

Research and Application of Seismic Isolation System for Building Structures

ZHOU Fu-lin¹, TAN Ping¹, XIAN Qiao-ling¹,
HUANG Xiang-yun¹, YANG Zheng²

(1. Earthquake Engineering Research and Test Center, Guangzhou University, Guangzhou 510006, Guangdong, China; 2. Beijing Urban Construction Design and Research Institute, Beijing 100037, China)

Abstract: Authors introduced the recent research, application and development on seismic isolation system for building structures in China. Some typical testing analysis and researches, including the mechanical tests for rubber bearings and the shaking table tests for structural models with isolation system were provided herein. The Chinese design codes for structures with isolation system were analyzed as well as different isolation structural systems with different location of isolation layers. Recent application status and typical examples were described, especially the largest isolation concrete buildings project in the world now. Finally, some discussions were made for the tendency of future development and some problems existed in seismic isolation system for civil building structures in China.

Key words: seismic isolation; building structure; shaking table test; technical code

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房屋隔震体系的研究与应用

周福霖¹, 谭平¹, 冼巧玲¹, 黄襄云¹, 杨铮²

(1. 广州大学 工程抗震研究中心, 广东 广州 510006; 2. 北京城建设计研究院, 北京 100037)

摘要:介绍了隔震技术在中国的研究进展与工程应用现状;阐述了一些典型的试验分析与研究成果,包括橡胶隔震支座力学性能试验与隔震房屋振动台模型试验的成果;列举了典型的隔震应用实例,特别是当今世界上最大的混凝土房屋隔震项目;分析了中国的隔震技术规程,以及几种隔震层所在位置不同的隔震结构体系;讨论了隔震结构目前存在的一些问题与未来中国隔震房屋的发展趋势。

关键词:隔震;房屋结构;振动台试验;技术规范

1 Tendency of Application on Seismic Isolation in China

1.1 Urgent Requirement of Widely Using Seismic Isolation for Buildings in China

(1) China is a very frequently seismic country,

which over 60% of national land is seismic area, and about 80% of large cities are located in the seismic area. Most of earthquakes which were over predicted are very strong and cause many buildings to collapse and also great number of people to die. People urgently require having the houses that are

ensured to be safe in strong earthquakes. Widely using seismic isolation will be able to satisfy this requirement^[1-2].

(2)There are about 500 buildings with seismic isolation rubber bearings have been built in China until 2005. Some railway bridges and highway bridges with seismic isolation rubber bearings have been built also in China. It has become a very strong tendency to widely using seismic isolation rubber bearings system in China now.

1.2 Significant Advantages of Structures with Seismic Isolation Rubber Bearings System

(1)Safe in strong earthquake. Comparing the seismic isolation structures with the traditional anti-seismic structures(Tab.1), responses of the isolated structures can be reduced to 1/8~1/2 of those of the traditional structures, according to the testing results and the records in real earthquakes^[3-4]. It is very effective to reduce response of structures in earthquake and is able to prevent the structure from damage or collapse in earthquake. So it can ensure the structures with isolation rubber bearings system to be safe in strong earthquakes.

(2) Save the structure cost. Comparing the seismic isolation structures with the traditional anti-seismic structures, the building cost of isolation structures can be saved 3%~15% of the general building cost in some cases, because re-designing the super structure which seismic response is very small, according to the final statistics results of 30 buildings with rubber bearings completed in southern, western and northern China^[5-6].

(3)Wide ranges of application. The seismic isolation rubber bearings system can be used in the following aspects:①new design structures and existed structures; ② important buildings and civil buildings especially for house buildings; ③both for protecting the building structures and for protecting the facilities inside the buildings^[7-8].

(4)Free architectural design. The seismic isolation rubber bearings system can be used in the buildings with irregular configuration, by putting the isolation layer on the suitable vertical level,

and by arranging the isolators with different stiffness and damping in plan of isolation layer. But it is impossible to be done for the traditional anti-seismic buildings that must be regular configuration very strictly^[9-10].

Tab.1 Technical and Economical Comparison of Seismic Isolation Buildings and Traditional

Anti-seismic Buildings

表 1 隔震房屋与传统抗震房屋的技术与经济对比

Type of Buildings	Traditional Anti-seismic Buildings	Seismic Isolation Buildings
Acceleration Response	1. 00	1/8~1/2
Working State of Structure During Earthquake	Inelastic	Basically elastic
Building Cost	1. 00	0. 85~0. 97
Building Configuration Requirements	Regular	Irregular

2 Test and Design of Seismic Rubber Bearings System

There are five kinds of materials have been used for isolators in China, including sand layer, graphite lime mortar layer, slide friction layer, roller and rubber bearing (Fig. 1, 2)—this is the laminated steel sheet rubber bearing with or without lead core^[11]. There are over 500 civil buildings with isolation rubber bearings built in China until now. These buildings include houses(about 70%), office, school, museum, library, and hospital. The number of buildings story is 3~19. The most of structural types of buildings are concrete frame or shear wall-frame structures.

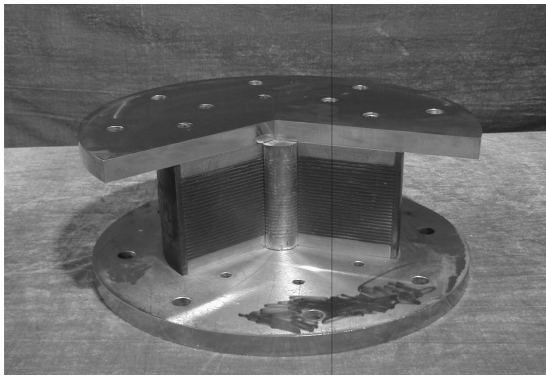


Fig. 1 Design of Isolation Rubber Bearing

图 1 橡胶隔震支座设计

Many tests have been finished and whole sets of

computation theory of seismic isolation rubber bearings system have been established in China now. The tests include two kinds of work as follows:

(1) Tests of rubber bearing isolators, include compression tests (capacities, stiffness), compression-shear cycle loading tests (stiffness, damping ratio and maximum horizontal displacement) (Fig. 3), low cycle fatigue failure tests, creep tests and ozone aging tests.



Fig. 2 Installation of Isolation Rubber Bearing
图 2 橡胶隔震支座安装

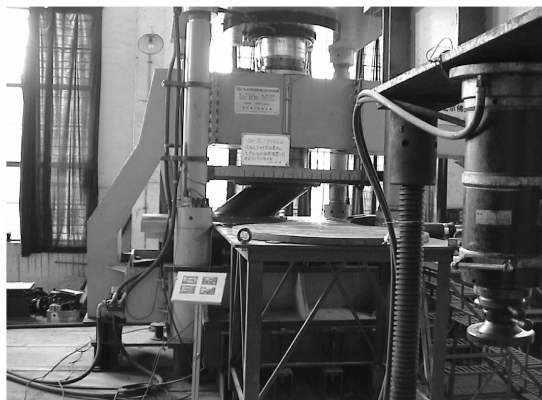


Fig. 3 Compression-Shear Test for Isolation Rubber Bearing
图 3 橡胶隔震支座压缩-剪切试验

(2) Shaking table tests for large scale structural model, including one 6 stories concrete shear wall-frame model are tested on the shaking table (Fig. 4). The testing results show that the acceleration responses on each stories of structure model are nearly the same. It means that the elements and joints of structure with isolation rubber bearings nearly work within elastic range only. The acceleration response of structure with isolation is only 1/10~1/3 of fixed structure. It means the rubber bearing isolation structure is more effective

to attenuate the structural response in earthquake than any other methods.

3 Different Isolation Structural Systems

3.1 Different Locations of Isolation Layer

There are five kinds of locations of isolation layer with rubber bearings in China.

(1) Base isolation.

Isolation layer is located on the base of building.

(2) Basement isolation.

Isolation layer is located on the certain story of the basement [Fig. 5(a)].

(3) Story isolation.

Isolation layer is located on the top of the first story [Fig. 5(b)] or certain story of super structure [Fig. 5(c)].

(4) Top isolation.

Isolation layer is located on the top of building [Fig. 5(d)], like TMD, is always used to add 1 or 2 stories on the top of existed building for seismic retrofit^[12].

(5) Over bridge linking isolation.

Isolation layer is located at the linking joints between over bridge and buildings [Fig. 5(e)] to decouple the

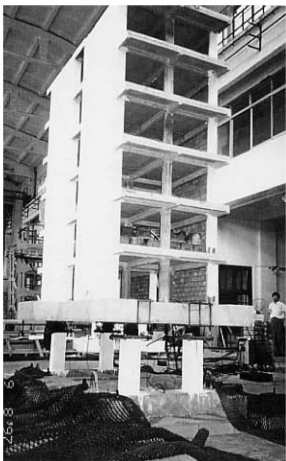


Fig. 4 Shaking Table Test for Isolation Structure
图 4 隔震结构振动台试验

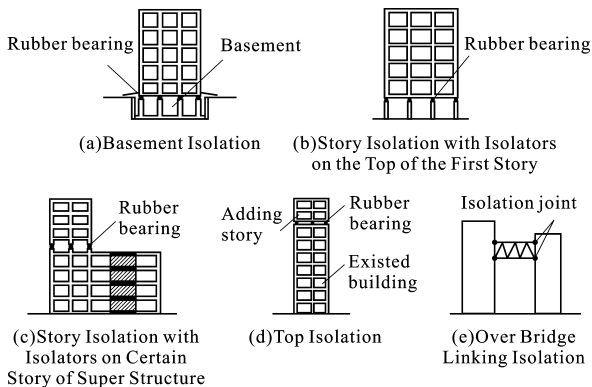


Fig. 5 Different Locations of Isolation Layer in Structure

图 5 结构中隔震层的不同位置

different model shapes of buildings linked by over bridge.

3.2 Different Design Levels for Isolation Buildings

There are three design levels of isolation buildings in China now^[13].

(1)Level 1. General structural design level for common isolation civil buildings; the compression stress of bearing is controlled in 12~15 MPa. The designing horizontal seismic load for super structural is allowed being decreased to be 1/8~1/2 of traditional anti-seismic structure, and is allowed to re-design the super structure for decreasing the section or reinforces of structural elements. In this design level, the cost of isolation building will be saved about 3%~15% comparing with the traditional anti-seismic building. The safety level will increase to be 2~4 times of the traditional anti-seismic structure.

(2)Level 2. Important structural design level for important isolation buildings; the compression stress of bearing is controlled in 10~12 MPa. The designing horizontal seismic load for super structure is allowed being decreased to be 1/4~1/2 of traditional anti-seismic structure, and is allowed to re-design the super structure for a little decreasing the section or reinforces of structural elements, or does not need to re-design the super structure. In this design level, the cost of isolation building will be balanced or increased about 3%~5% comparing with the traditional anti-seismic building. But the safety level will increase to be 3~6 times of the traditional anti-seismic structure.

(3)Level 3. Special important structural design level for special important isolation buildings; the compression stress of bearing is controlled in 8~10 MPa or lower. The designing horizontal seismic load for super structure is not allowed being decreased. Also it does not need to re-design the super structure. In this design level, the cost of isolation building will be increased about 5%~7% comparing with the traditional anti-seismic building. But the safety level will increase to be 4~8 times of the traditional anti-seismic structure.

4 Technical Code on Seismic Isolation in China

Technical codes on seismic isolation consist of three different sets of codes in China.

(1)Technical specification for seismic isolation with laminated rubber bearing isolators (CECS 126:2001). This is the national code for design and construction of buildings and bridges with seismic isolation in China.

(2)Standard of laminated rubber bearing isolators(JG 118-2000). This is the national standard of isolators for laminated rubber bearing in China.

(3)Seismic isolation and energy dissipation for building design(chapter 12 in the code for seismic design of buildings, GB 50011-2001). This is a part of national code in China for seismic design of buildings^[14].

Some main introductions for all these three codes(standards) on seismic isolation in China are described as below:

(1)Provide the design methods of seismic isolation for buildings, bridges, special structures and industry facilities.

(2)Provide the design methods of seismic isolation for new design structures also for retrofit of existed structures.

(3)Allow following three design level depending on the importance of structures and requirements of owners in the areas with different economic situation in China. Level 1, for general structures, using isolation will save building cost about 3%~15%. Level 2, for important structures, using isolation will increase building cost 3%~5%. Level 3, for special important structures, using isolation will increase building cost 5%~7%. But the isolation buildings designed by any level will increase the seismic safety about 2~8 times comparing with the traditional anti-seismic buildings.

(4)Provide two methods of structural analysis for seismic isolation of structures. ① equivalent shear method, it is the static analysis methods for structures that are not higher than 40 m or 10 sto-

ries, regular configuration with shear deformations predominantly;② time-history analysis, it can be used for all structures.

(5)Allow reducing the seismic shear load for designing super structure for saving the building cost for general civil buildings or for some poor economic areas.

(6) Allow choosing the different compression stress level for isolators.

σ is 12~15 MPa, for general civil buildings or for some poor economic areas.

σ is 10~12 MPa, for important buildings or for general areas.

σ is 8~10 MPa or $\sigma \leq 8$ MPa, for special important buildings or for rich areas.

(7)Control the maximum horizontal shear displacement D_{max} of isolation layer. D_{max} shall not be larger than 0.55 times of diameter of bearings and 300% shear strain deformation of bearings. D_{max} shall be the total displacement including both translation and torsion of structural system.

(8)Require high quality of rubber bearing to be proved by completing test.

5 Examples of Seismic Isolation Buildings in China

5.1 Example 1

RC frame multi-stories house building with base isolation. Some 7 or 8 stories RC frame house building—one of the most popular isolation building types in China was built from 1991 in China. Rubber bearings layer is located on the base(Fig. 6). The design



Fig. 6 RC Frame 7 Stories House Building with Story Isolation

图 6 带层间隔震的钢筋混凝土框架 7 层住宅楼

level is Level 1. The compression stress of bearing is nearly 15 MPa. The designing horizontal seismic load for super structural was decreased to be 1/4 of traditional anti-seismic structure. The super structure was re-designed for decreasing the section or reinforces of structural elements. The cost of isolation building is saved about 7% comparing with the traditional anti-seismic building. The safety level increases to be over 3 times of the traditional anti-seismic structure. There are about 180 buildings of this type have been built in China.

5.2 Example 2

RC frame-shear 13 stories museum with story isolation. One 13 stories RC frame-shear museum was built in 1996 with 28 000 m² in southern China (Fig. 7). The rubber bearings layer is located on the top of the column in the first story because the building without basement. The design level is Level 2. The compression stress of bearing is nearly 12 MPa. The designing horizontal seismic load for super structural is allowed to be decreased to be 1/4 of traditional anti-seismic structure. The cost of isolation building is increased about 2% comparing with the traditional anti-seismic building. But the safety level increases to be 4 times of the traditional anti-seismic structure. It protects not only the structure, but also the history relic inside the building.



Fig. 7 RC Frame-Shear 13 Stories Museum with Story Isolation

图 7 带层间隔震的抗剪钢筋混凝土框架 13 层博物馆

5.3 Example 3

RC frame 2 stories platform adds 9 stories house with story isolation. The seismically isolated artificial ground is the largest area in the world

(Fig. 8,9). There is a very large platform(2 stories RC frame) with 1 500 m wide and 2 000 m long to cover a railway area in Beijing. There are 50 isolation buildings(7~9 stories RC frame) built on the top floor of the platforms. The rubber bearings layer is located on the top floor of the platform to isolate the seismic motion also to isolate the railway vibration.

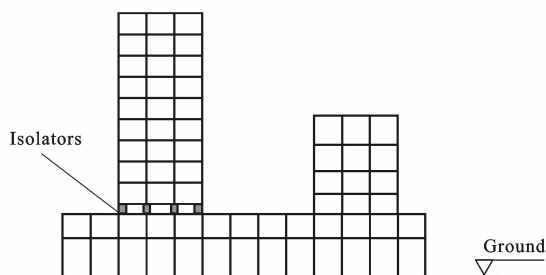


Fig. 8 Stories Isolation Used in IHBSH

图 8 层间隔震用于地铁站隔震住宅楼



Fig. 9 Part of View of IHBSH

图 9 地铁站隔震住宅楼部分视图

6 The Isolated Buildings Which is the Largest Area in the World

6.1 The Background of Using Isolation for This Large Area of Buildings

(1)The very large area of subway and railway communication hub on the ground is located nearly in the center of Beijing, where the land is very expensive. The city government urgently wants to effectively use the land in this large area as house buildings, also wants to solve the seismic and environmental problems of railway vibration and noise in the center area of Beijing. This project is named as Isolation House Buildings on Subway Hub(IHBSH).

(2)There is a very large platform of 2 stories RC frame, which is used to put all equipment and facilities for railway hub in it, and cover the noise

from the railway trains. The size of platform is 1 500 m wide and 2 000 m long. There are 50 house buildings(7~9 stories RC frame) built on the top floor of the platforms. The floor area of all isolation house buildings is approximately 480 000 m² which is the largest area using seismic isolation in the world. From the results of analysis and test, using stories isolation is the best way for seismic design(design ground motion 200~300 Gal). The rubber bearings layer is located on the top floor of the platform (Fig. 8,9).

6.2 Design and Shaking Table Tests

(1)The design level is Level 2. The compression stress of bearing is about 10 MPa. The size of rubber bearings mainly is $\Phi 700$.

(2)The shaking table test had shown that the horizontal seismic loads were decreased to be 1/4 for super structure and 1/2 for platform structure comparing with the traditional anti-seismic structure(Fig. 10). During the strong earthquake(400 Gal) input, the structure is perfect with no any damage for putting isolators between the platform and the building, but the structure is severely damaged and nearly collapses for fixing joint between the platform and the building.



Fig. 10 Shaking Table Tests for Structural Model of IHBSH

图 10 地铁站隔震住宅楼结构模型的振动台试验

6.3 Technical and Economical Comparison of Isolation with Non-isolation

The comparison results of isolation, energy dissipation and traditional design from analysis are listed in Tab. 2.

The large benefits of using stories isolation are described as below:

(1) The seismic safety of structures increases to 4 times.

(2) The construction cost could save 25%.

(3) The number of building stories could rise from 6 stories to 9 stories, therefore, the building floor area increases from 380 000 m² to 480 000 m², adding 100 000 m².

Tab. 2 Comparison Results of Isolation, Energy Dissipation and Traditional Design

表 2 隔震、消能和传统设计的对比结果 %

Design Method	Seismic Shear Force	Construction Cost
Traditional Design	100	100
Energy Dissipation	80	95
Isolation	25~35	75

(4) The whole pure profit of real estate reaches ¥240 million~¥600 million calculated from pure profit ¥6 000/m² × 100 000 m² (whole pure profit ¥75 million).

(5) The environmental problems of railway vibration and noise in the center area of the city could be solved.

7 Existed Problems and Recent Researches on Seismic Isolation Rubber Bearings System in China

Some problems existed and recent researches, developments on seismic isolation in China are briefly described as below:

(1) The economic problems of isolation buildings are being studied in China. How to decrease the seismic isolation buildings cost and keep the high safety level is the urgent problem that asked to be solved. This problem influences directly widely application of seismic isolation for buildings, especially for some strong seismic areas in which economic situation is not allowed to expend more money for building's construction. Many Chinese experts are finding some optimum design methods for decreasing the cost of isolation buildings, also increasing the safety level, have gotten great progress for solving this problem.

(2) The works of expanding the application ranges of seismic isolation are being done now. In some cases, such as, for high-rise buildings, or for flexible structural buildings whose structural natural period is rather long; for soft soil site whose dominate natural period of site is rather long; for some areas which are near to the active faults and the vertical ground motion is very significant while earthquakes happen. Many Chinese experts have done some successful designs and testing research projects for solving these problems.

(3) Some new systems of seismic isolation are being found. The story isolation and top isolation are widely used for retrofit of existed buildings. The mixed isolators of rubber bearings with slide friction layer are used in some cases. A series of shaking table tests for the models of these new systems of seismic isolation have been carried out in Guangzhou University (former South China Construction University). The optimum design methods concerned these new systems of seismic isolation have been suggested.

(4) A great number of testing and researches for rubber bearings have been done for keeping high quality and wide application with low prices in China. Many researching and testing works are being done in Guangzhou University now, such as, new detail and optimum design for isolators; testing for permanence of isolators; long time testing of creep of rubber bearings on constant load; the isolators acted simultaneously by shear forces, vertical load and moments.

(5) Providing the products of isolation bearings with high quality and low cost to satisfy the great demands of rubber bearings in China and other countries in the world.

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