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Study on seismic response reduction of high-rise building

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Abstract. With the needs of social development, the importance of high-rise building construction has become increasingly obvious. The safety of high-rise buildings, especially the safety under earthquakes, has always been an important problem. This paper collates and summarizes a large number of research results related to seismic resistance and isolation of high-rise buildings, and obtains the commonly used seismic resistance and isolatiors as well as improvement measures and possible directions for future development. Currently, commonly used methods and improvement measures mainly focus on changing the material, form and distribution position of the isolators, changing the energy consumption principle and distribution position of the dampers, and mixing the isolators and the damping device. A possible future research direction is to improve the soil layer near the foundation of high-rise buildings, such as adding artificial materials to improve its weakening effect on seismic waves. Research on the seismic resistance and isolators of high-rise buildings will help high-rise buildings to be used more reliably and rationally in the future, thereby fully realizing the social value of high-rise buildings.

Keywords: Seismic Resistance, Isolators, Seismic Response Reduction, Dampers, High-Rise Buildings.

1. Introduction

With the rapid development of cities and population growth, the usable land area is greatly decreasing. Under such premise, the construction of high-rise building has important commercial value and social value. When considering the safety of high-rise building, its seismic response is an unavoidable and significant issue, especially in areas with high earthquake risk such as China and the Pacific Rim.

The original idea of anti-seismic design is to improve the strength, stiffness and ductility of the structure. However, this method will highly increase the volume of materials and the weight of structure, reduce the usable area of the building and also increase the effect of earthquake. At the same time, this method allows structural components to undergo large plastic deformation during strong earthquake to consume seismic energy. This idea is not applicable when there are valuable structures or precision equipment inside that cannot be damaged.

In the following decades, the concept of structural control was born, that is, to adjust and control the seismic response by setting certain devices, mechanisms, structures or applying external forces at certain positions of the building. Structural control is divided in four categories, which are passive control, active control, semi-active control and hybrid control. At present, the most commonly used methods include installing seismic isolators at certain positions of the building to weaken or prevent the impact of seismic vibration on upper structure, and installing various forms of dampers to absorb energy

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transmitted by the earthquake and reduce seismic response. However, this existing methods still have some defects. For instance, when reducing the influence of high-frequency components in seismic motion through isolators, the cost may be the deformation of isolators. If the deformation of isolators becomes larger and larger, it may affect the connection between the seismic isolators and the surrounding structure and stress concentration may occur. When using dampers at the same time, as isolator deformation occurs, dampers' performance may degrade. As a result, excessive forces might be generated to upper structures and the seismic response will increase accordingly. What's more, though some forms of isolators and dampers offer relatively good performance, they are too costly to be used on a large scale.

It is worth noting that high-rise buildings will face some difficulties and challenges that mid and low-rise buildings do not have when searching for ways to reduce seismic response. This paper will provide a brief introduction of the development of widely used methods of seismic resistance, isolation and damping in high-rise building and their shortcomings, including high cost and performance degradation caused by various reasons. After that, some improvement methods that have been already applied in practice will be mentioned, such as measures to change the location and materials of isolators and ways the damper dissipates energy. Finally, some corresponding ideas and future development trends for seismic reduction that might have practical significance will be noted.

2. Methods and improvements used in high-rise building

2.1. Isolator

The most commonly used forms of isolators at present are base isolators and inter-story isolators, as shown in figure 1.

Figure 1. Friction pendulum system [1].

2.1.1. Existing flaws. First of all, as far as the basic isolation method is concerned, when doing theoretical analysis, the model is usually simplified as the tense integrity model shown in figure 2 [2]. This model consists of an upper and lower frame, connected by steel ropes. By conducting shaking table tests on such a model, it can be seen that base isolation measures can absorb the energy transferred to the upper structure from the earthquake, extend the natural period of the structure, and reduce the structural displacement during earthquakes. However, in high-rise buildings, basic isolation measures will face some difficulties. For example, from the shaking table test of the tense integrity model, it's clear that base isolator are subject to shear forces. When the building height is low, the overall stiffness is large, and the shear force on the base isolator can reduce the displacement of the superstructure. However, for high-rise buildings with smaller overall stiffness, the shear force may actually cause the building to bend.

As for inter-story isolator, the two parts of a high-rise building divided by isolator may produce large relative displacements, which will lead to the gradual loss of function of the isolator during its service life, or even due to stress concentration and excessive torque, it may be completely destroyed [2].

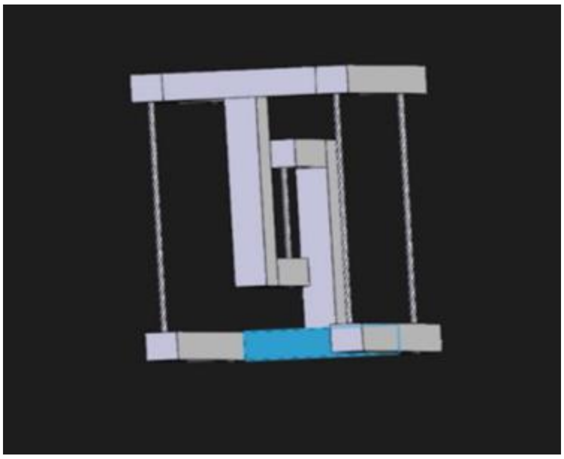

Figure 2. Assembly model of Base Isolator [1].

2.1.2. Improvement measures. In response to the above defects, there are currently some common improvement measures. For example, after testing a 1/30 scale model on a shaking table, it can be learned that changing the base isolator to an isolation layer composed of lead rubber bearings can effectively control the vibration of the superstructure. By increasing the peripheral stiffness of the isolation layer and expanding the area of the base isolation layer, the gravity distribution of the base isolator can also be optimized to improve the ability of high-rise buildings to resist overturning and bending [3]. In general, lead rubber bearing isolators can reduce the impact of earthquakes by about half, and the inter-story displacements and displacements of high-rise buildings can also be reduced by about half.

Another improvement measure is applicable when friction pendulum is used as the base isolation layer.Friction pendulum anti-vibration isolation bearings have many advantages. It has stable hysteretic performance and excellent durability, high reliability under factors such as temperature and long-term load, it can also adjust the lateral stiffness and self-alignment by itself. And its vibration period has nothing to do with the mass carried by the structure. Friction pendulum can be used in both base isolation form and inter-story isolation form. Therefore, one idea is to use a hybrid isolation control system, which uses these two different forms of isolation at the same time. By using hybrid isolation control systems, high-rise buildings can be divided into several independent units with smaller heights by different isolation layers. When each unit is calculated individually, issues such as inter-story displacement, overturning moment, aspect ratio, and degree of bending can be controlled within the range allowed by the actual situation [2].

Through shaking table tests and analysis, it can be known that when a hybrid isolation control system is used, the vibration reduction effect on the superstructure can reach 50%-80%. This method accurately targets the defects exposed by high-rise buildings when facing large earthquakes, and can simultaneously weaken the building structure response of low-order and high-order modes.

2.2. Damper

Commonly used types of dampers in construction include metal yield dampers, friction dampers, viscoelastic dampers.

2.2.1. Existing flaws. Metal yield dampers absorb energy by yielding metal materials such as lead and steel. However, metal yield dampers have long been prone to problems such as buckling and out-of-plane instability, which will make the energy dissipation capacity of the damper unstable and difficult to predict. To address this defect, the existing solution is to change the cross-sectional shape of the damper. At the same time, restraint supports can also be added outside the damper to limit the buckling and instability of the damper. In addition, the metal material of the damper can also be

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optimized, for example, the damper can be made of a more energy-consuming material that does not cause fatigue and does not generate participation stresses.

Friction dampers dissipate energy through friction between contact surfaces. Due to the high flexibility of the friction damper design, it can take different forms for different building characteristics, so there are no obvious shortcomings. For high-rise buildings, an improvement idea that has been proposed is to install steel coupling beams with friction dampers. Steel coupling beams can easily maintain their performance under earthquakes, and the dampers are connected in series with bolts to easily release residual deformation. In addition, the friction plate of this type of damper is easy to disassemble, and the working loss of the damper can be better followed up.

Viscoelastic dampers mainly consume energy through the deformation of viscoelastic materials and have good plastic deformation capabilities and durability. However, the performance of this type of damper is easily affected by external environments such as temperature, and its own strain amplitude will also change its performance. For high-rise buildings, the improvement idea is similar to the other dampers mentioned above, that is, a viscoelastic coupling damper is obtained by adding damping components to the connecting beams. Such a damping form can ensure the stability of the temperature, and can control the temperature change within a very small range in the face of complex and severe external interference, thereby ensuring the stability of the energy consumption performance of the damper.

Another type of damper that is commonly used is the tuned mass damper. Its principle is to form a tuned resonance effect between the damper and the main body of the high-rise building to absorb the energy transferred to the superstructure. Later, many new dampers with similar principles were extended, such as electrorheological dampers and so on. Dampers such as these have many advantages, but the influence of soil properties on the performance of tuned mass dampers is often ignored when performing theoretical analyses. Therefore, the actual use effect of tuned mass dampers in high-rise buildings may be somewhat different from the conclusions obtained from theoretical analysis. Therefore, in future research, how to incorporate the influence of different types of soil into the analysis is an improvement direction.

2.2.2. Improvement measures. However, no matter how the above types of dampers are improved, one problem that cannot be completely solved is that the dampers cannot completely return to their original position after experiencing an earthquake. If the damper encounters multiple earthquakes during its working life, the accumulated deformation may cause the damper to completely lose its original performance, seriously threatening the safety of high-rise construction, not only causing huge safety risks, but also greatly improving the building quality. maintenance costs. To address this problem, self-centering dampers shown in figure 3 have been proposed.

The self-centering damper connects the energy dissipation device and the self-centering device. When subjected to external forces of different values, the stiffness of the overall structure can be changed. At the same time, the prestressing device ensures that the damper can return to its original position after unloading. Common structures and materials used in self-centering devices include steel tendons and strands, shape memory alloys, mechanical springs, and more. Of course, there are not many self-centering dampers currently used in actual high-rise buildings. This is due to the fact that self-centering dampers are delicately manufactured, have high costs, and have high production technology requirements. Its large-scale production method needs further research and development [4].

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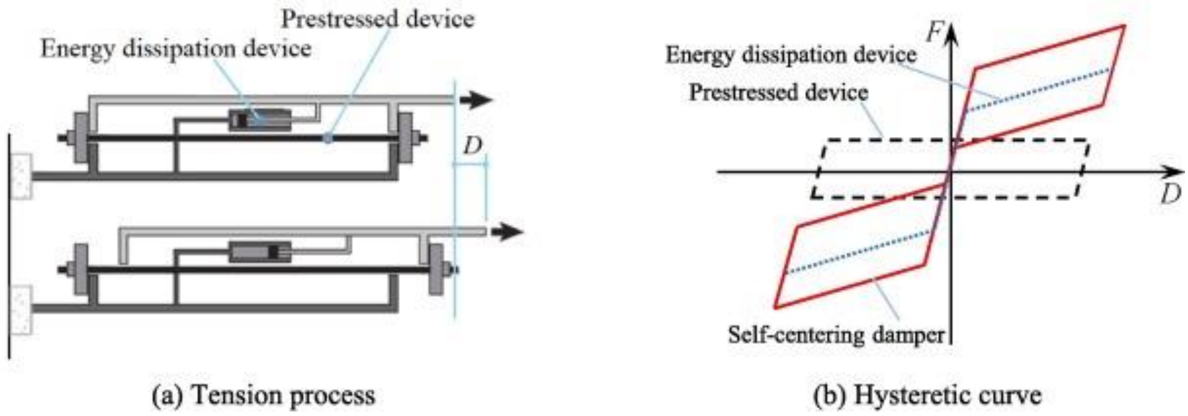

Figure 3. Self-centering damper [4].

2.3. *Mixed use of dampers and isolators*

As mentioned earlier, since the seismic isolation device can easily become a weak point in a high-rise building, when its performance is attenuated, the interaction with the building structure can easily aggravate the structural damage. Therefore, an improvement idea is to use a mixture of isolatiors and dampers. For example, use a damping that exerts a control force independent of the vibration frequency, that is, rate-independent damping. When this kind of damping is combined with a seismic isolators, it will be particularly suitable for the seismic resistance of high-rise buildings as low-frequency structures because the control force generated is insensitive to changes in vibration frequency. Of course, this method makes many idealized assumptions during research, such as simplifying the behavior of the entire structure to linear elasticity. Therefore, its practical application effect needs to be further improved [5].

2.4. *Other improvements*

As shown in figure 4, since most high-rise buildings are composed of cores and peripheral structures, the seismic resistance of high-rise buildings can be improved by strengthening the legs. The traditional method of outrigger optimization is generally by changing the cross-sectional shape, material, distribution position and quantity of the outriggers. These methods can only improve the seismic resistance of structures to a limited extent. Another novel improvement method is to add dampers and buckling restraint supports to the outrigger system. Through the energy absorption of the damper and the limitation of deformation by the buckling restraint brace, the energy dissipation of the entire system is small, which greatly reduces the seismic response of high-rise buildings [6].

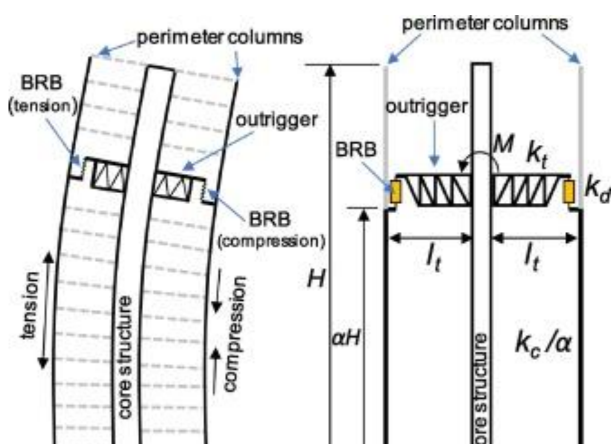

Figure 4. The deformed structure and simplified structure equipped with BRB-outrigger [6].

3. Future directions

The various measures mentioned above each have their own future directions for improvement. However, despite continuous improvements, seismic isolators and dampers in general still face complex pre-technical research, delicate manufacturing, expensive installation costs and maintenance costs. For developing countries that still need to build a large number of high-rise buildings, the construction costs are too high, resulting in that even if the isolators and dampers are effective, they cannot be used on a large scale.

For a long time, researchers have devoted themselves to thinking about how to attach various devices to the superstructure and contacts that can reduce the seismic response, but have ignored that in addition to the superstructure and foundation, the soft soil area near the foundation can also become a breakthrough point. In recent years, some researchers have proposed methods to absorb part of the seismic waves by changing the soil. This may be a feasible research direction in the future [7].

For example, one of the ideas is geotechnical isolation system. The method is to absorb the energy of seismic waves to a certain extent by adding rubber to the soil layer near the foundation and mixing it with the soil. Based on this idea, placing tires directly in the soil has also become a feasible solution. Tires are mainly composed of rubber, which has good stretchability, flexibility and durability. At the same time, the specific gravity is low, and it can absorb energy during the deformation process and play a certain damping effect [8]. If waste tires, just as figure 5 shows, are used in the earthquake resistance of high-rise buildings, waste can be used effectively and environmentally friendly, and the safety of high-rise buildings can also be improved [9]. It is a very valuable development direction for developing countries. The next research that needs to be done is to use various experimental methods such as triaxial tests to clarify the soil-rubber mixing ratio that can achieve the best earthquake resistance for different soils under different environmental conditions. Furthermore, the ability of the soil to absorb seismic waves when various other materials are mixed with the soil can also be explored. Some studies have found that rubber sand mixtures can significantly reduce the acceleration and displacement transmitted to the upper structure when mixed with soil, and can be used in the construction of high-rise buildings.

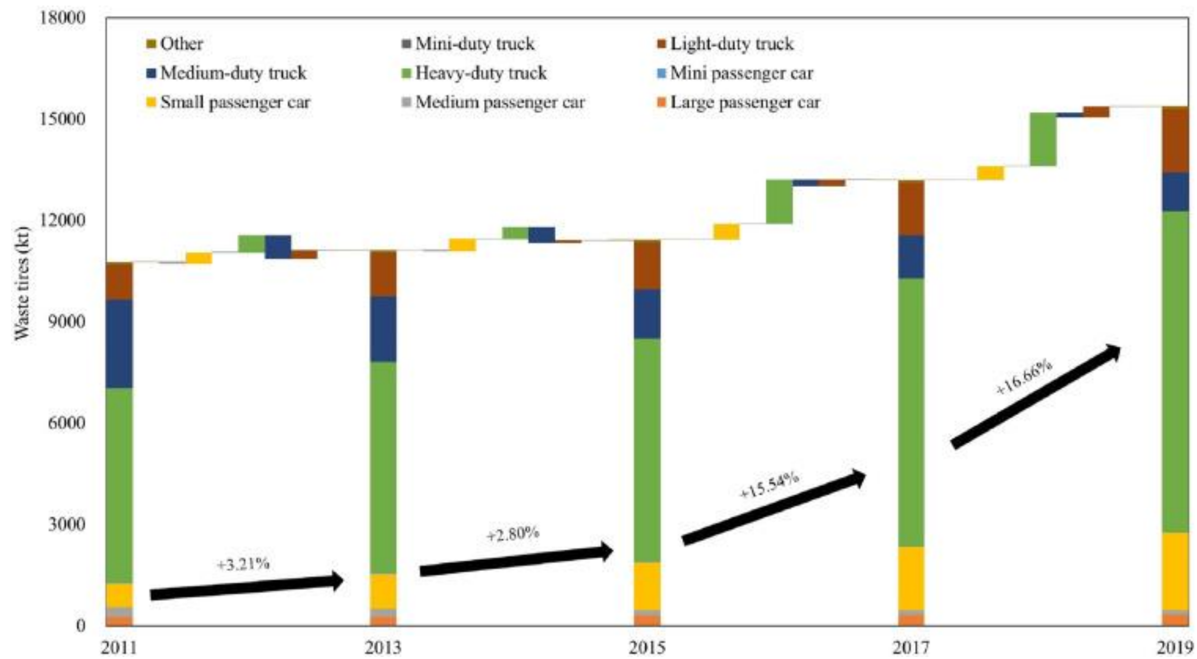

Figure 5. Waste tire generation in China in 2011–2019 [10].

4. Conclusion

This study mainly discusses measures and improvement ideas based on isolators and energy-dissipating dampers to reduce the impact of earthquakes on high-rise buildings. It also discusses ideas such as

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optimizing the building's outrigger system and optimizing soil properties. The main conclusions drawn are as follows:

(1) The disadvantage of vibration isolators is that they may cause excessive bending of high-rise buildings, excessive movement between stories, and create weak points. Improvements in vibration isolators include using the friction pendulum principle, adopting hybrid isolation control systems, and changing the material of the vibration isolator, such as using lead rubber.

(2) Defects of the damper include unstable working status, susceptibility to external conditions such as temperature, and inability to completely reset after experiencing multiple earthquakes. These defects can be improved in a small and targeted manner. But a more radical improvement idea is to use self-centering dampers. However, due to complex technology and high cost, self-centering dampers cannot yet be used on a large scale.

(3) The mixed use of isolators and dampers can effectively improve the seismic performance of high-rise buildings, but many current studies are still ideal. The seismic resistance of the building can be improved by changing the materials, structural features and layout of the outrigger structures in high-rise buildings, and dampers and buckling restraint supports can also be added to the outrigger system. One future direction is to modify soil properties near the foundations of high-rise buildings. By mixing rubber and other substances into the soil, the soil's absorption of seismic waves can be effectively improved.

References

[1] Zhang C W, Duan C K, Sun L, Zhu L M and Hsiao P C 2023 Shaking table test of multiple-type isolation control strategies for high-rise structure based on friction pendulum *Soil Dyn. Earthq. Eng.* **171(8)** 107935

[2] Divyah N, Prakash R, Srividhya S and Ajay Prakash K 2023 Control of vibrations in high-rise structures using base isolation technology *Materials Today: Proceedings* **5** 141

[3] Li J R, Luo W L, Liang Q H, Wang D Y, Zhou Y and He Z M 2023 Shaking table test of seismic performance of high-rise over-track building with base isolation *J. Build. Eng.* **75(9)** 106749

[4] Xu G, Guo T, Li A Q, Wang S Y, Zhang R J, Zhu R Z and Xu J 2023 Review on self-centering damper for seismic resilient building structures *Struc.* **54(8)** 58-77

[5] Luo H, Tang Z and Zhu H P 2023 High-performance isolation systems with rate-independent linear damping for seismic protection of high-rise buildings *Soil Dyn. Earthq. Eng.* **171(8)** 107976

[6] Lin P C and Tsai S J 2022 Seismic performance and design of the damped-outrigger system incorporating buckling-restrained brace for buildings with various heights *Struc.* **44(10)** 1565-1582

[7] Erenson C 2023 Dispersion characteristics of clayey soils containing waste rubber particles *J. Rock Mech. Geotech. Eng.* **4** 1-9

[8] Ghorbanzadeh S and Seyedi Hosseininia E 2023 A numerical study on the seismic design of buildings seated over an RSM layer *Struc.* **55(9)** Pages 46-58

[9] Chen Z P, Liang Y H, Lin Y Z and Cai J M 2022 Recycling of waste tire rubber as aggregate in impact-resistant engineered cementitious composites *Const. Build. Mate.* **359(12)** 129477

[10] Li J R, Luo W L, Liang Q H, Wang D Y, Zhou Y and He Z M 2023 Shaking table test of seismic performance of high-rise over-track building with base isolation *J. Build. Eng.* **75(9)** 106749