

World Housing Encyclopedia Report

Country: Colombia

Housing Type: Concrete Shear Wall Buildings

Contributors:

Luis Gonzalo Mejía

Laura Isabel Osorio G.

Primary Reviewer:

Marcial Blondet

Report Number: 109

Created on: 6/11/2004

Last Modified: 7/11/2004

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1 General Information

1.1 Country

Colombia

1.3 Housing Type

Concrete Shear Wall Buildings

1.4 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.



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

1.5 Typical Period of Practice for Buildings of This Construction Type

How long has this construction been practiced	
< 25 years	
< 50 years	X
< 75 years	
< 100 years	
< 200 years	
> 200 years	

Is this construction still being practiced?	Yes	No
	X	

Additional Comments: Actually, these buildings are often used for the construction of government-subsidized housing (Vivienda de Interés Social) for low- to middle-income people.

1.6 Region(s) Where Used

The Andean and Caribbean regions of Colombia have most of the concrete shear wall buildings. They are found primarily in the big cities. (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.

1.7 Urban vs. Rural Construction

Where is this construction commonly found?	
In urban areas	X
In rural areas	
In suburban areas	
Both in rural and urban areas	

Additional Comments: 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.

2 Architectural Features

2.1 Openings

Typical description of openings for a 320m² 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.

2.2 Siting

	Yes	No
Is this type of construction typically found on flat terrain?	X	
Is this type of construction typically found on sloped terrain? (hilly areas)	X	
Is it typical for buildings of this type to have common walls with adjacent buildings?		X

The typical separation distance between buildings is 1 meters

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 $2 \times 0.005 \times$ 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.

2.3 Building Configuration

Generally, the buildings are rectangular or square, with some setback in the plan. They are usually regular in plan and in height.

2.4 Building Function

What is the main function for buildings of this type?	
Single family house	
Multiple housing units	X
Mixed use (commercial ground floor, residential above)	
Other (explain below)	

Additional Comments: 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.

2.5 Means of Escape

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).

2.6 Modification of Buildings

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.

3 Socio-Economic Issues

3.1 Patterns of Occupancy

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

3.2 Number of Housing Units in a Building

40 units in each building.

Additional Comments: 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.

3.3 Average Number of Inhabitants in a Building

How many inhabitants reside?	During the day / business hours	During the evening / night
< 5		
5 to 10		
10-20		
> 20	X	
Other	X	X

Additional Comments: 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.

3.4 Number of Bathrooms or Latrines per Housing Unit

Number of Bathrooms: 1

Number of Latrines: 0

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

3.5 Economic Level of Inhabitants

Economic Status		House Price/Annual Income (Ratio)
Very poor		/
Poor	X	12500/2000
Middle Class	X	20000/10000
Rich	X	28000/40000

Additional Comments: 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

3.6 Typical Sources of Financing

What is the typical source of financing for buildings of this type?	
Owner Financed	X
Personal Savings	X
Informal Network: friends and relatives	
Small lending institutions/microfinance institutions	
Commercial banks / mortgages	X
Investment pools	
Combination (explain)	X
Government-owned housing	X
Other	

Additional Comments: The poor have access to state financial aid if they have a monthly automatic savings plan in a financial institution. Most middle-class 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-class 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.

3.7 Ownership

Type of Ownership/Occupancy	
Rent	X
Own outright	X
Own with Debt (mortgage or other)	X
Units owned individually (condominium)	X
Owned by group or pool	
Long-term lease	
Other	

4 Structural Features

4.1 Lateral Load-Resisting System

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.

4.2 Gravity Load-Bearing Structure

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.

4.3 Type of Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	
Masonry	Stone masonry walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	
		2	Massive stone masonry (in lime or cement mortar)	
	Earthen walls	3	Mud walls	
		4	Mud walls with horizontal wood elements	
		5	Adobe block or brick walls	
		6	Rammed earth/Pise construction	
	Unreinforced brick masonry walls	7	Unreinforced brick masonry in mud or lime mortar	
		8	Unreinforced brick masonry in mud or lime mortar with vertical posts	
		9	Unreinforced brick masonry in cement or lime mortar (various floor/roof systems)	
	Confined masonry	10	Confined brick/block masonry with concrete posts/tie columns and beams	
	Concrete block masonry walls	11	Unreinforced in lime or cement mortar (various floor/roof systems)	
		12	Reinforced in cement mortar (various floor/roof systems)	
		13	Large concrete block walls with concrete floors and roofs	
Concrete	Moment resisting frame	14	Designed for gravity loads only (predating seismic codes i.e. no seismic features)	
		15	Designed with seismic features (various ages)	
		16	Frame with unreinforced masonry infill walls	
		17	Flat slab structure	
		18	Precast frame structure	
		19	Frame with concrete shear walls-dual system	
		20	Precast prestressed frame with shear walls	
	Shear wall structure	21	Walls cast in-situ	X
		22	Precast wall panel structure	
		23	With brick masonry partitions	
Steel	Moment resisting frame	24	With cast in-situ concrete walls	
		25	With lightweight partitions	
		26	Concentric	
	Braced frame	27	Eccentric	
		28	Thatch	
Timber	Load-bearing timber frame	29	Post and beam frame	
		30	Walls with bamboo/reed mesh and post (wattle and daub)	
		31	Wooden frame (with or without infill)	
		32	Stud wall frame with plywood/gypsum board sheathing	
		33	Wooden panel or log construction	
		34	Building protected with base isolation devices or seismic dampers	
Various	Seismic protection systems	35		
	Other			

4.4 Type of Foundation

Type	Description	
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	X
	Mat foundation	X
	No foundation	
Deep Foundation	Reinforced concrete bearing piles	X
	Reinforced concrete skin friction piles	
	Steel bearing piles	
	Wood piles	
	Steel skin friction piles	
	Cast in place concrete piers	
	Caissons	
Other		

Additional Comments: 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.

4.5 Type of Floor/Roof System

Material	Description of floor/roof system	Floor	Roof
Masonry	Vaulted		
	Composite masonry and concrete joist		
Structural Concrete	Solid slabs (cast in place or precast)	X	X
	Cast in place waffle slabs		
	Cast in place flat slabs		
	Precast joist system		
	Precast hollow core slabs		
	Precast beams with concrete topping		
	Post-tensioned slabs		
Steel	Composite steel deck with concrete slab		
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		X
	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			

Additional Comments: 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.

4.6 Typical Plan Dimensions

Additional Comments: These dimensions can vary in length and width between 10 m and 30 m.

4.7 Typical Number of Stories

Additional Comments: 7-20 stories

4.8 Typical Story Height

2.40 meters

Additional Comments: 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.

4.9 Typical Span

2.4-3.5 meters

Additional Comments: 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.

4.10 Typical Wall Density

Additional Comments: 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.

4.11 General Applicability of Answers to Questions in Section 4

The description above reflects the general structural characteristics of shear wall buildings found in major urban areas of Colombia.

5 Evaluation of Seismic Performance and Seismic Vulnerability

5.1 Structural and Architectural Features: Seismic Resistance

Structural/ Architectural Feature	Statement	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.	X		
Building configuration	The building is regular with regards to both the plan and the elevation.	X		
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.	X		
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.	X		
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.	X		
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	X		
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: 1) Less than 25 (concrete walls); 2) Less than 30 (reinforced masonry walls); 3) Less than 13 (unreinforced masonry walls).	X		
Foundation- wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	X		
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	X		
Wall openings	The total width of door and window openings in a wall is: 1) for brick masonry construction in cement mortar: less than 1/2 of the distance between the adjacent cross walls; 2) for adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; 3) for precast concrete wall structures: less than 3/4 of the length of a perimeter wall.			X
Quality of building materials	Quality of building materials is considered to be adequate per requirements of national codes and standards (an estimate).	X		
Quality of workmanship	Quality of workmanship (based on visual inspection of few typical buildings) is considered to be good (per local construction standards).	X		
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	X		
Other				

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 Seismic Vulnerability Rating

Vulnerability						
	High (Very Poor Seismic Performance) A	B	Medium C	D	E	Low (Excellent Seismic Performance) F
Seismic Vulnerability Class			<			>

0 - probable value

< - lower bound

> - upper bound

6 Earthquake Damage Patterns

6.1 Past Earthquakes Reported To Affect This Construction

Year	Earthquake Epicenter	Richter magnitude(M)	Maximum Intensity (Indicate Scale e.g. MMI, MSK)
1999	4.46N, 75.72W,depth: 17 km (Armenia)	6	IX MM (Armenia)
1985	4.1N, 76.62W,depth: 73 km (Pereira)	6.4	VIII MM (Pereira)
1983	2.46N, 76.69W,depth: 22 km (Popayán)	5.5	IX MM (Popayán)
1979	4.8N, 76.2W,depth: 108 km (Mistrató)	6.7	VIII MM (Manizales)

Additional Comments: 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.

7 Building Materials and Construction Process

7.1 Description of Building Materials

Structural Element	Building Material	Characteristic Strength	Mix Proportions/ Dimensions	Comments
Walls	Reinforced concrete	$f'_c = 21 \text{ MPa}$ to 35 MPa $f_y = 420 \text{ MPa}$ for	1:1.5-1.8:2.5	
Foundations	Reinforced concrete	$f'_c = 21 \text{ MPa}$ $f_y = 420 \text{ MPa}$ for	1:2:3	
Roof and floors	Reinforced concrete	$f'_c = 21 \text{ MPa}$ to 28 MPa $f_y = 420 \text{ MPa}$ for	1:1.8-2:2.5	

Notes:

1. Concrete: f'_c is the nominal compression, 28-day strength of concrete.

Steel: f_y is the nominal yield strength of steel. Presently, it is common to find all steel with $f_y = 420 \text{ MPa}$, but until a few years ago it was a common practice to use steel with $f_y = 280 \text{ MPa}$ for the reinforcement with diameter less than or equal to #U 3/8 inches.

2. Mix proportions are: cement:sand:aggregate

Today, it is common to find additional additives in the mix that improve the finishing process, curing time, and handling ease.

7.2 Does the builder typically live in this construction type, or is it more typically built by developers or for speculation?

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

7.3 Construction Process

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 approved, 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.

7.4 Design/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.

7.5 Building Codes and Standards

	Yes	No
Is this construction type addressed by codes/standards?	X	

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

7.6 Role of Engineers and Architects

Building design is done by architects and structural engineers. Both professions play the most important role in each stage of the design and construction

7.7 Building Permits and Development Control Rules

	Yes	No
Building permits are required	X	
Informal construction		X
Construction authorized per development control rules	X	

7.8 Phasing of Construction

	Yes	No
Construction takes place over time (incrementally)		X
Building originally designed for its final constructed size	X	

7.9 Building Maintenance

Who typically maintains buildings of this type?	
Builder	
Owner(s)	X
Renter(s)	X
No one	
Other	

7.10 Process for Building Code Enforcement

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.

7.11 Typical Problems Associated with this Type of Construction

Typical problems are associated mainly with the large amount of reinforcement in the thin walls that does not permit the successful casting and vibration of the concrete. This causes unfilled spaces inside the structural elements (honeycombs). Another construction problem associated with the slab construction process can occur if the workers sink the steel reinforcement in the mix during the casting process without determining the minimum requirements for coverage or the distance from the extreme compression fiber to the center of tension reinforcement based on the assumptions found in the analysis and design. The difference in the joint detailing, as specified in the structural drawings and the way it actually appears in the final construction, is another typical problem.

8 Construction Economics

8.1 Unit Construction Cost (estimate)

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.

8.2 Labor Requirements (estimate)

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.

9 Insurance

9.1 Insurance Issues

	Yes	No
Earthquake insurance for this construction type is typically available	X	
Insurance premium discounts or higher coverages are available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features		X

Additional Comments: 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.

9.2 If earthquake insurance is available, what does this insurance typically cover/cost?

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.

10 Seismic Strengthening Technologies

10.1 Description of Seismic Strengthening Provisions

Type of intervention	Structural Deficiency	Description of seismic strengthening provision used
Retrofit (Strengthening)	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.

10.2 Has seismic strengthening described in the above table been performed in design practice, and if so, to what extent?

No.

10.3 Was the work done as a mitigation effort on an undamaged building, or as repair following earthquake damage?

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.

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

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

10.5 Who performed the construction: 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.

10.6 What has been the performance of retrofitted buildings of this type in subsequent earthquakes?

N/A

11 References

Normas Colombianas de Diseño y Construcción Sismo Resistente NSR-98 (Colombian Code of Seismic Resistant Construction and Design NSR-98).

Interview with construction engineers who are part of the construction firm OPTIMA S.A.

Structural illustrations given by the consulting and structural firm, ALVARO PÉREZ A. Y CÍA. (Some illustrations have been modified for this presentation).

12 Contributors

Name	Luis Gonzalo Mejía	Laura Isabel Osorio G.
Title	Consulting Structural Engineer	Civil Engineer/Structural Designer
Affiliation	L.G.M y Cia.	Luis Gonzalo Mejia C. y Cia. Ltda.
Address	Calle 49b #79b -12	Cra. 79 No. 45-72
City	Medellin	Medellín
Zipcode		
Country	Colombia	Colombia
Phone	(574) 2342678	(574) 2 50 67 87
Fax	(574) 4217659	(574) 2 50 67 87
Email	lgm@une.net.co	laura osorio eng@yahoo.ca
Webpage	www.lgm.com.co	

13 Figures



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

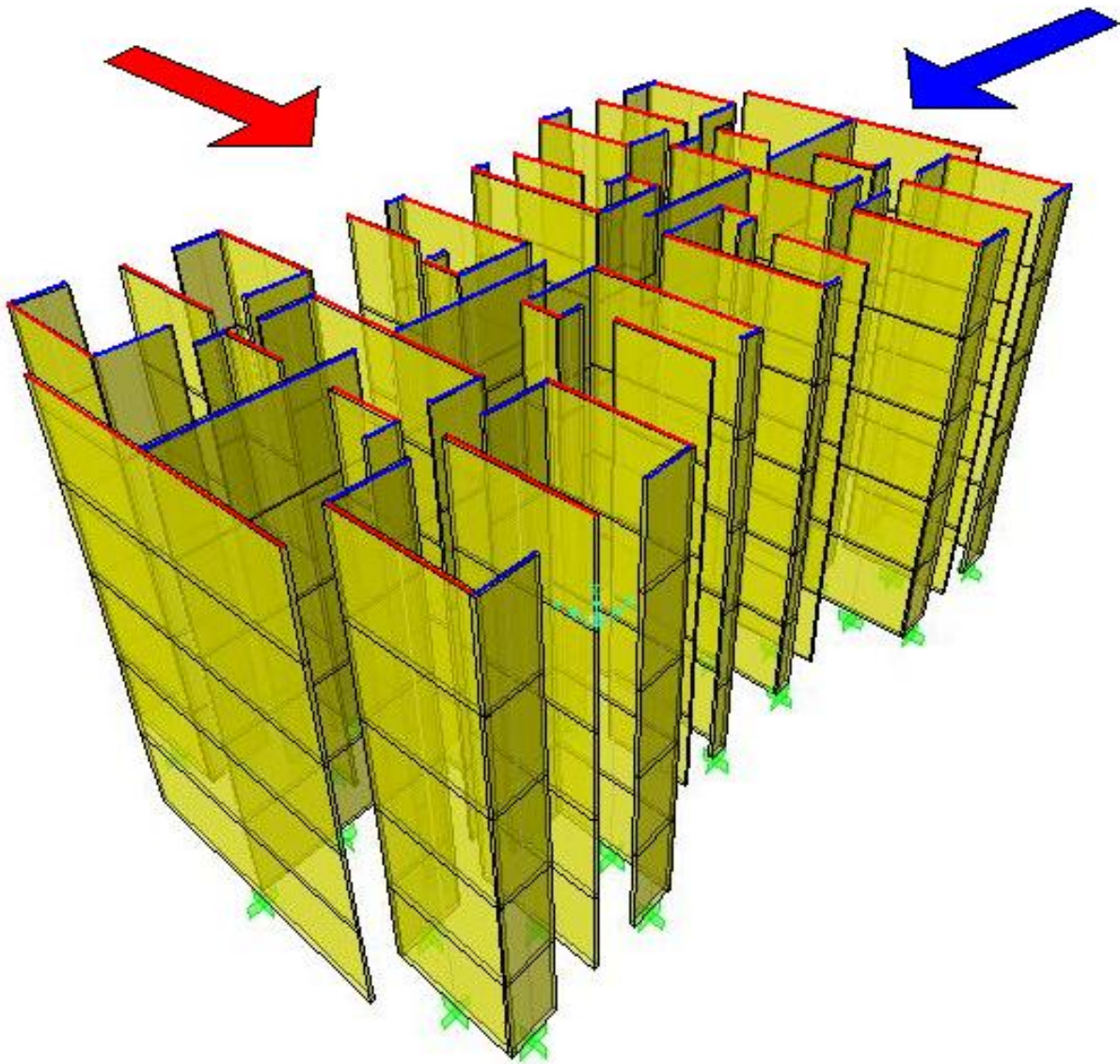


Figure 2. Perspective Drawing showing key load-bearing elements

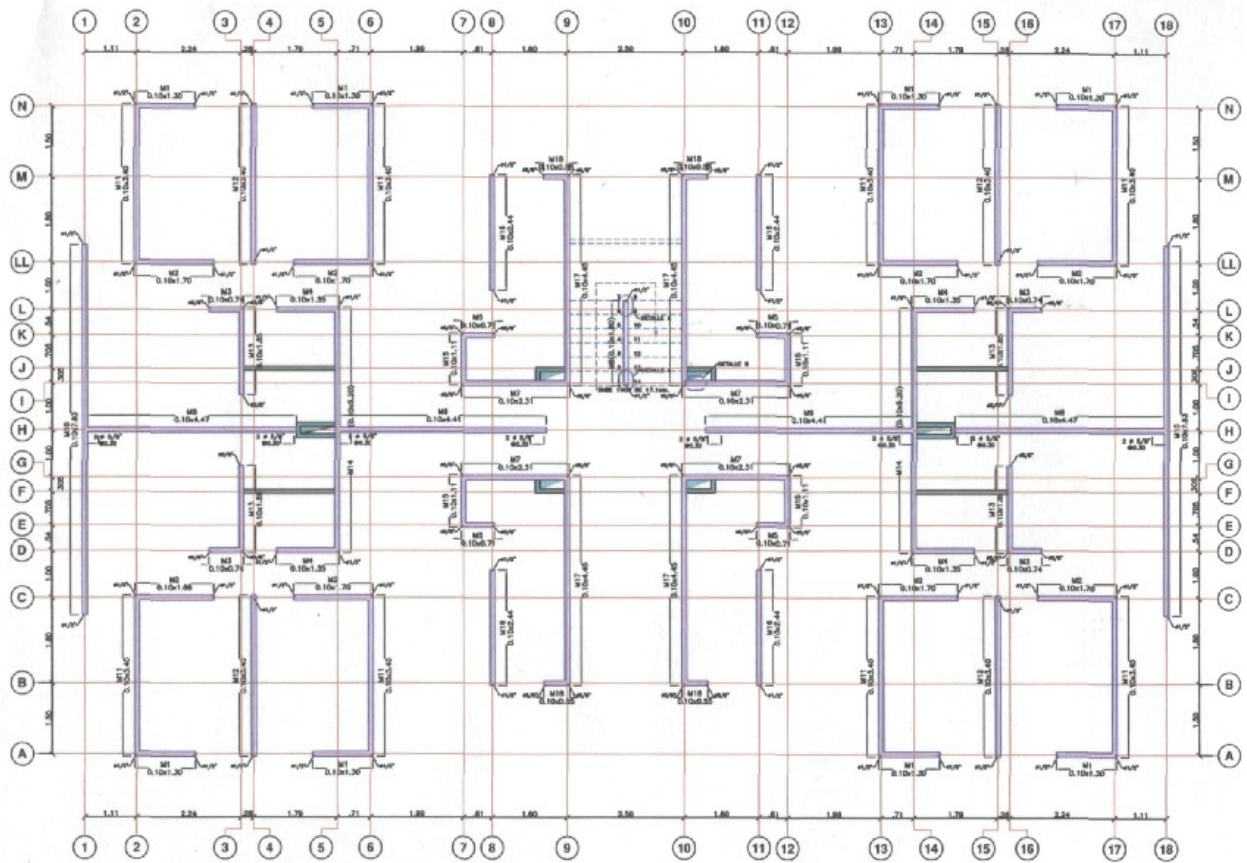


Figure 3. Plan of a typical building. Photo courtesy Alvaro Pérez y Cía Consulting Firm.

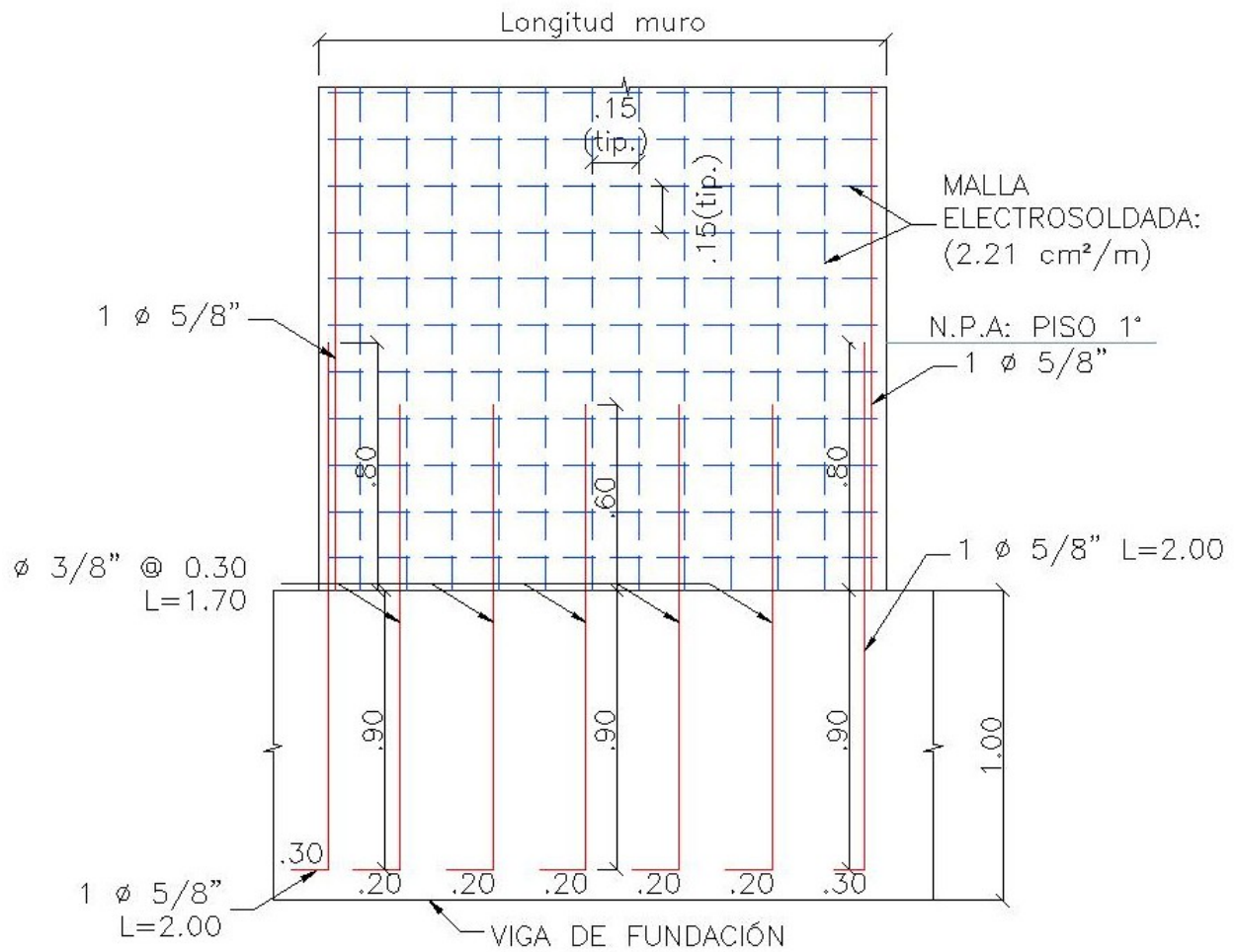


Figure 4a. Detail showing anchorage of the shear wall to the foundation beam. Seven story project.
Figure courtesy of Alvaro Pérez y Cía Consulting Firm.

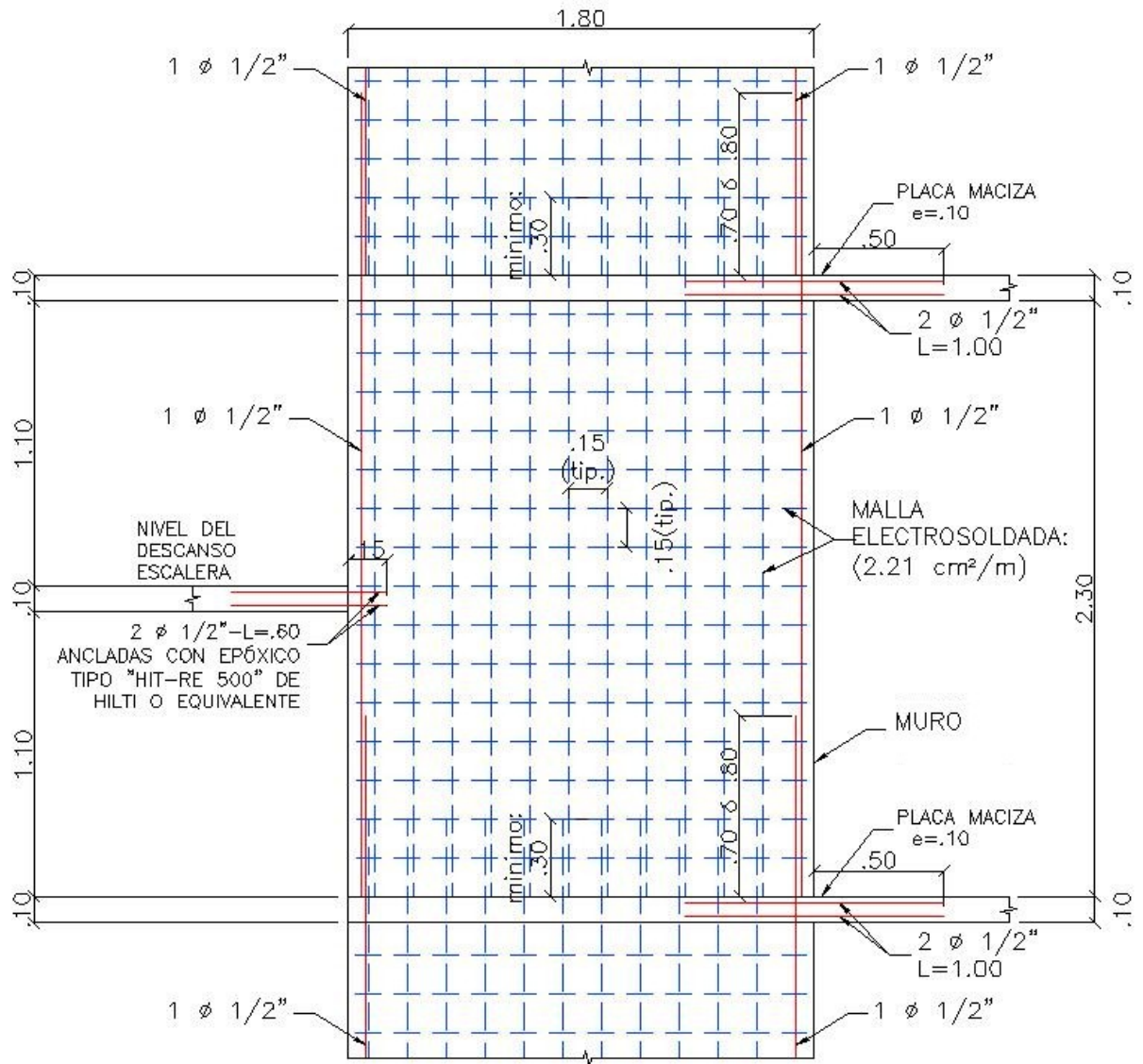
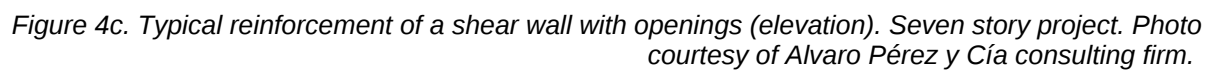


Figure 4b. Typical reinforcement of a shear wall (elevation). Seven story project. Photo courtesy of Alvaro Pérez y Cía consulting firm.



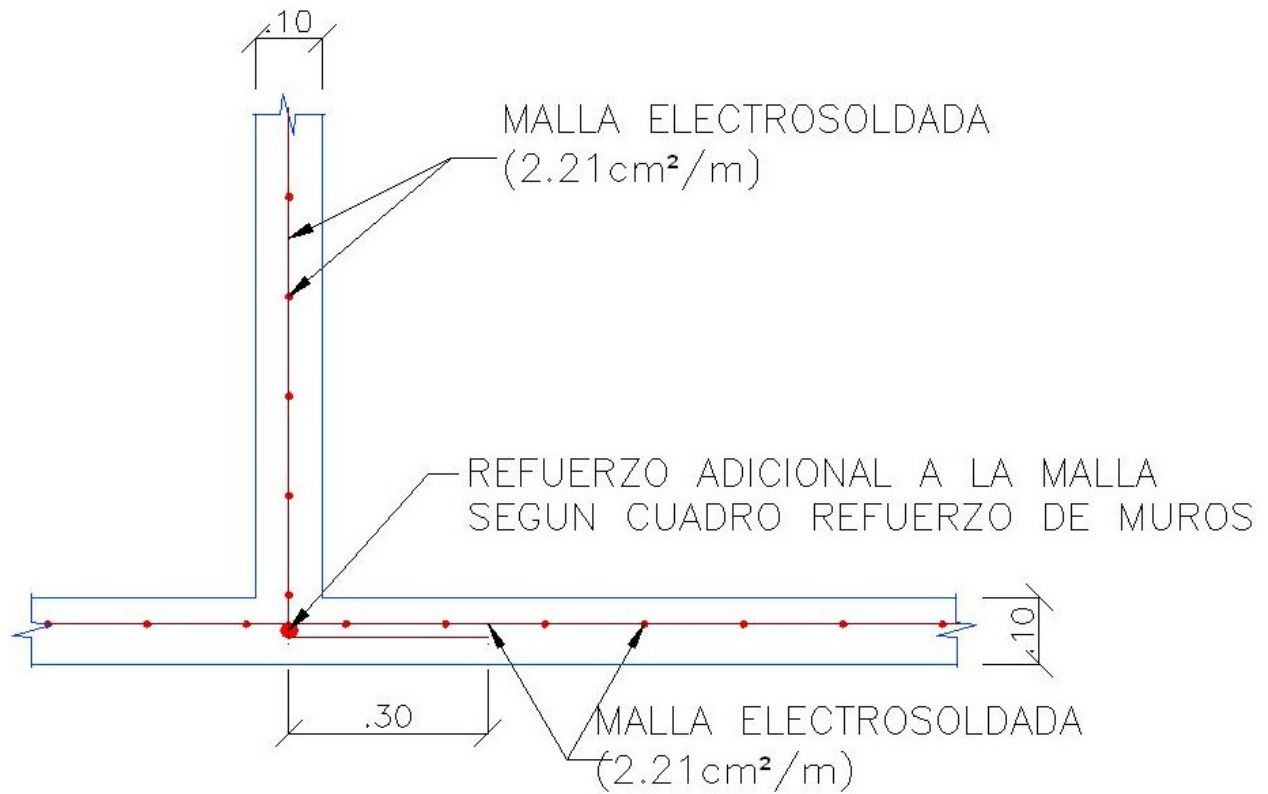


Figure 4d. Additional reinforcement in shear walls intersection (plan). Photo courtesy of Alvaro Pérez y Cía consulting firm

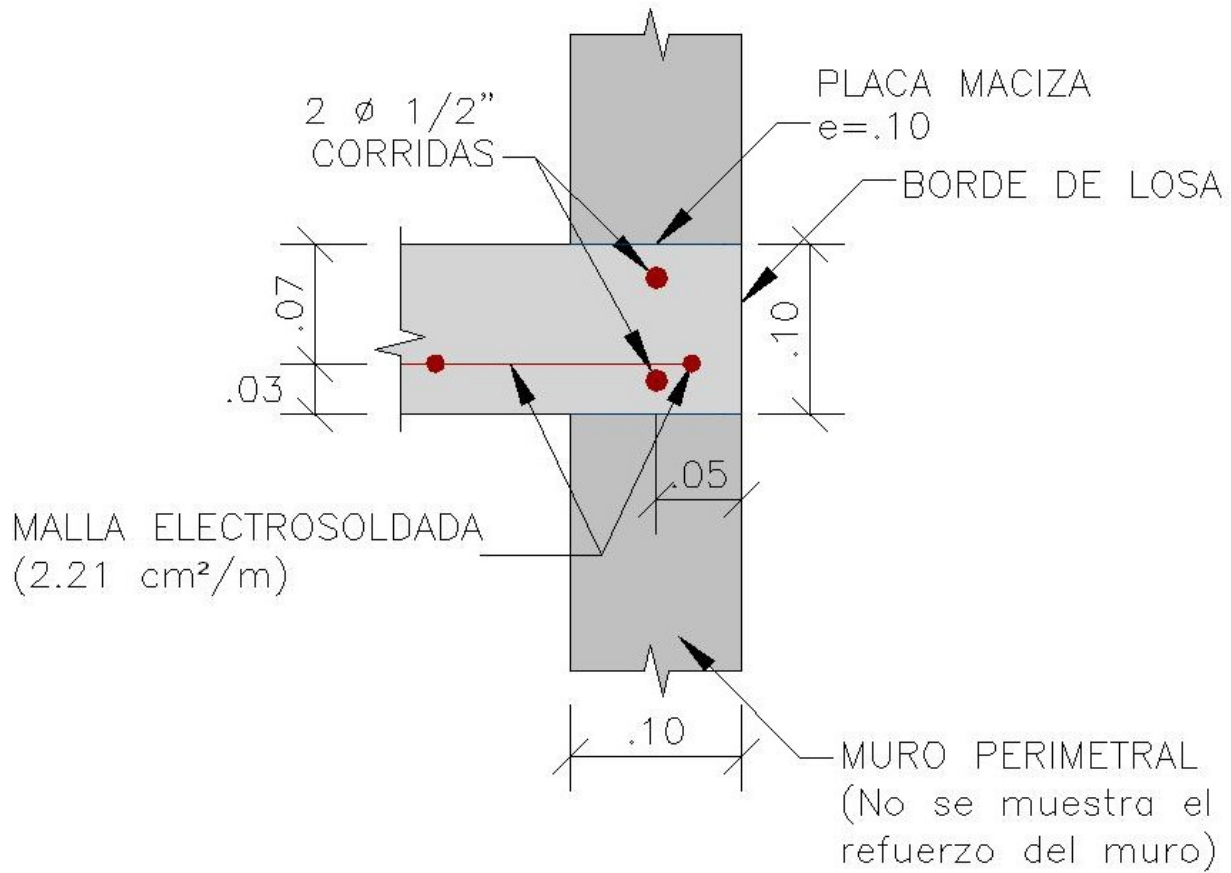


Figure 4e. Typical connection between slab and shear wall. Photo courtesy of Alvaro Pérez y Cía consulting firm

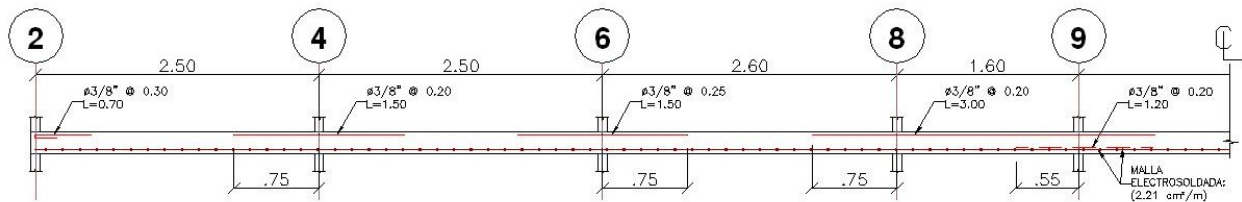


Figure 4f. Slab typical section. Photo courtesy of Alvaro Pérez y Cía consulting firm

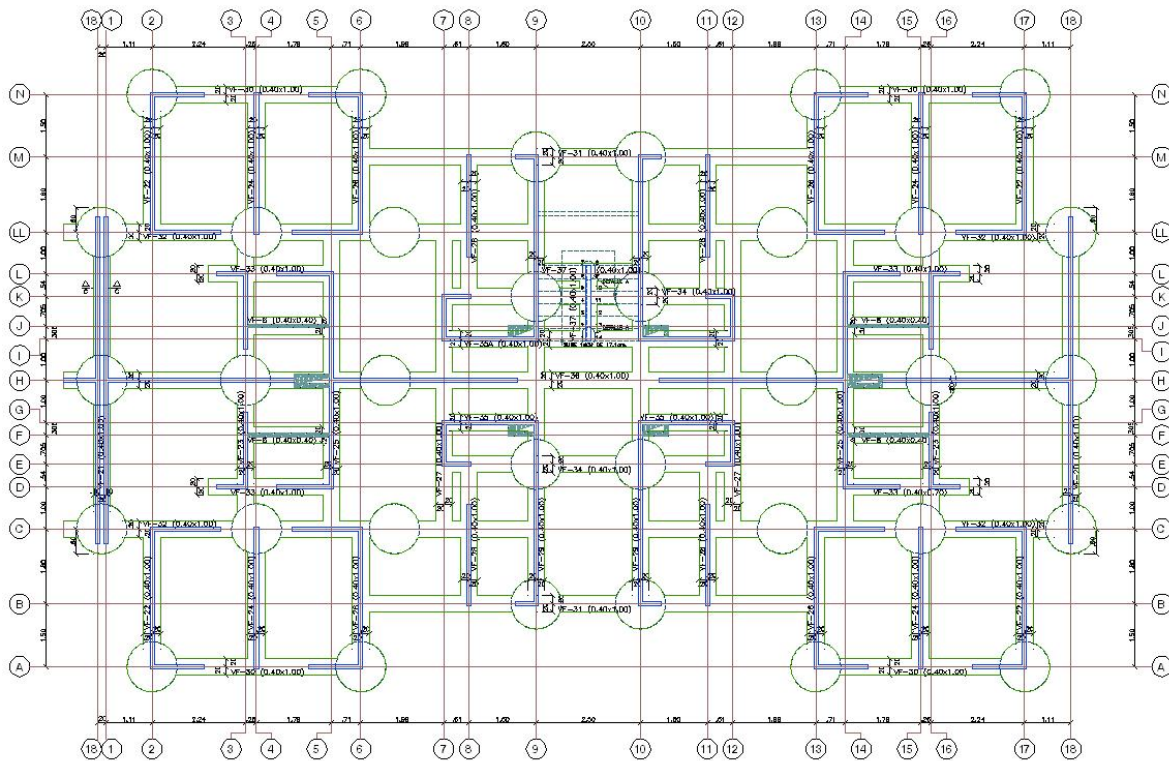


Figure 4g. Foundation plan Seven story project. Photo courtesy of Alvaro Pérez y Cía consulting firm

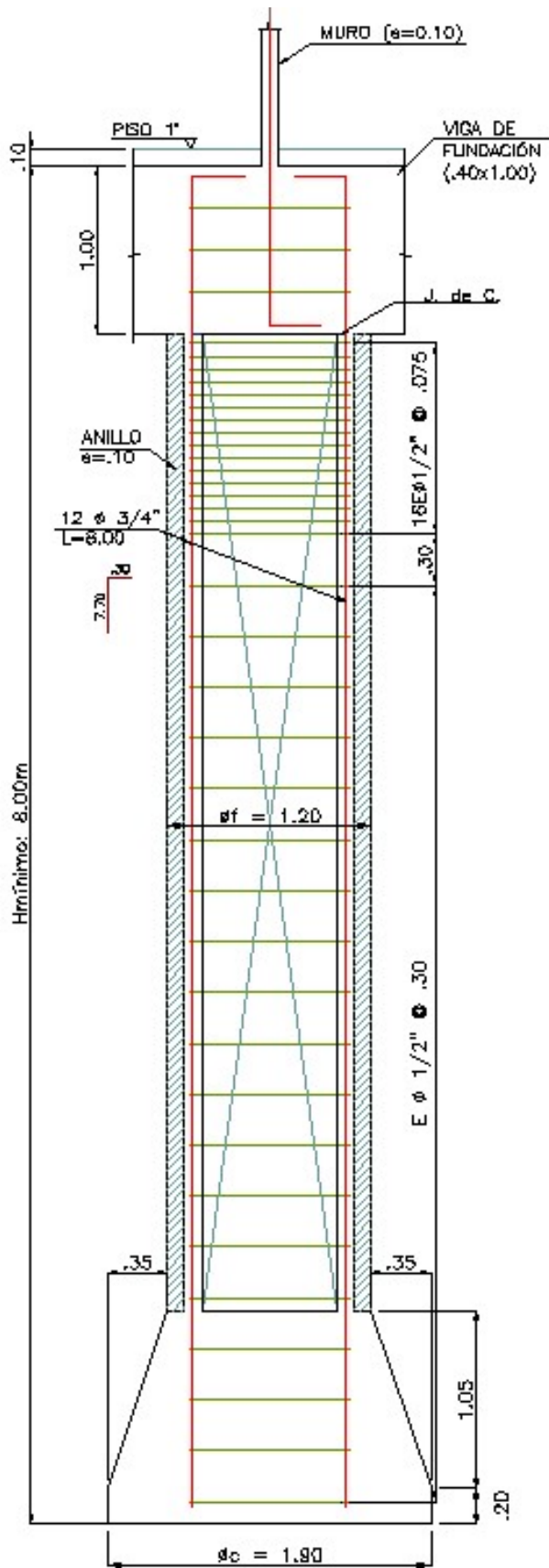


Figure 4h. Typical hollow reinforced pile (elevation). Common foundation type. Seven story project. Photo courtesy of Alvaro Pérez y Cía consulting firm

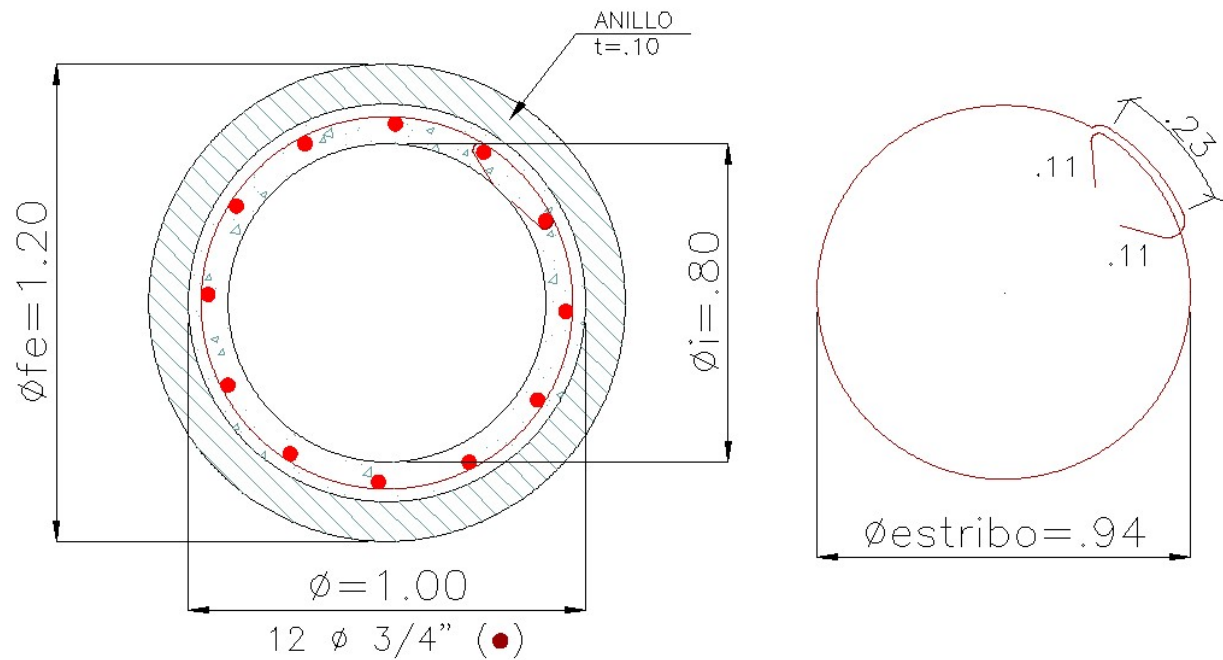


Figure 4i. Typical hollow reinforced pile (transverse section). Common foundation type. Seven story project. Photo courtesy of Alvaro Pérez y Cía consulting firm

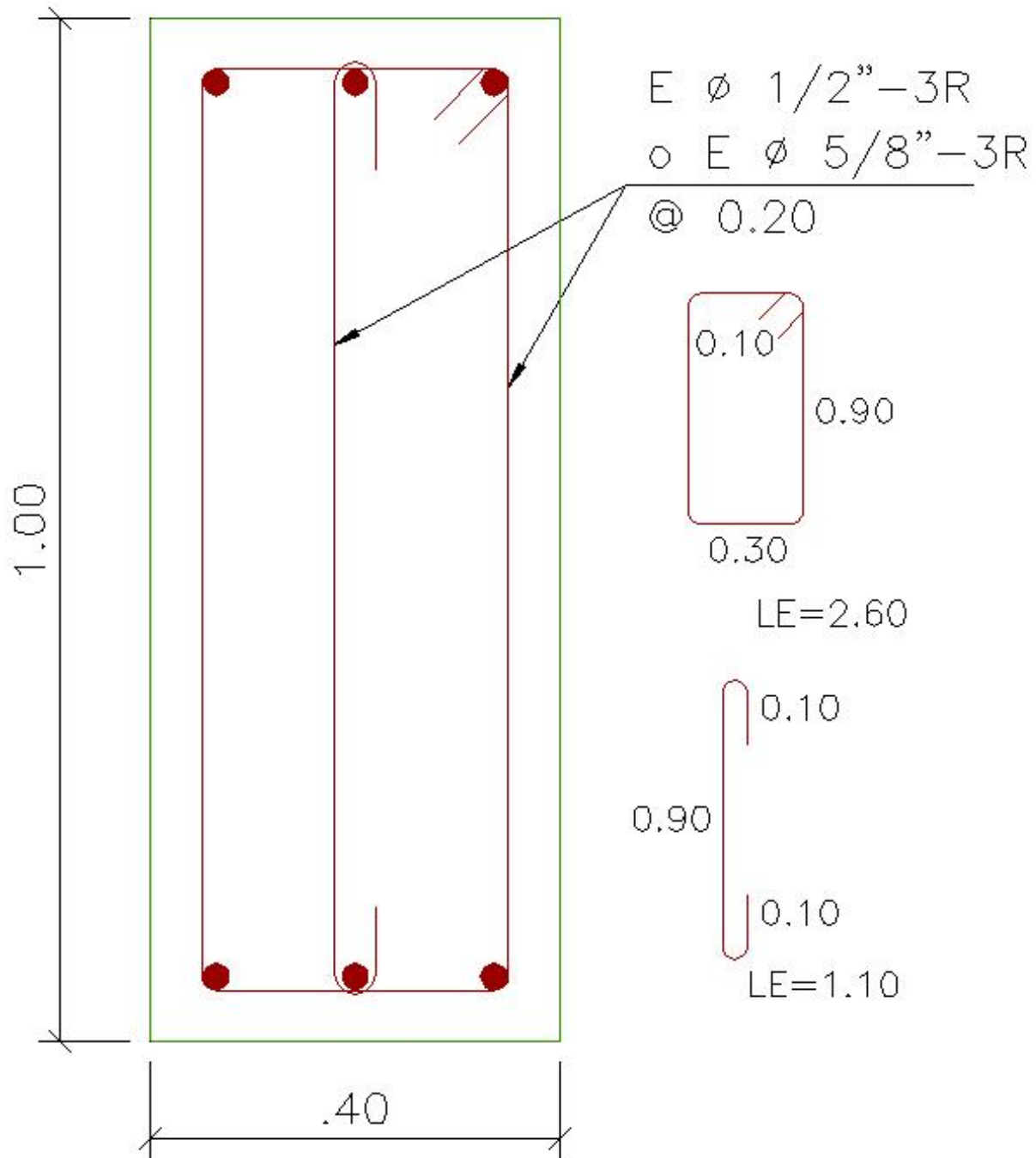


Figure 4j. Typical section of foundation beam (transverse section). Seven story project. Photo courtesy of Alvaro Pérez y Cía consulting firm



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.



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 pile. OPTIMA S.A. construction project.



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