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Research and Application of Seismic Isolation Technology

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ABSTRACT

This paper systematically reviews the development and application status of seismic isolation and damping technologies for building structures. The research indicates that the seismic isolation and damping technologies for building structures have currently entered a mature development stage, and their promotion and application have also received extensive attention. This paper focuses on explaining the commonly used seismic isolation and damping technologies in the field of building structures and their action principles, and conducts an in-depth discussion on damping devices and isolation devices based on different seismic isolation and damping principles. Finally, combining with industry development trends, this paper puts forward several suggestions for the development directions and application prospects of seismic isolation and damping technologies for building structures in the future.

KEYWORDS

Seismic Damping Technology; Seismic Isolation Technology; Building Engineering.

1. INTRODUCTION

Earthquakes are natural phenomena caused by the release of energy within the earth. The main cause of earthquake is the collision between plates leading to dislocation and rupture at the edge and inside of the plate. Natural earthquakes can be divided into tectonic earthquakes, volcanic earthquakes and fall earthquakes according to their genesis. Among them, tectonic earthquakes account for more than 90% of the total number of earthquakes in the world, and their force is the strongest. China is located at the intersection of the circum-Pacific seismic belt and the Eurasian seismic belt, and the seismic activity is characterized by high intensity and wide distribution[1]. More than 70% of China's land area is located in areas with earthquake intensity above 6 degrees, of which 30% is located in areas with high intensity of 7 degrees and above. In the Wenchuan earthquake in 2008, the average inter-story displacement angle of the frame structure with seismic design reached 1/150, resulting in the failure of a large number of non-structural components and functions, while the Wenchuan Earthquake Memorial Hall used pendulum isolation technology to control the structural displacement within 120mm in the magnitude 8 earthquake, and the equipment operated normally, which became a typical example of the effectiveness of seismic isolation technology. As a major natural disaster that threatens the safety of human life and property, the structural problems caused by earthquakes have always been the focus of research in the field of engineering.

In recent years, with the acceleration of domestic urbanization, a large number of multi-high-rise, super-high-rise and long-span buildings have emerged, and the "hard resistance" of seismic design that relies on structural strength and ductility has gradually become limited. For example, the large size of members in high-intensity areas affects functions, and the high cost of post-earthquake repair has put forward new requirements for the earthquake resistance of Chinese building structures. Seismic isolation technology has become the core direction of modern seismic engineering through the innovative ideas of "flexible energy dissipation" and "energy isolation". my country has been exploring seismic isolation technology since the 1960s. After theoretical research, test verification and engineering application, the 2001 "Code for Seismic Design of Buildings" included seismic isolation and energy dissipation and shock absorption technologies into the national standard. The 2013 "Building Energy Dissipation and Damping Technical Regulations" further promotes the maturity of technology. In 2014, the Ministry of Housing and Urban-Rural Development issued "Several Opinions on the Promotion and Application of Seismic Isolation Technology in Housing Construction Projects (Provisional)", which clearly pointed out that seismic isolation technology can effectively reduce earthquakes and improve the seismic fortification capabilities of housing construction projects, and requires comprehensive promotion The application of seismic isolation technology in housing construction projects promotes the development of seismic isolation technology in building structures[2].

In this paper, the dynamic principles of rubber isolation bearings, pendulum isolation bearings, tensile isolation bearings, viscous dampers, buckling restrained braces and other seismic isolation technologies are expounded, the application of seismic isolation technology in building structures is summarized, the types of commonly used seismic isolation technology products are introduced, the problems existing in the application of seismic isolation technology at present are proposed, and the direction and prospect of seismic isolation technology in building structures in China in the future are prospected.[3]

2. DEFINITION OF SHOCK ABSORPTION TECHNOLOGY

2.1. Definition of Shock Absorption Technology

Seiic Damping Technology (Seiic Damping Technology) is a passive control technology for structural seismic response by adding energy dissipation devices (such as dampers, energy dissipation braces, etc.) in building structures, which convert the energy input from ground motion into heat energy, kinetic energy and other forms of energy dissipation through the deformation or movement of the devices. Its core feature is that it does not change the inherent period of the structure, but through additional damping ratio, it can suppress the amplitude of structural vibration and the damage of the main structure and non-structural components. Different from the idea of "isolation energy transfer" in the isolation technology, the vibration absorption technology follows the principle of "energy dissipation" and realizes vibration control through "dynamic braking". It is suitable for high-rise buildings, large-span and complex structures that are difficult to implement base isolation.

The energy balance equation of the damping system can be expressed as:

Ein = Ek + Ee + Ed + Er;

Ein is the seismic input energy, Ek is the structural kinetic energy, Ee is the structural elastic strain energy, Ed is the energy dissipated by the shock absorber, and Er is the radiation and loss energy. In the state, the damping device needs to dissipate 60%-80% of the input energy (Ed $\geq$ 0.6 Ein), so that the remaining energy (Ek + Ee) is not enough to cause the structure. According to different energy consumption mechanisms, it can be divided into three categories:

Viscous/viscoelastic energy dissipation: Using fluid viscous resistance or the hysteresis effect of polymer materials (such as viscous dampers, viscoelastic dampers), the damping force is related to the speed, and the energy is converted into heat energy through the molecule, accounting for about 30%-50%.

Plastic deformation energy dissipation: relying on the plastic flow of metal materials after yield (such as mild steel dampers, buckling constrained supports), the hysteretic curve is full, and the energy dissipation efficiency is high (energy dissipation in a single cycle reaches 90% of the material's yield energy), accounting for 40%-60%.

Slip energy dissipation: work is done through the interface (such as dampers), the force is proportional to the positive pressure, and the energy dissipation is stable, accounting for 20%-30%.

2.2. Classification of Seismic Absorption Techniques

According to the device form and energy dissipation mechanism, shock absorption technologies can be divided into four categories, and the principle differences are shown in Table 1.

Table 1. Classification of shock absorption techniques

Type of technology	Core energy dissipating element	Energy conversion	Applicable structural characteristics	Typical damping ratio increase
Viscous damper	Viscous fluid + Piston	Fluid viscosity → Heat energy	High-rise/super-high-rise (wind-earthquake control)	10%-20%
Viscoelastic damper	Viscoelastic materials (rubber + resin)	Molecular chain → Thermal energy	Medium-height buildings (frequent earthquakes)	8%-15%
Metal damper	Mild steel/Low yield point steel	Plastic deformation → Heat energy	Buildings in high intensity areas (rare earthquakes)	20%-30%
Damper	Sheet + Spring	Interfacial slip → Thermal energy	Long-span structure (vibration)	15%-25%
Buckling restrained brace	Steel core + Confinement casing	Tension-compression plastic deformation → Heat energy	Frame structure (reinforcement)	25%-35%

Viscous/viscoelastic damper: The damping force is related to the deformation speed, which is suitable for controlling high-frequency vibration (> 1Hz) and responding to high-frequency components (such as P waves and S waves) in ground motion. The viscous damper has no additional stiffness and is suitable for installation on existing structures; The viscoelastic damper has both stiffness and damping, and can have a structure period of 10%-15%.

Metal/damper, BRB: The damping force is related to the deformation amplitude, and depends on material yield or interface slip to start energy dissipation. It is suitable for medium and low frequency vibration (0.2-3Hz), and the effect is better for long-period components of ground motion (such as surface waves). The metal damper dissipates energy through material damage (there is stiffness degradation), the damper dissipates energy through pure slip (the performance is stable but needs to be maintained by pre-pressure), and the BRB avoids buckling through a restraint mechanism to achieve symmetrical energy dissipation between tension and compression.

It can be seen from the above-mentioned principle analysis that the seismic absorption technology can effectively improve the seismic performance without changing the main form of the structure through the passive control strategy of "additional energy dissipation", especially suitable for the strengthening of existing buildings and the seismic design of complex structures. Its core advantage lies in flexibility and adaptability, while the key challenge lies in the stability of damper performance and the optimization of layout, which needs to be selected in combination with specific engineering requirements.

3. SEISMIC ISOLATION TECHNOLOGY

3.1. Definition of Seismic Isolation Technology

Isolation technology is to effectively separate the superstructure from the foundation (or substructure) by setting an isolation layer at the bottom or between floors of the building structure, and use the flexible deformation of the isolation device to extend the natural vibration period of the structure and dissipate seismic energy, so as to The passive seismic control technology of large-scale earthquake movement transmission to the superstructure can more effectively protect the safety of the building structure and indoor equipment, and can significantly improve the functional recovery ability of the building structure after the earthquake. The core feature is that through "energy isolation" rather than "hard resistance", 80%-90% of the earthquake input energy is blocked in the isolation layer, so that the earthquake response of the superstructure is 40%-70%, and "small earthquakes are not damaged, moderate earthquakes can be repaired, and large earthquakes are safe" seismic goals.

The isolation layer is composed of isolation devices (such as rubber isolation bearings, pendulum bearings, etc.), connecting members and damping elements, forming a flexible layer whose horizontal stiffness is much lower than that of the superstructure (the horizontal stiffness is usually 1/10-1/50 of the superstructure). It mainly controls the horizontal earthquake action (accounting for 70%-80% of the structure energy), and some isolators can take into account the vertical vibration control (such as the vertical stiffness of high damping rubber bearings ≥ 1000 kN/mm).

Over the years, scholars from all over the world have carried out extensive and in-depth research on seismic isolation technology, and have achieved remarkable results. At present, seismic isolation technology has been more mature products and engineering applications, and has been widely used in buildings such as residences, hospitals, schools, museums and libraries.

3.2. Seismic Isolation Bearings.

According to the different working principles of isolation bearings, isolation bearings can be divided into rubber isolation bearings (elastic isolation system) and pendulum isolation bearings (sliding isolation system). The classification of isolation bearings is shown in Table 2.

Table 2. Classification of isolation bearings

Type of technology	Representative device	Energy consumption	Stiffness characteristic	Periodicity	Self-resetting capability	Applicable intensity
Elastic Isolation (Rubber)	NRB/LRB/HDRB	Rubber shear + Lead plasticity	Linear/Bilinear	2.0-3.0s	None	6-9 degrees
Sliding isolation (pendulum type)	FPS/ESB(Flex Skateboard)	Slip + Gravity reset	Nonlinear (negative stiffness)	2.8-4.5s	Have(≤5%)	8-9 degrees
Hybrid isolation	Rubber + Combined support	Elastic deformation + Sliding energy dissipation	Multilinearity	2.5-3.5s	Partial reset	7-9 degrees

Elastic isolation has simple structure and low cost (30%-40% lower than FPS), which is suitable for a large number of applications in moderate intensity areas (such as 6-8 degree fortified buildings in Yunnan and Sichuan in my country). However, there is no self-reset ability, and the residual displacement after the earthquake needs manual work; Rubber aging leads to stiffness degradation (annual degradation rate 1%-2%), which requires regular testing (vulcanization degree testing every 5 years).

The self-reset characteristic of sliding isolation is significant, and the repair cost after earthquake; The large curvature radius design can withstand super-large displacements in rare earthquakes (for example, the displacement of an FPS isolation building in the Kobe earthquake in 1995 was 800mm, which is still safe). However, the coefficient is affected (dust pollution can make μ 20%), and it needs to be cleaned regularly; The initial stiffness is low, and small vibration may occur under wind load (additional dampers are required to control).

3.3. Of Seismic Isolation Bearings

In recent years, seismic isolation building gradually from the low-level, simple building structures to high-level, complex building structures in the direction of the current commonly used seismic isolation devices, stacked rubber seismic isolation bearing and pendulum seismic isolation bearing, there are the following limitations, difficult to building structures, high-performance seismic isolation needs:

Insufficient tensile capacity restricts the application of seismic isolation devices in high-rise buildings. Rubber isolation bearings have poor tensile properties and are prone to interlayer tearing when the tensile stress exceeds 1.0 MPa. Pendulum isolation bearing in tension will occur face detachment of the situation, so completely does not have tensile performance[4]. In some high-rise buildings or buildings subject to vertical seismic effects, when the seismic intensity is high, the seismic isolation bearing will produce a large tensile force, thus limiting the promotion and application of seismic isolation technology[5].

Conventional seismic isolation bearings are mainly for horizontal seismic isolation, and have no significant seismic isolation effect on vertical earthquakes or vertical vibration. Buildings located in high seismic intensity zones, around fracture zones, or in nuclear power plants where there is important equipment may have the need for vertical isolation. And the impact of vertical vibration on the normal use of buildings is increasingly being[6].

The control bandwidth is narrow, the control effect is significantly affected by external conditions, and it is difficult to balance the building's need to control the displacement of the seismic isolation layer and the acceleration of the superstructure. Due to the existence of the base isolation layer, the self-oscillation period of the building structure increases, and under seismic action, the isolation layer deformation is larger, through the addition of large-tonnage viscous dampers around the seismic isolation device, although it can effectively control the displacement of the isolation layer, but the larger damping force will increase the seismic response of the superstructure[7].

It is difficult to accurately assess the state of use and damage. When an earthquake occurs, the seismic isolation bearing deformation is concentrated and consumes a large amount of seismic input energy, which is the most likely to occur in the critical and weak parts. If the seismic isolation bearing in the construction process or the normal use of the stage of early damage is not detected in time and continue to accumulate to a certain extent, it may lead to the sudden failure of the entire structure, causing serious damage to the life and property[8].

In order to expand the scope of application of seismic isolation technology, many scholars have carried out in-depth research on the above problems, and have obtained abundant research results. Including tensile isolation bearing, three-dimensional seismic isolation bearing, etc., which promotes the further development of seismic isolation technology.

3.3.1. Tensile Isolation Bearing

Currently commonly used seismic isolation bearings for buildings are seriously insufficient in tensile capacity and cannot prevent the structure from overturning. The existing tensile isolation bearing is usually an improvement of the commonly used seismic isolation bearing, and while improving the tensile capacity of seismic isolation bearing, it should avoid affecting its horizontal seismic isolation and pressure-bearing capacity as much as possible, which can be divided into four types according to its construction form, respectively, vertical constraint strengthened, vertical constraint relaxation, material improvement and combination of structural type, as shown in Table 3.

Table 3. Main types of tensile isolation bearings

Structure type	Specific forms
Vertical constraint strengthening class	Guide rail type, SMA connection, spring connection, etc
Vertical restraint relaxation class	Removable rubber vibration isolation bearing座
Material improvement class	High-strength material vibration isolation bearing
Combined structure class	Stacked rubber bearing tensile mechanism

Pan Peng et al.[9] developed a semi-active pull-out isolation device. It is composed of conventional building isolation bearings and semi-active pull-out components arranged around them. The semi-active pull-out components are reliably connected with the building structures at the upper and lower ends of the isolation bearings through connectors. The cylinder body of the module is closed and separated into two independent oil chambers, and the two chambers are connected through an external oil pipeline, and a hydraulic valve whose opening and closing is controlled by a support tension and pressure sensor is installed on the pipeline.

In the actual force process, when the isolation support is under vertical pressure, the tension and pressure sensor feeds back the pressure signal and controls the hydraulic valve to open. At this time, it can slide freely in the cylinder body, and the anti-pull component is in a state of free expansion and contraction, which will not adversely affect the horizontal isolation performance of the support; When there is a vertical tension on the isolation support, the trigger signal of the tension and pressure sensor makes the hydraulic valve close quickly, and the movement is limited, and the anti-pull component immediately locks the length, so as to bear all the vertical tension, effectively avoiding the isolation support from bearing the tension, Realize reliable tensile effect.

Vertical restraint release type tensile isolation bearing avoids bearing tension by releasing part of the vertical restraint, but it cannot completely eliminate the risk of structural overturning. Qisong Miao et al [10]developed a lift-off rubber seismic isolation bearing, which connects the upper cover plate of the bearing and the upper pier through a limit pin, and a preset detachment gap is set between the end of the limit pin and the upper cover plate. When the bearing is subjected to vertical pressure, the horizontal shear force is transmitted to the upper cover plate through the limit ring plate to ensure that the horizontal seismic isolation performance of the bearing is not affected; when the bearing is subjected to vertical tensile force, the upper cover plate and the upper abutment are separated within the range of small deformation, so as to avoid the bearing body from being subjected to the tensile force. Material-enhanced tensile isolation bearings have excellent tensile capacity by optimizing the material properties of the bearings. Japan's Takenaka Kobo store and Bridgestone company in the rubber matrix mixed with carbon fiber and other reinforcing materials, significantly improving the bearing's compressive load capacity, hardness, resistance to compression deformation and tensile strength, verified by the test of the tensile strength of the rubber bearing to increase 40% -60%, effectively expanding the scope of application of the rubber seismic isolation bearing. Combined structure tensile isolation bearing through the structure form of multiple parallel connection to realize the tensile function. Su key et al [11]proposed a stacked rubber seismic isolation bearing tensile mechanism, as shown in Figure 4, the mechanism will be three stacked rubber bearings are symmetrically arranged in parallel. When the bearing system is subjected to vertical tension, the center bearing tension is transformed into the axial pressure of both sides of the bearing through the connection, using the excellent compressive properties of the rubber bearing to offset the overall tension, so that the tensile capacity of the combined bearing is increased to the compressive capacity of a single bearing 1.5-2.0 times, while the good horizontal seismic isolation performance.

3.3.2. Three-dimensional Isolation Bearing

The response caused by rail transit vibration in surrounding buildings is mainly vertical vibration, and the impact of rail transit vibration on surrounding buildings can be reduced through vertical vibration isolation. However, buildings such as nuclear power plants may have vertical isolation requirements, and vertical rigidity is required. Low vertical isolation bearings. However, the vertical isolation structure is subjected to overturning torque under horizontal earthquake action, which will cause a large tension-compression deformation of vertical isolation bearings on both sides of the structure, and may lead to vertical isolation bearings or sway. The vertical earthquake or rail transit vibration response is reduced by the lower vertical stiffness of the bearings, and the horizontal earthquake action of the superstructure is reduced by horizontal isolation, so as to reduce the overturning moment and avoid the structural sway. Three-dimensional isolation bearings can be divided into two types: single structure and combination according to deformation mechanism and structure.

Three-dimensional isolation bearings with single structure are characterized by a single deformation component that can produce large shear and axial deformation at the same time. Such bearings are generally simple in structure, clear in force principle, relatively small in size, but relatively small in bearing capacity and deformation capacity, so they are suitable for low-rise buildings. At present, there are mainly thick laminated rubber three-dimensional isolation bearings and air spring three-dimensional isolation bearings.

The characteristic of the combined structure of three-dimensional isolation bearings is that a single deformed component can not occur large shear deformation and axial deformation at the same time because of the high stiffness or constraints in some directions, and the overall bearing can achieve three-dimensional deformation through the combination of multiple deformed components. Usually, the bearing capacity and deformation capacity of such bearings are relatively large, but the structure is relatively complex and the size is relatively large. The most common combination of three-dimensional isolation bearings is to combine mature horizontal isolation bearings (rubber isolation bearings, pendulum, etc.) with vertical isolation units with relatively small vertical rigidity, such as metal springs, thick laminated rubber bearings, air springs, etc., so that the horizontal deformation and vertical deformation are concentrated in different parts of the bearings. The deformation mechanism of this type of support is clear and clear, and the horizontal and vertical performances are easy to be designed separately.

Based on the idea of vertical and horizontal combination, researchers from all over the world have also developed a variety of three-dimensional isolation devices with pendulum bearings as horizontal isolation units. Because of the high bearing capacity and strong horizontal deformation capacity of the pendulum bearing, and the period is only determined by the geometric size of the pendulum element and is not affected by the change of vertical load, it is conducive to the realization of high-performance three-dimensional isolation devices. Cao Yingri et al. [12]studied a three-dimensional isolation bearing composed of a dish spring and a single surface pendulum. The test results show that the vertical and horizontal performance of the bearing can be decoupled. In the finite element analysis of base-isolated structures, bearings can effectively reduce the response of the superstructure caused by horizontal earthquake and vertical subway vibration.

4. APPLICATION CASES OF VIBRATION ISOLATION TECHNOLOGY AND COMMENTS

4.1. Hong Kong-Zhuhai-Macao Bridge Project

The Hong Kong-Zhuhai-Macao Bridge (HZMB) is a mega cross-sea link connecting Hong Kong, Zhuhai and Macao, with a total length of about 55 kilometers, of which the main project is about 26 kilometers long, making it the world's longest seismic isolation bridge across the sea. The bridge spans the seismically active region of the Pearl River Estuary, with a design seismic intensity of VII degree, and at the same time needs to cope with the complexity of strong typhoons and marine corrosion. The core objective of its seismic isolation technology is to ensure that the bridge will not be damaged by small earthquakes, can be repaired by medium earthquakes, and will not fall down by large earthquakes, and to ensure the rapid recovery of the transportation lifeline after the earthquake. The HZMB adopts the synergistic technology system of "engineering seismic isolation + energy dissipation and damping", which includes the following core measures: (1) Seismic isolation bearing technology Lead-core rubber seismic isolation bearings and high damping rubber bearings are mainly adopted, and pendulum bearings are used in some sections. Lead core rubber bearing through the rubber layer of flexible deformation isolation of seismic energy, lead core to provide additional damping dissipation of energy, both seismic isolation and energy dissipation double role. Pendulum bearings utilize spherical sliding to extend the structural self-oscillation period, seismic force amplification effect, and at the same time through energy dissipation. In the bridge pier and girder connection set bearing, the whole bridge uses thousands of various types of seismic isolation bearing, the maximum design bearing capacity of a single bearing reaches thousands of tons[13]. (2) Energy dissipation and shock absorption technology Viscous fluid dampers are installed at the bridge expansion joints and tower beam connections to consume seismic kinetic energy through liquid flow and reduce the amplitude of structural vibration. Soft steel dampers are used in some nodes to dissipate energy through yielding plastic deformation of materials and protect the main structure[14]. The "engineering seismic isolation + dissipation and damping" synergistic technology system adopted by the HZMB has excellent seismic performance: high damping efficiency, test data show that the seismic isolation system can make the bridge seismic response of more than 80%, and effectively protect the piers, girders and other key components; to adapt to the demand for large displacements, the maximum design displacement of the pendulum bearing can be up to ± 1 meter, and can adapt to the temperature changes due to the cross-sea bridge, and can be used to reduce the vibration amplitude. Adapt to large displacement requirements, the maximum design displacement of the pendulum bearing can reach ± 1 meter, can adapt to the large deformation of the bridge across the sea due to temperature changes, earthquake, to avoid collision or fall off the beam; bearing corrosion-resistant rubber materials (such as neoprene) and stainless steel cladding, combined with cathodic protection technology, can be more than 120 years of service in the marine salt spray, the bridge design requirements for service life; Typhoon - earthquake synergistic protection: isolation system is not only the seismic response, but also through the flexible deformation of the typhoon to alleviate the structural vibration, to achieve the "a Typhoon-earthquake synergistic protection: the seismic isolation system not only responds to earthquakes, but also mitigates typhoon-induced structural vibration through flexible deformation, realizing the application of one technology in multiple scenarios. The project breaks through the foreign technology blockade, independently developed 10,000 tons of lead-core rubber bearings, the cost of which is 30% higher than that of imported products, which promotes China's bridge seismic isolation technology to be among the forefront of the international community; the integration of fiber optic sensing, inclinometers and other equipment, real-time monitoring of bearing deformation, the working status of the damper to provide data support for the health management of the structure, and to pioneer the "intelligent seismic isolation" technology. The integration of fiber optic sensing, inclinometer and other equipment for real-time monitoring of bearing deformation, damper operating status, providing data support for structural health management, pioneering the first "intelligent seismic isolation". Good performance also leads to the cost, construction and maintenance costs are high, the initial investment: seismic isolation bearing and damper costs account for about 5% -8% of the total cost of the bridge (bridge only 1% - 2%), for the ultra-long cross-sea project, the total investment is significant. Later maintenance cost is high, and the sea operation is difficult and safety risk is high. Despite the anticorrosive design, seawater erosion may lead to deterioration of the rubber bearing performance, and further verification of the reliability of the 100-year cycle is needed[15].

4.2. Kunming New Airport Seismic Isolation Terminal Project

Kunming Changshui International Airport is an important hub in Southwest China, and its terminal building project is located in a high seismic intensity zone (seismic intensity VIII, design basic seismic acceleration value of 0.2g), which puts forward very high requirements on the seismic performance of the structure. The main building of the terminal is a concrete frame - steel roof structure with a floor area of about 540,000 square meters and a building height of 45 meters. In order to cope with the risk of strong earthquakes, the project adopts a comprehensive seismic isolation system that combines layer-spaced seismic technology and viscous damper energy dissipation and damping technology, which is China's first landmark project that adopts layer-spaced seismic in a large public building[16].

The technical principle of layer spacing seismic technology: a seismic isolation layer is set up between the first and second floors of the terminal building, and the upper structure (above the second floor) and the lower structure (the first floor and the foundation) are flexibly connected by seismic isolation devices. The seismic isolation layer consists of lead-core rubber seismic isolation bearings and elastic skateboard bearings. The horizontal flexible deformation of the bearings prolongs the structural self-vibration period and the transfer of seismic energy to the superstructure.

Viscous damper energy dissipation and damping technology

Technical principle: Viscous fluid dampers are installed between the seismic isolation layer and part of the frame columns to consume the seismic energy through the viscous flow of damping medium and further reduce the amplitude of structural vibration[17].

Through the seismic isolation layer, the horizontal seismic effect of the superstructure is significant. As verified by the shaking table test, the structural interlayer displacement angle under seismic effect is only 1/1200 (about 1/300 for the structure), which is much lower than the normative limit (1/550), and can basically realize the goal of "small quake is not bad, medium quake is repairable, and large quake does not fall". The seismic isolation layer effectively isolates the impact of ground vibration on the upper precision equipment (such as baggage system and electromechanical pipelines) and guarantees the continuity of operation after the earthquake. Seismic isolation of the foundation needs to set up a seismic isolation layer underground, which may affect the function of the basement; while the layer seismic isolation will be placed between the first and second floors, which does not take up underground space, and facilitates the arrangement of transportation hubs under the terminal building, optimizing the functional layout of the building. Compared with the seismic design, the cost of seismic isolation devices is reduced, but the cross-section size of the beams and columns of the superstructure, the amount of reinforcing steel, and the cost of later maintenance are reduced. As a landmark building, its seismic isolation technology provides a replicable engineering example for large public buildings in high intensity zones and promotes the application of seismic isolation technology in complex structures in China.

Seismic isolation between floors is mainly for horizontal seismic effects, while there is a vertical seismic risk in Kunming (the designed vertical seismic acceleration is 65% of the horizontal one). Although the seismic isolation bearings have a certain vertical stiffness, the superstructure still needs to strengthen the design of vertical resistance to avoid the vertical earthquake caused by the bearing tensile. Lead-core rubber bearings have aging problems, and the stiffness and damping performance of the bearings and the sliding performance of the slip plate bearings need to be monitored regularly. The hot and humid climate of Kunming may accelerate the deterioration of rubber materials and maintenance costs. Layer spacer seismic layer involves the collaborative work of multiple types of bearings, which requires high construction accuracy and difficult construction organization[18].

4.3. Beijing Tonghuijiayuan Project

Beijing Tonghui Jiayuan is China's first large-scale residential project to utilize inter-story seismic isolation technology. Located above the Sihui Transportation Hub in Chaoyang District and completed in 1998, it has a total floor area of 480,000 square meters and comprises 17 nine-story residential buildings. At the time of its completion, it was the world's largest complex of buildings utilizing inter-story seismic isolation. What makes this project unique is its structure built atop a subway facility-all residential buildings are constructed on a large platform 11.6 meters high within a subway depot, requiring them to withstand both vibrations from subway operations and seismic risks (seismic fortification intensity of VIII, with a basic design seismic acceleration of 0.2g). Since traditional seismic design struggled to meet safety requirements in such a complex vibration environment, an integrated vibration-reduction system combining three-dimensional seismic isolation bearings and viscous dampers was adopted, marking a milestone in China's residential vibration-reduction technology.

The seismic isolation system incorporates an isolation layer between the metro platform and the first floor of the residential buildings, using flexible connections to decouple the upper residential structure from the lower platform, thereby preventing metro vibrations from being directly transmitted to the building. The three-dimensional seismic isolation bearings can simultaneously absorb both horizontal and vertical vibration energy, extending the horizontal natural period to 2.8 seconds (compared to approximately 1.2 seconds for traditional structures) and reducing seismic forces by approximately 60%. The system also incorporates limiting and energy-dissipating devices, including viscous dampers (108 in total, with a maximum thrust of 160 metric tons) installed in the seismic isolation layer. These dampers further reduce structural displacement through fluid energy dissipation, limiting the maximum deformation of the isolation layer to within 200 millimeters. To address the high-frequency, low-amplitude vibrations generated by subway operations, the vertical vibration transmission ratio was reduced to below 0.3 by increasing the thickness of the rubber bearings and optimizing damping parameters, significantly improving resident comfort.[19] The seismic isolation system remains stable even under strong winds. Through calculations of wind-induced vibration responses and optimization of the bearing stiffness distribution, the structural safety under typhoon conditions is ensured. The suppression of subway vibrations is particularly effective; through the vertical flexible design of thick rubber bearings, floor vibration acceleration caused by subway operations is reduced by more than 70%[20].

As the world's first residential complex featuring large-scale inter-story seismic isolation, its successful experience provides a replicable technical model for buildings constructed above subway lines and residential structures in high-seismic-intensity zones, driving the expansion of China's seismic isolation technology from public buildings to the residential sector. The impact of subway vibrations on the daily living environment is minimal, resulting in a significant increase in public satisfaction[21].

5. CONCLUSION

After decades of theoretical research and engineering practice, the seismic isolation technology of building structures has changed from a single base isolation to a diversified technical system covering shock absorption, seismic isolation, and seismic coordination, and has become the core support of modern seismic engineering.

(1) The vibration absorption technology can effectively suppress the amplitude of structural vibration through additional energy dissipation devices such as viscous dampers and buckling restrained braces, especially in the strengthening of high-rise buildings, long-span buildings and existing buildings. The Hong Kong-Zhuhai-Macao Bridge adopts a synergistic system of "lead rubber bearings and viscous dampers", which makes the earthquake response more than 80%, verifying the reliability of the shock absorption technology under complex conditions.

(2) Seismic isolation technology extends the structural period through rubber bearings, pendulums and other devices to isolate the transmission of earthquake energy. Kunming New Airport Terminal adopts story isolation technology to control the inter-story displacement angle at 1/1200, which provides a demonstration for large-scale public buildings in high-intensity areas.

(3) Seismic isolation technology breaks through "hard resistance", significant structural damage through "energy isolation" and "flexible energy consumption", the versatility of the technology (wind-seismic coordination) and post-earthquake functional capabilities (such as hospitals, Rapid recovery of transportation hubs) makes it the first choice for important infrastructure.

At present, the tensile capacity of isolation bearings is insufficient, and the effect of vertical isolation is limited, which restricts high-rise buildings and complex applications; The damping device has the problems of performance degradation and high maintenance cost. The displacement control of isolation layer and the performance stability under the coupling action of multi-disasters (such as earthquake-typhoon-ocean corrosion) of long-span structures still need to be broken through. Faced with the needs of complex building structures and diversified functions in the process of urbanization, seismic isolation technology will be deeply expanded in the direction of high performance, intelligence, greening, and integration.

Tensile and three-dimensional isolation technology, semi-active pull-out bearings, combined structural tensile mechanisms, improve the tensile capacity to 1.5-2.0 times the compressive capacity of a single bearing; Promote the disk spring-pendulum combined three-dimensional isolation bearing to realize the decoupling control of vertical vibration and horizontal earthquake, and the demand for vertical isolation in nuclear power plants and super high-rise buildings.

Apply new materials and introduce smart materials such as graphene-reinforced rubber and shape memory alloy (SMA) to improve the aging resistance and self-reset ability of the support.

Carry out intelligent monitoring and health management: integrate optical fiber sensing and Internet of Things technology, establish a real-time monitoring system for shock absorption and isolation devices, and realize the integration of "state perception-risk early warning-maintenance decision-making".

REFERENCES

[1] Zhou, X. C., Zheng, P. S., Ye, Y., et al. (2020). Analysis and research on seismic technology in building structure design. *IOP Conference Series: Earth and Environmental Science*, 474(7), 072083.

[2] Shahraki, A. M., Hajipour, A., & Rabiei, N. (2026). Mitigating dynamic response in base-isolated mid-rise steel structures using NTMDI under earthquake excitation. *Innovative Infrastructure Solutions*, 11(7), 387. https://doi.org/10.1007/s41062-026-02796-7

[3] Sagdiev, K. S., Yuvmitov, A. S., Egamberdiev, B. O., Toshpulatov, S. U., & Toshmatov, E. S. (2023). Simulation of the structure of a multistory building with seismic isolation and the testing technique on a laboratory bench under dynamic (seismic) impacts. *E3S Web of Conferences*, 402.

[4] Liu, W. G., Yang, Q. R., Zhou, F. L., & Feng, D. M. (2004). Theoretical and experimental study on nonlinear elastic tensile properties of rubber seat. *Earthquake Engineering and Engineering Vibration*, (2), 158–167.

[5] Connolly, D. P., Marecki, G. P., Kouroussis, G., Thalassinakis, I., & Woodward, P. K. (2016). The growth of railway ground vibration problems - A review. *Science of the Total Environment*, 568.

[6] Kawasaki, N., Yamamoto, T., Fukasawa, T., et al. (2015). Parametric design study about seismic isolation system for fast reactor JSFR. In *Proceedings of the ASME 2015 Pressure Vessels and Piping Conference*. ASME.

[7] Du, Y. F., Zhao, L. J., Zhang, T., et al. (2015). Study on construction and whole process monitoring of ultra-long complex isolated structures. *Engineering Mechanics*, 32(7), 1–10, 25.

[8] Wang, K. Y., Chen, D. B., Guo, M. L., et al. (2010). Deformation and service monitoring of isolation bearings during steel structure construction. *Building Structure*, 40(8), 49–52.

[9] Pan, P., Ai, H. H., & Wang, H. S. (2021). Semi-active damper pull-out isolation device (Patent No. CN113431203A). National Intellectual Property Administration, PRC.

[10] Miao, Q. S., Bu, L. G., He, D. D., et al. (2019). Research and application of tensile problems of earthquake-isolated building supports. *Building Structures*, 49(18), 13–18, 4.

[11] Su, J., Wen, L. H. H., & Zhou, F. L. (2010). Study on the tensile mechanism of new laminated rubber seismic isolation bearing. *Industrial Architecture*, 40(12), 43–46, 54.

[12] Cao, Y. R., Pan, P., Sun, J. B., et al. (2022). Research on mechanical properties and isolation effect of disc spring-simple pendulum 3D isolation device. *Journal of Building Structure*, 43(7), 44–53.

[13] Zhou, F., Xiang, Z., Ge, H., et al. (2026). Targeted dual-objective optimization of an inerter isolation system for concurrent displacement and acceleration mitigation. *The Structural Design of Tall and Special Buildings*, 35(6), e70158. https://doi.org/10.1002/tal.70158

[14] Yu, T., Wang, B., Xu, H. L., et al. (2026). Multi-stage metallic gap dampers for seismic pounding mitigation in base-isolated buildings: Concept development, validation, and self-centering enhancement. *Engineering Structures*, 362, 123044. https://doi.org/10.1016/j.engstruct.2026.123044

[15] Zhang, X., Zhou, Y., Sun, J., et al. (2026). Seismic response and mitigation mechanism of cantilever retaining walls with EPS composite soil isolation structures in liquefiable ground. *Geotextiles and Geomembranes*, 54(4), 651–667. https://doi.org/10.1016/j.geotexmem.2026.03.003

[16] Zhang, S., Lian, Z., Zhang, H., et al. (2026). Seismic mitigation performance and energy dissipation characteristics of high-rise isolated connected structures with TNSAD. *Structures*, 84, 111081. https://doi.org/10.1016/j.istruc.2026.111081

[17] Jing, W., Zhang, H., Zhang, Y., et al. (2025). Seismic mitigation performance of 3D-isolated liquid storage tank under horizontal-rocking coupled earthquake excitations. *Bulletin of Earthquake Engineering*, 24(3), 1–36. https://doi.org/10.1007/s10518-025-02350-3

[18] Pianese, G., Habieb, A., Losanno, D., et al. (2025). Numerical investigation of high-damping rubber cores to enhance the damping performance of elastomeric seismic isolators. *Engineering Structures*, 345, 121463. https://doi.org/10.1016/j.engstruct.2025.121463

[19] Zhang, H., Mu, Y., Ding, K., et al. (2025). Shock absorption control of sand-layer isolation liquid storage structure with soft steel. *Applied Sciences*, 15(20), 10966. https://doi.org/10.3390/app152010966

[20] Zhongyuan, L., & Huaiping, P. (2026). Dynamic analysis and reinforcement design of high-rise buildings: Seismic performance enhancement via damping isolation devices. *Journal of Structural Design and Construction Practice*, 31(1). https://doi.org/10.1061/jsdccc.sceng-1945

[21] Lyu, Q., Zhang, Z., Fu, B., et al. (2025). Seismic mitigation mechanism and optimal parameter analysis of tuned negative stiffness amplifying damper (TNSAD) for base-isolated structures. *Journal of Building Engineering*, 111, 113568. https://doi.org/10.1016/j.jobe.2025.113568