



World Housing Encyclopedia Report

Country: Colombia

Housing Type: Clay brick/concrete block masonry walls with concrete floors (predating seismic codes or with a few seismic features)

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1 General Information

1.1 Country

Colombia

1.3 Housing Type

Clay brick/concrete block masonry walls with concrete floors (predating seismic codes or with a few seismic features)



FIGURE 1: Typical Building

1.4 Summary

Typical multi-family housing construction found in urban areas of Colombia. It is a modern construction practice and represents approximately 50% of the housing stock for medium-rise (4- to 6-story high) buildings constructed in the last 25 years. This type of construction generally predates seismic codes, however some buildings of this type were constructed after the first edition of the Colombian Seismic Code was issued in 1984. This type of construction can be found either on flat or on sloped terrain; vertical stiffness irregularity in the sloped terrain conditions may introduce additional unfavorable effects. Due to poor construction practices and poor detailing of reinforcement, this construction is considered to be very vulnerable to earthquake effects.

1.5 Typical Period of Practice for Buildings of This Construction Type

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

Is this construction still being practiced?	Yes	No
	X	

Additional Comments: This is a modern construction for 4- to 6-story high buildings constructed in the last 25 years.

1.6 Region(s) Where Used

This housing type is widely used throughout Colombia. It represents approximately 50% of the existing housing stock of medium rise buildings (4- to 6-story high).

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: Majority of buildings of this type found in rural areas are 1- and 2-story high.

2 Architectural Features

2.1 Openings

Information about the openings in a typical median building is summarized below :

Number of openings 5
Size (m²) 0 1.80
Opening area/wall area Between 0.5 and 1.0m from corners
Position of opening Doors Windows
Facade 5
Interior 7 2.0
Total 30%

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 10 meters

2.3 Building Configuration

Typically, a square plan (4 flats per floor) or a rectangular plan (2 flats per floor)

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: Many buildings of this type are of mixed use.

2.5 Means of Escape

Usually building does not have additional means of escape.

2.6 Modification of Buildings

There are no many modifications in this building type. The most typical modification pattern observed is demolition of interior walls.

3 Socio-Economic Issues

3.1 Patterns of Occupancy

Normally one family occupies one housing unit.

3.2 Number of Housing Units in a Building

5 units in each building.

Additional Comments: On the average, 5 floors per building; consequently, there are 20 units in buildings of a square plan (four apartments per floor), and 10 units in buildings of a rectangular plan (two apartments per floor).

3.3 Average Number of Inhabitants in a Building

How many inhabitants reside in a typical building of this construction type?	During the day / business hours	During the evening / night
< 5		
5 to 10	X	
10-20		
> 20		X
Other		

3.4 Number of Bathrooms or Latrines per Housing Unit

Number of Bathrooms: 2

Number of Latrines: 2

Additional Comments: 2 or 3 bathrooms per housing unit (apartment)

3.5 Economic Level of Inhabitants

Economic Status		House Price/Annual Income (Ratio)
Very poor		/
Poor	X	10000/1500
Middle Class	X	40000/6000
Rich		/

Additional Comments: The above are average values. House price for middle class section ranges from US\$ 30,000 to 50,000. The approximate economic distribution of population in Colombia is as follows: Economic Status % Annual Income Very poor 35 <1000 Poor 35 1000 - 2000 Middle Class 25 2000 - 10000 High Middle Class 4 10000 - 40000 Rich 1 >40000

3.6 Typical Sources of Financing

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

Additional Comments: The main source of financing for the poor people is informal network (friends and relatives) and (sometimes) small lending institutions. For the middle class population, the main sources of financing are personal savings and commercial banks.

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

This is a bearing wall system, wherein the walls provide stiffness for in-plane lateral loading and stability to resist lateral loads (wind and seismic effects). Floor slabs are either 100 mm thick R.C. Slabs or different types of slab and joist floors; in some cases, slabs with concrete joists and tile blocks are used. The roof is normally made from rafters, sheathing roofing felt and asbestos-cement tile or R.C. slab. Floor slab can act as a rigid diaphragm; the same is not true for the wooden roof because a continuous R.C. beam (bond beam) atop the walls is often absent.

4.2 Gravity Load-Bearing Structure

The walls carry both lateral and gravity loads down to the R.C. strip foundation. In poor soil conditions, pile foundations are used because of the great susceptibility to settlement of the bearing walls. It is important to mention that the slabs span normally in one direction so the walls in one direction sustain gravity and lateral loads and the walls in the cross direction carry lateral loads only.

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)	X
	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)	X
		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	
		22	Precast wall panel structure	
Steel	Moment resisting frame	23	With brick masonry partitions	
		24	With cast in-situ concrete walls	
		25	With lightweight partitions	
	Braced frame	26	Concentric	
		27	Eccentric	
Timber	Load-bearing timber frame	28	Thatch	
		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	
Various	Seismic protection systems	34	Building protected with base isolation devices or seismic dampers	
	Other	35		

Additional Comments: Most buildings of this construction are of types 9 and 11 per the above table; however, some buildings are of type 10 and other of type 12.

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

Additional Comments: In some Colombian cities e.g. Bogotá, deep foundations are mandatory in a typical case. However, in other cities e.g. Medellín, R.C. strip footings are normally used.

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	
	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		
	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 single roof		
	Wood planks or beams that support clay tiles		
	Wood planks or beams that support slate, metal asbestos-cement or plastic corrugated sheets or tiles		X
	Wood plank, plywood or manufactured wood panels on joists supported by beams or walls		
Other			

Additional Comments: The floor is considered to be a rigid diaphragm that transfers the loads to the wall, although in many instances the floor-to-wall connections are deficient. The roof is considered to be a flexible structure.

4.6 Typical Plan Dimensions

Length: 17 - 17 meters

Width: 17 - 17 meters

Additional Comments: Common plan dimensions: square plan buildings= 17.0 m X 17.0 m; Rectangular plan = 17.0 m X 8.0 m

4.7 Typical Number of Stories

5

4.8 Typical Story Height

2.6 meters

4.9 Typical Span

3.0 meters

4.10 Typical Wall Density

6% to 8.5%

4.11 General Applicability of Answers to Questions in Section 4

This contribution describes is a typical building and the range of variation in the parameters is included in the response to the questions.

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.			
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	Insufficient reinforcement for diaphragm action	X		

Additional Comments: Foundation Performance: Occasionally, there are buildings with induced weaknesses caused by foundation movements (please see Figure 5G and 5H). Wall-Roof connections: See Additional Comments in Section 4.5 "Type of floor/roof system".

5.2 Seismic Features

Structural Element	Seismic Deficiency	Earthquake-Resilient Features	Earthquake Damage Patterns
Wall	-Unreinforced or with insufficient vertical and horizontal reinforcement. - Stepped construction (offsets) for example half of the buildings with six stories and the other half with five due to the sloping terrain (resulting in no uniform vertical stiffness distribution).		
Frame (columns, beams)			
Roof and floors	- Absence of continuous boundary members, chords and collectors. -Weak roof-wall and floor-wall connections.		
Other	-Poor quality of workmanship and materials. -Foundations designed only for vertical loads without considerations for overturning moments.		

Additional Comments: For the illustration of seismic deficiencies please see Figures 5A, 5B, 5C, 5D, 5E, 5F, 5G, and 5H.

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	>			

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)
36185	4.46N, 75.72W, depth: 17 km (Armenia)		IX MMI (ARMENIA)
34738	4.1N, 76.62W, depth: 73 km (Pereira)		VIII MMI (PEREIRA)
30406	2.46N, 76.69W, depth: 22 km (Popayán)		IX MMI (POPAYAN)
29182	4.8N, 76.2W, depth: 108 km (Mistrató)		VIII MMI (MANIZALES)

Additional Comments: Typical earthquake damages are illustrated in Figures 6A, 6B, 6C, 6D, 6E, 6F, 6G, 6H, and 6I.

7 Building Materials and Construction Process

7.1 Description of Building Materials

Structural Element	Building Material	Characteristic Strength	Mix Proportions/ Dimensions	Comments
Walls	Concrete block masonry walls Clay brick masonry walls Cement mortar Cement grout	$f_m = 10.0$ MPa $f_m = 3-10.0$ MPa 5.0 - 10.0 MPa 10.0 MPa	w / h / l 150 X 200 X 400 mm 120 X 200 X 400 mm 200 X 100 X 400 200 X 150 X 400 Cement : Sand 1:6 to 1:4 1:4	N/A 3 MPa for unreinforced or confined masonry and 10MPa for masonry with interior reinforcement Better strengths for buildings with vertical reinforcement, because they have some seismic features. For walls with vertical reinforcement
Foundations	Reinforced concrete	$f'_c = 20.0$ MPa	1 : 2 : 3	Cement/sand/aggregates
Frame				
Floors	R.C. slabs or hollow tile	10.0 - 20.0 MPa	1:3:5 -> 1:2:3	Cement/sand/aggregates
Roof wood rafters with asbestos-cement tiles, sometimes R.C. slab	Abarco (Cariniane piriformis)	9.0 MPa	50 x 100 mm	Whenever the roof is in R.C. properties are the same as floors.

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

Whenever engineered, this construction type is built for speculation purposes.

7.3 Construction Process

This is a typical construction process: firstly, the terrace is formed, followed by the construction of strip foundation. Subsequently, walls, slabs and roof are built, and the masons are skilled or semi-skilled. No equipment is used except for the simple tools. Normally, buildings of this type are built by a developer (in some cases by the owner).

7.4 Design/Construction Expertise

The masons involved in the construction are usually skilled and semi-skilled. Architects and engineers participate in the design of buildings of this type built for inhabitants belonging to the middle economic class. However, architects and engineers are not involved in the informal construction developed in areas inhabited by poorer sections of the society.

7.5 Building Codes and Standards

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

Title of the code or standard: 1984: Colombian code for earthquake resistant buildings CCCSR-84. 1998: Colombian code for earthquake resistant design and construction of buildings NSR-98 Prior to 1984, the ACI and UBC codes were widely used.

Year the first code/standard addressing this type of construction issued: 1984

When was the most recent code/standard addressing this construction type issued? 1998

7.6 Role of Engineers and Architects

Often engineers and architects participate in the design phase of the project especially when the buildings are built for the middle class. If engineers and architects are involved in the construction, there is a "resident" (architect or engineer) on the site during the construction. Unfortunately, he/she is concerned mainly with the project cost aspects (rather than with the construction quality). Engineers and architects do not play any role in informal projects developed for poor people.

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	

Additional Comments: Some of these buildings, especially those of unreinforced masonry construction (types 9 and 11, Table 4.3) or confined masonry (type 10, Table 4.3) are informal construction.

7.8 Phasing of Construction

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

Additional Comments: The above statements are true, except for the case of informal construction.

7.9 Building Maintenance

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

7.10 Process for Building Code Enforcement

After an earthquake, the authorities enforce the use of building codes, however shortly thereafter these regulations are not enforced with an adequate effort.

7.11 Typical Problems Associated with this Type of Construction

As the amount of reinforcement is it rather limited (and in some cases does not exist at all), and the quality of materials and workmanship is generally poor, this construction type is very susceptible to earthquake effects, as illustrated in Figures 6A, 6B, 6C, 6D, 6E, 6F, 6G, 6H and 6I).

8 Construction Economics

8.1 Unit Construction Cost (estimate)

On the average \$300,000 Colombian pesos/ m² (\$US 150 /m²)

8.2 Labor Requirements (estimate)

It is possible to construct one floor per month on the average (when the building is designed for its final size and engineers/architects participate in the construction).

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 only for engineered buildings. At the present time, premium discounts are not available for seismically strengthened buildings, however the insurance companies are dealing with this matter.

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

Although there are many unclear aspects in this matter, in general the insurance covers the previously fixed value of the building. The insurance cost varies from 0.1 to 0.15% of the building value.

10 Seismic Strengthening Technologies

10.1 Description of Seismic Strengthening Provisions

Type of intervention	Structural Deficiency	Description of seismic strengthening provision used
Retrofit (Strengthening)	Walls # Unreinforced or with insufficient vertical and horizontal reinforcement # Stepped construction (offsets) for example half of the buildings with six stories and the other half with five due to the sloping terrain (resulting in non-uniform vertical stiffness distribution)	See Additional Comments
	Roof and floors: # Absence of continuous boundary members, chords and collectors. # Weak roof-wall and floor-wall connections.	See Additional Comments
	Other : # Poor quality of workmanship and materials. # Foundations designed only for vertical loads without considerations for overturning moments.	See Additional Comments

Additional Comments: Due to the fact that this construction type in general belongs to poor or middle class population, the costs of seismic strengthening is so prohibitive and unaffordable; this is a major reason for a very limited experience in this area. For the above reason, only scarce efforts have been made in the area of seismic strengthening. As illustrated in Figures 7A and 7B, an appropriate seismic strengthening technique includes the installation of new end confining members in the selected walls. An alternative seismic strengthening technique that would be appropriate for buildings of this type (using the Fiber Reinforced Polymers) is very expensive.

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?

N/A

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

N/A

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

N/A

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)

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13 Figures



FIGURE 1: Typical Building

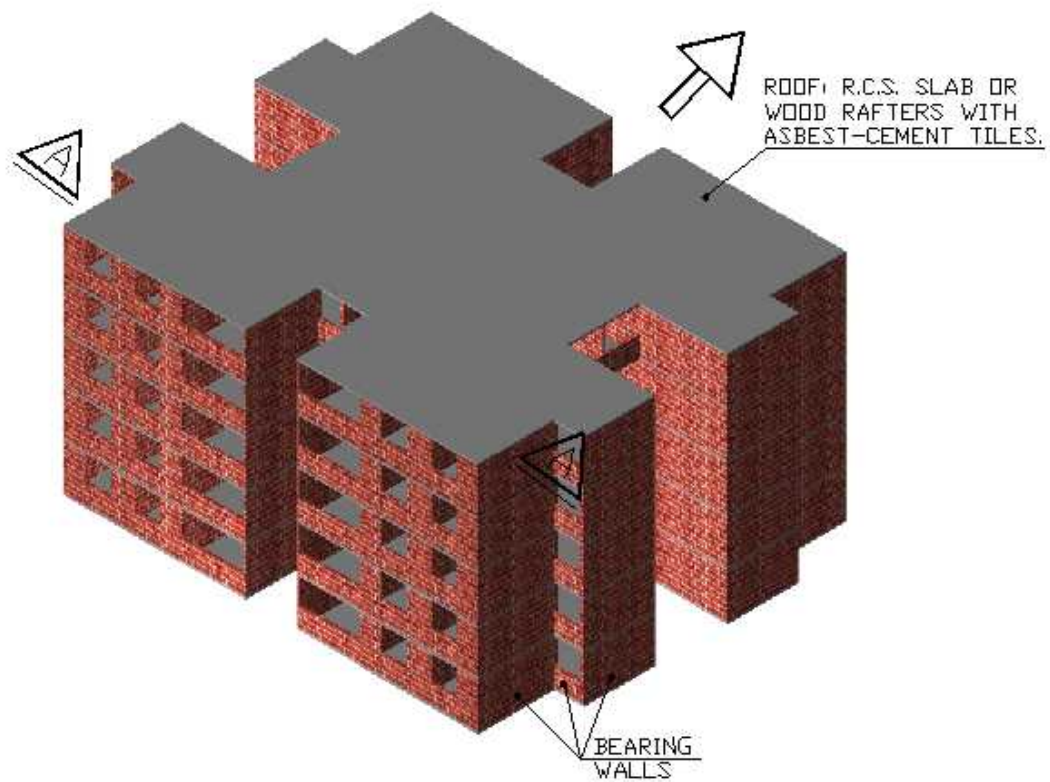


FIGURE 2A: Key Load-Bearing Elements

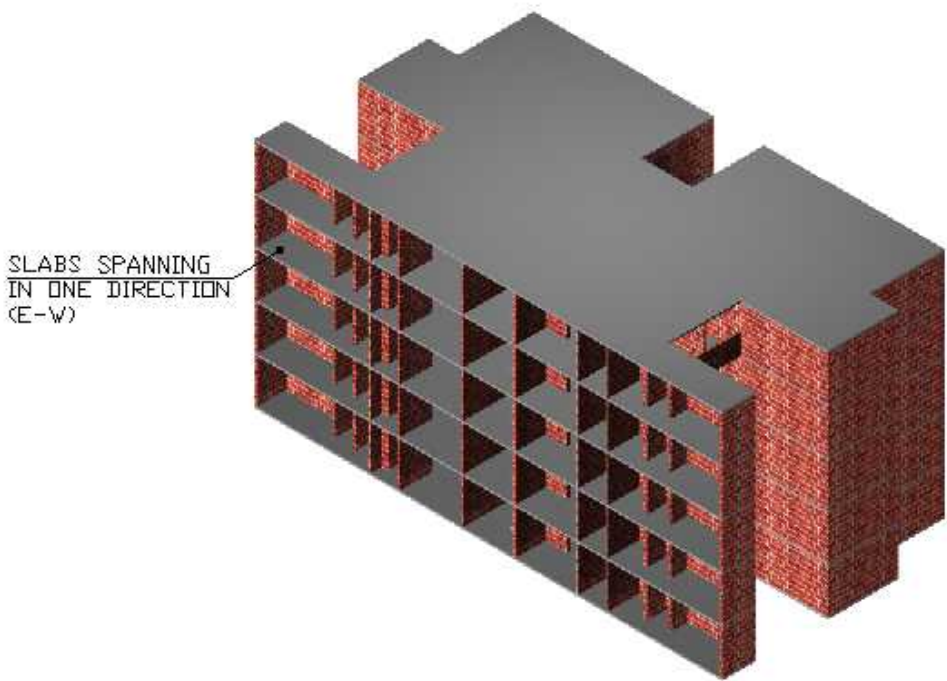


FIGURE 2B: Key Load-Bearing Elements

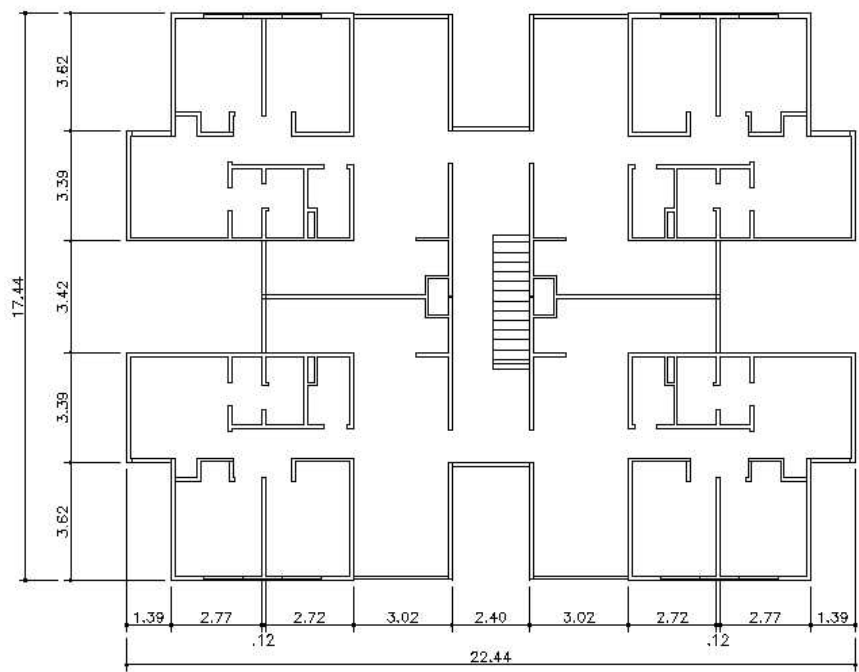


FIGURE 3: Plan of a Typical Building

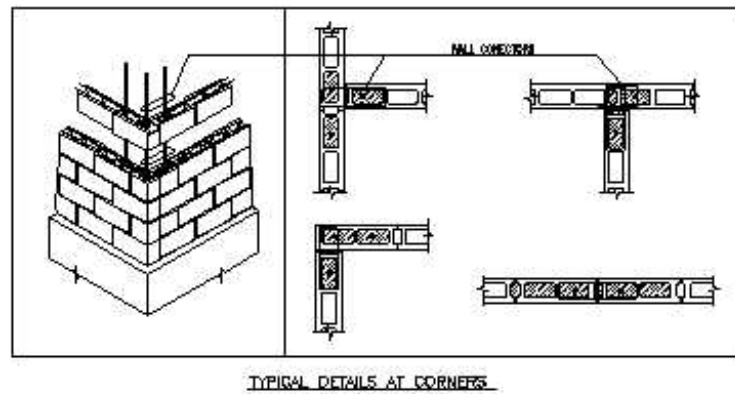
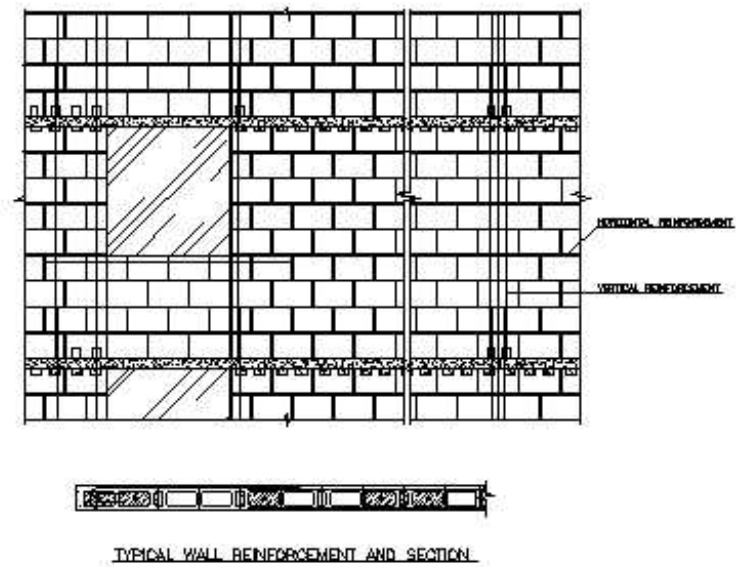


FIGURE 4A: Critical Structural Details - Typical Wall Reinforcement in New Buildings.



FIGURE 4B: Critical Structural Details - Modern buildings Built with Continuous R/C Bond Beams.



FIGURE 5A: Key Seismic Deficiencies - Inadequate Reinforcement and Poor Grouting (note the reinforcement bar slippage)



FIGURE 5B: Seismic Deficiencies - Discontinuous R/C Bond Beams.



*FIGURE 5C: Poor construction practice - unreinforced masonry walls and the absence of cross walls
(note that both clay bricks and concrete blocks were used for the wall construction).*



FIGURE 5D: Vertical Stiffness Discontinuity - Walls Interrupted at the First Story and Replaced with Columns.



FIGURE 5E: Seismic Deficiencies - An Example of a Building Collapse Caused by Gravity Loads Only (buildings with such weaknesses have very little chance to survive earthquake effects).



FIGURE 5F: Seismic Deficiencies - Poor Quality of Materials (mortar and grout); Inadequate Vertical and Horizontal Reinforcement.



FIGURE 5G: A building weakened due to tilting induced by a pre-earthquake foundation settlement

(separation between the two buildings was 100 mm at ground level but 0 mm at the top). Such buildings are likely to suffer more extensive earthquake damage.



FIGURE 5H: A building weakened due to tilting induced by a pre-earthquake foundation settlement (separation between the two buildings was 100 mm at ground level but 0 mm at the top). Such buildings are likely to suffer more extensive earthquake damage.



FIGURE 6A: Typical Earthquake Damage- Failure of Load bearing Masonry Walls



FIGURE 6B: Typical Earthquake Damage - Inadequate Reinforcement (Detail A shown on Figure 6)



FIGURE 6C: Typical Earthquake Damage- Lateral Movement of the Collapsed Building Relative to the Foundations



FIGURE 6D: Typical Earthquake Damage - Detail B Shown on Figure 6b



FIGURE 6E: Typical Earthquake Damage - Poor Workmanship and Inadequate Reinforcement (this is an enlarged detail B shown of Figure 6c)



FIGURE 6F: Typical Earthquake Damage Illustrating Two Similar Confined Masonry Buildings (note that the building on the right-hand side collapsed while the one on the left remained standing)



FIGURE 6G: Typical Earthquake Damage- Collapsed Roof; note the absence of continuous RC bond beam and the wall-roof connection; the water tank at the roof "walked off" and had contributed to the roof collapse.



FIGURE 6H: Typical Earthquake Damage - Importance of the Details in Seismic Design : The "access bridge" to this building did not have adequate bearing length and had collapsed, thus leaving inhabitants without a means of escape

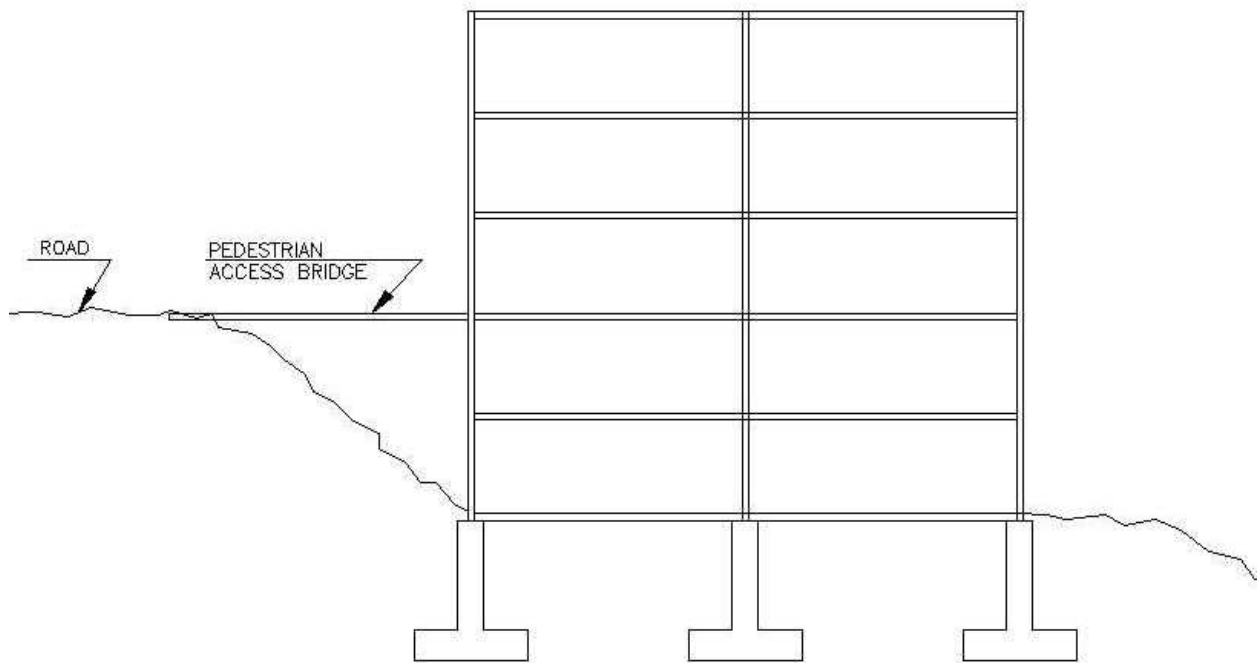


FIGURE 6I: Typical Earthquake Damage - Importance of the Details in Seismic Design : The "access bridge" to this building did not have adequate bearing length and had collapsed, thus leaving inhabitants without a means of escape



FIGURE 7A: Seismic Strengthening Techniques-Installation of New Concrete Tie Columns



FIGURE 7B: Seismic Strengthening Techniques - Installation of New Concrete Tie Columns