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Research status and development trend of rubber isolation bearings in earthquake engineering

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Abstract

Earthquakes, as an unpredictable natural disaster, have caused tremendous damage to buildings and infrastructure, as well as casualties. Traditional seismic design methods focus on enhancing the rigidity of building structures to resist the effects of seismic forces. In the face of extreme situations such as rare earthquakes, relying solely on increasing structural rigidity to withstand seismic effects is neither economical nor safe. Seismic isolation technology, especially the application of rubber seismic isolation bearings, has become an important means to improve the seismic performance of buildings. This paper reviews the current application status of rubber bearing seismic isolation technology at home and abroad, analyzes its applicability and limitations in different seismic zones and building types, discusses the latest research progress of rubber bearing seismic isolation technology, looks forward to future development trends, and points out key research areas for the future, providing a reference for researchers in the field of earthquake engineering.

Keywords

Earthquake; seismic isolation technology; rubber seismic isolation bearing; current application status; development trend.

1. Introduction

Earthquakes are sudden natural disasters with immense destructive power, often resulting in the collapse and severe damage of buildings, causing significant casualties and property losses. Therefore, how to enhance the seismic resistance of buildings and mitigate the impact of earthquake disasters has always been a focal point in the engineering and academic communities. Seismic isolation technology, as an effective means of earthquake resistance, involves installing a seismic isolation layer between the foundation and the upper structure of a building. By utilizing the deformation and energy dissipation effects of seismic isolation devices, it reduces the transmission of seismic energy to the upper structure, thereby enhancing the seismic performance of the building. Seismic isolation technology ensures the overall safety of the structure, prevents the damage of non-structural components, and avoids the damage of interior decoration and indoor equipment, as well as the secondary disasters caused by them [1]. Rubber seismic isolation bearings, with their excellent seismic isolation effect and broad application prospects, have become the core of seismic isolation technology.

2. Research Background

2.1. Current Research Status Abroad Research Progress

Seismic isolation technology was proposed as early as the end of the 19th century. In 1818, Japanese researcher Hiroshi Kawai proposed placing cross-arranged round logs under the foundation of buildings to isolate seismic forces. In 1870, a patent in Los Angeles, USA, proposed a double-concave rolling ball bearing seismic isolation technology, which is very similar to the seismic isolation principle of the commonly used double-concave friction pendulum bearing [3].

At the World Conference on Earthquake Engineering in 1965, Japanese researcher Kiyofumi Matsushita believed that pendulum devices could be used as seismic isolation layers for buildings. This was the first demonstration of seismic isolation technology in a precise mathematical analytical form. Due to the insufficient development of science and technology at that time, seismic isolation building design had not yet entered into practice and was still in the theoretical analysis stage. However, the application ideas of seismic isolation design were already relatively mature, basically comparable to the level of modern seismic isolation design thinking [4]. The birth of the above-mentioned seismic isolation concepts laid a solid theoretical foundation for subsequent practical applications. In 1975, New Zealand scholar H. Robinson [5] took the lead in developing lead-rubber laminated bearings, which greatly promoted the practical application of seismic isolation technology. In 1985, American engineers built the first building to use seismic isolation technology - the Foothill Justice Center, located in Cucamonga, California, USA [6]. It was the first building in the world to use high-damping rubber bearings for seismic isolation. During the 1995 Great Hanshin earthquake, the seismic isolation effect of the WEST Building in Japan was significant. The building used 45 lead-rubber seismic isolation bearings and 65 natural rubber seismic isolation bearings [7].

2.2. Domestic Application Status

China's research on seismic isolation technology started relatively late but has developed rapidly. In modern times, China began researching basic seismic isolation technology in 1950, and through the accumulation and summarization of foreign research, it directly entered the research on modern seismic isolation technology. In the 1960s, Li Li from our country proposed the idea of seismic isolation and began research on it. In 1981, Li Li and others conducted research on sand layer cushion seismic isolation, and in 1983, Shui Guobin and others conducted research and experiments on sliding block seismic isolation, achieving good results [8]. In the late 1980s, Chinese researchers began to focus on the research of rubber bearing seismic isolation technology. In 1993, academician Zhou Fulin presided over the design and construction of China's first seismically isolated building using rubber bearings - a commercial and residential eight-story frame structure on Linghai Road, Shantou City, opening the way for the promotion and application of seismic isolation technology [9]. In the late 1990s, significant progress had been made in the research on rubber seismic isolation bearings, and a relatively complete set of seismic isolation bearing technology had been basically formed [10]. In 2001, building seismic isolation and energy dissipation technology was included as an independent chapter in the national standard "Code for Seismic Design of Buildings" (GB50011-2002), marking the mature development of seismic isolation and energy dissipation technology in China [11]. In 2010, the "Code for Seismic Design of Buildings" (GB50011-2010) further relaxed the requirements for building seismic isolation, expanding seismic isolation technology from basic seismic isolation to interlayer seismic isolation, and advocating the use of new types of seismic isolation bearings [12]. The Dalian Bay Bridge, which was built in 2012 and will take 5 years to complete, has a total length of 24km. The bridge adopts an innovative self-anchored cable-stayed-suspension bridge structural system. During the design stage, through precise proportional modeling and loading correction techniques, an in-depth analysis of EI-Centro seismic waves was conducted, and it was ultimately decided to install lead-rubber bearings at the main tower and side piers [13]. This design measure significantly reduced the internal forces of key control sections of the bridge and the displacements between nodes, greatly weakening the impact of lateral earthquakes on the bridge, marking the successful application of lead-rubber seismic isolation technology in the construction of long-span bay bridges. As of 2015, there are more than 6000 buildings using seismic isolation technology nationwide, far exceeding the number in Japan and the United States. Among them, the most representative building is Beijing Daxing International Airport, which was completed in 2019. Its terminal building utilizes a total of 1152 sets of seismic isolation devices, making it the world's largest single seismic isolation building.

3. The Applicability and Limitations of Rubber Isolation Bearings

3.1. Applicability

Rubber isolation bearings are suitable for various seismic zones and building types. In high-intensity earthquake areas, buildings equipped with rubber isolation bearings can effectively extend the natural vibration period of the structure, reduce the coupling between the structure and seismic motion, thereby significantly reducing the horizontal seismic forces and vibration transmission caused by earthquakes, and enhancing the seismic performance of the building. Rubber isolation bearings are also suitable for high-rise buildings, bridges, tunnels, and other engineering structures, effectively reducing the impact of earthquakes on these structures. Furthermore, rubber isolation bearings have the advantages of simple construction and low maintenance costs, making them widely used in practical engineering.

3.2. Limitation

Despite the numerous advantages of rubber seismic isolation bearings, they also possess certain limitations. Rubber materials are prone to aging at high temperatures, which affects the seismic isolation effect, and may be damaged under extreme seismic actions, compromising the overall safety of buildings. The performance of rubber materials may degrade under extreme high or low temperatures, which may limit their application in certain special environments. The design and construction of rubber seismic isolation bearings require high technical proficiency and expertise, imposing high demands on construction personnel. Furthermore, the design and manufacturing of rubber seismic isolation bearings necessitate precise engineering techniques and quality control to ensure that they achieve the expected performance in practical applications. In some cases, the cost of rubber seismic isolation bearings may also be relatively high, which may affect their application in projects with limited economic budgets.

4. Latest Research Progress

In recent years, with the advancement of technology and the deepening of research, rubber isolation bearing technology has made significant progress. Wang Peng et al. [14] designed an improved isolation bearing and studied its mechanical properties and energy dissipation capacity through numerical simulation analysis. The research results showed that before being restrained, the improved isolation bearing had low horizontal stiffness, fully exhibited its isolation performance, and almost no energy dissipation capacity; after being restrained, the lead core fully exhibited its energy dissipation characteristics, and the energy dissipation performance of the bearing increased with the increase in lead core thickness; the improved isolation bearing could exhibit variable stiffness characteristics under different working conditions, which helps to solve the contradiction problem of traditional rubber bearings in terms of stiffness requirements. Zhou Qunlin [15] proposed a new type of isolation bearing - SMA sliding lead core rubber bearing. Through experimental research and numerical simulation analysis, he systematically studied the mechanical properties of SMA strands and SMA sliding lead core rubber bearings, and ultimately proposed a seismic design method for isolation continuous beam bridges based on displacement using SMA sliding lead core rubber bearings. The research results showed that this isolation bearing has multi-level fortification characteristics, achieving bridge protection under earthquakes of different intensities, and has certain engineering application prospects. Ma Qianying et al. [16] studied and designed a new type of steel plate weakened laminated rubber bearing. They tested and analyzed the horizontal and vertical mechanical properties of the designed bearing. The test results showed that under

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different compressive stresses and loading frequencies, the steel plate weakened rubber bearing not only had sufficient vertical bearing capacity and energy dissipation capacity compared to ordinary laminated rubber bearings, but also exhibited good vertical isolation performance, effectively reducing vertical stiffness and reducing the response of the structure in the vertical direction.

5. Development Trend and Outlook

5.1. Development Trend

In the future, rubber isolation bearing technology will further develop in the following aspects:

(1) Technological innovation: With the advancement of technology, the continuous emergence of new materials, processes, and technologies will drive the continuous innovation and upgrading of rubber isolation bearing technology.

(2) Intelligent control: The widespread application of intelligent control systems will enable rubber isolation bearings to make adaptive adjustments based on seismic characteristics, thereby enhancing their seismic performance.

(3) Standardization and modularization: The standardized and modularized design and construction methods will reduce construction difficulty and cost, promoting the widespread application of rubber isolation bearing technology.

5.2. Prospect

With the continuous development and improvement of seismic isolation technology, rubber seismic isolation bearings will play an increasingly important role in earthquake engineering. In the future, rubber seismic isolation bearings will not only be applied in traditional construction fields, but also expanded to urban rail transit, military equipment, energy facilities, and other fields. With the global emphasis on environmental protection and sustainable development, the advantages of rubber seismic isolation bearings in energy conservation and emission reduction will also be further utilized.

6. Key Areas for Future Research

(1) Long-term performance evaluation and life prediction: Through laboratory testing and on-site monitoring, establish a more precise long-term performance evaluation model and life prediction method for rubber isolation bearings.

(2) Environmental impact and sustainability research: Investigate the environmental impact of the manufacturing process and usage phase of rubber isolation bearings, as well as exploring ways to achieve more sustainable design and recycling practices.

(3) Application research under complex geological conditions: Focusing on the variable geological conditions, we study the optimal design and reliability verification of rubber isolation bearings to ensure their effectiveness under extreme conditions.

(4) Standardization and normalization research: Establish and refine national standards and industry norms for the design, manufacturing, installation, and maintenance of rubber seismic isolation bearings to guide engineering practice.

(5) Cost-benefit analysis: Investigate how to reduce the manufacturing cost of rubber isolation bearings while ensuring safety and performance, thereby enhancing their economic efficiency.

7. Conclusion

In summary, rubber isolation bearings demonstrate immense potential and application value in the field of earthquake engineering. Isolated buildings equipped with rubber isolation

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bearings exhibit excellent seismic damage reduction effects. Currently, in some high-intensity areas in China, the adoption of isolation bearing technology for important projects such as schools and hospitals is becoming a trend. As one of the key technologies in earthquake engineering, the research and application of rubber isolation bearings will continue to receive attention. The future development direction will be to enhance performance, implement intelligent monitoring, and integrate multiple technologies to achieve more efficient and safer seismic protection. It is anticipated that in the near future, rubber isolation bearings will play a greater role in earthquake protection worldwide, providing solid protection for human life and property safety.

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