Study on Energy Dissipation of Viscous Damper for Long-Span Suspension Bridges

Feiyan Huang, Guangzhao Peng and Xuanyi Wang

School of Civil Engineering, Beijing Jiaotong University, Beijing, China.
National Experimental and Teaching Center for Civil Engineering, Beijing Jiaotong University, Beijing, China.

Abstract. Viscous dampers are important devices to dissipate the vibration energy of long-span bridges. In this paper, nonlinear time history analysis was used to study the effects of this type of damper on suspension bridges. The influence of nonlinear viscous dampers on the seismic response of long-span suspension bridges was analyzed, which was based on a real project. The quantitative relationship between the displacement of the bridge girder and the tower with the damping coefficient and velocity index was investigated. The results showed that the displacement of the bridge girder under earthquakes can be effectively reduced by selecting the appropriate damping coefficient and velocity index of the nonlinear viscous dampers, and the best energy dissipation and seismic reduction effect for long-span suspension bridges can be obtained.

1. Introduction

Because of its long span ability and beautiful shape, the suspension bridge has become the most competitive bridge type in the long-span bridges [1]. While the long-span suspension bridge has the characteristics of long vibration period and large flexibility, the beam end is easy to produce large displacement along the bridge under the action of strong earthquakes, which will affect the normal use of the structure. Therefore, how to improve the seismic performance of suspension bridge structure has become the key point for bridge structure engineering researches. In recent years, the damping measures of setting energy dissipation devices such as elastic connection devices, metal elastoplastic dampers or liquid viscous dampers between tower and beams have been widely used. As for the damping mechanism of liquid viscous damper and its application in suspension bridge, many scholars have studied and published relevant literature successively. Wang et al. [2] had studied The influence of nonlinear viscous damper on the seismic performance of the bridge on the background of Donghai Bridge; In the research of Wang [3], it shows that for the super-long span suspension bridge, the displacement response of the girder end can be reduced by setting the elastic connection device or damper between the tower and the girder, but the damping effect of the damper is more comprehensive considering the response of other parts. Xun et al. [4] took towers of a self-anchored suspension bridge as an example. It was found that when the damping coefficient or velocity index of liquid viscous damper are smaller, the longitudinal seismic displacement and internal force responses of the bridge become smaller respectively. Zhu et al. [5] conducted the research on the damping design of large-span suspension bridge based on Dalian Star Bay Cross-Sea Bridge. It showed that the joint action of central buckle and liquid viscous damper under seismic load was an effective seismic measure. By the calculation and comparison analysis, Wu et al. [6] found that in the longitudinal bridge through the set of nonlinear viscous damper between the tower and girder can effectively control the large displacement of the girder end under earthquakes, and
it will improve the seismic performance of the structure. Chen et al. [7] studied the reasonable parameters of viscous dampers in the self-anchored suspension bridge, and found that the viscous damper provides a certain damping to the structure, and under the condition of consistent excitation and traveling wave excitation, the dampers have a good damping effect. Taking the actual project of Dahe Bridge in Dadong Road as an example in this paper, the energy dissipation and damping effect of nonlinear viscous damper on large-span suspension bridge was studied by using nonlinear time history analysis method, and some suggestions on the damper parameters were given. It may provide some references for the design and analysis of damping of long-span suspension bridge.

2. Finite Element Analysis Model

2.1. Overview on Dahe Bridge

As shown in Figure 1, Dahe Bridge in Dadong Road, is a single-span suspension bridge with 1250m span, across both side of the Dapingzi and Dongdi, the following are labeled A.B side. The ratio of rise to span is 1/9.5.

![Figure 1. Layout of Dahe Bridge in Dadong Road.](image)

The main girder is steel truss structure, and the center spacing of the upper and lower truss takes 7.8m. The stiffening beam and the sling are connected by the lug plate. The section of the main girder is shown in Figure 2.

![Figure 2. Standard cross section of steel truss girder.](image)

The tower adopts double-beam rigid concrete tower. The height of cable tower in side A is 269.88m, and the height of cable tower in side B is 252.88m. Both sides of the tower are set two beams at the upper and lower position.
2.2. Finite Element Model
Based on the structural design parameters of Dahe Bridge in the Dadong Road, the dynamic analysis model of the bridge was constructed by using the finite element software SAP2000 and the seismic performance analysis was carried out by the time history method, which the model is shown in Figure 3. The main girder and the tower were simulated by frame element, and the main cable and sling were also simulated by frame element, to consider the influence of vertical effect and geometric stiffness caused by constant loads. The bottom of the tower was constrained, and the anchorage joints were constrained in hinges. The finite element model has totally 2014 nodes and 4962 elements.

![Finite element model of the suspension bridge.](image)

3. Damping Mechanism of Viscous Damper
A viscous damper is an energy dissipation device with a throttle hole, a piston and an oil cylinder. This kind of device uses the pressure of the piston before and after the oil flowing through the throttle hole to produce damping force and dissipate the vibration energy to achieve the damping effect. The damping force of viscous damper has a certain correlation with the velocity of motion, and its relationship is as the following:

\[ F = C \cdot V^\alpha \]  

In the formula: \( F \) = damping force, kN; \( C \) = damping coefficient, kN·s/m; \( v \) = velocity, m/s; \( \alpha \) = velocity index. (In seismic engineering, \( \alpha \) is generally in the range of 0.2-1.0)

When the damping index \( \alpha \) is 1, the damping force and the motion velocity are linearly correlated, which is called the linear viscous damper, and in practical engineering the nonlinear viscous damper is used more commonly (Table 1).

| \( \alpha \) | Damping coefficient C (KN·s/m) |
|---|---|
| 0.3 | 500 1000 1500 2000 2500 3000 3750 7500 11250 15000 18750 |
| 0.4 | 500 1000 1500 2000 2500 3000 3750 7500 11250 15000 18750 |
| 0.5 | 500 1000 1500 2000 2500 3000 3750 7500 11250 15000 18750 |

4. Analysis of Damping Effect
As the damping coefficient \( C \) and the velocity index \( \alpha \) change, the viscous damper has different effects on the seismic response of the structures. In the study, \( C \) and \( \alpha \) was taken as the variables. The relative displacement responses at different positions of the bridge with different parameters were analyzed, so as to determine the optimal design parameters of the viscous dampers.
4.1. Analysis on the Influence of Main Girder Displacement

![Figure 4](image1.png)

**Figure 4.** Relative displacement of B-side main girder (mm).

![Figure 5](image2.png)

**Figure 5.** Relative displacement of A-side main girder (mm).

When the velocity index is same, the displacement of the main girder relative to the cable tower decreases with the increase of the damping coefficient.

4.2. Analysis on the Influence of Displacement of Tower

(1) Displacement analysis of B-side

![Figure 6](image3.png)

**Figure 6.** The beams below the B-side tower (mm).
When the velocity index is certain, the displacement of the lower beam and the top of the tower decreases with the increase of the damping coefficient on the whole, and the variation amplitude is small. When the velocity index is 0.5 and the damping coefficient is 2500 KN·s/m, the displacement of the lower beam on the left and right sides of the tower is a minimum value of 52mm. While the velocity index is 0.5 and the damping coefficient is 12500 KN·s/m, the displacement of the lower beam on the left and right sides of the tower is a minimum value of 19mm.

2) Displacement analysis of A-side

![Figure 8. The beams below the A-side tower (mm).](image)
When the velocity index is certain, the displacement of the main position of the tower decreases first and then increases with the increase of the damping coefficient. When the velocity index is 0.5 and the damping coefficient is 2000 KN·s/m, the minimum displacement of the lower beam of the left and right column is 67 mm.

When the velocity index is 0.3 and the damping coefficient is 3000KN·s/m, the displacement at the top of the left and right columns is the minimum value of 16 mm.

4.3. Suggestions on the Parameters of Viscous Dampers

Based on the above analysis of the different parameters of the damper, it is suggested to select a damper with a velocity index of α=0.5 and a damping coefficient of 2000 KN·s/m, the control effect of which is in Tables 2-4.

Table 2. Displacement control effect of main beam relative to beam under cable tower.

| Working conditions | A Left side (mm) | A Right side (mm) | B Left side (mm) | B Right side (mm) |
|--------------------|-----------------|------------------|-----------------|------------------|
| α=0, C=0           | 122             | 122              | 143             | 143              |
| α=0.5, C=2000      | 96              | 96               | 84              | 84               |
| Control percent    | 22%             | 22%              | 41%             | 41%              |

Table 3. Displacement control effect of main position at B-side cable tower.

| Working conditions | The lower beam of the left column (mm) | The top of the tower of the left column (mm) | The lower beam of the right column (mm) | The top of the tower of the right column (mm) |
|--------------------|----------------------------------------|----------------------------------------------|----------------------------------------|----------------------------------------------|
| α=0, C=0           | 61                                     | 23                                           | 61                                     | 23                                           |
| α=0.5, C=2000      | 52                                     | 20                                           | 52                                     | 20                                           |
| Control percent    | 15%                                    | 10%                                          | 15%                                    | 10%                                          |

Table 4. Displacement control effect of main position at A-side cable tower.

| Working conditions | The lower beam of the left column (mm) | The top of the tower of the left column (mm) | The lower beam of the right column (mm) | The top of the tower of the right column (mm) |
|--------------------|----------------------------------------|----------------------------------------------|----------------------------------------|----------------------------------------------|
| α=0, C=0           | 97                                     | 24                                           | 97                                     | 24                                           |
| α=0.5, C=2000      | 69                                     | 17                                           | 69                                     | 17                                           |
| Control percent    | 29%                                    | 26%                                          | 29%                                    | 26%                                          |
5. Conclusions
The nonlinear time-history analysis method is used to analyze the parameters of the damper, and the optimum results are determined. The main conclusions can be obtained as follows:

(1) When the velocity index is the same, the displacement of the main girder relative to the lower beam of the cable tower decreases with the increase of the damping coefficient.

(2) The addition of the viscous damper to the bridge can effectively reduce the relative displacement of the main position of the bridge structure under earthquakes, and reduce the displacement of the main girder.

(3) The damping coefficient and velocity index plays a key role in the damping effect of the liquid viscous damper. If the reasonable parameters were selected, the structural displacement responses can be eliminated greatly and the perfectly results of resisting earthquakes can be achieved.

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