World Housing Encyclopedia

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

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

HOUSING REPORT
Street front building with arcade at the first floor (pre-1970's construction)

Report #	61
Report Date	05-06-2002
Country	TAIWAN
Housing Type	RC Moment Frame Building
Housing Sub-Type	RC Moment Frame Building : Designed for gravity loads only, with URM infills
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Important
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Summary

This building type is common in most Taiwanese cities and towns. It represents a construction practice that was followed before1970 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. 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 residences. Neighboring units of similar design are constructed together to form a shady corridor for pedestrians to walk in. The number of connected units 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) typical 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 the load. Many buildings of this type collapsed in the 1999 Chi-Chi earthquake.

1. General Information

Buildings of this construction type can be found in almost all cities and towns on the island. This type of housing construction is commonly found in both rural and urban areas. This construction type has been in practice for less than 50 years.

Currently, this type of construction is not being built. .

Figure 1: Typical Building

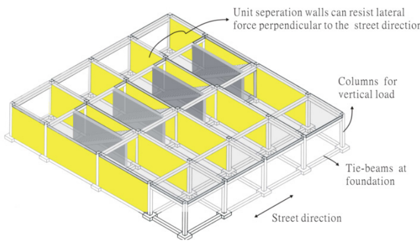

Figure 2A: Key Load-Bearing Elements

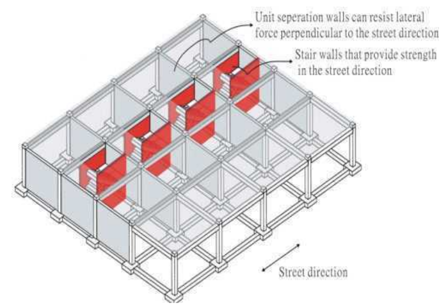

Figure 2B: Key Loadbearing Elements - Wall Layout in the Street Direction

2. Architectural Aspects

2.1 Siting

These buildings are typically found in flat terrain. They share common walls with adjacent buildings.

2.2 Building Configuration

Rectangular shape is most common. 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.

2.3 Functional Planning

The main function of this building typology is mixed use (both commercial and residential use). In a typical building of this type, there are no elevators and 1-2 fire-protected exit staircases. Usually only one stairway is designed for a housing unit, therefore there is only one means of escape.

2.4 Modification to Building

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.

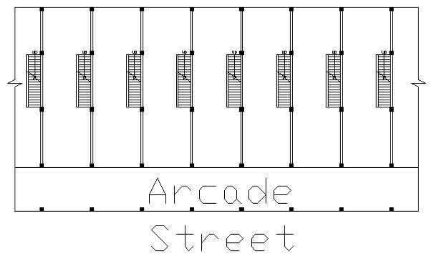

Figure 3A: Plan of a Typical Building

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	☐
		17	Flat slab structure	☐
		18	Designed for gravity loads only, with URM infill walls	☑

Structural concrete	Moment resisting frame	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 others (described below). 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.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is others (described below). 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.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 10 and 10 meters, and widths between 4.5 and 4.5 meters. The building has 4 to 5 storey(s). The typical span of the roofing/flooring system is 4.5 meters. Typical Story Height: 4 m at the first floor and 3 m for upper stories. The typical storey height in such buildings is 3 meters. The typical structural wall density is none. 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%.

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	☐

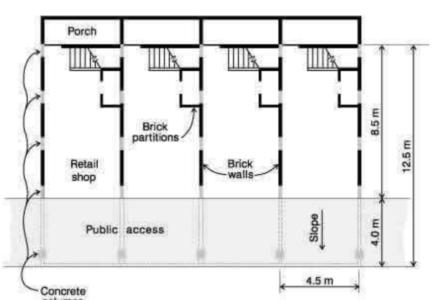

Figure 3B: Plan of a Typical Building - Ground Floor Level (Source: EERI 2001)

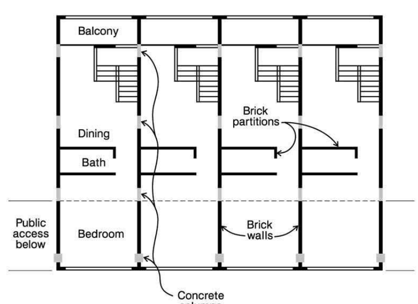

Figure 3C: Plan of a Typical Building- Upper Floor Levels (Source: EERI 2001)

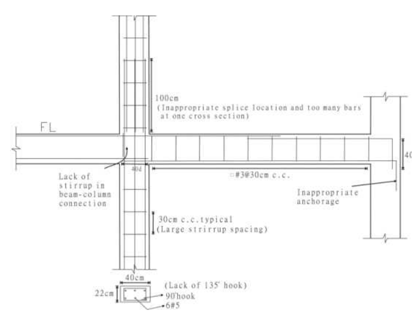

Figure 4: Critical Structural Details - RC Frame Reinforcement Details

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 5-10 housing unit(s). 10 units in each building. Number of housing units varies from 6 to

10. 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. More than 50 may dwell in the building during the night. Grandparents and parents may live with two or three children in the same unit. Also rooms may be rented to tenants for extra income.

4.2 Patterns of Occupancy

Usually one family per housing unit.

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)	☐

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

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 2 bathroom(s) without toilet(s), no toilet(s) only and 1 bathroom(s) including toilet(s).

There are 2 - 3 bathrooms in housing unit. .

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	-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
	No major deficiencies		
	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 damage and building collapses have been due to the large demands on the bottom story columns caused by soft story and torsional effects (see Figure 6A)

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is *C: MEDIUM VULNERABILITY (i.e., moderate seismic performance)*, the lower bound (i.e., the worst possible) is B: MEDIUM-HIGH VULNERABILITY (i.e., poor seismic performance), and the upper bound (i.e., the best possible) is *D: MEDIUM-LOW VULNERABILITY (i.e., 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	X
2001	Taipei	6.8	

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.

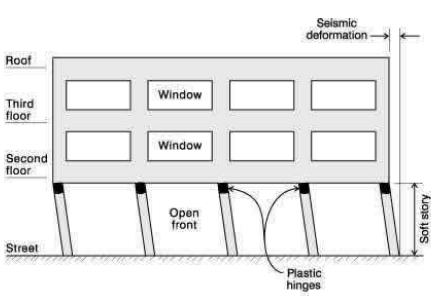

Figure 5A: Seismic Deficiency: Soft-story deformation of open front at t he street level

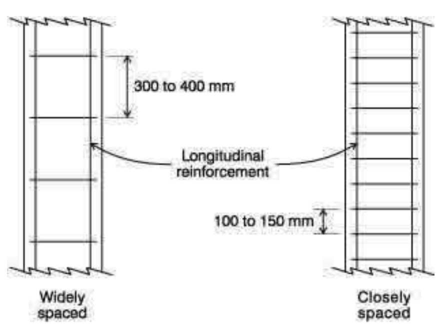

Figure 5B: Seismic Deficiency - Widely spaced hoop reinforcement (Source: EERI 2001)

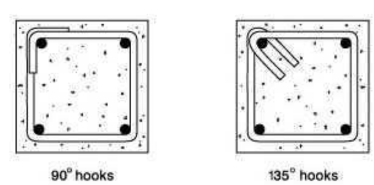

Figure 5C: Seismic Deficiency: Column ties -90 degree hooks were used instead of 135 degree hooks (Source: EERI 2001)

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 ofa 5-story building in the March 31, 2002 Taipei earthquake

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Brick wall	Compression:130 kg/cm^2 Tension: 37 kg/cm^2	Brick dimensions are 5 X 11 X 23 cm	
Foundation	Reinforced Concrete	fc'= 175 kg/cm^2 fy= 2800 kg/cm^2	1:2:4	
Frames (beams & columns)	Reinforced Concrete	fc'= 175 kg/cm^2 fy= 2800 kg/cm^2	1:2:4	
Roof and floor(s)	Reinforced Concrete	fc'= 175 kg/cm^2 fy= 2800 kg/cm^2	1:2:4	

6.2 Builder

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

6.3 Construction Process, Problems and Phasing

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. 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

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. 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.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. Building construction technique code in 1974 first addressed the seismic force and wind force for building design. 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 1998. 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.

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.

6.6 Building Permits and Development Control Rules

This type of construction is an engineered, and not 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

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

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
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

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?

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

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

Both.

8.3 Construction and Performance of Seismic Strengthening

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

Less stringent in retrofit work.

Who performed the construction seismic retrofit measures: 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.

What was the performance of retrofitted buildings of this type in subsequent earthquakes?

Yet to be discovered by the next major earthquake.

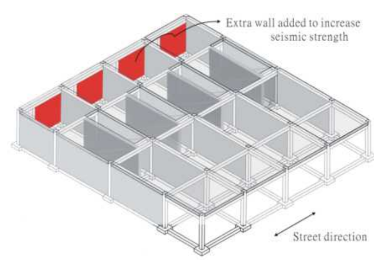

Figure 7: Illustration of Seismic Strengthening Techniques

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