World Housing Encyclopedia Report

Country: Taiwan

Housing Type: Street front building with arcade at the first floor (pre-1970's construction)

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1 General Information

1.1 Country
Taiwan

1.3 Housing Type
Street front building with arcade at the first floor (pre-1970's construction)

1.4 Summary
This building type is common in most Taiwanese cities and townships and it represents a construction practice that had been followed over 30 years ago (pre-1970s) and is no longer used. The main load-bearing structure consists of reinforced concrete frames designed for gravity loads only with brick masonry infill walls. Brick walls were built before the concrete was poured thereby serving as a formwork for concrete. Buildings of pre-1970 construction were characterized with a better bond between the masonry and concrete as compared to the buildings of more recent construction, in which reinforced concrete frames serve as main load-bearing system for lateral and gravity loads (note that the modern construction practice has been described in another contribution by the same authors). Buildings of this type are medium-rise (4 to 5 stories high). Usually, the first floor (typically 4 m high) is used for commercial purposes while the upper stories (typically 2 to 4 stories above, floor height 3 m) are used for storage and residential use. There is an "arcade" at the street level so that people may walk in it to hide from the strong sunlight or rainfall. Neighboring units of a similar design are constructed together to form a shady corridor for pedestrians to walk in. However, neighboring units may not be built at the same time. The number of units connected together varies from 6 to 10. These units may be connected in one row, or in an "L" shape, or in the "U" shape along the street block. There are several structural deficiencies characteristic for this construction: (1) the weak and soft first story because the commercial space demands a large opening at the street level; (2) a typical architectural building layout has walls in one direction only, perpendicular to the street. As a consequence, there are few earthquake-resisting elements in the other direction; (3) extra rooftop additions increase loadings. Building owners also tend to reduce the number of columns for a wider store front view. Many buildings of this type collapsed in the 1999 Chi-Chi earthquake.


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

1.6 Region(s) Where Used

This building type was widespread in almost all the cities and towns on the island.

1.7 Urban vs. Rural Construction

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

2 Architectural Features

2.1 Openings

Walls perpendicular to the street (side walls) are mostly used to separate building units, therefore these walls do not have any openings. Other walls may have openings, but the openings were not the major cause of capacity reduction. Major seismic problems are due to the architectural layout of these buildings, characterized with the total absence of walls or a very few walls in the direction parallel to the street. As a consequence, columns are the only elements resisting earthquake forces in the direction parallel to the street. This structural deficiency has led to a significant damage or even collapse of the columns in the 1999 Chi-Chi earthquake.

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 meters

2.3 Building Configuration

Rectangular shape is most common.

2.4 Building Function

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

2.5 Means of Escape

Usually only one stairway is designed for a housing unit, therefore there is only one means of escape.

2.6 Modification of Buildings

Typical patterns of modification include: additional story/stories were added on roof, demolishing interior wall at the ground floor to be used as a commercial space.

3 Socio-Economic Issues

3.1 Patterns of Occupancy

Usually one family per housing unit

3.2 Number of Housing Units in a Building

10 units in each building.

Additional Comments: Number of housing units varies from 6 to 10.

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		
10-20	X	
> 20		
Other		X

Additional Comments: Other - more than 50. Grandparents and parents may live with two or three children in the same unit. Also rooms may be rented to tenants for extra income.

3.4 Number of Bathrooms or Latrines per Housing Unit

Number of Bathrooms: 2
Number of Latrines: 0

Additional Comments: There are 2 - 3 bathrooms in housing unit.

3.5 Economic Level of Inhabitants

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

Additional Comments: Varies, according to locations. Typical annual income for a middle class family in Taiwan ranges from $US 25,000 to $US 60,000.

3.6 Typical Sources of Financing

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

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

The main structural system for these buildings consists of RC frames built around brick masonry walls. Brick walls, usually 240 mm thick, were laid before the concrete was poured and were tightly connected to the adjacent concrete members. These brick walls are characterized with a good bond with RC members and they act integrally with RC members in resisting seismic forces. Columns are able to carry gravity loads only due to their rather small dimensions and the lack of seismic detailing in the reinforcement. At the time of original construction, column strength was not taken into account in the seismic design. In the later period (post-1980s) the RC frames were built as main load-bearing structures for lateral and gravity loads and the walls were built as infill after the frame construction was completed. Buildings of pre-1970 construction were characterized with a better bond between the masonry and concrete as compared to the buildings of more recent construction.

Wall layout is a critical factor that influences the seismic resistance of these buildings.

In each housing unit, two end walls separate different units, most of the walls run only perpendicular to the street. Such structural characteristics make these buildings very strong for the seismic effects in the wall direction (perpendicular to street). However, due to the lack of lateral load-resisting elements in the other direction (parallel to the street), seismic resistance of these buildings is inadequate.

In some buildings, there are walls parallel to the street direction because of the layout of stairways as shown in Figure 2B. These buildings have demonstrated better seismic performance, as observed in the 1999 Chi-Chi earthquake.

4.2 Gravity Load-Bearing Structure

Floor weight on different stories is transferred to solid RC floor slabs, usually 120 mm thick, which are supported by RC beams (usually 600 to 800 mm deep and 400 mm wide). Loads are transferred from the beams to the brick walls, usually 240 mm thick. The width of RC columns was often equal to the wall thickness (240 mm), such that the columns could appear as if they are "hidden" in the walls, whereas the column depth was on the order of 500 mm. The foundations are mostly isolated (spread) footings connected with tie-beams. In general, deformed steel reinforcement has been used for the improved bond properties between the concrete and steel. Transverse reinforcement in the columns is usually spaced at 300 mm on centre. The reinforcement bars are usually terminated under the beam-column connection. Longitudinal reinforcement ratio in columns varies from 1 to 2.9 %, depending on the design or building height. Concrete strength varies from 10 to 20 MPa and was mostly mixed on site. Reinforced concrete slabs were cast monolithically with the beams and columns. As a result, honeycombing can be observed on the column surface if concrete was not sufficiently vibrated during the construction.

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		
Structural Concrete	Solid slabs (cast in place or precast)	X	X
	Cast in place waffle slabs		
	Cast in place flat slabs		
	Precast joist system		
	Precast hollow core slabs		
	Precast beams with concrete topping		
	Post-tensioned slabs		
Steel	Composite steel deck with concrete slab		
Timber	Rammed earth with ballast and concrete or plaster finishing		
	Wood planks or beams with ballast and concrete or plaster finishing		
	Thatched roof supported on wood purlins		
	Wood 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		
	Wood plank, plywood or manufactured wood panels on joists supported by beams or walls		
Other			

4.6 Typical Plan Dimensions

Length: 10 - 10 meters
Width: 10 - 10 meters

4.7 Typical Number of Stories

4 - 5

4.8 Typical Story Height

3 meters

Additional Comments: 4 m at the first floor and 3 m for upper stories

4.9 Typical Span

4.5 meters

4.10 Typical Wall Density

The wall density perpendicular to the street direction at the first floor is approximately 5%. Parallel to the street direction, it may range from 0.3% to 1%.

4.11 General Applicability of Answers to Questions in Section 4

This contribution is not based on a case study of one building.

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
Wall	-Unreinforced brick masonry walls are laid out in one direction only, resulting in the increased vulnerability in the other direction due to the absence of vertical elements of lateral-load resisting system, as illustrated in Figure 2A.		In a major earthquake (of intensity similar to or larger than the design level earthquake), collapse of buildings is expected to take place due to the lack of structural strength in the weak direction.
Frame (columns, beams)	- Column reinforcement is usually spliced at the top of the slab where the column bending moments are the largest (see Figure 4). As a result of this poor construction practice, seismic capacity of the columns is largely reduced. Majority of the buildings that collapsed in the Chi-Chi earthquake were constructed this way. - Lack of the 135 degree stirrup hook was another major defect in building construction (see Figure 5b). - Widely spaced column ties, usually spaced at 300 mm on centre which is less than the current code requirement for ductile columns that prescribes 100 mm c/c tie spacing for columns end zones. (see Figure 5a)		Collapsed columns
Roof and floors	No major deficiencies		
Building Configuration	The open front at the bottom story is the most obvious configuration irregularity characteristic for this construction type. This feature creates undesirable soft-story and torsional effects, as illustrated in Figure 5A (Source: EERI 2001).		Extensive damages and building collapses due to the large demands on the bottom story columns caused by soft story and torsional effects (see Figure 6A)

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)
2001	Taipei	6.8	
1999	Chi-Chi, Taiwan	7.3	X

<u>Additional Comments:</u> Although many buildings of this construction type sustained significant damage in the 1999 Chi Chi earthquake, most of them performed satisfactorily. Earthquake damages are illustrated in Figure 6A. The main causes for damage observed after the earthquake are (EERI, 2001): 1) Poor configuration attributable to the open front combined with inadequate column lateral reinforcement (ties). The large displacement demands from the soft-story and torsional effects often damaged the plastic hinge regions of the columns at the open front. All damaged columns were observed to have non-ductile confinement reinforcement details consisting of widely spaced horizontal hoops, more than 300 mm apart, and 90 degree hooks. Usually, the lack of confinement reinforcement in the plastic hinge regions resulted in brittle failure. In some cases, hinge rotation caused buildings to permanently lean out of plumb. In other cases, buildings with no signs of earthquake damage remained standing next to the seemingly identical buildings that sustained the total collapse of entire bottom stories. 2) There was also widespread damage to the unreinforced brick partitions and perimeter walls. Although partitions are usually considered nonstructural elements, the collapse of or damage to unreinforced brick partitions represents a significant falling hazards, and it forced many people out of their homes. 3) Performance of this construction type in the earthquake was significantly influenced by the infill wall layout. Because brick infills significantly influence the structural characteristics and yet are not considered in the design, the seismic performance of this building type is highly unpredictable. A five-story building of this construction type (constructed in the early 1970's) collapsed in the March 31, 2002 Taipei earthquake. The bottom two stories were flattened in the earthquake. Fortunately no one died in this building owing to the quick response of the rescue team established after the 1999 Chi-Chi earthquake in central Taiwan. According to a local newspaper, a garage shop purchased several units at the first floor. The first floor walls were torn down to satisfy the spatial needs of a garage. As a result, a weak story formed and the building leaned forward and collapsed in the first few seconds in the earthquake.

7 Building Materials and Construction Process

7.1 Description of Building Materials

Structural Element	Building Material	Characteristic Strength	Mix Proportions/ Dimensions	Comments
Walls	Brick wall	Compression:130 kg/cm² Tension: 37 kg/cm²	5 X 11 X 23 cm	
Foundations	Reinforced Concrete	fc'= 175 kg/cm² fy= 2800 kg/cm²	1:2:4	
Frame	Reinforced Concrete	fc'= 175 kg/cm² fy= 2800 kg/cm²	1:2:4	
Roof and floors	Reinforced Concrete	fc'= 175 kg/cm² fy= 2800 kg/cm²	1:2:4	

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

It is mostly built by developers. Builders do not necessarily live in these buildings.

7.3 Construction Process

The brick walls were constructed first, and RC frames were subsequently constructed around the brick walls. The brick walls, zigzagged at edge, served as a form for RC columns. As a result of concrete shrinkage after the concrete was cast, the brick walls were firmly enclosed in the RC frame. This has resulted in a very good bond between the frame and the brick wall.

7.4 Design/Construction Expertise

Due to the absence of major earthquakes before the 1999 Chi-Chi earthquake in Taiwan, contractors were reluctant to spent extra workmanship in the seismic detailing. Therefore in most of the construction sites, seismic detailing for RC structure is insufficient.

7.5 Building Codes and Standards

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

Title of the code or standard: Building construction technique code in 1974 first addressed the seismic force and wind force for building design.
Year the first code/standard addressing this type of construction issued: 1974
When was the most recent code/standard addressing this construction type issued? 1998

7.6 Role of Engineers and Architects

All buildings in Taiwan need the signature of a registered architect before government approval is granted. However, some architects may not have adequate knowledge for the latest development in seismic design.

7.7 Building Permits and Development Control Rules

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

7.8 Phasing of Construction

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

7.9 Building Maintenance

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

7.10 Process for Building Code Enforcement

Building permits are granted after the architectural drawings are reviewed to satisfy building codes. Construction work proceeds afterwards. At this stage, the design architect is usually responsible for monitoring whether appropriate construction methods and materials were used. After the construction work is finished, government official will inspect the building to ensure that everything is built to the design drawings before building permit is issued.

7.11 Typical Problems Associated with this Type of Construction

Some architects may not fulfill their duty in controlling the construction quality, especially when the contractors do not consider seismic detailing.

8 Construction Economics

8.1 Unit Construction Cost (estimate)

To include the material (for all the structural and nonstructural components) and labor: 75 US$/m² (for currency at the time of the original construction)

8.2 Labor Requirements (estimate)

Usually, it takes 10 days to build one story (structural part only), including the bar installation, forming, and pouring of concrete.

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

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

10 Seismic Strengthening Technologies

10.1 Description of Seismic Strengthening Provisions

Type of intervention	Structural Deficiency	Description of seismic strengthening provision used
Retrofit (Strengthening)	Absence of walls at the ground floor level in the direction parallel to the street	- Installation of new walls near the rear door or staircase to increase seismic strength in the direction parallel to the street, as illustrated in Figure 7. - Installation of new steel braces.
	Weak columns	-Steel jacketing or fiberwrap

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

It is generally accepted by builders. However, recent economic downturn may weaken the will to retrofit.

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

Both

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

Less stringent in retrofit work

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

Contractors performed retrofit construction. Only small percentage of the work involved architects or engineers.

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

Yet to be discovered by the next major earthquake.

11 References

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12 Contributors

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13 Figures

FIGURE 1: Typical Building

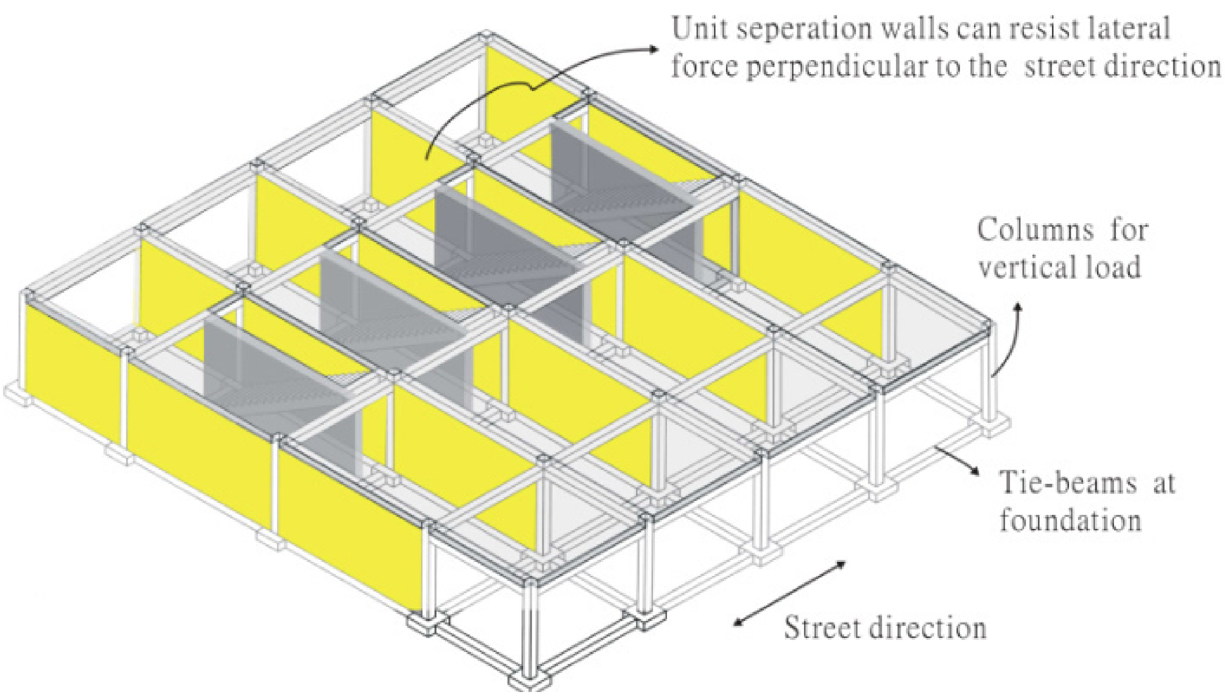

FIGURE 2A: Key Load-Bearing Elements

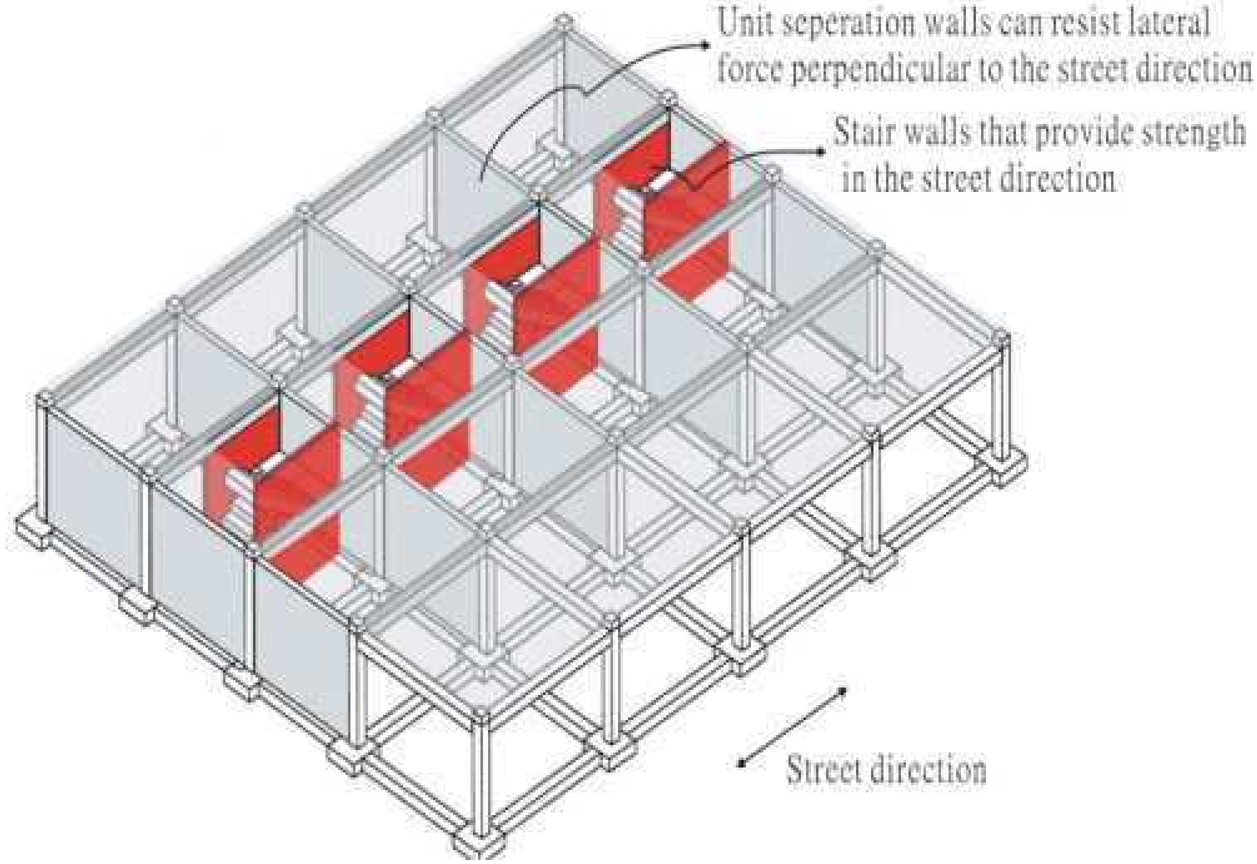

FIGURE 2B: Key Loadbearing Elements - Wall Layout in the Street Direction

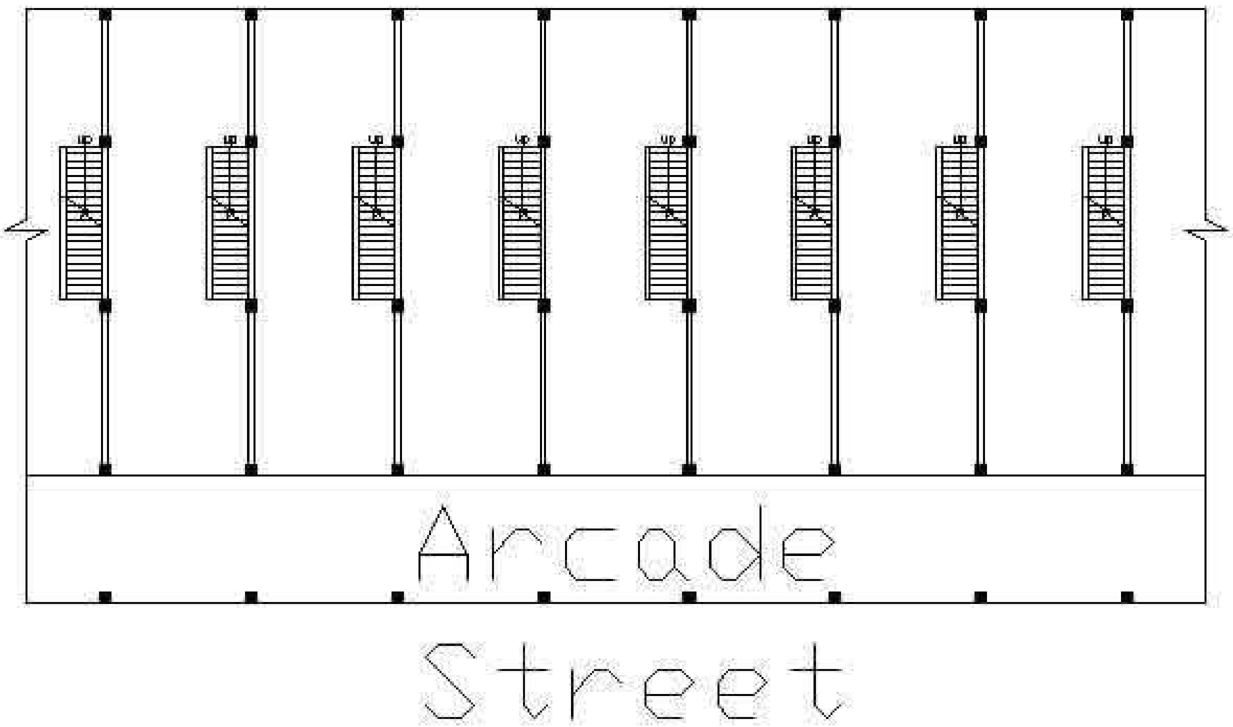

FIGURE 3A: Plan of a Typical Building

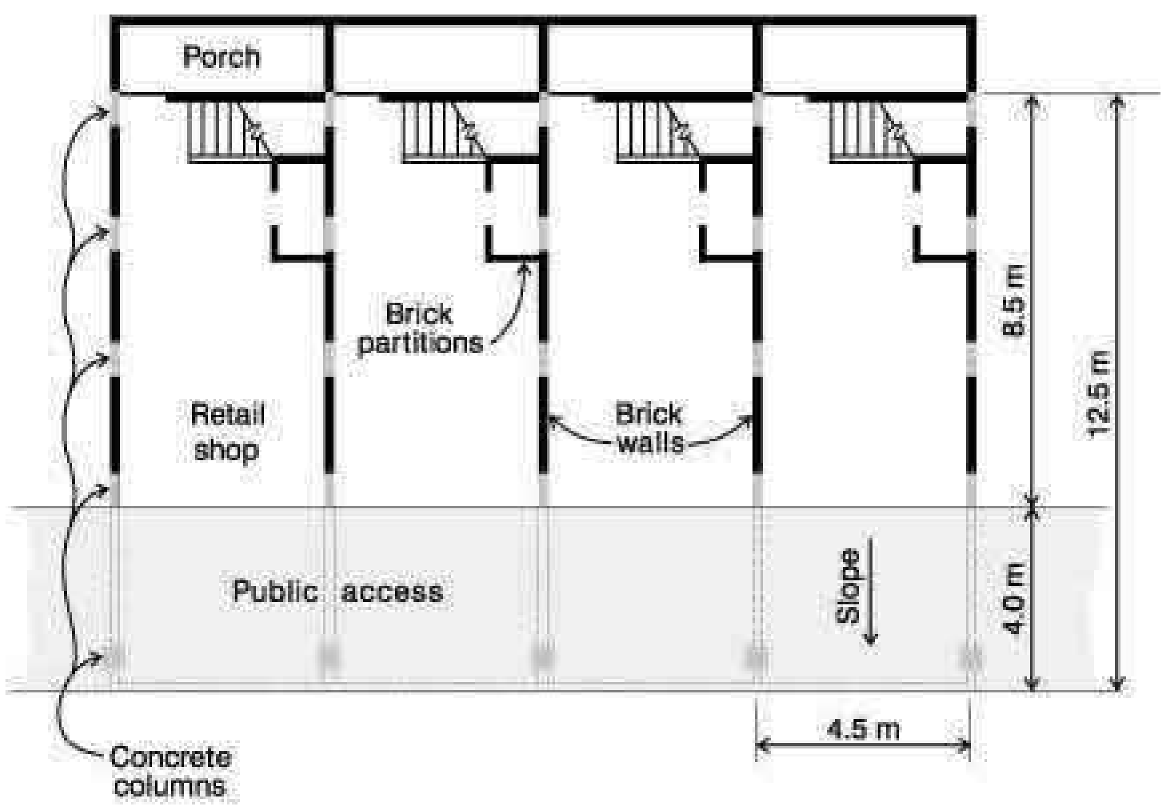

FIGURE 3B: Plan of a Typical Building - Ground Floor Level (Source: EERI 2001)

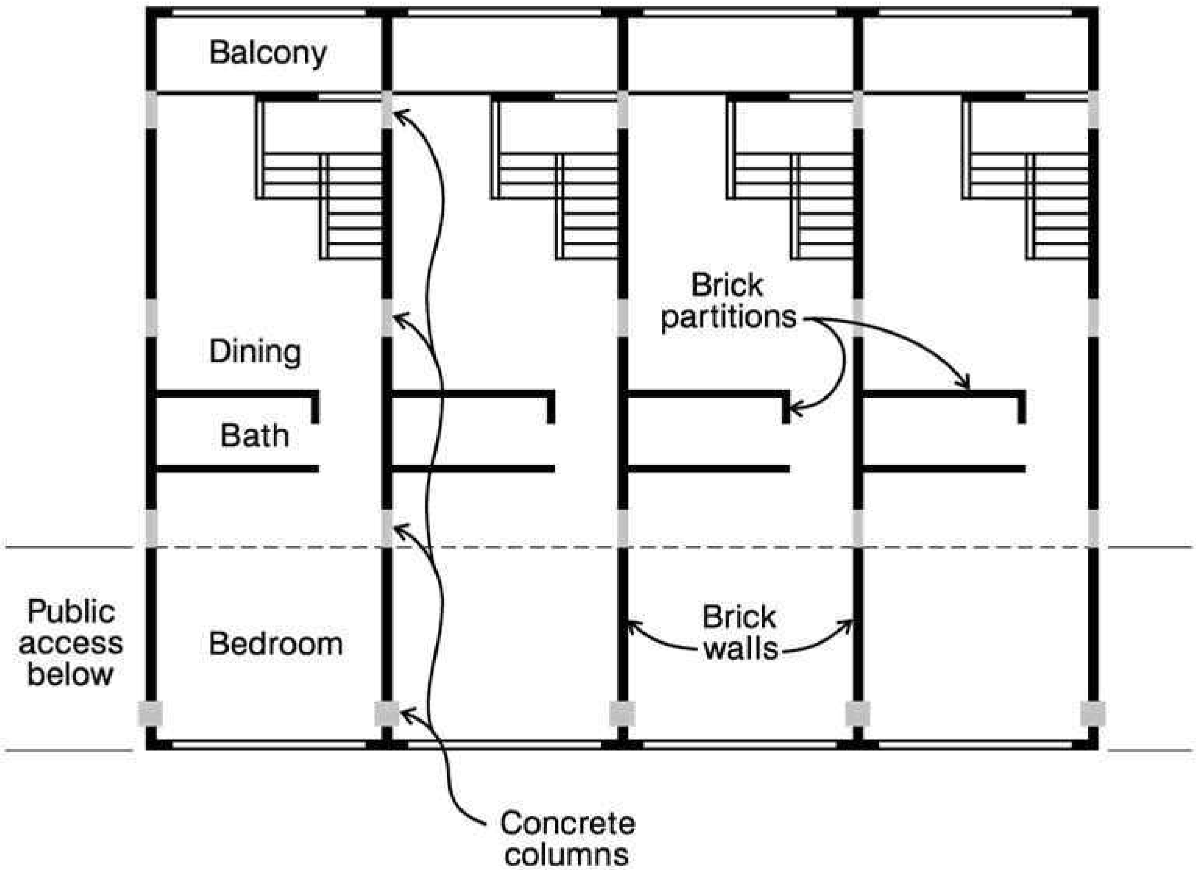

FIGURE 3C: Plan of a Typical Building - Upper Floor Levels (Source: EERI 2001)

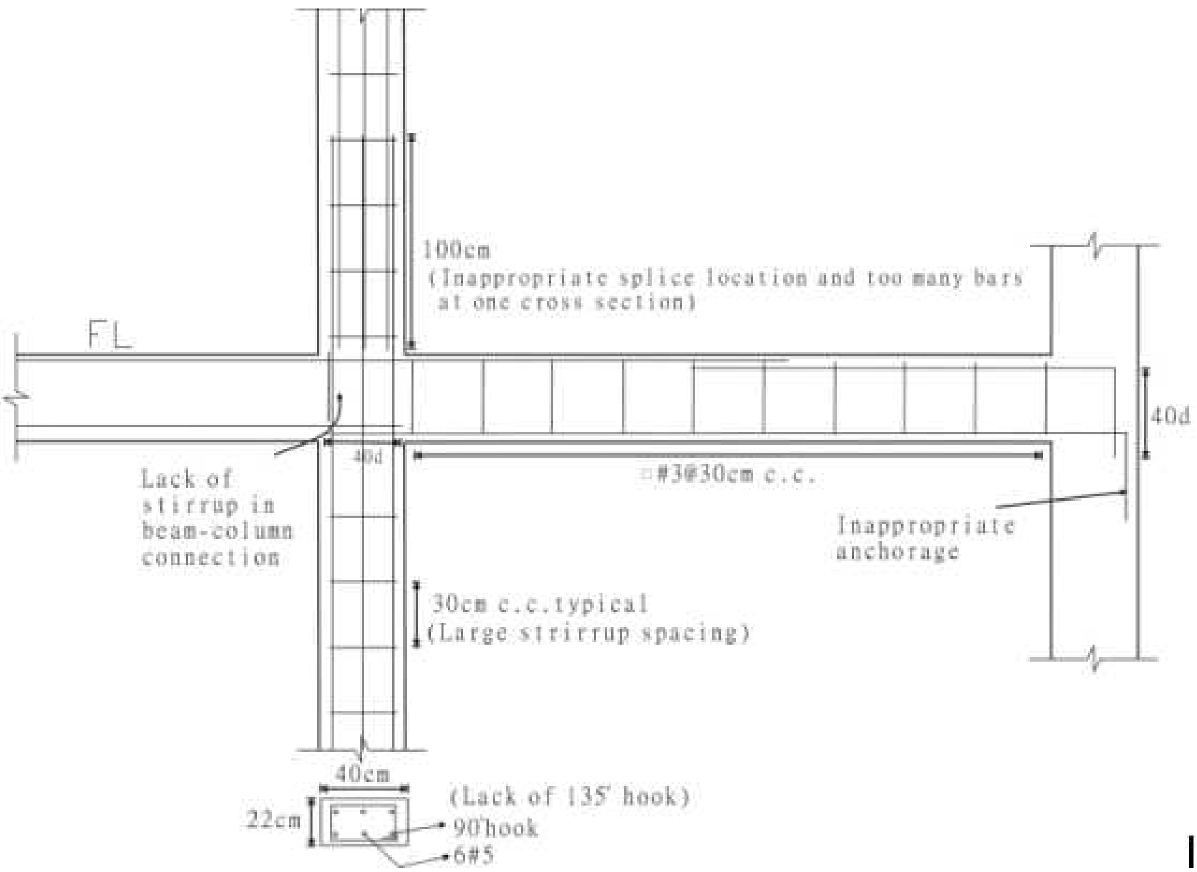

FIGURE 4: Critical Structural Details - RC Frame Reinforcement Details

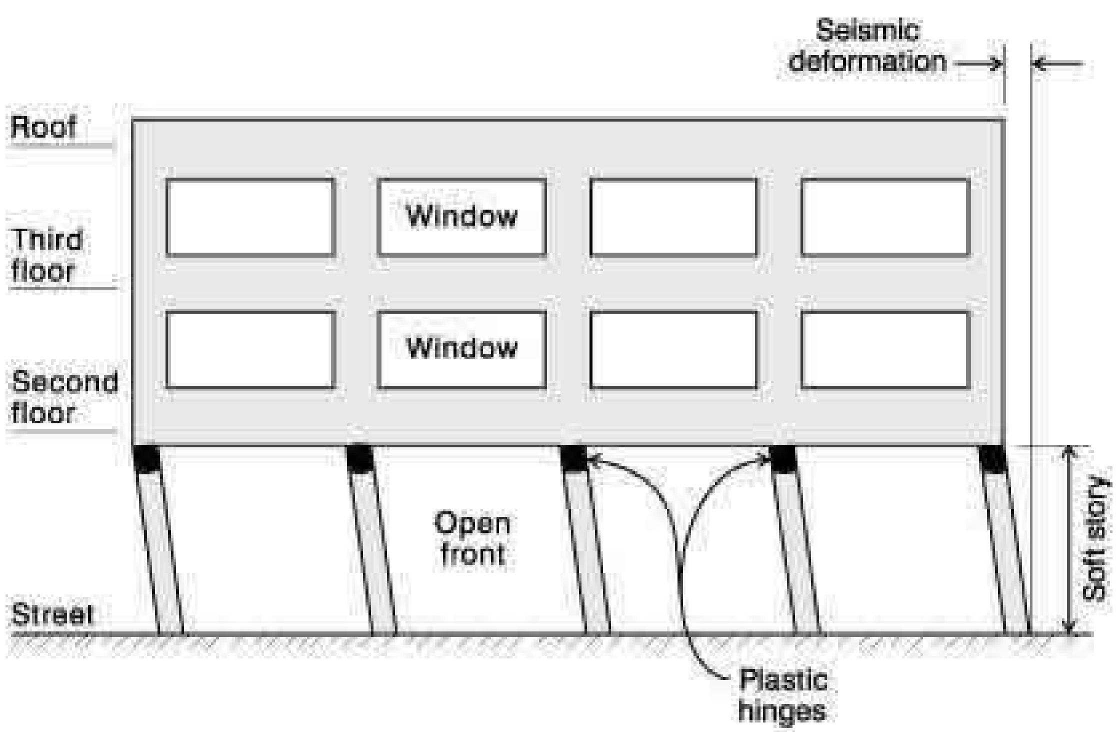

FIGURE 5A: Seismic Deficiency: Soft-story deformation of open front at the street level

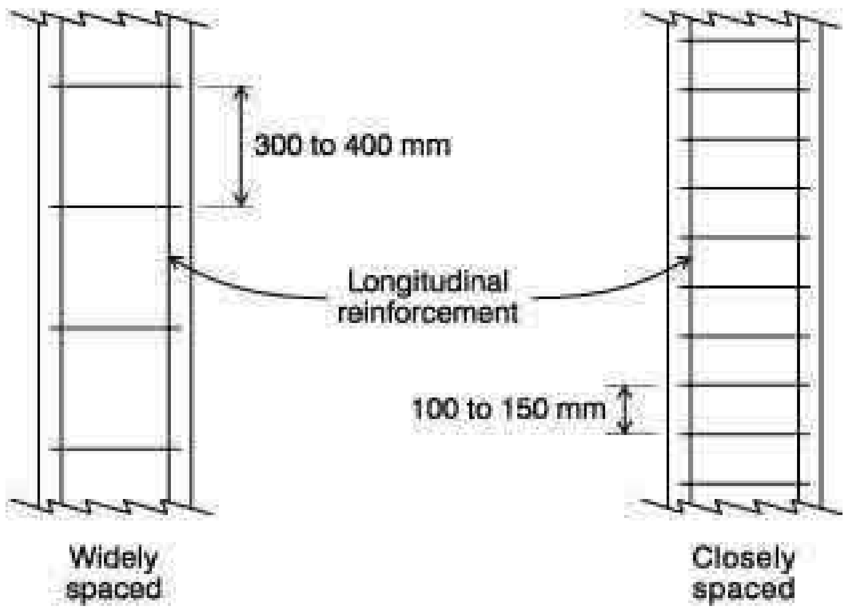

FIGURE 5B: Seismic Deficiency - Widely spaced hoop reinforcement (Source: EERI 2001)

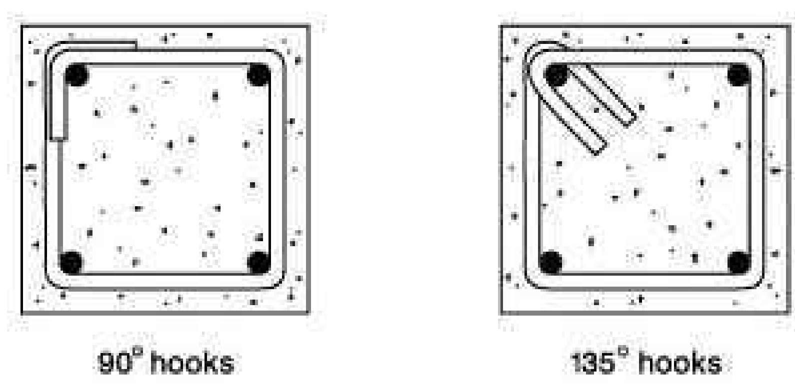

FIGURE 5C: Seismic Deficiency : Column ties -90 degree hooks were used instead of 135 degree hooks (Source: EERI 2001)

FIGURE 6A: A Photograph Illustrating Typical Earthquake Damage (1999 Chi Chi earthquake)

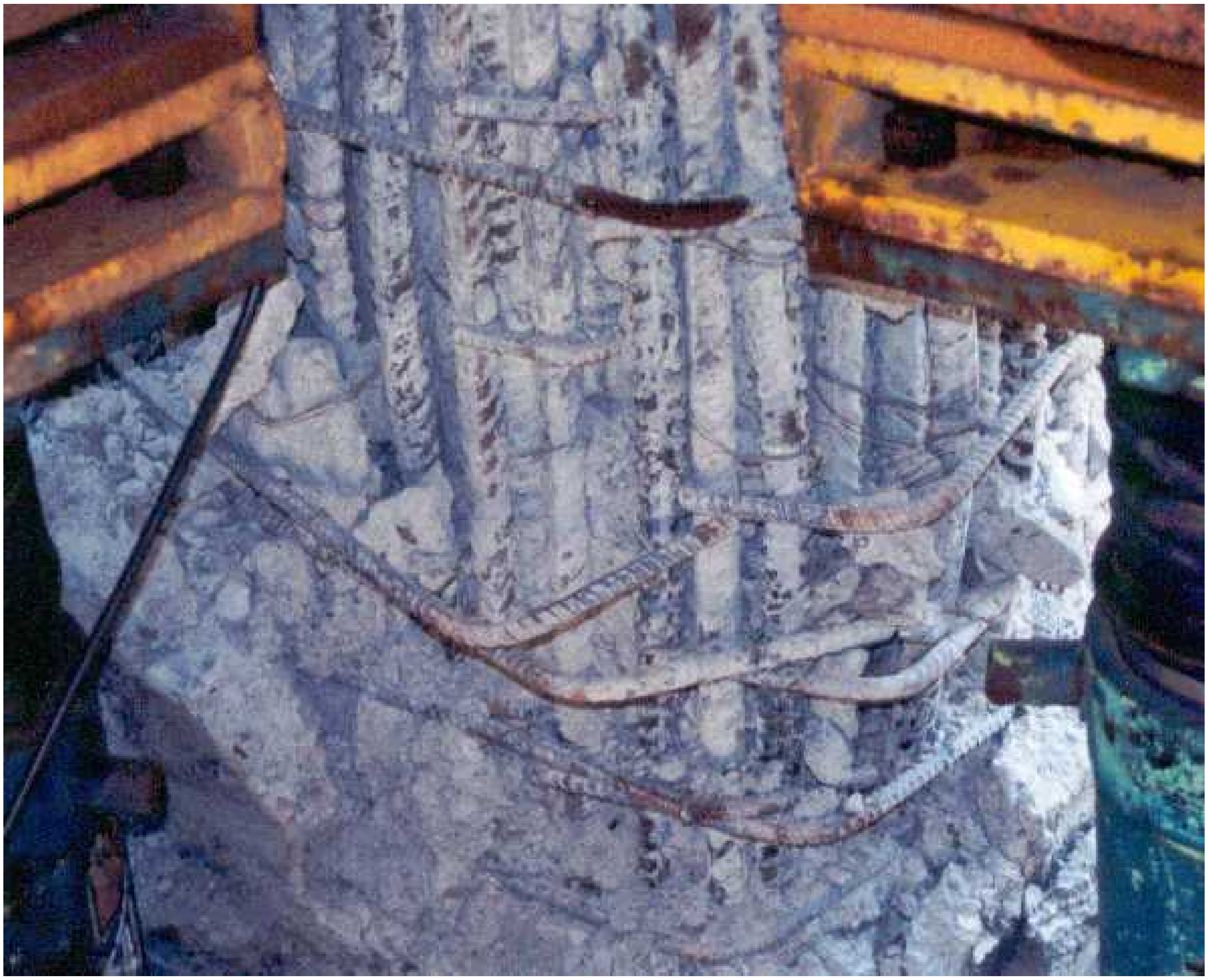
FIGURE 6B: Earthquake Damage - Opening of 90 degree column hooks in the 1999 Chi Chi earthquake (Source: EERI 2001)

FIGURE 6C: Earthquake Damage - Collapse of a 5-story building in the March 31, 2002 Taipei earthquake

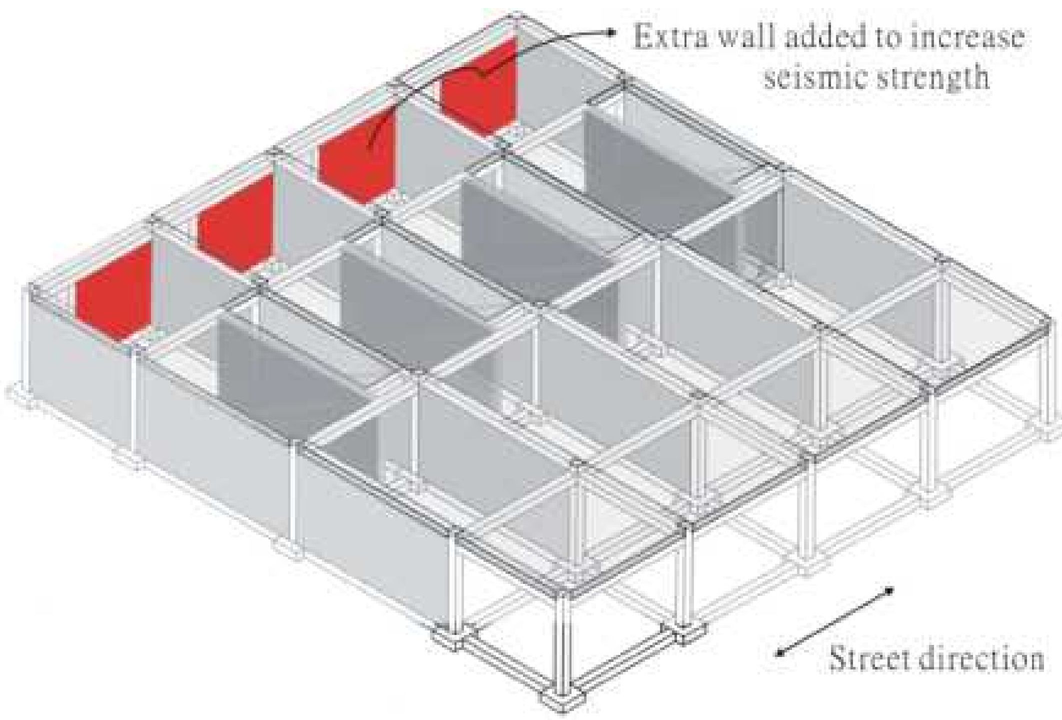

FIGURE 7: Illustration of Seismic Strengthening Techniques