ENERGY DISSIPATION DESIGN WITH VISCOUS DAMPERS IN HIGH-RISE BUILDINGS

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SUMMARY:
Wind load and earthquake load are two main lateral loads should be resist in high buildings. The structural responses arising from wind load and earthquake load will increase exponentially with the height increasing in high-rise buildings. Conventionally, the structure is designed to increase the stiffness and strength to mitigate the dynamic response. An alternative method is promoted by adding special devices, such as viscous damper (VD), to dissipate energy of the building. The energy induced by earthquake will absorbed by these devices and the load acted on the main structure of the building will reduce significantly. In the paper, different configurations of viscous dampers work in extra high-rise buildings are described. a super high-rise development in high intensity seismic area installed VD is analyzed. The seismic responses of the structure with viscous dampers are studied by time-history analysis. The investigation result shows that viscous dampers substantially reduce the structural dynamic response and the benefits may be realized.

Keywords: high-rise building, viscous damper, energy dissipation, dynamic response

1. INTRODUCTION

High-rise building is increasing rapidly in China owing to numerous demanding and the rise of land price. As for super high rise building, gravity, wind load and earthquake load are main actions that should be resisted by the structure. Especially, the wind load and earthquake load will increase significantly as the height of building increasing, and the dynamic response will increase faster. Conventionally, the design approach taken to control the dynamic response is to increase the stiffness and strength of the lateral resisting structure, that is, more rigid structural system, larger member size and stronger material are used. However, any increase in stiffness and strength leads to larger seismic loading owing to the stronger ground motions associated with shorter periods and larger gravity.

It is common that the dynamic response reduces with increasing damping. An innovative method to control the dynamic response is to mitigate vibration by adding supplementary damping system to a building. As more energy induced by the earthquake dissipated by the damping devices, the main structural members, such as columns, beams and shear walls which carry gravity load will resist less lateral load. Therefore, they are protected from earthquake by these devices, which resulting in a building with better seismic performance and less construction cost.

In the paper, the application of viscous damper (VD) to the high-rise building is described. And a super high-rise development in high intensity seismic area installed VD is analyzed. The investigation result shows that VD will substantially reduce the structural dynamic response and the benefits may be realized.

2. VISCOUS DAMPER

Viscous damper (VD) is one of damping devices that often used in the buildings and bridges for vibration mitigation. VD, shown in Figure 2.1, is piston-type device with arrangements of seals and piston orifices to provide a resistance forces as function of velocity between the two ends of the device. Different manufacturers supply a wide variety of devices, operating at high or low fluid pressure and generally having non-linear force versus velocity relationship of the form $F=Cv^{\alpha}$, with α in the range 0-2.0 and C denoting damping coefficient. VD may be categorized as three kinds: linear VD (α=1), non-linear VD (α<1) and super linear VD (α>1). Super linear VD is rarely applied in the building since its damping force increases sharply with increasing relative velocity.

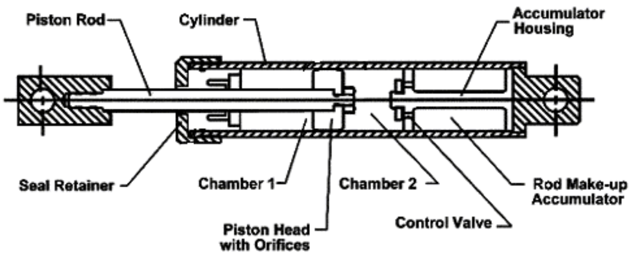


Figure 2.1 Viscous Damper Sketches

Figure 2.2 shows the relationship between the damping force F and relative velocity v. As for non-linear VD, the damping force increases rapidly when the velocity is small, and slowly when velocity large. The force of linear VD is proportional to the velocity resulting too big force for high velocity. The connections of linear VD is too vulnerable to realize its function of dissipating energy and fail to protect the main structure from earthquake motion. The hysteretic curve of VD is illustrated in Figure 2.3. The hysteretic curve of non-linear VD is fuller than that of linear VD. The non-linear VD is more widely applied in the building than the linear VD.

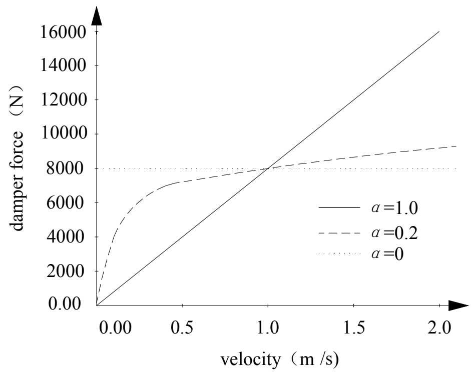


Figure 2.2 Relationship of damper force and velocity

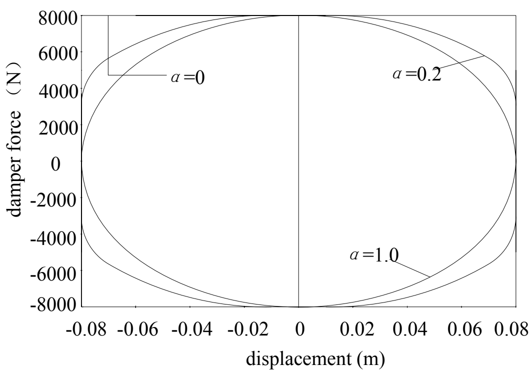
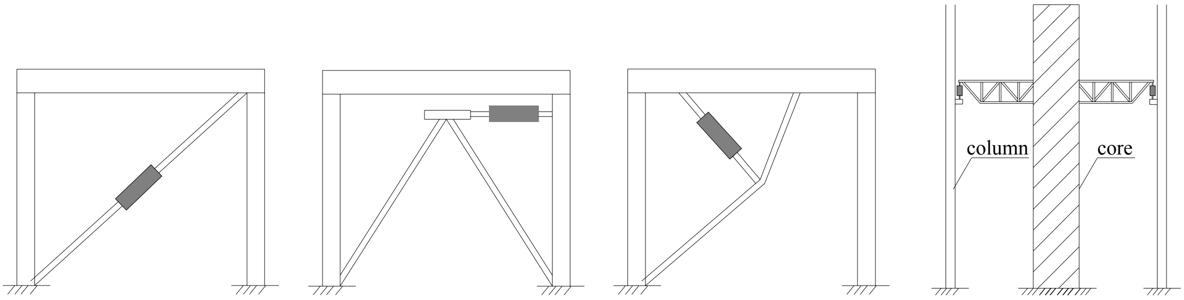


Figure 2.3 Hysteretic curves of VD s

Compared with Buckling Restrained Brace (BRB) and Tuned Mass Damper (TMD), VD shows better adoption to the high rise building in seismic regions to reduce the dynamic response induced by the earthquake. VD will increase the supplementary damping without increasing structural stiffness, and the overall damping will achieved effectively without frequency tuning.

VD will work and induce damping only if the two points it connects have significant relative movement. VD can be installed in structures in different configurations to achieve relative movement. Figure 2.4 shows some configurations often used in high-rise buildings. In Diagonal Brace Damper and Chevron Brace Damper, interstory displacement under lateral load will cause the relative movement of the two ends in the devices. While in the Toggle Damper, relative movement between the two ends are enlarged by special configuration. For Cantilever Truss Damper, the relative movement is L/H times to interstory displacement, in which L means the length of cantilever truss, H is the height of floor to floor. The relative movement will larger than the interstory displacement if the cantilever length is larger than the story height.



(a) Diagonal Brace Damper (b) Chevron Brace Damper (c) Toggle Damper (d) Cantilever Truss Damper

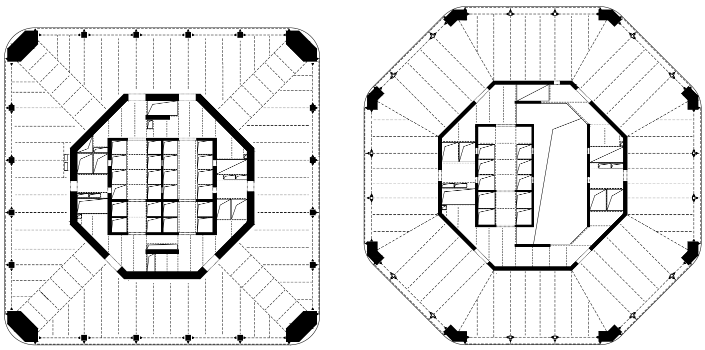
Figure 2.4 Damper configurations

3. BUILDING INSTALLED WITH VD

3.1 Description of the Building Structure

South Asia Gate Tower (SAGT, shown in Figure3.1) is located in Kunming, 8 degree-earthquake fortification zone in China. The tower is 342m high with 82 stories above the ground. The tower is mix-used containing retail, office, resident and hotel. The lateral structural system consists of perimeter mega columns, reinforced concrete core and steel belt trusses at levels 9, 22, 36, 50, 64 and82. The closed form of RC core provides a large amount of the overall lateral and torsion stiffness of the building. The perimeter mega frame, composed of composite columns and belt trusses, provides additional stiffness, structural integrity, and redundancy for the overall building. Four mega columns in the corner bifurcate into eight inclined mega columns from the 23rd story.

Figure 3.1 Architectural rendering of SAGT



(a) Plan below level 23 (b) Plan above level 23

Figure 3.2 Typical plan of SAGT

3.2 Configuration of VD in SAGT

As one of the highest structures in 8 degree-earthquake fortification zone, SAGT may be subjected to strong lateral motions in earthquake. Therefore, vitiation mitigation method is considered in the structural design, and VDs are introduced into the building after comparison.

Cantilever Truss Dampers are innovatively used in the building. The trusses are cantilevered from the RC core to the perimeter mega columns, and VD connects the trusses end and the columns. The cantilever length of which is 2-3 times to the story height, which results in a bigger relative velocity for the VD under lateral motions. To keep the plan and space for architectural function, cantilever trusses are placed on the refugee and M&E floors. Furthermore, VD should be placed on the floor with larger story drift in order to create a bigger relative movement between the two ends of VD. At last, Cantilever Truss Dampers are set at three levels 36, 50 and 64 according to the story drift of the tower, showed in Figure 4. There are 8 cantilever trusses on each floor. The cantilever trusses are designed with 6m high to achieve enough bending moment, so that the trusses deformation will be little enough to eliminate the relative velocity lose.

Four dampers are attached to one cantilever truss and column with a total of 96 VDs are installed in the tower. The VD parameters are showed in Table 3.1.

Table 3.1 General information of VD parameters

α	C (kN*(s/m) $^{\alpha}$)	F (kN)	D (mm)	Quantity
0.3	4000	1500	±150	96

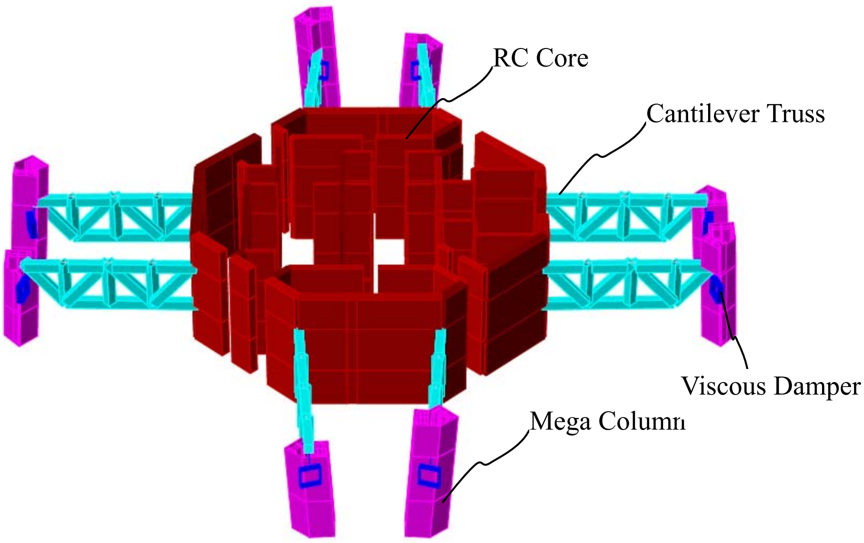


Figure 3.3 Cantilever Truss Dampers in SAGT

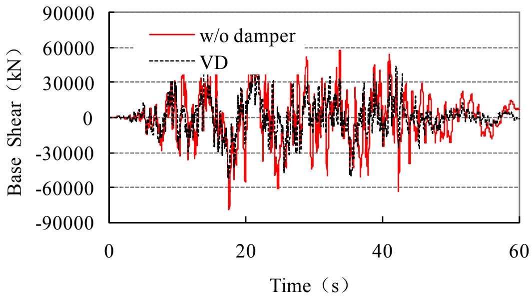
4. DYNAMIC ANALYSIS

The structural dynamic analysis is carried out by ETABS computer program, in which VD is modulated by damper element. The intrinsic damping ratio of the structure is 0.02. A total of three time history records, named H755A, H78A and H78B respectively, are used, the peak acceleration of which is 70 cm/s2 for the minor. Non-linear time history is performed to evaluate the structural dynamic response with VDs. Additionally, the benefits of VD are illustrated by the dynamic response comparison of structure with and without VDs.

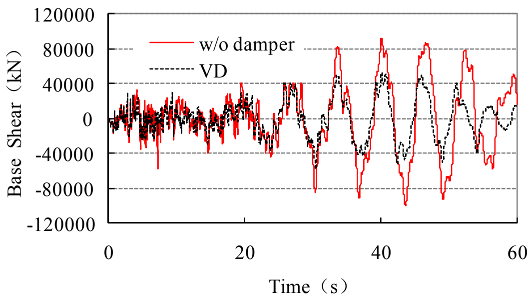
The periods of first 3 structural modes are 6.32s, 6.07s and 3.36s. The first 2 modes are translational vibration of two main directions X and Y. With symmetric plan and layout, the structure has similar translational modes in the two main directions. The 3rd mode is torsion, with a period much lower than the first translational mode, shows that the structure has enough torsion stiffness.

4.1 Structural Base Shear and Story Shear

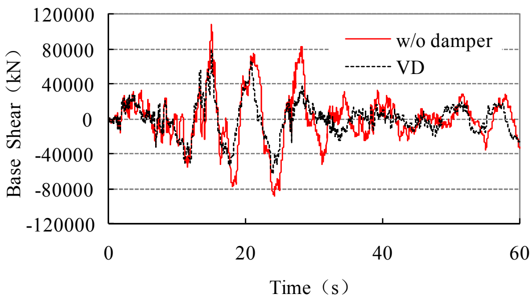
Figure 4.1 shows the time history of structural base shear under minor earthquake with VD and without VD. The peak base shear will decrease up to 28% when VDs are introduced into structure. The maximum story shears of structure are obviously reduced when VDs are used, as shown in Figure 4.2.



(a) H755A



(b) H78A



(c) H78B

Figure 4.1 Time history of Base Shear

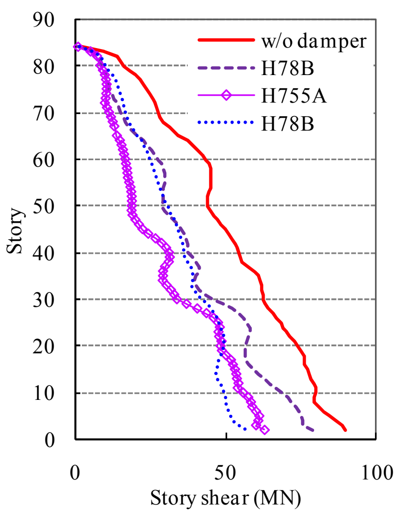


Figure 4.2 Story shear under minor earthquake

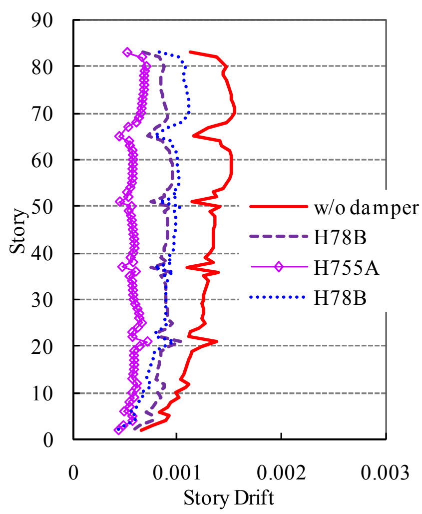
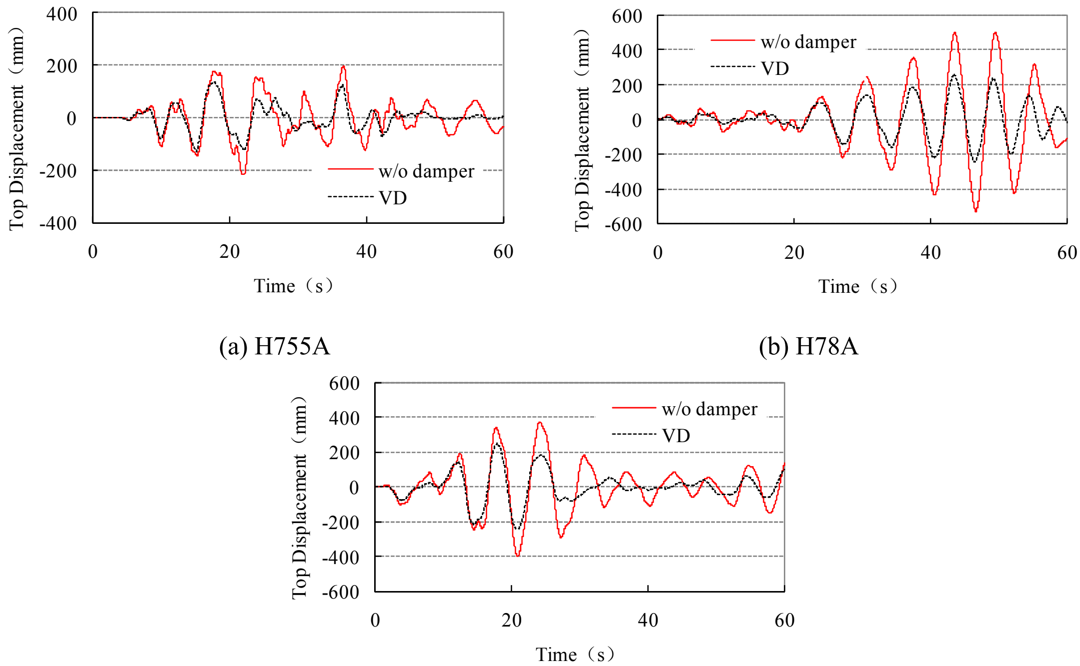


Figure 4.4 Story drift under minor earthquake

4.2 Top Displacement and Story Drift

The structural deformation of minor earthquake load, often expressed in top displacement and story drift, is usually strictly controlled to assure overall lateral stiffness and prevent damage of nonstructural partitions and cladding and. After VDs introduced, the structural deformation indexes are much improved, the top displacement and maximum story drift decreases up to 38% and 50% respectively, which are shown in Figure 4.3 and Figure 4.4.



(a) H755A (b) H78A

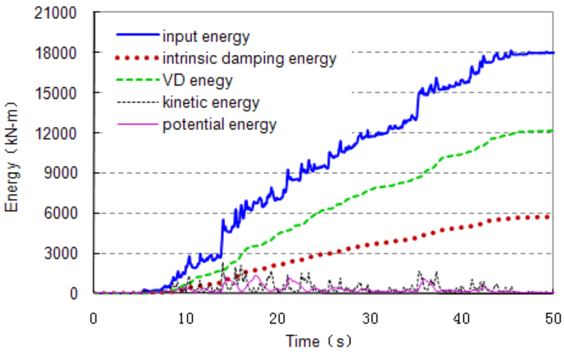
(c) H78B

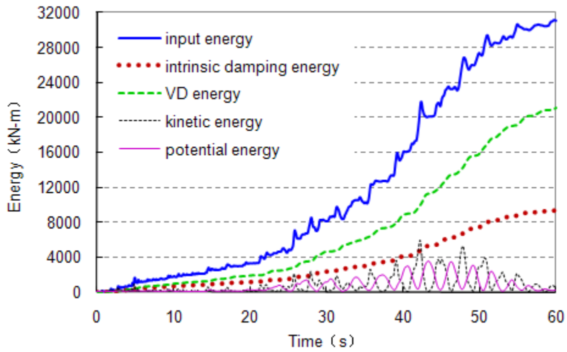
Figure 4.3 Time history of top displacement

4.3 Energy Dissipation and Equivalent Additional Damping

During earthquake, the ground motion will arise in the structural vibration. When the structure is elastic, the energy absorbed by structure can be divided into four parts, that is, kinetic energy, potential energy, intrinsic damping energy and VD energy. During elasticity, all of energy induced by earthquake will finally dissipated by damping, including intrinsic damping and viscous damping. And no energy will be dissipated by the kinetic energy and potential energy because they just transfer into each other.

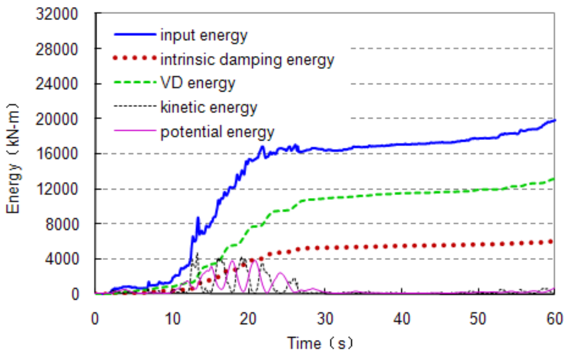
The energy dissipation in the structure of SAGT when suffered minor earthquake are plotted in Figure 4.5.Nearly 2/3 energy is dissipated by viscous dampers and 1/3 by the building intrinsic damping. Therefore, the additional damping introduced by VD is twice of the intrinsic damping. According to the energy theory, the equivalent additional damping ratio of the structure will reach to 0.08 since the structural intrinsic damping is 0.04.





(a) H755A

(b) H78A



(c) H78B

Figure 4.5 Energy dissipation categories under minor earthquake

5. CONCLUSIONS

This paper presents an innovative method for the design of super high-rise building where Cantilever Truss Dampers are induced. Time history analysis result shows that the structural dynamic responses, such as force and displacement, are virtually eliminated when VDs are applied. VDs dissipate nearly 2/3 energy induced by the minor earthquake. The viscous damping ratio will be twice as structural intrinsic damping according to the energy theory. The investigation illustrates that viscous dampers work effectively to dissipate energy and the benefit can be realized.

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