World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

an initiative of
Earthquake Engineering Research Institue (EERI) and
International Association for Earthquake Engineering (IAEE)

HOUSING REPORT

Highrise reinforced concrete buildings with open space at the ground floor

Report#	63
Last Updated	
Country	Taiwan
Author(s)	Su, Chi Tung, Yao, George C.,
Reviewers	Durgesh C. Rai,

Important

This encyclopedia contains information contributed by various earthquake engineering professionals around the world. All opinions, findings, conclusions & recommendations expressed herein are those of the various participants, and do not necessarily reflect the views of the Earthquake Engineering Research Institute, the International Association for Earthquake Engineering, the Engineering Information Foundation, John A, Martin & Associates, Inc. or the

participant’s organizations.

General Information

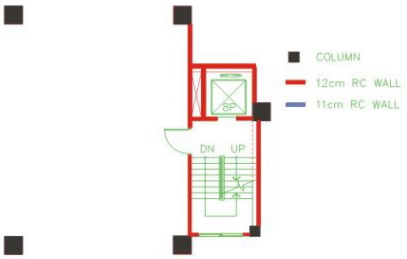
Building Type:	Highrise reinforced concrete buildings with open space at the ground floor
Country:	Taiwan
Author(s):	Su, Chi Tung Yao, George C.
Last Updated:	
Regions Where Found:	Buildings of this construction type can be found in in both rural and urban areas. This type of housing construction is commonly found in both rural and urban areas.
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 zig-zag 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.
Length of time practiced:	Less than 25 years
Still Practiced:	Yes
In practice as of:	

Building Occupancy:	Residential, 20-49 units
Typical number of stories:	12-20
Terrain-Flat:	Typically
Terrain-Sloped:	3
Comments:	As a rule there are 10-30 housing units in the one building

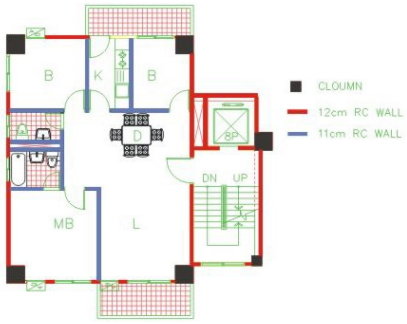
Features

Plan Shape	Other
Additional comments on plan shape	Floor plan boundaries in this type of building are usually lined up in parallel or zig-zagged to obtain largest space for lighting.
Typical plan length (meters)	10
Typical plan width (meters)	7
Typical story height (meters)	3
Type of Structural System	Structural Concrete: Moment Resisting Frame: Designed with seismic effects, with URM infill walls
Additional comments on structural 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/cm#; however, the actual strength may be even less than 2100 N/cm#. 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.
Gravity load-bearing & lateral load-resisting systems	
Typical wall densities in direction 1	0-1%
Typical wall densities in direction 2	5-10%

Additional comments on typical wall densities	At the ground floor: 0.9%. Upper stories : 6%
Wall 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.
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications 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.
Type of Foundation	Shallow Foundation: Mat foundation
Additional comments on foundation	
Type of Floor System	Other floor system
Additional comments on floor system	Structural Concrete: cast in place solid slabs
Type of Roof System	Roof system, other
Additional comments on roof system	Structural Concrete: cast in place solid slabs
Additional comments section 2	When separated from adjacent buildings, the typical distance from a neighboring building is 10 meters.



PLAN: 1+2ND LEVEL PLAT



PLAN: 3RD~12TH LEVEL PLAT

Plan of a Typical Building

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	RC	Characteristic Strength- fc=2800 N/cm2, fy=42000 N/cm2 Mix Proportion/Dimensions- mostly from plant
Foundations	RC	Characteristic Strength- fc=2800 N/cm2, fy=42000 N/cm2 Mix Proportion/Dimensions- mostly from plant
Floors	RC	Characteristic Strength- fc=2800 N/cm2, fy=42000 N/cm2 Mix Proportion/Dimensions- mostly

		from plant
Roof	RC	Characteristic Strength- fc=2800 N/cm2, fy=42000 N/cm2 Mix Proportion/Dimensions- mostly from plant
Other		

Design Process

Who is involved with the design process?	EngineerArchitect
Roles of those involved in the design process	Structural designers usually rely on computer softwares 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. 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.
Expertise of those involved in the design process	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. 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.

Construction Process

Who typically builds this construction type?	Contractor
Roles of those involved in the building process	It is mostly built by developers who do not necessarily live in the building.
Expertise of those involved in building process	
Construction process and phasing	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

phasing	masonry which is laid after the structure is completed. RC partition walls are cast together with the structure itself. This building is not typically constructed incrementally and is designed for its final constructed size.
Construction issues	

Building Codes and Standards

Is this construction type address by codes/standards?	Yes
Applicable codes or standards	Building Construction Technical Code of the Republic of China. The first code/standard addressing this type of construction was issued 1974; the most recent code/standard addressing this construction was issued 1999.
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 checking all 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.

Building Permits and Development Control Rules

Are building permits required?	Yes
Is this typically informal construction?	No
Is this construction typically authorized as per development control rules?	Yes
Additional comments on building permits and development control rules	

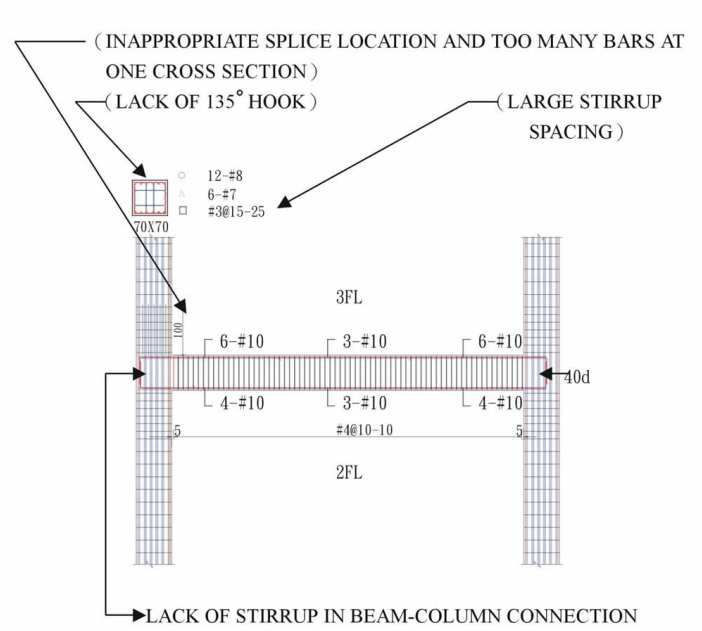
Building Maintenance and Condition

	A developer may have his own construction company,

Typical problems associated with this type of construction	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.
Who typically maintains buildings of this type?	Owner(s)
Additional comments on maintenance and building condition	

Construction Economics

Unit construction cost	500 US$/m2
Labor requirements	450 days for a 12-story building.
Additional comments section 3	



Critical Structural Details

Socio-Economic Issues

Patterns of occupancy	Usually two to four family occupy a typical floor. Each building typically has 10-30 housing unit(s).

Number of inhabitants in a typical building of this construction type during the day	10-20
Number of inhabitants in a typical building of this construction type during the evening/night	>20
Additional comments on number of inhabitants	
Economic level of inhabitants	Middle-income class
Additional comments on economic level of inhabitants	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: 5:1 or worse
Typical Source of Financing	Owner financedPersonal savingsInformal network: friends or relativesCommercial banks/mortgages
Additional comments on financing	
Type of Ownership	RentOwn outrightOwn with debt (mortgage or other)Units owned individually (condominium)
Additional comments on ownership	
Is earthquake insurance for this construction type typically available?	No
What does earthquake insurance typically cover/cost	
Are premium discounts or higher coverages available for seismically strengthened buildings or new buildings built to incorporate seismically resistant features?	No
Additional comments on premium discounts	
Additional comments section 4	

Earthquakes

Past Earthquakes in the country which affected buildings of this type

Year	Earthquake Epicenter
1999	Chi-Chi, Taiwan

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	Failure of columns in open storey leads to a total collapse. 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.
Additional comments on earthquake damage patterns	

Structural and Architectural Features for Seismic Resistance

The main reference publication used in developing the statements used in this table is FEMA 310 “Handbook for the Seismic Evaluation of Buildings-A Pre-standard”, Federal Emergency Management Agency, Washington, D.C., 1998.

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.

Structural/Architectural Feature	Statement	Seismic Resistance
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.	TRUE
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	FALSE
Building Configuration-	The building is regular with	FALSE

Horizontal	regards to the plan. (Specify in 5.4.2)	
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.	TRUE
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.	TRUE
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.	TRUE
Wall and Frame Structures-Redundancy	The number of lines of walls or frames in each principal direction is greater than or equal to 2.	TRUE
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);	TRUE
Foundation-Wall Connection	Vertical load-bearing elements (columns, walls) are attached to the foundations; concrete columns and walls are doweled into the foundation.	TRUE
Wall-Roof Connections	Exterior walls are anchored for out-of-plane seismic effects at each diaphragm level with metal anchors or straps.	TRUE
Wall Openings		TRUE

Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national codes and standards (an estimate).	FALSE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	FALSE
Maintenance	Buildings of this type are generally well maintained and there are no visible signs of deterioration of building elements (concrete, steel, timber).	FALSE

Building Irregularities

Additional comments on structural and architectural features for seismic resistance	
Vertical irregularities typically found in this construction type	Other
Horizontal irregularities typically found in this construction type	Other
Seismic deficiency in walls	Discontinuous at the ground floor.
Earthquake-resilient features in walls	
Seismic deficiency in frames	Inadequate strength and redundancy.
Earthquake-resilient features in frame	
Seismic deficiency in roof and floors	
Earthquake resilient features in roof and floors	
Seismic deficiency in foundation	
Earthquake-resilient features	

in foundation	

Seismic Vulnerability Rating

For information about how seismic vulnerability ratings were selected see the Seismic Vulnerability Guidelines

	High vulnerability		Medium vulnerability		Low vulnerability	
	A	B	C	D	E	F
Seismic vulnerability class			|-	o	-|	

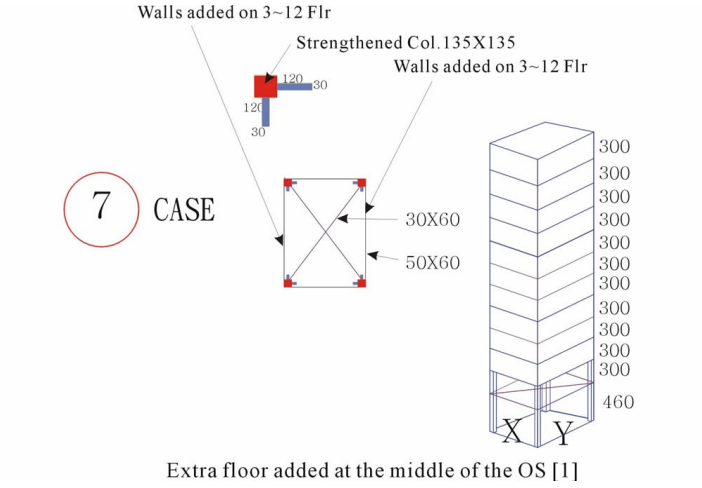
A Photograph Illustrating Typical Earthquake Damage

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic 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 bracing 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

Additional comments on seismic strengthening provisions	
Has seismic strengthening described in the above table been performed?	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 a repair following earthquake damages?	In most cases as a part of the repair work. In some undamaged buildings the above technique is also used as a mitigation measure.
Was the construction inspected in the same manner as new construction?	Yes
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.
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 indicates that adding diagonal bracing at the OS will be the best solution to solve the soft-story effect.
Additional comments section 6	



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

Illustration of Seismic Strengthening Techniques

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.

Authors

Name	Title	Affiliation	Location	Email
Su, Chi Tung	Architect		#413 Chien Kuo I Rd., Kaohsiung 80703 Taiwan	aaronsu@ms45.hinet.net
Yao, George C.	Professor	Dept. of Architecture	#1 University Rd. NCKU, Tainan 701 Taiwan	gcyao@mail.ncku.edu.tw

Reviewers

Name	Title	Affiliation	Location	Email
Durgesh C. Rai	Professor	Civil Engineering, Indian Institute of Technology	Kanpur 208016, INDIA	dcrai@iitk.ac.in