Effect of structure period and stiffness ratio on seismic performance of structure with additional metal dampers

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Abstract: The energy dissipation structure is set up in certain parts as energy dissipation device, which consumes most energy caused by the earthquake to reduce the seismic response of structures. Based on the study of additional metal dampers and generating calculation method of equivalent damping ratio, vibration differential equations and computer programs are established. Taking damping ratio f_k as a parameter and structure period T_f as a independent variable for elastic-plastic time history analysis, change rules of the particle displacement and the absolute acceleration response value are discussed. Thus the following conclusions are obtained: (1) The smaller structure period and the larger Stiffness ratio will lead to the better displacement damping effect. (2) When f_k is at the range of 1 to 6, acceleration response value decreases and gains the smallest value as f_k is 4; when f_k is at the range of 7 to 10 acceleration response value does not decrease all the time.

Introduction

In recent years, the loss caused by the earthquake is more and more serious, people have gradually realized that the importance of control the disaster caused by the earthquake. Through the study scholars found reasonable and effective way is adding control device to the structure to compose energy dissipation structure. Dampers consume most of the energy from the earthquake, thereby reducing the seismic response of structures[1]. In this paper, install a metal single-mass damper system as the research object, vibration differential equations and computer programs are established for elastic-plastic time history analysis. Comparison the seismic response of energy dissipation structure and original structure, to study the energy dissipation structure damping performance.

Analysis model

The research object of this paper is the energy dissipation structure with additional metal damper, Figure 1 is additional metal damper structure diagram; Figure 2 is additional metal dampers structural analysis model. Where in the 1-2 segment represents additional system consisting of a metal damper and support, k_d represents a metal damper elastic stiffness, k_b represents the stiffness of support, k_a represents elastic stiffness of additional system, its size is[2]:

$$k_a = \frac{1}{1/k_d + 1/k_b} \quad (1)$$

3-4 segment represents the main part of the original structure, k_f represents the elastic stiffness of the structure; damping 5-6 segments indicates the original structure, c represents the damp of original structure, m represents the mass, the total stiffness of the structure with additional damper is
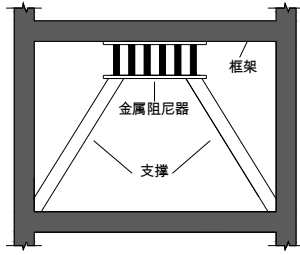
$$k = k_a + k_f \quad (2)$$
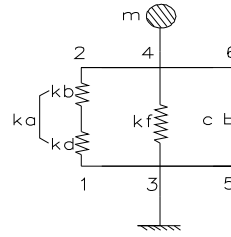
Fig.1 Additional metal damper
structure diagram

Fig.2 Additional metal dampers
structural analysis model

Equivalent viscous damping ratio

When structure go into the plastic state, the area enclosed by hysteresis curve equal to the energy absorbed by structure from seismic force. In the actual design, it is impossible by the hysteresis curve area calculate the equivalent viscous damping ratio; this article will use another method to calculate the equivalent damping ratio[3]:

$$h_{eq} = h_0 + \frac{2}{mpp}\ln\frac{1+p(m-1)}{m^p} \quad (3)$$

p is calculated using the following formula

$$p = \frac{1}{1+k_a/k_f} \quad (4)$$

Suppose the original structure is always in an elastic state, and the damper into the plastic state. Using formula (3) to calculate the equivalent damping ratio.By changing the stiffness ratio and ductility factor, to observe the equivalent damping ratio[4] ,and obtain the following conclusions:

Figure (a) and (b) shows that when m unchanged, h_{eq} increases with the increasing of stiffness ratio, when the stiffness ratio unchanged, h_{eq} increases with the increasing of m .From the figure we can see the best ductility factor ranging from 4-8.
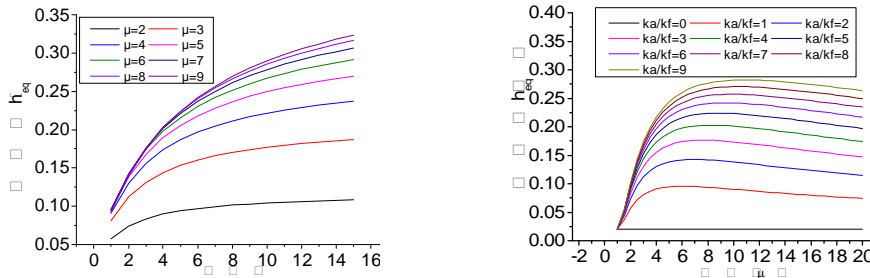
(a) Relationship between h_{eq} and k_a/k_f (b) Relationship between h_{eq} and m

Fig.3 Equivalent damping ratio

The example model

In this paper, single-layer steel frame structure is used for the study object. Suppose mass distribution is $1000 k_g/m^2$,then the Quality of single-layer structure is $m = 1200000 kg$ .The cycle of original structure is taken as T_f =0.1s-3.0s. The stiffness of metal damper according to the elastic stiffness ratio $f_k = 0-10$. (f_k is the ratio of damper stiffness and rigidity of the original structure) . Additional support stiffness is $k_b = 1.2\times10^{11} kN/m$, Suppose the structure is always in an elastic state, and the damper into the plastic state. The original structure is linear elastic restoring force model, the damper is an ideal elastoplastic restoring force model(Plastic stiffness is 0)Restoring force of study model as follows: Elastic stiffness calculated by $T_f = 2p\sqrt{m/k_f}$ .The first yield stiffness sk1 taken as elastic stiffness structure. The first yield displacement taken as $up_1 = 0.01m$.

The results of time history analysis

In this paper, the elastic stiffness ratio f_k as a parameter, the original structure period is variable, to elastic-plastic time history analysis, analysis of energy dissipation structure displacement reaction, acceleration response. The value of the original structure period 0.1s-3.0s, elastic stiffness than taking 0-10, T_f is original construction period, T_0 is the cycle of energy dissipation structure. In this paper, Art hachinohe wave, Art kobe EL wave and wave, Hachi wave are used to analysis. And compare the displacement response and acceleration response of the structure. Peak of ground acceleration is 400cm/s^2, the time interval is 0.01s, the role of time is 50s.

Displacement reaction

In fig.4, the abscissa represents the original structure period, the ordinate represents the displacement reaction, parameter is stiffness ratio fk. In fig.5, the abscissa represents the original structure period, the ordinate represents displacement ratio γ, parameter is stiffness ratio f_k.

As shown in the figure the greater stiffness of the damper, the smaller displacement reaction of energy dissipation structure, damping effect is more obvious. With the increase of f_k, displacement reaction of energy dissipation structures are less than the displacement of the original structure, namely additional metal damper structure has good shock effect.
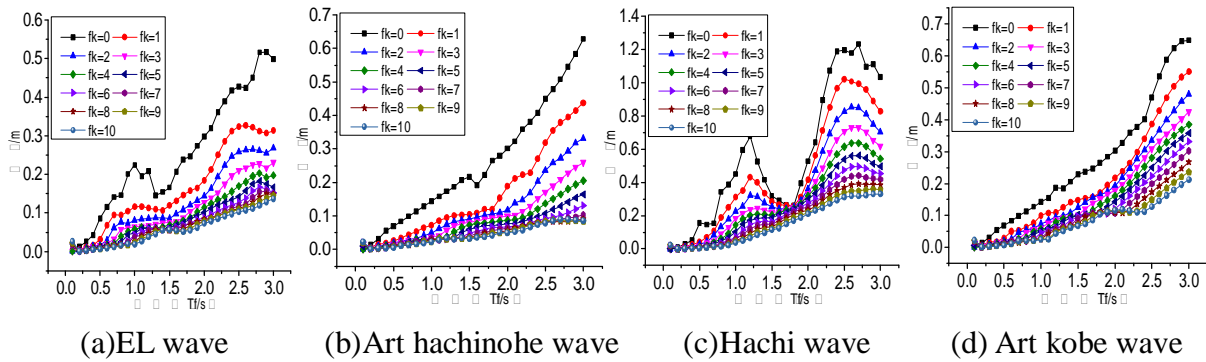

| (a)EL wave | (b)Art hachinohe wave | (c)Hachi wave | (d) Art kobe wave |

Fig.4 Displacement response

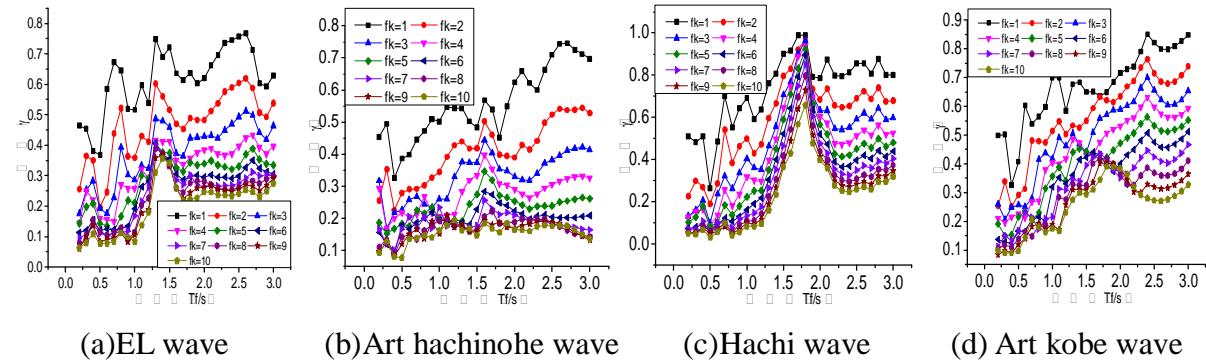| (a)EL wave | (b)Art hachinohe wave | (c)Hachi wave | (d) Art kobe wave |

Fig.5 Displacement response ratio

The acceleration response

In fig.6, the abscissa represents the original structure period, the ordinate represents the acceleration reaction, parameter is stiffness ratio f_k. In fig.7, the abscissa represents the original structure period, the ordinate represents acceleration ratio γ, parameter is stiffness ratio f_k.

By the following figure shows the acceleration response is related with cycle of original structure and the stiffness of the damper. when the value of f_k from 1 to 6, the acceleration response value of additional damper structure can be reduced, and when the stiffness ratio f_k is 4,

acceleration value is least. but when the value of f_k from 7 to 10, the acceleration response values were not fully reduced.
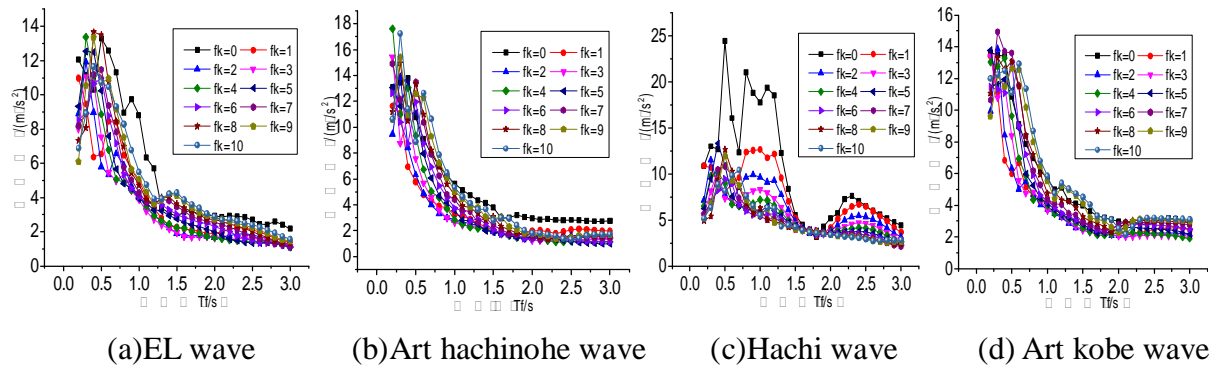

| (a)EL wave | (b)Art hachinohe wave | (c)Hachi wave | (d) Art kobe wave |

Fig.6 Acceleration response

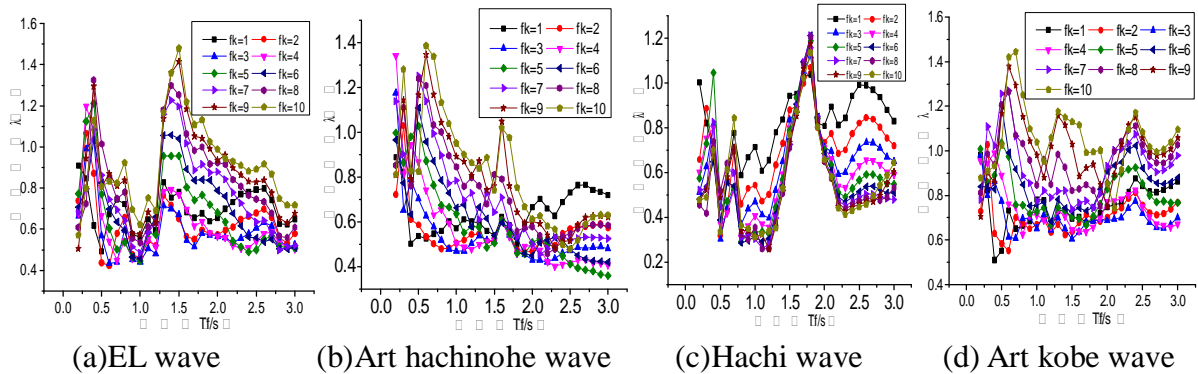| (a)EL wave | (b)Art hachinohe wave | (c)Hachi wave | (d) Art kobe wave |

Fig.7Acceleration response ratio

Conclusions

In this paper, based on the study of energy the dissipation structure with additional metal dampers. Consider the calculation method of equivalent damping ratio, vibration differential equations and computer programs are established , Taking stiffness ratio f_k as a parameter and structure period as a independent variable for elastic-plastic time history analysis. The displacement and the acceleration response are discussed, the following beneficial conclusions are obtained:

(1) The smaller structure period and the larger Stiffness ratio will lead to the better displacement damping effect.

(2) When f_k is at the range of 1 to 6, acceleration response value decreases and gains the smallest value as f_k is 4; when f_k is at the range of 7 to 10 acceleration response value does not decrease all the time.

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