World Housing Encyclopedia

an Encyclopedia of Housing Construction in
Seismically Active Areas of the World

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International Association for Earthquake Engineering (IAEE)

HOUSING REPORT
Non-engineered Unreinforced Brick Masonry Building

Report #	10
Report Date	05-06-2002
Country	COLOMBIA
Housing Type	Unreinforced Masonry Building
Housing Sub-Type	Unreinforced Masonry Building : Brick masonry in lime/cement mortar
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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.

1. General Information

Buildings of this construction type can be found 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. This type of housing construction is commonly found in both rural and urban areas.

There are not any important differences between the houses in urban and rural areas.

This construction type has been in practice for less than 50 years.

Currently, this type of construction is being built. Traditional construction practice for low-rise buildings (1- to 4-story high) followed in the last 50 years.

Figure 1: Typical Building

2. Architectural Aspects

2.1 Siting

These buildings are typically found in sloped and hilly terrain. They do not share common walls with adjacent buildings. 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.

2.2 Building Configuration

Buildings of this type are generally of a rectangular plan shape. Information about the openings in a typical 2-story house with an average plan area of 35.0 m^2 is summarized below: [Number of openings, Size (m^2), 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%.

2.3 Functional Planning

The main function of this building typology is multi-family housing. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. Usually buildings of this type do not have additional means of escape.

2.4 Modification to Building

Typical modification is vertical expansion (construction of new stories).

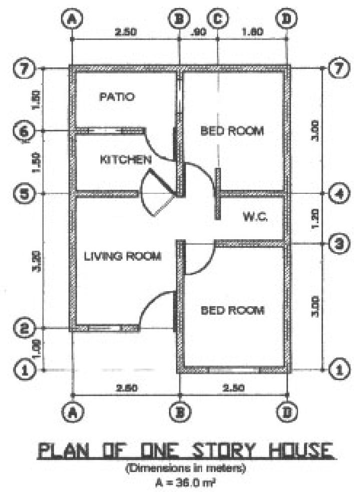

Figure 2: Plan of a Typical Building

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	☐
		17	Flat slab structure	☐

Structural concrete	Moment resisting frame	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	☐
	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)	☐

Refer to section 4.1 for the description of floor and roof characteristics.

3.2 Gravity Load-Resisting 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.

3.3 Lateral Load-Resisting System

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.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 15 and 15 meters, and widths between 6 and 6 meters. The building is 2 storey high. The typical span of the roofing/flooring system is 3 meters. Typical Plan Dimension: Length varies from 10 to 15 m, and the width varies from 3 to 6 m. Typical Span: Typical span varies from 2.5 to 3.0 meters. The typical storey height in such buildings is 2.5 meters. The typical structural wall density is none. 0.1.

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 floor can be considered as a rigid diaphragm and the roof as a flexible one.

3.6 Foundation

Type	Description	Most appropriate type
	Wall or column embedded in soil, without footing	☐
	Rubble stone, fieldstone isolated footing	☐

Shallow foundation	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	☐

Unreinforced "cidopeus" concrete. This is a type of strip footing.

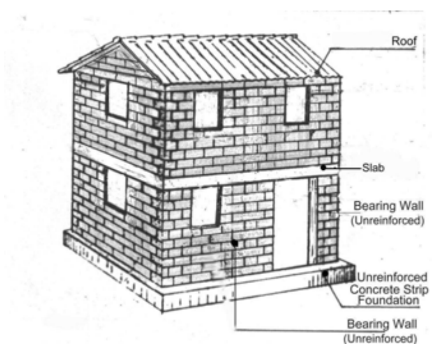

Figure 3A: Key Load-bearing Elements

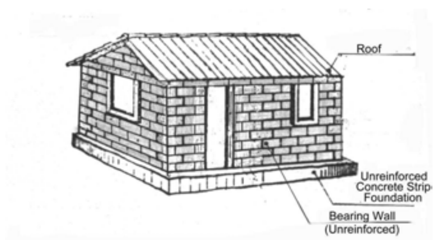

Figure 3B: Key Load-bearing Elements

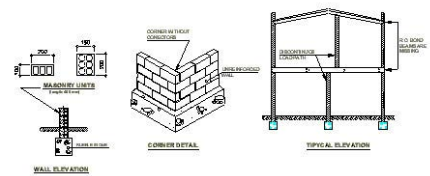
Figure 4: Wall Elevation

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 3 housing unit(s). In rural areas, one housing unit/building; in urban environments, two or three housing units in a building. 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

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.

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)	☐

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.

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)	☐

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. In each housing unit, there are 1 bathroom(s) without toilet(s), 1 toilet(s) only and 1 bathroom(s) including toilet(s).

In rural areas 1, in urban areas 2 per housing unit. .

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 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.	☐	☑	☐
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: 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)	☐	☑	☐
Additional Comments				

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	-Unreinforced walls, -Unclear earthquake load path (discontinuous path), -Unequal stiffness distribution, -Sometimes very slender walls (drift and instability problems), -Stepped construction		
Frame (columns, beams)			
Roof and floors	-Absence of continuous boundary members (chords and collectors) -Weak roof-wall and floor-wall connections		
Other	-Poor quality of workmanship and materials.		

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance), the lower bound (i.e., the worst possible) is A: HIGH VULNERABILITY (i.e., very poor seismic performance), and the upper bound (i.e., the best possible) is C: MEDIUM VULNERABILITY (i.e., moderate 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
1979	4.8N, 76.2W, depth: 108 km (Mistrató)	6.7	VIII MMI (MANIZALES)
1983	2.46N, 76.69W, depth: 22 km (Popayán)	5.5	IX MMI (POPAYÁN)
1995	4.1N, 76.62W, depth: 73 km (Pereira)	6.4	VIII MMI (PEREIRA)
1999	4.46N, 75.72W, depth: 17 km (Armenia)	6	IX MMI (ARMENIA)

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

Figure 5A: Key Seismic Deficiencies: Wall Weakness due to Electrical and Water Conduits

Figure 5B: Key Seismic Deficiencies: Poor Quality of Materials

Figure 5C: Key Seismic Deficiencies: Very Slender Walls

Figure 5D: Key Seismic Deficiencies: Poor Quality of Materials

Figure 5E: Key Seismic Deficiencies: Discontinuous Boundary Members

Figure 6: Typical Earthquake Damage: Partial Collapse

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Bricks with cement mortar	3.0 MPa, 9.0 MPa	w /h/l 150 X 200 X 400 mm 100 X 200 X 400 mm Cement: Sand 1:8	Typical dimensions: variable Compression determined based on the gross area. Compression strength determined using 50 mm cubes
Foundation	Plain rubble stone	f'c = 10.0-15.0 MPa		The concrete by itself (without stones) has f'c 15.0 MPa.
Frames (beams & columns)				
Roof and floor(s)	Concrete (Hollow tile floor)	f'c= 10.0 - 15.0 MPa	1:2:4->1:3:5	Cement/sand/aggregates

6.2 Builder

At the beginning, the builder occupies the first floor of the building. As the house construction progresses and other stories are added, this building can become a multiple housing unit, and the additional units in the other stories are leased.

6.3 Construction Process, Problems 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.

6.4 Design and Construction Expertise

Engineers and architects do not participate in this type of building construction. The construction labor is semi-skilled.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. 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. The year the first code/standard addressing this type of construction issued was 1984. The most recent code/standard addressing this construction type issued was 1998. Title of the code or standard: 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. Year the first code/standard addressing this type of construction issued: 1984 When was the most recent code/standard addressing this construction type issued? 1998.

So far, there are no established procedures related to the building code enforcement for this type of construction.

6.6 Building Permits and Development Control Rules

This type of construction is a non-engineered, and not authorized as per 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 permits are required to build this housing type.

6.7 Building Maintenance

Typically, the building of this housing type is maintained by Owner(s). Due to the difficult economic situation of inhabitants of this construction type, these buildings are seldom maintained.

6.8 Construction Economics

Although the labor 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^2. (125 $US /$m^2$). 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 finishing etc.

7. Insurance

Earthquake insurance for this construction type is typically unavailable. 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
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
Poor quality of workmanship and materials	

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 7D. 2. Whenever possible, end elements (columns-posts) are added in the selected earthquake resistant walls, as illustrated in Figure 7B and 7G 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 7A, 7B, 7C, and 7F. It is considered that the implementation of the above described techniques would result a significant enhancement of seismic stability in buildings of this type.

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. Seismic strengthening has been used in practice by the author of this contribution as illustrated in Figures 7A, 7B, 7C, 7D, 7E, 7F, and 7G.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
The work was done as a mitigation effort.

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 work was performed by a contractor and an engineer was involved.

What was 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.

Figure 7A: Illustration of Seismic-strengthening Techniques

Figure 7B: Seismic-strengthening Techniques: Construction of New Columns and Bond Beams

Figure 7C: Seismic-strengthening Techniques: Construction of New Bond Beams

Figure 7D: Seismic-strengthening Techniques: Construction of the Wall-Roof Connection

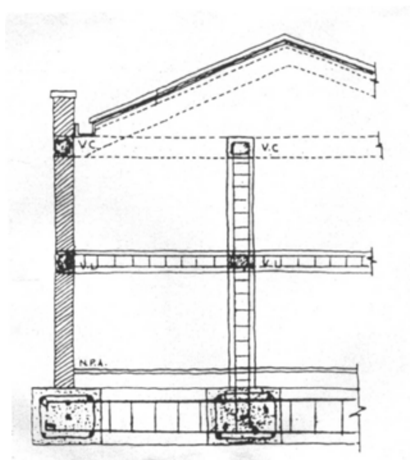

Figure 7E: Seismic-strengthening Elements

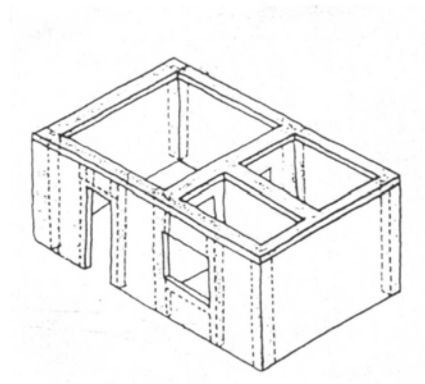

Figure 7F: Seismic-strengthening Techniques: Construction of New RC Ring Beam

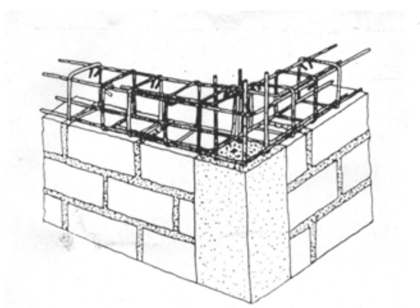

Figure 7G: Seismic-strengthening Techniques: Construction of New RC Tie-Columns

Reference(s)

1. Colombian Code for Earthquake-Resistant Design and Construction of Buildings (CCCSR-84 and NSR-98)

2. Basic Aspects for the Design and Construction of Earthquake-Resistant 1- or 2-story Buildings
   Mejia, Luis Gonzalo
   (in Spanish)

3. Specifications for the Earthquake-Resistant Design of 1- or 2-story Houses Per the Colombian Code NSR-98
   Mejia, Luis Gonzalo
   (in Spanish)

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