World Housing Encyclopedia

an Encyclopedia of Housing Construction in Seismically Active Areas of the World

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Earthquake Engineering Research Institute (EERI) and
International Association for Earthquake Engineering (IAEE)

HOUSING REPORT
High-rise, reinforced concrete buildings with open space at the ground floor

Report #	63
Report Date	05-06-2002
Country	TAIWAN
Housing Type	RC Moment Frame Building
Housing Sub-Type	RC Moment Frame Building : Designed for seismic effects, with URM infills
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Summary

This is an urban housing construction. Typically, these are 12-story apartment buildings with a parking area in the basement. The first and second floor are classified as Open Space (OS) and the ground floor is used by the residents for gardening and for leisure and social gatherings.

The common features in these buildings are: (1) The two lower floors were designed for the OS with a net height of approximately 7.6 meters. (2) There are many walls above the third floor in both horizontal directions but very few walls on the OS except around the elevator shaft and the staircases. If the elevator is located at the corner of the building, 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 the parking area on the basement level. The primary load-resisting system is reinforced concrete moment-resisting frame on a mat foundation. The fact that the partition walls are dense at the third floor and above, creates 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.

1. General Information

Buildings of this construction type can be found in in both rural and urban areas. This type of housing construction is commonly found in both rural and urban areas. This construction type has been in practice for less than 25 years.

Currently, this type of construction is being built. .

Figure 1: Typical Building

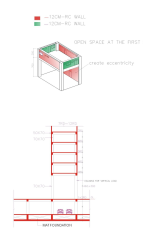


Figure 2: Key Load-Bearing Elements

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They do not share common walls with adjacent buildings. When separated from adjacent buildings, the typical distance from a neighboring building is 10 meters.

2.2 Building Configuration

Floor plan boundaries in this type of building are usually lined up in a parallel or zigzag manner to maximize lighting space. To satisfy the need for sunlight and ventilation, most of the buildings have been designed as moment-resisting RC frames. Usually, the only area where a structural wall has been designed into a building is where the elevator shaft surrounds the staircase. Nonstructural exterior/interior walls less than 12 cm thick may be present, but their contribution to strength and stiffness was not incorporated into the structural design.

2.3 Functional Planning

The main function of this building typology is multi-family housing. In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. Usually, there are at least two separate means of escape (stairs) on each floor in compliance with the national fire code.

2.4 Modification to Building

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

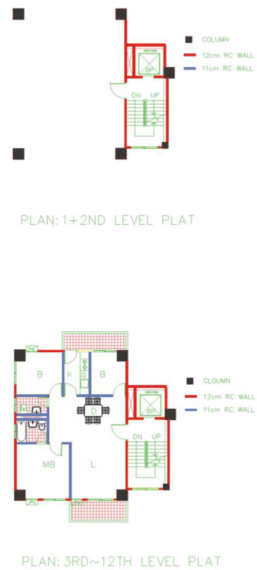


Figure 3: Plan of a Typical Building

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	☐
Structural concrete	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	☐
	Structural wall	22	Moment frame with in-situ shear walls	☐
		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 structural walls (with frame). At the first floor and the basement levels, columns are usually the sole structural members to transfer vertical loads. In many cases, only four columns are present on the first floor. As a result, columns are designed with high percentage of reinforced, high-strength concrete; however, the construction quality may not meet the 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/cm²; however, the actual strength may be even less than 2100 N/cm².

3.3 Lateral Load-Resisting System

The lateral load-resisting system is reinforced concrete moment resisting frame. 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 third floor and above, which leads to a soft-story configuration in the lateral load-resisting system.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 10 and 10 meters, and widths between 7 and 7 meters. The building has 12 to 20 storey(s). The typical span of the roofing/flooring system is 8 meters. Typical Story Height: The ground story is usually 4.6 meters. Typical Span: varies between 7.5 m adn 10 m. The typical storey height in such buildings is 3 meters. The typical structural wall density is none. At the ground floor: 0.9%. Upper stories: 6%.

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	☑	☑

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

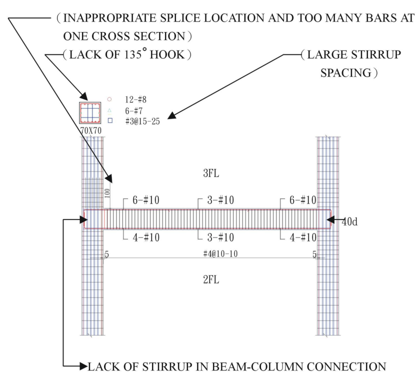


Figure 4: Critical Structural Details

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 10-20 housing unit(s). 20 units in each building. As a rule there are 10-30 housing units in the one building. The number of inhabitants in a building during the day or business hours is 11-20. The number of inhabitants during the evening and night is more than 20.

4.2 Patterns of Occupancy

Usually two to four families occupy a typical floor.

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)	☐

The price of housing is much higher in the capital Taipei. Economic Level: For Middle Class the Housing Price Unit is 240000 and the Annual Income is 30000.

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)	☐

In each housing unit, there are no bathroom(s) without toilet(s), 1 toilet(s) only and 1 bathroom(s) including toilet(s).

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		
		Yes	No	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	Quality of workmanship (based on visual inspection of 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**
Wall	Discontinuous at the ground floor		
Frame (columns, beams)	Inadequate strength and redundancy		Failure of columns in open story leads to a total collapse
Roof and floors			
Other			

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 are usually 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 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is *D: MEDIUM-LOW VULNERABILITY (i.e., good seismic performance)*, the lower bound (i.e., the worst possible) is C: MEDIUM VULNERABILITY (i.e., moderate seismic performance), and the upper bound (i.e., the best possible) is *E: LOW VULNERABILITY (i.e., very good 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**
1999	Chi-Chi, Taiwan	7.3	

Figure 5: A Photograph Illustrating Typical Earthquake Damage

6. Construction

6.1 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	
Foundation	RC	fc=2800 N/cm², fy=42000 N/cm²		
Frames (beams & columns)	RC	fc=2800 N/cm², fy=42000 N/cm²		
Roof and floor(s)	RC	fc=2800 N/cm², fy=42000 N/cm²		

6.2 Builder

This construction is built mostly by developers who do not necessarily live in the building.

6.3 Construction Process, Problems and Phasing

A contractor is usually hired to do the construction work. Concrete is generally purchased from premix plants and the steel reinforcement cage is assembled at 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. The construction of this type of housing takes place in a single phase. Typically, the building is originally designed for its final constructed size.

6.4 Design and Construction Expertise

Structural designers usually rely on computer software for the analysis. The designer must pass a national exam and be government certified. He/she is expected to use the latest technology in creating the structural design. However, it has been discovered that some designers use a 2D instead of a 3D analysis. Driven by free market competition, some designers have even deliberately chosen to reduce design load estimates to build a less expensive structure. As a result, many of these buildings collapsed in the 1999 Chi-Chi earthquake and the designers responsible 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 only on paper and not seek expert advice during the construction. Architects hired by developers usually have little to do with the overall building geometry because developers have already decided on 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.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Building Construction Technical Code of the Republic of China. The year the first code/standard addressing this type of construction issued was 1974. The most recent code/standard addressing this construction type issued was 1999. 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.

Architects design a building and submit the drawings to the concerned government agency which verifies for compliance with all the safety rules required in the design. A construction permit is issued after the government agency is satisfied that all rules have been 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 with resulting poor construction quality. Architects continually have difficulty in checking all the construction details and this often leads to a large number of disputes. After the construction work has been completed, a government official inspects the new building to check the overall appearance of the building and to 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 is issued to the building owner.

6.6 Building Permits and Development Control Rules

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

6.8 Construction Economics

450 days for a 12-story building.

7. Insurance

Earthquake insurance for this construction type is typically unavailable. For seismically strengthened existing buildings or new buildings incorporating seismically resilient features, an insurance premium discount or more complete coverage is unavailable.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
Soft and weak first open story	Steel or RC braces or RC shear walls may be added to strengthen the ground story. Beams and horizontal braces 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.

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?

Some measures have been undertaken in a few buildings undergoing seismic strengthening.

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

8.3 Construction and Performance of Seismic Strengthening

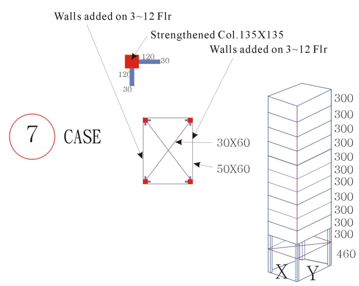
Was the construction inspected in the same manner as the new construction?

Yes, the construction inspected in same manner as the new construction.

Who performed the construction seismic retrofit measures: 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.

What was 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.



Extra floor added at the middle of the OS [1]

Figure 6: Illustration of Seismic Strengthening Techniques

Reference(s)

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

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