Research and Development of Isolation Bearings

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Abstract

Earthquakes can cause a large number of casualties. Data show that 80% of the damage is caused by the collapse of buildings or structures. Seismologists have done a lot of research for this reason. So far, isolation technology has become the most effective technology to reduce earthquake damage. Therefore, this paper makes a simple study of the existing isolation technology, and discusses the isolation bearings according to the location characteristics and structural types. The vertical isolation technology is compared and analyzed, and several typical three-dimensional isolation devices are discussed and analyzed, thus the thinking and Prospect of the existing isolation technology are put forward.

Keywords

Seismic Isolation Technology ,Vertical Isolation ,Three-dimensional Seismic Isolation Device.

1. Introduction

Earthquake will cause a large number of building and bridge damages causing more casualties, and leading to huge economic losses. Therefore, reducing earthquake harm has become an urgent issue for earthquake workers.

According to statistics, usually, about 80% earthquake casualties are due to the collapse of buildings or structures directly or indirectly, which has put forward the requirements of our earthquake researchers. In resisting earthquake and reducing the disaster losses, former seismic design theory adopted by most of countries is: we can increase the stiffness of the structure by designing the structure thereby to establish a system of ductility. That is to say improving bearing capacity and ductility of the structure and resisting seismic action. Resistance to house collapse mainly depends on its accumulated energy dissipation and destruction of the structure. Essentially, it is based on "hard resistance". In recent decades, isolation technology is an effective building disaster reduction technology. The isolation layer is set up in the building, which makes the upper part of the building flexibly separate from the foundation, and extends the natural vibration period to a longer period. This reduces the acceleration of the local response of the building. In addition, by effectively increasing the damping of the structure to absorb the energy transmitted by the earthquake, so as to ensure the safety of the building. Because the natural vibration period of fixed structure buildings is in the frequency band, violent vibration will occur in the course of earthquake. The vibration isolation system of buildings can reduce the acceleration and displacement response of buildings and reduce the damage of buildings caused by earthquakes. Some practical projects have achieved good results in the experience of earthquakes.

At present, various countries have already issued the seismic isolation technology standards, which also marks that the seismic isolation technology has become increasingly mature. From the most widely used building rubber bearing isolation technology, horizontal isolation technology already quite mature, but the vertical vibration isolation technology and three-dimensional isolation technology researches are still relatively rare[7]. While to the buildings which need to be considered the near field effect in the large span spatial structure and near the earthquake fault zone, vertical seismic action may even exceed horizontal earthquake action, Therefore, the study of vertical isolation bearings has become a top priority.

2. Seismic isolation structure classification

According to the location of isolation layer, isolation structure can be divided into base isolation, top isolation and isolation[1]. Base isolation refers to the installation of flexible isolation layer between the foundation and the superstructure of a building. In this way, the vibration period of the building structure can be prolonged and the displacement of the structure can be concentrated on the isolation layer. The superstructure will act as a rigid body with relatively small displacement to protect the building from damage and collapse. Layer separation is to place the isolation layer in the middle of the structure. In the isolation system, the flexible bearing consumes seismic energy, reduces the seismic response of the main structure, avoids the destruction and collapse of the structure, and achieves the purpose of damping control. Compared with the first two methods, the effect of top isolation is obviously insufficient, and only has a significant effect on the first mode of vibration. At present, the most widely used isolation technology is base isolation, and its effect is the most remarkable.

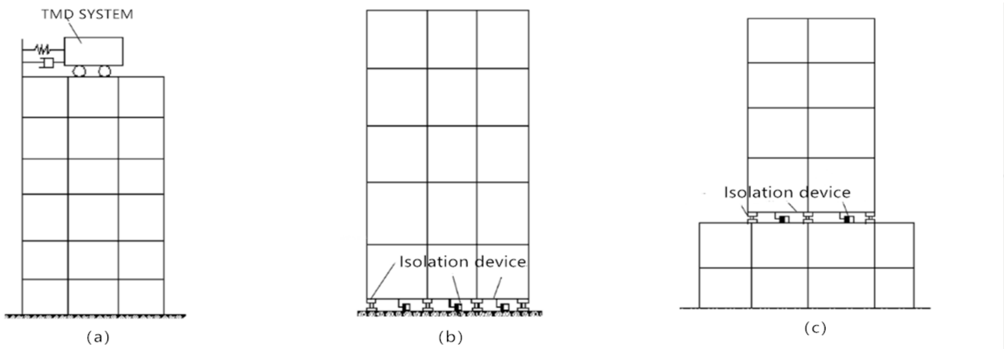


Figure 1: (a) Top-storey isolation (b) Base isolation (c) Mid-storey isolation

3. Isolation bearing type

There are many types of isolation bearings[2], which can be divided according to the type of isolation components: (i) rubber isolation bearing (ii) friction sliding isolation bearing (iii) rolling isolation bearing (iv)magnetically levitated isolation bearing (v) composite isolation support (vi) other types. Because of its many types, here are two common isolation bearings.

The rubber isolation bearing is the most widely used isolation technology, and it is also a reliable seismic isolation tested by earthquake. Rubber bearings can be divided into[7]: (1) ordinary laminated rubber bearings (LNR); (2) high damping rubber bearings (HDR); (3) lead laminated rubber bearings (LRB). Rubber isolation bearing is a product formed by a special vulcanization process which superimpose a plurality of thin steel sheets and rubber products on each other. It also has a large vertical rigidity to support the main body of the building structure, and meanwhile a small horizontal rigidity to ensure that the isolation layer has a good horizontal deformation ability. However, the rubber isolation bearing has poor fireproofing ability, obvious aging performance problem, and it is difficult to weaken the vertical earthquakes.

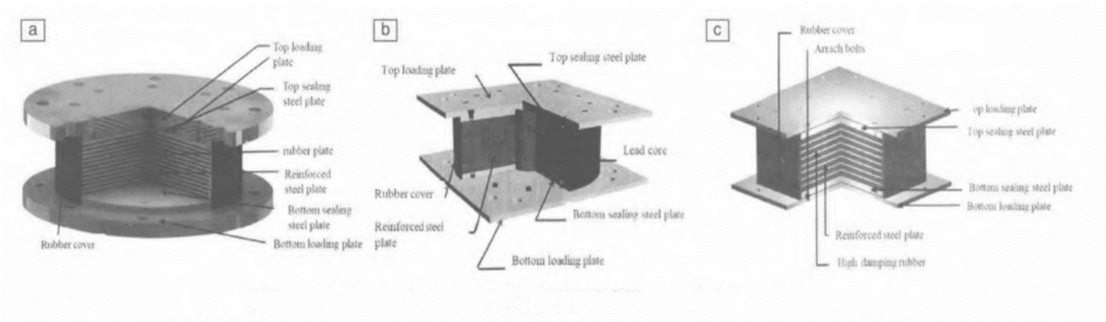
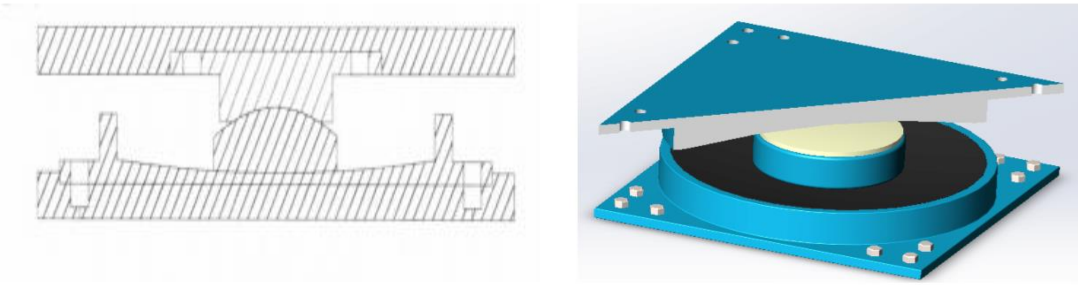


Figure 2: (a) Natural rubber bearing (b) lead rubber bearing (c) high damping rubber bearing

At the same time, friction pendulum isolation technology is one of the earliest isolation technology in China. Sliding blocks and sliding surfaces are set between the upper structure and the foundation of the building to make the building slide horizontally relative to the foundation when the earthquake occurs. Sliding friction is used to consume the energy generated by the earthquake. At the same time, it has self-resetting function and high bearing capacity. Because of friction slip, the transmission energy of earthquake to superstructure is weakened. Compared with rubber vibration isolation technology, friction sliding vibration isolation technology eliminates the requirements of fire prevention, aging resistance and temperature. Because of the structural characteristics of friction isolation technology, it has larger displacement capacity, higher bearing capacity and better durability. Friction pendulum bearings have obvious advantages under conventional loading and complex stress conditions. Friction pendulum isolation system is also the most effective and promising isolation technology at present.



(b)

Figure 3: (a) Friction pendulum isolation bearing sectional view (Li Xiaodong[3])
(b) Friction pendulum isolation bearing (Wang Shaohua[3])

4. Vertical seismic isolation technology

Vertical isolation technology has always been the difficulty of isolation technology, and it is also the main direction of many scholars' research and analysis. Traditional vertical isolation technologies, such as disc spring, magnetic levitation technology and coil spring, have been successfully applied in some projects. For space grid, a vertical spring isolation device of disc spring is proposed. Air spring is suitable for vertical vibration of machinery. In addition, a new type of variable stiffness coil spring is used in the construction field, which can significantly reduce the vertical seismic action. The new vertical isolation device has a magnetic suspension isolation bearing, which theoretically completely isolates the vertical seismic action, but the results need to be further studied. A ball-gathering vertical vibration isolation device with good vertical stiffness was also found through experiments. At present, most vertical isolation devices adopt the method of reducing the vertical stiffness to reduce the seismic impact effect, but the impact of the weakened vertical stiffness on the horizontal isolation effect has not been systematically analyzed. The advantages and disadvantages of several simple vertical isolation devices are shown in the table below[6].

Tab1. Vertical seismic isolation effect analysis table

Seismic isolation method	Advantage	Disadvantage	range of application
disc springs type	Simple structure and good deformability	Less damping	Equipment, Building, Bridge
air springs type	Good isolation effect	High cost, easy aging	Equipment
Bolt spring type	Simple construction	Normal isolation effect	Equipment, Building, Bridge
Magnetic levitation type	Good isolation effect	High cost	Equipment, Building
Composite isolation type	low cost	Normal isolation effect	Rural architecture
Vertical Isolation of Assembly Ball type	Simple structure	Easy to age and deform	Middle and Low-rise Buildings
Vertical TMD System	Good shock absorption	High cost	Building, Bridge

5. 3D seismic isolation technology

Three-dimensional isolation devices can generally be divided into two types: combined and independent. The combined three-dimensional isolation device consists of horizontal and vertical isolation components in series or in parallel, such as friction pendulum three-dimensional isolation device, laminated rubber cushion dish spring group three-dimensional isolation device. In contrast, the independent three-dimensional isolation device is an integrated device without horizontal and vertical isolation components, such as metal cable air spring three-dimensional isolation device, etc.

With the financial support of the Japanese government, Yoshihiko Morita, Hirohiko Inoue and Kazuo Fujita[8] have developed a three-dimensional isolation system for nuclear power plant reactors, which consists of hydraulic and pneumatic devices, vertical isolation system and conical disc springs. A three-dimensional base isolation device consisting of laminated rubber bearings and U-type lead dampers was used to isolate FBR reactor in Guangtian and Shuizhiyaoban[9]. The results show that the bearing has good isolation effect. Fujita S has developed a new three-dimensional isolation system. The other systems are composed of helical spring and rubber bearing. The results show that they have good vertical stiffness and good isolation effect. Academician Ou Jinping used disc spring series triangular steel plate shock absorber to improve the energy dissipation capacity of the support. Zhao Yamin[11-12] of Beijing University of Technology has developed a combined vertical vibration isolation support of disc spring, which consists of a central main disc spring and eight circular disc spring columns. The test results show that the support can withstand large vertical displacement and large frictional energy dissipation, but there are still problems of loss and rust. The durability of the support under the design reference period is still to be further studied. Academician Zhou Fulin[15] put forward a three-dimensional isolation system of laminated rubber cushion piston vertical isolation bearing, that is, adding a piston vertical isolation bearing on the ordinary rubber cushion to adjust the vertical stiffness of the isolation bearing without affecting the horizontal stiffness. Improve the stability of the isolation device.

In 2007, Academician Zhou Fulin[15] and his team conducted a three-dimensional isolation study of a nine-storey residential building in a small district of Beijing, with 103 isolation bearings. The test results of buildings with three-dimensional isolation device and traditional structures show that the isolation effect of three-dimensional isolation device is good, and the seismic performance of the lower platform structure and the upper platform structure is better improved, but its applicability and durability still need to be further studied.

In summary, although great progress has been made in the research of three-dimensional isolation, there is no fully adaptable and mature active control of three-dimensional isolation device, which needs further exploration and research, which is also an important direction of the development of seismic engineering.

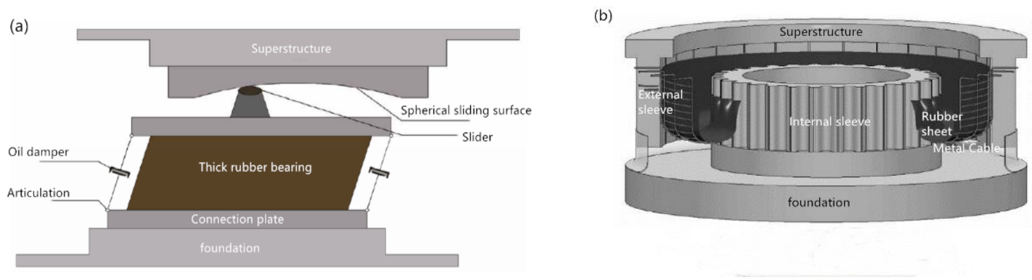


Figure 4: (a) Friction pendulum 3D-isolation bearing（Kimoto[4]）
(b) 3D-isolation with cable reinforced air spring（Kageyama[5]）

6. Problems and Development of Seismic Isolation Technology

At present, isolation technology and theory are relatively mature. Horizontal isolation technology has been applied to some projects and three-dimensional isolation research has made some progress[13-17], but there are still many problems needing further studies. The existing problems of isolation technology are as follows:

Most of the vertical isolation technologies have passed the test and theoretical verification, but there are also uplift resistance and overturning resistance. When the vertical seismic action exceeds a certain limit, there may be a large tension, which will cause the danger of collapse of buildings and cause serious consequences.

Whether the damage mechanism of three-dimensional isolation devices and horizontal isolation devices will be different under rare earthquakes or not is very important for the safety and reliability of structures.

The tensile performance of isolation devices is not high[10], and the tensile performance affects the performance of isolation devices directly.

The multi-dimensional response spectrum method is based on the elastic assumption and can only analyze the maximum seismic response. It can not distinguish the mechanism of structural damage. The multi-dimensional vibration analysis method is still in the process of perfection. Many non-linear problems deserve further study and analysis.

At present, although horizontal isolation devices have been applied to a large number of projects, the research and application of three-dimensional isolation devices are still less. At the same time, flexible isolation layers are used to consume most of the energy generated by earthquakes, while increasing the natural vibration period of structures to improve the safety of building structures. But almost all isolation devices can not achieve complete isolation, i.e. complete isolation of the impact of earthquake action. Therefore, the device that can completely isolate seismic action is still the main research emphasis. In recent decades, isolation technology is becoming more and more mature. Vertical isolation bearings, tension bearings and three-dimensional isolation bearings have made their own progress, but there are still no mature three-dimensional isolation technology products that can be widely popularized.

Especially, most of the isolation devices are in the passive control stage. The research of active control and intelligent control should be a important research trend in the future.

References

[1]Yao Dan (2018). Research on mechanical properties of segmented sliding friction pendulum isolation bearing. Southwest Jiaotong University Master Degree Thesis.

[2]Zayas V, Low S, Mahin S. A simple pendulum technique for achieving seismic isolation. Earthquake Spectra,1990,6(2):317-333.

[3]Yabana S, Matsuda A. Mechanical properties of laminated rubber bearings for three-dimensional seismic isolation .12th world conference on earthquake engineering, Auckland, New Zealand, Paper.

[4]Kimoto K, Ito Y. Feasibility study on 3-Dimensional Base Isolation System with Laminated Thick Rubber Bearings and Friction Pendulum Sliders. Summaries of technical papers of Annual Meeting Architectural Institute of Japan. B-2, StructuresII, Structural dynamics nuclear power plants. Architectural Institute of Japan, 1998:499-500.

[5]Kageyama M, Iba T, Somaki T, et al. Development of cable reinforced 3-dimensional base isolation air spring.ASME 2002 Pressure Vessels and Piping Conference. American Society of Mechanical Engineers, 2002: 19-25.

[6]Li Hong-nan,Li Zhong-xian,Qi Ai, et al. Vibration and Control of Structures.Beijing:China Architecture&building press,2005,199～206(in Chinese).

[7]Code for seismic design of building (GB50011-20010). Beijing: China Construction Industry Publishing House,2010.

[8]Nishi T. Nobuo M. Chinese Journal of Polymer Science.2013,31(1):50—57.

[9]Warn G P. Ryan K L. Journal of building.2012,2(3):300—325.

[10]Wang Wenbin,Zhao xiaoxia,Chen Yuyuan. Journal of Inland Earthqtutke,2006,20(2):172-177.

[11]Zhang Yumin,Su Youpo and Su Jingyu. Mechanical Performance of a Vertical Seismic Isolation System Employing a Dish Spring. Journal of Chongqing Jianzhu University.2008,30(6):51-54.

[12]Zhang Yumin,Su Youpo and Liang Jun. A study on vertical seism ic isolation system by disk spring. Journal of Harbin Institute of Technology.2005,37(12).

[13]LEW M, HUDSON M B. The effect of vertical groundmotion on base -isolated building system. Journal of Earth-quake Spectra,1999,15(2): 371 -375.

[14]Nagarajaiah S, Reinhorn A M, Constantinou M C. Nonlinear Dynamic Analysis of Three-Dimensional Base Isolated Structures (3D-BASIS). Journal of Structure Divididon, ASCE,119(1):130-149.

[15]Gang Jiayu(2018).Investigation on three-dimensional disc spring-high damping rubber isolation bearing. Master of Engineering Degree Thesis, Beijing University of Technology.

[16]Robinson W H, Tucker A G. A Lead-Rubber Shear Damper. Bulletin of the New Zealand National Society for Earthquake Engineering, 1977,10(3):151-153.

[17]Robinson W H, Tucker A G. Test results for Lead-Rubber Bearings for the William M. Clayton Building, Toe Toe Bridge and Waiotukupuma Bridge. Bulletin of the New Zealand National Society for Earthquake Engineering, 1983, 14(1): 21-33.