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# **Research on Correlation between Metal Damper Parameters** and Damping Effect Based on Numerical Analysis

### Yan Yan<sup>1,\*</sup>, Xingzhu Pei<sup>2</sup>, Yi Fan<sup>3</sup>

<sup>1</sup>Jiangsu University of Science and Technology, Zhenjiang, China, 202003 <sup>2</sup>Jiangsu University of Science and Technology, Zhenjiang, China, 202003 <sup>3</sup>Jiangsu University of Science and Technology, Zhenjiang, China, 202003

\*Corresponding author e-mail:1064108090@qq.com

Abstract: In this paper, the damping effect of the metal damper as the parameters are changed is studied by adding a metal damper to the single-particle model. The influence of metal damper parameters on the damping effect is studied by changing the lateral stiffness  $k_d$ , yield displacement  $u_{dv}$  and yield strength  $F_d$  of the metal damper. Using a time history analysis program written by the fortran language to calculate the structural seismic response values as the parameters are changed. Calculate the response values of displacement, velocity, acceleration and energy consumption, plot the curves and analyze them. Research shows that the lateral stiffness  $k_d$ , yield displacement  $u_{dy}$  and yield strength  $F_d$  of the metal damper have significant effects on the damping effect of the metal damper. The study gives the optimum multiplier of the ratio of the lateral stiffness under multiple earthquakes, and the optimal multiple of the ratio of the yield displacement are also given. The results of the research provide reference for the design of the energy dissipation and seismic systems.

#### 1. Introduction

The structure is subjected to the input of seismic energy when subjected to the influence of seismic waves. Therefore, the building needs to have a certain energy consumption capacity to ensure that the building will not be damaged during the earthquake<sup>[1]</sup>. Adding energy-dissipation devices to the building can effectively absorb seismic energy and ensure the safety of the main structure. The metal has good hysteresis characteristics after entering the plastic state, and can absorb a large amount of energy during the elastic-plastic deformation process<sup>[2]</sup>, so it is used to make different types of dampers.

Most of the existing research is just related to the yield strength of metal dampers<sup>[3]</sup>. In this paper, two other factors related to yield strength are considered: stiffness, yield displacement. The effects of all three parameters on the energy dissipation system are studied.

#### 2. Metal damper parameters and hysteresis curves

Figure 1 uses a double line model to represent the restoring force-displacement hysteresis curve of the metal damper. Figure 2 is the skeleton model of hysteresis curve<sup>[4]</sup>. They summarize the mechanical properties of the damper and measure the ability of the structure or component to absorb  $energy^{[5]}$ .



Figure 1.Hysteresis curve of metal damper Figure 2.Skeleton model of hysteresis curve

The three main parameters of the metal damper: stiffness, yield displacement, and yield strength correspond to the first stiffness  $k_d$ , the first yield displacement  $u_{dy}$ , and the yield strength  $F_d$  in the skeleton model of the hysteresis curve. The relationship between the three is in accordance with the formula (1)

$$\mathbf{F}_{\mathbf{d}} = \mathbf{k}_{\mathbf{d}} \times \mathbf{u}_{\mathbf{d}\mathbf{v}} \tag{1}$$

In order to study the effects of  $k_d$ ,  $u_{dy}$ , and  $F_d$  on the damping effect of metal dampers, the metal damper is added to the original structure and the following two cases are used to discuss the seismic response of the energy dissipation system:

Situation 1:Keep the yield displacement  $u_{dy}$  unchanged, change the damper lateral stiffness  $k_d$  and the yield strength  $F_d$  changes with it;

Situation 2:Keep the lateral stiffness  $k_d$  unchanged, change the yield displacement  $u_{dy}$  and the yield strength  $F_d$  changes with it.

#### 3. Calculation model

The original structure adopts a single particle point model, and a metal damper is added to form an energy dissipation system. The connection form is shown in Figure 3. The original structure lateral stiffness:  $k_f = 1.18 \times 10^8 \text{N/m}$ ; the quality:  $m = 1.55 \times 10^7 \text{kg}$ ; the height: h = 42.54 m.And the natural vibration period of the original structure is 2.276 s.



Figure 3. Single particle energy dissipation system

#### 4. Vibration differential equation and earthquake ground motion

The vibration differential equation of the energy dissipation system under earthquake action is:

$$[m]{\ddot{x}}+[c]{\dot{x}}+[k_{f}+k_{d}]{x}=-[m]{1}{\ddot{x}}_{g}$$
(2)

In equation(2), [m]represents the structural mass; [c] is the internal viscous damping matrix of the structure, expressed by Rayleigh type damping;  $k_f$  represents the lateral stiffness of the main structure, and  $k_d$  represents the lateral stiffness of additional metal damper. { $\ddot{x}$ }, { $\dot{x}$ }, {x} indicate structural acceleration, velocity and displacement response;  $\ddot{x}_g$  indicates ground motion acceleration.

In this paper, two seismic artificial waves are used to analyze the elastoplastic time history of the structure and calculate the structural seismic response with the Wilson- $\theta$  method. The duration of the seismic waves are 60s and 120s, the time interval are both 0.01s. The acceleration time history curves

are shown in Figure 4. In order to obtain the situation of the structure under the common earthquake of 8 degree fortification intensity, the peak value of the seismic waves acceleration are set to  $70 \text{ cm/s}^2$ .



(a)Seismic Wave: Building 01

(b)Seismic Wave: Building 02

#### Figure 4. Seismic waves

#### 5. Seismic response analysis

#### 5.1. Metal damper settings

Situation 1:The lateral stiffness  $k_d$  of the metal damper is set to 1, 2, 3, ..., 20 times of the lateral stiffness of the original structure. The yield displacement  $u_{dy}$  of the metal damper is 0.00433m.

Situation 2: The original structure is attached with a metal damper, the lateral stiffness  $k_d = 1.18 \times 10^8 \text{N/m}$ , and the initial yield displacement  $u_{dy} = 0.00433 \text{m}$ . Maintain the lateral stiffness of the metal damper and change the yield displacement of the metal damper, which is 1, 2, 3, ..., 20 times of the original displacement.

The shear-displacement curves of the metal damper in two cases are shown in Figure 5.

#### 5.2. Calculation results

Figure 6 ,Figure 7 and Figure 8 respectively show the maximum displacement reaction value, the maximum velocity reaction value and the maximum acceleration reaction value of the structure under earthquake action. In situation 1, with the increase of the damper lateral stiffness  $k_d$  and the yield strength  $F_d$ , the maximum displacement value and maximum velocity response of the structure decrease. The maximum acceleration value decreases first and then increases. In situation 2,with the increase of the damper yield displacement  $u_{dy}$  and the yield strength  $F_d$ , the maximum response value of displacement ,velocity and acceleration decrease first, then rise, and finally reach a certain value.



Figure 5.Shear-displacement curve of metal damper



Figure 8. Maximum acceleration response

Fig. 9, Fig. 10, Fig. 11 respectively show the energy consumed by the metal damper, the energy consumed by the original structure, and the ratio of the energy consumed by the metal damper to the total consumed energy in the case that the structure in different situation.

Figure 9 (a) shows that the energy consumption of the metal damper increases with the increase of the lateral stiffness  $k_d$  and the yield strength  $F_d$  of the additional metal damper; Figure 9 (b) shows the metal damper with the increase of the yield displacement  $u_{dy}$  and the yield strength  $F_d$ . The energy consumption of the damper increases first, and then decreases after reaching the peak value. Figure 10 illustrates the energy consumption of the original structure.

Figure 10(a) shows that in Situation 1, the energy consumption of the original structure is first reduced and then increased. Figure 10 (b) shows that in Situation 2, the energy consumption of the original structure is first reduced and then increased. Finally, it tends to a fixed value.

Figure 11 (a) illustrates that the increase in the metal dampers  $k_d$  and  $F_d$  causes the proportion of the energy consumption of the metal damper to increase first and then gradually decrease. (b) Explain that the increase of the metal damper  $u_{dy}$  will increase the proportion of the energy consumption of the metal damper is greatly.



Figure 11. Proportion of energy consumed by metal dampers

It is inferred by comparison that in the case of situation 1, the damping effect of the metal damper first increases and then gradually decreases. When the structure is subjected to seismic waves with multiple earthquakes, the lateral stiffness of the metal damper is preferably 5 times of the lateral

stiffness of the original structure. Because if the multiple increased continuously, the structural seismic response values (displacement value, velocity value) are not much reduced, but the acceleration value of the system is greatly increased.

In situation 2, the metal damper will make the damping effect of the metal damper better when the parameter increase is not large. With the increase of the parameters, the damping effect of the metal damper will gradually become smaller, and the ability to consume seismic energy gradually disappear. The yield displacement of the metal damper is 3 times the initial yield displacement as the best effect. Continue to increase the multiple, structural seismic response values: displacement value, velocity value, acceleration value will increase. The metal damper consumes less energy and the original structure absorbs more energy.

By comparing the structural response value and energy consumption in two situations, it can be found that the same increase in the yield strength of the metal damper and the increase in the lateral stiffness of the metal damper are better than the increase in the yield displacement of the metal damper.

#### 6. Conclusion

Through the analysis of the above example model, the following conclusions are drawn:

When the passive energy dissipation structure is added with a metal damper, increasing the lateral stiffness  $k_d$  and the yield strength  $F_d$  of the metal damper will make the damping effect better. When the structure is subjected to multiple earthquakes, the lateral stiffness of the metal damper is preferably 5 times the lateral stiffness of the original structure.

As the yield displacement  $u_{dy}$  and the yield strength  $F_d$  of the metal damper increase, the damping effect of the metal damper slightly increases and then continues to decrease. When the structure is subjected to multiple earthquakes, the yield displacement of the metal damper is preferably 3 times the initial displacement of the metal damper.

In order to increase the damping effect of the metal damper, it is better to change the lateral stiffness  $k_d$  and the yield strength  $F_d$  of the metal damper.

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