World Housing Encyclopedia

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

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HOUSING REPORT
Multistory base-isolated brick masonry building with reinforced concrete floors and roof

Report #	9
Report Date	05-06-2002
Country	CHINA
Housing Type	Seismic Protection Systems
Housing Sub-Type	Seismic Protection Systems: Buildings Protected with Seismic Dampers
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Summary

This is typically a 5- to 8-story building with commercial enterprises on the ground floor and residences above. Brick masonry buildings have been used in China for thousands of years. This construction practice possesses the advantage of easy manufacture and low cost;

however, the brittleness of the brick masonry material combined with weak seismic resistance induces severe damage or collapse of buildings and causes thousands of deaths during an earthquake. Since 1990, base-isolated brick masonry buildings with reinforced concrete floors/roof have been used more widely in China. The base-isolated building consists of an isolation system (laminated rubber isolation devices) superstructure and substructure. The base-isolation system is located on top of the walls or columns in the basement or at the ground floor level of a building without a basement. The superstructure consists of conventional multi-story brick masonry walls and reinforced concrete floors/roof. The substructure is part of the building beneath the isolation system and consists of the basement and the foundation structure. The base-isolated masonry structure results in an increase in seismic safety by a factor of 4-12 times as compared to that of a non-isolation masonry structure. The high seismic resistance of the base isolation structure house has been proven by shake table tests and in many actual earthquake events in China and other countries. The wide usage of base isolation technology indicates that the era of strong earthquake-proof buildings is coming in China.

1. General Information

Buildings of this construction type can be found in the urban areas of western, eastern, northern, southern and central China. This type of housing construction is commonly found in 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

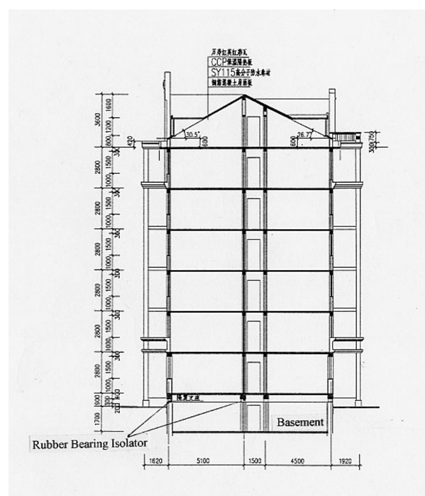


Figure 2: Building Elevation showing the Location of Base Isolation Devices

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 6 meters.

2.2 Building Configuration

Buildings of this type have rectangular plan shapes. For a typical floor, one window with 1,800 mm width and 1,500 mm height in each 3,100 mm length of outside wall. One or two doors each with 900 mm width and 2,100 mm height in each 3,300 mm length of inside wall. The overall windows and doors areas are about 26% of the overall wall surface area.

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.

2.4 Modification to Building

No modifications could be observed.

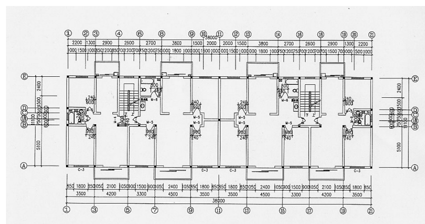


Figure 3: Typical Floor Plan

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	☐

Structural concrete	Moment resisting frame	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)	☐

Isolators consist of laminated rubber bearings. Superstructures are unreinforced brick masonry buildings with reinforced concrete floor/roof slabs.

3.2 Gravity Load-Resisting System

The vertical load-resisting system is reinforced masonry walls. Gravity load is carried by the masonry load-bearing walls, which transfer them to the foundation through the isolation pads.

3.3 Lateral Load-Resisting System

The lateral load-resisting system is reinforced masonry walls. System of structure: The base isolation house structure system consists of isolation layer (laminated rubber bearing isolators), superstructure and substructure. The isolation layer is located on the top of walls or columns in basement or in the first story of house without basement. The superstructure consists of common multi-stories brick masonry wall with reinforced concrete floors/roof, which is same as the general house structure supported on the rubber bearing isolators. The substructure consists of a common basement and base, which is same as the general building structure. The laminated rubber bearing isolators are the key lateral load resisting elements of seismic resistance. Their features are: Size: diameter 350 mm - 600 mm, height 160 mm -200 mm. Component: thickness 3-8mm rubber layers bond with thickness 1-3 mm steel sheets interval each other. Characteristics of isolation pads: High vertical stiffness and high vertical compression capacity for supporting superstructure. Low horizontal stiffness, large horizontal deformation capacity for isolating ground motion.Suitable value of damping ratio for dissipating ground motion energy. Adequate initial horizontal stiffness for resisting wind loads. Seismic performance: During earthquake, the isolation structure will work as follows: 1. All horizontal deformations of superstructure elements will concentrate on the isolation layer, the structure will be kept within the elastic limit, so that no damages will occur in the structure. 2. The natural period of isolation structure will become very long due to the low horizontal stiffness of isolation layer, so that the isolation structural seismic response will be reduced to 1/4 - 1/8 of the non-isolation structural seismic response, protecting the structure from any damage and becoming very safe in strong earthquake. 3. The horizontal deformation of rubber bearing isolators will be limited by enough damping ratio.

3.4 Building Dimensions

The typical plan dimensions of these buildings are: lengths between 48 and 48 meters, and widths between 12 and 12 meters. The building is 6 storey high. The typical span of the roofing/flooring system is 3 meters. Typical Story Height: According to China code, the limited number N of stories for unreinforced brick masonry house in seismic areas is: Seismic Intensity (Ground motion) VI (55 gal) VII (110 gal) VIII (220 gal) IX (400gal) N general buildings 8 7 6 4 N isolation building 9 8 7 - 8 5 - 6 Typical Span: The span, center-to-center distance between the walls for wall structures, is 3.2 - 4.2. The typical storey height in such buildings is 3 meters. The typical structural wall density is none. .

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	☑	☑

The floor/roof is considered to be a rigid diaphragm.

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	☐

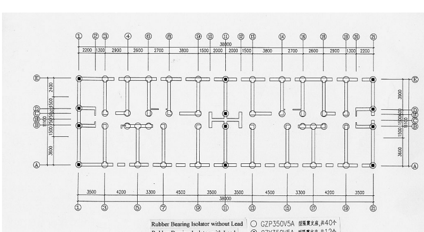


Figure 4: Floor Plan Showing the Layout of Isolation Devices

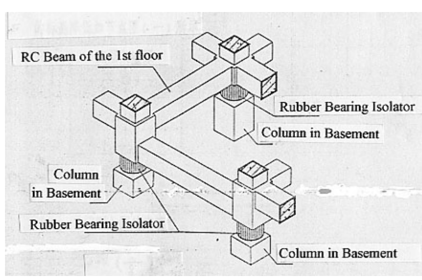


Figure 5A: Perspective Drawing Showing Connection between Isolators and Adjacent Structural Elements

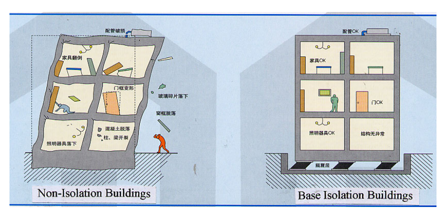


Figure 5B: Comparison of Seismic Performance for a Base Isolated and a Conventional Building

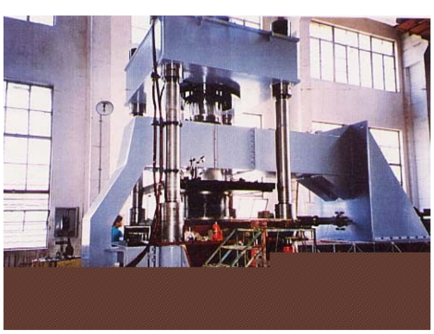
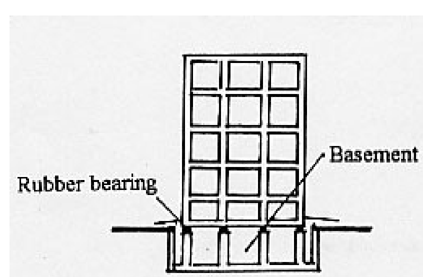


Figure 5C: Testing Facility for Base Isolation


Figure 5D: Components of Rubber Isolation



Devices

Devices

Figure 5E: Building Elevation Showing the Location of Base Isolation Devices

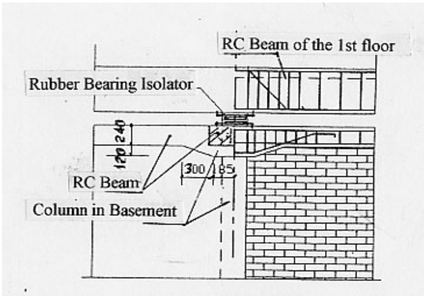


Figure 5F: Base Isolation Device and the Connection with Adjacent Structural Elements

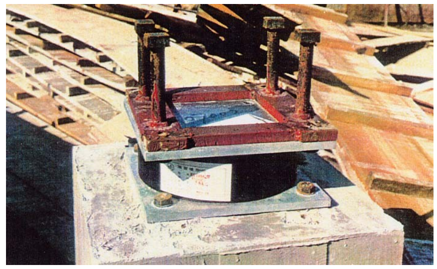


Figure 5G: Installation of Base Isolation Devices

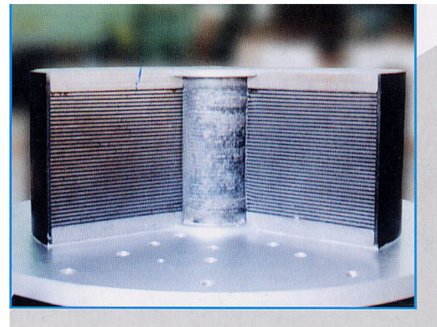


Figure 5H: Lead-Core Rubber Isolation Devices

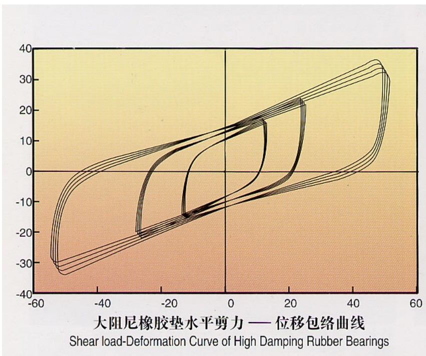


Figure 5I: Load-Deformation Curve for Isolation Devices

4. Socio-Economic Aspects

4.1 Number of Housing Units and Inhabitants

Each building typically has 21-50 housing unit(s). 32 units in each building. Usually there are 10 - 32 units in building. One family typically occupies one housing unit. The number of inhabitants in a building during the day or business hours is more than 20. The number of inhabitants during the evening and night is others (as described below). On average, Chinese families consist of 4 persons. Night time occupancy is more than 40 persons. On average, a Chinese family consists of 4 persons.

4.2 Patterns of Occupancy

10 - 32 families typically occupy one house. (2 - 4 families typically occupy each floor and there are usually 5 - 8 floors in a house.).

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)	☐

Economic Level: For Middle Class the Housing Price Unit is 200,000 and the Annual Income is 30,000.

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 1 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**		
		True	**False**	**N/A**
Lateral load path	The structure contains a complete load path for seismic force effects from any horizontal direction that serves to transfer inertial forces 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	The superstructure and foundation is individually connected to the rubber bearing isolators with bolts which possess adequate seismic resistant to transfer the seismic forces (vertical loads, shear loads and moments) between the foundation and superstructure.			

5.2 Seismic Features

Structural Element	**Seismic Deficiency**	**Earthquake Resilient Features**	**Earthquake Damage Patterns**
Wall			
Frame		During earthquake, the isolation structure will work as follows: 1. All horizontal deformations of superstructure	

(columns, beams)		elements will concentrate on the isolation layer, the structure will be kept within the elastic limit, so that no damages will occur in the structure. 2. The natural period of isolation structure will become very long due to the low horizontal stiffness of isolation layer, so that the isolation structural seismic response will be reduced to 1/4 - 1/8 of the non-isolation structural seismic response, protecting the structure from any damage and becoming very safe in strong earthquake. 3. The horizontal deformation of rubber bearing isolators will be limited by enough damping ratio.	
Roof and floors			
Other			

1. The natural period of isolation structure is very long due to the low horizontal stiffness of isolation layer. This causes the isolation structural seismic response to reduce to 1/4 - 1/8 of the response of similar non-isolation structure. This protects the structure from any damage and makes it very safe in strong earthquake 2. No damage has been observed for base-isolation buildings in many strong earthquakes in China so far.

5.3 Overall Seismic Vulnerability Rating

The overall rating of the seismic vulnerability of the housing type is *E: LOW VULNERABILITY (i.e., very good seismic performance)*, the lower bound (i.e., the worst possible) is D: MEDIUM-LOW VULNERABILITY (i.e., good seismic performance), and the upper bound (i.e., the best possible) is *F: VERY LOW VULNERABILITY (i.e., excellent 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
1994	Taiwan Straits, China	7.3	VIII (220 GAL)
1995	Yunan Province	6.5	VIII (220 GAL)
1996	Yunan Province	7	VIII (220 GAL)
2000	Xinjian Autonomous	6.2	VII (110 GAL)

No damage has been observed in base-isolation buildings during these earthquakes.

Figure 6A: Typical Earthquake Damage of Brick Masonry Buildings Without Base Isolation (1976 Tangshan Earthquake)

Figure 6B: Base Isolated Brick Masonry Building Undamaged in the 1996 Yunan Earthquake (Magnitude 7.0)

6. Construction

6.1 Building Materials

Structural element	Building material	Characteristic strength	Mix proportions/dimensions	Comments
Walls	Brick masonry	Compression fc = 4.2 MPa, shear fv = 0.2 MPa	mortar 1:6 cement/sand, brick size 240 x 115 x 53 mm	
Foundation	RC	Compression fc = 10 MPa, steel yield fy= 235 MPa		Low strength concrete and mild-steel is used for foundation.
Frames (beams & columns)				
Roof and floor(s)	RC	Compression fc = 17 MPa, Steel yield fy = 335 MPa		

6.2 Builder

It is typically built by developers for sale.

6.3 Construction Process, Problems and Phasing

The entire process of building construction is as follows: 1. Developer buys the land and then entrusts the designer for designing the building with base isolation. 2. Developer selects the construction company for constructing the designed building. 3. Developer buys the rubber bearing isolators from special factory. 4. Developer entrusts the testing center to test and check the characteristics of rubber bearing isolators that will be used in the construction. 5. Contractor constructs the foundation and basement. 6. Contractor fixes the rubber bearing isolators on top of the basement. This process may be manually done. 7. Contractor constructs the superstructure on rubber bearing isolators. 8. Contractor constructs the non-structural elements and finishing of the building. 9. The quality of construction is checked to ensure that it is acceptable. The superstructure is checked to ensure that it has free space to move in horizontal and vertical directions during earthquake. The horizontal space should be greater than 200 mm, and the vertical space should be greater than 20 mm. 10. Developer sells the house. 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

The design of superstructure and substructure of buildings can be done by the general structural engineers.The structural engineers who have enough knowledge and experience in designing the base-isolation buildings can do the design of base-isolation system. Engineers design the base-isolator, superstructure and substructure. Architects design the building plan, and details of architectural treatment for isolation layer.

6.5 Building Codes and Standards

This construction type is addressed by the codes/standards of the country. 1. Building design code for seismic resistance (GB50011-2001). 2. Technical rule for seismic isolation with laminated rubber bearing isolators (CECS 126-2001). 3. Standard of rubber bearing isolators (JG 118-2000). The year the first code/standard addressing this type of construction issued was 2000. Same as above. The most recent code/standard addressing this construction type issued was 2000.

Building code is enforced through quality control procedures during construction. Separate quality certification is not required.

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 Builder.

6.8 Construction Economics

RMB 1200 / m² (US$ 145 / m²). 20 days are required for the construction of foundation and basement, during which labor with only general technical level is required 3 days are required for fixing the rubber bearing isolators, during which labor with only general technical level is required 60 days are required for constructing the superstructure (around 10 days each storey), during which labor with only general technical level is required.

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. NA.

8. Strengthening

8.1 Description of Seismic Strengthening Provisions

Strengthening of Existing Construction :

Seismic Deficiency	Description of Seismic Strengthening provisions used
NA	NA

No damages have been experienced for this type of buildings during past earthquakes in China. So far, there has been no necessity to strengthen the isolation buildings.

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?
NA.

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

8.3 Construction and Performance of Seismic Strengthening

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

Who performed the construction seismic retrofit measures: a contractor, or owner/user? Was an architect or engineer involved?
NA.

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

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