Application of Viscous Dampers for Super Tall Residential Buildings in High-Wind Strong-Seismic Area

*Kun Ding[1)], Xin Zhao[2)], Yue Yang[3)] and Liwei Ye[4)]

[1), 2), 3)] Tongji Architectural Design (Group) Co., Ltd., Shanghai, China
[4)] Xiamen Wansha tiancheng real estate development Co. Ltd., Xiamen, China
[1)] dingkun22@163.com

ABSTRACT

The structural design for the lateral system of super tall building is commonly controlled by stiffness and human comfort performances under lateral loads in high-wind strong-seismic area. Super tall residential buildings have even higher human comfort performance requirements since they are commonly developed as luxury properties due to huge investment amount. Viscous damping systems have been applied widely in engineering practices due to clear mechanism, compacted system and maintenance free features, especially it can mitigate vibration responses under both wind loads and earthquake actions. A super tall residential building project located in Xiamen city of southeast China was employed in this study to investigate the viscous damping system selection, optimal damper placement, highly effective deformation amplification devices, damping parameter optimization and additional damping ratio calculation. It can be illustrated that the application of highly effective viscous damping system not only can improve the human comfort performance of super tall residential buildings under small wind, but also can reduce the lateral deformation under high winds and strong earthquakes to realize more efficient structural design.

1. INTRODUCTION

With the increase of building height, modern super tall buildings become more and more slender, and the structural natural frequency becomes closer to the predominant frequency of strong wind. In high-wind and strong-seismic area, the lateral stiffness in both wind load and earthquake action and the human comfort performance under wind load becomes a very important design constraint, especially for super tall residential buildings which have a demand of high human comfort performance.

Viscous damper have been proved to be one of the most efficient devices to absorb and dissipate large amounts of energy from both wind and earthquake. Because of the small inter-story deformations under wind load, adopting motion

---

[1), 3), 4)] Structural Engineer
[2)] Senior Structural Engineer

amplification devices can amplify the damper displacement under wind load, and improve the efficiency of the viscous dampers dramatically(Mc Namara 2003, Astaneh 2002, Yuri 2003).

Dijingyuan project in Xiamen city consists of No.1~7 buildings, No.1~5 buildings are super tall residential buildings with 62 stories, and the height is 245.75m. No.6~7 buildings are multi-storey commercial building with 3 stories overground, and the height is 18m. The total construction area is about 540,000 square meters.

As a region of high-wind strong-seismic, the seismic precautionary intensity in Xiamen is 7 degrees (0.15g), and the basic wind pressure with 50-year return periods is 0.8kPa, stiffness and comfort of the structure is difficult to meet the requirements. Taking No.3 building as an example(Fig.1 shows the typical floor plan), this article describes the energy dissipation design process by using viscous dampers and the vibration reduced effect.

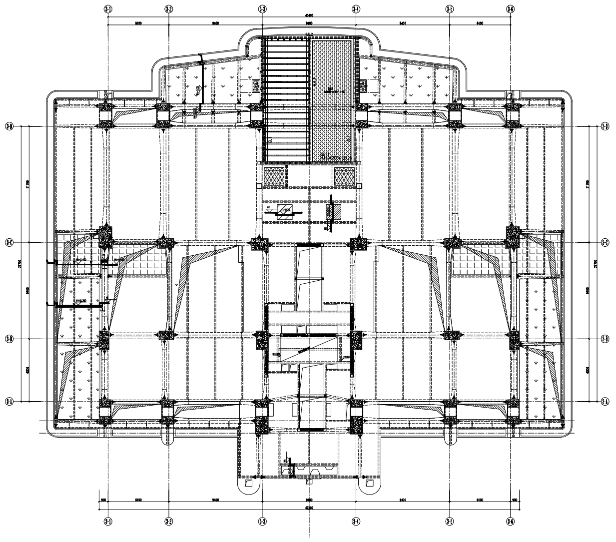


Fig.1 Typical floor plans of No.3 Building

2 STRUCTURAL SYSTEM

2.1 Lateral resisting system

Steel frame-brace (shear walls) structural system is adopted as lateral force resisting system of this building, it mainly consists of the following components: (1) buckling-restrained steel plate shear walls; (2) concrete-filled square steel tube columns; (3) steel frame beams; (4) buckling-restrained braces and common steel braces.

Buckling-restrained steel plate shear wall(Stefano 2005) is a new member of resisting lateral force and dissipating energy, which takes ordinary steel plate or low yield-point steel plate as the main member of lateral resisting system, and special devices are used on both sides of the plate prevent the out-plane buckling. It can provides great stiffness within elastic stage, steel plate can only yield under lateral force and will never buckling. So the bearing capacity of steel plate wall can be fully played. In addition, the plump hysteresis curves under periodic lateral force shows it can absorb energy effective during moderate or large earthquake.

Concrete-filled square steel tube columns undertake most of vertical and horizontal load, the column sizes at the first floor is 2500x1500x60, the steel tube thickness of the columns decrease from 60mm to 30mm. The huge columns are divided into two or three caves by steel diaphragm along the longitudinal direction, typical column cross section is shown in Fig.2.

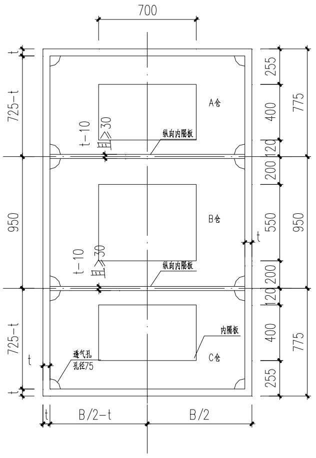


Fig.2 Typical column cross section

Steel frame beam has significantly affect on the lateral stiffness of the structure, on the one hand, it involved in the overall lateral resistance by forming frame with concrete-filled steel tube column, on the other hand, it’s a part of the gravity-loading system to bear vertical load from the floors.

Buckling-restrained brace and common steel support are used in No.3 building. By using external sleeve, the restrained brace will not buckling, beam and column members are also prevented from destruction, so the stiffness and strength of the brace can be fully played. Its core steel plate is low yield point steel and ordinary low-carbon steel.

2.2 Gravity system

This project adopts composite floor system, which is composed of steel beams and concrete slab.

Since this project is the super high-rise luxury residental buildings, beam is not allowed to appear in spaces like living room and bedroom, the distance between the beams is quite large, so temporary support combined with cast-in-situ concrete slab are adopted instead of steel deck. In the terrace and flower beds, steel-bars truss floor is adopted because of the difficulties in installing temporary supports.

3. VISCOUS DAMPER INTEGRATED DESIGN

3.1 Viscous dampers design procedure

The design procedure of viscous dampers are as followed,

1) The targeted additional damping ratio for wind-induced vibration comfort is determinated as 2% based on the wind tunnel test results, and the targeted additional damping ratio for stiffness analysis is determinated as 1%;
2) Preliminary determinate the location, the numbers, layout and parameter of viscous dampers based on the demands of architect and owner.
3) Executing the time history analysis of wind loads and earthquake waves based on the computational model set up with the viscous damper elements.
4) Calculating the additional damping ratio and judging whether the results meeting the expected value.
5) Adjusting the damper parameter or adding the numbers of damper until the additional damping ratio meeting the expected value if the results do not meeting the requirement.
6) Calculating the structural response in considere of the additional damping ratio, incresing the damping ratio make the structure easy to meeting the stiffness and wind vibration comfort performance,meanwhile check other design criteria.

3.2 Additional damping ratio calculation

The calculation of additional damping ratio can use the energy estimation method specified by Chinese Code of Seismic Design of Buildings (GB50011-2010) and Code of Building Energy Dissipation Design (JGJ297-2013). The equation is as shown in Eq.(1). And the additional damping ratio can be verified by the equivalent reaction method which means the maximum story drift of structure with damping devices is smaller than that of structure with additional damping ratio(GB50011-2010) (JGJ297-2013).

$$\zeta_d = \sum_{j=1}^{n} W_{cj} / 4\pi W_s \tag{1}$$

Where, ζ_d refers to the additional damping ratio; W_{cj} refers to the *j-th* damper's energy consumption; W_s refers to the elastic energy of structure under the lateral actions.

Without considering the torsion, the elastic energy of structure under the horizontal loads can calculated as Eq.(2).

$$W_s = \sum F_i u_i / 2 \tag{2}$$

Where, F_i refers to the standard value of horizontal loads of the *i-th* node; u_i refers to the displacement of *i-th* node under horizontal loads.

The dissipated energy of nonlinear viscous dampers in one period under horizontal loads can calculated as Eq.(3).

$$W_{cj} = \lambda_1 F_{dj\max} \Delta u_j \quad (3)$$

Where, λ_1 refers to gamma function of damping exponent α, $F_{dj\max}$ refers to the maximum damping forces under horizontal loads of *j-th* dampers.

3.3 Viscous damper location

In order not to affect the residential people, the viscous dampers are located in refuge story in 43 F and 59a F. Considering the suggestion from the architect and the owner, the location of viscous dampers are shown in Fig.3.

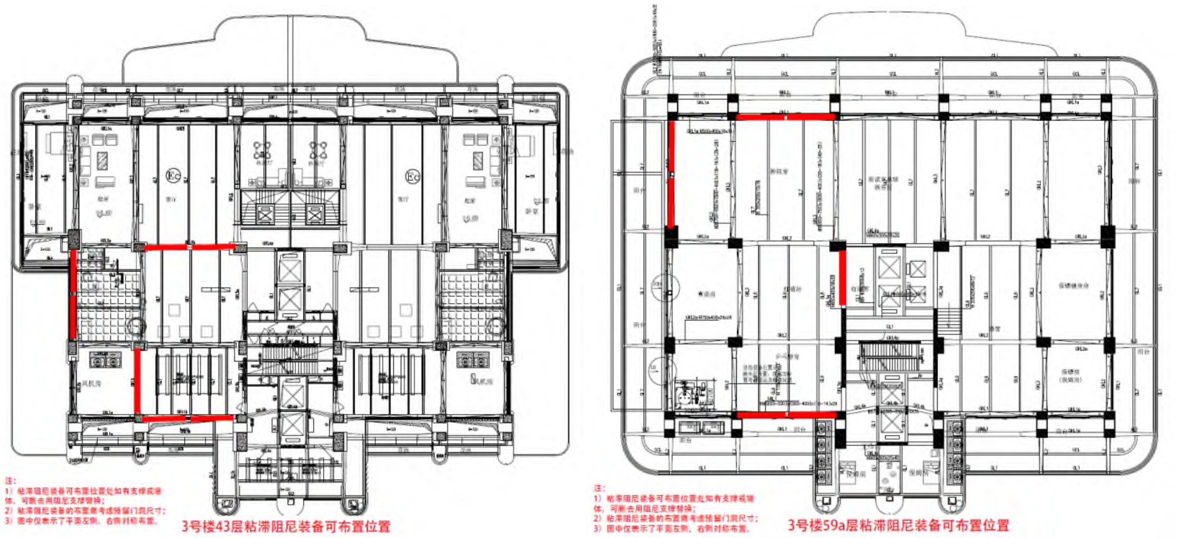
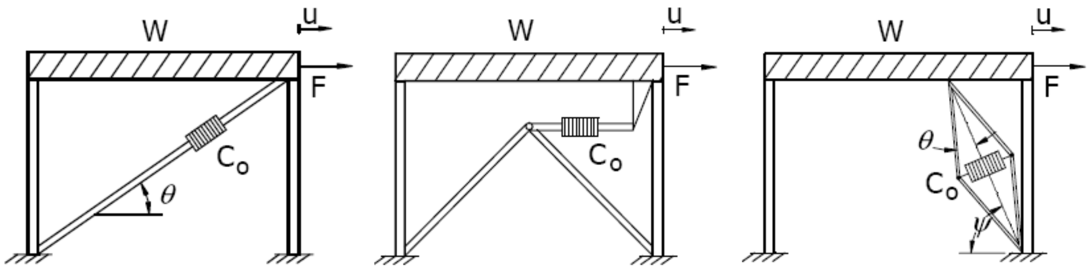


Fig.3 Viscous damper symmetrical location

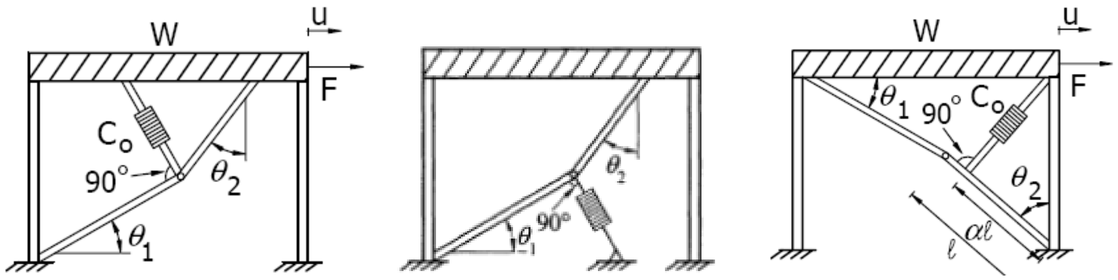
3.4 Viscous damper layout

Traditional layout of viscous dampers is diagonal brace or chevron brace. Actually, traditional damper layout is low-effective and small-energy dissipation. Constantinou et al. Investigated the toggle brace damper system and verified its ability to amplify the axial displacements of dampers and the efficiency of energy dissipation through both cyclic loading tests and shaking table tests. Fig.4. shows the typical layout of viscous dampers in the building.

Reverse toggle layout is very prevalent in the buildings,such as Tianjing International Trade Center et.al , it can amplified the displacement of dampers two or three times, the numbers of dampers can reduce one half in the same of the damper parameter, it can reduce the damper cost. Considering the building function, reverse toggle are selected, as shown in Fig.4.



(a)Diagonal brace (b)Chevron-type (c)Scissor-Jack



(d)upper toggle (e)lower toggle (f)reverse toggle

Fig. 4 Typical layout of viscous dampers

3.5 Viscous damper parameter design

（1）Selection of damping exponent α

Viscous dampers is velocity-dependent energy dissipation device, and the damping force formula is $F = Cv^{\alpha}$. The value of damping exponent α usually between 0.3 to 2.0.

In general, the smaller of damping exponent, the better of energy dissipation effect. When α is equal to 1, the damping force has a linear relationship with velocity. And as α close to zero, the hysteresis curves trend to rectangular, as shown in Fig.5.

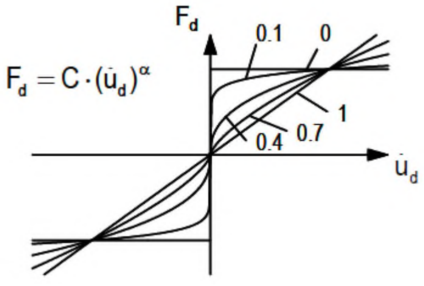


Fig.5 The damping force-velocity relationship of viscous dampers

As for the building, the viscous dampers need work both in wind load and earthquake action. To ensure the viscous dampers work well under the minor wind loads and the damping force not increase too fast in order to protect the structure in the severe earthquake,the damping exponent α selected as 0.3.

（2）Selection of damping coefficient C

On the one hand, the damping coefficient can not be too large, because it will cause the larger output damping forces, beyond the scope of product. On the another hand, the value of damping coefficient should make the additional damping ratio meet the expected value. Through analysis for many times, the damping coefficient was finally determinated C=700 kN/(mm/s)0.3.

4. Analysis results

4.1 Acceleration response

Comparing the maximum acceleration at the corner of floor between uncontrolled structure and controlled structure (as shown in Fig.6), acceleration at the top floor of uncontrolled one reached 25.2gal, which is beyond the specification limits. However, by installing dampers, the top acceleration fall to 14.5gal with 40% decrease. Furthermore, to review the reasonability of the additional damping ratio, time-history analysis of uncontrolled structure has been carried out, and the result is similiar to that of controlled structrue, which proves the additional damping ratio calculated from energy method is reasonable. Comparison of acceleration time-history is shown in Fig.7.

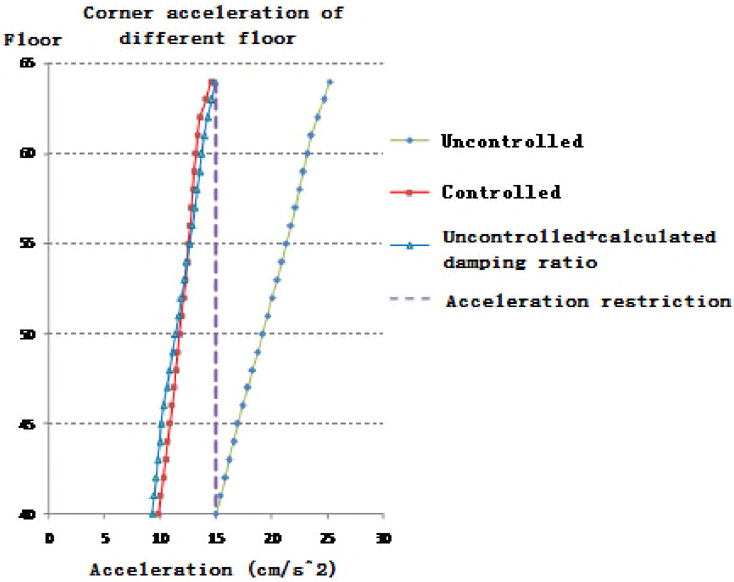


Fig.6 Acceleration under 10-year return period wind load

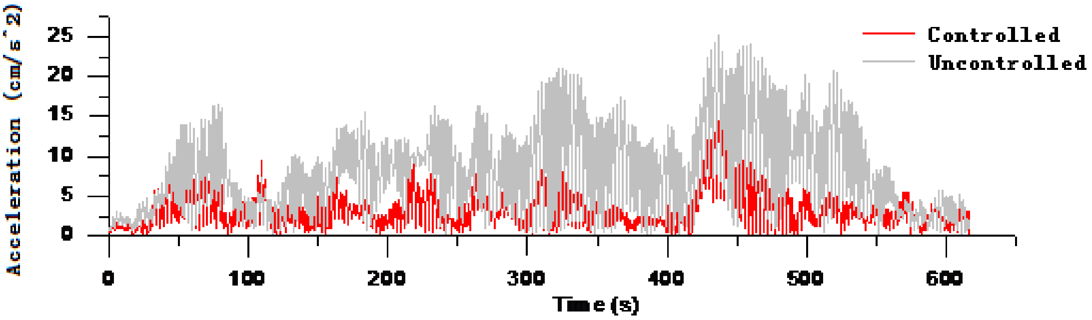
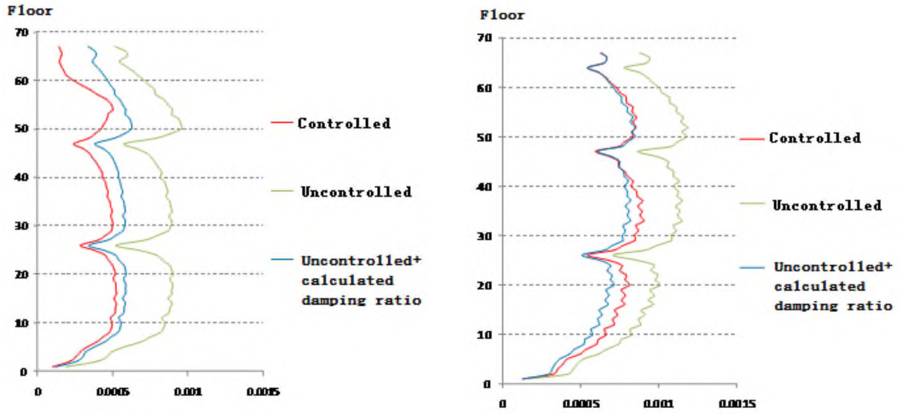


Fig.7 Top acceleration comparison

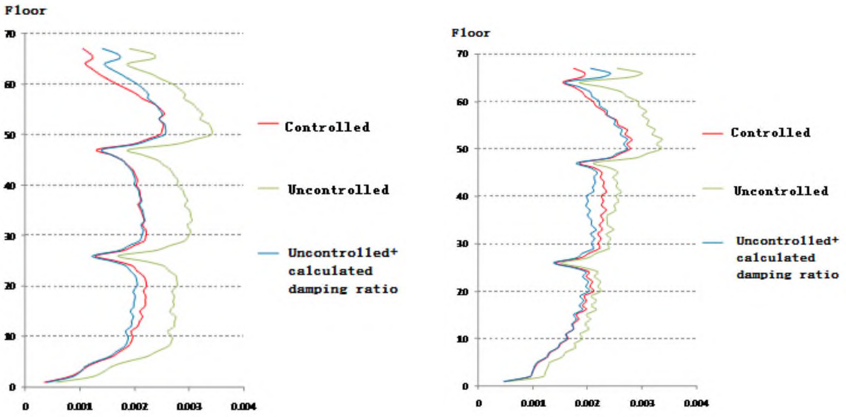
4.2 Inter-story drift response

According to the story drift curve,as shown in Fig.8 and Fig.9, it can be found that story drift reduced significantly by adding dampers. The viscous damper has a great response reduced effect.



(a) X direction (b) Y direction

Fig.8 Story drift in wind load



(b) X direction (b) Y direction

Fig.9 Story drift in earthquake action

4.3 Viscous damper hysteric curves

Through the above analysis, damping force is about 1000~1200kN under wind load with 10-year return period, the maximum damping force is about 2000~2500kN in the small earthquake, the largest displacement of damper is about ±100mm, typical hysteresis curve of damper is shown in Fig.10.

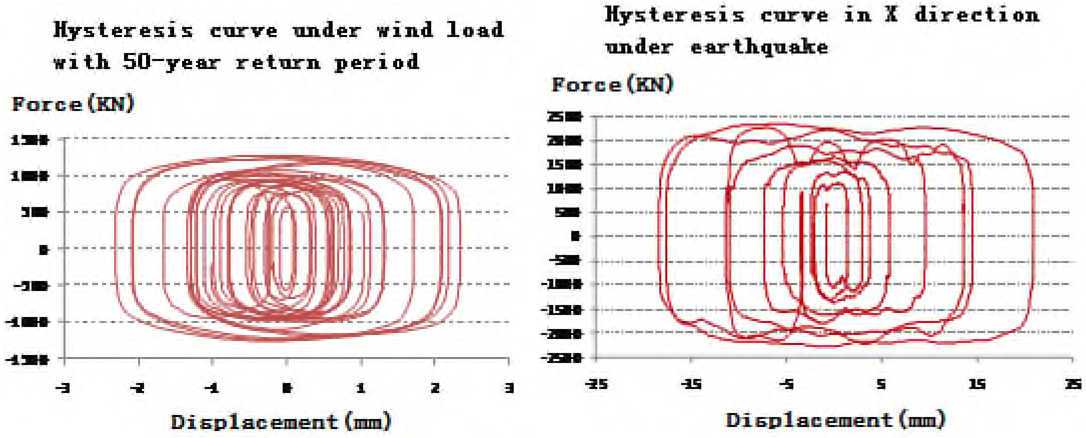


Fig.10 Typical ysteresis curves of viscous damper

5. CONCLUSIONS

Viscous dampers have been applied widely in engineering practices, especially in high-wind strong-seismic area,because it can mitigate vibration responses under both wind loads and earthquake actions.

Through the practice application in Dijingyuan project in Xiamen city, the following conclusions can be drawn:

(1) Maximum acceleration response at the top floor under wind loads can be sifnificantly reduced by adding viscous damping system.

(2) Story drifts under both wind loads and earthquake actions can be sifnificantly reduced by adding viscous damping system.

(3) Plump hysteresis curve of viscous damping shows the great energy dissipation capacity.

It can be illustrated that the application of high-performance viscous damping system not only can improve the human comfort performance of super tall residential buildings under wind loads, but also can reduce the lateral deformation under high winds and strong earthquakes.

REFERENCES

[1]Astaneh-AslA.Seismic behavior and design of composite steel plate shear walls[R].Steel TIPS Report Berkeley:Department of Civil and Enviromental Engineering,Univertity of California 2002.

[2]Mc Namara RJ, Taylor D P. Fluid viscous dampers for high-rise buildings[J]. The Structural Ddsign of Tall and Special Building, 2003,12(2):145-154.

[3]Stefano Berton,John E. Bolander. Amplification System for Supplemental Damping Devices in Seismic Applications[J].Journal of Structural Engineering 2005,6(6).

[4]Yuri Ribakov,Andrei M. Reinhorn. Design of Amplified Structural Damping Using Optimal Considerations[J].Journal of Structural Engineering 2003,10(10).
[5] (GB50011-2010)Seismic Design of Buildings[S].
[6] (JGJ297-2013)Building Energy Dissipation Design[S].