Control Characteristics of Mega-sub Controlled Structure System with Friction Damper under Rare Earthquake

Tao Li, Xun'an Zhang, Qianqian Wang

Abstract—In this paper, the seismic responses control characteristics of Mega-structure, Mega-sub Controlled Structure System (MSCSS) without dampers and MSCSS inserted friction dampers are investigated respectively under rare earthquake by using the elastic-plastic time history analysis method. The distribution of plastic hinges and different control efficiency of these structures under rare earthquake are demonstrated comprehensively. The results show that the control efficiency will be best when friction dampers are installed in bottom five-storey of second and third sub-structure. Under rare earthquake, both the Mega-structure and MSCSS are not destroyed,but the number of plastic hinges appearing in the former are more than in the latter. Under super rare earthquake, for example, as the maximum peak value of seismic acceleration reaches 1000 gal, the Mega-structure is destroyed, but the MSCSS without dampers still has certain bearing capacity, in which there are some plastic hinges appearing; the MSCSS inserted friction dampers only has a few plastic hinges, it has stronger bearing capacity than the other two structures, and more important, the responses control efficiency of this structure is still obvious. It is demonstrated in the paper that friction dampers can improve the control capacity of MSCSS and has good control characteristic, they also can effectively reduce the displacement and acceleration responses of sub-structures.

Keywords—Mega-sub Controlled Structure System, friction dampers, rare earthquake, control characteristics

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Ⅰ. INTRODUCTION

In order to reduce the responses of tall buildings under external forces such as earthquakes and winds, the passive control method is used pervasively. Tuned mass damper system and damper devices are applied to some tall buildings for altering the dynamic characteristics of the structures under external loads.

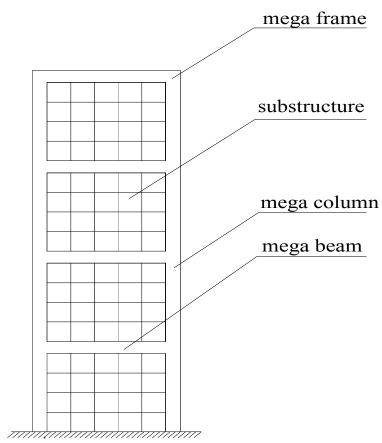

Fig.1 Conventional mega-structure

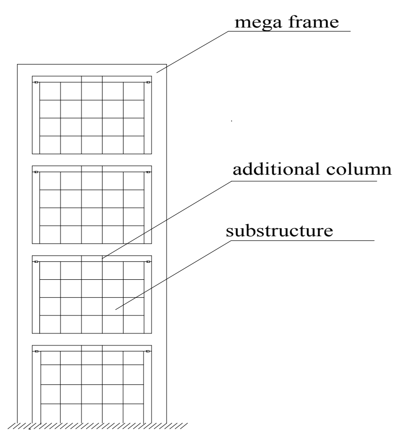

Fig.2 Mega-sub controlled structure system

Mega-sub controlled structure system is a new form of structure, it was first introduced by Feng and Mita [1]. This structure type which was developed from Mega-structure also consists of mega frame and substructure, but the restraints between the main frame

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and substructure are relieved [2], as shown in Fig.1and Fig.2. MSCSS itself has the control function of TMD, because the substructures are isolated relatively from the main frame and it can provide building with tuning control force as a TMD. The mass ratio of tuning mass and main structure in common TMD system is from 1% to 5%, the mass ratio of substructures and main frame in MSCSS is more than 60%, so the tuning control force is considerable in MSCSS[3]-[4].

Although MSCSS has a great potential of seismic resistance, the coupling damping forces between main frame and substructure are provided by structure member materials (the bottom column of substructure). These forces are too small to meet the requirements of substructure to give full play to their tuning and cushioning capacities. So it is necessary to introduce the concept of friction energy dissipation in MSCSS, to investigate the control efficiency and arrangement of the friction dampers in MSCSS.

Seven arranging schemes of friction dampers in MSCSS are researched in this paper, and the best arranging scheme is concluded by using the elastic time history analysis method. The distribution of the plastic hinges and the differences of control efficiency between Mega-structure, MSCSS without friction dampers and MSCSS installed friction dampers under rare earthquakes are also investigated in the paper by using the elastic-plastic history method.

Ⅱ. COMPUTATION MODEL AND EQUATION

A. Computation model

Finite element model is used in this computation.

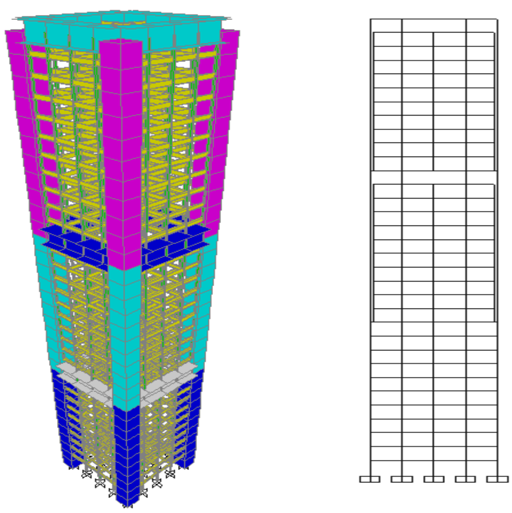

Fig.3 Simplified model of MSCSS

Research object of the structural system is presented in Fig.3. The TC edifice in Japan, a design of Mega-structure, is referenced in the model. The main frame is composed of 3 mega floors. Each substructure contains 11 steel floors. The height between mega floors is 46m, 48m and 48m, the height between substructure floors is 4m and the total width of structure is 32m [5]-[6]. The simplified modeling method is introduced, as in [7]. The dynamic responses of MSCSS are computed by SAP2000 software with elastic time history method and elastic-plastic time history method.

B. Kinematic equation

The kinematic equation may be expressed as:

$$\boldsymbol{M}\ddot{\boldsymbol{u}}(t)+\boldsymbol{C}\dot{\boldsymbol{u}}(t)+\boldsymbol{K}\boldsymbol{u}(t)=\boldsymbol{F}(t) \tag{1}$$

Wherein: $\boldsymbol{M}$, $\boldsymbol{C}$, $\boldsymbol{K}$, $\boldsymbol{F}$ (t) is the mass matric, damping matric, stiffness matric and external load vector respectively; $\boldsymbol{u}$ is the displacement vector.

The nonlinear Hiber-Huges-Tylor direct integral method is adopted in the time history analysis. HHT method is essentially a development of Newmark method, but it introduces a "α" coefficient to modify the kinematic equation [8], as expressed in (2).

$$\begin{aligned}&\boldsymbol{M}\ddot{\boldsymbol{u}}(t)+(1+\alpha)\boldsymbol{C}\dot{\boldsymbol{u}}(t)+(1+\alpha)\boldsymbol{K}\boldsymbol{u}(t)\\&=(1+\alpha)\boldsymbol{F}(t)-\alpha\boldsymbol{F}+\alpha\boldsymbol{C}\dot{\boldsymbol{u}}(t)+\alpha\boldsymbol{K}\boldsymbol{u}(t)\end{aligned} \tag{2}$$

Type: "α" coefficient values range from 0 to 1/3.

The mass and stiffness proportional damping is adopted in the computation process. The mass and stiffness proportional damping coefficients are computed with the first and second frequency.

C. Force-displacement curve of plastic hinge

According to the criteria provided by the Applied Technology Council and Federal Emergency Management Agency, the force- displacement curve of plastic hinge is described by four control points in SAP 2000 software [8].

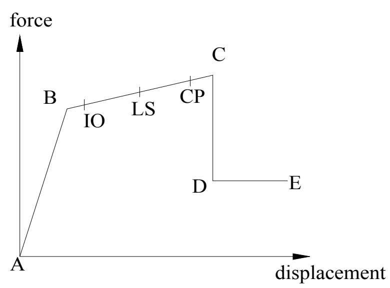

Fig.4 Force-displacement diagram

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Point B represents the yield point; point C represents the ultimate bearing capacity; point D represents the residual strength; point E represents the complete failure point. After subjected to earthquake, the structural state is divided into four cases:

Before Point IO, the structure is at the operational state; point IO is the immediate occupancy state; Point LS is the life safety state; Point CP is the collapse prevention state.

Ⅲ. COMPUTATION AND ANALYSIS

A. *Arranging schemes of friction damper*

The importing seismic wave is El Centro seismic wave. The peak value of acceleration is based on the value of the seismic fortification intensity with 8 degree. Time history lasts for 20 seconds.

Fig.5 shows the arranging schemes of the friction dampers. Fig.5-a shows that the dampers are arranged at the bottom five floors of the second and third mega floor; fig.5-b shows the dampers at the medium five floors; fig.5-c shows them at the top five floors; fig.5-d shows them at the odd floors; fig.5-e shows them at the even floors; fig.5-f shows them at the outboard two spans.

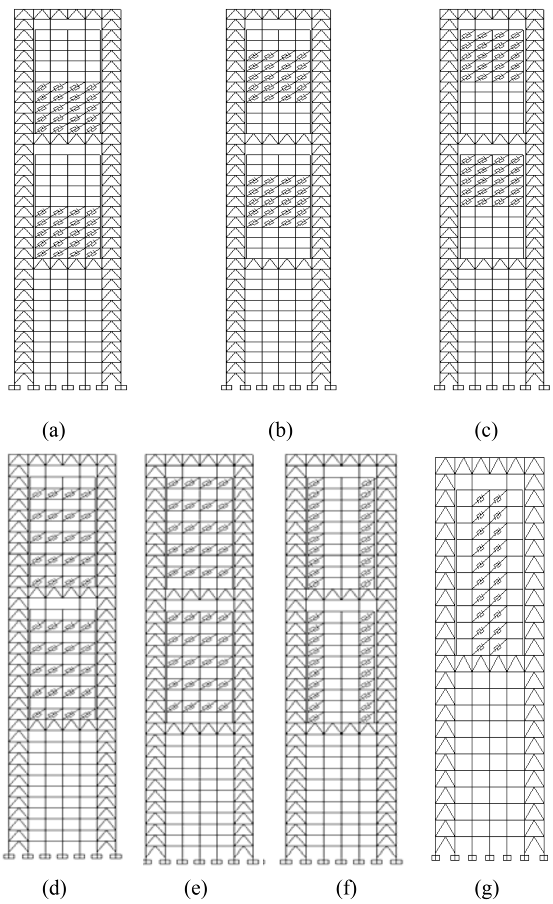

Fig.5 seven arranging schemes of friction dampers

The envelope diagrams of maximum acceleration and displacement of each floor in the first and second substructure under El Centro seismic wave action are presented in fig.6 and fig.7. The response merit of control efficiency of each structural floor in the scheme can be compared in these two figures:

a>g>d>e>b>f>c

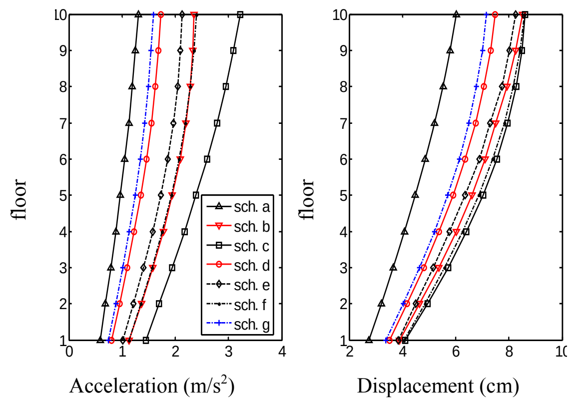

Fig.6 storey acceleration and displacement envelope diagram in the first substructure

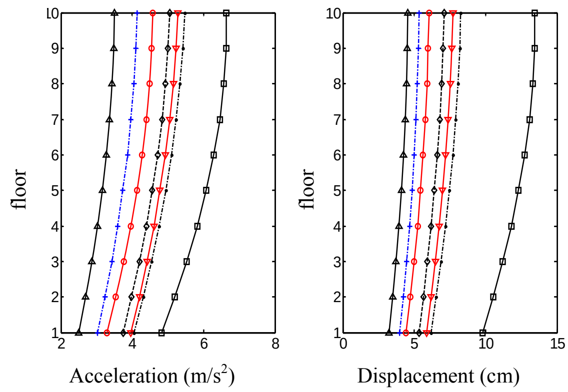

Fig.7 storey acceleration and displacement in the second substructure

The figures show that the acceleration control efficiency of each scheme is better than the displacement control efficiency. The acceleration control rate of the first substructure in the scheme “a” is better than the scheme “b” and “c”, increasing 34% and 61% respectively; the displacement control rate of the first substructure in the scheme “a” is superior to the scheme “b” and “c”, increasing 29% and 47% respectively.

The acceleration control rate of the second substructure in the scheme “a” is increased 26% and 60% severally, compared with the scheme “b” and “c”; the displacement control rate of the second substructure in the scheme “a” is increasing 21% and 46% respectively, compared with the scheme “b” and “c”.

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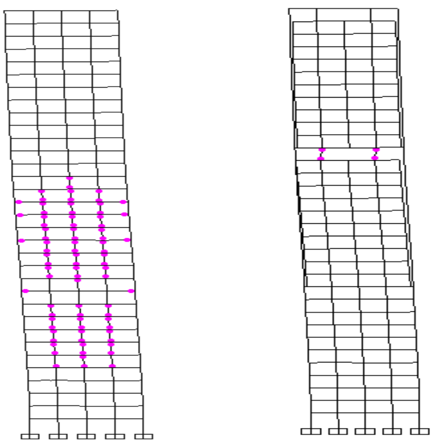
The acceleration control rate of the top floor in the main frame in the scheme “a” is increased 26% and 60% respectively, better than the scheme “b” and “c”; the displacement control rate of the top floor in the main frame in the scheme “a” is superior to the scheme “b” and “c”, increasing 22% and 46% respectively.

The results show that putting the friction dampers in the bottom five floors of the second and third mega floor is the best arrangement.

B. Comparison of the Mega-structure and MSCSS without friction dampers

It can be observed from the response result of the Mega-structure and MSCSS without friction dampers under rare seismic wave action that both structures are not destroyed and there are only several plastic hinges appearing in these two structures. But the amount of the plastic hinges in the Mega-structure is obviously more than it in the MSCSS. The distribution of plastic hinges is shown in the fig.8. Fig.8-a presents Mega-structure; Fig. 8-b presents MSCSS without friction dampers.

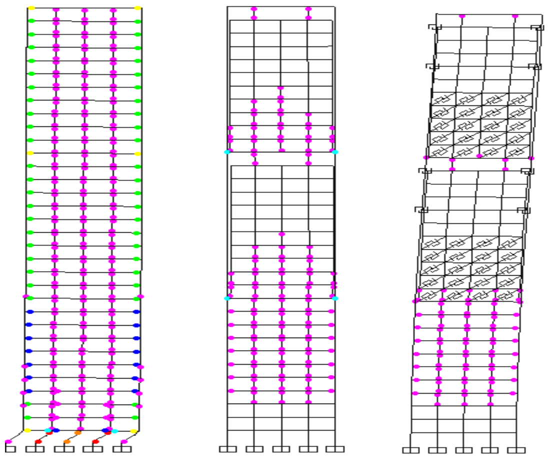


(a) (b)

Fig.8 Distribution of plastic hinges under rare earthquake (e.g. peak acceleration value is 400gal)

The computation about Mega-structure is broken at 5.21 second when the seismic peak acceleration value is adjusted to 1000 gal. The distribution of plastic hinges in Mega-structure at this time point is shown in the fig.9-a. The plastic hinges appear in the whole structure and some of them are in the collapse prevention state which is shown in the fig.4. The force values of plastic hinges in the bottom and several beams are beyond the value of the point CP. This state shows that the structure is destroyed. The amount of the plastic hinges in the MSCSS is less than the amount of those in the Mega-structure. The force values of all plastic hinges in the MSCSS are not beyond the value of point B, except the plastic hinges appearing in the first and second mega beam. The control capacity of the MSCSS is still good. The distribution of plastic hinges in MSCSS is shown in the fig.9-a. Fig.9-a presents Mega-structure; fig.9-b presents MSCSS without friction dampers; fig.9-c presents MSCSS with friction dampers.

The results show that the earthquake resistant behaviour of the MSCSS is more excellent than the Mega-structure. The MSCSS have the better behaviour under the super rare seismic forces.



(a) (b) (c)

Fig.9 Distribution of plastic hinges under super rare earthquake (e.g. peak acceleration value is 1000gal)

C. *Comparison of the MSCSS without friction dampers and MSCSS with friction dampers*

Comparison by plastic hinges distribution

The fig.9 presents the plastic hinges distribution of three kinds of structure under super rare earthquake action, for instance, the peak acceleration value is 1000 gal. It is shown that the amount of the plastic hinges in the MSCSS with friction dampers is apparently less than the MSCSS without friction dampers and the Mega-structure. Inserting friction dampers can increase the structural safety and reliability. The sectional dimension of structural component can also be reduced by inserting the friction dampers in the structure. At this condition, the structure can be built to meet the standard of building reliability and the cost of building is also decreased.

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Comparison by acceleration and displacement

The displacement and acceleration time history curve of main structure is shown in the fig.10; the first substructure and the second substructure under El Centro seismic wave action are presented in the fig.11 and fig.12 severally.

The maximum displacement response value of the top floor in the main structure of MSCSS without friction dampers is 48.27 cm, which is shown in the fig.10. The maximum displacement value of the top floor in the first and second substructure is 32.26 cm and 47.1 cm respectively. They are shown in the fig.11 and fig.12.

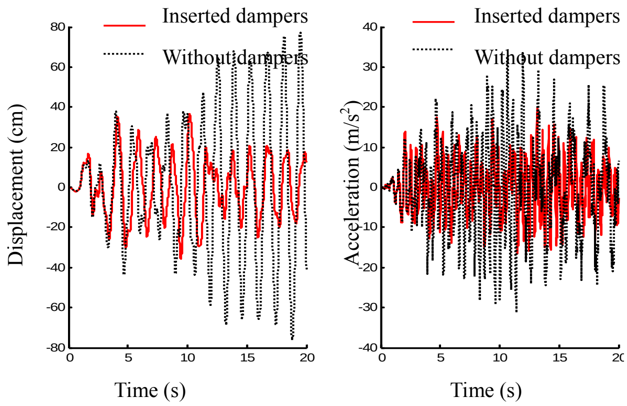

Fig.10 Displacement and acceleration time history curve of the top floor in the main structure

The maximum displacement value of the top floor in the main frame of the MSCSS with dampers is 36.67 cm, as shown in the fig.10.

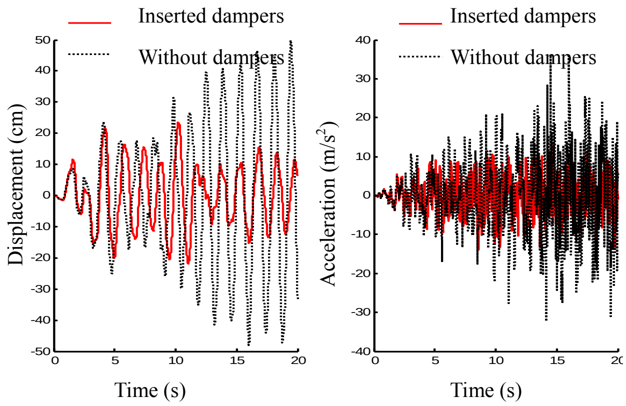

Fig.11 Displacement and acceleration time history curve of first substructure

The maximum acceleration value of the first substructure is 25.14 cm, as presented in the fig.11. This value of the second substructure becomes 36.06 cm, as expressed in the fig.12. The control rates based on the displacement of the main frame, the first substructure and the second substructure of MSCSS are 24%, 22% and 23% respectively.

The maximum acceleration value of the top floor in the main structure of the MSCSS without friction dampers is 13.89 m/s^2, which is shown in the fig.10. The maximum acceleration values of the top floor in the first and second substructure are 11.85 m/s^2 and 13.37 m/s^2 respectively, as expressed in the fig.11 and fig.12.

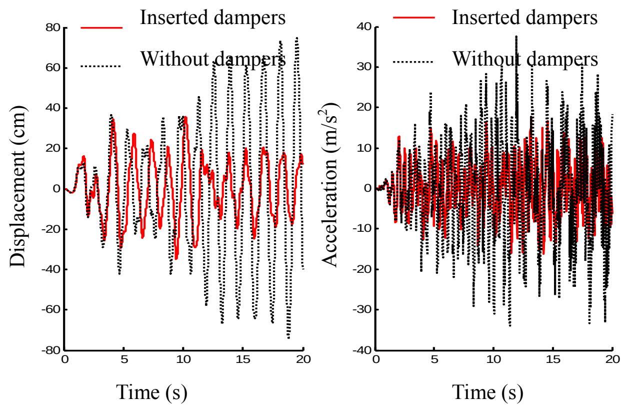

Fig.12 Displacement and acceleration time history curve of second substructure

The maximum acceleration value of the top floor in the main frame of MSCSS with dampers is 11.3 m/s^2, as shown in the fig.10. The maximum acceleration value of the first substructure is 6.83 m/s^2, shown in the fig.11. This value of the second substructure becomes 10.74 m/s^2, as presented in the fig.12. The acceleration control rates based on the acceleration of the main frame, the first substructure and the second structure of the MSCSS are 19%, 42% and 20% respectively.

Ⅳ. CONCLUSION

The earthquake resistant performances of MSCSS are superior to the conventional Mega-structure when subjected to the rare earthquake. Inserting friction dampers can not only improve the control capacity of the displacements and accelerations of the MSCSS under rare seismic forces, it can also decrease the responses of the substructure. This is the main difference of shock absorption mechanism between MSCSS and TMD system.

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