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

Street front building with arcade at the first floor (contemporary construction)

Report#	62
Last Updated	
Country	Taiwan
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Important

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General Information

Building Type:	Street front building with arcade at the first floor (contemporary construction)
Country:	Taiwan
Author(s):	Yao, George C. M.S. Sheu
Last Updated:	
Regions Where Found:	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.
Summary:	This building type is common for many Taiwanese cities and townships. The street front buildings are medium-rise reinforced concrete frames with infill brick masonry walls serving as partitions. Usually, the first floor (typically 4 m high) is used for commercial purposes while the upper stories (typically 2 to 4 stories above, floor height 3 m) are used for storage and residential use. There is an #arcade# at the street level so that people may walk in it to hide from the strong sunlight or rainfall. Neighboring units of similar design are constructed together to form a corridor for pedestrians to walk in. However, these neighboring units may not be built at the same time. The number of units connected together varies from 6 to 10. These units may be connected in a row, or in an L shape, or in the U shape along the street block. There are several structural deficiencies associated with this building type: (1) the weak and soft first story because the commercial space demands a large opening at the street level; (2) a typical architectural building layout has walls in one direction only, perpendicular to the street; as a consequence, there are little earthquake-resisting elements in the other direction; (3) extra rooftop additions increase loadings. Also, building owners tend to reduce the number of columns for a wider store-front view. Many buildings of this type collapsed in the Chi-Chi earthquake of 1999.
Length of time practiced:	76-100 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Mixed residential/commercial

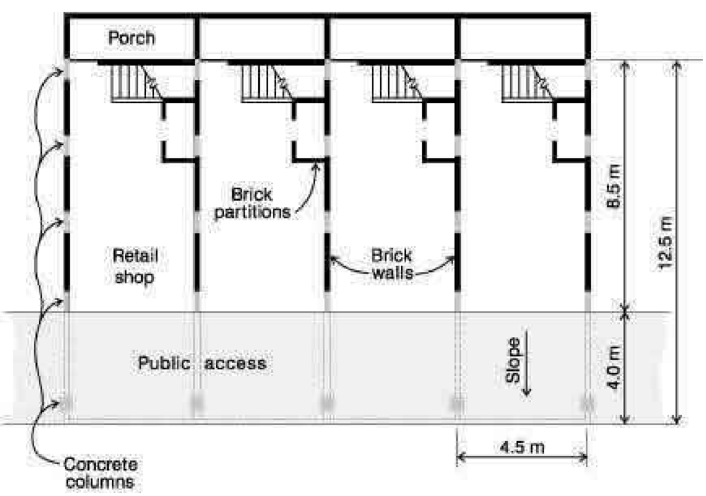
Typical number of stories:	4 or 5
Terrain-Flat:	Typically
Terrain-Sloped:	3
Comments:	

Features

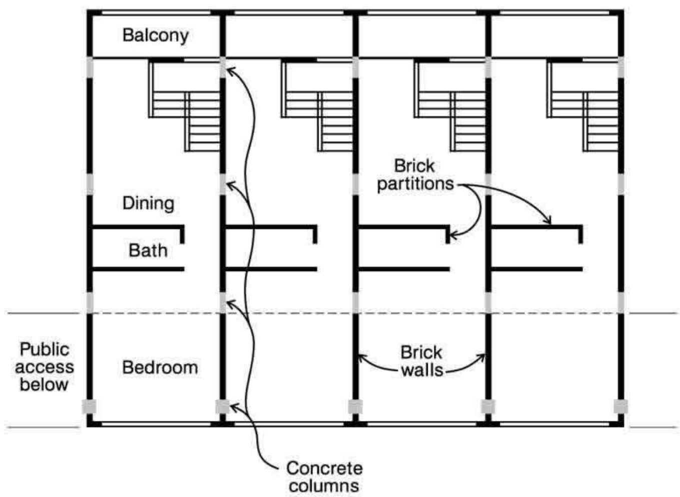
Plan Shape	Rectangular, solid
Additional comments on plan shape	Rectangular shape is most common.
Typical plan length (meters)	10
Typical plan width (meters)	4.5
Typical story height (meters)	3
Type of Structural System	Structural Concrete: Moment Resisting Frame: Designed for gravity loads only, with URM infill walls
Additional comments on structural system	Lateral load-resisting system: The main lateral load resisting system in these buildings consists of reinforced concrete frames with infill brick masonry walls serving as partitions. Key loadbearing elements are illustrated in Figure 3. Columns are designed for seismic effects, however due to the inadequate construction and the lack of the seismic detailing, these columns have demonstrated inadequate seismic resistance (especially in the 1999 Chi Chi earthquake). Due to the fact that the quality control of the brick walls had not been stringent, these infill walls have a limited ability to resist seismic forces. However, the walls certainly contribute to structural stiffness and strength in these buildings. For low-rise buildings it is considered to err on the safe side if the effect of infills is neglected in the structural analysis. Most of the walls are made of brick masonry (typical wall thickness 120 mm); however, in the last decade, some builders have used 120 mm thick RC walls instead of the traditional brick walls. Some walls at the rear side (kitchen area) are not full height. Sometimes windows are cut through the walls, and ventilation equipment or pipes may pass through these walls. As a result, the rear walls have a limited contribution to lateral load resistance in these buildings. Wall layout is a critical factor that influences the seismic resistance of these buildings. In each housing unit, two end walls separate different units. Majority 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. Typical floor plans are illustrated in Figures 4-6. In some buildings, walls are laid out parallel to the street direction due to the layout of stairways (which is also parallel to the street), as illustrated in Figure 18. These buildings have demonstrated better seismic performance as compared to the buildings with different wall layout, as observed in the 1999 Chi-Chi earthquake. Gravity load-bearing system: Floor weight on different stories is transferred to solid RC floor slabs (usually 120 mm thick), which are supported by RC beams (typically 400 to 600 mm deep and 300 mm wide). Loads are then transferred from the beams to the brick masonry walls, usually 120 mm thick, and RC columns, with dimensions ranging from 300 x 500 mm to 400 x 500 mm. Transverse column reinforcement (ties) are 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. The reinforcement is usually terminated outside the beam-column joint. Longitudinal column reinforcement ratio varies from 1 to 2.9 %, depending on the design or floor height. Concrete strength varies from 10 to 20 MPa and was mostly pre-mixed in plant and delivered to site. Reinforced concrete slabs were cast monolithically with beams and columns on each floor. As a result, honeycombing can be observed on the column surface if concrete was not sufficiently vibrated during the construction. The foundations are mostly shallow spread footings connected with tie-beams.
Gravity load-bearing & lateral load-resisting systems	
Typical wall densities in direction 1	4-5%
Typical wall densities in direction 2	0-1%
Additional comments on typical wall densities	The wall density perpendicular to the street direction at the first floor level is approximately 5%. The wall density in the direction parallel to the street may range from 0.3 to 1%.
Wall Openings	Walls perpendicular to the street (side walls) are mostly used to separate building units, therefore these walls do not have any openings. Other walls may have openings, but the openings were not the major cause of capacity reduction. Major seismic problems are due to the architectural layout of these buildings, characterized with the total absence of walls or a very few walls in the direction parallel to the street. As a consequence, columns are the only elements resisting earthquake forces in the direction parallel to the street. This structural deficiency has led to a significant damage or even collapse of the columns in the 1999 Chi-Chi earthquake.

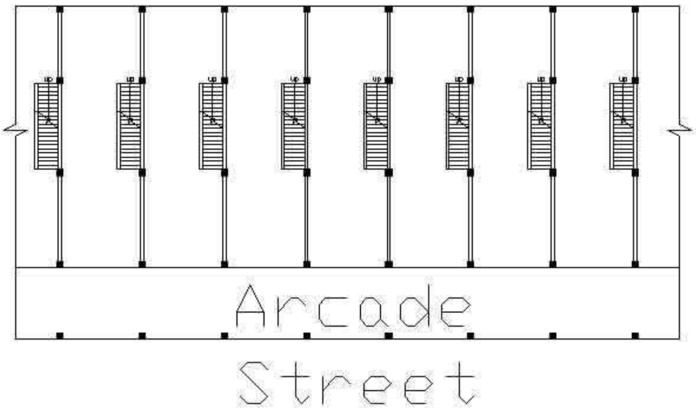
Is it typical for buildings of this type to have common walls with adjacent buildings?	Yes
Modifications of buildings	Typical patterns of modification include: addition of one or more floors (vertical expansion), demolishing the interior walls at the ground floor level for the commercial space. Initially, building permits are originally given for 3 or 4 story construction. However, most owners build 1 or 2 extra stories without seeking the permit for vertical expansion after the original building permit has been approved by the local government.
Type of Foundation	Shallow Foundation: Reinforced concrete isolated footing
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	



Plan of a Typcial Building



Typical Floor Plan -Past Practice (Source: EERI 2001)



Typical Ground Floor Plan- Past Practice (Source: EERI 2001)

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	Wall: Brick wall Frame: Reinforced concrete	Wall: Characteristic Strength- Compression: 110 kg/cm.sq. Tension:33 kg/cm.sq. Brick dimensions: 50x110x230 mm Frame: Characteristic Strength- fc#=210 kg/cm.sq. fy=4200 kg/cm.sq. Mix Proportion/Dimensions- plant - mixed concrete
Foundations	Reinforced concrete	Characteristic Strength: fc#=210 kg/cm.sq. fy=4200 kg/cm.sq. Mix Proportion/Dimensions: plant - mixed concrete
Floors	Reinforced concrete	Characteristic Strength: fc#=210 kg/cm.sq. fy=4200 kg/cm.sq. Mix Proportion/Dimensions: plant - mixed concrete
Roof	Reinforced concrete	Characteristic Strength: fc#=210 kg/cm.sq. fy=4200 kg/cm.sq. Mix Proportion/Dimensions: plant - mixed concrete
Other		

Design Process

Who is involved with the design process?	EngineerArchitect
Roles of those involved in the design process	All buildings in Taiwan need the signature of a registered architect before government approval granted. However, some architects may not have adequate knowledge for the latest development in seismic design. Developers have the tendency to choose an A/E that may compromise structural design for sales strategy. As a consequence, building code requirement becomes the upper bound for structural design in many recent projects.
Expertise of those involved in the design process	

Construction Process

Who typically builds this construction type?	Contractor
Roles of those involved in the building process	This construction is mostly built by developers. Builders do not necessarily live in these buildings.
Expertise of those involved in building process	
Construction process and phasing	In the contemporary (post-1980) construction of this type which is described in this contribution, RC frame structure is constructed first, and the brick walls are then built as an infill. Therefore, brick walls are not tightly connected to the RC frames. However, in the older buildings of this type (of the pre-1970s vintage) which are described in another contribution by the same authors, the brick walls were constructed first, and RC frames were subsequently constructed around the brick walls. This building is not typically constructed incrementally and is designed for its final constructed size.
Construction issues	Due to the absence of major earthquakes before the 1999 Chi-Chi earthquake in Taiwan, contractors were reluctant to make extra effort into workmanship related to the seismic detailing. Therefore, in most of the construction sites, seismic detailing for RC structures is inadequate.

Building Codes and Standards

Is this construction type address by codes/standards?	Yes
Applicable codes or standards	Building construction technique code in 1974 first addressed the seismic force and wind force for building design; the most recent code/standard addressing this construction was issued 1998.

Process for building code enforcement	Building permits are granted after the architectural drawings are reviewed to satisfy building codes. Construction work proceeds afterwards. At this stage, the design architect is usually responsible for monitoring that appropriate construction methods and materials are being used in the construction. After the construction is finished, government official inspects the building to ensure that everything is built to the design drawings before a permit of occupancy is issued.

Building Permits and Development Control Rules

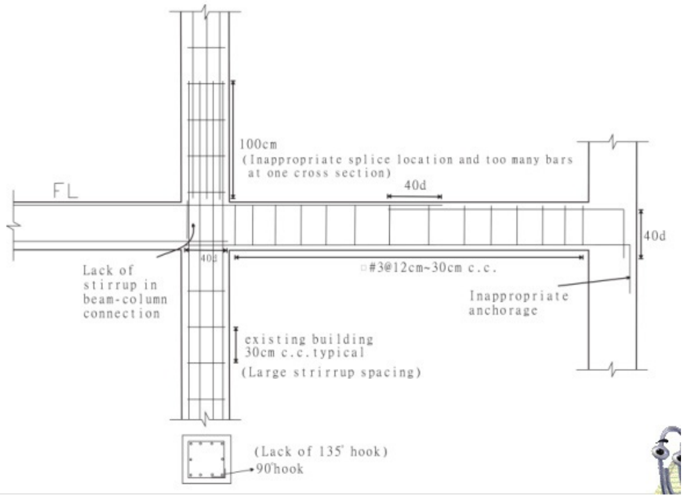
Are building permits required?	Yes
Is this typically informal construction?	No
Is this construction typically authorized as per development control rules?	No
Additional comments on building permits and development control rules	

Building Maintenance and Condition

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

Construction Economics

Unit construction cost	To include the material (for all the structural and nonstructural components) and labor: 300 $US/ m.sq.(contemporary construction).
Labor requirements	Usually, it takes 10 days to build one story (structural part only), including the bar installation, forming, and pouring of concrete.
Additional comments section 3	



Critical Structural Details - RC Frame Reinforcement Details

Socio-Economic Issues

Patterns of occupancy	Usually one family per housing unit. Each building typically has 6-10 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	Other
Additional comments on number of inhabitants	Other - more than 50: Grandparents and parents may live with two or three children, so there may be 5-8 family members. Also, in some cases rooms may be rented to tenants for the extra income.
Economic level of inhabitants	Middle-income class
Additional comments on economic level of inhabitants	Ratio of housing unit price to annual income: 1:1 or better A typical annual income for a middle class family is $US 25, 000 to $US 60,000; however, the income varies depending on the location.
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

	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 Figures 11-16. 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 nonductile

Damage patterns observed in past earthquakes for this construction type	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.
Additional comments on earthquake damage patterns	#NAME?

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.	FALSE
Building Configuration-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	FALSE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	FALSE
Roof Construction	The roof diaphragm is considered to be rigid and it	TRUE

	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.	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.	FALSE
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);	FALSE
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.	FALSE
Wall Openings		TRUE
Quality of Building Materials	Quality of building materials is considered to be adequate per the requirements of national	TRUE

	codes and standards (an estimate).	
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).	TRUE

Building Irregularities

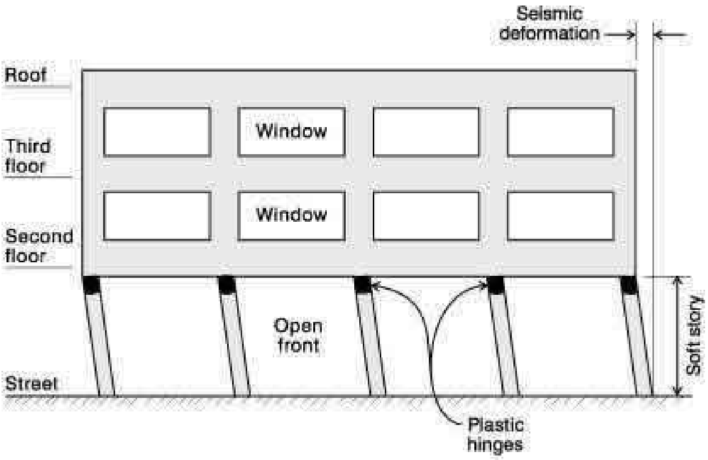
Additional comments on structural and architectural features for seismic resistance	
Vertical irregularities typically found in this construction type	Torsion eccentricity
Horizontal irregularities typically found in this construction type	Soft/weak story
Seismic deficiency in walls	-Unreinforced brick 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 3. .
Earthquake-resilient features in walls	
Seismic deficiency in frames	- Column reinforcement is usually spliced at the top of the slab where the column bending moments are the largest (see Figure 7). As a result of this poor construction practice, seismic capacity of the columns is largely reduced. Majority of the buildings
Earthquake-resilient features in frame	
Seismic deficiency in roof and floors	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 8. (Source: EERI 2001)
Earthquake resilient features	

in roof and floors	
Seismic deficiency in foundation	No major deficiencies
Earthquake-resilient features in foundation	

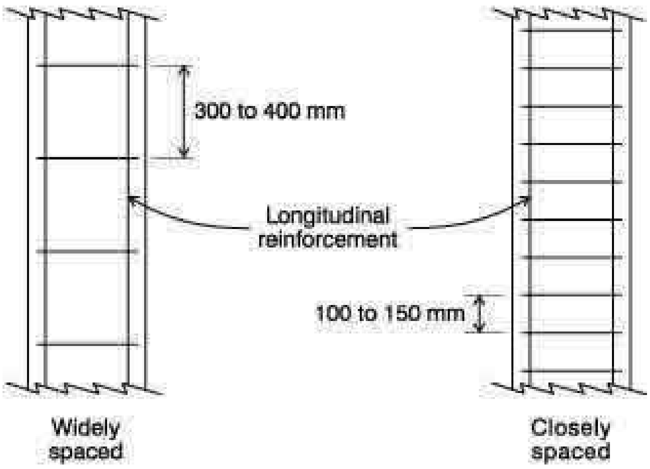
Seismic Vulnerability Rating

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

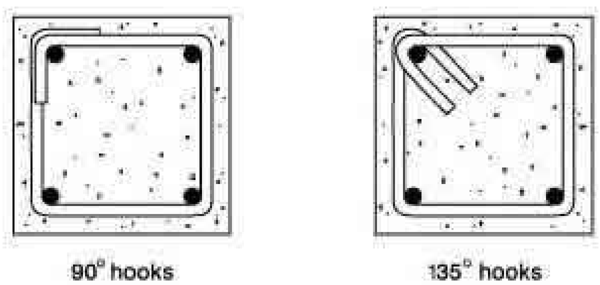
	High vulnerability		Medium vulnerability		Low vulnerability	
	A	B	C	D	E	F
Seismic vulnerability class		|-	o	-|		



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



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



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

A Photograph Illustrating Typical Earthquake Damage

Earthquake damage - Collapsed Three-story building in the 1999 Chi Chi earthquake (Source: EERI 2001)

Earthquake Damage - Partial Collapse of a Three-story building in the 1999 Chi Chi Earthquake (Source: EERI 2001)

Earthquake Damage - Pancake Collapse of an Entire City Block in the 1999 Chi Chi earthquake (Source: EERI 2001)

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

Collapse of a Concrete Frame Building in the 1999 Chi Chi Earthquake (Source: EERI 2001)

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic Strengthening
Lack 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 Figures 17 and 18. - Installation of new steel braces.
Weak columns	#NAME?
New Construction- Planning of stairways and walls parallel to the street direction	Walls laid out parallel to the street direction due to the layout of stairways, as illustrated in Figure 18.

Additional comments on seismic strengthening provisions	
Has seismic strengthening described in the above table been performed?	Yes. Seismic strengthening 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 a repair following earthquake damages?	Both
Was the construction inspected in the same manner as new construction?	Less stringent in retrofit work
Who performed the construction: a contractor or owner/user? Was an architect or engineer involved?	Contractors performed retrofit construction. Only small percentage of the work involved architects or engineers.
What has been the performance of retrofitted buildings of this type in subsequent earthquakes?	Yet to be discovered by the next major earhtquake.
Additional comments section 6	

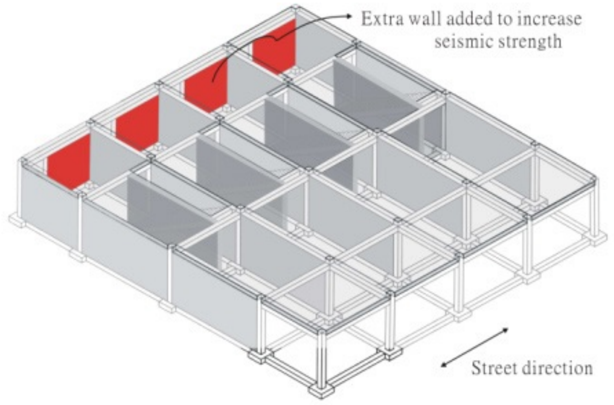
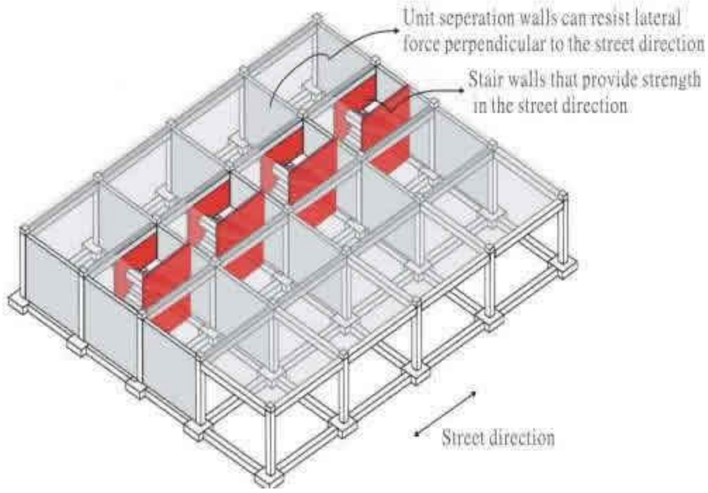


Illustration of Seismic Strengthening Techniques



Seismic Strengthening (New Construction) - Wall Layout in the Street Direction

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Taiwan

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