ISSN: 1813-4890

Overview of research on the development of seismic isolation bearings

Congbo Song, Bo Liu, Guowei Ni

North China University of Science and Technology, Tangshan 063000, China

Abstract

Earthquake is one of the natural disasters, which releases huge energy when it occurs. There are many seismic fault zones in China, such as the North China Seismic Zone and the Central Seismic Zone, etc., and many earthquakes in the inland areas are located near these seismic zones. Seismic isolation technology refers to the addition of seismic isolation bearings in the middle of the substructure and superstructure, seismic isolation bearings to hinder the propagation of earthquakes. During earthquakes, the lower part of the building has large stiffness, short period and high acceleration, adding seismic isolation bearings between the superstructure and the foundation makes the seismic isolation bearing and the superstructure combined as a whole, and the seismic isolation bearing has small stiffness, which can reduce the structural stiffness, reduce the resonance under the seismic condition, and ensure the safety performance of the superstructure. This paper briefly describes the advances in seismic isolation bearings.

Keywords

Earthquake, Seismic isolation bearing, Safety performance.

1. Introduction

China is prone to earthquakes, Wenchuan, Yushu, Tangshan and other earthquakes, so that many people lose their precious lives. Non-seismically isolated buildings consume seismic energy on the basis of the structure itself, which belongs to the “hard” type, but this way of resisting seismic loads has too many shortcomings. Seismically isolated buildings have been tested in earthquakes time and time again and have excellent seismic isolation properties. Today, more countries in the world are working on advanced seismic isolation bearings. Seismic isolation technology has now entered a new and more mature stage through continuous development. At present, the more common forms of foundation seismic isolation are rubber type bearings, slip type bearings, composite seismic isolation devices, etc. In order to improve the safety performance of buildings and reduce the hazards caused by earthquakes, many scholars at home and abroad have carried out a lot of scientific research on the seismic performance of buildings in earthquakes, and have made good progress.

2. Progress on friction type seismic isolation bearings

The first FPS friction pendulum vibration table test in China was completed by Yang Lin et al [1] as early as 2005, which set up a vibration isolation layer composed of FPS friction pendulum between the foundation and superstructure, and successfully proved the obvious effect of FPS friction pendulum vibration isolation through the FPS friction pendulum vibration table test of a five-story frame.

Based on the common friction type bearing, many scholars at home and abroad proposed a new type of friction type seismic isolation bearing.

Aiming at the limiting problem of friction-type bearing, Zhang Hailong et al [2] studied a new type of limiting seismic isolation bearing, which adopts molybdenum dioxide as the friction

ISSN: 1813-4890

material of the vibration isolation bearing, and this study simulated and analyzed the bearing. A finite element model was established and used for slip vibration isolation analysis. Commonly used friction materials, in addition to molybdenum dioxide, polytetrafluoroethylene friction energy dissipation is also good, Lin S [3] based on the ordinary friction pendulum bearing, the polytetrafluoroethylene plate stress was studied, and a new bi-directional variable curvature friction pendulum bearing was proposed in order to meet the needs of foundation seismic isolation under large building structures. The effects of slider factor and pressure factor on the bearing were investigated through tests, and this study showed that the hysteresis curve was fuller and the bearing had better energy dissipation performance.

Domestic scholars Lin Shuchao et al [4], in the following year also studied the new two-way variable curvature friction pendulum isolation bearing, the study is based on the principle of friction pendulum bearing construction, the use of finite element software to study the bearing. It was found that the horizontal force and displacement hysteresis curves of BDVCFPB were in good agreement with the theoretical model.

Numerous scholars at home and abroad have experimented with double concave friction pendulum bearings.In 2006, C on s t an t i o u et al [5] investigated a new type of friction pendulum bearing, which has sliding surfaces on both the upper and lower bearing plates, and has twice as much sliding displacement as compared to the FPB.Ates et al [6] investigated the stochastic response of seismically isolated bridges under the action of spatially varying ground shaking, based on the isolation of bridges,the study Double concave friction pendulum isolation bearings were applied to bridge structures. The results show that the friction pendulum system with single and double concave surfaces has an important effect on the random response of bridges under spatially varying ground shaking.

During earthquakes, ordinary friction pendulum bearings have residual displacement, so that the bearings can not be self-resetting, in order to address such problems, Biao W et al [7], studied a new type of FPB - double concave surface spring friction pendulum . The study obtained the restoring force model of the support through theoretical analysis. The vibration damping effect of simply supported girder bridges of high-speed railroads configured with DCFPS was evaluated, and the optimal spring parameters of DCFPS were determined. The results show that DCFPS has good self-resetting performance and hysteresis curve.

Chen Zhangwei et al [8], used finite element software to study the friction coefficients of the upper sliding surface and the lower sliding surface of such bearings, and the hysteresis curves, critical displacement curves, and the residual displacements of the bearings of the seismic isolation bearings were different at different friction coefficients. The study shows that the friction coefficient of the seismic isolation bearing becomes larger, its energy dissipation capacity also becomes larger, and the recovery capacity is opposite to it.Based on the ordinary friction type bearing, many scholars at home and abroad proposed a new type of variable stiffness slip bearing.

When strong seismic action occurs, the traditional slip bearing will be difficult to reset and large displacement problems, He Congjun et al [9], developed a new type of seismic isolation bearing, variable stiffness slip bearing, which was modeled by finite element software, the hysteresis performance and the state of the stress distribution was studied; the study conducted a time-distance analysis, and in a single-layer spherical mesh-shell structure, a three-way seismic action was carried out, and a comparison was made between the fixed-stiffness slip bearing and the variable stiffness slip bearing. Stiffness slip bearing, the study indicated that: NFB can reduce the seismic action of the mesh shell structure under multi-dimensional earthquake, have good relative displacement of nodes, bearing displacement control ability and bearing self-resetting ability.

ISSN: 1813-4890

In the following year, Cheng Ya [10] also conducted a study on variable stiffness slip bearing, which theoretically and numerically analyzed the hysteretic performance of the bearing, established a model through finite elements, comprehensively analyzed the static performance and seismic performance of single-layer spherical mesh shell structure applying NFB, and determined the principle of NFB parameter selection through parametric analysis to achieve the optimal seismic damping effect. The study compared constant stiffness friction slip bearings, and the results showed that the NFB had better self-recovery ability and good energy dissipation performance.

Zhongzhe Duan [11] proposed a new type of friction pendulum isolation bearing, the study modeled an actual engineering entity, input seismic waves, one artificial wave and two natural waves, to investigate its dynamic response under seismic isolation and un-isolated, the study shows that the new type of friction pendulum isolation bearing has a good seismic isolation effect on the structure.

The tensile capacity of the bearing is insufficient when the overturning force is large, Liu Shuai [12] studied the sliding bearing with wedge-shaped track. The study can horizontal displacement can be very large, wedge track and slider will have a tensile effect, through the ABAQUS model of the bearing, the study of the mechanical properties of the bearing research shows that: the vertical compression and tension capacity of the bearing is good, the bearing tensile and the wedge angle relationship is large, compression shear, tensile shear case, the bearing horizontal to the seismic performance is good.

3. Research progress of rubber type seismic isolation bearing

Based on the weak tensile capacity of ordinary rubber seismic isolation bearing, the isolation layer is easy to be damaged when the earthquake comes, in 2015, Wang Dong et al[13] proposed a new type of rubber seismic isolation bearing with a small horizontal lateral stiffness, which can effectively prevent the seismic action from being transmitted upward. Through the test and theoretical analysis, this study obtained the horizontal stiffness in compression state and tensile state calculation formula,this study shows that the calculation results and test results are more consistent.

In the following year, Pei Meng et al [14] studied a new type of variable cross-section laminated rubber seismic isolation bearing based on the problem of tensile and compressive stresses on rubber bearings, which makes the bearing tensile stresses decrease and the ultimate deformation capacity become larger, and in the shear-pressure state, the larger the horizontal displacement is, the smaller the maximum tensile stresses on the rubber of the new type of bearing are, and the distribution of the vertical reaction force of this bearing is better than that of the ordinary bearing. In the later stage, the effective pressure-bearing area of the study is larger than the ordinary bearing, and the ultimate horizontal displacement is larger than the ordinary bearing.

Along with the development of the times, the subway has come into our life, but the subway has vibration during operation, based on this, the thick rubber bearing can be used to reduce the vibration brought by the train and subway during operation.TRBs may be in tensile state in higher structures.Zengde Z et al [15] carried out a numerical and analytical study on the tensile properties of TRBs. Thick rubber bearings have very small vertical stiffness and higher vertical resistance to earthquakes, but the oscillating effect of the superstructure will increase. Liu Xuhong et al [16] developed a new type of seismic isolation bearing, prestressed thick-layer rubber seismic isolation bearing. This study concluded that PRBs have a good limiting ability on the swing angle of the superstructure than TRBs, and the more intense the earthquake, the more obvious the limiting function.

ISSN: 1813-4890

Based on the cost of rubber bearings, Fabrizia C et al [17] designed and fabricated a new recycled rubber FREI.Mechanical characterization of the recycled compound showed that RC exhibits a typical soft compound response even with low tensile deformation capacity. To prevent debonding between different layers, the adhesion of RC to polyester and nylon fabrics was investigated. These devices showed good performance and provided new ideas for the development of low-cost and environmentally friendly seismic isolation bearings for use in house construction. In the same year, Amedeo F [18] investigated recycled rubber fiber reinforced bearings, which were experimentally studied to have similar energy consumption as high damping natural rubber bearings compared to conventional rubber bearings.

Lead core rubber bearing is based on rubber bearing in which a lead core is added to increase the energy dissipation, Liu Yanhui et al [19] found through tests that the speed is very fast reciprocating load acting on the lead core rubber seismic isolation bearing, the more the number of times of loading, the more the characteristic strength of the bearing decreases significantly, the rate of decline in the later stage is smaller than the rate of decline in the early stage, the stiffness changes very little after yielding.

Zheng Wenzhi et al [20] proposed a new type of lead-core rubber bearing, based on the excellent nature of SMA, established a model of seismic isolation bearing and shape memory alloy cords, explored the hysteresis curve of the bearing, and then subsequently did the experiments to get the data to be compared to increase the accuracy and credibility of the research for the girder bridge near-field seismic action of the design of seismic system provides a reference meaning.

Xiaohong L et al [21]. studied a new type of shape memory alloy cable-restrained sliding lead-core rubber bearing, which combines the good limiting and resetting characteristics of shape memory alloy to improve the performance of the bearing. The study introduced the working theory of SMA-SLRB, and verified the mechanical model of SMA-SLRB by experimental method. A displacement-based seismic design method for SMA-SLRB isolated continuous girder bridges was established. The seismic actions on the bridge using SMA - SLRB and SLRB are compared with the arithmetic examples, and it is pointed out that the seismic isolation performance of SMA - SLRB is better than SLRB.

Based on the horizontal and vertical two-dimensional seismic isolation bearing is more, in 2009, Zhang Yongshan et al [22] proposed three-dimensional seismic isolation bearing that can resist seismicity, and this study showed that the bearing has better seismic isolation performance through the test. Based on the excellent nature of SMA, SY Yang et al [23] studied the shape memory alloy cable disc spring three-dimensional composite bearing, based on the principle of seismic isolation, mechanical properties, structure and so on, the study in the space mesh structure using this bearing. The study shows that the bearing has good seismic isolation effect.

In 2015, Wang Tao et al [24] applied the three-dimensional seismic isolation bearing to nuclear power plants, and used the form of thick rubber bearing compared with ordinary rubber seismic isolation bearing to test the mechanical properties, and the results show that the shear performance of the thick rubber bearing is similar to the ordinary rubber seismic isolation bearing, but the vertical deformation capacity of this bearing due to the ordinary rubber seismic isolation bearing, which is one-eighth of the vertical stiffness of the bearing, which protects the nuclear power plant. The bearing can protect the internal facilities of nuclear power plants from damage under earthquake.

Most of the traditional bearings are two-dimensional bearings, and connecting two bearings in series will provide a three-dimensional seismic isolation effect. Chen Zhaotao et al [25] studied a vertical variable stiffness three-dimensional seismic isolation device, which consists of a lead-core rubber bearing and a combination of hydraulic cylinders, with the former controlling the horizontal deformations and the latter controlling the vertical deformations. The study

introduced the bearing working pressure, deduced the stiffness calculation formula of the combined hydraulic cylinder, and constructed the hysteresis model. The stiffness calculation formula and hysteresis model were tested by shaking table test. It is found that the damping rate of this new type of bearing for building acceleration and internal force of rods is better than that of horizontal seismic isolation bearing.

4. Conclusion

Seismic isolation bearings can enhance the safety performance of the structure, reduce casualties and property damage in an earthquake. Rubber type bearings, friction type bearings have their own shortcomings, composite seismic isolation system generally use different bearings in series or parallel connection method to combine the bearings together, if two or more bearings are combined together, and respectively to play the strengths of many shortcomings will be improved. With the development and popularization of seismic isolation technology, experts and scholars have researched a lot of advanced seismic isolation technology, looking forward to more superior performance of seismic isolation bearing to come out.

References

[1] YANG Lin, ZHOU Xiyuan, SU Youbo et al. Experimental study and theoretical analysis of FPS friction pendulum isolation system shaking table[J]. Special Structures,2005(04):43-46.

[2] ZHANG Hailong, ZHAN Meng, WANG Shiliang. Finite element analysis of seismic action of interstory slip-isolated structures[J]. Journal of Earthquake Engineering,2016,(04):558-563.

[3] Lin S, Han J,Zhao H.Experimental and Theoretical StudiesofBidirectional Variable Curvature Friction Pendulum Bearing[J]. KSCEJournal of Civil Engineering, 2020, 24(7)

[4] LIN Shuchao, FAN Guangli, KANG Jinjun et al. Optimized design of variable curvature friction pendulum system and its finite element verification[J]. Industrial Building,2021,51(03):128-135.

[5] Fenz D M, Constantinou M C. Behaviour of the double concave Friction Pendulum bearing[J]. Earthquake Engineering & Structural Dynamics, 2006

[6] Ates S .Investigation of effectiveness of double concave frictionpendulum bearings[J].Computers and Concrete,2012,9(3):195-213.

[7] Biao W ,Kecheng W ,Weihao W , et al.Seismic isolation effect of a new type of friction pendulum bearing in high-speed railway girder bridge[J].Structures,2023,51776-790.

[8] CHEN Zhangwei, DONG Jinkun, LI Xi et al. Study on energy dissipation performance of double concave friction pendulum bearing with different friction coefficients[J]. Journal of Liaoning University of Technology (Natural Science Edition),2022,42(01):56-59.

[9] HE Congjun, CHENG Ya, ZHOU Xuhong. Research on seismic isolation performance of new variable stiffness slip bearing in mesh shell[J]. Journal of Hunan University (Natural Science Edition), 2022,49(03):145-153.

[10] CHENG Ya. Research on new variable stiffness slip bearing and its application in single-layer spherical mesh shell[D]. Hunan University,2023.

[11] Duan Zhongzhe. Study on the seismic isolation performance of a new type of friction pendulum isolation bearing[D]. Qingdao University of Technology, 2023.

[12] LIU Shuai, XIA Zhou. Numerical simulation study on mechanical performance of slip bearing with wedge track[J]. World Earthquake Engineering,2022,38(04):143-150.

[13] WANG Dong,LU Xilin. Experimental study on mechanical properties of seismic isolation bearing with tensile function[J]. Journal of Building Structures,2015,36(09):124-132.

[14] Pei Meng, Lu Fei, Zhang Fu. Research on bearing characteristics of new laminated rubber seismic isolation bearings[J]. Structural Engineer,2016,32(02):111-117.

[15] Zengde Z ,F. M V ,Ying Z .Numerical and analytical investigations on tensile behavior of thick rubber bearings[J].Engineering Structures,2024,301117313-.

[16] LIU Xuhong, CHEN Shanghong, QI Cai, LUO Caisong, ZHOU Qing. Study on the effect of oscillation on the seismic response of seismically isolated structures with prestressed thick rubber bearings[J]. Engineering Seismic Resistance and Reinforcement Retrofitting,2022,44(05):106-112.

[17] Fabrizia C,Daniele L,Luigi P. An experimental study on a novel reclaimed rubber compound for fiber-reinforced seismic isolators[J]. Structures,2022,45.

[18] Amedeo F ,Andrea C ,Donatello C .Identification and Calibration of Advanced Hysteresis Models for Recycled Rubber–Fiber-Reinforced Bearings[J].Buildings,2022,13(1):65-65.

[19] LIU Yanhui, JIANG Tingting, ZHONG Weijian, ZHOU Fulin, TAN Ping. Study on the seismic effects of base isolated structures considering the degradation of mechanical properties of lead-core rubber isolation bearings[J]. Journal of Civil Engineering,2022,55(08):46-54.

[20] ZHENG Wenzhi, TAN Ping, WANG Hao et al. Study on seismic performance of energy-consuming self-resetting sliding lead-core rubber bearings for seismically isolated bridges[J/OL]. Chinese Journal of Highway, 1-11[2024-01-23].

[21] Xiaohong L ,Qunlin Z ,Yongtao M , et al.Displacement-based seismic design of SMA cable-restrained sliding lead rubber bearing for isolated continuous girder bridges[J].Engineering Structures, 2024,300

[22] ZHANG Yongshan, YAN Xueyuan, WANG Huanding, WEI Lushun, ZHAO Guifeng. Experimental study on the mechanical properties of three-dimensional seismic isolation anti-tilting bearings[J]. Engineering Mechanics,2009,(S1):124-129.

[23] Yang S Y, Niu J. Numerical analysis on isolation effect of the SMA-disc spring three-dimensional composite bearings[C].Advanced Materials Research,2012: 2245-2249.

[24] WANG Tao, LI Jichao, WANG Fei. Research on mechanical properties of thick rubber bearing for three-dimensional seismic isolation of nuclear power plants[J]. Nuclear Power Engineering, 2015,36(05):37-40.

[25] CHEN Zhaotao, DING Yang, SHI Yundong et al. Research on vertical variable stiffness three-dimensional seismic isolation device and its seismic isolation performance for large-span space structures[J]. Journal of Building Structures,2019,40(10):35-42.