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Research and Application Status of Soft Steel Dampers

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Abstract

Soft steel dampers have stable hysteresis characteristics and can effectively dissipate energy under repeated loads, providing good shock absorption effects for structures. It can be used for both seismic design of new buildings and seismic reinforcement of existing buildings. Suitable for various structural forms of buildings, including concrete structures, steel structures, and heavy-duty wooden structures. It is also applied in bridge structures, which can effectively reduce the vibration response of bridges under earthquake, wind vibration, etc., and improve the seismic performance and safety of bridges. Countries with rapid development in the application of structural control technology, such as the United States, Japan, Canada, New Zealand, and Mexico, are the main ones. Italy, France, Russia, Singapore, and other countries are also actively applying it in practical engineering. More than a hundred buildings abroad have adopted soft steel dampers.

Keywords

Soft Steel Damper; Architecture; Structure; Anti-seismic.

1. Introduction

In the field of engineering structures today, how to effectively improve the safety and stability of structures under dynamic loads such as earthquakes and wind vibrations is a crucial issue. With the development of society, the requirements for seismic and wind resistance performance of important structures such as buildings and bridges are constantly increasing. Traditional structural design methods are gradually showing certain limitations when facing extreme disasters. Structural vibration control technology has emerged as an innovative concept, aiming to regulate the dynamic response of the structure by setting specific control devices in the structure. Among numerous vibration control devices, soft steel dampers have attracted much attention due to their unique advantages. Soft steel dampers, as a type of energy dissipation and shock absorption device, utilize the excellent plastic deformation ability of soft steel materials after yielding to dissipate energy.

2. Research History and Existing Problems of Soft Steel Dampers

2.1. Brief Introduction to the Research History of Soft Steel Dampers

Since the late 20th century, numerous scholars and research institutions at home and abroad have conducted extensive and in-depth research on soft steel dampers. On the one hand, through extensive theoretical analysis and experimental research, the mechanical properties, energy dissipation mechanisms, and various factors affecting the performance of soft steel dampers are explored; On the other hand, in practical engineering, continuous attempts are being made to apply soft steel dampers to different types of structures to verify their actual seismic reduction effects.

With the continuous improvement of people's requirements for seismic performance of building structures, various shock absorption and energy dissipation devices have emerged.

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Soft steel dampers, as an effective seismic reduction device, have received widespread attention and application in the field of structural seismic resistance. It can dissipate a large amount of energy under the action of earthquakes and other dynamic forces, thereby protecting the main structure from serious damage.

Developed countries such as the United States and Japan have accumulated rich experience in the application of soft steel dampers abroad. Many important construction and bridge projects have adopted soft steel dampers for seismic design and achieved significant results. In China, although related research started relatively late, significant progress has been made, and more and more domestic engineering projects are considering the use of soft steel damper technology.

However, despite some achievements in the research and application of soft steel dampers, there are still some urgent problems that need to be solved, such as how to further optimize their structural form to improve performance and reduce costs, how to more accurately establish their mechanical models, and how to develop comprehensive design specifications. A thorough review and analysis of the research and application status of soft steel dampers is of great significance for promoting the development of this field and its widespread application in practical engineering.

2.2. Mechanical Properties of Soft Steel Dampers

The hysteresis curve of the soft steel damper is full and stable, with good energy dissipation capacity. The shape and characteristics of the hysteresis curve reflect the force and deformation relationship of the damper during cyclic loading.

The yield strength of a soft steel damper is a key parameter that determines the level of load at which the damper begins to dissipate energy. Different design requirements require the selection of soft steel materials with different yield strengths.

The stiffness of the damper affects the overall dynamic characteristics of the structure. In the design process, it is necessary to adjust the stiffness of the soft steel damper reasonably according to the specific situation of the structure.

2.3. Energy Dissipation of Soft Steel Dampers

Soft steel dampers can dissipate a large amount of energy under earthquake action, and their energy dissipation capacity is closely related to factors such as the material properties of soft steel, the construction form of dampers, and loading conditions.

Due to the repeated action of dynamic loads such as earthquakes, soft steel dampers need to have good low cycle fatigue performance. By reasonable design and material selection, the fatigue life of dampers can be improved.

3. Basic Principle of Soft Steel Damper

In the field of seismic resistance in building structures, soft steel dampers play a crucial role as an important energy dissipation and seismic reduction device.

The basic principle of soft steel dampers is based on the plastic deformation of metal materials. Soft steel has good plasticity and ductility. When subjected to external forces, it can undergo significant plastic deformation without brittle failure. When the building structure vibrates under dynamic loads such as earthquakes, the soft steel damper will deform accordingly.

From an energy perspective, the energy input from earthquakes into structures mainly includes kinetic energy and potential energy. If these energies are not effectively dissipated, it will lead to increased vibration of the structure and even cause structural damage. Soft steel dampers dissipate energy through their own plastic deformation. During the deformation process, the grains inside the soft steel undergo microstructural changes such as slip and rotation,

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converting the input mechanical energy into other forms of energy such as thermal energy, effectively reducing the vibration response of the structure.

The working process of soft steel dampers can be divided into several stages. In the small deformation stage, the soft steel damper mainly exhibits elastic deformation, which contributes to the stiffness of the structure to a certain extent. As the deformation increases, the soft steel begins to enter the plastic deformation stage. At this stage, the energy dissipation capacity of the damper gradually increases, and it consumes a large amount of energy through its own yielding and plastic flow. When the deformation reaches a certain degree, the soft steel damper may exhibit local strain strengthening, but overall it still maintains good energy dissipation performance.

In practical applications, soft steel dampers can be designed and installed according to different building structures and design requirements. Common types of soft steel dampers include shear type, bending type, and tension compression type. Shear type soft steel dampers mainly dissipate energy through the shear deformation of soft steel. They are usually composed of multiple layers of soft steel sheets stacked together, and under seismic action, relative shear deformation occurs between the soft steel sheets. The bending type soft steel damper utilizes the bending deformation of soft steel to dissipate energy, and its structural form is similar to a cantilever beam or simply supported beam. The tension compression type soft steel damper mainly dissipates energy through the axial tension compression deformation of soft steel, and it can be installed at the beam column nodes and other parts of the structure.

4. Construction form of Soft Steel Damper

4.1. Flat Plates

Made of multi-layer flat soft steel connected by high-strength bolts or welding. Soft steel plates usually have a certain thickness and can withstand shear forces in the horizontal direction. When the structure undergoes relative displacement, the soft steel plate undergoes relative displacement between layers, and the soft steel enters a plastic yield state, dissipating energy through shear deformation. This type of damper has a simple structure, is easy to manufacture, and can provide relatively stable damping force.

4.2. U-shaped

It has a U-shaped shape and is usually bent from a soft steel plate. The U-shaped opening can be designed according to actual needs to accommodate different installation spaces and stress conditions. Under the action of external forces such as earthquakes, the two wings of U-shaped soft steel will undergo bending deformation, and the soft steel will enter the plastic stage, reducing the vibration response of the structure through bending energy dissipation. U-shaped soft steel dampers can generate significant plastic deformation during bending deformation, have high energy dissipation efficiency, and have relatively balanced energy dissipation capacity in different directions.

4.3. Ribbed Soft Steel Damper

On the basis of traditional soft steel dampers, reinforcing components such as stiffeners and stiffeners have been added. These stiffeners can be steel plates welded onto a soft steel body, or other forms of reinforcement structures. Stiffening components can improve the overall stiffness and stability of dampers. When the soft steel deforms, the stiffening components work together with the soft steel, which can limit the local buckling of the soft steel and increase the energy dissipation capacity of the damper.

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4.4. Composite Soft Steel Damper

Combine various forms of soft steel dampers, such as combining shear and bending soft steel dampers, or combining tension compression dampers with other types. By utilizing the energy dissipation characteristics of different types of soft steel dampers under different stress directions and deformation modes, multi-directional and multi-mode energy dissipation can be achieved, improving the comprehensive performance of dampers and their ability to control complex structural vibrations.

5. Application of Soft Steel Dampers in Engineering Structures

In high-rise buildings, soft steel dampers can be installed at key parts of the structure, such as between the core tube and the outer frame, between floors, etc. Under earthquake action, soft steel dampers dissipate energy through their own plastic deformation, effectively reducing the acceleration and displacement response of floors, thereby improving the seismic performance of building structures and reducing the risk of structural damage. The use of soft steel dampers can reduce the size and steel consumption of structural components in building structures while meeting seismic requirements. For example, by reasonably arranging soft steel dampers, the design internal forces of structural components such as beams and columns can be reduced, thereby achieving optimized structural design and reducing engineering costs.

Steel structure buildings themselves have the characteristics of light weight and high strength, but they are prone to significant deformation under earthquake action. The combination of soft steel dampers and steel structures can fully utilize the energy dissipation characteristics of soft steel and effectively suppress the vibration of steel structures. For example, installing soft steel dampers at the beam column nodes of steel frame structures can quickly enter a state of energy dissipation during earthquakes, reduce stress concentration in the node area, and protect the overall stability of the steel structure. For some steel structure buildings that require high comfort, such as office buildings, shopping malls, etc., soft steel dampers can effectively reduce structural vibrations caused by wind loads and improve the comfort of indoor personnel.

Soft steel dampers are an effective means of seismic reinforcement for existing buildings. Soft steel dampers can be attached to appropriate positions in the structure without changing the original building structure, such as adding soft steel dampers in the peripheral frame columns, stairwells, and other areas of the building. In this way, during earthquakes, soft steel dampers can provide additional energy dissipation capacity for buildings, enhance the seismic resistance of existing buildings, and extend the service life of buildings. Compared with traditional reinforcement methods, using soft steel dampers for reinforcement construction is relatively simple, does not require large-scale demolition and reconstruction of the original structure, has less impact on the normal use of the building, and can flexibly arrange dampers according to the actual situation of the building.

In beam bridges, soft steel dampers can be installed between piers and beams, or between adjacent beams. When a bridge is subjected to vehicle loads, earthquake effects, or wind loads, the soft steel damper absorbs energy through its own deformation, reduces the vertical, horizontal, and longitudinal vibrations of the beam, and improves the overall stability of the bridge structure. For example, in a simply supported beam bridge, soft steel dampers can effectively control the displacement of the beam end and prevent the occurrence of beam drop phenomenon. By reducing the impact force of the beam on the bridge pier, the soft steel damper can reduce the stress on the bridge pier and extend its service life. At the same time, it can also reduce the wear and damage of bearings and lower the maintenance cost of bridges.

In arch bridges, soft steel dampers can be installed at key locations such as arch feet, arch ribs, and tie beams. Arch bridges generate complex internal forces and deformations when subjected to vehicle loads, earthquake loads, etc. Soft steel dampers can effectively improve the stability

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of arch bridge structures and reduce deformation and vibration of arch ribs through energy dissipation. The installation of soft steel dampers can change the dynamic characteristics of arch bridges, making their response to dynamic loads smoother and reducing the risk of structural resonance.

6. Future Research Directions of Soft Steel Dampers

The exploration of high-performance materials aims to find new materials with higher strength, better toughness, better fatigue resistance, and corrosion resistance to improve the performance and service life of dampers. For example, the development of new alloy materials, composite materials, or nanomaterials may have better performance in damping characteristics, load-bearing capacity, and reliability.

Exploring the direction of complex structure and multifunctional design, developing dampers with complex structures to meet different engineering application requirements. For example, designing dampers with multi-directional energy dissipation capability can effectively absorb vibration energy in multiple directions; Or develop composite dampers that integrate multiple functions such as damping, support, and connection, reducing the number of components in the structure and improving its overall integrity and reliability.

Exploration of the application direction in extreme environments, exploring the application of dampers in extreme environments such as high temperature, low temperature, high pressure, high radiation, etc. Study the performance changes and reliability of dampers in extreme environments, develop damper products suitable for extreme environments, and meet the special needs of aerospace, deep-sea exploration, nuclear energy and other fields.

Exploration of biomedical applications, expanding the application of dampers in the biomedical field, such as vibration reduction for medical devices, damping control for artificial joints, etc. Research on biocompatible materials and biomechanical properties, design dampers that meet biomedical requirements, and provide support for the development of medical technology.

7. Future Research Directions of Soft Steel Dampers

Soft steel dampers are of great significance in the field of structural seismic resistance. From its principle, it utilizes the plastic deformation of soft steel materials to achieve energy dissipation. Under external forces such as earthquakes, the yield deformation of soft steel components converts the energy input into thermal energy and other forms of dissipation, effectively reducing the dynamic response of the structure and protecting the main body of the structure.

In engineering applications, it can reduce the bending moment and shear force of beam column nodes in building structures, and reduce the displacement between high-rise building floors; In bridge structures, vibration between bridge piers and main beams can be reduced, and cable vibration of cable-stayed bridges can also be controlled. The application of high-performance materials can lead to the development of new soft steel materials; Intelligent soft steel dampers combined with sensors and control systems can achieve precise shock absorption; Combined with other shock absorption technologies, a composite shock absorption system can be formed. Soft steel dampers have obvious advantages and broad prospects in the field of structural seismic resistance. Continuous research and innovation will enable them to play a greater role in ensuring the safety of people's lives and property and social stability.

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