status: For Poor Class the Housing Price unit is 10000 and the Annual Income is 1500. For Middle Class the Housing Price unit is 40000 and the Annual Income is 6000.
Typical Source of Financing	Combination
Additional comments on financing	The main source of financing for the poor people is 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)Units owned individually (condominium)
Additional comments on ownership	
Is earthquake insurance for this construction type typically available?	Yes
What does earthquake insurance typically cover/cost	Earthquake insurance is available only for engineered buildings. At the present time, premium discounts are not available for seismically strengthened buildings, however the insurance companies are dealing with this matter. Although there are many unclear aspects in this matter, in general the insurance covers the previously fixed value of the building. The insurance cost varies from 0.1 to 0.15% of the building value.
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)
34738	4.1N, 76.62W, depth: 73 km (Pereira)
36185	4.46N, 75.72W, depth: 17 km (Armenia)

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	Typical earthquake damages are illustrated in Figures 7-13.
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 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	FALSE

	seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	
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.	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	FALSE

	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.	TRUE
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	TRUE
Wall Openings		N/A
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	FALSE
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	Foundation Performance: Occasionally, there are buildings with induced weaknesses caused by foundation movements (please see Figure 12). Wall-Roof connections: See Additional Comments in Sections 2.10 & 2.11 #Type of floor/roof system#.
Vertical irregularities	

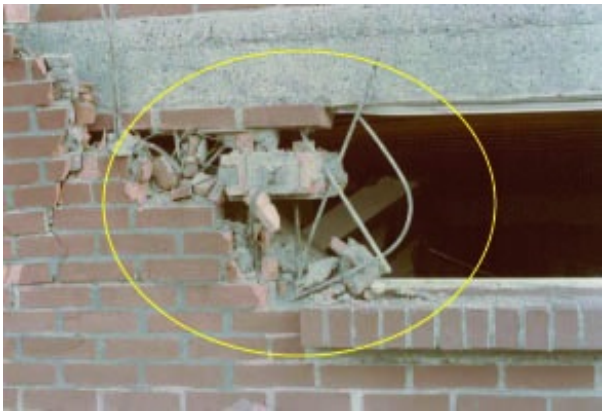
typically found in this construction type	Other
Horizontal irregularities typically found in this construction type	Other
Seismic deficiency in walls	-Unreinforced or with insufficient vertical and horizontal reinforcement. - Stepped construction (offsets) for example half of the buildings with six stories and the other half with five due to the sloping terrain (resulting in nonuniform vertical stiffne
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	-|			

Typical Earthquake Damage - Failure of Load bearing Masonry Walls



Typical Earthquake Damage - Inadequate Reinforcement (Detail A shown on Figure 16)

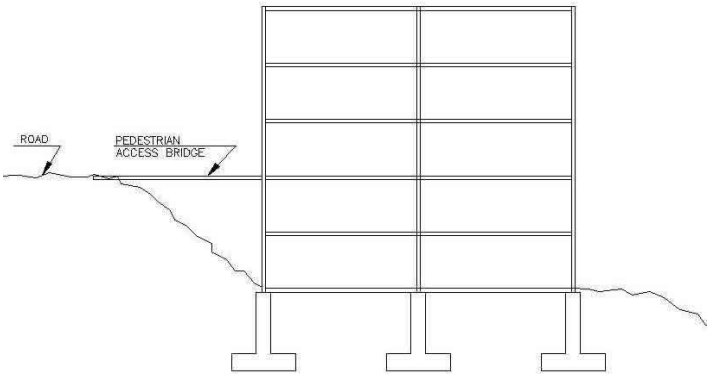
Typical Earthquake Damage - Detail B Shown on Figure 17

Typical Earthquake Damage - Poor Workmanship and Inadequate Reinforcement (this is an enlarged detail B shown of Figure 18

Typical Earthquake Damage Illustrating Two Similar Confined Masonry Buildings (note that the building on the right-hand side collapsed while the one on the left remained standing)

Typical Earthquake Damage - Collapsed Roof; note the absence of continuous RC bond beam and the wall-roof connection; the water tank at the roof "walked off" and had contributed to the roof collapse

Typical Earthquake Damage - Importance of the Details in Seismic Design : The "access bridge" to this building did not have adequate bearing length and had collapsed, thus leaving inhabitants



Typical Earthquake Damage - Importance of the Details in Seismic Design : The "access bridge" to this building did not have adequate bearing length and had collapsed, thus leaving inhabitants without a means of escape

without a means of escape

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic Strengthening
Walls -Unreinforced or with insufficient vertical and horizontal reinforcement. - Stepped construction (offsets) for example half of the buildings with six stories and the other half with five due to the sloping terrain (resulting in nonuniform vertical stiffness distribution).	See Additional Comments
Roof and floors: - Absence of continuous boundary members, chords and collectors. - Weak roof-wall and floor-wall connections.	See Additional Comments
Other : -Poor quality of workmanship and materials. -Foundations designed only for vertical loads without considerations for overturning moments.	See Additional Comments

Additional comments on seismic strengthening provisions	Due to the fact that this construction type in general belongs to poor or middle class population, the costs of seismic strengthening is so prohibitive and unaffordable; this is a major reason for a very limited experience in this area. For the above reason, only scarce efforts have been made in the area of seismic strengthening. As illustrated in Figures 24 and 25, an appropriate seismic strengthening technique includes the installation of new end confining members in the selected walls. An alternative seismic strengthening technique that would be appropriate for buildings of this type (using the Fiber Reinforced Polymers) is very expensive.
Has seismic strengthening described in the above table been performed?	No
Was the work done as a mitigation effort on an undamaged building or as a repair following	N/A

earthquake damages?	
Was the construction inspected in the same manner as new construction?	N/A
Who performed the construction: a contractor or owner/user? Was an architect or engineer involved?	N/A
What has been the performance of retrofitted buildings of this type in subsequent earthquakes?	N/A
Additional comments section 6	

Seismic Strengthening Techniques- Installation of New Concrete Tie Columns

Seismic Strengthening Techniques- Installation of New Concrete Tie Columns

References

1. Normas Colombianas de y construccion Sismo Resistente (NSR-98)

Authors

Name	Title	Affiliation	Location	Email
Luis Gonzalo Mejia	Consulting Structural Engineer	L.G.M y Cia.	Calle 49b #77b #12 Medellin Colombia	lgm@epm.net.co

Reviewers

Name	Title	Affiliation	Location	Email
Sergio Alcocer	Director of Research	Circuito Escolar Cuidad Universitaria, Institute of Engineering, UNAM	Mexico DF 4510, MEXICO	salcocerm@iingen.unam.mx