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

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

HOUSING REPORT
Concrete Shear Wall Buildings

Report #	109
Report Date	06-11-2004
Country	COLOMBIA
Housing Type	RC Structural Wall Building
Housing Sub-Type	RC Structural Wall Building : Moment frame with in-situ shear walls
Author(s)	Luis G. Mejia, Juan C. Ortiz R., Laura I. Osorio G.
Reviewer(s)	Marcial Blondet

Summary

These buildings are characterized mainly by cast-in-place, load-bearing, reinforced-concrete shear walls in both principal directions. The buildings are usually multiple housing units found in the major urban areas of Colombia, especially in the Andean and Caribbean regions. They represent about 2 to 3% of the housing stock in the cities with a population between one to seven million. These buildings typically have 7 to 20 stories, generally with a cast-in-place

reinforced-concrete floor slab system. In general, these buildings have good seismic performance because of their regular mass distribution in height and symmetrical plan configuration and the great stiffness and strength of the walls that can restrict story drift to less than or equal to 0.005h. In some cases, if the buildings were constructed after the first Colombian Seismic Code in 1984, poor seismic detailing is found.

1. General Information

Buildings of this construction type can be found in the Andean and Caribbean regions of Colombia. Concrete shear wall buildings are found primarily in the big cities of the Andean region: Bogotá, Medellín, Cali, Pereira, Armenia, Manizales, Bucaramanga, and Ibagué. Cities of the Caribbean region: Barranquilla, Cartagena, and Santa Marta). Approximately 2 percent of the housing in these cities is of this type. This type of housing construction is commonly found in urban areas.

This building type is found principally in densely populated urban areas where there is a need to provide many housing units in a relatively small area.

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

Currently, this type of construction is being built. Actually, these buildings are often used for the construction of government-subsidized housing (Vivienda de Interés Social) for low- to middle-income people.

Figure 1. Typical Building (21 story public housing project). Photo courtesy OPTIMA S.A.

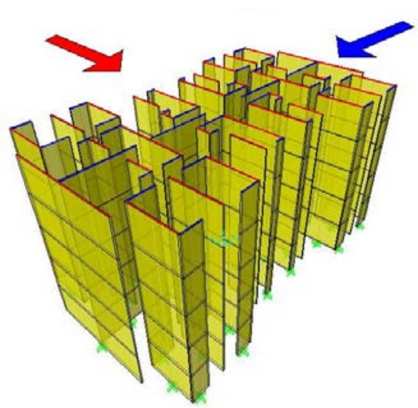

Figure 2. Perspective Drawing showing key load-bearing elements

Figure 5f. Formwork used for exterior walls. Note its irregular surface. OPTIMA S.A. construction project.

Figure 5g. Pulley used for material extraction from pile excavation. Also used to lift the worker who works down there. OPTIMA S.A. construction project.

Figure 6a. Cap's reinforcement basket of a hollow

Figure 6b. Perspective view of the reinforcement foundation beams. OPTIMA S.A. construction

pile. OPTIMA S.A. construction project.

project.


Figure 6c. Concrete placement into walls and slab. Note the preparation of the upper level walls and placement of the electrical nets. OPTIMA S.A. construction project.


Figure 6d. Wall's reinforcement already placed and armed. OPTIMA S.A. construction project.


Figure 6e. Element, commonly called "panelita", used to maintain the necessary cover and to ensure the correct placement of the reinforcement into the wall. OPTIMA S.A. construction project.


Figure 6f. Opening in the slab for the hydraulics and electrical nets. OPTIMA S.A. construction project.


Figure 7. Precast stair supports. OPTIMA S.A. construction project.


Figure 8. Perspective view of a finished room. Typically this is how an owner receives his apartment from the Social Interests Project (Public Housing Dept.) OPTIMA S.A. construction project.

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat, sloped and hilly terrain. They do not share common walls with adjacent buildings. In the absence of rigorous enforcement of regulations, it was once common practice not to separate adjacent buildings in very populated urban areas. Now, regulations are strictly enforced and the minimal separation between buildings according to NSR-98 must be at least 2 x 0.005 x the total height of the building. For a 10-story building that can be as tall as 25 m, the minimum separation from a similar building must be at least 0.25 m. In a block of individual buildings, each can be separated by up to 1 m When separated from adjacent buildings, the typical distance from a neighboring building is 1 meters.

2.2 Building Configuration

Generally, the buildings are rectangular or square, with some setback in the plan. They are usually regular in plan and in height. Typical description of openings for a 320 m2 floor plan (4 house units): In the facade walls the openings are primarily in bedrooms and living rooms, and represent 25% of the wall area in bedrooms and 15 to 20% of the wall area in living rooms. The number of openings in the facade walls range from 4 to 16. with a width ranging from 1.5m to 2.5m and a height ranging from 1.2m to 2.0m. The openings in inner walls are typically doors, representing 10% of the wall area. There can be as many as 20 for 4 units, with a typical width of .9m and a typical height of 2.0m. The percentage of openings in the façade walls is greater than in the inner walls, principally due to the need for lighting.

2.3 Functional Planning

The main function of this building typology is multi-family housing. The buildings are typically used for multiple housing units and usually do not have garages because of the small span in both directions of the structural walls. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. There is one principal staircase in the center of each building. In buildings over 7 stories, there is usually also an elevator (which, theoretically, cannot be used in an emergency).

2.4 Modification to Building

The most popular modification is probably the addition of balconies. In general, most modifications are nonstructural, such as re-surfacing floors or walls, or adding new nonstructural masonry walls inside the individual units.

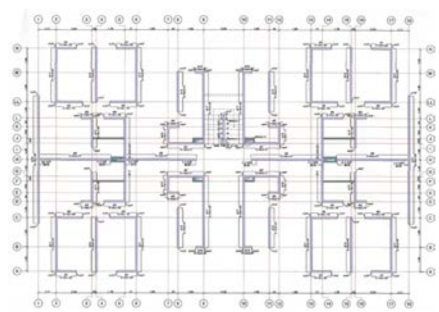

Figure 3. Plan of a typical building. Photo courtesy Alvaro P

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	☐
		18	Designed for gravity loads only, with URM infill walls	☐

Structural concrete	Moment resisting frame	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)	☐

3.2 Gravity Load-Resisting System

The vertical load-resisting system is reinforced concrete structural walls (with frame). The gravity load is carried by the reinforced-concrete slabs that form each floor (generally, two-way slabs) supported directly on shear walls, or in some cases, by lintels. These walls take the gravity loads, carrying them to the foundations. When the slabs span in one direction, the walls that support them take both the gravity and lateral loads, and the walls in the orthogonal direction take only the lateral loads.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is reinforced concrete structural walls (with frame). Shear reinforced-concrete walls provide adequate stiffness and strength in conjunction with the in-plane rigid diaphragm floor of concrete slabs, which join together in a rigid system. In more recent years, in compliance with requirements for seismic detailing, lintel beams join some walls, resulting in elements that can dissipate energy during an earthquake.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 10 and 10 meters, and widths between 30 and 30 meters. The building has 7 to 20 storey(s). The typical span of the roofing/flooring system is 2.4-3.5 meters. Typical Plan Dimensions: These dimensions can vary in length and width between 10 m and 30 m. Typical Number of Stories: 7-20 stories Typical Story Height: Generally, the typical floor has a free height of 2.20 m, and the solid slab plus the finishing floor are 0.20 m. Sometimes, in upper-middle-class projects, the story height can be about 2.60 m. Typical Span: In general, in units with areas between 50m2 and 85m2 (2 or 3 rooms, kitchen, living room and 1 or 2 bathrooms), the interior spaces are small and do not require large spans. In a few cases, spans up to 4.50m can exist. The typical storey height in such buildings is 2.4 meters. The typical structural wall density is up to 5 %. The ratio between the wall density and the floor area is about 3% to 5%. The walls in one principal direction can be 70% of the orthogonal direction.

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	☑	☑

For seismic analysis, the floor and the roof are considered as rigid diaphragms that transfer the load to the wall, although in many situations the wall-slab connection is poorly detailed. In some cases the roof level is made of timber if a flexible diaphragm is believed to be desirable.

3.6 Foundation

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	☐

It consists of reinforced concrete end-bearing piles. Generally, in good superficial soil conditions, reinforced-concrete strip footing or mat foundations are used. Deep foundations in reinforced-concrete bearing piles are sometimes used in poor soils because of the great susceptibility of the bearing walls to settling, or because of the necessity of stabilizing the structure.

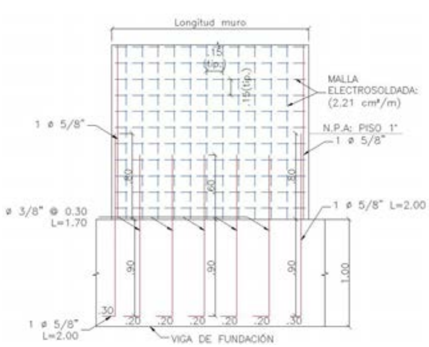

Figure 4a. Detail showing anchorage of the shear wall to the foundation beam. Seven story project. Figure courtesy of Alvaro P

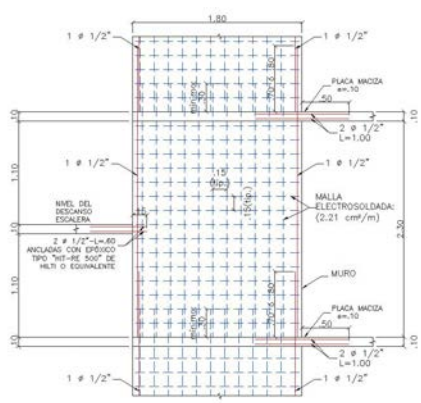

Figure 4b. Typical reinforcement of a shear wall (elevation). Seven story project. Photo courtesy of Alvaro P

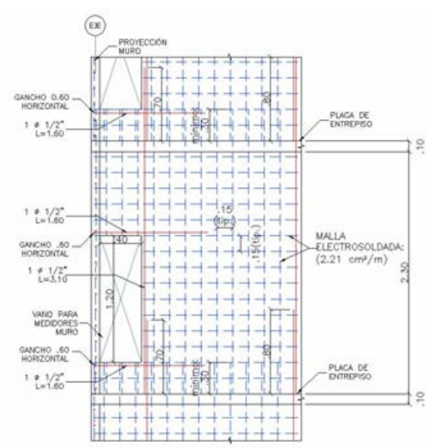

Figure 4c. Typical reinforcement of a shear wall with openings (elevation). Seven story project. Photo courtesy of Alvaro P

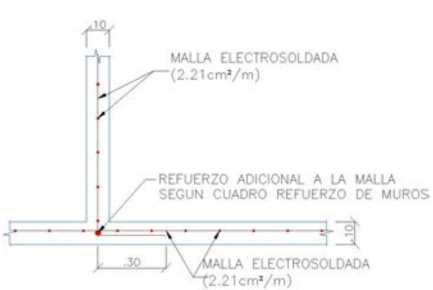

Figure 4d. Additional reinforcement in shear walls intersection (plan). Photo courtesy of Alvaro P

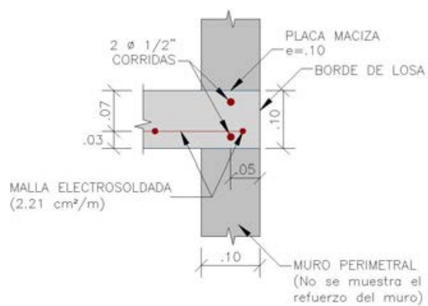

Figure 4e. Typical connection between slab and shear wall. Photo courtesy of Alvaro P

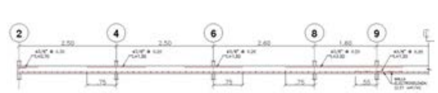
Figure 4f. Slab typical section. Photo courtesy of Alvaro P

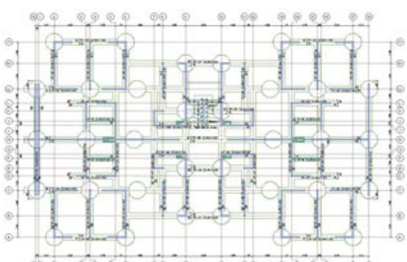

Figure 4g. Foundation plan Seven story project. Photo courtesy of Alvaro P

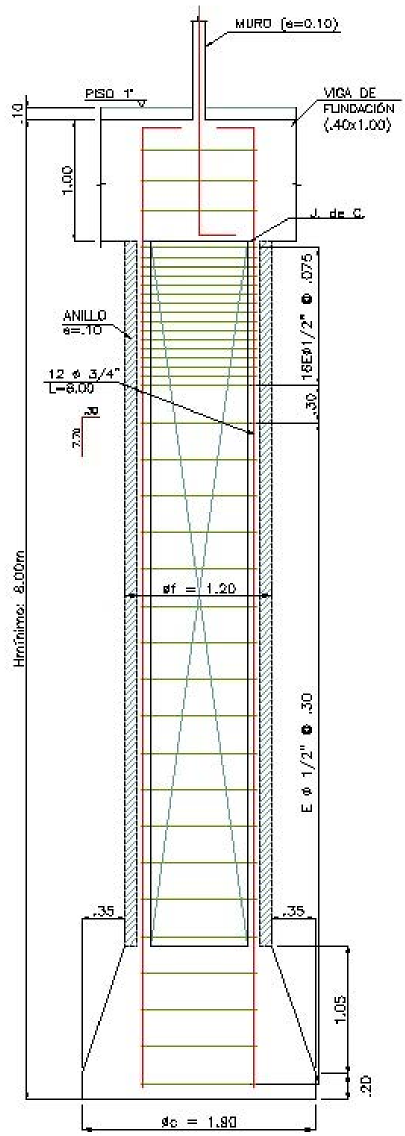

Figure 4h. Typical hollow reinforced pile (elevation). Common foundation type. Seven story project. Photo courtesy of Alvaro P

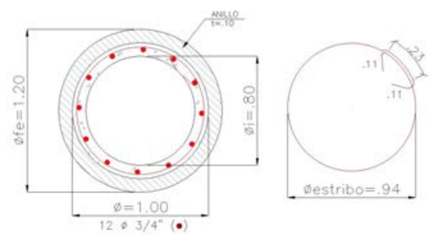

Figure 4i. Typical hollow reinforced pile (transverse section). Common foundation type. Seven story project. Photo courtesy of Alvaro P

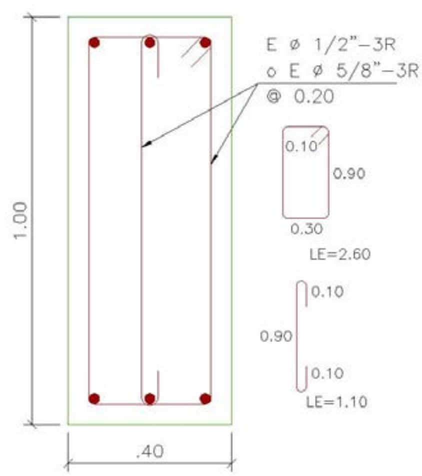

Figure 4j. Typical section of foundation beam (transverse section). Seven story project. Photo courtesy of Alvaro P

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 21-50 housing unit(s). 40 units in each building. A typical 10-story building can have 40 units, with 4 units per floor. This number can vary from 20 to 100 units depending on the number of stories and on the number of units per floor. The number of inhabitants in a building during the day or business hours is others (as described below). The number of inhabitants during the evening and night is others (as described below). During the day there can be as many as 100 people and in the evening as many as 150 people in a building. Most of the occupants are families, whose adult members generally work during the day while the children attend school. Therefore, there are few residents in these buildings during the day. On weekends, the number increases because people are at home. There is a similar increase in the number during the week nights when most people are at home.

4.2 Patterns of Occupancy

Typically, one family, consisting of 4 to 6 persons, occupies one housing unit.

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 following is an approximate economic distribution of the population in Colombia (the annual income listed above is the high end of the range expressed below): Economic Status % Population Annual Income (U.S. $) Very Poor 35 < 1,000 Poor 30 1,000-2,000 Middle Class 25 2,000-10,000 Upper Middle Class 4 10,000-40,000 Rich 1 > 40,000 Economic Level: For Poor families the housing price unit is 12500 and the annual income is 2000. For middle class families the housing price unit is 20000 and the annual income is 10000. For rich families the housing price unit is 28000 and the annual income is 40000.

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 poor have access to state financial aid if they have a monthly automatic savings plan in a financial institution.

Most middle-dass housing is financed by bank loans and in some cases with a combination of these loans and personal savings. Finally, a small percentage of upper-middle-dass people buy apartments with their own money, as a means of investment. Today, 40 to 60% of the projects are sold before they are constructed. Project owners prefer to do this to avoid taking out bank loans by financing the project themselves. In each housing unit, there are 1 bathroom(s) without toilet(s), no toilet(s) only and 1 bathroom(s) induding toilet(s).

Typically, there is one bathroom per one- or two-room apartment. Larger apartments can have two or three baths. .

4.4 Ownership

The type of ownership or occupancy is renting, outright ownership , ownership with debt (mortgage or other) and individual 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		
		Yes	No	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	Generally, these types of buildings have been designed by engineers and are well-detailed for seismic forces. In some cases, primarily in older buildings, there are deficiencies in the detailing of the seismic wall-slab and wall-foundation connections. Most of these buildings have shown good performance in moderate earthquakes, but in the absence of recent large-magnitude earthquakes in Colombia, it is not known how these buildings will actually perform.			

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall	In some cases there is poor seismic detailing in wall-slab and wall-foundation connections, differing from analysis and design assumptions. Inadequate reinforcement development length is one example of this poor detailing. In some new buildings, there is a tendency to use very thin walls with only one layer of reinforcement, which can generate stability problems and cause buckling failure during an earthquake.	The great stiffness that the wall system provides in conjunction with the slabs leads to a well-controlled story drift that minimizes the nonstructural damage.	In large-magnitude earthquakes damage in the connections can occur due to seismic deficiencies. Diagonal cracks are expected, but not severe damage or collapse.
Frame (Columns, beams)	N/A	N/A	N/A
Roof and floors	In some cases, with very thin slabs without boundary members like chords and collectors and/or with openings in plan, the diaphragm performance cannot be assumed.	Generally, slabs perform well as a diaphragm floor system	Cracking of slabs due to seismic deficiencies.
Foundations	In most cases, superficial wall foundations are designed assuming fixed-support conditions. The walls are detailed from the point-of-view of strength, but without enough stiffness to guarantee this fixity. During an earthquake some rotation can occur in the base of the wall, which would not have been considered in the analysis.	Generally, foundations perform well in moderate earthquakes.	In large earthquakes, damage in the connections with the walls can occur, due to seismic deficiencies.

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 VULNERABILITY (i.e., moderate seismic performance), and the upper bound (i.e., the best possible) is F: VERY LOW VULNERABILITY (i.e., excellent 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 MM (Manizales)
1983	2.46N, 76.69W,depth: 22 km (Popayán)	5.5	IX MM (Popayán)
1985	4.1N, 76.62W,depth: 73 km (Pereira)	6.4	VIII MM (Pereira)
1999	4.46N, 75.72W,depth: 17 km (Armenia)	6	IX MM (Armenia)

Buildings of this type have not yet been subjected to large-magnitude earthquakes in Colombia. In moderate earthquakes, like those listed above, the structural system has performed well, but in some cases there has been nonstructural damage.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Reinforced concrete.	f'c = 21 MPa to 35 MPa fy = 420 MPa	1:1.5-1.8:2.5	
Foundation	Reinforced concrete.	f'c = 21 MPa fy = 420 MPa	1:2:3	
Frames (beams & columns)				
Roof and floor(s)	Reinforced concrete.	f'c = 21 MPa to 28 MPa fy = 420 MPa	1:1.8-2:2.5	

6.2 Builder

These buildings are typically built for housing projects by developers and then sold to the general population.

6.3 Construction Process, Problems and Phasing

Generally, a construction company buys the land and contracts with an architectural firm and a structural engineer to design the building. The construction process is simple; first, a design is pproved, and then the foundations, walls and slabs are built. It is very common today to use a metal formwork and build one story per week, in a building with four units per story, but it can also be built completing one story per day depending on cash flow requirements. Equipment can be used to make the mix on site or this can be contracted with a pre-mix company. Placement can be done manually by workers carrying the concrete in buckets, by pumping the concrete, or by a combination of both methods. 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

Generally, in this kind of building, the design and construction are supervised by engineers possessing proficiency and expertise. In every case, the project should be reviewed and approved by a state agency and theoretically, by law, must be supervised during the construction process by a contractor not associated with the construction firm. Building design is done by architects and structural engineers. Both professions play the most important role in each stage of the design and construction.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. NSR-98 (Normas Colombianas de Diseño y Construcción Sismo Resistente) Colombian Code of Seismic Resistant Design and Construction, 1998. The year the first code/standard addressing this type of construction issued was CCCSR-84 (Código Colombiano de Construcciones Sismo Resistentes) Colombian Code of Seismic Resistant Construction, 1984. Prior to 1984, the ACI and UBC codes were widely used. NSR-98 is an accurate adaptation of ACI 318-95, with a few modifications in accordance with Colombian characteristics. Regulations found in ACI 318, sections 10 and 11, are mandatory, and for moderate and high seismic areas, the regulations in chapter 21.6 are required, too. The most recent code/standard addressing this construction type issued was 1998. Title of the code or standard: NSR-98 (Normas Colombianas de Diseño y Construcción Sismo Resistente) Colombian Code of Seismic Resistant Design and Construction, 1998. Year the first code/standard addressing this type of construction issued: CCCSR-84 (Código Colombiano de Construcciones Sismo Resistentes) Colombian Code of Seismic Resistant Construction, 1984. Prior to 1984, the ACI and UBC codes were widely used. National building code, material codes and seismic codes/standards: NSR-98 is an accurate adaptation of ACI 318-95, with a few modifications in accordance with Colombian characteristics. Regulations found in ACI 318, sections 10 and 11, are mandatory, and for moderate and high seismic areas, the regulations in chapter 21.6 are required, too. When was the most recent code/standard addressing this construction type issued? 1998.

The building design and construction must follow the provisions of NSR-98. Permits are required to develop the project, but in some cases after the permits have been given, the owner or contractor changes some of the building characteristics (mainly, the layout plan) without the approval of the state organization that issued the permits.

6.6 Building Permits and Development Control Rules

This type of construction is an engineered, and authorized as per development control rules. 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) and Tenant(s).

6.8 Construction Economics

The construction cost varies depending on the place and the economic class of the buyer. For poor people, in apartments of 45 m2 to 55 m2, the construction cost per square meter can be between 90 US/m2 to 100 US/m2. For middle- to upper-middle-class people, in apartments of 70 m2 to 85 m2, the construction cost per square meter can be between 130 US/m2 to 160 US/m2. The final cost per square meter for the purchaser of the unit can reach between 1.0 to 1.6 times the construction costs. Today, it is common to find subsidized housing projects constructed in a short time. The structure for a 7- to 10-story building can be constructed within only 2.5 to 3.5 months depending of the foundation type, and its delivery to the buyer can be practically immediate because of minimal nonstructural detailing. In 20- to 25-story projects, the construction time for the structure is between 9 and 11 months, and the final delivery to the buyer is between 13 to 15 months. Generally, the construction time depends on the project's cash flow.

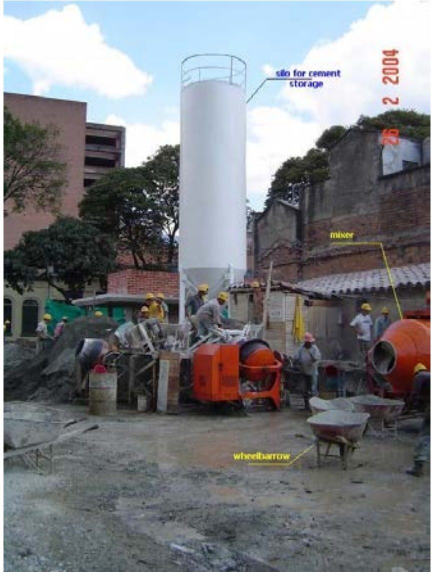

Figure 5a. Concrete producer plant on building site. OPTIMA S.A. construction project.

Figure 5b. Workers waiting to fill wheelbarrows from the concrete mixer.

Figure 5c. Wheelbarrow lift structure to transport concrete up to high floors. OPTIMA S.A. construction project.

Figure 5d. Wheelbarrow lift stopped at the 19th level. Workers waiting for the wheelbarrows. OPTIMA S.A. construction project.

Figure 5e. Concrete placement into the form work. OPTIMA S.A. construction project.

7. Insurance

Earthquake insurance for this construction type is typically available. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable. Earthquake insurance is available for an engineered building of this type. Today, insurance companies do not calculate the insurance cost based on the vulnerability level of the building, and so a premium discount is not available. There are some studies exploring this possibility. The cost of earthquake insurance can vary from 0.1 to 0.15% of the building's value. In case of damage the insurance covers between 70 and 100% of the cost depending of the annual premium.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Lintel beams damage	After a great earthquake, a well-designed building will dissipate energy by damage in the lintels. Seismic strengthening consists of rebuilding the lintel by sealing its cracks.
Slab-Wall connection	Improve the seismic detailing of the joint by partially demolishing (dismantling), constructing a beam collector detailed with stirrups in the connection interface, and rebuilding it with low retraction concrete.
Strengthening of Foundation-Wall connection	Increasing foundation and wall size in accordance with the recent code regulations. The foundation can be retrofitted in its perimeter and above, increasing its strength and stiffness. Walls can be retrofitted increasing their width with a new layer of reinforcement joined with connectors to the existing wall or with confined elements added to its borders.

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?

No.

Was the work done as a mitigation effort on an undamaged building, or as repair following an earthquake?
The common practice is to repair the building damage after an earthquake. After an earthquake the inhabitants of damaged and undamaged housing units of all construction types are concerned about the seismic strengthening of their houses or buildings. As time passes, people who were not affected forget.

8.3 Construction and Performance of Seismic Strengthening

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

In some cases, the owner probably hires a company to inspect the repair work.

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?

In this type of building repair, usually an engineer provided by the contractor or by the owner is involved.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?

N/A.

Reference(s)

1. Colombian Code of Seismic Resistant Construction and Design NSR-98
2. Interview with construction engineers who are part of the construction firm OPTIMA S.A.
3. Structural illustrations given by the consulting and structural firm, ALVARO P

Author(s)

1. Luis G. Mejia
   Consulting Structural Engineer, Luis Gonzalo Mejia C. y Cia. Ltda.
   Calle 49b #79b-12, Medellin , COLOMBIA
   Email:lgm@epm.net.co FAX: (574) 4217661

2. Juan C. Ortiz R.

Civil Engineer/Structural Designer, Luis Gonzalo Mejia C. y Cia. Ltda.
Dg. 75 B No. 6-110 Apto. 201, Medellin , COLOMBIA
Email:jcor_ic@hotmail.com FAX: (574) 421 76 61

3. Laura I. Osorio G.
Civil Engineer/Structural Designer, Luis Gonzalo Mejia C. y Cia. Ltda.
Cra. 79 No. 45-72, Medell , COLOMBIA
Email:laura osorio eng@yahoo.ca FAX: (574) 2 50 67 87

Reviewer(s)

1. Marcial Blondet
Professor
Civil Engineering Dept., Catholic University of Peru
Lima 32 , PERU
Email:mblondet@pucp.edu.pe FAX: 51-1-463-6181

Save page as