World Housing Encyclopedia Report

Country: Taiwan

Housing Type: High-rise reinforced concrete buildings with open space at the ground floor.

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1 General Information

1.1 Country
Taiwan

1.3 Housing Type
High-rise reinforced concrete buildings with open space at the ground floor.

1.4 Summary
This is an urban housing construction. Typically, these are 12-story high apartment buildings with a basement used for parking. The first and second floor are classified as Open Space (OS) and the ground floor is used as gardening area and for leisure and social gathering of the residents. In 1984, the Taiwanese government enacted a law to encourage building owners to construct OS buildings which demanded first floor height be at least 5 meters. The owners in return were awarded with extra floor area. As a result, many buildings were built with the OS at the ground floor. The common features in these buildings are:

1. The bottom two floors were designed for the OS with a net height approximately 7.6 meters.
2. There are a lot of walls above the third floor in both horizontal directions but very few walls at the OS except the elevator shaft and the stair cases. If the elevator is located on the edge of the building plan, torsional effect may be present.
3. Architects tend to design zigzag floor plans for these buildings in order to maximize view angle and natural lighting.
4. Very few columns were designed into these buildings in order to maximize parking area at the basement.

The primary load resisting system is reinforced concrete moment resisting frame on a mat foundation. Partition walls are dense at the 3rd floor and above, which leads to a soft-story configuration in the lateral load-resisting system. Many buildings of this type collapsed in the 1999 Chi-Chi earthquake due to the soft story effect caused by the OS design.

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	X
< 50 years	
< 75 years	
< 100 years	
< 200 years	

> 200 years	

Is this construction still being practiced?	Yes	No
	X	

1.6 Region(s) Where Used

The OS buildings were designed and built in both rural and urban area.

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

Most of the buildings are designed to be moment resisting RC frames. This is because of the architectural needs for sun light and ventilation. Usually, an elevator shaft surrounded by a stair case is the only area where a structural wall was designed into a building. Nonstructural exterior/interior walls less than 12 cm thick may be present, but their contribution to strength and stiffness was neglected in the structural design.

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 m is minimum distance and 10 m is maximum meters

2.3 Building Configuration

Floor plan boundaries in this type of building are usually lined up in parallel or zigzagged to obtain largest space for lighting.

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)	

2.5 Means of Escape

Usually there are at least two separate Means of Escape (stairs) per floor in compliance with the national fire code.

2.6 Modification of Buildings

Interior walls in individual apartments may be removed and rearranged to satisfy diverse needs of residents. Sometimes the open first storey area may be altered to suit different usage requirements legally or illegally.

3 Socio-Economic Issues

3.1 Patterns of Occupancy
Usually two to four family occupy a typical floor.

3.2 Number of Housing Units in a Building
20 units in each building.

Additional Comments: As a rule there are 10-30 housing units in the one building

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

3.4 Number of Bathrooms or Latrines per Housing Unit
Number of Bathrooms: 2
Number of Latrines: 2

3.5 Economic Level of Inhabitants

Economic Status		House Price/Annual Income (Ratio)
Very poor		/
Poor		/
Middle Class	X	240000/30000
Rich		/

Additional Comments: Price of housing is much higher in the capital Taipei.

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 primary load resisting system is RC moment resisting frame on a mat foundation. There are usually no walls in the OS and basement, whereas partition walls are dense at the 3rd floor and above, which leads to a soft-story configuration in the lateral load-resisting system.

4.2 Gravity Load-Bearing Structure

At the first floor and the basement, usually columns are sole structural members to transfer vertical loads. In many cases, only four columns are present at the first floor. As a result, columns are designed with high percentage of reinforcement and high strength concrete , however, the construction quality may not meet designer's original intent.

Columns are usually 70 X 70 cm and beams are 50 X 70 cm. Slabs are 12 cm thick. In design the compressive strength of concrete is usually taken as 2800 N/cm^2, however, the actual strength may be even less than 2100 N/cm^2.

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)	
		15	Designed with seismic features (various ages)	X
		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	
	Reinforced concrete strip footing	
	Mat foundation	X
	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
12 - 20

4.8 Typical Story Height
3 meters

Additional Comments: The ground storey is usually 4.6 meter.

4.9 Typical Span
8 meters

Additional Comments: Typical Span has value with limits of 7.5 m -10 m.

4.10 Typical Wall Density
At the ground floor: 0.9%. Upper stories : 6%

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	Discontinuous at the ground floor		
Frame (columns, beams)	Inadequate strength and redundancy		Failure of columns in open storey leads to a total collapse
Roof and floors			

Additional Comments: Columns usually are designed with large percentage of longitudinal reinforcement. At the construction site, if mechanical fasteners were not instead of splicing bars, the congested bars usually are not adequately bonded to surrounding concrete. Another construction deficiency commonly found was the negligence of the 135 degree hook for stirrups. As a result, no appreciable ductility in columns was observed in the 1999 Chi-Chi earthquake.

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	Chi-Chi, Taiwan	7.3	

7 Building Materials and Construction Process

7.1 Description of Building Materials

Structural Element	Building Material	Characteristic Strength	Mix Proportions/ Dimensions	Comments
Walls	RC	fc=2800 N/cm², fy=42000 N/cm²	mostly from plant	
Foundations	RC	ditto		
Frame	RC	ditto		
Roof and floors	RC	ditto		

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 who do not necessarily live in the building.

7.3 Construction Process

A contractor is usually hired to do the construction work. Concrete is mostly purchased from premix plants and steel reinforcement cage is assembled on the site. Columns, beams, walls, and slab are usually poured together. Infill walls inside an apartment unit can be brick masonry which is laid after the structure is completed. RC partition walls are cast together with the structure itself.

7.4 Design/Construction Expertise

Structural designers usually rely on computer software for the analysis. The designer must be government certified for which they clear a national exam. He/she is expected to use the latest technology to perform structural design.

However, it was found that some designers may use a 2D instead of a 3D analysis. Driven by the free market competition, some designers even deliberately choose to reduce design load estimates to have a less expensive structure. As a result, many of these buildings collapsed in the 1999 Chi-Chi earthquake and erring designers were prosecuted.

In theory, all contractors must hire at least a licensed Civil Engineer, Structural Engineer, or Architect to ensure the quality of construction. However, a few contractors may be willing to hire a professional on paper only and do not consult their expert advice in construction work.

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 Technical Code of the Republic of China.
Year the first code/standard addressing this type of construction issued: 1974
When was the most recent code/standard addressing this construction type issued? 1999

7.6 Role of Engineers and Architects

Architects hired by developers usually have little to do with the overall building geometry because developers have already decided the most profitable building layout based on their market survey. As a result, the OS soft-story structural systems are developed early in the planning stage before an architect is hired.

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

Architects design a building and submit the drawings to the concerned government agency which verifies for the compliance of all safety rules required in the design. A construction permit is issued after the government agency is satisfied that all rules are met. A contractor can then start construction work under the supervision of the design architect. Contractors by law should hire licensed engineers to guarantee construction quality. But some of them follow the law only on paper and have a poor construction quality. Architects always have difficulty in checking all the construction details which often leads to a large number of disputes. After the construction work is completed, a government official will inspect the new building to check the overall appearance of the building, and make sure the application forms for building permits are stamped by both the architect and the contractor's engineer. If all items are satisfactory, a building permit will be issued to the building owner.

7.11 Typical Problems Associated with this Type of Construction

A developer may have his own construction company, which can construct the new building. In this case, a developer- hired supervising architect will have difficulty in maintaining the quality of the construction work. If the contractor is different from the developer's firm, the architect may not come to the construction site as often as needed. This also has a serious effect on the construction quality.

8 Construction Economics

8.1 Unit Construction Cost (estimate)

500 US$/$m^2$

8.2 Labor Requirements (estimate)

450 days for a 12-story building.

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)	Soft and weak first open story	Steel or RC brace or RC shear walls may be added to strengthen the ground story. Beams and horizontal bracings may be added on the column mid- height of the OS buildings at the first floor.
	Weak columns	FRP, CRP, or steel plates may be added to strengthen column capacity

10.2 Has seismic strengthening described in the above table been performed in design practice, and if so, to what extent?
It has adopted in a few buildings undergoing seismic strengthening.

10.3 Was the work done as a mitigation effort on an undamaged building, or as repair following earthquake damage?
In most cases as a part of the repair work. In some undamaged buildings the above technique is also used as a mitigation measure.

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?
Usually a licensed structural engineer will be involved in the design and a contractor will do the construction.

10.6 What has been the performance of retrofitted buildings of this type in subsequent earthquakes?
Not yet tested in real earthquakes. Analytical model studies on added beams or diagonal bracing in the OS area were performed [1]. Reference 1 indicated that adding diagonal bracing at the OS will be the best solution to solve the soft-story effect.

11 References

Su, C.T., Cheng, J.S., and Lu, J.T(2001)Comparison of Seismic Capacity in Different Structural Systems During the 1999 Chi-Chi Earthquake, The Final Report to the Structural Dynamic Course, NCKU Professional Advancement Class.

12 Contributors

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13 Figures

FIGURE 1: Typical Building

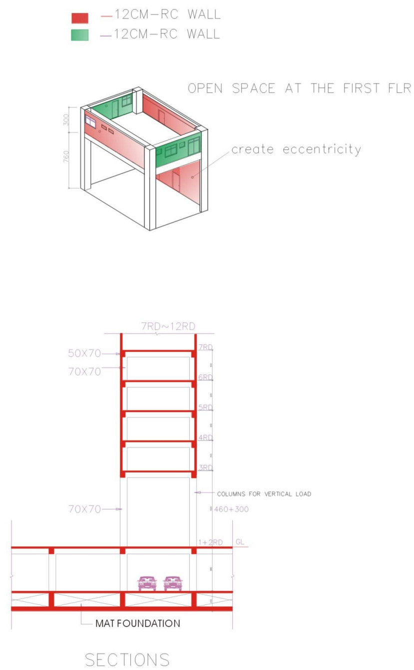
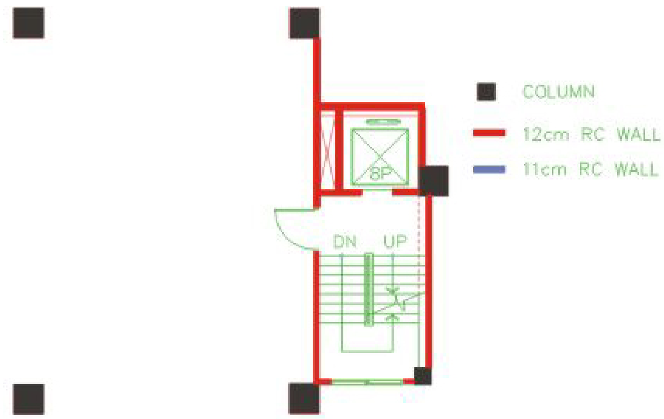
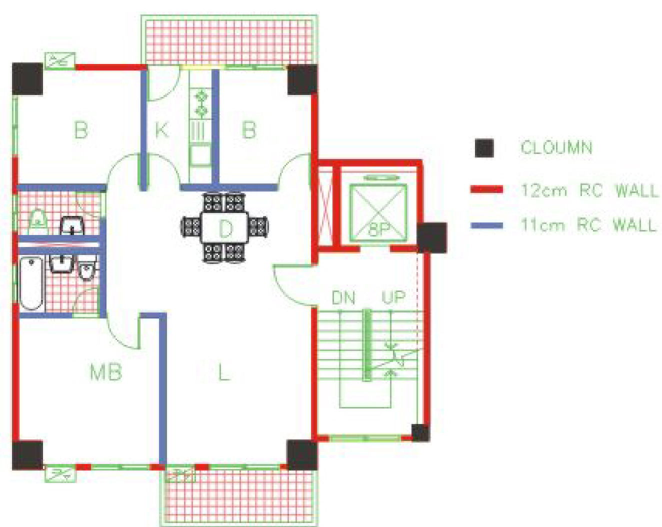


FIGURE 2: Key Load-Bearing Elements



PLAN: 1+2ND LEVEL PLAT



PLAN: 3RD~12TH LEVEL PLAT

FIGURE 3: Plan of a Typical Building

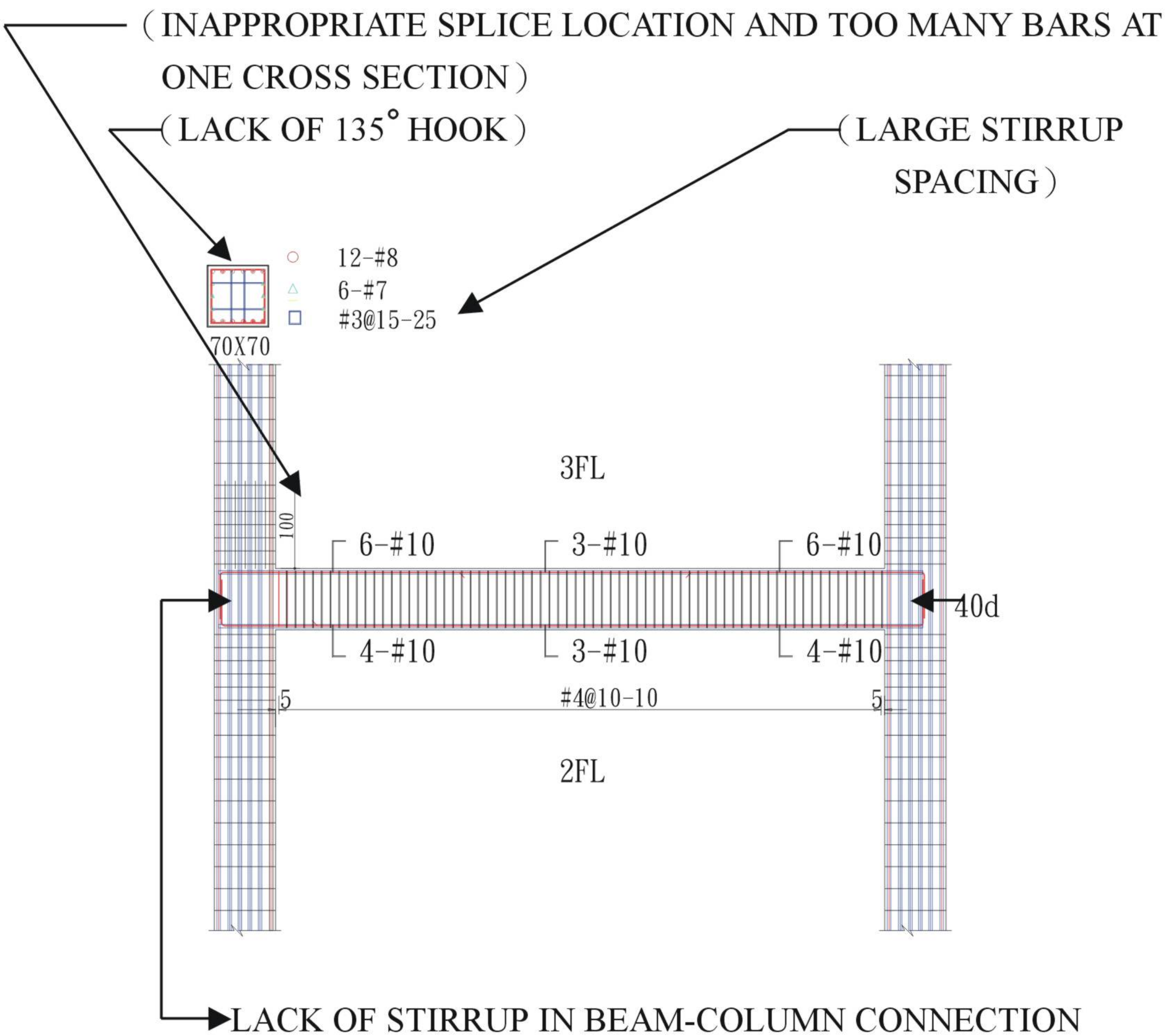


FIGURE 4: Critical Structural Details

FIGURE 5: A Photograph Illustrating Typical Earthquake Damage

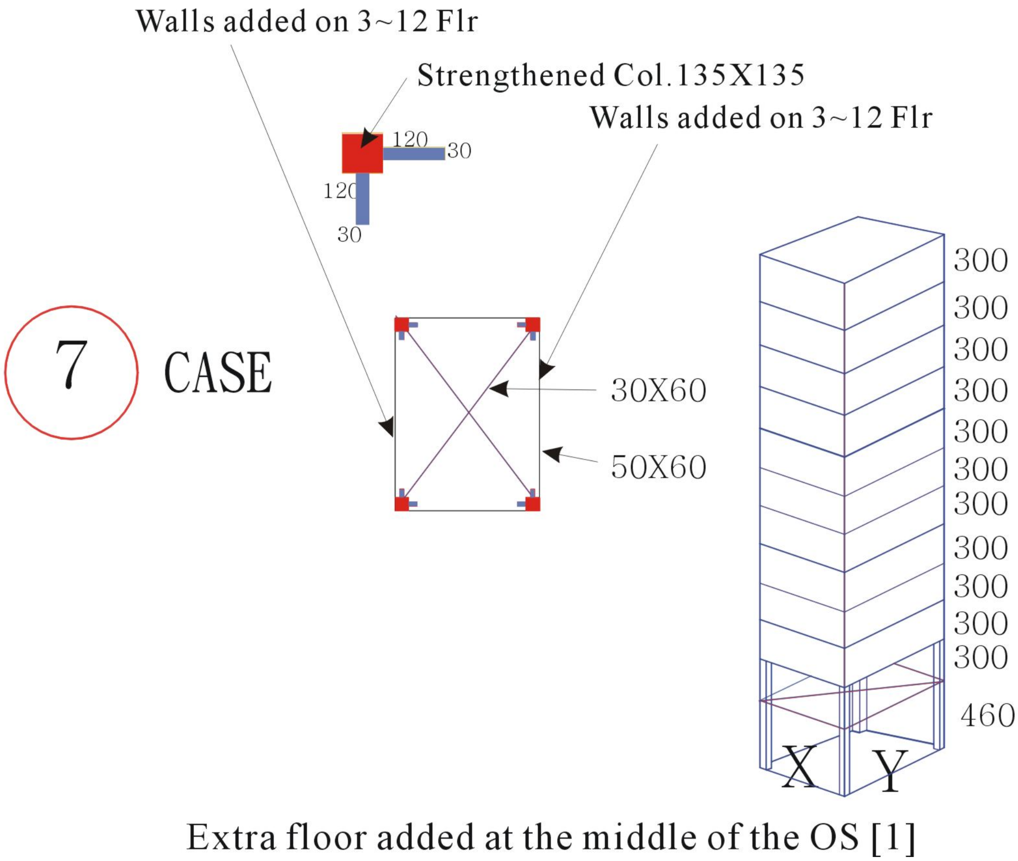


FIGURE 6: Illustration of Seismic Strengthening Techniques