World Housing Encyclopedia Report

Country: Colombia

Housing Type: Gravity concrete frame buildings (predating seismic codes).

Contributors:
Luis Gonzalo Mejía

Primary Reviewer:
Sergio Alcocer

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Table of Contents

1 General Information

1.1 Country
Colombia

1.3 Housing Type
Gravity concrete frame buildings (predating seismic codes).

1.4 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.

FIGURE 1: Typical Building

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: A traditional construction practice followed in the last 50 years.

1.6 Region(s) Where Used
This housing type is widely used in Colombia and represents 60% of the existing housing stock.

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

2 Architectural Features

2.1 Openings

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.

2.2 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?		

The typical separation distance between buildings is meters

2.3 Building Configuration

In general the configuration is rectangular.

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)	

<u>Additional Comments:</u> These buildings may be of mixed use, too.

2.5 Means of Escape

Usually buildings of this type do not have any additional means of escape.

2.6 Modification of Buildings

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

3 Socio-Economic Issues

3.1 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.

3.2 Number of Housing Units in a Building

5 units in each building.

Additional Comments: Number of housing units ranges from 5 to 10.

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	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 (i.e. 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: 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

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 / mortages	
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 type of building frame does not have any earthquake-resisting features.

4.2 Gravity Load-Bearing Structure

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.

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)	X
		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		

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

4.5 Type of Floor/Roof System

Material	Description of floor/roof system	Floor	Roof
Masonry	Vaulted		
	Composite masonry and concrete joist	X	
Structural Concrete	Solid slabs (cast in place or precast)		
	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: Floors are considered as rigid diaphragms and the roof as a flexible one.

4.6 Typical Plan Dimensions

Length: 20 - 20 meters
Width: 10 - 10 meters
Additional Comments: Width varies from 8 to 10 m.

4.7 Typical Number of Stories

5

4.8 Typical Story Height

2.6 meters

4.9 Typical Span

4.0 meters

Additional Comments: Typical span varies from 3 to 4 m.

4.10 Typical Wall Density

Additional Comments: N/A

4.11 General Applicability of Answers to Questions in Section 4

This contribution describes a generic construction type.

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 form 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				

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.		

Additional Comments: 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 Seismic Vulnerability Rating

	Vulnerability					
	High (Very Poor Seismic Performance) A	B	Medium C	D	E	Low (Excellent Seismic Performace) 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)
1999	4.46N, 75.72W, depth: 17 km (Armenia)	6	IX MMI (ARMENIA)
1995	4.1N, 76.62W, depth: 73 km (Pereira)	6.4	VIII MMI (PEREIRA)
1983	2.46N, 76.69W, depth: 22 km (Popayán)	5.5	IX MMI (POPAYAN)
1979	4.8N, 76.2W, depth: 108 km (Mistrató)	6.7	VIII MMI (MANIZALES)

Additional Comments: 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.

7 Building Materials and Construction Process

7.1 Description of Building Materials

Structural Element	Building Material	Characteristic Strength	Mix Proportions/ Dimensions	Comments
Walls				
Foundations	Reinforced Concrete	20.0 MPa	1 : 2 : 3	Cement/sand/aggregates
Columns	Reinforced Concrete	20.0 MPa		
Floors	Concrete slab (hollow tile floor)		1 : 2 : 3	Cement/sand/aggregates
Roof (rafters with Spanish tiles)	Abarco (Cariniana piriformis)	9.0 MPa	50 mm X 100 mm	Sometimes a R.C. slab is used
Columns	Reinforced concrete	20.0 MPa	1 : 2 : 3	Cement/sand/aggregates

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

This construction type is built for speculation purposes.

7.3 Construction Process

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.

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. 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.

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: 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).

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: 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.

7.9 Building Maintenance

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

Additional Comments: As a direct consequence of a difficult economic situation of the inhabitants of this construction type, the buildings are seldom maintained.

7.10 Process for Building Code Enforcement

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

7.11 Typical Problems Associated with this Type of Construction

The lack of adequate transverse reinforcement in beams and columns, the excessive lateral drift, the irregularities and the poor workmanship lead to catastrophic failures of buildings of this type.

8 Construction Economics

8.1 Unit Construction Cost (estimate)

On the average, 300,000 Col. Pesos/m^2 (150 US dollars/m^2).

8.2 Labor Requirements (estimate)

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.

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: 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.

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 cost of insurance varies from 0.1 to 0.15% of the total 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)	Beams and columns	Technique #1: Addition of stirrups to avoid brittle failure of concrete columns and beams (FIGURE 7A)
		Technique #2: Installation of new longitudinal and transverse reinforcement in columns (FIGURE 7B)
		Technique #3: Installation of new longitudinal and transverse reinforcement in beams and columns (FIGURE 7C)

Additional Comments: 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.

10.2 Has seismic strengthening described in the above table been performed in design 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.

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

The work was done as a mitigation effort.

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

Yes.

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

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

10.6 What has been 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.

11 References

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

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

12 Contributors

Name	Luis Gonzalo Mejía
Title	Consulting Structural Engineer
Affiliation	Luis Gonzalo Mejia C. y Cia. Ltda.
Address	Calle 49b #79b-12
City	Medellin
Zipcode	
Country	Colombia
Phone	(574) 2342678
Fax	(574) 4217661
Email	lgm@epm.net.co
Webpage	

13 Figures

FIGURE 1: Typical Building

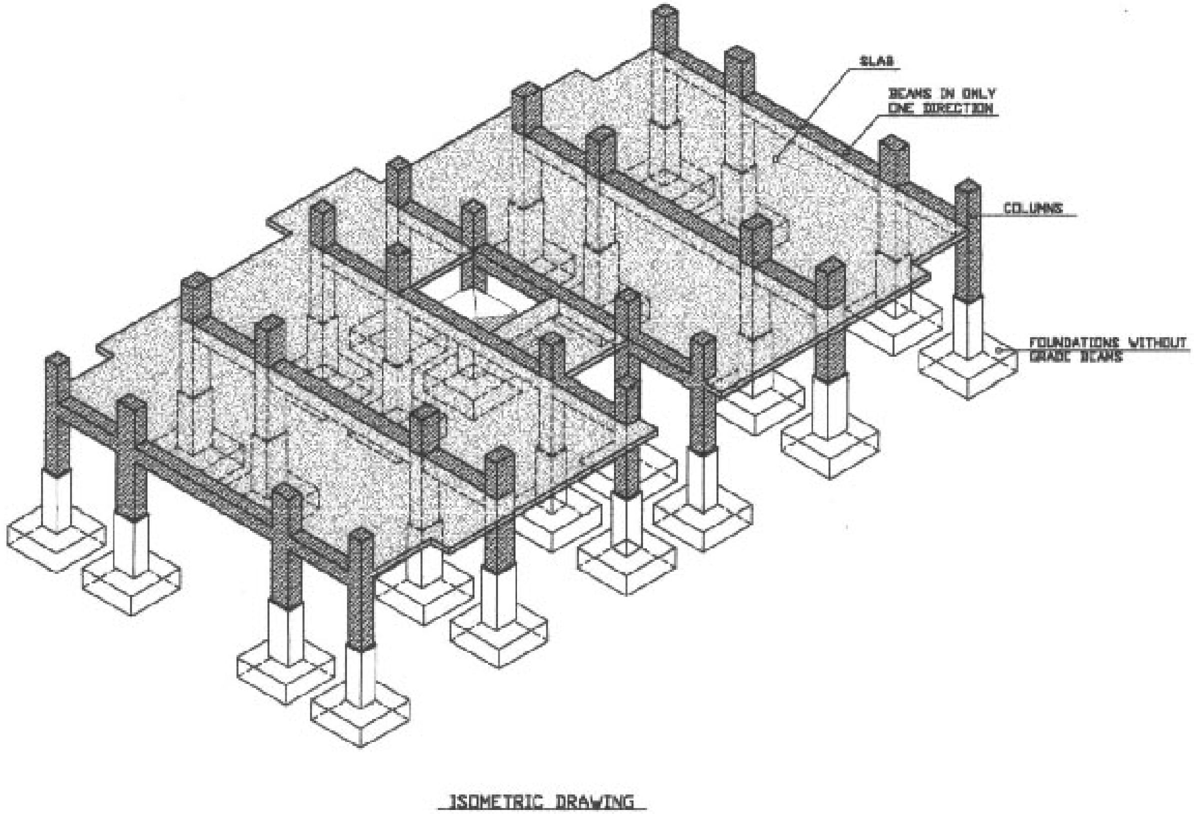

FIGURE 2: Key Load-bearing Elements

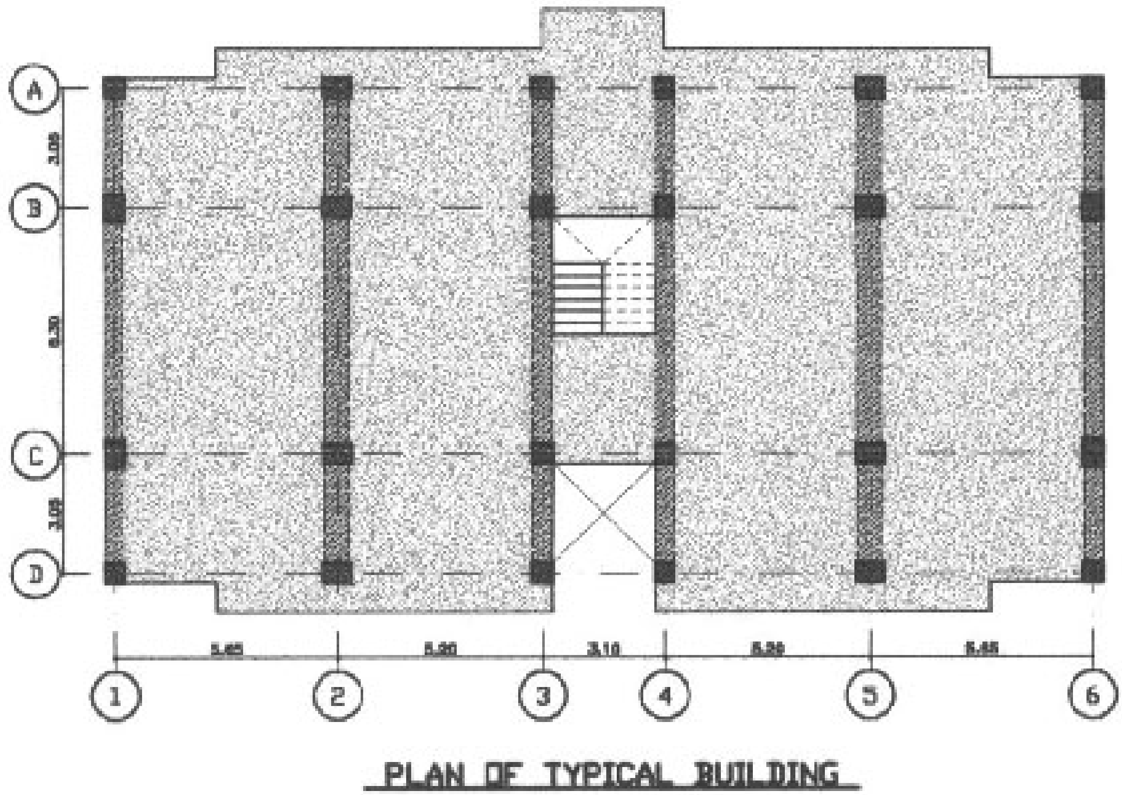

FIGURE 3: Plan of a Typical Building

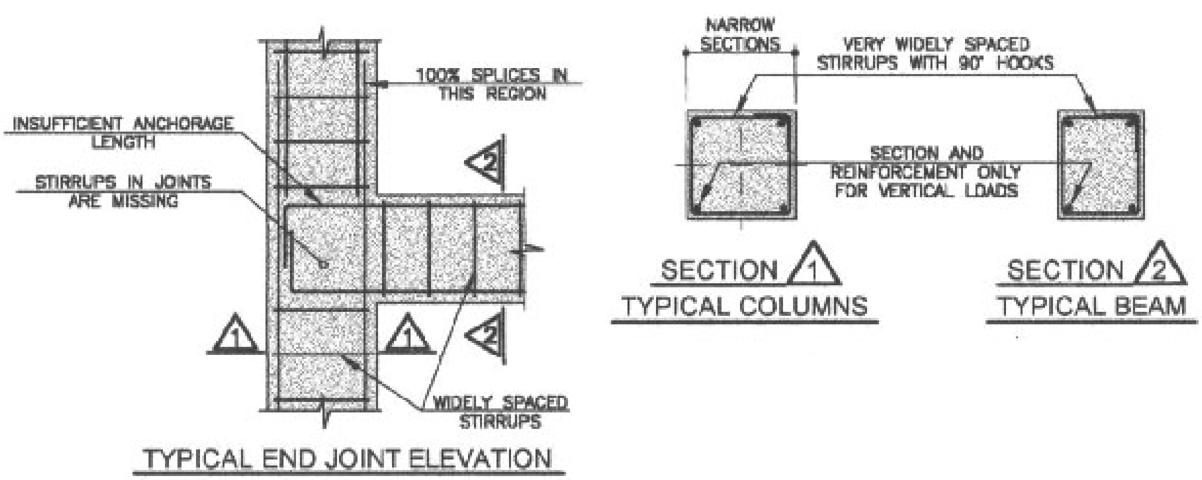

FIGURE 4: Critical Structural Details

FIGURE 5A: Poor Construction Practice: Beams constructed in one direction only

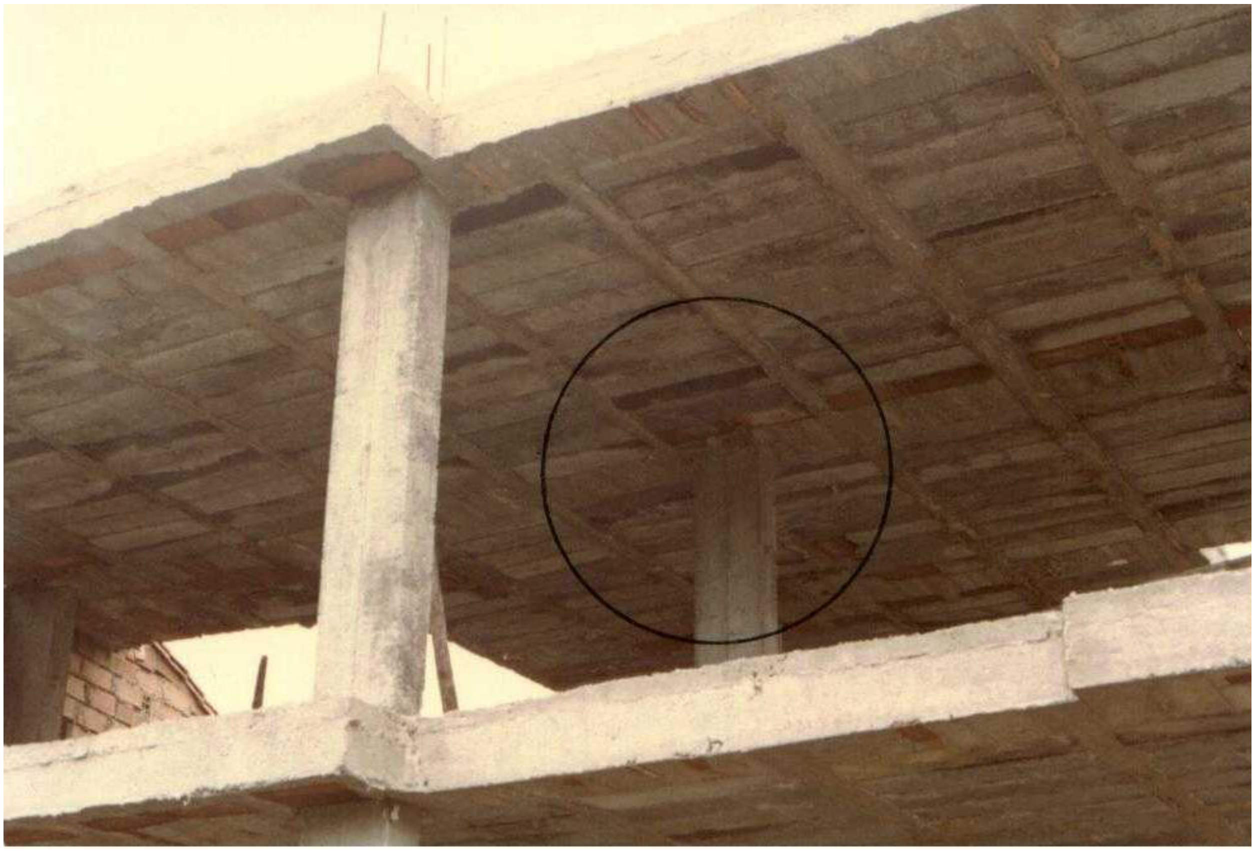

FIGURE 5B: Poor Construction Practice: Beams constructed in one direction only

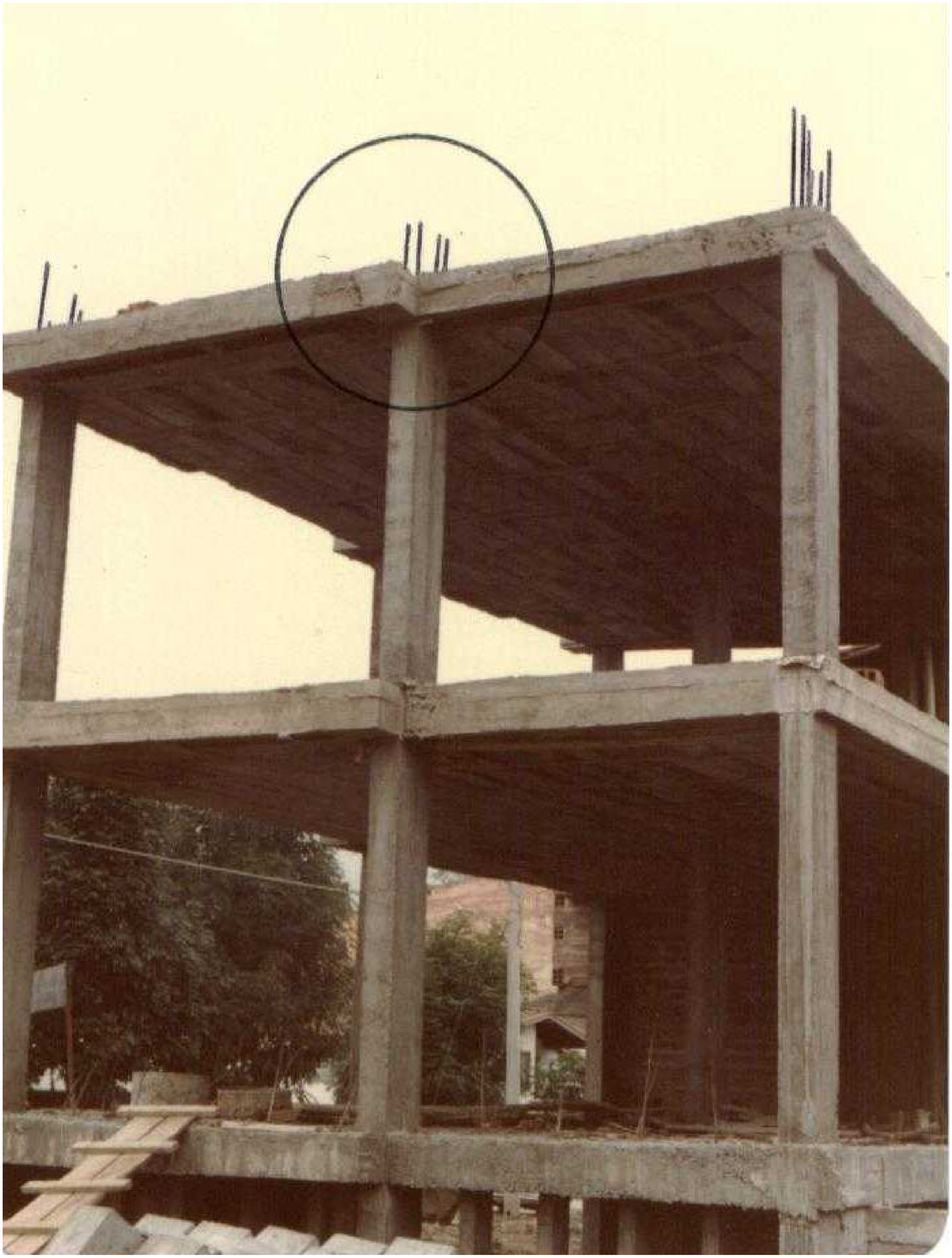

FIGURE 5C: Poor Construction Practice: Inadequate splice length and location (100% splices at the column base)

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: Dirty groundwork and inappropriate column and bar anchorage

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

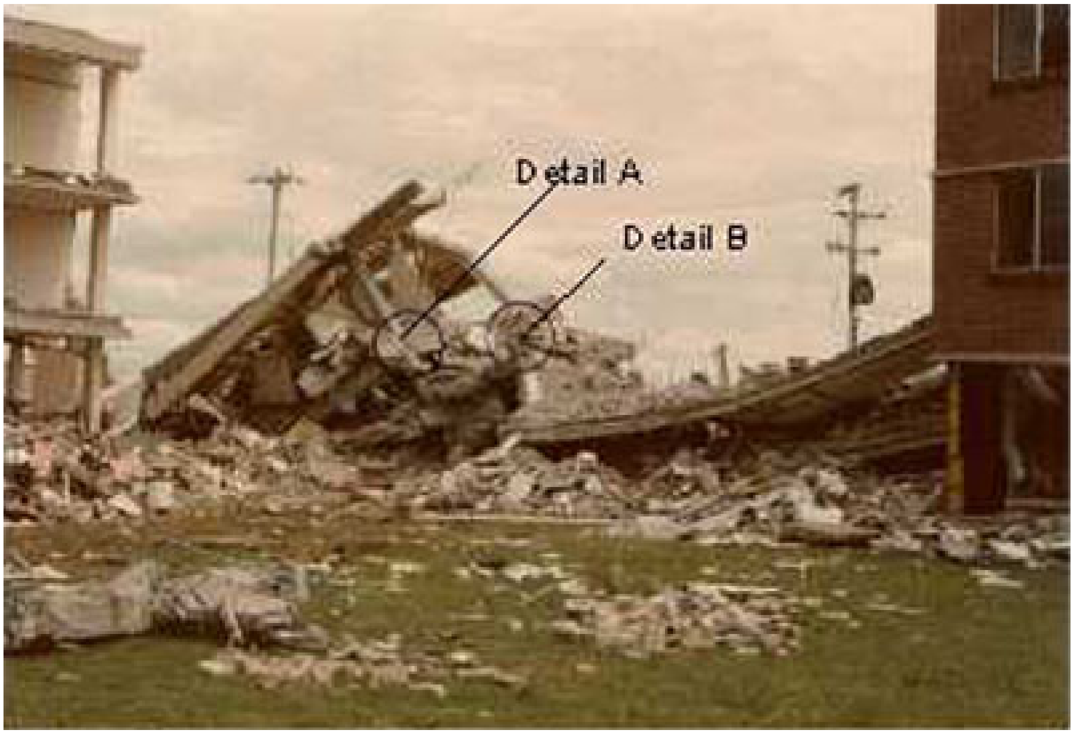

FIGURE 6A: Earthquake Damag: Collapsed Building

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 reinforcement (Note the collapsed first story.)

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

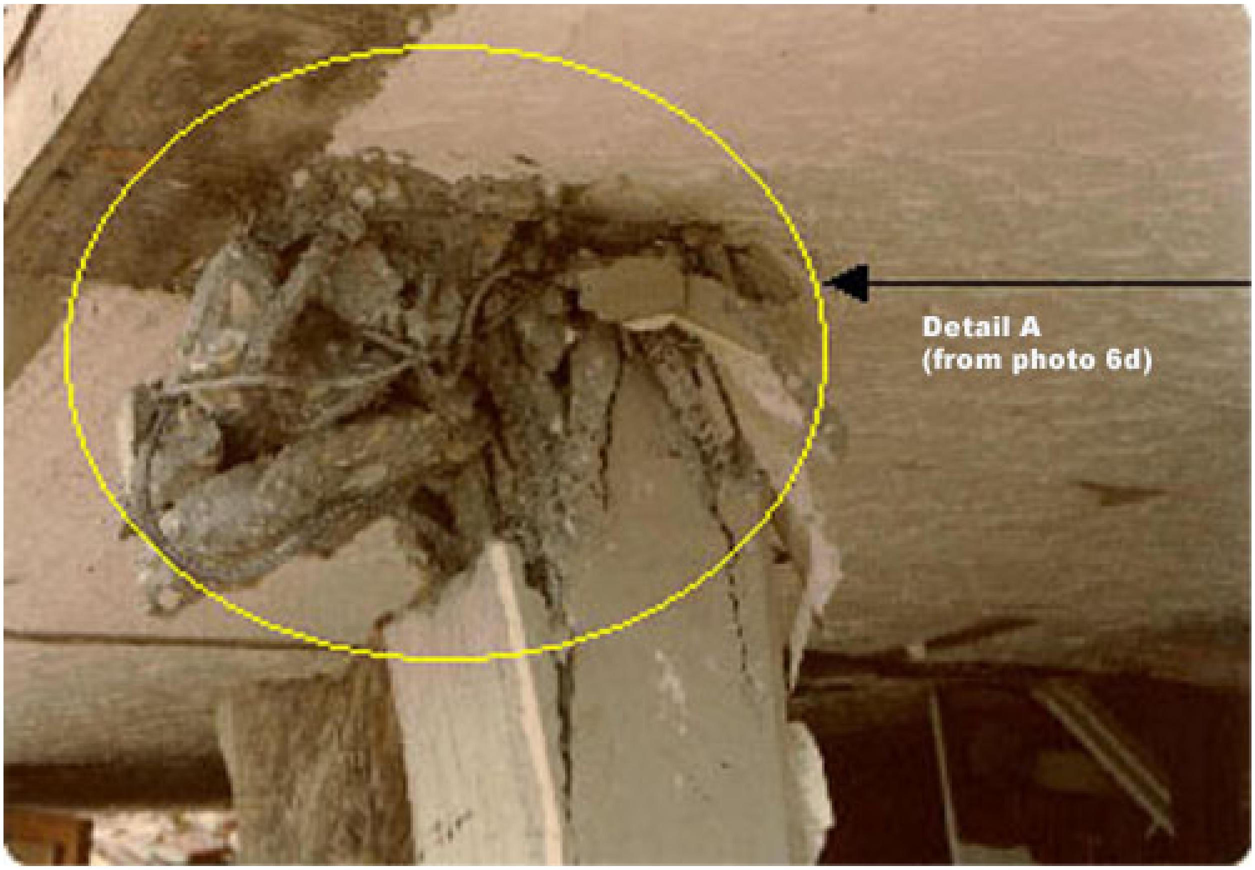

FIGURE 6F: Collapsed building; Detail A shows too widely spaced stirrups

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

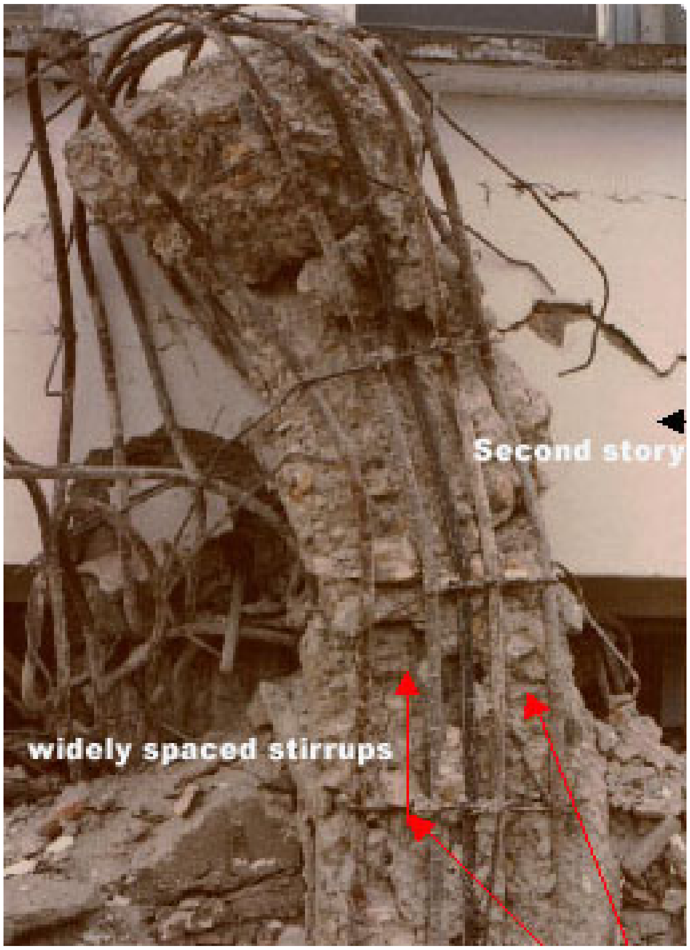

FIGURE 6H: First-story column collapse due to the widely spaced stirrups and poor quality of aggregate

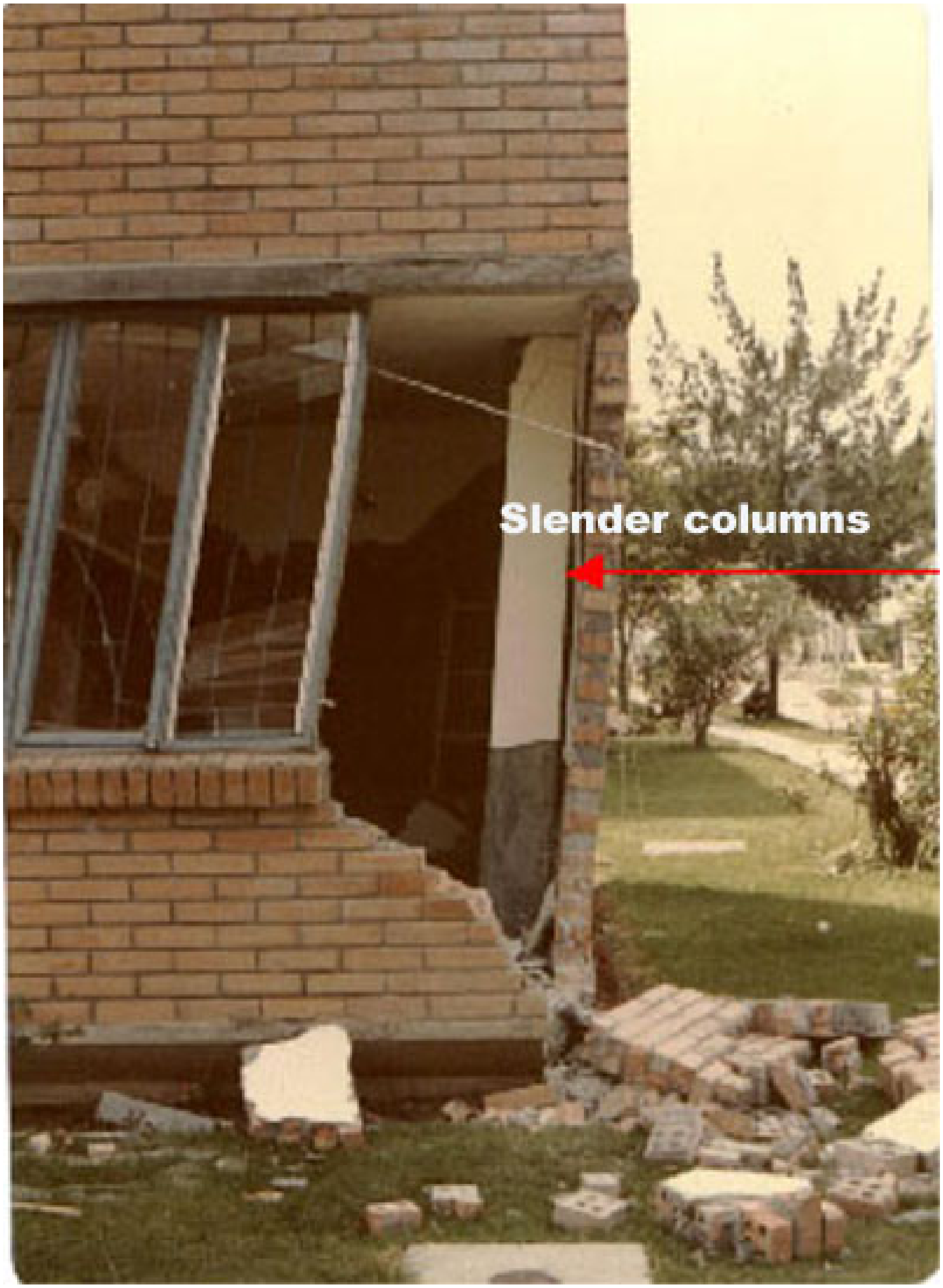

FIGURE 6I: Earthquake Damage: Very Slender Columns

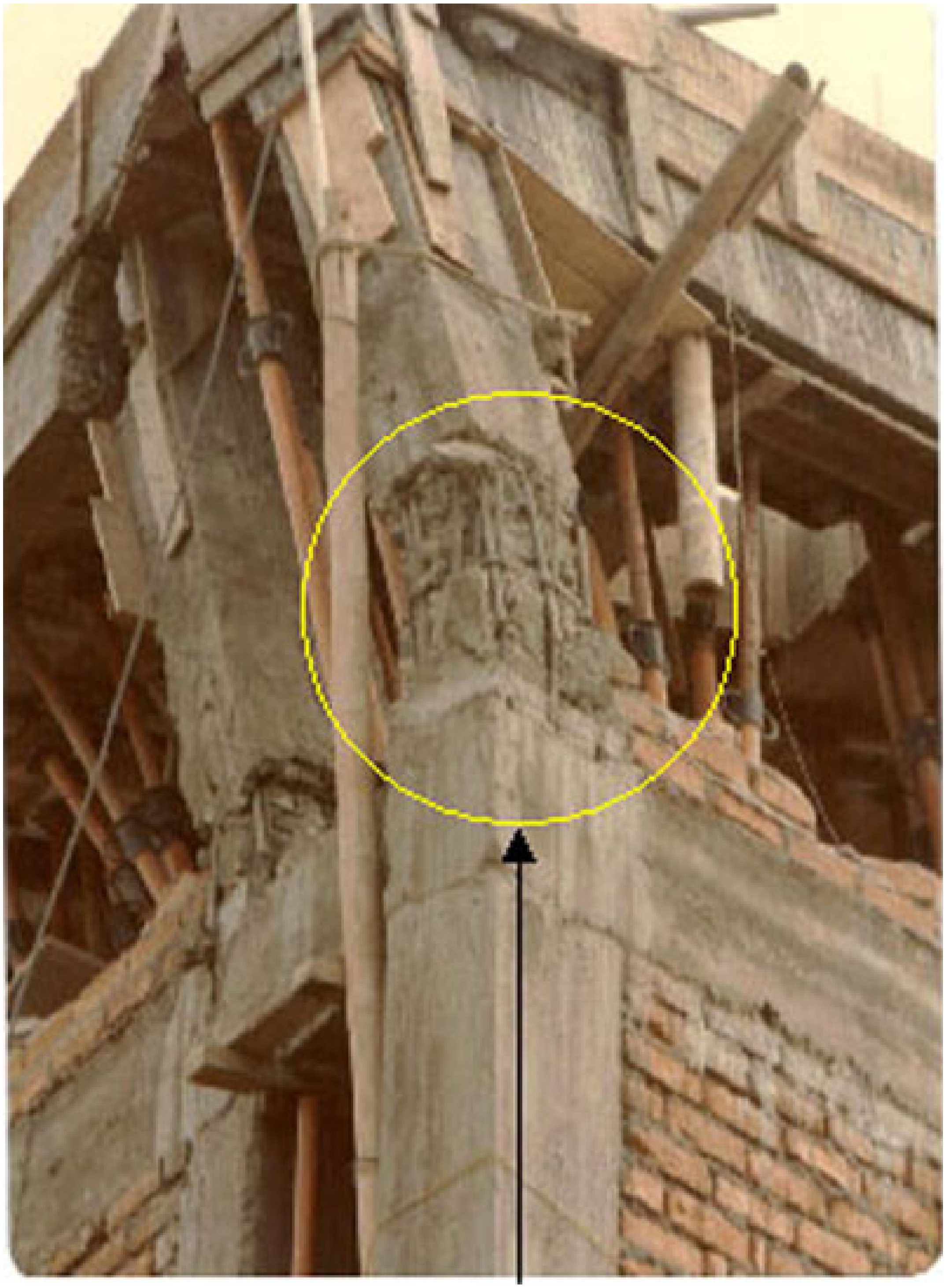

FIGURE 6J: Earthquake Damage: Inadequate Column Splices

FIGURE 6K: Earthquake Damage: Inadequate Concrete Cover

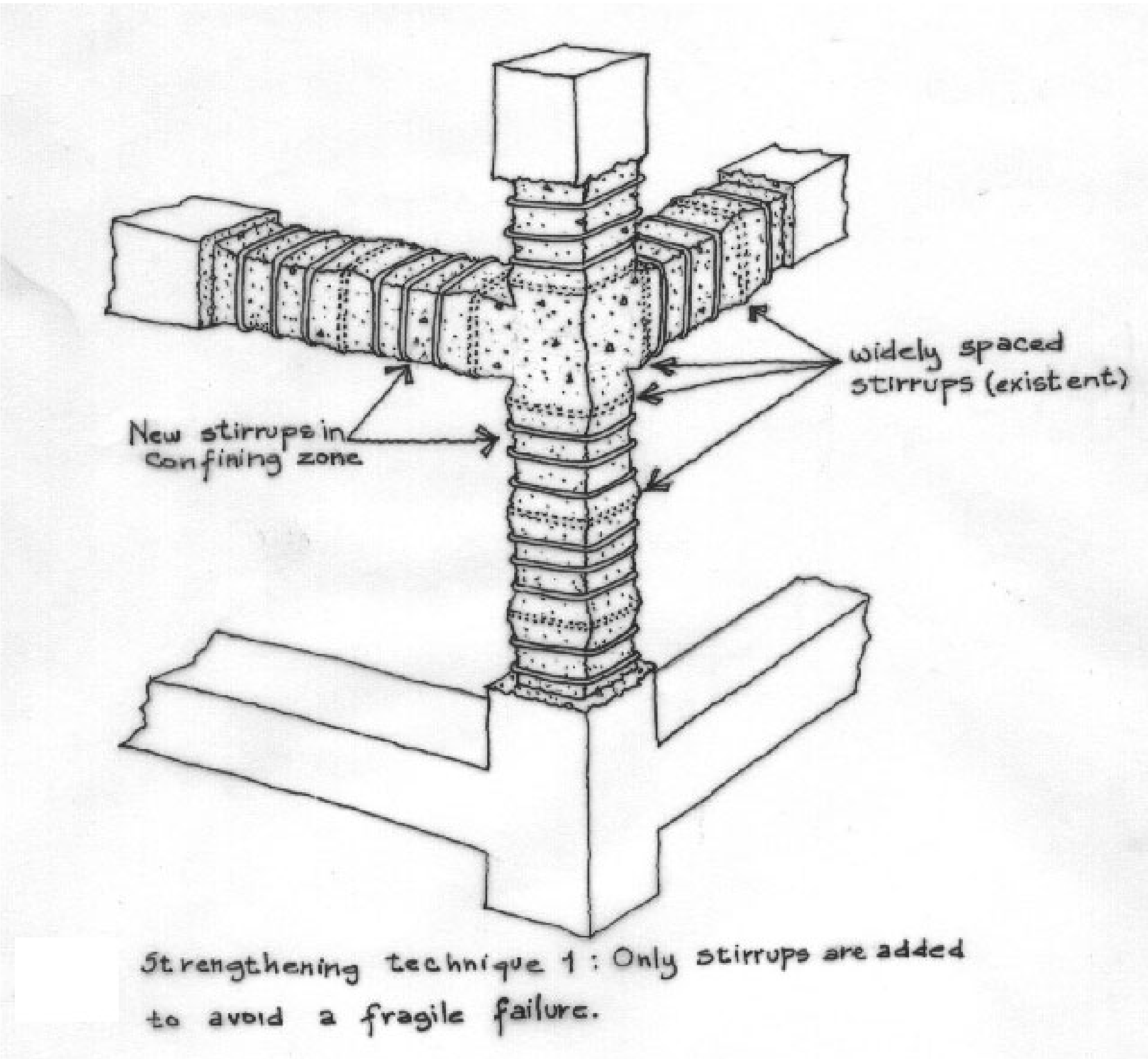

FIGURE 7A: Illustration of Seismic Strengthening Techniques

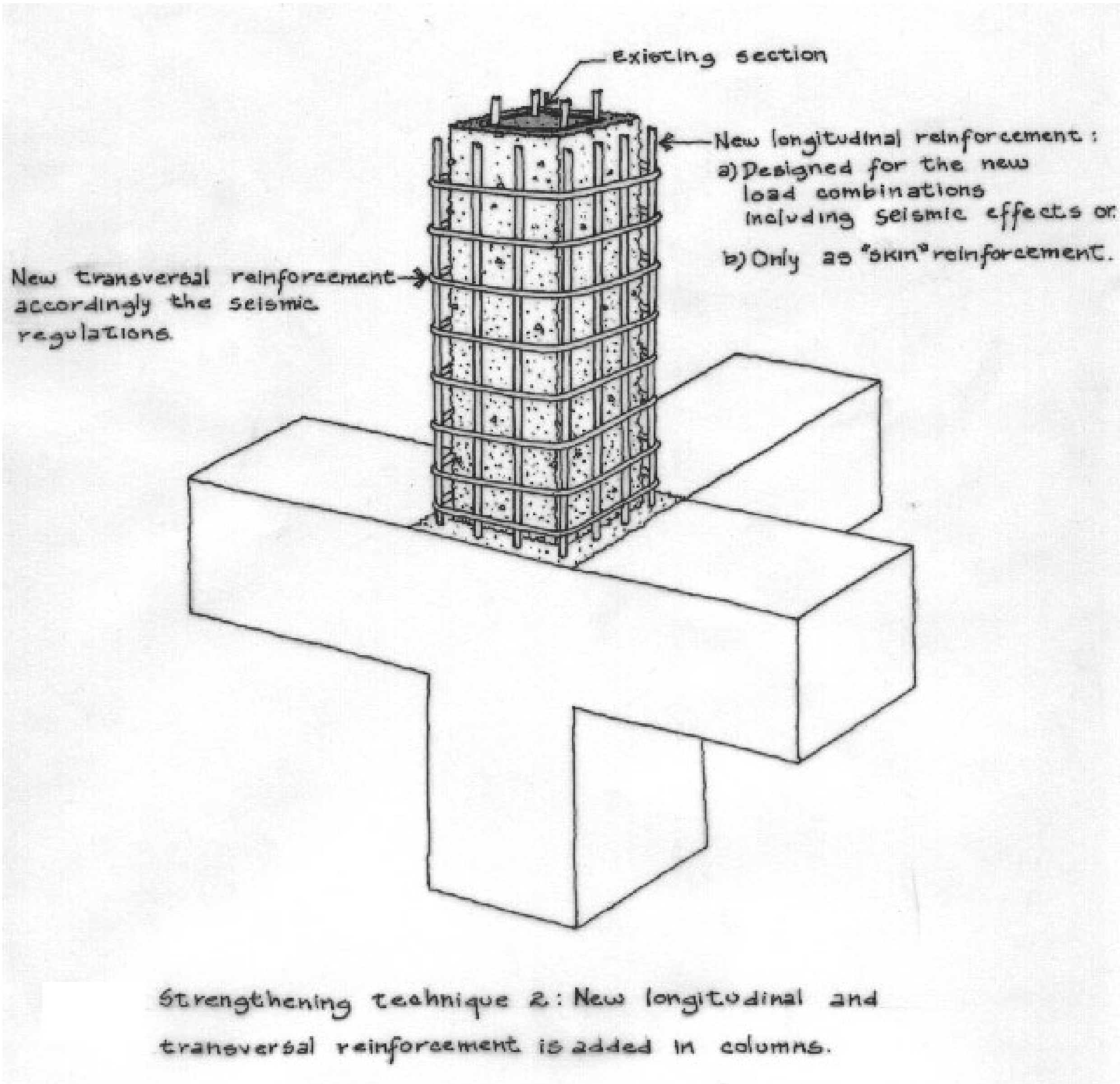

FIGURE 7B: Illustration of Seismic Strengthening Techniques

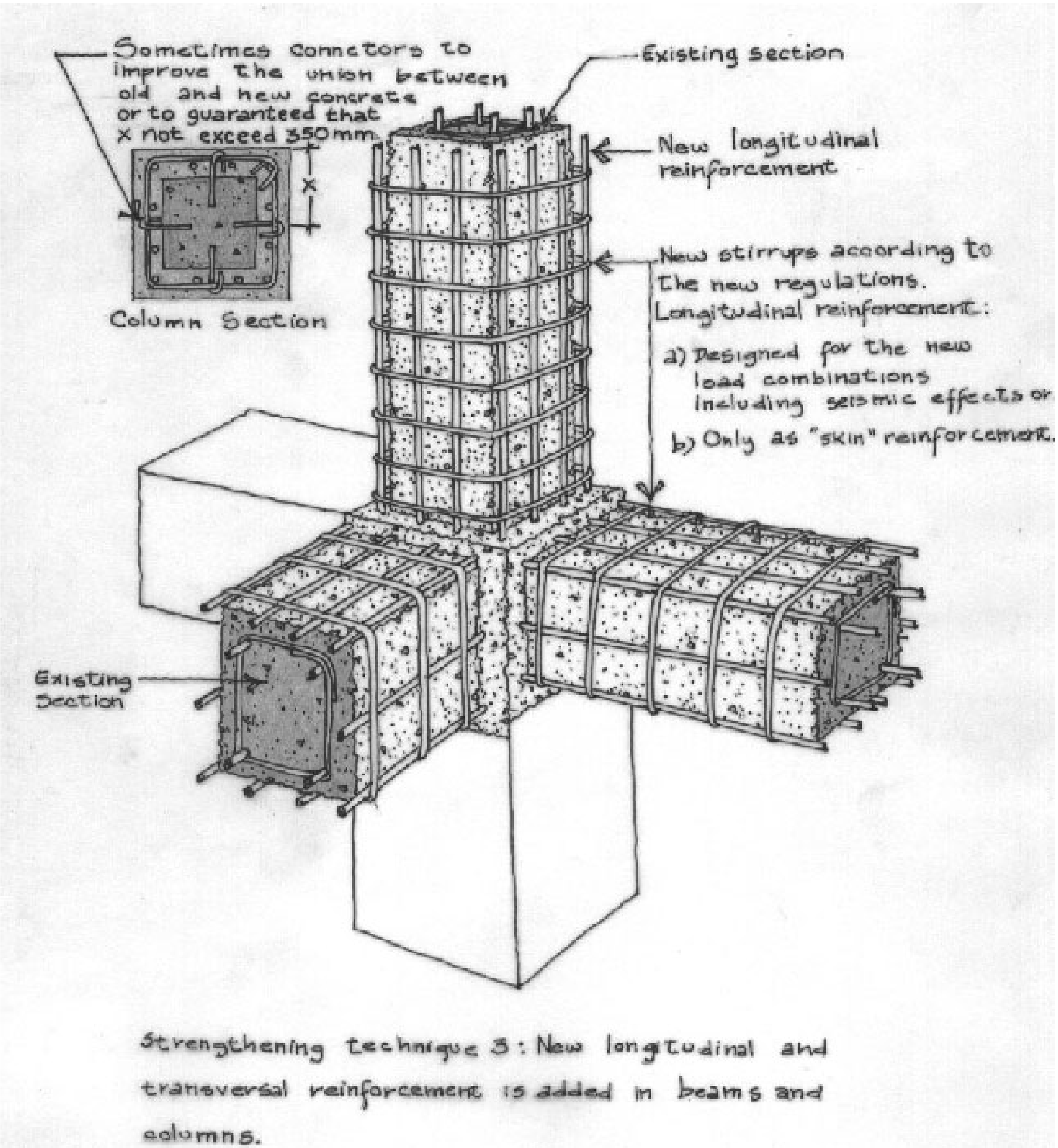

FIGURE 7C: Illustration of Seismic Strengthening Techniques

New added longitudinal and transversal reinforcement

Anchorage of the new longitudinal reinforcement into the foundation

Epoxy injection of the cracks

Extraction of concrete cores

FIGURE 7D: Seismic Strengthening Techniques: Field Implementation

In some cases, new stirrups are installed to reinforce a beam-column joint. In this case, the existing concrete in the joint area must be carefully demolished.

FIGURE 7E: Seismic Strengthening Techniques: Field Implementation