World Housing Encyclopedia

A Resource on Construction in Earthquake Regions

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International Association for Earthquake Engineering (IAEE)

HOUSING REPORT

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

Report#	9
Last Updated	
Country	China
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Reviewers	Ravi Sinha,

Important

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General Information

Building Type:	Multistory base-isolated brick masonry building with reinforced concrete floors and roof
Country:	China
Author(s):	Fu L. Zhou Zhong G. Xu Wen G. Liu
Last Updated:	
Regions Where Found:	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.
Summary:	This is typically a 5- to 8-story building with commercial enterprises on the ground floor andresidences 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 resistanceinduces severe damage or collapse of buildings and causes thousands of deaths during anearthquake. Since 1990, base-isolated brick masonry buildings with reinforced concretefloors/roof have been used more widely in China. The base-isolated building consists of anisolation system (laminated rubber isolation devices) superstructure and substructure. Thebase-isolation system is located on top of the walls or columns in the basement or at theground floor level of a building without a basement. The superstructure consists ofconventional multi-story brick masonry walls and reinforced concrete floors/roof. Thesubstructure is part of the building beneath the isolation system and consists of the basementand the foundation structure. The base-isolated masonry structure results in an increase inseismic safety by a factor of 4-12 times as compared to that of a non-isolation masonrystructure. The high seismic resistance of the base isolation structure house has been proven byshake table tests and in many actual earthquake

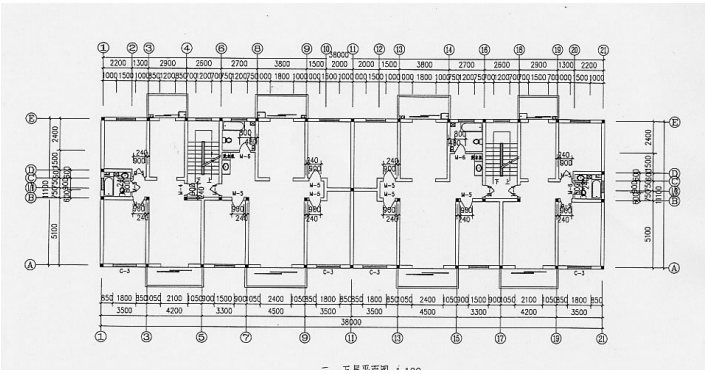
	events in China and other countries. The wideusage of base isolation technology indicates that the era of strong earthquake-proof buildingsis coming in China.
Length of time practiced:	25-60 years
Still Practiced:	Yes
In practice as of:	
Building Occupancy:	Residential, 20-49 unitsOther
Typical number of stories:	6
Terrain-Flat:	Typically
Terrain-Sloped:	Never
Comments:	The main function of this building typology is mixed use (both commercial and residential use).According to China code, the limi

Features

Plan Shape	Rectangular, solid
Additional comments on plan shape	
Typical plan length (meters)	48
Typical plan width (meters)	12
Typical story height (meters)	3
Type of Structural System	Other: Seismic Protection Systems: Building protected with base-isolation
	The vertical load-resisting system is reinforced masonry walls. Gravity load is carried by the masonry load-bearingwalls, which transfer them to the foundation through the isolation pads. The lateral load-resisting system is reinforced masonry walls. System of structure: The base isolation house structuresystem consists of isolation layer (laminated rubber bearing isolators), superstructure and substructure. The isolationlayer is located on the top of walls or columns in basement or in the first story of house without basement. Thesuperstructure consists of common multi-stories

Additional comments on structural system	brick masonry wall with reinforced concrete floors/roof, which issame as the general house structure supported on the rubber bearing isolators. The substructure consists of acommon basement and base, which is same as the general building structure. The laminated rubber bearing isolatorsare 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 sheetsinterval each other. Characteristics of isolation pads: High vertical stiffness and high vertical compression capacity forsupporting superstructure. Low horizontal stiffness, large horizontal deformation capacity for isolating groundmotion.Suitable value of damping ratio for dissipating ground motion energy. Adequate initial horizontal stiffnessfor resisting wind loads. Seismic performance: During earthquake, the isolation structure will work as follows: 1. Allhorizontal deformations of superstructure elements will concentrate on the isolation layer, the structure will be keptwithin the elastic limit, so that no damages will occur in the structure. 2. The natural period of isolation structure willbecome very long due to the low horizontal stiffness of isolation layer, so that the isolation structural seismic responsewill be reduced to 1/4 - 1/8 of the non-isolation structural seismic response, protecting the structure from any damageand becoming very safe in strong earthquake. 3. The horizontal deformation of rubber bearing isolators will be limitedby enough damping ratio.
Gravity load-bearing & lateral load-resisting systems	Isolators consist of laminated rubber bearings. Superstructures are unreinforced brick masonry buildings withreinforced concrete floor/roof slabs.
Typical wall densities in direction 1	4-5%
Typical wall densities in direction 2	4-5%
Additional comments on typical wall densities	
Wall Openings	For a typical floor, one window with 1,800 mm width and 1,500mm 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 wallsurface

	area.
Is it typical for buildings of this type to have common walls with adjacent buildings?	No
Modifications of buildings	No modifications could be observed.
Type of Foundation	Shallow Foundation: Reinforced concrete strip footing
Additional comments on foundation	
Type of Floor System	Other floor system
Additional comments on floor system	Structural Concrete: cast-in-place and precast solid slabs The floor is considered to be a rigid diaphragm.
Type of Roof System	Roof system, other
Additional comments on roof system	Structural Concrete: cast-in-place and precast solid slabs The roof is considered to be a rigid diaphragm.
Additional comments section 2	When separated from adjacent buildings, the typical distance from a neighboring building is 6 meters.



Typical Floor Plan

Building Materials and Construction Process

Description of Building Materials

Structural Element	Building Material (s)	Comment (s)
Wall/Frame	Brickmasonry	Compression fc = 4.2

		MPa, shearfv = 0.2 MPamortar 1:6 cement/sand, brick size240 x 115 x 53 mm
Foundations	RC	Compression fc = 10 MPa, steelyield fy= 235 MPa Low strength concrete and mild-steel is used for foundation.
Floors	RC	Compression fc = 17 MPa, Steelyield fy = 335 MPa
Roof	RC	Compression fc = 17 MPa, Steelyield fy = 335 MPa
Other		

Design Process

Who is involved with the design process?	EngineerArchitect
Roles of those involved in the design process	The design of superstructure and substructure of buildings can be done by the general structural engineers.Thestructural engineers who have enough knowledge and experience in designing the base-isolation buildings can do thedesign of base-isolation system. Engineers design the base-isolator, superstructure and substructure. Architectsdesign the building plan, and details of architectural treatment for isolation layer.
Expertise of those involved in the design process	

Construction Process

Who typically builds this construction type?	Other
Roles of those involved in the building process	It is typically built by developers for sale
Expertise of those involved in building process	
	The entire process of building construction is as follows: 1. Developer buys the land and then entrusts the designer fordesigning the building with base isolation. 2. Developer selects the construction

Construction process and phasing	company for constructing thedesigned building. 3. Developer buys the rubber bearing isolators from special factory. 4. Developer entrusts thetesting 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 thebasement. This process may be manually done. 7. Contractor constructs the superstructure on rubber bearingisolators. 8. Contractor constructs the non-structural elements and finishing of the building. 9. The quality ofconstruction is checked to ensure that it is acceptable. The superstructure is checked to ensure that it has free space tomove 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 ofhousing takes place in a single phase. Typically, the building is originally 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	1. Building design code for seismicresistance (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.
Process for building code enforcement	Building code is enforced through quality control procedures during construction. Separate quality certification is notrequired.

Building Permits and Development Control Rules

Are building permits required?	Yes
Is this typically informal construction?	No

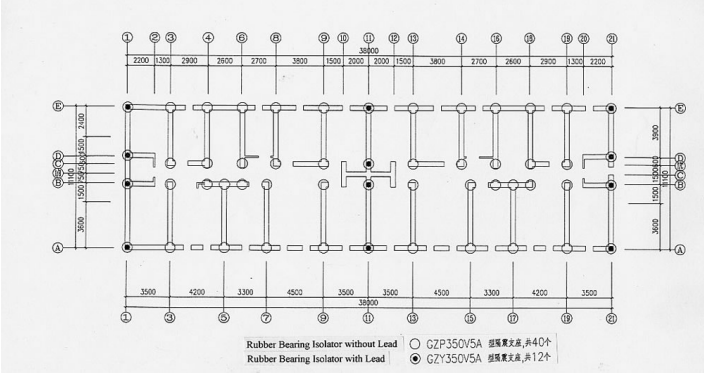
Is this construction typically authorized as per development control rules?	Yes
Additional comments on building permits and development control rules	

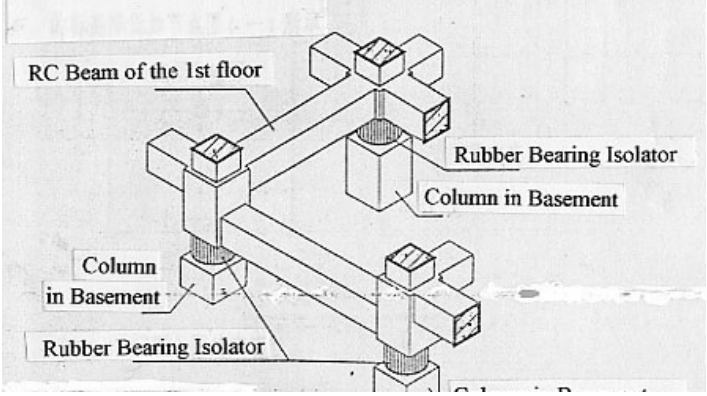
Building Maintenance and Condition

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

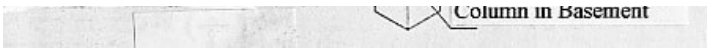
Construction Economics

Unit construction cost	RMB 1200 / m2 (US$ 145 / m2).
Labor requirements	20 days are required for the construction of foundation and basement, duringwhich 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.
Additional comments section 3	

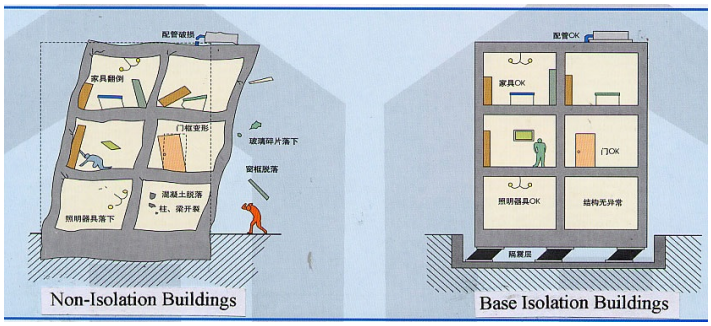




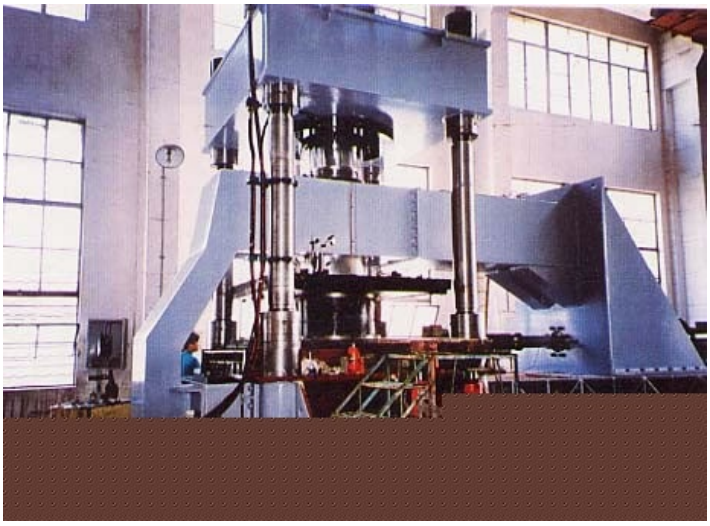
Floor Plan Showing the Layout ofIsolation Devices



Perspective Drawing ShowingConnection between Isolators and AdjacentStructural Elements

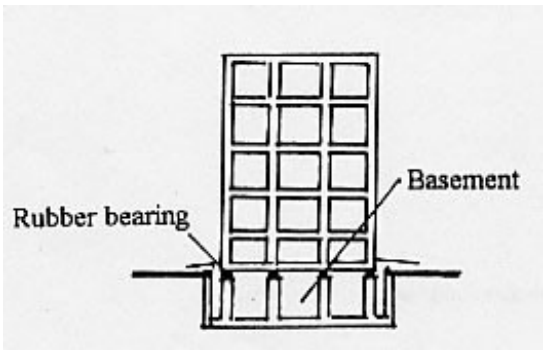


Comparison of Seismic Performance fora Base Isolated and a Conventional Building

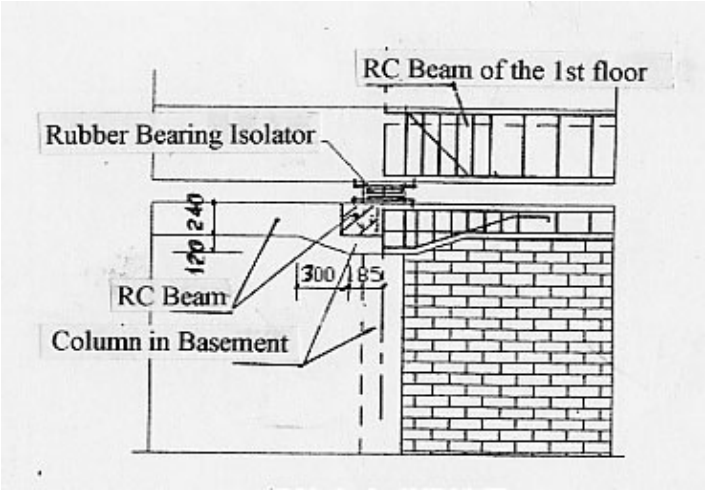


Testing Facility for Base Isolation Devices

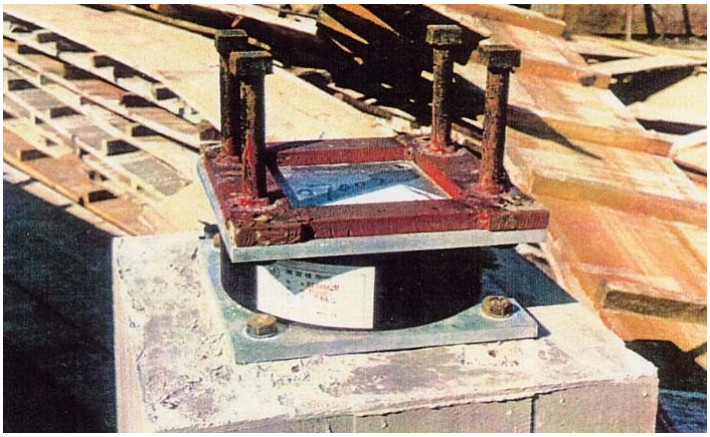
Testing Facility for Base Isolation Devices



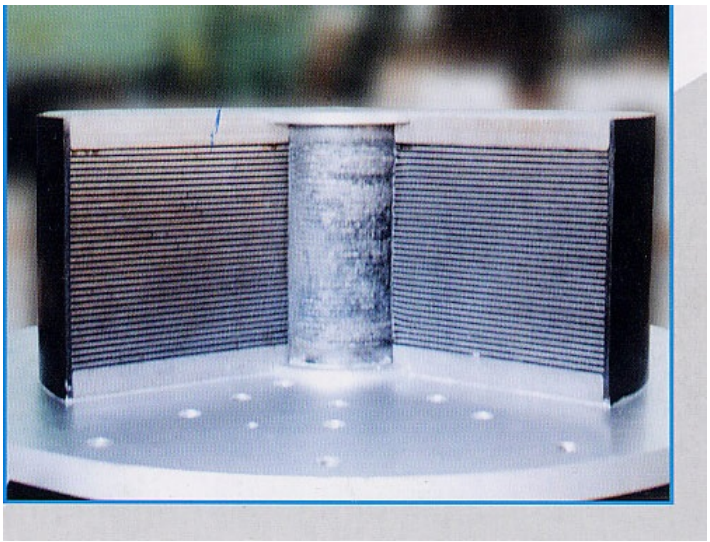
Building Elevation Showing theLocation of Base Isolation Devices



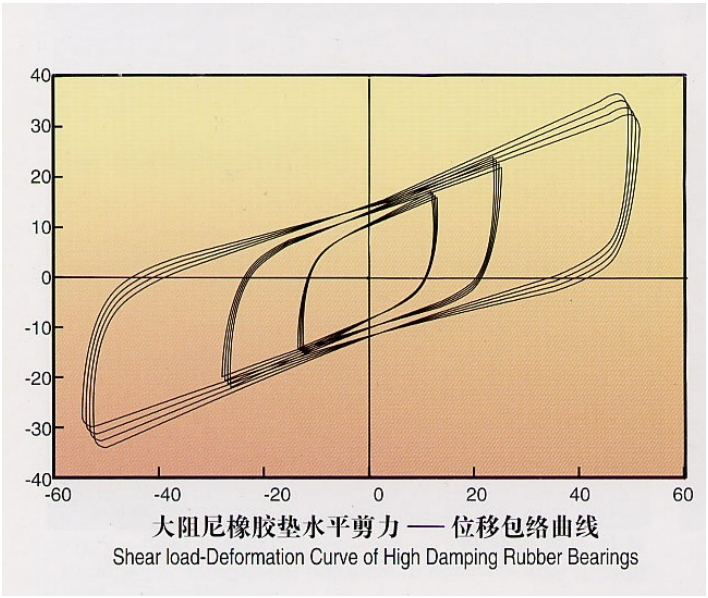
Base Isolation Device and theConnection with Adjacent Structural Elements



Installation of Base Isolation Devices



Lead-Core Rubber Isolation Devices



Load-Deformation Curve for IsolationDevices

Socio-Economic Issues

Patterns of occupancy	Each building typically has 21-50 housing unit(s). One family typically occupies one housing unit.10 - 32 families typically occupy one house. (2 - 4 families typically occupy each floor and there are usually 5 - 8 floors ina house.). Onaverage, Chinese families consist of 4 persons.
Number of inhabitants in a typical building of this construction type during the day	>20

Number of inhabitants in a typical building of this construction type during the evening/night	>20
Additional comments on number of inhabitants	Night time occupancy is more than 40 persons.
Economic level of inhabitants	Middle-income class
Additional comments on economic level of inhabitants	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: 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
1994	Taiwan Straits, China
1995	Yunan Province
1996	Yunan Province
2000	Xinjian Autonomous
2006	Yunan Province
2008	Shichuan Province
2010	Shangdong Province
2013	Shichuan Province
2014	Xinjiang Province

Past Earthquakes

Damage patterns observed in past earthquakes for this construction type	No damage.
Additional comments on earthquake damage patterns	1. The natural period of isolation structure is very long due to the low horizontal stiffness of isolation layer. Thiscauses the isolation structural seismic response to reduce to 1/4 - 1/8 of the response of similar non-isolationstructure. This protects the structure from any damage and makes it very safe in strong earthquake 2. No damage hasbeen observed for base-isolation buildings in many strong earthquakes in China so far.

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	TRUE

	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-Vertical	The building is regular with regards to the elevation. (Specify in 5.4.1)	TRUE
Building Configuration-Horizontal	The building is regular with regards to the plan. (Specify in 5.4.2)	TRUE
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);	TRUE

	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.	N/A
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).	TRUE
Quality of Workmanship	Quality of workmanship (based on visual inspection of a few typical buildings) is considered to be good (per local construction standards).	TRUE
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	The superstructure and foundation is individually connected to the rubber bearing isolators with bolts which possess adequate seismicresistant to transfer the seismic forces (vertical loads, shear loads and moments) between the foundation and superstructure.

Vertical irregularities typically found in this construction type	No irregularities
Horizontal irregularities typically found in this construction type	No irregularities
Seismic deficiency in walls	
Earthquake-resilient features in walls	
Seismic deficiency in frames	
Earthquake-resilient features in 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 nodamages will occur in the structure. 2. The natural period of isolation structure will become very long due to thelow 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 becomingvery safe in strong earthquake. 3. The horizontal deformation of rubber bearing isolators will be limited byenough damping ratio.
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	-|

Typical Earthquake Damage of Brick Masonry BuildingsWithout Base Isolation (1976 Tangshan Earthquake)

Base Isolated Brick Masonry Building Undamaged in the 1996Yunan Earthquake (Magnitude 7.0)

Retrofit Information

Description of Seismic Strengthening Provisions

Structural Deficiency	Seismic Strengthening

Additional comments on seismic strengthening provisions	No damages have been experienced for this type of buildings during past earthquakes in China. So far, there has beenno necessity to strengthen the isolation buildings.
Has seismic strengthening described in the above table been performed?	
Was the work done as a mitigation effort on an undamaged building or as a repair following earthquake damages?	

Was the construction inspected in the same manner as new construction?	
Who performed the construction: a contractor or owner/user? Was an architect or engineer involved?	
What has been the performance of retrofitted buildings of this type in subsequent earthquakes?	
Additional comments section 6	

References

Seismic Control of StructuresZhou F. L.China Seismic Publishing House 1997

Design Method of Isolating And Energy Dissipating System for Earthquake Resistant StructuresZhou F. L., Stiemer S. F. and Cherry S.Proc. of 9th World Conference on Earthquake Engineering, Tokyo-Kyoto. Aug. 1988. Vol. VIII 1998

A New Isolation and Energy Dissipating System for Earthquake Resistant StructuresZhou F. L., Stiemer S.F. and Cherry S.Proc. of 9th European Conference on Earthquake Engineering. Moscow, Sept. 1990 1990

The Technical Report on Mission As Consultant of UNIDOZhou, F.L.Summary of the International Post-SMiRT conference Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control ofVibrations and Structures, Santiago, Chile. August 1995 1995

Progress of Application and Development in Base Isolation and Passive Energy dissipation for civil andIndustrial StructuresZhou, F.L.Proc of International Post-SMiRT Conference Seminar. Cheju, Korea, August 1999 1999

Progress of Application, New Projects, R and D and Development of Design Rules for Seismic Isolation andPassive Energy Dissipation of Civil Buildings, Bridges and Nuclear and Non- Nuclear Plants in P R ChinaZhou, F.L.Proc.of International Post-SMiRT Conference Seminar on Seismic Isolation, Passive Energy Dissipation and Active Control of SeismicVibration of Structures. Taormina, Italy, August 1997 1997

7. New System of Earthquake Resistant Structures in Seismic ZoneZhou, FL.Computational Mechanics in Structural Engineering. Elsevier Applied Science Publishers Ltd., London and New York 1991

Recent Research Development and Application on Seismic Isolation of Buildings in P R ChinaZhou,F.L., Kelly,J.M., Fuller,K.N.G., and Pan,T.C.Proc. of International Workshop IWADBI, Shantou, China, May 1994 1994

Design control of structural response for seismic isolation systemZhou, F.L.Earthquake Engineering and Engineering Vibrations, No.1, 1993 1993

Technical rule for seismic isolation with laminated rubber bearing isolatorsZhou,F.L. and Zhou,X.Y.Chinese Engineering Construction Standard, CECS 126:2001, Beijing, China 2000

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