The 2016 World Congress on
Advances in Civil, Environmental, and Materials Research (ACEM16)
Jeju Island, Korea, August 28-September 1, 2016

Optimization of Scissor-jack-Damper's Parameters and Performance under the Constrain of Human Comfort

*Xin ZHAO[1)] and Zhuang MA[2)]

[1)] *Tongji Architectural Design(Group) Co.,Ltd.,Shanghai,China*
[2)] *Department of Structure Engineering, Tongji University, Shanghai, China*
[1)] *22zx@tiadri.com*

ABSTRACT

Several damping device installation configurations that can magnify the energy dissipation capacity of damping devices have been emerged, such as toggle-brace system and scissor-jack system. The scissor-jack-damper system owns its unique advantages of good compactness. However, the research and utilization of scissor-jack-damper is still in the initial stage and has been rarely applied in engineering practices. In this paper, the theoretical basis and design process for finding optimum geometry parameter and damping coefficient of the scissor-jack damper system are developed to obtain the minimum number of the scissor-jack-dampers. A 250-meter real super-tall building project is employed to illustrate the effectiveness and applicability of the proposed performance based optimal human comfort design method of scissor-jack dampers for super tall buildings.

1. INTRODUCTION

Several damping device installation configurations that can magnify the energy dissipation capacity of damping devices have been emerged, such as toggle-brace system (Fig.1a) and scissor-jack system (Fig.1b). Similar to the toggle-brace damper (Constantiou 2001), the scissor-jack damper is capable of providing a significant increase in the damping ratio while reducing both the drift and acceleration response (Sigaher 2003). The scissor-jack-damper system also owns its unique advantages of good compactness with its near-vertical installation. However, the research and utilization of scissor-jack-damper is still in the initial stage and has been rarely applied in engineering practices. To date, the scissor-jack damper has been installed as the primary seismic protection system in the Olympic Committee Building in Cyprus (Sigaher 2004). In addition to the building applications, the scissor-jack damper has also been investigated for reducing vibrations in the cable –stayed bridges, as well as in seismically excited flexible truss towers.

[1)] Professor
[2)] Graduate Student

For the scissor-jack damper system, the relative displacements and velocities of the structure are amplified to the damper, and the resulting damper force is then amplified back to the structure. The end result is that the force exerted on the structure is larger than the force produced by traditional diagonal –braced (Fig.1c) or chevron-braced (Fig.1d) configurations with its special configuration mechanism.

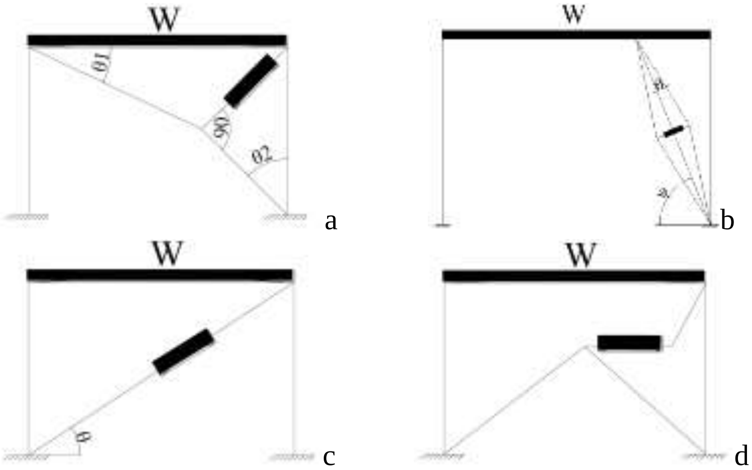


Fig.1 various types of configurations

(a) toggle-brace system (b) scissor-jack system

(c) diagonal–braced system (d) chevron-braced system

2. THEORY BASIC

As shown in the Fig.2, the scissor-jack-damper system consists of a viscous damper arranged in a shallow truss. The initial orientation of the truss is such that its centerline makes the angle ψ with the horizontal member of the frame. Each truss member has length l and is arranged so that its longitudinal axis makes the angle θ with the centerline of the truss. All components of the scissor-jack system are allowed the rotate because of the pined connection between the damper-to-truss and truss-to-frame.

The mechanism of the scissor-jack-damper system magnifies the frame deformation u and the damper will produce relative axial displacement u_D. The magnification factor is

$$f = \frac{u_D}{u}, (1)$$

Where $u_D = |A'B' - AB|$.

Through the scissor-jack system, the motion of the frame is amplified to the damper, and the damper force is amplified back to the frame.

$$f = \frac{F}{F_D}, (2)$$

Where F is the force exerted on the frame, F_D is the force of the damper.

According to the derivation of Constaninou in his former research, the magnification factor can be expressed in a simple equation

$$f = \frac{\cos\psi}{\tan\theta}, (3)$$

Constantiou (2001) also noted that the Equation (3) only provides a very good approximation to the exact damper deformation for small changes in θ .and the practical values of the magnification factor lie in the range 2 to 5.

The derivation of the Equation (3) doesn't consider the influence of the reduction in height due to column rotation and only takes into account rigid body motion of the frame. More accurate derivation and equation can be referred to the research of Constantiou (2001) and Kenneth (2012).

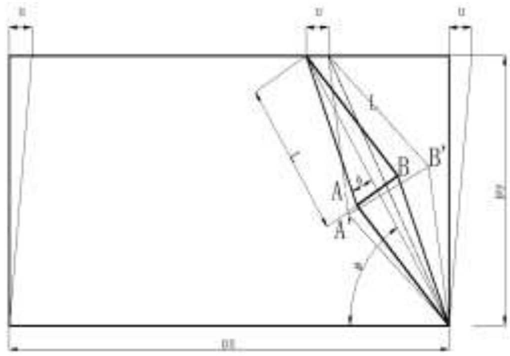


Fig.2 geometry of the scissor-jack damper in a deformed single-story frame

After the geometry analysis of the scissor-jack system in a deformed single-story frame, the test of the equation (3) is necessary. The validity of the scissor-jack and the equation (3) has been tested by Constantiou (2001) through a experiment on the Buffalo earthquake simulator, the frame of which was a single frame with scissor-jack dampers. The Etabs was taken advantage of to implement the simulation of the motion of the frame with scissor-jack damper and the angle ψ and θ were decided to be 60°and 8°, and then the magnification factor was also determined. The simulation model is a three story frame which installed several scissor-jack dampers in two directions. It is shown in Fig.3. The simulation model was imposed single direction wind load. According to the simulation results, the magnification factor in simulation is basically agreeing with the theoretical value that calculated through the equation (3). The simulation results are presented in Fig.4.

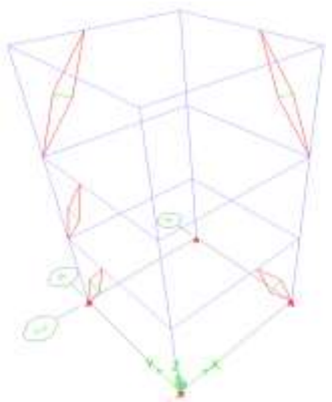


Fig.3 model with scissor-jack damping system

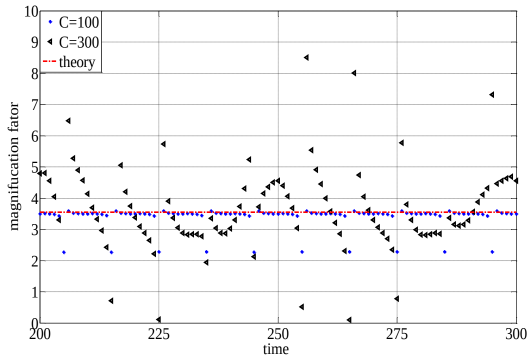


Fig.4 comparison of simulation results with theoretical value

From the Fig.4, another find which is the influence of damping coefficient (C, kN/(mm/s)0.3)on the function of scissor-jack-dampers was presented. The influence of the damping coefficient on the function of scissor-jack-dampers can be further investigated.

3. GEOMETRY OPTIMIZATION OF SCISSOR-JACK-DAMPER SYSTEM

The magnification factor or theoretical amplification efficiency of scissor-jack damper was determined by the two variables, namely two angles ψ , θ. Any change in each angle will cause the change of amplification efficiency. Therefore the geometry optimization of scissor-jack damper makes great sense for improving the work efficiency of the damper system. The mathematical model of the optimal geometry parameter of the scissor-jack damper is formulated as follows:

Max $f(\psi,\theta)=\dfrac{\cos\psi}{\tan\theta}$, (4a)

$s.t.:(\psi+\theta)<90^\circ$, (4b)

$45^\circ \le \psi \le 90^\circ$, (4c)

$5^\circ \le \theta \le 15^\circ$, (4d)

$x \le py$, (4e)

$\dfrac{py}{2} \le L \le py$, (4f)

$f(\psi,\theta-0.3^\circ)-f(\psi,\theta)<0.2$, (4g)

$2<f(\psi,\theta)<5$, (4h)

Formula (4c-4d) defines the bounds of two angles which consider the compactness advantage of the scissor-jack-damper system. The procedure to find the optimal geometry parameters is given in detail:

(1) The ψ defined as 85° at first.

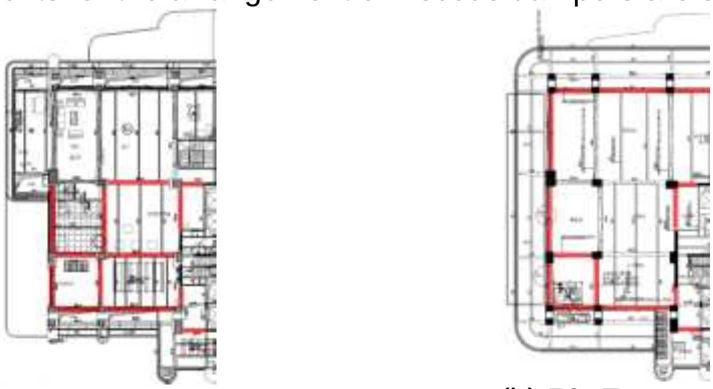
(2) When the ψ determined, the θ varies from 5° to 15°, the change step of which is 0.3°. The magnification factor is then calculated by Matlab program when each θ is determined. If the difference between adjacent values is more than 0.2, the program stops.

(3) Check out the value calculated in the step (2), if the final value is less than 5, the value of ψ minus 5° and returns back to step (2). Or else, the optimization stops and the optimal angles are the combination of angles which make magnification maximum.

In the end, the optimal combination of angles is determined through the above process. The ψ is determined as 60° while the θ is determined as 6°.

4. CASE STUDY

The 250m high super tall residential building project is located in Xiamen. Viscous dampers are only allowable to be set on two reinforced layers: 43F and 59aF. The allowable placements for the arrangement of viscous dampers are showed in Figure 5.



(a) 43F (b) 59aF

Fig. 5 the allowable placements for the arrangement of viscous dampers

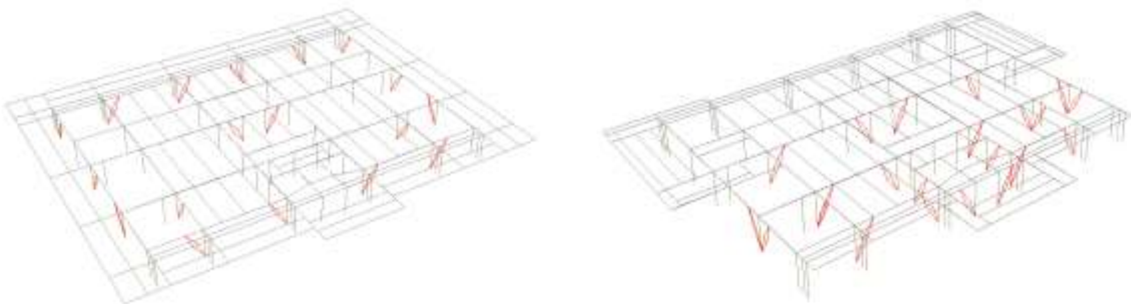
Firstly, the scissor-jack-dampers are set at the all allowable placements under wind loads. After the time-history analysis, the energy consumption of every damper could be calculated and the rank of the damper could also be determined. To prove the validity of the optimization result, two schemes of damper layout were adopted. The geometric parameters of two kinds of damper are presented in the table 1.

Table 1 geometric parameters of each kind of damper

	ψ	θ	f
scheme 1	60°	8°	3.56
scheme 2	60°	6°	4.76

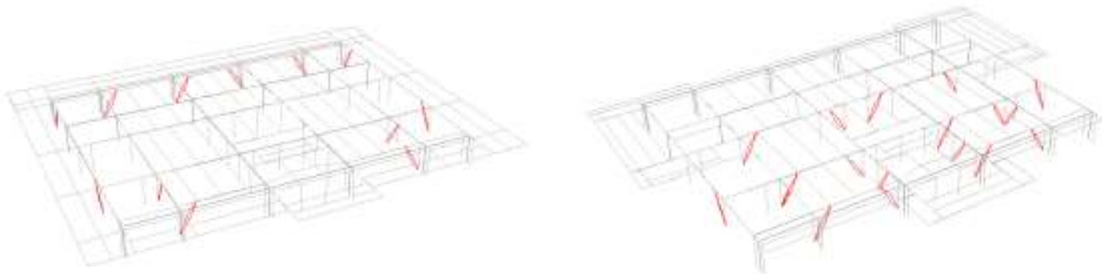
To make the dampers work more efficient, the placements that the dampers are set should take consideration of the rank that obtained before and the symmetrical placement. In order to make the two kinds of schemes more comparable, the same performance target should be set and the coefficient of the two kinds of dampers should be the same. In this comparison, the human comfort is set as the same constrain to meet.

After several times adjustments and analysis, the final placements schemes of the dampers are determined and are shown in the Fig.3 and Fig.4.



(a) 43F (b) 59aF

Fig.6 placements of scissor-jack-dampers of scheme 1



(a) 43F (b) 59aF

Fig.7 placements of scissor-jack-dampers

After installing several dampers, both schemes improve the properties of the primary structure. Human comfort is the constrain that both schemes must meet and the constrain value is $0.15m/s^2$. The number of scissor-jack dampers is key comparison factor of two schemes and the maximum force of dampers id considered as additional comparison factor. The result is shown in the table 2.

Table 2 results of two schemes

	Magnification factor	Damping coefficient	Number of dampers	maximum force	Vertex acceleration
Scheme 1	3.56	900	40	1472kN	0.145
Scheme 2	4.76	900	30	1600kN	0.146

From the above table, the obviously result that the scheme 2 is better than scheme 1and the geometry optimization of scissor-jack damper system is valid.

5. CONCLUSIONS

In this paper, the scissor-jack-damper system is introduced briefly and the theory derived by the former researchers is validated by the analysis software. The authors proposed a new geometry optimization algorithm of scissor-jack damper system, which is proved valid in controlling the human comfort property of super tall building.

6. Acknowledgements

The authors are grateful for the support from the Shanghai Excellent Discipline Leader Program (No.14XD1423900) and Key Technologies R & D Program of Shanghai (Grant No. 09dz1207704).

REFERENCES

Constantiou, M.C., Tsopelas, P., and et al. (2001), “Toggle-brace-damper seismic energy dissipations systems”, *Journal of structural engineering New York*,**127**(2), 105-112.

Sigaher, A.N, Constantiou, M.C.(2003), “Scissor-Jack-Damper Energy Dissipation System”, *Earthquake Spectra*.,**19**(1), 133-158 .

Sigaher, A.N., Constantiou, M.C.(2004), “Scissor-Jack-Damper Energy Dissipation System” *Techinal Report MCEER-04-0010*.

Walsh, K.K., Cronin, K.J., Rambo-Roddenberry, M.D., and et al. (2012), “Dynamic analysis of seismically excited flexible truss tower with scissor-jack dampers”, *stuct.Control Health Monit*,(19):723-74.