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Experimental Study of the External Viscous Shear Dampers

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Abstract. In order to avoid the disaster caused by earthquake and wind-induced vibration to the building structure or bridge structure, this essay puts forward a new type of external viscous shear dampers. The authors did correlation tests of frequency and fatigue tests, getting the mechanical properties of the damper. And by comparison with numericals simulation and engineering verifications, this paper draws these conclusions: firstly, the numerical simulation results are consistent well with the experimental results, which verifies the validity of the theoretical model; secondly, this external viscous shear type damper can absorb large energy, and the shape of its hysteresis curve is full. It shows that this kind of damper can make the structure have good seismic performance, which is of benefit to the building to achieve the purpose of not collapsing in a large earthquake. What's more, it also shows that this damper can enhance the seismic performance of the building structure or bridge engineering.

1. Introduction

When an earthquake or wind occurs, the structure receives a large amount of input energy, resulting in a vibration response (velocity, acceleration, and displacement) of the structure. If the vibration reaction of the structure is to be terminated, energy conversion or consumption must be carried out. In the traditional earthquake resistant structure system, the admissible structure and the load-bearing component are damaged in the earthquake, that is to say, most of the energy is consumed by the damage of the dependent structure and the load-bearing component, which causes the structural component to be seriously damaged or collapsed in the earthquake. It is unreasonable and unsafe. The structure energy dissipation and damping system is a new technology for earthquake prevention and disaster prevention. The new technology is to design some non load-bearing components of the structure into energy dissipation members. Or in some parts of the structure, when large earthquakes or strong winds occur, the energy dissipation components or energy dissipation devices take the lead in entering the inelastic state with the increase of the lateral deformation of the structure. In this way, the earthquake or wind vibration energy of the input structure is greatly damped and the vibration response of the structure is attenuated rapidly, so that the main body structure can avoid the obvious inelastic state. As an effective passive control device, viscous dampers can provide a relatively large additional damping to the structure, making the structure more reasonable and ensuring the safety of the structure.

2. Test Situation

In this paper, an external viscous shear damper is presented and tested. The external dampers vibrate frequently in the wind environment. In order to ensure its durability, the stability of the damper should meet the following conditions: the pulsating wind displacement was ±5mm after 100,000 times; not less than 2mm/s; the sealing system will not leak after the frequency cycle test be less than 1Hz; the variation of mechanical hysteresis curves of damping devices in second and 99998th cycles is less than 15%. Therefore, the frequency correlation of the external damper and the fatigue test of 0.2Hz were conducted in this experiment. The external damper has two damping cavities, the initial interval between the bottom of the damping cavity and the bottom of the damping plate is 40mm, and there are 4 surface layers of the viscous body.

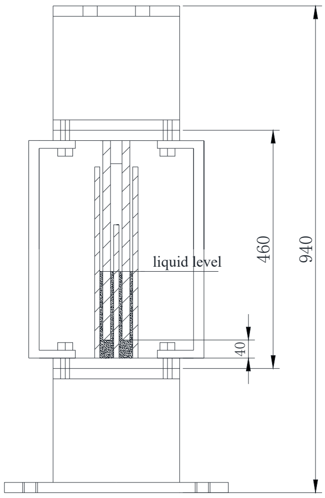

Figure1.Schematic diagram of damper installation

Figure2.Physical diagram of damper installation

3. Experiment Results and Analysis

3.1. Frequency correlation test and analysis

The external viscous shear damper has two damping cavities, the initial interval between the bottom of the damping cavity and the bottom of the damping plate is 40mm, and the number of viscous body layers is 4. After installation, use caliper to check whether the components on the test piece are in the center position of the lower part with calipers, and the interval between the upper and lower components is 40mm, so as to ensure the error within the permitted range. The test was respectively conducted with loading frequencies of 0.1hz, 0.2hz, 0.4hz and 0.8hz, and the input loading amplitude is ±5m, which corresponds to the number period of the load cycle. The test process is controlled by computer, and the displacement data of the test box is collected automatically by the equipment. The test conditions are shown in the following table.

Table 1. Frequency correlation test conditions and parameters.

Sequence number of test conditions	Setting parameters of the test					
	Input frequency(HZ)	Input amplitude(mm)	Waveform	Reference maximum speed (mm/s)	Ambient temperature(°C)	Specimen temperature (°C)
1	0.1	±5	Sine wave	3.14	16.3	16.3
2	0.2	±5	Sine wave	6.28	16.3	16.3
3	0.4	±5	Sine wave	12.56	16.3	16.3
4	0.8	±5	Sine wave	25.12	16.3	16.3

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The hysteresis curve of the damper is shown in Figure 3, it can be seen that the hysteretic curve of the damper is basically symmetric and full, which is similar to an elliptic shape and indicates that the energy dissipation performance is excellent. When the frequency increases to 0.8hz, the additional stiffness of the damper will be slightly displayed. When the frequency is increased to 0.8Hz, the additional stiffness of the damper will be displayed slightly. From the above four frequency dependence tests, we can see that the damper has stable performance. Many scholars at home and abroad have deeply studied the calculation method of setting this kind of nonlinear viscous damper structure system. It is generally believed that the damping ratio of the structure is greatly increased by the nonlinear damper. Establishing the mechanical calculation model of viscous dampers correctly is the premise of structural analysis. The nonlinear fluid viscous damper model is studied in this essay, and the relationship between damping force and acceleration at both ends should be:

$$f_d = C_a sgn(\dot{u})|\dot{u}|^a$$

Corresponding to the test, for the nonlinear dampers, the relative displacement at both ends is simple harmonic wave, that is $u(t) = u_0 \sin(\omega t)$, so the output damping force by the damper is:

$$f_d = C_a v^a = C_a sgn(u_0 \omega \cos(\omega t))|u_0 \omega \cos(\omega t)|^a$$

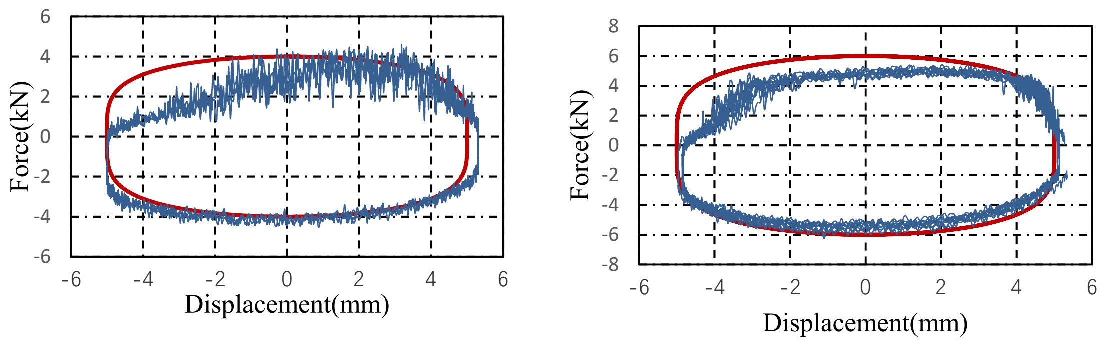
The work calculation formula is:

$$dw_d = f_d \times du$$

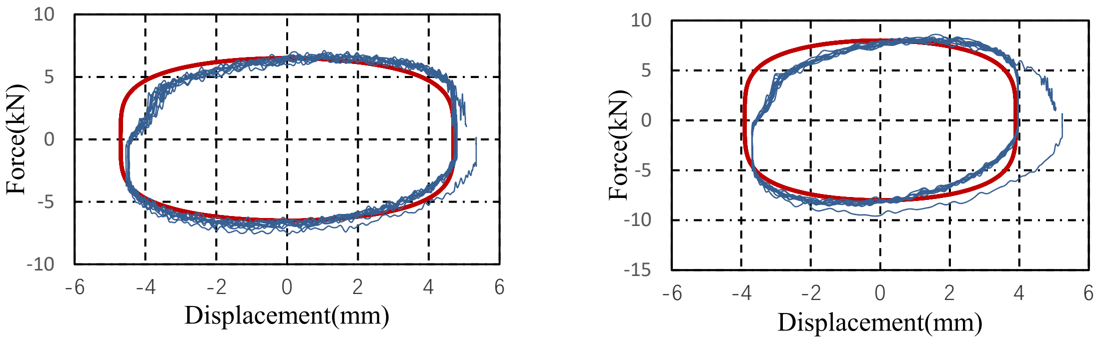
Therefore, when the relative displacement of the nonlinear viscous damper is sinusoidal, the external force of the damper in one cycle ($T = 2\pi/\omega$) is:

$$w_d = \int f_d \times du = \int_0^T c_a u_0^{1+a} \omega^{1+a} sgn(\dot{u})|\cos(\omega t)|^a \cos(\omega t)\, dt$$

Therefore, from the above formula, obtaining the viscosity coefficient $a = 0.5$, drawing the conclusions by fitting calculation and comparing the force displacement hysteretic relationship curve with the experimental curve, we can see that the numerical simulation results are identical with the experimental results.



(a)Conditions: frequency 0.1Hz, displacement±5mm (b)Conditions: frequency 0.2Hz, displacement±5mm



(c)Conditions: frequency 0.4Hz, displacement±5mm (d)Conditions: frequency 0.8Hz, displacement±5mm

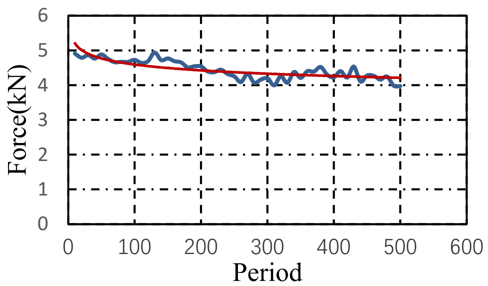
Figure3.Comparison between simulation and test hysteretic curve

3.2. Fatigue test and analysis

In order to ensure that the damper has good performance guarantee under the long-term wind load, the damper needs to carry out fatigue test. Fatigue test conditions are shown in the following table (table 2), The fatigue test loads at a frequency of 0.2hz, its input amplitude is ±5mm, and its cycle period is 500 times.

Table 2. Fatigue test conditions and parameters.

Sequence number of test conditions	Setting parameters of the test						
	Input frequency(HZ)	Input amplitude(mm)	Wave form	Reference maximum speed（mm/s）	Cycle period	Ambient temperature(℃)	Specimen temperature（℃）
1	0.2	±5	sine wave	6.28	500	16.5	16.5



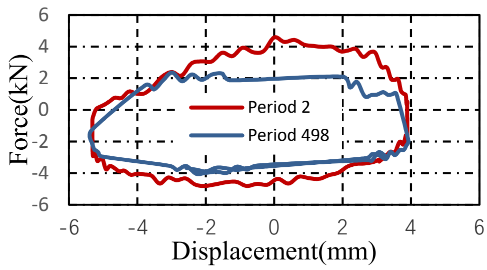


Figure 4. Hysteresis comparison of fatigue test Figure 5. Performance changes of dampers in fatigue test

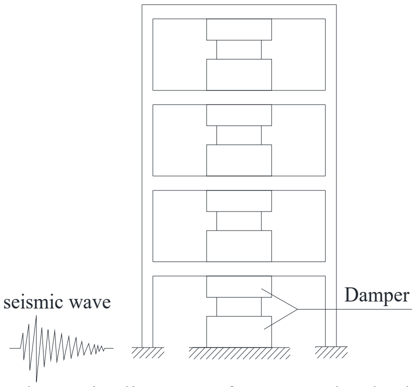
The test analysis results are shown in figure.4 and figure.5. The fatigue of the damper tends to be stable, and the performance of fatigue decreases less than 15%. The curve of fatigue performance is reasonably fitted to the following formula:

$$y = -0.243\ln(x) + 5.72$$

The formula can show that the change of the fatigue performance of the structure is still less than 15% in the later long period.

4. Numerical simulation

Take the frame structure of a four-story building as an example, and arrange this kind of damper for analysis and calculation. Load a rare earthquake with a simulated seismic intensity of 8 degrees (500Gal), set up the site category as class II, characteristic period Tg=0.45s, the height of the layer is 4m, and select EI-Centro wave (as shown in figure 8) for calculation.



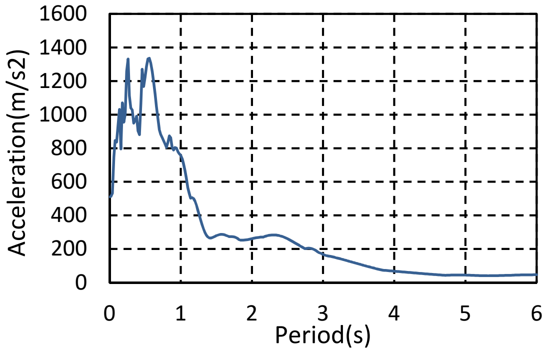


Figure 6. schematic diagram of structural calculation simulation Figure 7. EI-Centro wave response spectrum

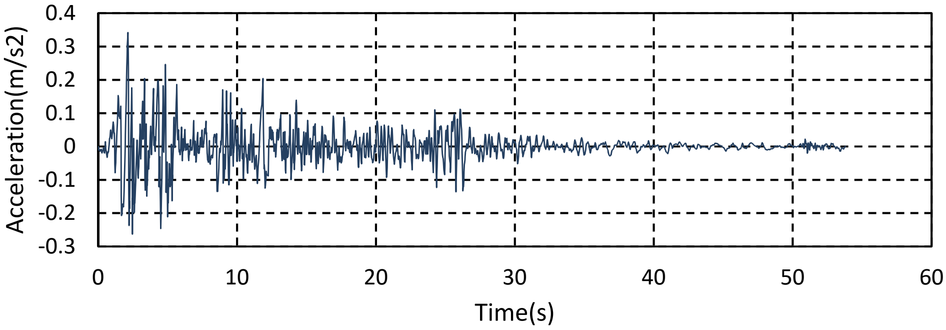
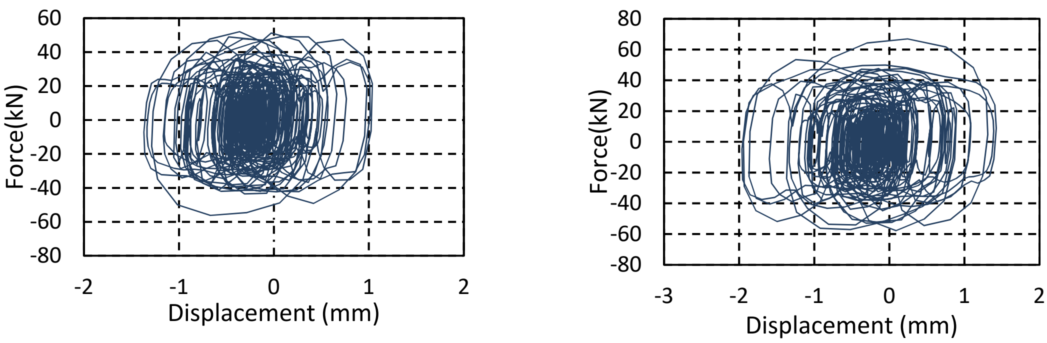
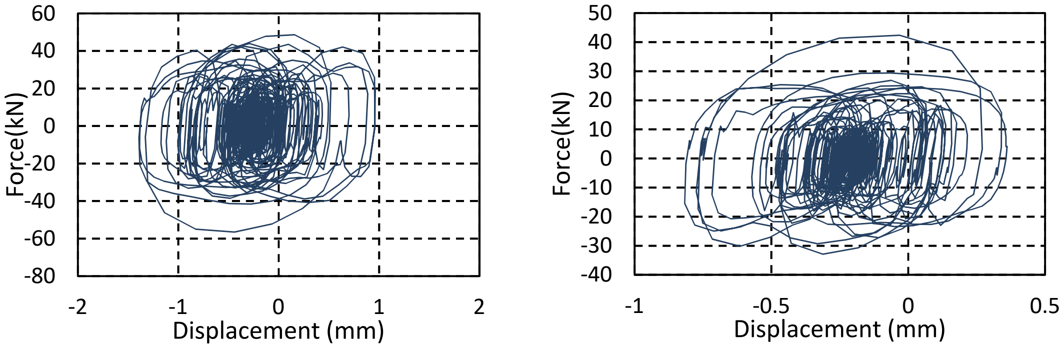


Figure 8. EI-Centro seismic wave

Through calculation and analysis, the maximum interstory drift angle of each floor meets the 1/100 limit specified in *GB 50011-2010 Code for Seismic Design of Buildings(Revised in 2016)*under the action of the seismic wave. After damping, the displacement angles between layers all meet the specified requirements. For shearing force of interstory, the interlaminar shear force of the damping structure is much lower than that of the undamping structure. The hysteresis curves of dampers on each floor are shown in Figure 9.



(a)Hysteretic curve of the first layer damper (b)Hysteretic curve of the second layer damper



(c)Hysteretic curve of the third layer damper (d)Hysteretic curve of the fourth layer damper

Figure 9. Hysteretic curve of the damper in different floor

The damping effect is shown in the following figure (Figure10, 11), the structure vibration is obviously reduced, and the damper absorbs larger energy. When the structure is subjected to a rarely occurred earthquake of 8 degree, the damping structure will suffer less damage than when it is not damped. This fully ensures that the damage degree of the main structure can be effectively controlled under the rare earthquake, the plastic development degree is relatively small and the damper absorbs the larger energy. Therefore, the damper can make the structure have good seismic performance, and is of benefit to the building to achieve the purpose of not collapsing in a large earthquake.

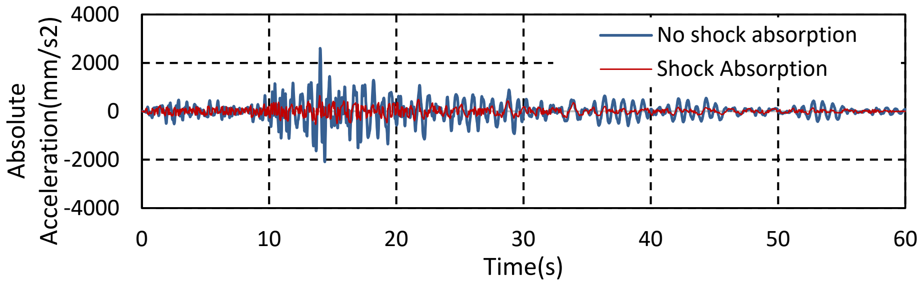


Figure 10. Comparison between shock absorption and non-shock absorption in EI-Centro wave X

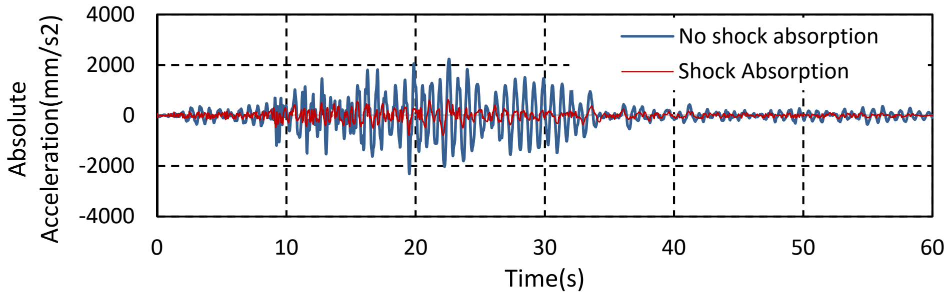


Figure 11. Comparison between shock absorption and non-shock absorption in EI-Centro wave Y

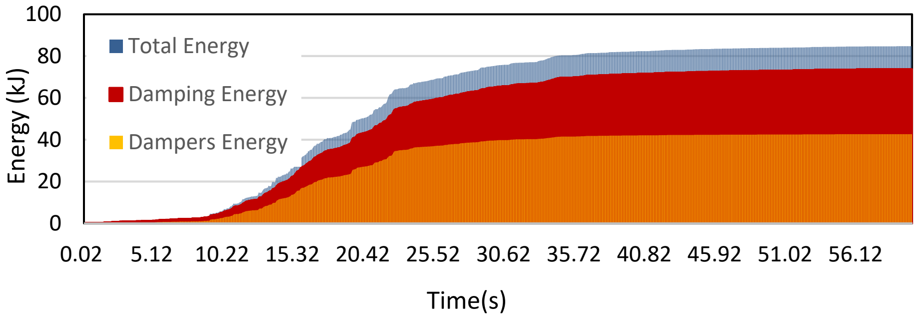


Figure 12. Seismic response energy diagram of building structure

5. Conclusion

Through structural design, simulation calculation and test verification, the external viscous shear type damper designed in this paper has strong plastic deformation ability, full hysteresis curve, large curve area, stable performance and good multi-directional energy dissipation characteristics, which can be applied to bridge engineering or building structure so as to enhance its seismic performance and avoid disasters caused by wind or earthquake uncertainty to building structures. The device has no degradation of strength and stiffness under repeated cyclic loading, which meets the requirements of building seismic codes. The comparison between the test and the numerical analysis shows that the simulation results of the external viscous shear type damper are in good agreement with the test results, which verifies the feasibility and accuracy of the numerical simulation calculation. The numerical simulation method can be used to guide the design in the scheme stage, thus saving the cost of the test. Therefore, the numerical simulation method can be used to guide the design at the scheme stage so as to save the cost of the experiment.

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