World Housing Encyclopedia

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HOUSING REPORT
Reinforced Clay Brick Masonry Building

Report #	175
Report Date	05-08-2013
Country	COLOMBIA
Housing Type	Reinforced Masonry Building
Housing Sub-Type	Reinforced Masonry Building: Clay brick masonry in cement mortar
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Summary

This type of single-story housing is typically built in urban areas around the Country. Nowadays also multistory buildings up to 10 stories can 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).

1. General Information

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 Bogotá and Medellín, 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.

This construction type has been in practice for less than 20 years.

Currently, this type of construction is still being built.

Figure 1. Typical one-story house (August 2011) [1].

Figure 2. Typical multistory building (big cities) [2].

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They 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.

2.2 Building Configuration

The typical shape of these buildings is rectangular. The openings are often located in the façade and there may be one or two openings of 1.2 to 1.5 meters width equally spaced (see **Figure 3** and **Figure 4**).

2.3 Functional Planning

The main function of this building typology is a multi/single-family housing depending on the income level. There are no elevators and no fire protected exit staircase. If more than one floor, there is not an additional exit stair beside the main stairs.

2.4 Modification to Building

Typical patterns of modifications observed are vertical expansions (adding new stories) and in some cases adding division walls for new rooms.

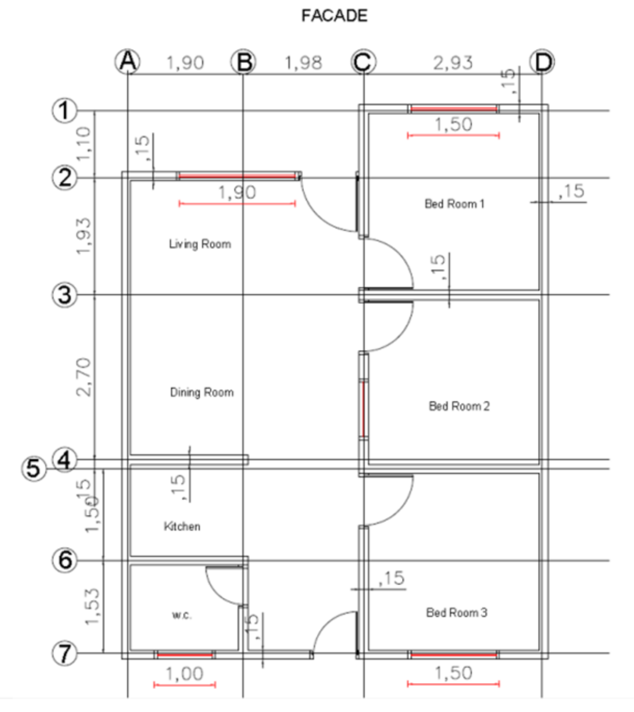

Figure 3. Plan view of typical housing.

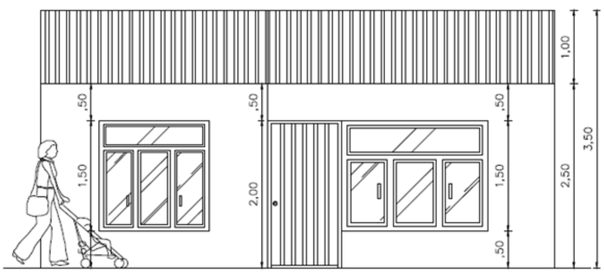

Figure 4. Facade of Typical housing.

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	[illegible]
	Braced frame	32	Concentric connections in all panels	☐
		33	Eccentric connections in a few panels	☐
	Structural wall	34	Bolted plate	☐
		35	Welded plate	☐

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
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)	☐

The walls are made of clay or concrete block masonry. Clay hollow units are the most commonly used (cf. **Figure 7, 8** and **9**).

3.2 Gravity Load-Resisting System

The vertical load-resisting system is reinforced-masonry walls.

3.3 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 in 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 structures 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 buildings, only the cores that contain vertical reinforcement are filled with mortar. The maximum distance between vertical reinforcement is 1.20 meters and 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).

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 10 and 15 meters and widths between 6 and 9 meters (see **Figure 3**). The typical span of the roof system is 4.65 meters. The typical story height is 2.5 meters (see **Figure 4**). The typical total wall area/plan area is between 3.0 % and 5.5 % in each direction.

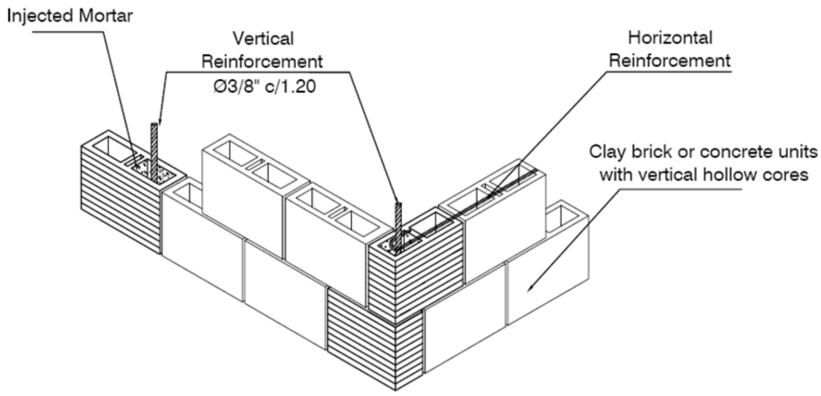

Figure 5. Details of the assembled reinforced masonry wall.

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	☐	☑

The roof system consists of corrugate sheets supported on steel trusses (normally tube sections of 2”x1”x1/4” (**Figure 6**).

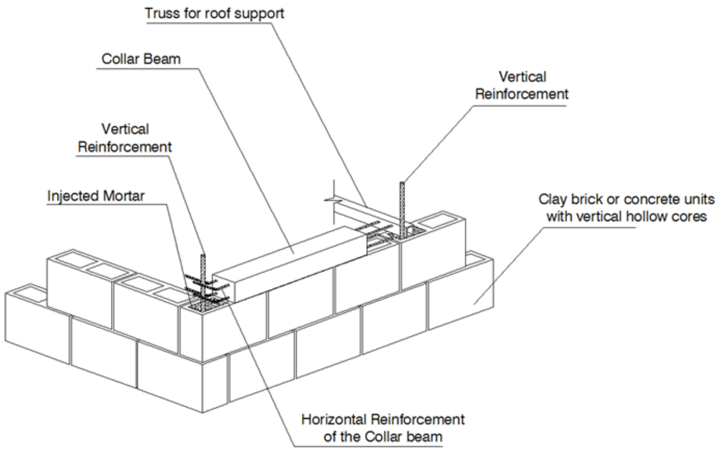

Figure 6. Details of the connections for the roof system.

3.6 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	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	☐
Deep foundation	Reinforced-concrete bearing piles	☐
	Reinforced-concrete skin friction piles	☐
	Steel bearing piles	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

Figure 7. Location of the reinforcement and application of the mortar [2].

Figure 8. Reinforced masonry walls' assembly after the mat foundation. (August 2011) [1].

Figure 9. Horizontal reinforcement placed in between the horizontal bed joints. (2 bars of 4mm diameter) (August 2011) [1].

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 1 housing unit. The number of inhabitants in a building during the day or business hours is around 4. The number of inhabitants during the evening and night is more than 4 and up to 6.

4.2 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.

4.3 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].

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)	☐

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 is 1 bathroom including toilet.

4.4 Ownership

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		
		True	False	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.	☐		☑ [1)]
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.		☐	☑ [2)]
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)		☑	☐

[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.

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Walls	The openings on the walls are in general too big (bigger than ½ 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.	The walls are reinforced and designed for support lateral loads and in general the mass of the structures is low (only one or two stories)	n.a.

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.

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 (i.e. moderate seismic performance),* and the upper bound (i.e., the best possible) is E: *LOW VULNERABILITY (i.e. very good seismic performance).*

The assignment of the vulnerability follows the European Macroseismic Scale EMS-1998 [7] where a classification of this building type into class D is suggested with a scatter from class C and E. However it is important to mention that the vulnerability rating is assigned assuming an excellent quality of the construction materials. If the housing is built with deficient materials (produced without quality control) the vulnerability will be higher.

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
	☐	☐	|······	——○——	——|	☐

○ Most likely vulnerability class; —— probable range; ········ range of less probable, exceptional cases

5.4 History of Past Earthquakes

Date	Epicenter, region	Magnitude	Max. Intensity
1875	Cúcuta, N.de S.	7.3	n.a.
1970	Northern part of Colombia	8	n.a.
1974	Panamá	7.3	n.a.
1987	Southern Part of Colombia	7.3	n.a.
1999	“Eje Cafetero” Andes region (Quindío)	6.2	n.a.
2004	West coast	7.2	n.a.
2007	North coast	7.3	n.a.
2008	North coast	5.7	n.a.

After the Popayán earthquake in 1984, most of the structures were considerable damaged and many of them collapsed. Many of the buildings were unreinforced/reinforced masonry and moment resistant reinforced concrete fames, but the first seismic code was not still developed. **Figure 10** shows the historical earthquakes with a Magnitude > 5 since 1875 in Colombia according to [5] and [6].

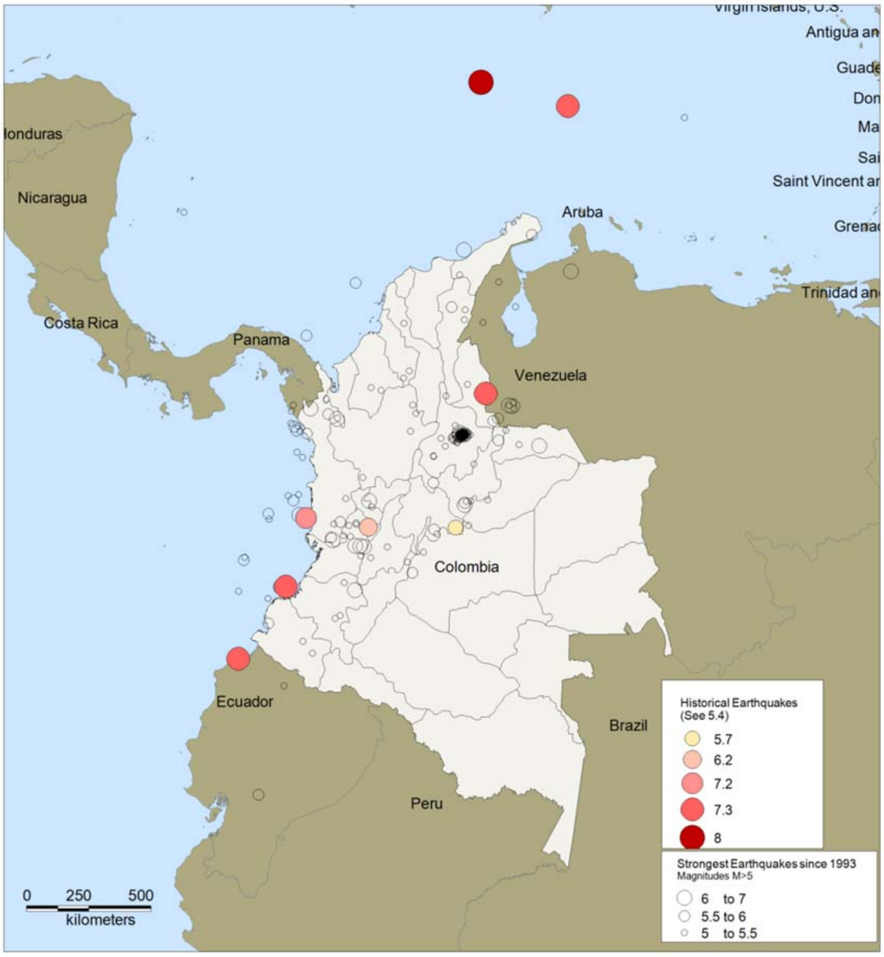

Figure 10. Strongest earthquakes in Colombia (see Table in Chapter 5.4).

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Clay bricks Concrete blocks. (Vertical hollow cores)	18 MPa 8-13 MPa.		
Foundation	Concrete, Steel.	Concrete f'c = 21MPa Steel fy=420 MPa.		
Frames (beams & columns)				
Roof and floor(s)	Floor: Reinforced concrete. Roof: Corrugated sheets.	Concrete f'c=21MPa		

6.2 Builder

Private contractors or construction companies, and in some cases they are contracted by the government.

6.3 Construction Process, Problems and Phasing

Depending on the size of the project, many or few builders are involved in the construction process.

The mat foundation is casted 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 the 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.

6.4 Design and Construction Expertise

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. 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.

6.5 Building Codes and Standards

The current code is from 2011 (NSR-10) [3] "Norma Sismoresistente Colombiana" and all the 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 the chapter "A" of the code, chapter "I" is about technical supervision and chapter "K" about complementary requirements depending on the occupancy and importance of the buildings. The law 400 of 1997 [9], defines the minimum requirements of professionals for designing, constructing and supervising.

6.6 Building Permits and Development Control Rules

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.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by the owner(s).

6.8 Construction Economics

The building cost is approximately $120-$200 per square meter.

7. Insurance

Earthquake insurance for this construction type is typically not available. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction:

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

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?

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 repair following an earthquake?

The work should be done as a mitigation effort on an undamaged building.

8.3 Construction and Performance of Seismic Strengthening

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

Yes.

Who performed the construction seismic retrofit measures: 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 was the performance of retrofitted buildings of this type in subsequent earthquakes?

There was no opportunity to observe the performance of the retrofitted buildings.

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