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Seismic Performance Analysis of Isolation Bearings Based on New Materials

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Abstract. As a traditional isolation technology, isolation bearing technology has also experienced many innovative research. In order to ensure that buildings and infrastructure can successfully mitigate the seismic consequences of earthquakes, new materials for isolation bearings are being studied. This paper first introduces three new materials: high performance rubber material, shape memory alloy (SMA) material and electro-rheological fluid (ERF) material. Then, their application in isolation bearing is discussed, and their anti-seismic principle and performance are analyzed. Finally, it is concluded that the selection of different new materials for isolation bearings under different conditions can improve the seismic performance of buildings and infrastructure. The three new materials proposed in this study have their own advantages and potential applications in isolation bearings, which provide more innovative and feasible choices for the design of isolation bearings. The purpose of this paper is to improve the seismic performance of the isolation bearing and ensure the effectiveness of the isolation bearing in reducing the seismic effect during the earthquake event, so as to ensure the safety of human life and property.

Keywords: Seismic isolation bearing; Seismic performance; High-performance rubber; Shape memory alloy; Electro-rheological fluid.

1. Introduction

Earthquake, as one of the most powerful and destructive natural disasters in nature, has brought huge loss of life and property to human society. In order to effectively deal with the threat of earthquake, protect the safety of buildings and infrastructure, and with the continuous improvement of people's requirements for the safety and comfort of buildings, isolation technology has emerged and continues to develop. At present, the seismic isolation technology of building structures has relatively mature technical products and engineering applications, and has been widely used in buildings such as houses, hospitals, schools, museums and libraries [1].

Traditional isolation bearings are usually made of rubber and steel, although these materials have been successfully used in shock absorption. However, there are some limitations in durability, energy dissipation ability, self-healing ability and so on. Building isolation technology can effectively reduce the seismic response of buildings caused by earthquakes, and has obvious advantages in seismic effect and social and economic benefits [2]. In this paper, three new materials are selected to study their seismic principle and performance analysis. The purpose of this paper is to study the application, advantages and prospects of new materials in isolation bearings, so as to further optimize the seismic performance of buildings and infrastructure, and ensure that they can effectively reduce the impact of vibration in earthquakes.

2. High-Performance Rubber Materials

Rubber bearings are currently the most widely used seismic isolation devices. Rubber materials have high elasticity, strong tensile properties, and damping properties. Commonly used natural rubber has a low damping ratio. Therefore, lead-core rubber bearings that combine lead with rubber are also widely used. However, lead metal is more polluting to the environment and easy to fatigue. Therefore, lead-core rubber materials must be replaced with new, high-performance rubber materials. High-damping rubber, which tries to increase rubber's damping performance to improve the seismic isolation performance of the bearings, is the main focus of research on high-performance rubber materials.

2.1. Structural Characteristics of High-Performance Rubber Bearings

High-damping rubber bearings operate on the same seismic isolation principle as regular rubber bearings. Because of the great tensile strength of the rubber material and its tendency to flex elastically, they are able to absorb seismic wave energy and lessen the damage to the above structure. The structure is also the same, as shown in Fig. 1 [3]. Therefore, the main difference between high-damping rubber bearings and general rubber bearings lies in the higher damping performance of the material. Currently, common methods to improve the damping performance of rubber materials include adding reinforcing agents, fillers, and other additives to raw rubber, or blending and copolymerizing different types of rubber [4]. The added reinforcing agents mainly include carbon black. Fillers include mica, graphite, and silicon dioxide. Blending mainly includes rubber-rubber blending, rubber-plastic blending, and rubber-fiber blending. Copolymerization mainly utilizes rubber molecules to make the material have cohesion [5].

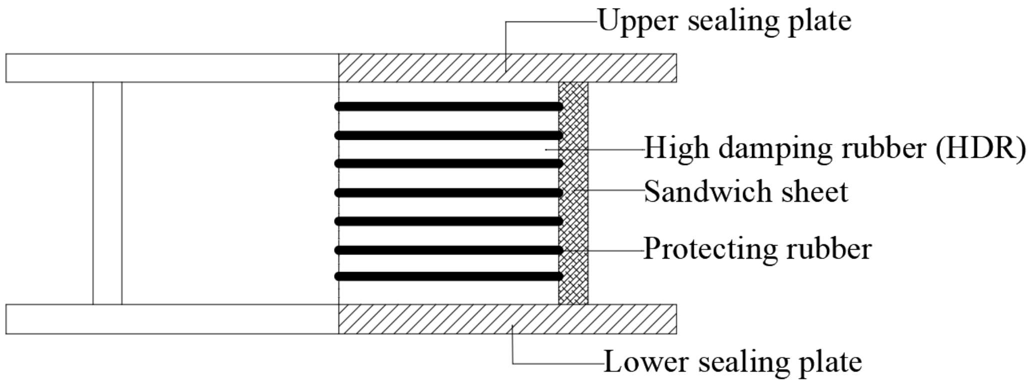

Figure 1. Schematic diagram of high damping rubber bearing structure [3]

2.2. Mechanical Performance of High-Performance Rubber Bearings

Many scholars have conducted experiments on the mechanical performance of high-damping rubber bearings. Zhuang et al. [6] conducted vertical performance tests, horizontal performance and horizontal shear strain correlation tests, and horizontal shear strain large deformation tests on high-damping rubber bearings in the laboratory using an electrohydraulic servo coordinated loading system. Their experiments confirmed that high-damping rubber bearings have stable performance, strong energy dissipation capacity, and ductility, showing high equivalent viscous damping, i.e., higher energy dissipation capacity, significant vibration reduction and isolation effects, and effective control of the seismic response of isolated structures. Compared with traditional lead-core laminated rubber bearings and laminated rubber bearings, high-damping rubber bearings have the advantage of low manufacturing and material costs.

3. Shape Memory Alloy (SMA)

SMA wire material is a material that has the ability to "remember" its initial shape. It will eliminate its deformation at low temperatures after being heated, and has pseudo-elasticity. The material is composed of two or more different metal elements. This is the place to fill in information about funds, sponsors, etc. that need to be thanked.

3.1. Seismic Performance Analysis of SMA Wire Spherical Seismic Bearing

The shape memory effect refers to the ability of certain materials with thermal elasticity or stress-induced martensitic phase transformation to fully recover to their original shape and volume after undergoing a certain degree of deformation in the martensitic phase state and being heated and above the temperature at which the martensitic phase disappears, as shown in Fig. 2.

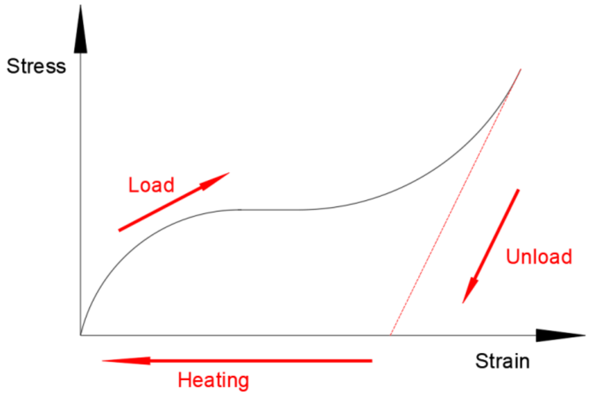

Figure 2. Schematic diagram of the shape memory effect [7]

SMA wire plays a role in anti-seismic bearings in structures, improving the deformation capacity and ductility of structures compared to ordinary steel concrete column, reducing the residual deformation of structures. The component recovery effect is good, significantly reducing structural damage, and showing better seismic performance.

3.2. Principle of SMA Wire Spherical Seismic Bearing

The "memory" function of SMA is derived from its internal special crystal structure. At a certain temperature, this alloy can be shaped into various shapes. When it is heated to a temperature higher than the deformation temperature, the crystal structure of the alloy will change, causing the material to recover to its original shape. The process of recovering from the deformed state to the original shape is the "memory" effect of SMA wire.

As shown in Fig. 3, the SMA wire spherical bearing is composed of a common laminated rubber bearing, SMA wire, disc springs, pulleys, guide tubes, and rigid shell, with two groups of SMA wire bi-directionally crossing through the pulleys fixed on the upper and lower steel plates of the common laminated rubber bearing, and fixed at both ends of the steel plates. Multiple disc springs are strung together and combined in a composite structure on the upper part of the common laminated rubber bearing, and are restricted from horizontal movement through guide tubes and rigid shells [7].

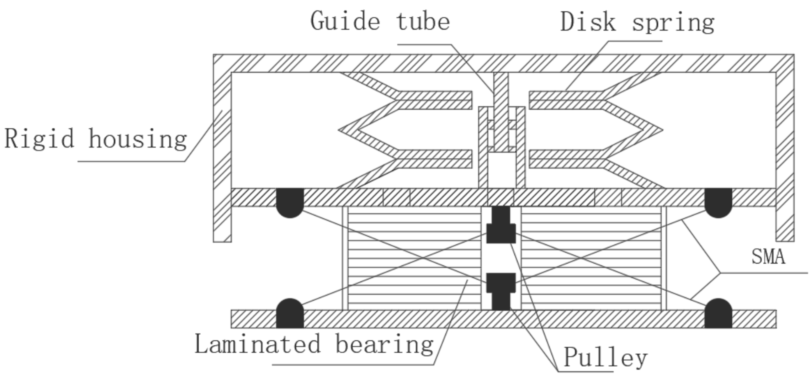

Figure 3. SMA seismic bearing structure diagram [8]

4. Electro-rheological Fluid (ERF)

With the development of science and technology, traditional materials in energy consumption, utilization, controllability, and the required cost cannot be satisfactory, smart materials came into being. As a material that can respond sensitively, continuously and timely to changes in external conditions, it plays an important role in isolation bearings and isolation systems. ERF is one of the most widely used shape memory materials in the world.

4.1. Electro-rheological Principle

ERF is an intelligent material, which is an electrolyte composed of non-conductive mother liquor and uniformly dispersed solid electrolyte particles. Under the action of an external electric field, electric particles are oriented or aggregated along the direction of the electric field, forming bundles of fiber chains. This transforms the electrolyte into a viscoelastic body with a certain shear yield stress. This change is also known as the electrokinetic effect, and the Bingham model is commonly used internationally to describe this change. Internationally, it has been found that the shear yield force of ERF is proportional to the electric field strength. The electro-rheological effect has three characteristics. The first characteristic is continuity, and it can change with the electric field strength. The second characteristic is reversibility, and it can "harden" when the battery strength increases, or become a fluid with the release of the electric field. The third characteristic is fast response speed, and the time required for the mechanical properties of ERF to change with the electric field is on the order of negative fourth of ten. Due to its reversible and reaction speed within microseconds, it can be used as a controllable damper in isolators.

4.2. Performance and Advantages of Electro-rheological Intelligent Isolation System

Intelligent isolation systems typically consist of four parts: sensing vibration signals, analyzing vibration signals, transmitting vibration signals, and controlling dampers to adjust. A conventional design consists of a damper made of ERF liquid (known as an electro-rheological damper), along with base isolation bearings, sensors, computers, and high-voltage power supplies [9].

When an earthquake occurs, the acceleration or displacement changes at the connection of the isolation bearing to the steel plate are sensed by sensors, and their signals are amplified and input into the computer. After computer analysis and calculation, commands are issued to adjust the voltage of the high-voltage power supply, which can change the damping performance of the current variable damper to ensure the seismic reduction effect of the upper structure and control the displacement of the isolation bearing within the allowable range. Compared to other isolation systems, the damping characteristics of the electric current variable fluid intelligent isolation system can remain stable during operation and are not easily affected by external factors. This helps ensure the long-term stable operation of the system, improve the reliability and service life of the equipment. Moreover, under the action of an electric field, the apparent viscosity of the ERF can rapidly increase, the flowability decreases, and even reach a state of stopping flow. This change is in milliseconds, so the electric current variable fluid intelligent isolation system can quickly respond to vibration signals and achieve rapid isolation. Therefore, the system has achieved significant seismic reduction effects in both horizontal and vertical isolation of multi-story and high-rise buildings, as well as in the vertical isolation of large-span trusses and grids.

5. Conclusion

This paper systematically introduces three new seismic isolation bearing materials, and draws the following conclusions:

(1) High-performance rubber materials enhance the seismic isolation performance of bearings by improving the damping properties of rubber. Common improvement methods currently include adding reinforcing agents to raw rubber or using different types of rubber for blending and copolymerization. High-damping rubber isolation bearings utilize the high tensile properties of the rubber material to absorb the energy of seismic waves, reducing damage to the superstructure.

(2) SMA wires in composite materials have the ability to “remember” their initial shape. When heated, SMA wires can return to their original shape, exhibiting pseudo-elasticity. SMA wire spherical seismic bearings leverage the “memory” effect of SMA wires to enhance the structural deformation capacity and ductility, reduce the residual deformation of the structure, and thus demonstrate better seismic performance.

(3) ERF is reversible and react in microseconds, so it can be used as controlled dampers in vibration isolators. The intelligent isolation system consists of a damper made of ERF and a base isolation bearing. This kind of damper has achieved remarkable damping effect in the horizontal damping of multi-storey and high-rise buildings, the vertical damping of large-span trusses and grids, and the horizontal and vertical vibration isolation of isolated buildings.

(4) The utilization of new materials contributes to the seismic performance enhancement of isolation bearings and guarantees their efficacy in mitigating the impact of vibrations during seismic events, therefore safeguarding people's lives and property. These materials offer more creative and viable solutions for the design of isolation bearings and reflect the most recent developments in materials science and engineering research.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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