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NEW SEISMIC ISOLATION SYSTEM FOR IRREGULAR STRUCTURE WITH THE LARGEST ISOLATION BUILDING AREA IN THE WORLD

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SUMMARY:

This paper introduces the design, analysis, tests and application of a new isolation system used in irregular structure, also briefly introduces the recent research, and development on seismic isolation of civil buildings in China.

A very large platform (2 stories RC frame) with plane size 1500m wide and 2000m long was built to cover the city railway communication hub area. About 50 isolation house buildings (9 stories RC frame) with 480,000 M^2 were built on the top floor of platform. A new advanced isolation system named Storied-Isolation was used to ensure the seismic safety for this irregular structure with the largest isolation house building area in the world. This new isolation system have been used widely in China.

There are over 400 buildings with seismic isolation have been built in China until 2003. This paper will introduce the recent research, and development on seismic isolation of civil buildings in China, including the tendency of application on seismic isolation, different isolation systems, different design level being used, design codes, application status and examples of application. Also the paper makes discussion of some problems on the future development of seismic isolation in China.

TENDENCY OF APPLICATION ON SEISMIC ISOLATION IN CHINA

Urgent requirement of widely using seismic isolation for buildings in China

- 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 are very strong which always were over predicted and cause many buildings collapse also great number of people died. 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].

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- There are over 400 civil buildings that of most are houses, 12 bridges and some special structures using seismic isolation in China now. It has become a very strong tendency to widely using seismic isolation in China now
- China is going to a period of large-scale urban construction, many buildings were designed with irregular shape by architectural demands. The traditional anti-seismic structural systems always could not meet the requirements for structural safety. In many cases, seismic isolation systems are safer and more reasonable, especially for the structures with irregular shape [3].

Many significant advantages of buildings with seismic isolation (Table 1):

- **Safe in strong earthquake.** Comparing the seismic isolation structures with the traditional anti-seismic structures, the response of isolating structures can be reduce to 1/2-1/8 of the response of traditional structures, according the testing results and the records in real earthquake also. It is very effective to reduce the response of structures in earthquake and is able to prevent the structure from damage or collapse in earthquake. So it can ensure the buildings with isolation to be safe in strong earthquakes [4].

- **Save the building cost.** Comparing the seismic isolation structures with the traditional anti-seismic structures in the areas of high earthquake intensity, the building cost of isolation structures can be saved 3～15 % of the building cost, because re-designing the supper structure which seismic response is very small, according the final statistics results of 30 buildings with rubber bearings completed in southern, western and northern China [5].

- **Wide ranges of application**. The seismic isolation can be used in, both new design structures and existed structures, both important buildings and civil buildings especially for house buildings, both for protecting the building structures and for protecting the facilities inside the buildings.

- **Free architectural design.** The seismic isolation can be used in the buildings with irregularities 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.

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Table 1 Technical and economical comparing of seismic isolation buildings and traditional anti-seismic buildings

	Traditional anti-seismic buildings	Seismic isolation buildings
Acceleration response	1.00	1/2 - 1/8
Working state of structure during earthquake	inelastic	basically elastic
Building cost	1.00	0.85 - 0.97
Building configuration Requirements	regular	irregular

Distinguishing feature of seismic isolation in China

Different building structural styles in different areas require different feature of seismic isolation, such as different material of isolators; different location of isolation layer; different safety level for isolation design.

Different material of isolators.

There are five kinds of material used for isolators.

- **Sand layer .** The isolation layer consist of the sand grains with diameter 0.5～0.8mm, is located on the base of buildings. There are 4 buildings using sand layer as isolation layer in North China in 1980～1984 [6]. The main advantage of this isolation device is very cheap. The main problems existed are too sensitive for foundation settlement and unable to recover the displacement after earthquakes.
- **Graphite lime mortar layer** . The isolation layer consist of the lime mortar mixing with graphite powder, is located on the base of buildings. There are 12 buildings using graphite lime mortar as isolation layer in North China in 1986～1997. The main advantage of this isolation device is very cheap. The main problems existed are too sensitive for foundation settlement and unable to recover the displacement after earthquakes
- **Slide friction layer.** There two kinds of this isolation layers. One kind of slide friction layer consist of up steel plate、down steel plate and a thick steel piece between two steel plates. Another kind of slide friction layer consists of two steel plates with Teflon on the interface of two steel plates. There are 14 buildings using this kind of isolation layer in West China in 1988～1998 [7]. The main advantage of this isolation device is simple. The main problems existed are too sensitive for foundation settlement and unable to recover the displacement after earthquakes
- **Roller.** The isolation layer consists of up and down plates (plane or curve plates) with the rollers between two steel plates. There are 2 buildings using this kind of isolation layer in Centro China in 1968～1978. The main advantage of this isolation device is effective to isolate the ground motion. The main problem existed is that the device needs to be maintained for keeping operation well in its whole long working life period.
- **Rubber bearing.** This is the laminated steel sheet rubber bearing with or without lead core. There are over 450 civil buildings with isolation rubber bearings built in China until now. These buildings include houses (about 70 %), office, school, museum, library, and hospital. The story of buildings is 3～19 stories. The most of structural types of buildings are concrete frame or masonry structures. The rubber bearings are the most popular isolators to be widely used in China because of its many unique features comparing with the other kinds of isolator [8][9].
  1. Effecting of isolation. It will decrease the structural response to be 1/2～1/8 of the traditional structural response.
  2. Stable character of isolators. Without maintaining in its long permanence working life is over 100 years [10].
  3. Recover perfectly the displacement after earthquakes.
  4. Vertical tension capacity. It could suffer the vertical motion of buildings during earthquake.
  5. Insensitive for foundation settlement. It could adjust the structure force by deformation of rubber bearings when foundation settlement of building happens before or after earthquakes.
  6. Decreasing the temperature stress in structures by free horizontal deformation of bearings during large change of temperature around the structure.
  7. Successful experiences of real earthquakes in China and other countries.

Different locations of isolation layer.

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

- **Base isolation**. Isolation layer is located on the base of building.
- **Basement isolation**. Isolation layer is located on the certain story of the basement (Fig.1).
- **Story isolation**. Isolation layer is located on the top of the first story (Fig.2) or certain story of supper structure (Fig. 3).
- **Top isolation**. Isolation layer is located on the top of building (Fig. 4), like TMD, is always used to

add 1-2 stories on the top of existed building for seismic retrofit.

- **Over bridge linking isolation**. Isolation layer is located at the linking joints between over bridge and buildings (Fig. 5) to decouple the different model shapes of buildings linked by over bridge

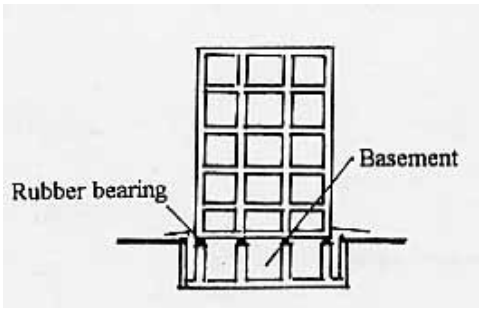

Fig. 1. Basement isolation.

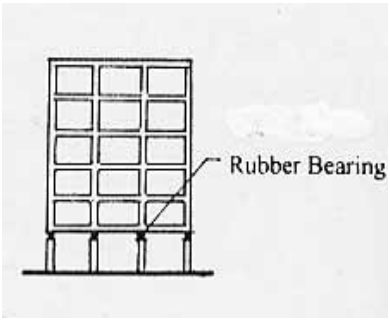

Fig. 2. Story isolation with isolators on the top of the first story

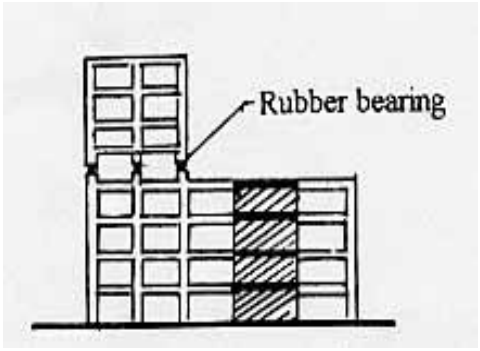

Fig. 3. Story isolation with isolators on certain story of supper structure

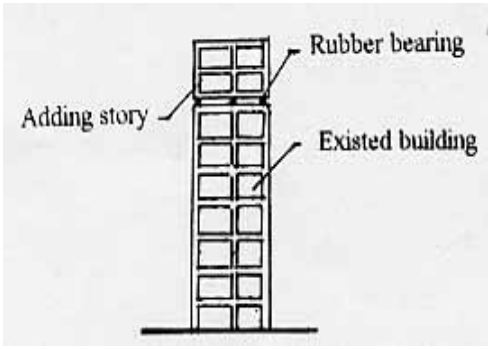

Fig. 4. Top isolation.

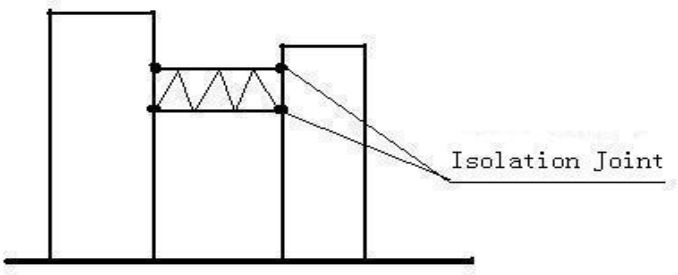

Fig. 5. Over bridge linking isolation.

Different designing levels for isolation buildings.

There are three design levels of isolation buildings in China now.

- **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 1/2～1/8 of traditional anti-seismic structure, and is allowed to re-design the supper 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. And the safety level will increase to be 2～4 times of the traditional anti-seismic structure.

- **Level 2. Important structural design level** for important isolation buildings: The 8compression stress of bearing is controlled in 10～12 MPa. The designing horizontal seismic load for super structure is allowed being decreased to be 1/2～1/4 of traditional anti-seismic structure, and is allowed to re-design the supper structure for a little decreasing the section or reinforces of structural elements, or does not need to re-design the supper 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.
- **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 supper 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.

Technical codes on seismic isolation in China

Technical codes on seismic isolation consists three different sets of codes in China:

- **Technical specification for seismic isolation with laminated rubber bearing isolators (CECS 2001).** This is the national code for design and construction of buildings and bridges with seismic isolation in China [11]..
- **Standard of laminated rubber bearing isolators (JG 118-2000).** This is the national standard of isolators for laminated rubber bearing in China.
- **Seismic isolation and energy dissipation for building design (Chapter 12 in code for seismic design of buildings, GB50011-2001).** This is a part of national code in China for seismic design of buildings, in which is the chapter 12.

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

—Provide the design methods of seismic isolation for buildings、bridges、special structures and industry facilities.

—Provide the design methods of seismic isolation for new design structures also for retrofit of existed structures.

—Allow to fellow three design level depending 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 the traditional anti-seismic buildings.

—Provide two methods of structural analysis for seismic isolation of structures:

Equivalent shear method, it is the static analysis methods for structures that are not higher than 40m or 10 stories, regular configuration and with shear deformations predominantly.

Time –history analysis, it can be used for all structures.

—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.
—Allow choosing the different compression stress level for isolators.
σ = 12～15 MPa, for general civil buildings or for some poor economic areas.
σ = 10～12 MPa, for important buildings or for general areas.
σ = 8～10 MPa or σ ≦8 MPa, for special important buildings or for rich areas.
—To control the maximum horizontal shear displacement Dmax of isolation layer.
Dmax shall not be larger than 0.55 times of diameter of bearings and 300% shear strain deformation of bearings.
Dmax shall be the total displacement including both translation and torsion of structural system.
—Require high quality of rubber bearing to be proved by complete testing.

Examples of application of seismic isolation buildings

- **Example 1. RC frame Multi-stories house building with base isolation**.
  Some 7～8 stories RC frame house building — one of the most popular isolation building types in China built from 1991 in China. Rubber bearings layer is located on the base. The design 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 supper 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. And 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.
- **Example 2. Masonry Multi-stories house building with basement isolation.**
  Some buildings group with basement isolation consists of over 60 buildings with 6～7 stories masonry house building — one of the most popular isolation building type in China built from 1996 in western China (Fig. 6). The rubber bearings layer is located on the top of the basement. The design 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 1/6 of traditional anti-seismic structure. The supper structure was re-designed the cost of isolation building is saved about 8% comparing with the traditional anti-seismic building. And the safety level increases to be 4 times of the traditional anti-seismic structure. There are about 270 buildings of this type have been built in China.

Fig. 6. Group of masonry multi-stories house building with basement isolation

- **Example 3. RC frame 7 stories house building with story isolation.**
  Some 7～8 stories RC frame house building is built from 1994 in China. 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 1. The compression stress of bearing is nearly 15 MPa. The designing horizontal seismic

load for super structural was decreased to be 1/3 of traditional anti-seismic structure. The supper structure was re-designed for decreasing the section or reinforces of structural elements. The cost of isolation building is saved about 4% comparing with the traditional anti-seismic building. And the safety level increases to be 2.5 times of the traditional anti-seismic structure. There are about 50 buildings of this type have been built in China.

- **Example 4. RC frame-shear 13 stories museum with story isolation.**
  One 13 stories RC frame-shear museum is built in 1996 with 28,000 meter square 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 supper structure was a little re-design a little decreasing the section or reinforces of structural elements. 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 satisfies to protect not only the structure, but also the history relic inside the building.

Fig. 7 RC frame-shear 13 stories museum with story isolation

- **Example 5. RC frame 2stories platform + 9 stories house with story isolation.**
  The Seismically isolated artificial ground which is the largest area in the world (Fig. 8). There is a very large platforms (2 stories RC frame) with 1500m wide and 2000m long to cover a railway area in Beijing City. 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. The detail is described in chapter 3.

Fig. 8 RC frame 2 stories platform + 9 stories house with story isolation.

THE LARGEST ISOLATION BUILDING AREA IN THE WORLD

The background of using isolation for this large area of buildings

- The very large area of subway and railway communication hub on the ground is located nearly the Beijing City center, where the land is very expensive. The City Authority urgently wants to effectively use the land in this large area as house buildings, also want to solve the seismic and environmental problems of railway vibration and noise in this city center area. This project is named Isolation House Buildings on Subway Hub..
- There is a very large platform of two 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 1500m wide and 2000m 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 M^2 which is the largest area using seismic isolation in the world. From the results of analysis and testing, 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. 9,10)

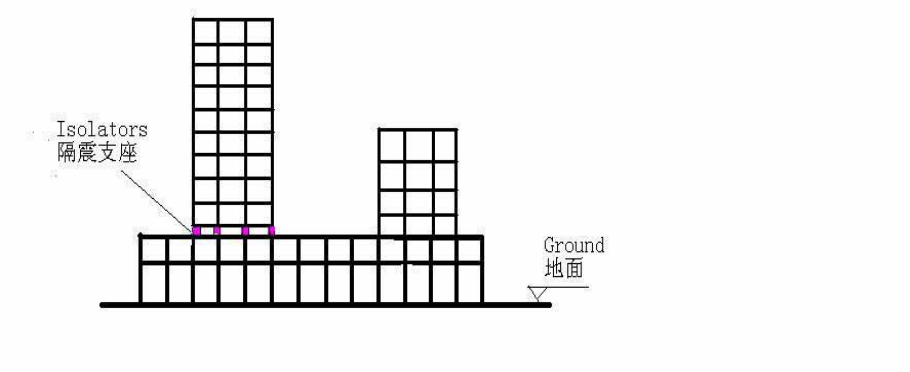

Fig. 9. Stories Isolation Structure System

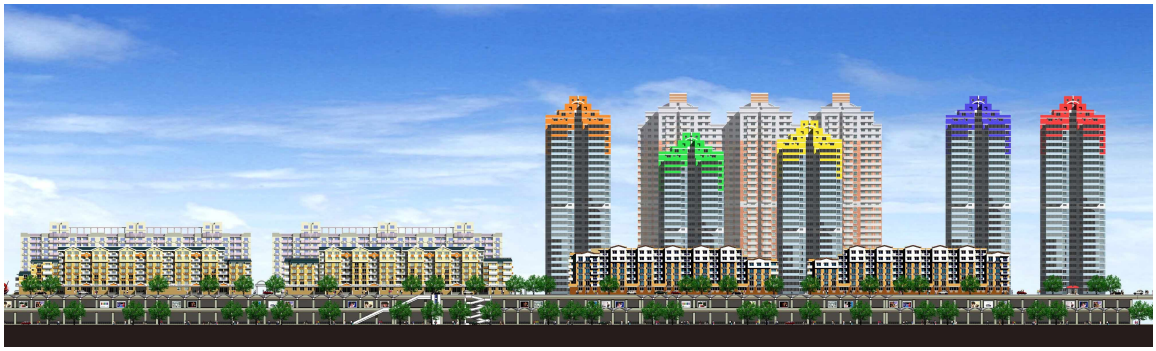

Fig. 10. A Part of view of Stories Isolation Building

Technical and economical comparison of isolation with no-isolation

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

Table 2 comparison results of isolation, energy dissipation and traditional design

	Seismic shear force	Construction cost
Traditional design	100 %	100 %
Energy dissipation	80 %	95 %
Isolation	25-35 %	75 %

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 increase from 380,000 M^2 to 480,000 M^2,
   adding 100,000 M^2
4. The whole pure profit of real estate reaches RMB 400 million--￥400,000,000
   Calculated from pure profit RMB ￥4000/ M^2 × 100,000 M^2
   (whole pure profit USD 50 million -- ＄50,000,000)
5. The environmental problems of railway vibration and noise in the city center area could be solved.

Design, shaking table tests and analysis:

- The design level is level 2. The compression stress of bearing is about 10 MPa.
  The size of rubber bearings mainly is ϕ 700
- The shaking table test shown that the horizontal Acceleration Response were decreased to be 1/4 for super structural and 1/2 for platform structure comparing with the traditional anti-seismic structure (Fig. 11,12). 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 severe damaged and nearly collapse for fixing joint between the platform and the build**ing.**
- The Acceleration values from analysis are larger than the Acceleration values from testing in most of cases (Fig.13). It means that the analysis could get the conservative result in most of cases.

Fig. 11 Shaking table tests for structural model of Stories Isolation Building

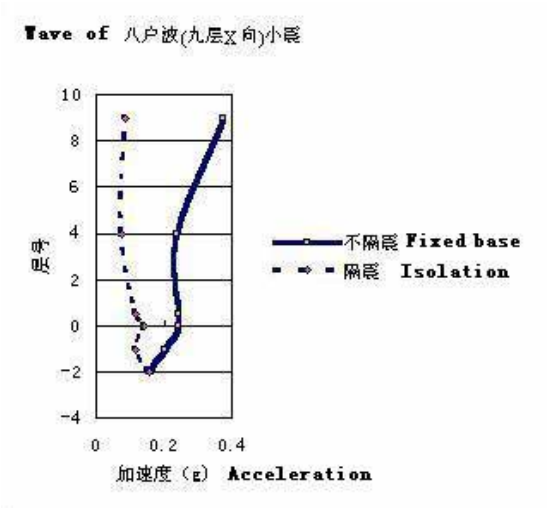

Fig. 12 The Acceleration Response Of Isolation and Fix Base When Input Ba Fu wave

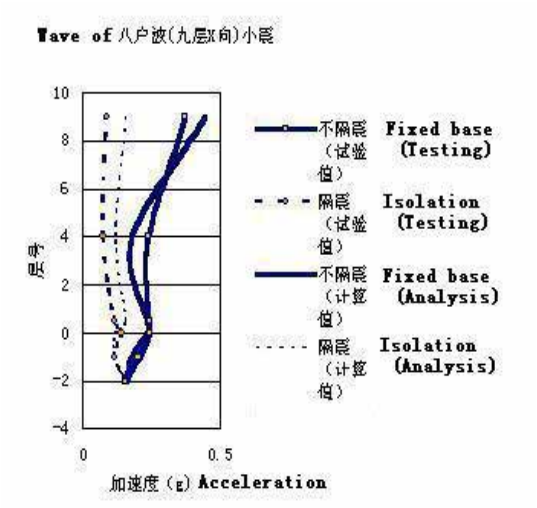

Fig. 13 The Acceleration Response of Testing and Analysis When Input Ba Fu wave

Existed problems and recent researches on seismic isolation

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

- The economic problems of isolation buildings are studying in China How to decrease the seismic isolation buildings cost also keeping 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 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 get great progress for solving this problem [12].
- The works of expanding the application ranges of seismic isolation are doing now. In some cases, such as, for high rise buildings, or for flexible structural buildings which structural natural period is rather long; for soft soil site which the 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 have done some successful designs and testing research projects for solving these problems [13][14].
- Some new systems of seismic isolation are finding. 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 [15].
- 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 doing 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.
- 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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