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Research and Development of Seismic Isolation Technology for Building Structure

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Abstract

The seismic isolation structure is composed of three parts: building superstructure, seismic isolation layer and foundation.,which mainly dissipates energy through the seismic isolation layer by extending the self-vibration period of the structure, thereby blocking the transmission of seismic waves upwards, and effectively protecting the safety of the superstructure and its interior. In order to deepen the understanding of basic seismic isolation technology, this paper mainly introduces the research dynamics from the aspects of model design, experimental research and numerical simulation of seismic isolation system, and summarizes the shortcomings of various studies to provide certain reference value for the development of basic seismic isolation system in the future.

Keywords

Basic Seismic Isolation System; Shaking Table Test; Mechanical Performance; Numerical Simulation.

1. Introduction

Geographically, China is located between the circum-Pacific seismic belt and the Eurasian seismic belt, and frequent earthquakes have caused heavy losses to personal safety and material resources. According to statistics, since the 20th century, China has had more than 800 earthquakes of magnitude 6; more than 100 destructive earthquakes have occurred since the founding of the People's Republic of China,Such buildings have caused non-negligible damage. Therefore, it is very necessary to develop and popularize the actual engineering of the shock absorption and isolation technology of buildings.

In ancient times, there were earthquake-isolated buildings, such as the Small Pagoda in Xi'an and the Forbidden City in Beijing. It was not until 1881 that the Japanese scholar Kozo Kawai proposed the concept of base isolation in a real sense , placing logs criss-crossed on the foundation, and rolling the logs to reduce the seismic energy. In history, the first isolation patent was born in 1870. Its principle is similar to that of a pendulum, and it is the prototype of a friction pendulum system. In 1909, the British doctor J.A. Calantarients proposed to add a layer of mica between the building and the foundation, relying on the sliding friction to resist and consume earthquake action, which is the earliest record of friction-slip isolation technology. After that, the seismic isolation technology gradually developed. The laminated rubber seismic isolation bearing was developed by New Zealand scholars in the 1950s, and then it was applied to practical projects one after another.

Around 1970, with the strong support of the state, basic seismic isolation technology in China was rapidly developed. A large number of scholars have begun to study building seismic technology, from the "hard resistance" of firmly connecting the foundation and the superstructure at the beginning to the "softness over rigidity" of setting a seismic isolation layer between the superstructure and the foundation. In just a few decades, seismic isolation technology has gradually matured, and has been widely used and promoted within a certain range. For the sake of economy, safety and applicability,

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it has become a research hot topic in the field of earthquake prevention and disaster reduction to replace traditional structural seismic isolation design with seismic isolation technology to enhance the ability of buildings to resist earthquake disasters.

This paper mainly summarizes the development study on rubber seismic isolation system, friction isolation bearings, combined seismic isolation systems,by mechanical performance, shaking table tests and computer simulations at home and abroad in recent years.It helps to review the development process and results of basic seismic isolation technology, and provides certain ideas and reference values for the future development of basic seismic isolation system.

2. Research Status of Basic Isolation Technology

2.1 Introduction of Basic Seismic Isolation Technology

The basic idea of seismic isolation[1] is to install a seismic isolation layer composed of seismic isolators and dampers between the foundation and the upper structure to protect the structure from destructive effects by effectively blocking the upward propagation of seismic waves.The principle is to reduce the deformation of the upper structure by reducing the natural frequency of the upper structure or introducing the energy dissipation of the damper.

The base isolation system is roughly divided into three categories, one is the elastic isolation bearing with rubber as the main material. For example, rubber isolation system, lead rubber isolation system.One type of friction bearings uses friction as the main energy consumption, which is subdivided into plane sliding bearings, friction pendulum bearings and rolling isolation bearings. One type is a combined isolation system formed by combining the respective advantages of the components, such as SMA-rubber isolation bearings, rubber isolation bearings with U-shaped dampers, series-parallel isolation bearings,and so on.

1. Rubber isolation system

Rubber as an elastic material, which can withstand large deformation and develop energy dissipation from the foundation to the superstructure Then rubber seismic isolation system appeared. With the application of rubber isolation bearings, scholars found that they could not meet the problems of vertical bearing capacity and energy dissipation, so they began to study the improvement of bearing capacity and energy dissipation of rubber isolation bearings, and developed laminated rubber bearings with steel plates, lead-core rubber bearings with the energy dissipation of dampers, and high-damping rubber isolation bearings,etc. lead rubber isolation bearings is shown in Figure1.

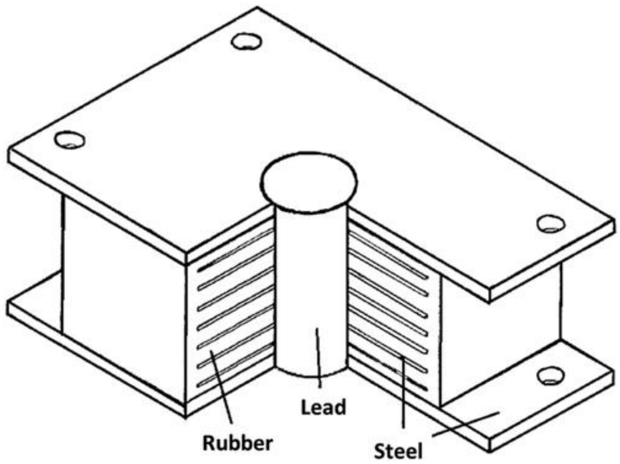

Figure 1. Lead rubber isolation bearings

2. Friction seismic isolation system

Friction isolation bearings mainly include sliding isolation system, friction pendulum and rolling isolation system. Slip isolation bearings are mainly through frictional slip energy dissipation and seismic isolation. Early plane slip bearings are mainly composed of PTFE, mica, sand layer and other materials, the advantage is that the friction coefficient is small, and the disadvantage is that automatic

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reset cannot be achieved. The friction pendulum bearing has been well developed since Zayas was proposed in 1985, using circular arc surface friction to take into account two-way seismic isolation, good bearing capacity and the reset ability provided by gravity, good seismic performance and stability. Subsequently, a variety of changes such as hyperboloid friction pendulum bearings (as shown in the Figure2, multiple friction pendulums and tapered friction pendulums appeared. However, the working process is accompanied by additional vertical displacement, which may adversely affect the structure or fail to meet the safety requirements of the equipment in the superstructure. Rolling isolation supports, including roller isolation bearings and ball isolation supports,as shoun in Figure3. It have their own advantages and disadvantages in performance. The ball has high flexibility and small friction coefficient, but it is very prone to instability; The contact area between the roller and the upper and lower support plates is large, the contact pressure on the upper and lower support plates is small, and the stability is high, but it can only be used for one-way seismic isolation and needs to be limited.

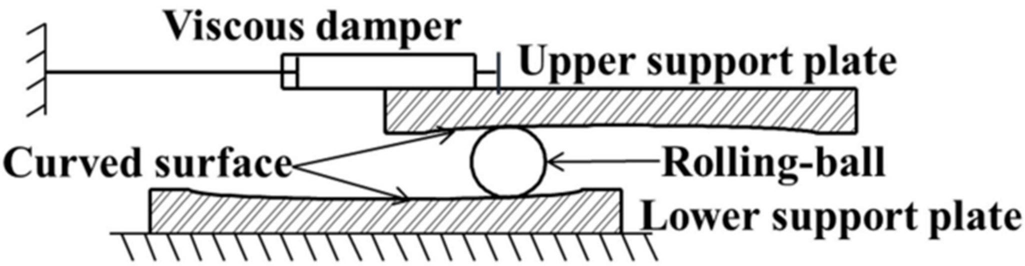

Figure 2. Friction pendulum system

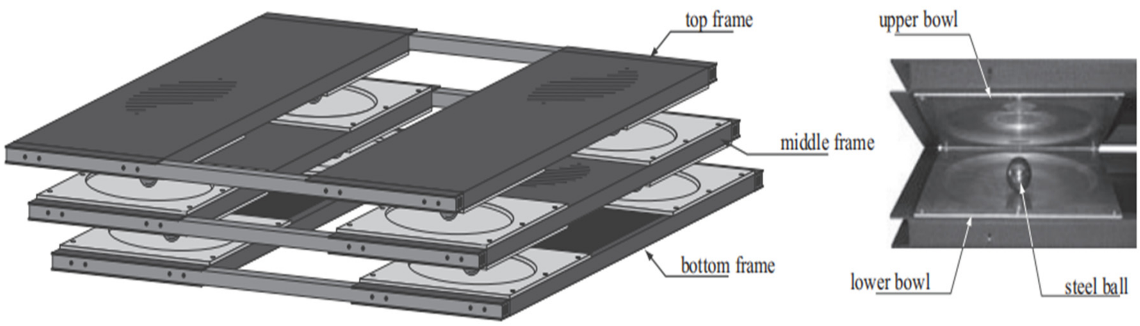

Figure 3. Rolling isolation system

3. Combined seismic isolation system

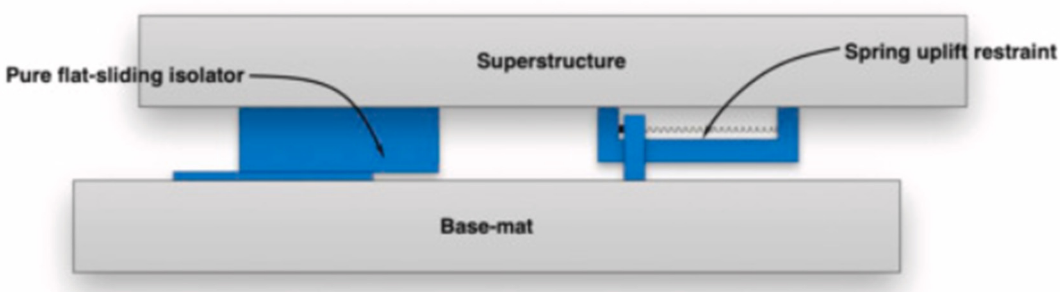

Figure 4. flat-spring friction system

The combined seismic isolation system is mainly combined and matched by the characteristics of each seismic isolation element, or multiple seismic isolation supports are connected in series and parallel to cope with the excitation of seismic waves and play a better seismic isolation effect. The earliest combined seismic isolation system was to use rubber and slip layer in series and parallel to

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suppress the displacement of the slip layer, and now it is tried to cooperate with various seismic components to apply multi-directional seismic excitation, such as variable stiffness laminated rubber isolation bearing, steel rod-rubber isolation bearing, flat-spring friction system (FFS) [2]for seismic isolation,as shown in Figure 4.

2.2 Experimental Research on Seismic Isolation System

2.2.1 Mechanical Performance

In order to accurately predict the structural dynamic response, the mechanical properties of the seismic isolation bearing need to be mastered, so mechanical performance tests are required to determine the horizontal and vertical stiffness, yield load, damping characteristics, etc. of the isolation bearing.The research on seismic isolation bearings by scholars at home and abroad starts from the test of mechanical properties of seismic isolation system.It was then applied to the structure.

The design of the Imperial Hotel Tokyo, Japan, completed in 1921, was the first application of seismic isolation bearings in modern architecture. Around 1970, American scholars began to try to add resin and other proprietary fillers to improve the energy consumption capacity of natural rubber isolation supports, and various types of high-damping rubber isolation bearings appeared; At this time, China began to conduct preliminary study and research on seismic isolation, the earliest is Professor Li's research of sand cushion seismic isolation support, after theoretical research and experimental performance test, China's first case of sand cushion seismic isolation four-story brick-concrete house was built in Beijing. In 1975, New Zealand scholar W.H. Robinson designed the lead-core rubber seismic isolation bearing, and applied it to build the world's first seismic isolation building, the William Wellington Government Office Building. Since then, many seismic isolation buildings have appeared, such as the New Zealand Museum with lead-core rubber pads and PTFE friction-skid bearings, and the seismic isolation residential building in Shantou with laminated rubber isolation bearings. In 1986, Kelly officially proposed a combined seismic isolation system that combines rubber seismic isolation bearings and friction-slip bearings, and combined seismic isolation bearings began to enter the field of vision of students.

In 2003, Yao conducted an experimental study on the mechanical properties of the developed self-damped rubber vibration isolation bearings under vertical and compression-shear loads, and gave the horizontal and vertical stiffness coefficients of the isolation devices. In the same year, Kelly[3] conducted tensile buckling analysis of the laminated rubber bearing, and the results showed that the simultaneous occurrence of tensile and shear deformation of the bearing could make the bearing avoid the influence of internal cavities. the hybrid bearing made of laminated rubber bearing and air spring was proposed by Morishita[4], in 2004. The new vibration isolation bearing mainly uses air spring to achieve vertical vibration isolation. Shape Memory Alloy (SMA) is a new type of functional material with shape memory effect, super elasticity and high damping, etc. Xue[5] combined SMA with common laminated rubber mats to produce SMA-rubber isolation bearings. The mechanical properties of SMA-rubber seismic isolation bearings were studied in 2005.

In 2010, Zhao [6]. proposed a three-dimensional seismic isolation bearing made of lead-core rubber isolation bearing and disc spring combination, and verified the horizontal seismic isolation advantage of lead-core rubber isolation bearing and vertical seismic isolation advantage of disc spring by mechanical performance test. The tests showed that the horizontal equivalent damping ratio and vertical equivalent damping ratio of the bearing reached about 20%, and the bearing capacity was high enough to be used for the three-dimensional vibration isolation of the building structure. To study the tensile performance of rubber bearing, Wang [7]proposed a lead-core laminated rubber bearing (TLRB) with tensile function in 2014, which not only has the seismic isolation effect but also can withstand the tensile force caused by earthquake to ensure the safety of the bearing when it is under tension compared with the common lead-core laminated rubber bearing (LRB). The horizontal and numerical mechanical properties were studied experimentally, and the calculation equation of the ultimate shear strain of the bearing was established to determine the safety range of TLRB that will not be damaged under the tensile-shear action.In 2016, Zhu[8] studied the effect of the eccentricity of the vertical load on the horizontal mechanical properties of the rubber bearing, and the results showed that the eccentricity of the vertical load will reduce the horizontal stiffness in the direction of the eccentric load, and under the eccentric vertical load Under the action of eccentric vertical load, the hysteresis curve of rubber bearing is obviously asymmetric. In the same year, Ai [9] analyzed the mechanical properties of lead-core rubber isolation bearings of different sizes and found that the vertical stiffness, horizontal equivalent stiffness and post-yield stiffness of lead-core rubber isolation bearings increased linearly with the increase of bearing diameter, while the equivalent damping ratio did not correlate significantly with the size of lead-core rubber isolation bearings. In 2020, Gao [10]developed a tandem-type variable stiffness laminated rubber seismic isolation bearing, and studied the vertical performance, horizontal performance and hysteresis performance of this tandem-type variable stiffness bearing by foot-rule bearing test, and gave the calculation model of this tandem-type variable stiffness bearing. In 2021, [11] Xu introduced in detail the physicochemical properties of the viscous damping material used in the new friction slip isolation bearing, and conducted theoretical and experimental studies to provide a material basis for the proposed new friction slip isolation bearing. In 2022, Huang [11]proposed the nested thick laminated bearing form, and the basic mechanical properties of the bearing were examined through tests, and the stability of the bearing was compared with that of the traditional thick laminated rubber bearing.

2.2.2. Shaking Table Test

The shaking table test is the most intuitive structural seismic test, and the test results have good comparability with the real seismic action, which is an important reference value for the seismic research and engineering design of the structure.

In 2000, Zhang [12]conducted a scaled-down shaking table test on the cell with foundation sliding bearing to verify the seismic isolation effect and the reliability of the multilayer seismic isolation structure.In 2003, Jin [13]input different seismic waves to the lead-core rubber isolation building model for experimental verification, the results show that the lead-core rubber bearing has good performance in both large and small earthquakes. In 2010, Fan [14]conducted a low circumferential repeated loading test on a seismic isolation building model with a combination of lead-core rubber isolation bearings and elastic skid plate isolation bearings to extract the hysteresis curve and skeleton curve and to study and analyze the pressure-bearing ratio of the combined seismic isolation system. The results showed that a better seismic isolation effect and energy dissipation capacity could be obtained by appropriately increasing the number of skid plate bearings.In 2011, Xin [15]also conducted a shaking table test on a two-story steel frame using a combination of rubber isolation bearings and elastic skid plate bearings in parallel to investigate the effects of frictional bearing ratio, seismic intensity and seismic waves on the displacement and acceleration of the seismic isolation structure. The shaking table test showed that the combined isolated bearing had good seismic isolation performance.In 2019, Zhou[16] designed a scaled-down friction pendulum isolated frame shear structure for reproducing the real behavior of the friction pendulum bearing in the shaking table test, and verified and analyzed it through the test to confirm the seismic isolation effect of the friction pendulum bearing.In 2021, Diao[17] designed and proposed a double-order sliding seismic isolated bearing (double-order bearing) to A shaking table test was conducted on a simply supported beam bridge test model, and the results showed that the double-order bearing seismic isolation scheme could effectively reduce the structural seismic response, after which a more in-depth study on the effect of double-order bearings in seismic isolation of multi-story structural foundations and the optimized design of bearing arrangement was needed. In 2022, in order to avoid incalculable damage to museum relics caused by earthquakes, Zou [18]developed a sliding type of seismic isolation bearing for relics. A horizontal shaking table was used to test the seismic isolation performance of the sliding heritage isolation bearing under multiple seismic wave excitation and to examine the seismic isolation effect.

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2.3 Numerical Simulation Analysis

In 1996, Jangid [19]et al. investigated the bidirectional seismic response of a single-story structure with sliding friction bearings, and found that the vibration response of the sliding structure was influenced by the bidirectional interaction of friction by comparing the response of a two-component excitation with the corresponding response generated by applying a single-component excitation independently in each direction.In 2010, Deng[20] used ABAQUS software to model the double-concave friction pendulum seismic isolation In 2011, Pei[21] mainly studied the seismic impact analysis of parallel composite isolation structure, taking the actual project as an example, and established three kinds of seismic analysis models, including traditional seismic structure, pure rubber isolation structure and composite isolation structure. The SAP2000 analysis model of work condition comparison was carried out for the comparative seismic response analysis, and it was concluded that the composite isolation structure more obviously reduced the seismic response of the seismic isolation layer and the superstructure, and had obvious seismic reduction effect. 2016, Wei[22]. newly introduced a new seismic isolation system with conical surface and sliding concave surface convex friction system for numerical simulation to evaluate the seismic isolation performance of CFS and compare the curved friction pendulum bearing to verify that it has higher lifting stability and stronger automatic centering capability. in 2020, Cao [23]proposed an improved friction dissipation bearing, the reset rubber-rigid friction sliding plate seismic isolation bearing, which was simulated and analyzed by ABAQUS finite element to study the traditional The simulation analysis was conducted by ABAQUS finite element to study the hysteresis performance comparison of traditional rigid sliding plate isolation bearing and reset rubber-rigid friction sliding plate isolation bearing. In 2021, Wang[24] proposed a structural model of seismic isolation with stiffened-ring lead-core steel pipe isolation bearing, and used ABAQUS finite element software to model the seismic isolation bearing to analyze the hysteresis performance and extract the skeleton curve, and studied the energy dissipation capacity of the main components of the isolation bearing in detail. In the same year, the optimal parameters of the stiffened ring lead-core steel pipe seismic isolation bearing components were determined. In the same year, based on the theoretical and experimental research of the new material, Xu [25]improved the pure friction slip isolation bearing, and the new friction slip isolation bearing was modeled by ANSYS finite element software and simulated by finite element software to investigate the hysteresis performance of the new friction slip isolation bearing. In 2022, Sun[26] combined the elastic buckling characteristics of steel plate with the mechanical properties of laminated rubber bearing and proposed a steel plate-laminated rubber composite seismic isolation bearing, and analyzed the mechanical properties of steel plate by ABAQUS software, and found that the shear stiffness of steel plate before and after buckling has bilinear characteristics.

3. Conclusion

With the continuous development of building seismic isolation technology, seismic isolation had evolved to a viable and dependable seismic protection strategy, which has driven scholars to in-depth research and innovation of various seismic isolation supports, and Q combines a variety of seismic isolation elements to maximize its effect, which is a new hot spot in seismic isolation research and development.

This article mainly outlines the development history and research process of domestic and foreign seismic isolation bearings, including mechanical properties, new material references, shaking table tests, numerical simulation analysis, etc.At the same time, some problems of various types of bearings themselves or in the research process are also found, and deeper research will be conducted for the problems in the future.

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