A Review and Prospect of The Influence of The Structure Composition of Viscous Dampers on The Damping Effect of Long-span Bridges

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Abstract

In this paper, the influence of the structure composition of viscous dampers on the damping effect of long-span Bridges is studied. Long-span Bridges are susceptible to various dynamic loads, such as vibrations caused by wind and earthquakes, which can lead to serious damage or even collapse. Viscous dampers are widely used to mitigate these effects by dissipating vibration energy. This paper analyzes all kinds of new viscous dampers developed in recent years, describes their differences and innovations from traditional dampers, summarizes their advantages and analyzes their practical applications.

Keywords

Viscous damper; Long-span bridge; Seismic performance; Summarize.

1. INTRODUCTION

1.1. Application status of viscous dampers

Since the 1980s, the construction of long-span Bridges has been very active.[1] Many long-span Bridges use viscous dampers to alleviate structural vibration. For example, the Yokohama Harbor Bridge in Japan, completed in 1989, used viscous dampers. The middle span of the bridge is 460 meters, and the viscous damper is used to control the bridge mechanically.[1] The Suzhou-Nantong Yangtze River Highway Bridge, which opened in 2008, is in Jiangsu Province, China.[2] With a main span of 1,088 meters, the bridge is currently the longest cable-stayed bridge in China. In terms of dampers, the bridge adopts viscous dampers to alleviate the vibration of the bridge structure caused by typhoons in eastern China. What's more, Jiangyin Yangtze River Highway Bridge is another long-span bridge in China.[3] Its main bridge is 1,385 meters long and uses viscous dampers like the Sutong Bridge. The Chinese government has successfully perfected the structure of viscous dampers on several previous long-span Bridges over the Yangtze River. In the Nanjing Yangtze River Third Bridge project, 54 liquid viscous dampers were designed and used on the approach bridge for the first time.[4] So far, many long-span Bridges using viscous dampers have been put into use in the world. And the governments of China, Japan and South Korea plan to build more long-span Bridges and more viscous dampers are put into the design and construction of long-span Bridges, which requires higher performance of viscous dampers.

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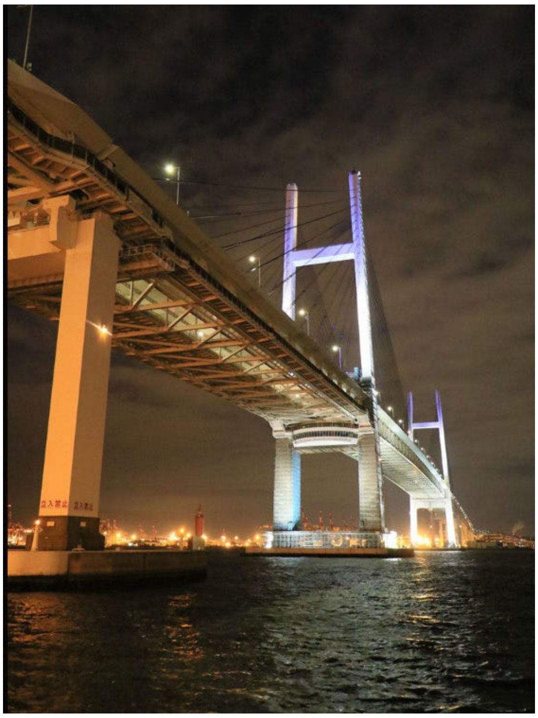

Figure 1. Yokohama Port Bridge

Figure 2. Suzhou-Nantong Yangtze River Highway Bridge

Figure 3. Jiangyin Yangtze River Highway Bridge

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Figure 4. Nanjing Yangtze River Third Bridge

1.2. Principle of viscous damper

Viscous dampers provide a force that always resists structural motion. The magnitude of this force is proportional to the relative velocity between the two ends of the damper. The formula of the reaction damping law is:F=CVN [5]

Where F is the damping force, C is an arbitrary constant (C remains constant throughout the velocity range), V is for velocity, N is an exponent (N ranges from 0.3 to 1.95 and remains constant throughout the speed range).

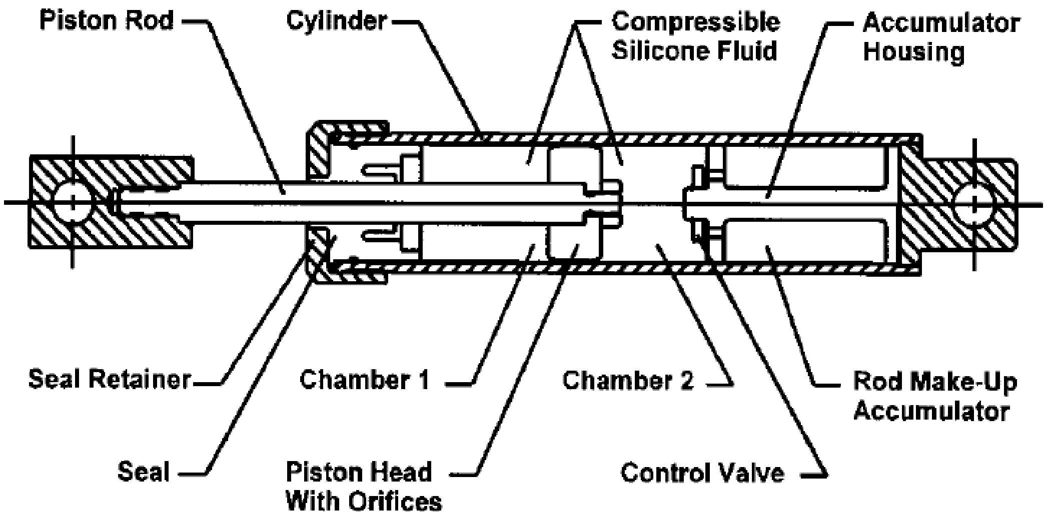

Figure 5. Typical viscous damper

The typical damper shown in Figure 5 consists of a liquid-filled chamber in which the upstream pressure energy is almost entirely converted to kinetic energy. As the fluid expands to its full volume on the other side of the piston head, it slows down and loses kinetic energy through turbulence. This results in a considerable pressure difference between the downstream and upstream of the piston head, creating a large force that impedes the motion of the damper.[5] In this way, the damper creates a kind of resistance, which is used to counteract the effects of

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earthquakes and wind. Reduce mechanical vibration: Viscous dampers can reduce the vibration of bridge structural systems, thereby reducing noise and vibration.

2. ADVANTAGES OF VISCOUS DAMPERS ON BRIDGES

(1) Improved bridges safety: Viscous dampers can help control the speed and position of the bridge structural system, thus improving the safety of the bridge. For example, the use of viscous dampers on large spans can prevent the collapse of Bridges due to earthquakes. [6]

(2) Reduced maintenance costs: The operation principle of the viscous damper is simple, and there are no wearing parts that need to be replaced regularly, so maintenance costs are low.

(3) Improve bridge life: Because the viscous damper can reduce the vibration and impact of the bridge structural system, it can extend the service life of the machine.

(4) Adaptable: Viscous dampers can be customized to different needs, including liquid viscosity, cylinder size and piston shape, to achieve the best results.

(5) High reliability: Since the viscous dampers have no mechanical contacts, their wear during use is almost negligible. This greatly improves the reliability of viscous dampers.

(6) Flexible control: Viscous dampers can change their damping characteristics by changing the viscosity of the liquid, thereby improving their control flexibility. In addition, multiple viscous dampers can be used to achieve more complex control.

(7) High energy absorption capacity: Since viscous dampers can absorb kinetic energy in mechanical systems, they can be used to reduce the energy generated by collisions or impacts, thereby protecting the safety of Bridges and people.

(8) Convenient for installation: Viscous dampers are usually easy to install and can be simply inserted into the bridge structure. This makes it easier to install and update viscous dampers on existing Bridges.

In general, a viscous damper is a damper widely used in bridge structural design, with many advantages that can improve the reliability, safety, accuracy and life of the machine, reduce maintenance costs and noise, and protect the safety of the bridge and those who use the bridge.

However, the structure rigidity of long-span bridge is low, and the damping is relatively small. During use, the main beam vibrates frequently (no more than 10 mm/s), subject to forces such as vehicles and pulsating winds. This vibration will keep the viscous damper in motion, causing its cumulative displacement to increase, and the seal will also be at risk of leakage due to long-term wear. To avoid this situation, it is necessary to take corresponding measures to absorb shock. [4]

3. NEW VISCOUS DAMPERS

3.1. Structural innovative viscous dampers

3.1.1. Durable viscous damper

Many of the world's long-span Bridges are over rivers and oceans. Considering humid air, earthquake zones, typhoons, and the effects of everyday traffic. Dampers of long-span Bridges need to be able to ensure that they do not leak for a long time. Otherwise, the damper leakage will bring about the decrease of the structural vibration mitigation ability of the bridge structural system, which has a high probability of causing the damage of the bridge structure.

Li et al. developed Durable viscous dampe. The use of viscous dampers on long Bridges built at sea will face the problem of leakage and corrosion caused by harsh environments such as corrosion. [7] For this purpose, we have developed a durable viscous damper with a speed index of 0.15 to 0.3, using technologies such as a combined seal and a ceramic-sprayed piston rod. In addition, Li et al. also designed an intelligent monitoring and evaluation system for this type of damper.

In order to verify the performance of the durable viscous damper, a sample FVD2000/±400-2000-0.23 was tested.

The test results show that the durable viscous damper has better mechanical properties. At 0.1mm/s, its damping force output is not more than 10% of the design maximum damping force. In the range of 1-1000mm/s, the deviation between the actual damping force and the theoretical damping force is no more than ±15%, which satisfies the designed constitutive relationship of F=2000V0.23. The low-speed index can effectively reduce the cumulative displacement of the beam end of the long-span bridge under the traffic and fluctuating wind.

In addition, after the fatigue wear test of 1000m, the hysteretic curve of the durable viscous damper did not change significantly. The surface of the ceramic-coated piston rod was smooth, and no damping medium leakage was observed, which showed that the wear resistance of the ceramic-coated piston rod was better and the sealing performance of the series seal was better.

Finally, the intelligent monitoring and evaluation system of the durable viscous damper can fully reflect the working state of the damper, guide the maintenance personnel to carry out the maintenance work scientifically, and further extend the service life of the viscous damper.

However, the experiment of the durable viscous damper has not completed the bridge data simulation experiment on the actual bridge modelling. The slow performance test, low speed performance test, fast performance test and endurance fatigue test are carried out with a single damper. Lack of certain practical application data support. The results of application in practical long-span Bridges need to be further tested.

3.1.2 Self-centering fluidic viscous damper

Zhu et al. developed the SC-FVD system, which comprises two key components: the SC unit and the viscous energy dissipation unit, as illustrated in Figure 1. The viscous energy dissipation unit, known as an FVD, is composed of a cylinder, piston, piston rod, seal cover, and silicone oil. [8] To ensure stability, the viscous damper's two ends are threaded into the end tube, which is securely fastened to the end cap. Both ends of the outer tube are also connected to the end covers, establishing a relatively fixed position between the viscous damper and the outer tube. This arrangement enables the transfer of the damper's viscous force to the outer tube through the end tube and end cap. The end tube is designed with a groove that facilitates uninhibited sliding of the connector.

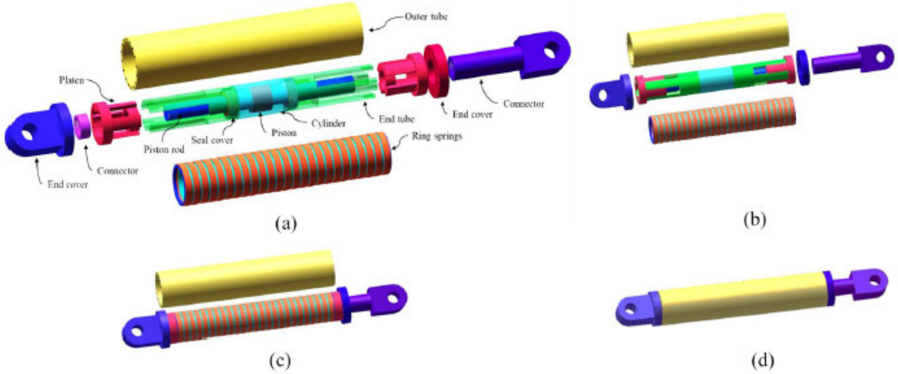

Figure 6. Structure of self-centering fluid viscous damper

The conclusion drawn from the work of numerical simulation experiment is:

(1) The proposed SC-FVD system comprises a ring spring and a fluid viscous unit, demonstrating excellent energy dissipation and re-entering capabilities. Utilizing velocity and

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displacement dependent systems allows the SC-FVD to effectively operate across a wide frequency range.

(2) By considering the influence of the pre-tensioned ring spring, the hysteresis curve of the SC-FVD exhibits an inclined shape, displaying stable and complete behavior. Moreover, the hysteresis curve experiences a sharp increase at zero displacement. Furthermore, at the conclusion of the testing, the damper exhibits nearly zero residual displacement, indicating its ideal SC capabilities.

(3) The SC-FVD demonstrates favorable fatigue performance, with only a 7% degradation rate in energy dissipation capacity and a 5% reduction in peak force observed after 30 loading cycles.

The analytical model provides accurate predictions of the lag response exhibited by the SC-FVD across various load amplitudes and frequencies. The deviation between the theoretical peak force and the measured peak force is less than 7%.

Compared with ordinary viscous dampers in fatigue tests, self-centering fluid viscous dampers have excellent damping effects, and wind and seismic effects are better when installed in building structures. However, there is a lack of three-dimensional modelling experimental data for long-span Bridges. The application effect on long-span Bridges needs to be further explored.

3.1.3 Viscous steel composite damping system

The CVSDS device consists of three parts, namely a viscous damper, a steel damper and a fuse lock device [9]. The girder and the viscous damper are connected via a hinge, and a pin is utilized to establish a connection between the damper's piston rod and the fixing plate of the fuse lock device. The movable plate within the fuse lock device is secured to the fixed plate by a combination of preloaded springs, including a pair of springs. The pre-tensioning spring has the role of maintaining the immobility of the movable plate until the pin experiences damage. In the event of pin failure, the preload spring inserts the movable plate into a designated aperture. The fixing plate of the fuse lock device is joined to the cover plate of the steel damper, while the bottom plate is merged with either the abutment or the tower.

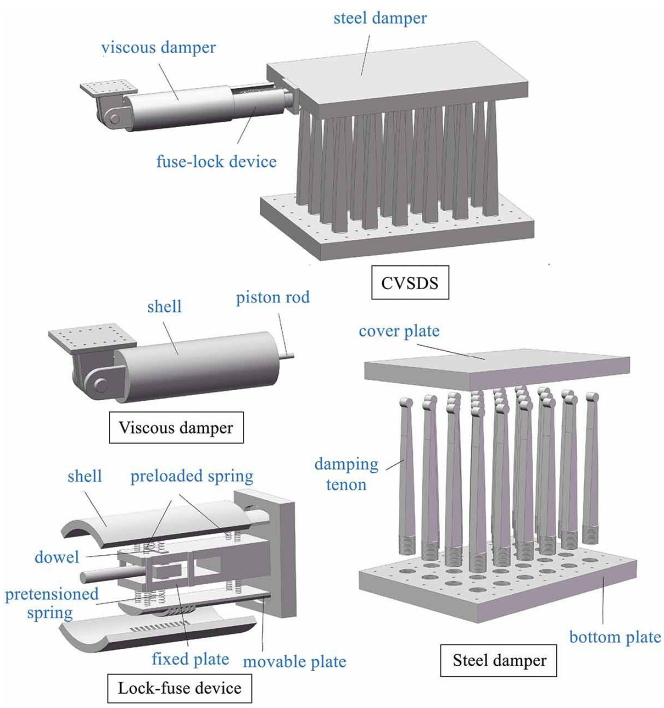

Figure 7. Structure of Viscous steel composite damping system

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The fundamental principle of the fuse locking device is to transmit the damping force from the viscous damper to the steel damper through the pin under braking loads and frequent seismic events. However, this force is intentionally kept below the shear strength of the pin, ensuring that the movable plate in the fuse locking device remains stationary due to the pre-tensioned spring's action. During this stage, the primary role of the steel damper is to provide stiffness and support, while the viscous damper actively mitigates dynamic forces. However, in rare occurrences of powerful earthquakes, the damping force generated in the viscous damper surpasses the shear strength of the pin. Consequently, the pin is sheared, causing the pre-tensioning spring to become inactive. As a result, the movable plate is inserted into a designated recess with the assistance of the preloaded spring. At this point, the shell of the viscous damper acts as a rigid link connecting the bridge and the steel damper. This signifies the cessation of the viscous damper's functionality, and the responsibility for energy dissipation is taken over by the steel damper. Following a significant earthquake, it is crucial to replace the damaged pins and damping tenons to ensure the device's proper performance in subsequent events.

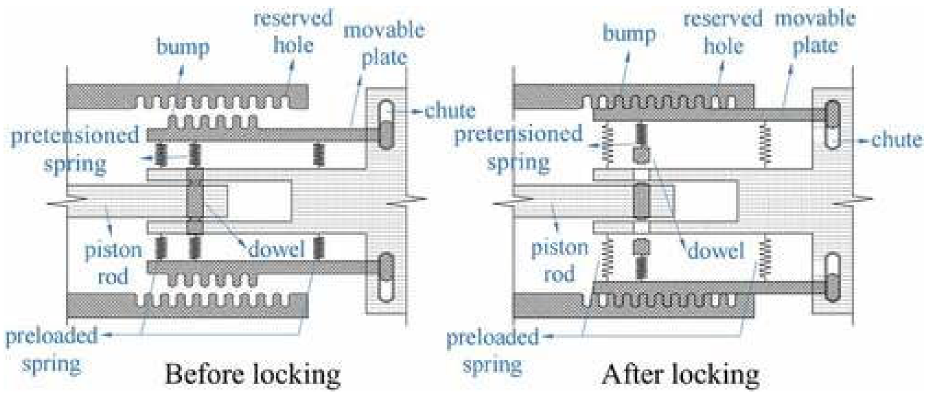

Figure 8. Schematic diagram of Viscous steel composite damping system

Hu et al. built a ground-anchored railway suspension bridge with a main span of 1060 meters and side spans of 130 meters and 90 meters, respectively, by using a three-dimensional numerical simulation method. [9] The CVSDS damping system is used as the damper of the bridge to verify the data and draw the following conclusions：

(1) The proposed fuse locking device successfully realizes the locking function.

(2) Viscous dampers and steel dampers work together very effectively. When the PGA of seismic excitation increases, the system will be locked earlier.

(3) CVSDS can reduce the longitudinal vibration of the girder and does not increase the internal force of the tower due to train braking and seismic excitation.

(4) Within CVSDS, the utilization of small tonnage viscous dampers offers a solution to the challenges posed by oil leaks and failures. Simultaneously, the incorporation of steel dampers allows for the optimal utilization of their resilience in rare seismic events, effectively circumventing any disadvantages resulting from temperature fluctuations.

3.2. Material innovative viscous damper

3.2.1 Polyborosiloxan-based viscous damper

Chen et al., Xi 'an University of Technology, replaced the damping material in the viscous damper with a double-exit rod. The damping materials commonly used in the field of civil engineering are mastic and silicone oil, and the damping materials in the literature are replaced with a new type of plasticized polyborosiloxane to improve the damping effect and durability of the damper. [10,11]

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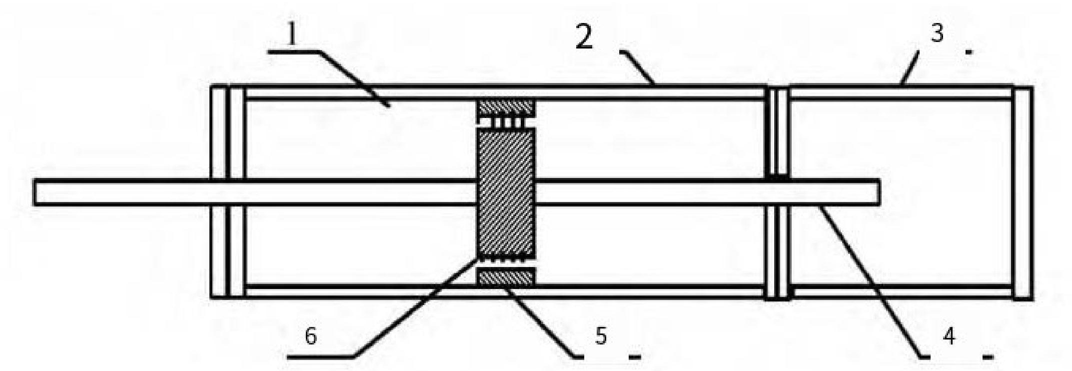

1. Damping material: 2. Master cylinder: 3. Auxiliary cylinder: 4. Guide rod: 5. Piston: 6. Damping hole.

Figure 9. The composition of Polyborosiloxan-based viscous damper

Chen et al. conducted thermodynamic performance tests, rheological performance tests, and dynamic performance tests of viscous dampers on such dampers and drew the following conclusions.

(1) As a viscous damping material, plasticized polyborosiloxane keeps the viscous flow state in the working temperature zone of the general damper, which is conducive to improving the working stability of the damper.

(2) Plasticized polyborosiloxane is a nonlinear damping material whose viscosity is affected by shear rate. Through the damper test, it is found that the rheological curve trend of the sample has not changed, that is, the mechanical properties of the material have hardly changed, showing good reversibility and stability.

(3) Using plasticized polyborosiloxane as damping medium of viscous dampers, viscous dampers with excellent damping properties can be obtained. The damping force output of the damper has a nonlinear relationship with the piston velocity. The greater the speed, the greater the damping force, and when the speed reaches the critical value, the damping force remains constant, which can avoid the huge damping force generated by the velocity impact, and then prevent the secondary damage of the bridge structure. However, after 5 reciprocating cycles of the damper loading, its output damping force will be reduced by about 50%.

Although the damping effect of the damper is better than that of the general material, the damping effect will be significantly reduced at high temperatures. The major design defect comes from the decreasing damping effect of the dampers during the reciprocating loading process, which is not useful for Bridges in high-intensity seismic areas. Therefore, the damping material design of the damper needs to be further improved.

4. CONCLUSION

This paper summarizes the development of new viscous dampers and analyses the advantages and disadvantages of dampers by listing several new dampers for long-span Bridges in recent years. In addition, the further development direction of viscous dampers in the future is proposed, and the following results are obtained:

(1) At present, the research of new dampers has obtained more data from 3D data modeling and simulation experiments. There is less data available on real Bridges. Therefore, it is necessary to collect real data to evaluate the damper performance in all aspects.

(2) At present, the research and development of new dampers has been relatively mature, and there are much research on the development of new dampers in the world. The main research direction is structural innovation and material innovation. At present, structural

innovation is mostly connected with other structures to achieve better damping effect, and the research in this area is relatively mature. However, there is a lack of research on damping materials, and there is a lack of a material that can replace the damping materials used by the existing bridge dampers with higher performance and durability, which needs further research in this area.

(3) The new viscous damper has a wide application prospect in the long-span bridge, especially in the high-intensity earthquake area, because of its better damping effect than the general damper. Through further in-depth research and practical applications, we can ensure the safety and longevity of long-span Bridges and contribute to the sustainable development of infrastructure.

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