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
Reinforced concrete multistory buildings

Report #	115
Report Date	19-01-2005
Country	MEXICO
Housing Type	RC Moment Frame Building
Housing Sub-Type	RC Moment Frame Building : Dual System - Frame with Shear Wall
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Summary

This report describes Reinforced Concrete (RC) multistory residential buildings in Mexico. This type of construction is found mostly in large cities where space limitations lead to this type of solution. Typically buildings of this type have eight or more stories. Members of the middle and upper classes are the target market for this type of construction. In areas of low seismic risk, waffle slab floor systems without structural RC walls are preferred by developers

primarily due to their speed of construction. In areas of medium to high seismic risk, it is typical for this type of building to have a dual system, which combines RC moment frames and RC structural walls as the main lateral load resisting elements. The RC floor systems are constructed of waffle slabs or solid slabs. RC buildings account for about 80% of the entire housing stock in Mexico. Buildings constructed after 1985 are expected to perform well under seismic forces, especially in Mexico City, where the building construction code has been substantially updated to incorporate lessons learned during the 1985 earthquake.

1. General Information

Buildings of this construction type can be found in four important regions in México: 1.- Mexico City and metropolitan area, capital city of Mexico, with 30% of the total housing stock in the country. 2.- Guadalajara, Capital City of the State of Jalisco, high seismicity 3.- Monterrey, Capital City of the State of Nuevo León, low seismicity. 4.- Cities at resort areas of the Pacific coast, such as Acapulco, Ixtapa, Huatulco. This type of housing construction is commonly found in urban areas. This construction type has been in practice for less than 75 years.

Currently, this type of construction is being built. .

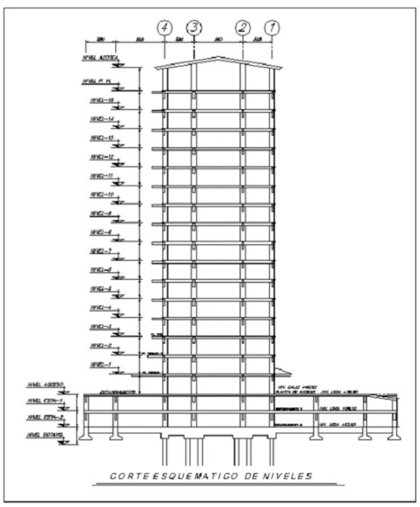

Figure 1: Structural Elevation

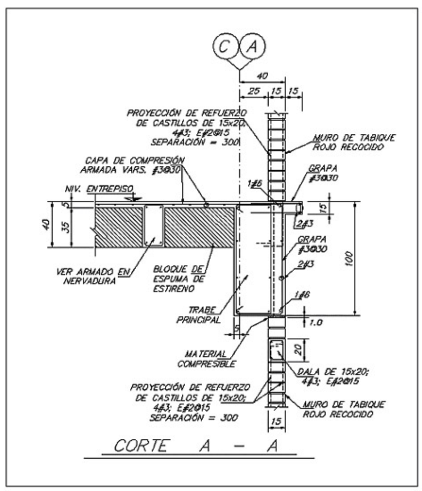

Figure 2: Section A-A

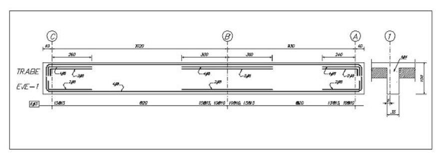

Figure 3: Typical reinforcement details in beam of axis 1, levels 3 to 5

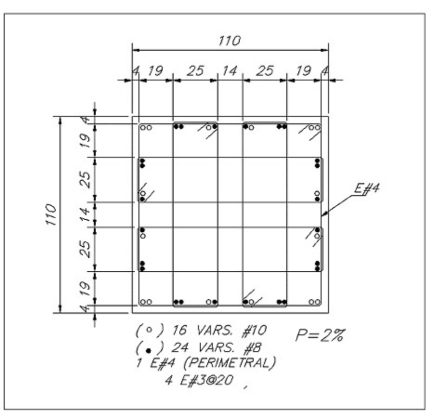

Figure 4: Column section, level parking-2 to level-2

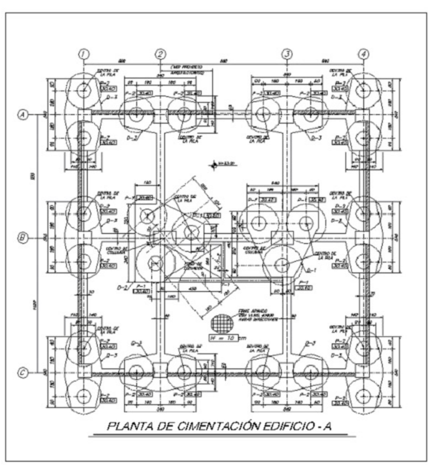

Figure 5: Foundation Plan

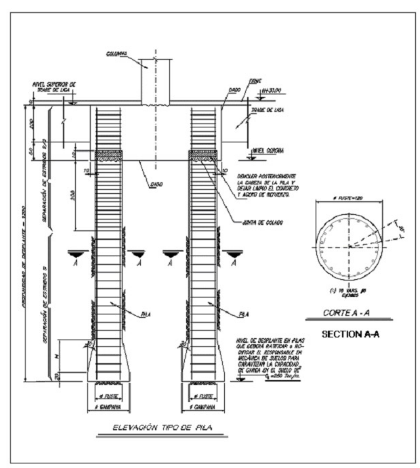

Figure 6: Elevation of piles

Figure 7: Floor construction, Santa Fe Building

Figure 8: Construction view, Santa Fe Building

Figure 9: Santa Fe Building during construction

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. When separated from adjacent buildings, the typical distance from a neighboring building is 0.20 meters.

2.2 Building Configuration

Rectangular. Mostly 2 openings are constructed at floor levels, leaving space for elevators and stairs. These openings are commonly located at the center of floor systems and are surrounded by concrete walls, which are part of the lateral load resisting system. Their sizes vary but typical dimensions are 2 x 5 m for stair ways and 2.5 x 2.5 m for elevators. Openings for doors are also located in RC walls. These walls are usually located at the building core and is unusual to locate RC walls at the building perimeter. Partitions in RC buildings for residential construction are usually constructed with day/concrete blocks.

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. Most buildings do not have an additional exit stair.

2.4 Modification to Building

A typical pattern for the modification of RC buildings is the demolition of partitions, which are not part of the lateral load system for the building.

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
	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	☐
Masonry	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	☐
		8	Brick masonry in mud/lime mortar with vertical posts	☐
		9	Brick masonry in lime/cement mortar	☐
		10	Concrete block masonry in cement mortar	☐
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	☐
		12	Clay brick masonry, with concrete posts/tie columns and beams	☐
		13	Concrete blocks, tie columns and beams	☐
	Reinforced masonry	14	Stone masonry in cement mortar	☐
		15	Clay brick masonry in cement mortar	☐
		16	Concrete block masonry in cement mortar	☐
Structural concrete	Moment resisting frame	17	Flat slab structure	☐
		18	Designed for gravity loads only, with URM infill walls	☐
		19	Designed for seismic effects, with URM infill walls	☐
		20	Designed for seismic effects, with structural infill walls	☐
		21	Dual system – Frame with shear wall	☑
	Structural wall	22	Moment frame with in-situ shear walls	☐
		23	Moment frame with precast shear walls	☐
	Precast concrete	24	Moment frame	☐
		25	Prestressed moment frame with shear walls	☐
		26	Large panel precast walls	☐
		27	Shear wall structure with walls cast-in-situ	☐
		28	Shear wall structure with precast wall panel structure	☐
Steel	Moment-resisting frame	29	With brick masonry partitions	☐
		30	With cast in-situ concrete walls	☐
		31	With lightweight partitions	☐
	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 moment resisting frame. Columns, beams and solid or waffle slabs.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is reinforced concrete structural walls (with frame). Moment resisting frames are used in low seismic areas and dual systems (combination of frames and RC walls) are used in medium and high seismic areas. In dual systems, shear walls are usually located at the building core and moment frames are located at the building perimeter.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 40 and 40 meters, and widths between 25 and 25 meters. The building has 10 to 25 storey(s). The typical span of the roofing/flooring system is 10.0 meters. Typical Span: The typical span ranges from 8.0 to 12.0 meters. The typical storey height in such buildings is 3.2 meters. The typical structural wall density is up to 2 %. 1 to 2 %.

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	☑	☐

In most design of RC buildings for residential construction, all diaphragms are considered rigid.

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, reinforced concrete skin-friction piles , cast in-place reinforced concrete piers and caissons.

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 21-50 housing unit(s). 30 units in each building. Minimum 10 - Maximum 48 The number of inhabitants in a building during the day or business hours is more than 20. The number of inhabitants during the evening and night is others (as described below). In the evening/night the inhabitants number greater than 50. In the evening/night the inhabitants number greater than 50.

4.2 Patterns of Occupancy

Typically in RC buildings, each apartment is occupied by a single family. The number of apartments in a building varies from building to building.

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)	☑

Economic Level: The ratio of price of each housing unit to the annual income can be 6:1 for middle class family and 5:1 for rich class family.

Ratio of housing unit price to annual income	Most appropriate type
5:1 or worse	☑
4:1	☐
3:1	☐
1:1 or better	☐

What is a typical source of financing for buildings of this type?	Most appropriate type
Owner financed	☐
Personal savings	☑
Informal network: friends and relatives	☐
Small lending institutions / micro-finance institutions	☐
Commercial banks/mortgages	☑
Employers	☐
Investment pools	☐
Government-owned housing	☑
Combination (explain below)	☐
other (explain below)	☐

In each housing unit, there are 2 bathroom(s) without toilet(s), no toilet(s) only and 2 bathroom(s) including toilet(s).

4.4 Ownership

The type of ownership or occupancy is renting, individual ownership and long-term lease.

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	

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake Resilient Features	Earthquake Damage Patterns
Wall		The use of walls provides a reduction in the expected seismic damage.	
Frame (columns, beams)	In general, frames are very sensitive to reinforcement detailing.		Collapse or severe damage in waffle-slab frame buildings was evident in the 1985 earthquake in Mexico City.
Roof and floors	They are not designed for specific seismic load paths, that is they are designed only for gravity loading. The current Mexico City building code is not clear in this aspect of floor system design. New detailing provisions enacted since the 1985 earthquake mostly addresses beam, columns and walls, and not much on floor systems.		
Other			

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is *E: LOW VULNERABILITY (i.e., very good seismic performance)*, the lower bound (i.e., the worst possible) is D: MEDIUM-LOW VULNERABILITY (i.e., good 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
1985	Michoacan Coast	8.1	
1995	Colima	8	
2003	Colima	7.6	

The 1985 Michoacan earthquake has been the strongest earthquake in the Richter magnitude scale since a period starting in the 1940's. This earthquake had its epicenter in the Pacific coast, not really near urban areas. This feature has been typical in most earthquakes affecting Mexico since the 1940's. It follows that in the last few decades the RC system evaluated in this report has only been subjected to strong ground shaking in Mexico City.

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Concrete	compression strength	variable	f'c= 30 MPa
Foundation	Concrete	compression strength	variable	f'c= 25 MPa
Frames (beams & columns)	Concrete	compression strength	variable	f'c= 30 MPa
Roof and floor(s)	Concrete	compression strength	variable	f'c= 25 MPa

6.2 Builder

Typically this construction type is built by developers.

6.3 Construction Process, Problems and Phasing

RC buildings for residential construction in Mexico is mostly constructed by developers. Depending on the type of soil, excavations for foundations is carried out with several types of excavator machineries. Ready-mix concrete is usually supplied for construction of these buildings. The construction of this type of housing takes place incrementally over time. Typically, the building is originally designed for its final constructed size.

6.4 Design and Construction Expertise

Local building codes require that a project be designed by a registered engineer. Architects are in charge of the building space distribution and of fulfilling the owner's requirements. Usually architects hire structural engineers for the design and construction of buildings.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. There is not a national building code and only few local codes are available; therefore, a number of regions in Mexico do not have building codes. In those cases some adaptations of the Mexico City building code are used. This code covers RC design and in most parts is based on the ACI 318 code. In some regions of the country where there is no local building code, the ACI 318 code is mostly followed. In Mexico City, the title of the current building code is "Reglamento de Construcciones del Distrito Federal" (Federal District Building Code). The year the first code/standard addressing this type of construction issued was In Mexico City the first code provisions were issued in 1920 and the 1942 building code for Mexico City was the first that had seismic provisions. Currently there is not a national building code. The most recent code/standard addressing this construction type issued was The most recent building code for Mexico City was released in 2004. Title of the code or standard: There is not a national building code and only few local codes are available; therefore, a number of regions in Mexico do not have building codes. In those cases some adaptations of the Mexico City building code are used. This code covers RC design and in most parts is based on the ACI 318 code. In some regions of the country where there is no local building code, the ACI 318 code is mostly followed. In Mexico City, the title of the current building code is 'Reglamento de Construcciones del Distrito Federal' (Federal District Building Code). Year the first code/standard addressing this type of construction issued: In Mexico City the first code provisions were issued in 1920 and the 1942 building code for Mexico City was the first that had seismic provisions. National building code, material codes and seismic codes/standards: Currently there is not a national building code. When was the most recent code/standard addressing this construction type issued? The most recent building code for Mexico City was released in 2004.

Building has to be designed by code requirements and plans need to be approved by a registered engineer. Plans are submitted to a code enforcement agency. However, usually the structural design is not reviewed by these agencies. It is assumed that the structural design is a responsibility only of the registered engineer. Building permits in Mexico City are granted by the local agency. In other parts of the country where there are local building codes these permits are granted by the corresponding local code enforcement agency. After the permit is granted, the code enforcement agency usually does not send inspectors to the construction site.

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 for RC buildings ranges from 1,300 $US/m2 to 2,200 $US/m2 depending on the type of apartments and location of the building. Usually 3 weeks are required for the construction of each floor level in a building. However, this construction time could increase due to rain or shortage of developer's money during construction.

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. Building insurance for residential construction is not a common practice in Mexico. One reason for this practice appears to be the high premium costs for covering seismic damage of buildings. Premium discounts are not available in Mexico for seismically strengthened buildings or new buildings built to incorporate seismically resistant features.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Low lateral stiffness especially in waffle-slab buildings	Several techniques for seismic rehabilitation have been used in Mexico. Among them the following can be mentioned: Column retrofit with RC or steel jackets, steel bracing of frames, use of new structural RC walls and even demolition of upper floors. However, current building code for Mexico City has no specific provisions for seismic strengthening of buildings.

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?
After the 1985 Mexico City earthquake several hundreds of RC buildings in Mexico City went through several of the seismic strengthening techniques here mentioned.

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

Retrofit work is done in both cases but it is most common after earthquake damage.

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?

Typically a contractor constructs a building under the instruction of an engineer.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
Since the 1985 Mexico City earthquake a large number of residential RC buildings have been retrofitted; however, the effectiveness of these retrofits has not been tested by another strong earthquake yet. An evaluation of building damage during the earthquake in Mexico City showed that previous repair and/or strengthening interventions in RC buildings were not sufficient and in general showed a poor seismic performance.

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