Study on damping effect of CFST frame – core wall structure with different dampers

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SUMMARY:
The use of concrete-filled steel tubular (CFST) frame-core wall mixed structures has attracted the interest of structural engineers in recent years, and several high-rise buildings have utilized this mixed structure in China. In this paper, a 30storey CFST frame-core wall mixed structure was studied, which was set different types of dampers. Elastic-plastic time-history analyses are performed on the structure with different dampers under three seismic waves action, whilst the calculation results are studied and analyzed comparatively. The results show that: under the strong earthquake action, it has a certain damping effect on the aspects of inter-story displacement angle, story shear force and energy dissipation of structure by setting the viscous dampers and the buckling-restrained brace (BRB) in CFST frame core wall structure. Arranging the same number dampers in the same locations, the structure with viscous dampers has superior control effect in seismic performance than that of the structure with BRB. In conclusion, the force mechanism of the CFST frame-core wall structure has been changed by setting viscous dampers and BRB in the mixed structure, whilst the seismic fortification lines of the structure has been increased, and the seismic performance of the structure has been improved, however setting locations and types of the damper should be optimized to maximize the damping effect in the design of practical engineering.

Keywords: CFST frame-core wall structure; viscous dampers; BRB; damping effect; seismic performance.

1. INTRODUCTION

In recent years, high-rise building structures get a rapid development in the worldwide, and the hybrid structures occupy a considerable proportion in completed and proposed buildings. As an important branch of the mixed structure, CFST frame core wall structure is adopted more and more widely. Shaking table test and finite element analysis for the concrete filled circular steel tube frame core wall structure and concrete filled square steel tube frame core wall structure with the same plan and elevation arrangement had been executed by Han et al (2009). Seismic reliability assessment of CFST frame – core wall structure had been studied basing on the branch and bound method by Wu (2006). Elastic-plastic time-history analysis for a CFST frame – core wall structure with strengthened storey had been performed by Huang (2006), the result showed that concentration of the seismic forces may happen because of the existing of truss extensive cantilever, and the weak story may appear near the strengthened storey. It can be found from the relational research that the force characteristics of the CFST frame core wall structure are complicated and the study on the whole seismic performance of the structure is seldom, so the scientific research is lag behind the engineering practice in a degree. The viewpoint that the research on seismic performance of the CFST hybrid structure should be strengthen is proposed by Zhong (2006). In recent years, energy dissipation technology has been widely used in structural engineering, and the design method of the structure with energy dissipation had been studied early by Soong T T (1997) and Dargush G F (2002). Viscous dampers had been set in a 45strory RC structure by Oosumikazumasa et al (2008), whilst the nonlinear analysis and calculation of this structure had been performed and the energy dissipation of the dampers had reached 70% to the total energy dissipation of the structure. CFST frame structures with viscous dampers have been tested on shaking table to study the dynamic characteristics and seismic response by Lü et al (2006). A CFST frame-core wall structure with dampers has been tested on shaking table for investigating the damping effect on the seismic performance of the hybrid structure by Ren and Zhou (2011). In this paper, a 30storey CFST frame-core wall mixed structure was studied. The refined nonlinear time history analysis was performed for different damping schemes, and the influence of different dampers on the seismic performance of structure was studied. The results would provide the reference basis for design and application of the hybrid structure with dampers.

2. CALCULATION MODEL

2.1 Selection of typical structure

The analysis model in this paper is a 30storey CFST frame-core wall structure, the plane dimensions of the structure is 24m× 24m, and the storey height is 4m. The model parameters are shown in Table 1 and the model dimensions are shown in Fig.1. Seismic fortification intensity of structure is 8.5 degrees, and the site characteristic period is 0.35s.

Table 1. Structural parameters

<table>
<tr><td colspan="5">Steel beam</td></tr>
<tr><td>Floor</td><td>Section（mm）</td><td colspan="2">Concrete grade</td><td>Steel grade</td></tr>
<tr><td>1-30</td><td>400×600×25×10</td><td colspan="2"></td><td>Q345</td></tr>
<tr><td colspan="5">CFST column</td></tr>
<tr><td>1-10</td><td>800×20</td><td colspan="2">C50</td><td>Q345</td></tr>
<tr><td>11-20</td><td>700×18</td><td colspan="2">C50</td><td>Q345</td></tr>
<tr><td>21-30</td><td>600×16</td><td colspan="2">C50</td><td>Q345</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td></td><td>Thickness（mm）</td><td>Concrete grade</td><td>Steel grade</td><td>Reinforcement</td></tr>
<tr><td>1-10</td><td>400</td><td>C40</td><td>HRB400</td><td>0.38%</td></tr>
<tr><td>11-20</td><td>300</td><td>C40</td><td>HRB400</td><td>0.452%</td></tr>
<tr><td>21-30</td><td>250</td><td>C40</td><td>HRB400</td><td>0.56%</td></tr>
</table>

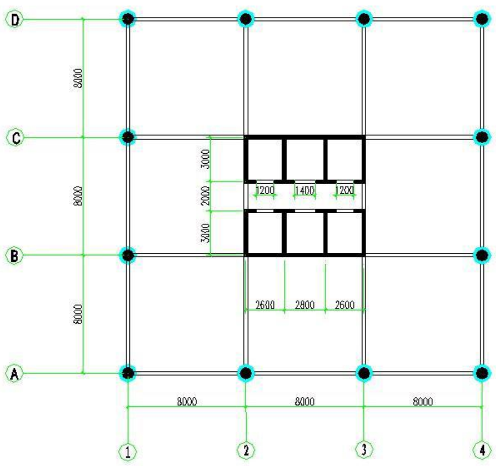


Fig. 1. Layout of structural model

2.2. Finite element model

1.2.1 Material constitutive relation

The material constitutive relations of this model are mainly including the constitutive relation of reinforced, concrete, steel and damper. In the aspect of confined concrete, the model of KENTPARK has been used widely (1988), which was chosen as the material constitutive model of the concrete in the core wall and the steel tube. The restriction effect of concrete in steel tube is come from the outside steel tube, so the equivalent stress strain relation model of the core concrete proposed by Han (2009) was adopted in this paper, and then the correlation coefficients of the KENTPARK model could be derived. Bilinear constitutive relation model of the reinforcement and steel was adopted.

1.2.2 Element selection

Nonlinear analysis of the CFST frame-core wall structure was performed by software Perform3D, and the fiber elements of beam, column and shear wall were selected during analysis process. Steel beam was divided into 12 parts along the height, and the CFST column was divided into 8 parts along the perimeter and 7 laps along the radius direction, then the internal three rings were the fiber elements of concrete. The MAXWELL model was adopted for the viscous dampers, and the relationship of viscous dampers speed and force were used to define the hysteretic performance of the damping element.

2.3. Arrangement and parameters of dampers

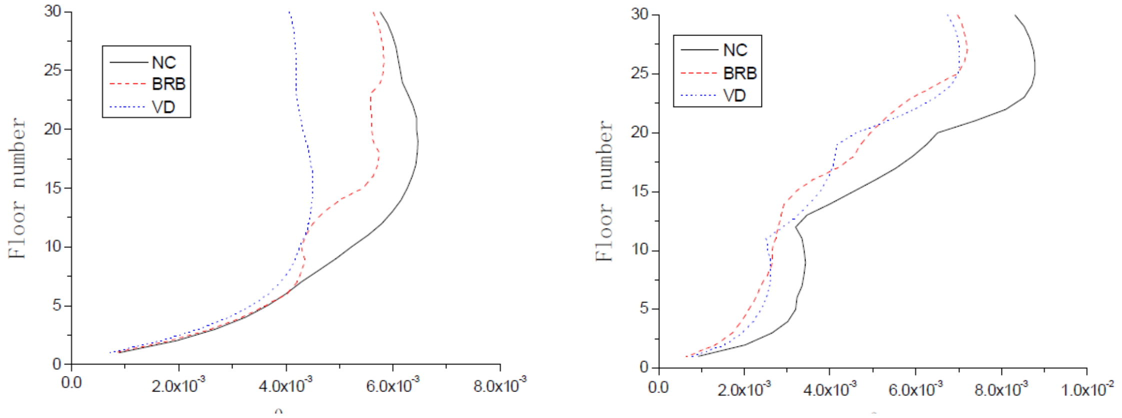
Same numbers of viscous dampers and BRB were set respectively in the mixed structure, and the installation form of monoclinic support arrangement was adopted. The dampers were set between the CFST columns in the storey 15, 1014 and 1923, and the parameters of the BRB and viscous dampers are shown in the Table 2.

Table 2. Parameters of the BRB and viscous damper

Damper Type	Initial stiffness (kN/mm)	Postyield stiffness ratio	Yield displacement(mm)
BRB	500	0.05	4
	Damping exponent	Ultimate velocity(mm/s)	Ultimate strength(kN)
Viscous damper	0.25	450	1000

3. INTERSTORY DISPLACEMENT ANGLE

The contrast curves of the inter-story displacement angle of different structures under El Centro and KOBE wave action are shown in Fig. 3. VD means structure with viscous dampers; BRB means structure with BRB; and NC means structure without damper in Figures below.



(a) El wave in Y direction (b) KOBE wave in Y direction

Fig. 3. Inter-story displacement angle of structures

It can be seen from Fig.3 that: (1) The maximum of the inter-story displacement angle for the three structures do not exceed the specification 1/100, which is the limit in China code. The maximum of the inter-story displacement angle would be reached under the KOBE wave action for the three structures. (2) The inter-story displacement angles are significantly reduced because of the BRB and viscous dampers. (3) The control effect of the maximal interstory displacement angle of the structure with viscous dampers is superior to that of the structure with BRB under earthquake wave action, and the control effects are shown in Table 3.

Table 3. Damping effect of maximum inter-story drift of structures

Seismic wave	NC structure	BRB structure		VD structure	
	θmax	θmax	Damping effect	θmax	Damping effect
El Centro	0.00646	0.00583	9.8%	0.00451	30.2%
KOBE	0.00878	0.0072	18.0%	0.00702	20.0%

BRB is the displacement-dependent damper, which can provide additional stiffness for structure, and then the stiffness of floor with BRB was increased obviously, so the inter-story displacement angles of the floor with BRB had been lower than that of the floor without damper. The viscous dampers in the structure just provided additional damping, and a part of input seismic energy could been dissipated by the viscous dampers, so the inter-story displacement angles of the floor were decreased for the whole structure, without the phenomenon of sudden change for the control effect. In general, the structure with viscous dampers has better damping effect in inter-story displacement angle than that of structure with BRB.

4. STORY SHEAR FORCE

The contrast curves of story shear force of the different structures under El Centro and KOBE wave action are shown in Fig.4.

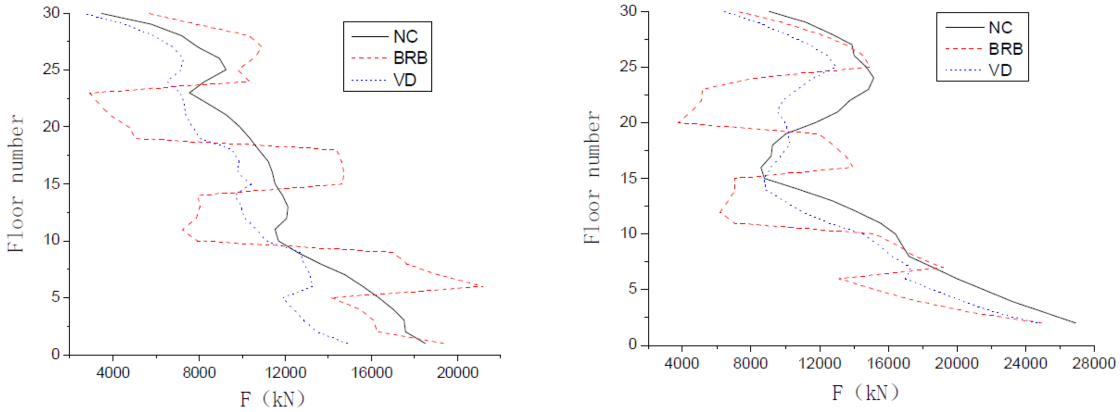


Fig. 4. Story shear force of structures

The Fig. 4 shows that:

(1) For BRB structure, the shear forces of stories with BRB are significantly less than that of NC structure, whilst the shear forces of stories without BRB are larger than or similar with that of NC structure.

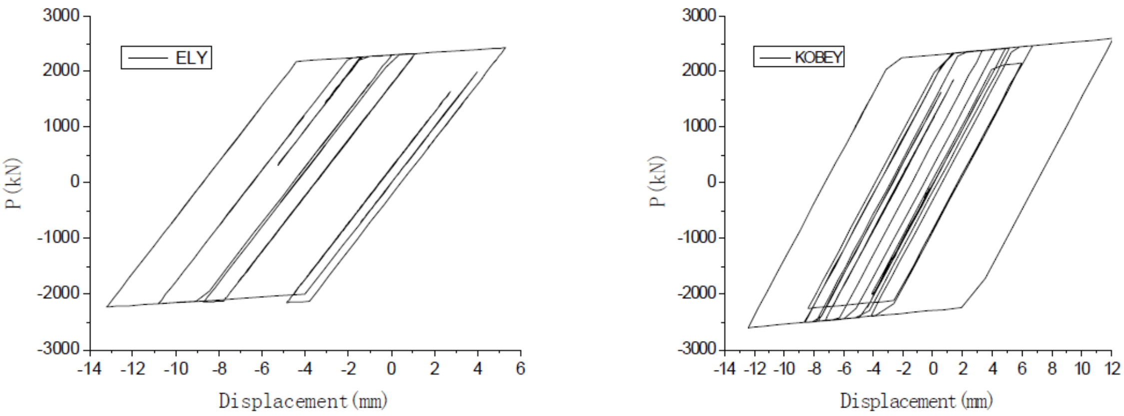
(2) For VD structure, the shear forces of stories with viscous dampers are significantly less than that of NC structure, whilst the shear forces of stories without viscous dampers are less than or similar with that of NC structure.

(3) By comparison with the VD structure, the control effects of the shear forces of stories with BRB are more obviously for BRB structure, but the shear forces of stories without BRB are enlarged and the control effects are inferior to that of the VD structure.

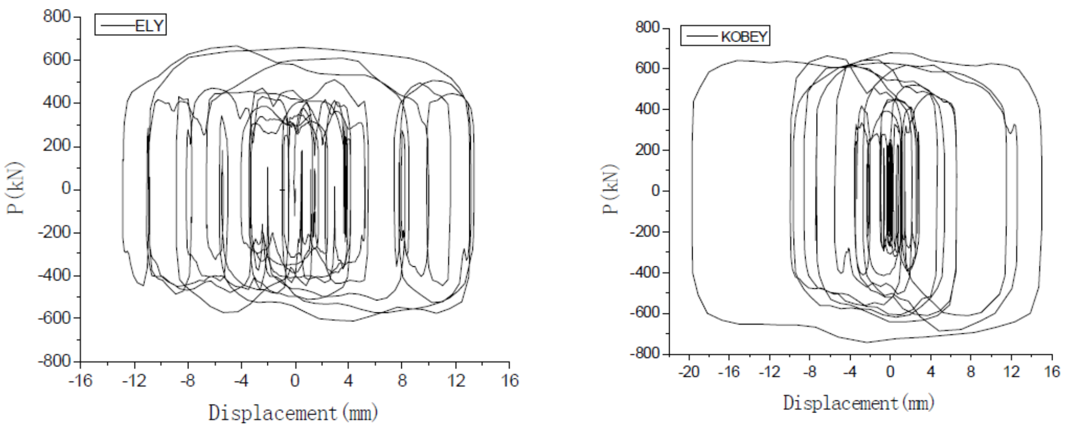
The viscous dampers could not provide additional stiffness for the structure, so the input earthquake energy would not be changed. Whilst the viscous dampers could dissipate earthquake energy, so the every story shear forces of VD structure could be reduced, and the damping effects of the story with viscous dampers were more obviously. For BRB structure, the structure stiffness was enlarged because of the additional stiffness by BRB, and the stiffness ratio between the floors was changed. The shear forces of floors without BRB were larger than that of NC structure, because the input earthquake energy was increased. But for the story with BRB, the BRB could undertaken a part of story shear force, so the shear force of frame and core wall was decreased, even the input earthquake energy was increased because of the additional stiffness.

4. **WORKING PERFORMANCE OF DAMPER**

The hysteresis curves of the BRB and viscous damper in the 23-story are shown in Fig.5.



(a) BRB



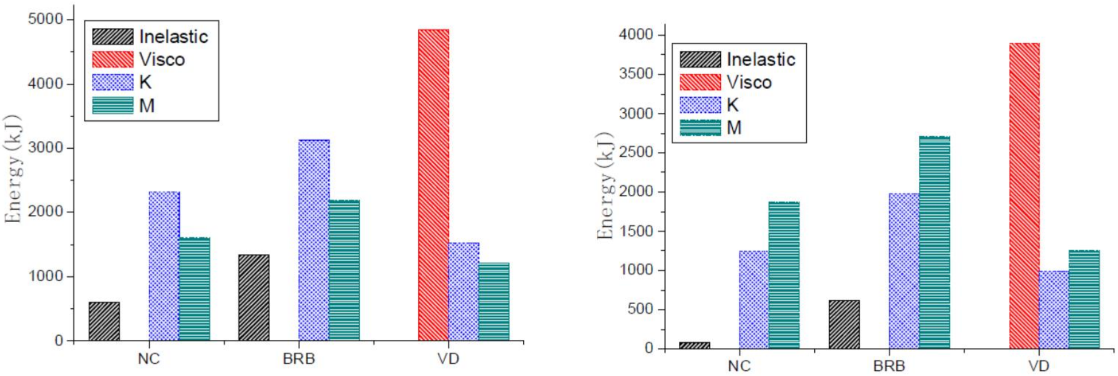
(b) VD

Fig. 5. Hysteretic curves of the dampers

It can be seen from the Fig. 5 that: Hysteretic curves of the BRB and viscous damper are plump under different seismic waves, and the dampers have superior energy dissipation capacity. The hysteretic curves of the viscous dampers are plumper than that of BRB, but the additional stiffness was added to the structure by BRB, whilst the BRB could be used as the steel brace under frequent earthquake action, so the relative displacement of structure could be controlled well.

5. DISSIPATION ENERGY

The dissipation energy graphs of the different structures under different seismic waves are shown in Fig. 6. (Inelastic: dissipation energy of the elastic-plastic deformation; Visco: viscous damping dissipation energy; K: damping dissipation energy of the structure stiffness; M: damping dissipation energy of the structure mass).



(a) EL wave in Y direction (b) KOBE wave in Y direction

Fig. 6. Dissipation energy graphs of structures

Combined with the contrast analysis, the Fig. 6 shows that: The dissipation energy of the NC structure and BRB structure could be divided into two parts: the inelastic and structural damping dissipation energy. The dissipation energy of the VD structure consists of inelastic dissipation energy, structural damping dissipation energy and dissipation energy by viscous dampers. The maximal inelastic dissipation energy of the NC structure is 1420kJ, and that of the BRB structure is 3595kJ including the dissipation energy by BRB. The maximal structural damping energy dissipation of the three structures is 4082kJ; 8212kJ and 3293kJ respectively.

Because of the additional stiffness provided by BRB, the total dissipation energy of BRB structure has been increased, so each part of dissipation energy would be higher than that of NC and VD structure. The viscous damper could provide additional damping for structure and dissipate energy, so the structural damping dissipation energy of the VD structure is obviously lower than the other two structures; moreover the dissipation energy of the elastic-plastic deformation is basically zero under different seismic waves.

The input earthquake energy of the NC structure was mainly dissipated by the structure itself. For the BRB and VD structure, the earthquake energy could be partially dissipated by the dampers, and then the damage of the structural members would be effectively reduced. In the aspect of dissipation energy, the VD structure has superior damping effect.

6. CONCLUSION

Elastic-plastic time history analysis was performed for 30storey CFST frame-core wall structure with different dampers. Inter-story displacement angles, story shear force, working performance of damper and dissipation energy were analyzed contrastively, and the conclusions are as follow:

(1) The seismic performance of CFST frame-core wall structure has been improved, because the BRB and the viscous dampers were set in the mixed structure and dissipate earthquake energy.

(2) Compared with the NC structure, when the viscous dampers were set in CFST frame-core wall structure, the inter-story displacement angle and story shear force are both reduced in some

degree, whilst dissipation energy of the elastic-plastic deformation is decreased obviously, and the structural damage is effectively slowdown.

(3) Compared with the NC structure, when the BRB were set in CFST frame-core wall structure, the inter-story displacement angle is reduced and the structural damage is slowdown in some degree, but the story shear force would have different changes for stories with dampers and without damper.

(4)Under strong earthquake action, the inter-story displacement angle and shear force of floor with BRB are less than that of floor with viscous dampers, however the inter-story displacement angle and shear force of floor without BRB are larger than that of floor with viscous dampers.

(5) Hysteretic curves of the dampers are plump under different seismic waves, and the hysteretic curves of the viscous dampers are plumper than that of BRB. The dampers in CFST frame-core wall structure have superior energy dissipation capacity.

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