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

Reinforced Masonry Building: Clay brick masonry in cement mortar

Report#	175
Last Updated	
Country	Colombia
Author(s)	Luis Carlos Hackmayer, Lars Abrahamczyk, Jochen Schwarz,
Reviewers	Dina D Ayala,

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:	Reinforced Masonry Building: Clay brick masonry in cement mortar
Country:	Colombia
Author(s):	Luis Carlos Hackmayer Lars Abrahamczyk Jochen Schwarz
Last Updated:	
Regions Where Found:	This type of single-story buildings can be found easily in urban areas throughout the country (see Figure 1). The construction of small houses using this structural system is increasing in the last years because of its use as affordable housing (economically supported by the government for low income level families). In big cities like Bogot# and Medell#n, these types of buildings can be found as multistory buildings up to 10 stories (see Figure 2). The relevant type in this report will be single-story buildings. This type of housing construction is commonly found in both rural and sub-urban areas.
Summary:	This type of single-story housing is typically built in urban areas around the country. Nowadays, multistory buildings up to 10 stories can also be found with the same structural system and is generally used for residential purposes; however, this report focuses on single-story buildings. This type of structure is, in general, earthquake resistant but the construction process should be somehow improved in terms of controls and checks. The vertical and horizontal loads are supported by the reinforced masonry walls. The vertical reinforcement bars are placed in the hollow cores of the clay masonry units and the horizontal reinforcement bars in between the horizontal bed joints of the units (the separation depends on the selected energy dissipation capacity).
Length of time practiced:	Less than 25 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Single dwellingOther
Typical number of stories:	1
Terrain-Flat:	Typically

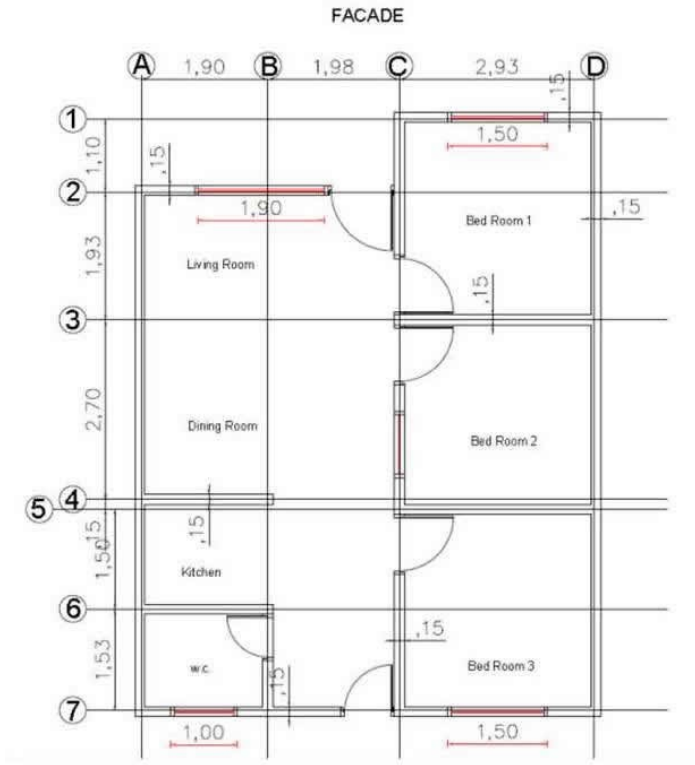
Terrain-Sloped:	Off
Comments:	The main function of this building typology is a multi/single-family housing depending on the income level.

Features

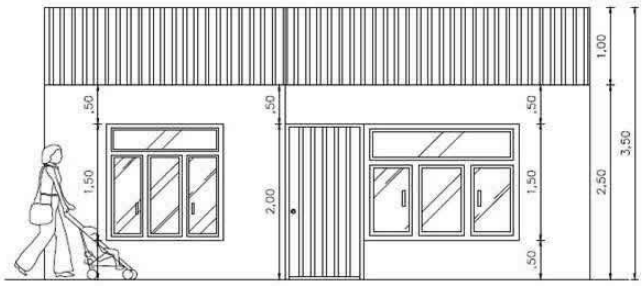
Plan Shape	Rectangular, solid
Additional comments on plan shape	
Typical plan length (meters)	10-15
Typical plan width (meters)	6-9
Typical story height (meters)	2.5
Type of Structural System	Masonry: Reinforced Masonry: Clay brick masonry in cement mortar
Additional comments on structural system	Lateral load-resisting system: The lateral load-resisting system is reinforced masonry walls. The horizontal actions are supported by masonry walls reinforced with vertical and horizontal steel rebar. The amount of vertical and horizontal reinforcement and the quantity of mortar-filled cores of the masonry walls depend on the selected energy dissipation capacity (R-factor). The criteria to select the energy dissipation capacity of the building is the responsibility of the structural engineer and should be based on experience, available materials at the construction site, location of the structure (closely related to the earthquake prone areas) since low energy dissipation structures are not allowed on high seismic areas, etc. The R-factor represents the structural response modification factor (behavior factor in the Eurocodes) and the basic values are tabulated in the Colombian seismic code for different structure types and energy dissipation capacities [3]. The building type under study corresponds to masonry walls with intermediate energy dissipation capacity (Ro=2.5 acc. to [3]). For this type of building, only the cores that contain vertical reinforcement are filled with mortar. The maximum distance between vertical reinforcement is 1.20 meters and there should be at least one bar of 12mm diameter located at the end of the walls and next to the openings. The horizontal reinforcement is placed each 0.6 meters in between the horizontal bed joints and is a bar of 4 mm diameter, in the openings two bars of 10 mm diameter are placed at the top and bottom with an extension of 0.6 meters into the wall (see Figure 5). At wall ends, where the horizontal and vertical reinforcement meet each other, the horizontal reinforcement is connected to the vertical through a standard loop with a length depending on the

	steel type and rebar diameter. Splices in the horizontal reinforcement should be generally avoided. In order to fulfill this requirement, in places where it is not possible to use a continuous rebar (i.e. walls longer than the maximum length of the rebar) a hook will be inserted in the filled cores (where a vertical reinforcement is placed). Gravity load-bearing system: The vertical load-resisting system is reinforced-masonry walls.
Gravity load-bearing & lateral load-resisting systems	The walls are made of clay or concrete block masonry. Clay hollow units are most commonly used (cf. Figure 7, 8 and 9).
Typical wall densities in direction 1	3-4%
Typical wall densities in direction 2	5-10%
Additional comments on typical wall densities	The typical total wall area/plan area is between 3.0 % and 5.5 % in each direction.
Wall Openings	The openings are often located in the facade and there may be one or two openings of 1.2 to 1.5 meters width equally spaced (see Figure 3 and Figure 4).
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	Typical patterns of modifications observed are vertical expansions (adding new stories) and in some cases adding division walls for new rooms.
Type of Foundation	Shallow Foundation: Mat foundation
Additional comments on foundation	The foundation is often a concrete slab, with longitudinal reinforcement for bending. The vertical reinforcement for the walls is placed before casting the slab, so the correct location is important since this will define the final wall location.
Type of Floor System	Other floor system
Additional comments on floor system	Structural concrete: Solid slabs (cast-in-place), Waffle slabs (cast-in-place)
Type of Roof System	Roof system, other
Additional comments on roof system	The roof system consists of corrugate sheets supported on steel trusses (normally tube sections of 2#x1#x1/4# (Figure 6).
Additional comments section 2	These buildings do not share walls with adjacent buildings and are normally located conforming lines of housing (separated from each other) called #conjuntos#. They represent several buildings of the same type with small gardens inside and public areas for each #conjunto#.

	They are normally separated several meters from other structures.



Plan view of typical housing.



Facade of Typical housing

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	Wall: Clay bricks Concrete blocks. (Vertical hollow cores)	Wall: Characteristic Strength- 18 MPa 8-13 MPa.
Foundations	Concrete, Steel.	Characteristic Strength: Concrete f'c = 21MPa Steel fy=420 MPa
Floors	Reinforced concrete.	Characteristic Strength: Concrete f'c=21MPa
Roof	Corrugated sheets	
Other		

Design Process

Who is involved with the	

Who is involved with the design process?	Engineer
Roles of those involved in the design process	
Expertise of those involved in the design process	The Colombian code allows structural designs only to those civil engineers with a master in structural engineering or have at least 5 years of specific experience in the area.

Construction Process

Who typically builds this construction type?	ContractorOther
Roles of those involved in the building process	Private contractors or construction companies, and in some cases they are contracted by the government.
Expertise of those involved in building process	The constructor has to be civil engineer or architect with more than 3 years of experience, and there is a compulsory inspection during the construction and has to be done by a civil engineer or architect with more than 5 years of experience.
Construction process and phasing	Depending on the size of the project, many or few builders are involved in the construction process. The mat foundation is cast in situ and the vertical reinforcement is placed before the cast, then the masonry units are assembled and the horizontal reinforcement is placed in between the horizontal bed joints of the units. Normally at the top of the wall, a concrete beam is built and supports for the roof are placed in the casting process, then the truss system for the roof is installed and the corrugated sheets are placed. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size.
Construction issues	

Building Codes and Standards

Is this construction type address by codes/standards?	Yes
Applicable codes or standards	The current code is from 2011 (NSR-10) [3] #Norma Sismoresistente Colombiana# and all of chapter #D# is about masonry structures. The first code (in 1984) established the first parameters and guided the design and construction, each chapter provides the minimum requirements of the materials and tests that have to be done during the construction. The earthquake requirements are defined in chapter #A# of the code, chapter ## is about technical supervision and chapter #K# is about complementary requirements depending on the occupancy and importance of the buildings. Law 400

	of 1997 [9], defines the minimum requirements of professionals for designing, constructing and supervising.
Process for building code enforcement	A specific governmental organization authorizes the construction after a complete set of architectural, structural and technical (i.e. hydraulic, electric) design memories and blueprints are submitted and signed by the each responsible professional.

Building Permits and Development Control Rules

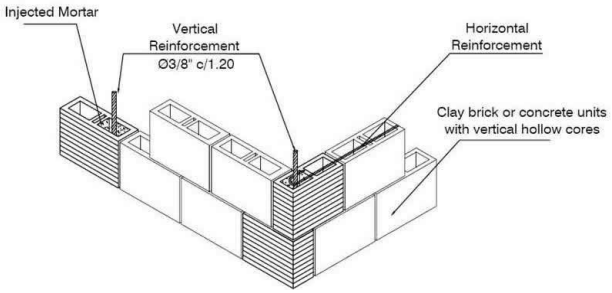
Are building permits required?	Yes
Is this typically informal construction?	No
Is this construction typically authorized as per development control rules?	Yes
Additional comments on building permits and development control rules	

Building Maintenance and Condition

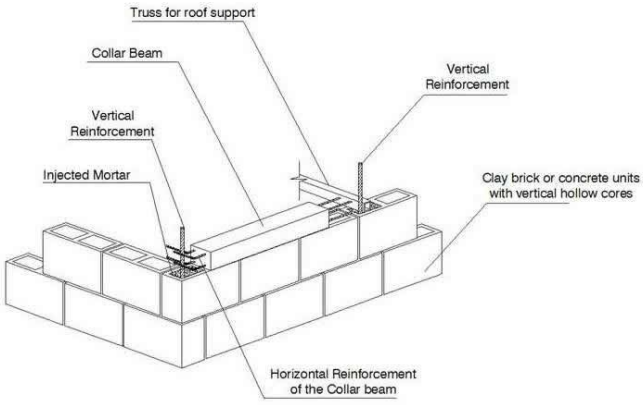
Typical problems associated with this type of construction	
Who typically maintains buildings of this type?	Owner(s)
Additional comments on maintenance and building condition	

Construction Economics

Unit construction cost	The building cost is approximately $120-$200 per square meter.
Labor requirements	
Additional comments section 3	The first Colombian code was developed in 1984 defining the design and construction requirements for reinforced masonry buildings and other types of structural systems. The code was updated in 1998 and the last version was in 2011, being more strict and specific. For reinforced masonry buildings, the code defines the minimum requirements for design, construction and maintenance but although the code is considered as law, the controls during the construction are not enough and often the requirements are not completely followed.



Details of the assembled reinforced masonry wall.



Details of the connections for the roof system.

Location of the reinforcement and application of the mortar [2].

Reinforced masonry walls' assembly after the mat foundation. (August 2011) [1].

Horizontal reinforcement placed in between the horizontal bed joints. (2 bars of 4mm diameter) (August 2011) [1].

Socio-Economic Issues

Patterns of occupancy	Typically one family occupies a house. Sometimes the house owner may rent out rooms to others, and in many cases (low economic groups) two families may share the

	house.
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	The number of inhabitants during the evening and night is more than 4 and up to 6.
Economic level of inhabitants	Low-income class (poor)Middle-income class
Additional comments on economic level of inhabitants	The Colombian social strata is divided into 5 different stratums called #estratos#, from 1 to 5, being 1 the lowest income, 2 the low middle class, 3 the middle class, 4 the upper middle class, 5 the upper class and 6 the wealthy. Formal reports talk about 35% of poverty and 17% of extreme poverty [8]. House Price/Annual Income (Ratio): 4:1, 5:1 or worse
Typical Source of Financing	Owner financedPersonal savingsSmall lending institutions/microfinance institutionsCommercial banks/mortgagesOther
Additional comments on financing	Employers
Type of Ownership	RentOwn outright
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
1875	C#cuta, N.de S.
1970	Northern part of Colombia
1974	Panama
1987	Southern Part of Colombia
1999	#Eje Cafetero# Andes region (Quind#o)
2004	West coast
2007	North coast
2008	North coast

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	After the Popayan earthquake in 1984, most of the structures were considerably damaged and many of them collapsed. Many of the buildings were unreinforced/reinforced masonry and moment resistant reinforced concrete frames, but the first seismic code was still not developed. Figure 10 shows the historical earthquakes with a Magnitude > 5 since 1875 in Colombia according to [5] and [6].
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	TRUE

	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.	N/A
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.	N/A
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);	TRUE
Foundation-Wall Connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete	TRUE

	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.	TRUE
Wall Openings		FALSE
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	TRUE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	TRUE
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

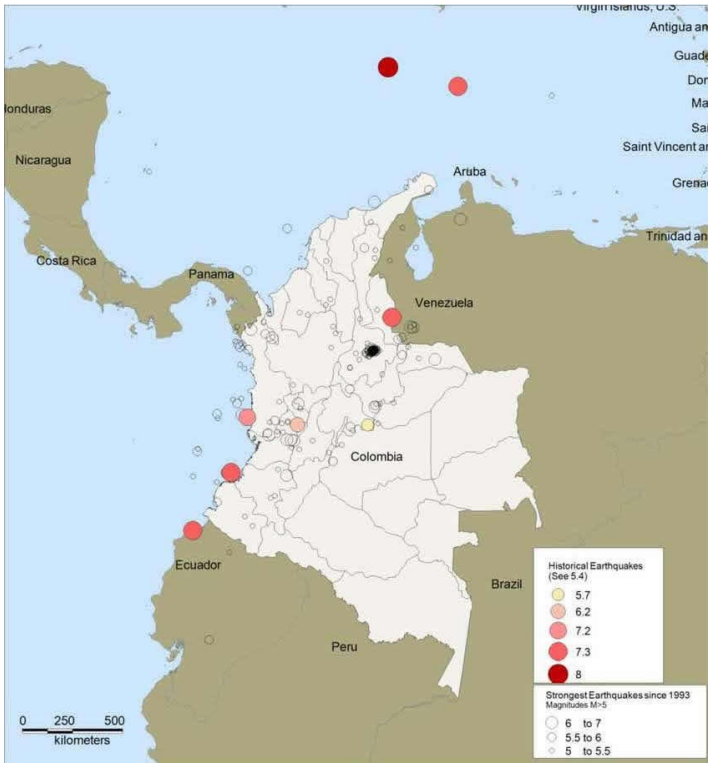
Additional comments on structural and architectural features for seismic resistance	1) Due to the light roof system it can#t be considered as rigid, but it should maintain its integrity. 2) In general there are no floor construction in the relevant building type of this report.
Vertical irregularities typically found in this construction type	Other
Horizontal irregularities typically found in this construction type	Other
Seismic deficiency in walls	The openings on the walls are in general too big (bigger than # the distance between the adjacent cross walls). In these cases the walls cannot be considered part of the structural system and the remaining walls should be able to support the horizontal actions.
Earthquake-resilient features in walls	The walls are reinforced and designed to support lateral loads and in general the mass of the structures is low

in walls	(only one or two stories)
Seismic deficiency in frames	
Earthquake-resilient features in frame	
Seismic deficiency in roof and floors	
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	-|	



Strongest earthquakes in Colombia (see Table in Chapter 5.4).

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic Strengthening
Wall openings bigger than recommended.	No strengthening techniques are adopted. On the design stage, spandrel beams are used around the openings.

Additional comments on seismic strengthening provisions	
Has seismic strengthening described in the above table been performed?	If new constructions follow the design code, no strengthening scheme is needed.
Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?	The work should be done as a mitigation effort on an undamaged building
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 seismic retrofit is controlled by the contractor and the inspector, both have to be engineers or architects.
What has been the performance of retrofitted buildings of this type in subsequent earthquakes?	There was no opportunity to observe the performance of retrofitted buildings.
Additional comments section 6	

References

Ing. Luis Carlos Hackmayer Saracino (2011). Pictures of reinforced masonry buildings during construction, Arauca, Colombia.

Ing. Luis Enrique Gil (2011). Pictures of reinforced masonry buildings during construction, Bogota, Colombia.

NSR-10 (2011). Norma sismoresistente Colombiana, Colombian seismic building code, Colombia.

Angelica Maria Herrera and Germ#n Guillermo Madrid (1999). Manual de construccion de mamposteria de concreto, Construction handbook of reinforced masonry.

Ingeominas. Earthquake catalogue of Colombian Institute of Geology and Mining.

U.S. Geological Survey. Strongest Earthquakes in Colombia. (last access: July 2013) URL: http://earthquake.usgs.gov/earthquakes/world/historical_country.php

Grunthal, G. (ed.), Musson, R., Schwarz, J., Stucchi, M. (1998). European Macroseismic Scale 1998, Cahiers de Centre Europ#en de G#odynamique et de Seismologie, Volume 15, Luxembourg.

Sarmiento Anzola, Libardo (1999). Exclusion, Conflicto y Desarrollo Social. Ed. Desde Abajo. Datos de Desplazamiento Forzado: Codees Informa No. 26. p.3. Exclusion, Conflict and Social Development.

Ley 400 de 1997: Por la cual se adoptan normas sobre Construcciones Sismo Resistentes, Diario Oficial No. 43.113, del 25 de agosto de 1997.

Authors

Name	Title	Affiliation	Location	Email
Luis Carlos Hackmayer	Alumni #Natural Hazards and Risks in Structural Engineering#	Bauhaus-Universitat Weimar		luis.carlos.hackmayer@uni-weimar.de
Lars Abrahamczyk		Earthquake Damage Analysis Center (EDAC)	Bauhaus-Universitat Weimar	lars.abrahamczyk@uni-weimar.de
Jochen Schwarz	Earthquake Damage Analysis Center (EDAC)	Bauhaus-Universitat Weimar	schwarz@uni-weimar.de	

Reviewers

Name	Title	Affiliation	Location	Email

Dina D Ayala	University College London CEGE Department		fra2dina@gmail.com	