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
Gravity Concrete Frame Buildings (Predating Seismic Codes)

Report #	11
Report Date	05-06-2002
Country	COLOMBIA
Housing Type	RC Moment Frame Building
Housing Sub-Type	RC Moment Frame Building : Designed for gravity loads only, with URM infills
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Reviewer(s)	Sergio Alcocer

Summary

This is typical multi-family housing construction found in urban areas of Colombia that predates seismic codes. This housing type is widely used and represents 60% of the existing housing stock. At the present time, poor people occupy buildings of this type. This

construction is rather vulnerable to seismic effects due to a limited amount of transverse reinforcement (ties); this is especially true for columns. This structural system is very flexible when subjected to lateral seismic loads. The quality of materials and workmanship is typically rather poor. In many cases, buildings of this type are constructed on a very steep terrain; soil condition is often rather poor.

1. General Information

Buildings of this construction type can be found in Colombia and represents 60% of the existing housing stock. This type of housing construction is commonly found in urban areas.

This construction is rarely practiced in rural areas, with a rather small population in the villages (from 15,000 to 35,000 inhabitants).

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

Currently, this type of construction is being built. A traditional construction practice followed in the last 50 years.

Figure 1: Typical Building

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 several meters.

2.2 Building Configuration

In general the configuration is rectangular. In general, openings (in the walls) have a very limited effect on seismic behavior of the framed construction. The interaction between frames and partitions can be neglected, as the failure of the partitions is expected to occur at the beginning of an earthquake due to other weaknesses.

2.3 Functional Planning

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

2.4 Modification to Building

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

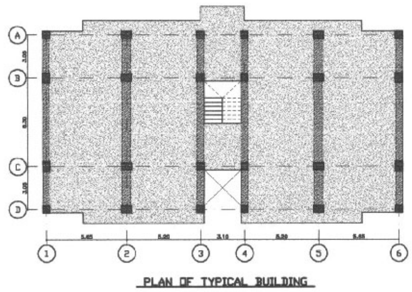

Figure 3: Plan of a Typical Building

3. Structural Details

3.1 Structural System

Material	Type of Load-Bearing Structure	#	Subtypes	Most appropriate type
Masonry	Stone Masonry Walls	1	Rubble stone (field stone) in mud/lime mortar or without mortar (usually with timber roof)	☐
		2	Dressed stone masonry (in lime/cement mortar)	☐
	Adobe/ Earthen Walls	3	Mud walls	☐
		4	Mud walls with horizontal wood elements	☐
		5	Adobe block walls	☐
		6	Rammed earth/Pise construction	☐
	Unreinforced masonry walls	7	Brick masonry in mud/lime mortar	☐
		8	Brick masonry in mud/lime mortar with vertical posts	☐
		9	Brick masonry in lime/cement mortar	☐
		10	Concrete block masonry in cement mortar	☐
	Confined masonry	11	Clay brick/tile masonry, with wooden posts and beams	☐
		12	Clay brick masonry, with concrete posts/tie columns and beams	☐
		13	Concrete blocks, tie columns and beams	☐
	Reinforced masonry	14	Stone masonry in cement mortar	☐
		15	Clay brick masonry in cement mortar	☐
		16	Concrete block masonry in cement mortar	☐
	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	☐
		22	Moment frame with in-situ shear walls	☐

Structural concrete	Structural wall			
		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. Like in a regular frame structure, gravity loads are carried by the joists, which are supported by the girders; the girders transfer the load to the columns. The floor slabs are often constructed using tile blocks and concrete joists and girders. Beams and columns are constructed in a manner typical for reinforced concrete structures.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is reinforced concrete moment resisting frame. This type of building frame does not have any earthquake-resisting features.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 20 and 20 meters, and widths between 10 and 10 meters. The building is 5 storey high. The typical span of the roofing/flooring system is 4.0 meters. Typical Plan

Dimensions: Width varies from 8 to 10 m. The typical storey height in such buildings is 2.6 meters. The typical structural wall density is none. .

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	☑	☑

Floors are considered as rigid diaphragms and the roof as a flexible one.

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	☐
	Reinforced-concrete bearing piles	☐
	Reinforced-concrete skin	☐

Deep foundation	friction piles	
	Steel bearing piles	☐
	Steel skin friction piles	☐
	Wood piles	☐
	Cast-in-place concrete piers	☐
	Caissons	☐
Other	Described below	☐

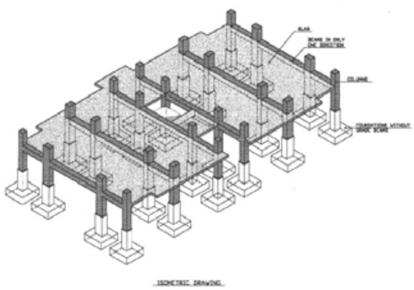

Figure 3: Key Load-bearing Elements

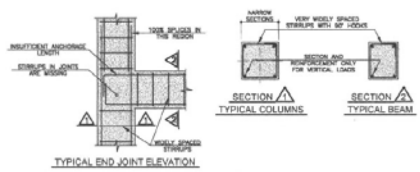

Figure 4: Critical Structural Details

Figure 5A: Poor Construction Practices: Beams constructed in one direction only

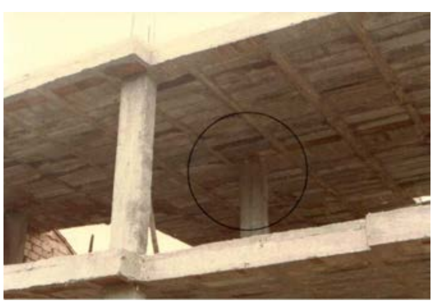

Figure 5B: Poor Construction Practice: Beams constructed in one direction only

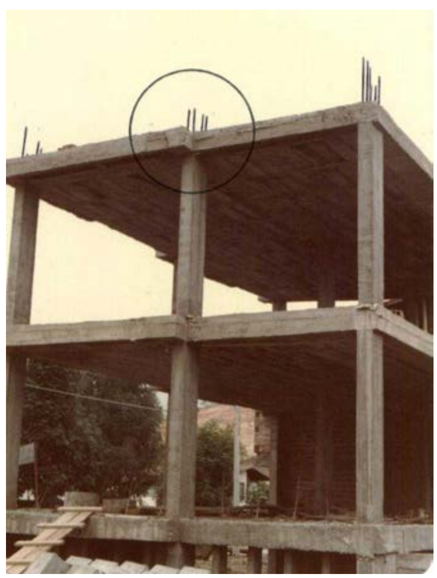

Figure 5C: Poor Construction Practice: Inadequate splice length and location (100% splices at the column base)

Figure 5D: Poor Design: Combination of Concrete Frames and Unreinforced Masonry Walls or Pilasters

Figure 5E: Poor Design: Combination of Concrete Frames and Unreinforced Masonry Walls or Pilasters

Figure 5F: Playing with the laws of equilibrium

Figure 5G: Playing with the laws of equilibrium

Figure 5H: Poor Workmanship: Drity groundwork and inappropriate column and beams

Figure 5I: Poor Construction Practice: Drains running across the girders. Stirrups are removed to allow for the pipeline passage

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 5-10 housing unit(s). 5 units in each building. Number of housing units ranges from 5 to 10. The number of inhabitants in a building during the day or business hours is 5-10. The number of inhabitants during the evening and night is more than 20.

4.2 Patterns of Occupancy

Typically, one family occupies a housing unit; however, in the urban areas inhabited by a poor population, up to 3- 4 families occupy 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)	☐

Following is the approximated economic distribution of population in Colombia Economic Status % Annual Income ($US) Very Poor 35 <1000 Poor 35 1000 - 2000 Middle Class 25 2000 - 10000 High Middle Class 4 10000-40000 Rich 1 >40000 Economic Status: For Poor Class the Housing Price unit is 10000 and the Annual Income is 15000. For Middle Class the Housing Price unit is 40000 and the Annual Income is 6000.

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

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

The main source of financing for the poor people is informal network (friends and relatives) and (sometimes) small lending institutions. For the middle class population, the main sources of financing re personal savings and commercial banks. In each housing unit, there are 2 bathroom(s) without toilet(s), 2 toilet(s) only and 2 bathroom(s) including toilet(s).

2 or 3 bathrooms per housing unit (i.e. apartment). .

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		
		True	False	N/A
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces from the building to the foundation.	☐	☑	☐
Building Configuration	The building is regular with regards to both the plan and the elevation.	☐	☑	☐
Roof construction	The roof diaphragm is considered to be rigid and it is expected that the roof structure will maintain its integrity, i.e. shape and form, during an earthquake of intensity expected in this area.	☐	☑	☐
Floor construction	The floor diaphragm(s) are considered to be rigid and it is expected that the floor structure(s) will maintain its integrity during an earthquake of intensity expected in this area.	☑	☐	☐
Foundation performance	There is no evidence of excessive foundation movement (e.g. settlement) that would affect the integrity or performance of the structure in an earthquake.	☑	☐	☐
Wall and frame structures-redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	☑	☐	☐
Wall proportions	Height-to-thickness ratio of the shear walls at each floor level is: Less than 25 (concrete walls); Less than 30 (reinforced masonry walls); Less than 13 (unreinforced masonry walls);	☐	☐	☑
Foundation-wall connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	☑	☐	☐
Wall-roof connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps	☐	☑	☐
Wall openings	The total width of door and window openings in a wall is: For brick masonry construction in cement mortar : less than ½ of the distance between the adjacent cross walls; For adobe masonry, stone masonry and brick masonry in mud mortar: less than 1/3 of the distance between the adjacent cross walls; For precast concrete wall structures: less than 3/4 of the length of a perimeter wall.	☐	☐	☑
Quality of building materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	☐	☑	☐
	Quality of workmanship (based on visual inspection of			

Quality of workmanship	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
Various	-Poor quality of workmanship and materials -Foundation without grade beams (horizontal ties), and built without regard to minimum embedment, especially on a steep terrain.		
Frame (columns, beams)	-Vertical irregularity (stepped construction/setbacks) -Small sections of columns and beams (drift problems) -Widely spaced stirrups in beams and columns -Poor anchorage of reinforcement -Columns often interrupted one story below the top level (i.e. there are no columns at the top storey level) -In some cases, there are mixed structural systems e.g. wall and frame structure		
Roof	-Weak roof-to-wall connections -Absence of continuous boundary members		
Floors	-Usually very flexible floors with missing boundary members chords and collectors.		

Typical seismic deficiencies related to this type of construction, mainly due to poor construction practices and workmanship, are illustrated in the FIGURES 5A, 5B, 5C, 5D and 5E.

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance), the lower bound (i.e., the worst possible) is A: HIGH VULNERABILITY (i.e., very poor seismic performance), and the upper bound (i.e., the best possible) is C: MEDIUM VULNERABILITY (i.e., moderate seismic performance).

Vulnerability	high	medium-high	medium	medium-low	low	very low
	very poor	poor	moderate	good	very good	excellent
Vulnerability Class	A	B	C	D	E	F
	☑	☐	☑	☐	☐	☐

5.4 History of Past Earthquakes

Date	Epicenter, region	Magnitude	Max. Intensity
1979	4.8N, 76.2W, depth: 108 km (Mistrató)	6.7	VIII MMI (MANIZALES)
1983	2.46N, 76.69W, depth: 22 km (Popayán)	5.5	IX MMI (POPAYÁN)
1995	4.1N, 76.62W, depth: 73 km (Pereira)	6.4	VIII MMI (PEREIRA)
1999	4.46N, 75.72W, depth: 17 km (Armenia)	6	IX MMI (ARMENIA)

Most buildings of this type collapsed, killing the inhabitants, especially in the areas with pronounced soil amplification. Typical patterns of earthquake damage are illustrated in FIGURES 6A, 6B, 6C, 6D, and 6E. The figures confirm the importance of good construction practice and its impact on seismic performance.

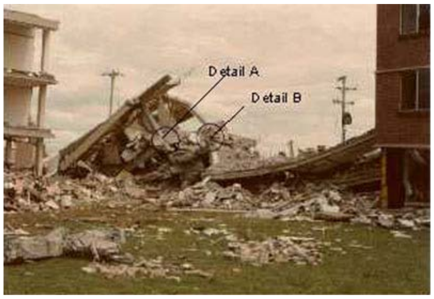

Figure 6A: Earthquake Damage: Collapsed Building

Figure 6B: Earthquake Damage: Reinforcement splices in the joint zone (Detail A)

Figure 6C: Earthquake Damage: Anchorage of beam reinforcement in the column cover area (It would be correct to anchor the reinforcement inside the joint.) Detail B

Figure 6D: Earthquake Damage: Inadequate longitudinal and transverse reinfrocement (Note the collapsed first story.)

Figure 6E: Collapsed building: Detail A shows too widely spaced stirrups

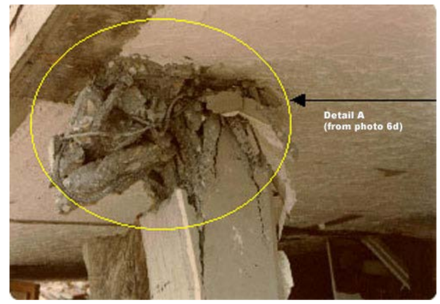

Figure 6F: Collapsed building: Detail A shows too widely spaced stirrups

Figure 6G: Collapsed 3-story building. (Note the total lateral drift between the 2nd and 3rd floor.)

Figure 6H: First-story column collapse due to the widely spaced stirrups and poor quality of aggregate

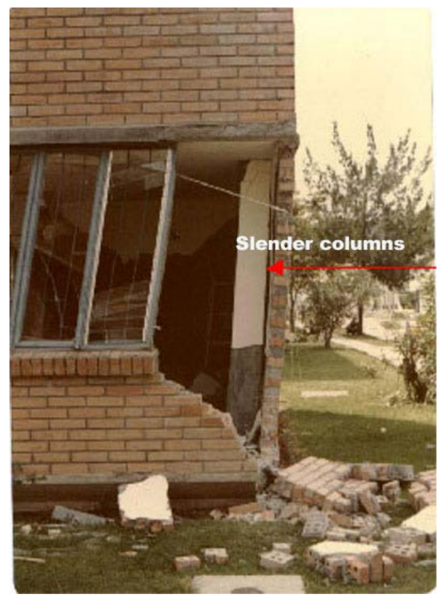

Figure 6I: Earthquake Damage: Very Slender Columns

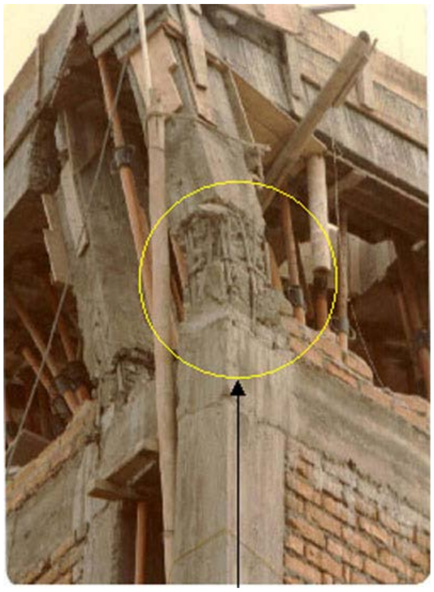

Figure 6J: Earthquake Damage: Inadequate Columns Splices

Figure 6K: Earthquake Damage: Inadequate Concrete Cover

6. Construction

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls				
Foundation	Reinforced Concrete	20.0 MPa	1 : 2 : 3	Cement/sand/aggregates
Frames (beams & columns)				
Roof and floor(s)	Abarco (Cariniana piriformis)	9.0 MPa	50 mm X 100 mm	Sometimes a R.C.slab is used

6.2 Builder

This construction type is built for speculation purposes.

6.3 Construction Process, Problems and Phasing

The construction process begins with forming a terrace, followed by the construction of the isolated footings (sometimes piers or piles), columns and floor slab etc. Finally, the partitions are installed and other "finishing work" is carried out. The masons are skilled or semi-skilled. No equipment is used, except for simple tools. The construction of this type of housing takes place incrementally over time. Typically, the building is originally not designed for its final constructed size. In the urban areas (districts) inhabited by poor population, construction of this type is usually informal and it takes place over time. However, buildings of this type built for the middle class are designed for its final size.

6.4 Design and 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. Often engineers and architects participate in the design phase of the project especially when the buildings are built for the middle class. In such a case, during the construction usually there is a "resident" (architect or engineer) at the site. Unfortunately, he is concerned mainly with the cost of the project. In informal projects developed for poor people engineers and architects do not play any role.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. 1984: Colombian Code for Earthquake-Resistant Buildings CCCSR-84. 1998: Colombian Code for Earthquake-Resistant Design and Construction of Buildings NSR-98 Prior to 1984, the ACI and UBC codes were widely used. The year the first code/standard addressing this type of construction issued was 1984. The most recent code/standard addressing this construction type issued was 1998. Title of the code or standard: 1984: Colombian Code for Earthquake-Resistant Buildings CCCSR-84. 1998: Colombian Code for Earthquake-Resistant Design and Construction of Buildings NSR-98 Prior to 1984, the ACI and UBC codes were widely used. Year the first code/standard addressing this type of construction issued: 1984 When was the most recent code/standard addressing this construction type issued? 1998.

After an earthquake, the authorities enforce the use of building codes, however shortly thereafter these regulations are no longer enforced with the same effort.

6.6 Building Permits and Development Control Rules

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

A very limited attention was paid to seismic aspects of the design in the construction of buildings of this type (construction of which pre-dated the 1984 seismic code). 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). As a direct consequence of a difficult economic situation of the inhabitants of this construction type, the buildings are seldom maintained.

6.8 Construction Economics

On the average, 300,000 Col. Pesos/m^2 (150 US dollars/m^2). When the building is designed for its final size and engineers or architects participate in the construction, it is possible to construct one floor per month on the average.

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. A few years ago, it was not possible to buy earthquake insurance; however, at the present time it is possible to buy earthquake insurance for engineered buildings. Although there are many unclear aspects in this matter, in general the insurance covers the previously fixed value of the building. The cost of insurance varies from 0.1 to 0.15% of the total building value.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Beams and columns	Technique #1: Addition of stirrups to avoid brittle failure of concrete columns and beams (FIGURE 7A)

The procedures illustrated below are not complex in design or construction, however they require good planning and a perfect coordination between the owner, the designer and the builder. It is important to note that there are different grades of difficulty with respect to the effectiveness among the techniques #1, 2, and 3 shown on Figures 7A, 7B and 7C respectively. For example, the technique #1 is considerably simpler in terms of construction as compared with the technique #3, however it is also much less effective as compared to the technique #3. In addition to the above techniques, new seismic strengthening techniques using carbon fibers are also in use.

8.2 Seismic Strengthening Adopted

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

Yes. Seismic strengthening has been used in practice by the author of this contribution, as illustrated in Figure 7A.

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

The work was done as a mitigation effort.

8.3 Construction and Performance of Seismic Strengthening

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

Yes.

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

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

What was the performance of retrofitted buildings of this type in subsequent earthquakes?
There were no major earthquake after the strengthening was performed, however the performance in moderate earthquakes has been very good.

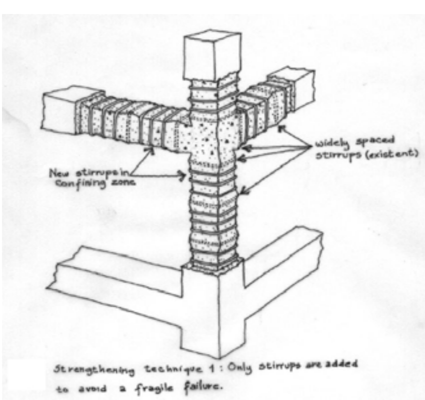

Figure 7A: Illustration of Seismic Strengthening Techniques

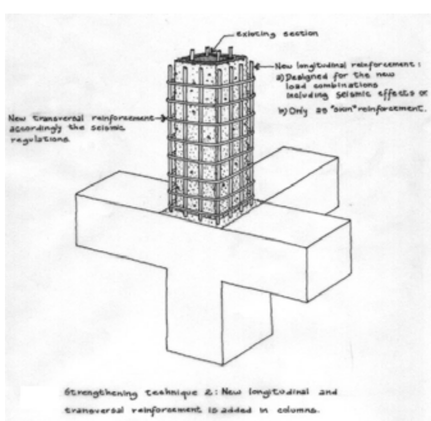

Figure 7B: Illustration of Seismic Strengthening Techniques

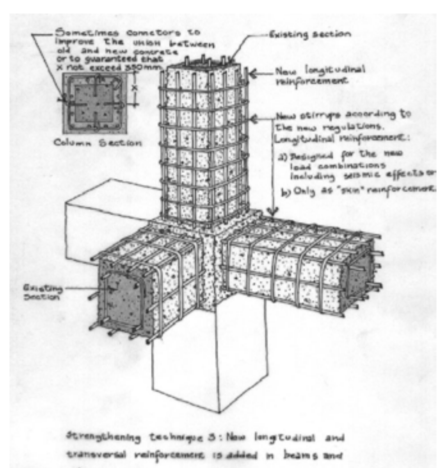

Figure 7C: Illustration of Seismic Strengthening Techniques

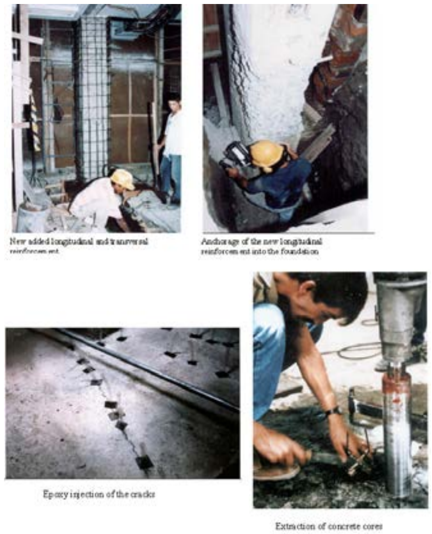

Figure 7D: Seismic Strengthening Techniques: Field Implementation

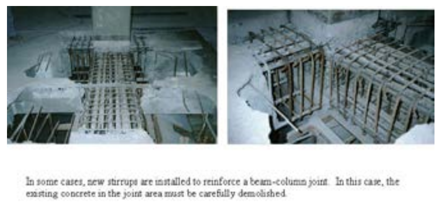

Figure 7E: Seismic Strengthening Techniques: Field Implementation

Reference(s)

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

2. How to Avoid a Brittle Failure in Columns
   Mejia, Luis Gonzalo
   (in Spanish)

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