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Parameter Optimization for the Integrated Optimal Design of Super Tall Buildings with Viscous Damping Walls

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Abstract

Viscous damping walls can effectively suppress the vibration amplitude of the super tall building structures under both earthquake and wind. Comparing with other viscous dampers, viscous damping walls can dissipate more energy due to shear type mechanism and larger contacting areas. There are differences in economic cost and energy-dissipating capacity between viscous damping walls with different parameters and viscous damping walls with better parameters cost more. By the introduction of viscous damping walls in super tall buildings, the material consumption of main structures can be reduced by the reduction of earthquake action and an integrated optimal design of super tall buildings with viscous damping walls was adapted in this paper. A parameter optimization method of viscous damping walls was proposed in this paper to consider the overall costs of the structure including the cost of material consumption and the cost of viscous damping walls and optimal number of the viscous damping walls. A super tall building located in high seismicity area was applied in the last part of the paper to illustrate the proposed parameter optimization method. Numerical analysis results show that the proposed method is reasonable and effective.

Keywords: parameter optimization method; viscous damping walls; overall costs; super tall buildings

1. Introduction

The application of energy dissipation control for high-rise structure become more and more extensive for many areas of China in high intensity seismic zone. As an new innovative high efficient energy dissipation device in recent years, viscous damping wall was firstly proposed by M.Miyazkai and Aiima[1] in 1986 and firstly manufactured successfully by Sumitomo Construction company（Arima et al.1988）[2]. Viscous damping wall is mainly composed of steel plate hanging in the upper floor, thin steel box fixed on the lower floor and viscous liquid of high viscosity between the inner and outer plates, as depicted in Fig.1. When the structure is subjected to wind or earthquake, relative displacement and relative velocity between the floors will make the steel plate moving in the viscous liquid and thus generate the shear deformation of the viscous liquid. Viscous damping walls consume energy through the internal friction produced by the flowing of the liquid, thereby reducing the seismic response of the structure, as depicted in Fig.2.

As the energy dissipation device of the structure, viscous damping wall can work in frequent earthquake, moderate earthquake and rare earthquake and can be flexibly arranged according to the locations of partition walls in tall buildings. Comparing with the traditional rod type viscous damper, viscous damping wall has more energy dissipation capacity [3]due to the larger friction area between the surfaces of embedded steel plate and the viscous media. There are many practical cases in high-rise building nowadays [4][5].

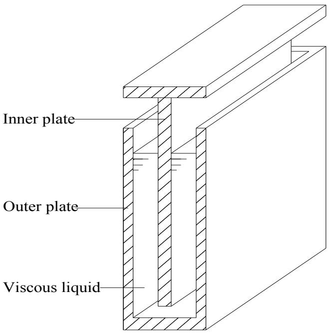

Figure 1: Viscous Damping Wall Unit

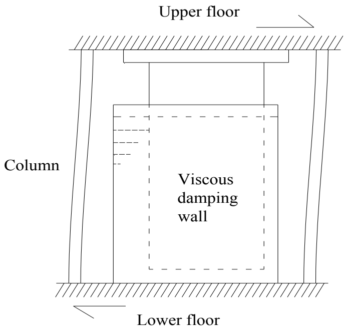

Fig 2: Work Status of Viscous Damping Walls

The research and application of viscous damping wall in China lags behind these in Japan [6] and other countries and specific system needs to be established and improved. Primary, the arrangement form of viscous damping walls is based on engineering experience and there is short of more convenient optimal placement algorithm. Then, there is not much research on the optimization space by the introduction of energy dissipation device in the past. Thirdly, there is lack of deep research on the parameter and number optimization of viscous damping walls.

Search the optimal parameter method based on the integrated optimal structural design for tall buildings with viscous damping walls [7] was proposed for parameter optimization to minimize the structure overall cost with the optimization variable of parameters provided by the manufacturer, and the optimal parameters of viscous damping wall and corresponding optimal additional damping ratio for the structure and optimal number of viscous damping walls will be derived.

2. Parameter optimization of viscous damping walls

Compared with the prototype design, the energy dissipation structure can be optimized since the response subjected to earthquake or wind is decreased due to the additional damping. The energy dissipation structure design with optimization based on the performance improvement design is called integrated optimization design. Integrated optimization design can not only ensure the performance of structure and reduce the failure cost due to the disasters, also reduce the cost of the main structure with optimization of the components. For the overall cost of structure, the integrated optimal design can indeed play advantage of the energy dissipation technology.

The overall cost of integrated optimal structure C cover two parts as follows:

$$C=C_d+C_s \tag{1}$$

Where: C_s refers to main structure cost; C_d refers to equipment cost namely the cost of viscous damping walls.

Compared with the prototype design structure， main structure cost C_s of integrated optimal structure decreased but the equipment cost C_d increased, and as the number of viscous damping wall added to structure grow, the additional damping increases and the optimization degree of the structure deepens, thus the main structure cost C_s get smaller and the equipment cost C_d become larger as depicted in Fig 3. The main structure cost and equipment cost are added up together to get overall cost of integrated optimal structure as depicted in Fig 3. The curve indicate that there is a lowest point in the overall cost curve and the lowest point namely the minimum cost corresponds to optimal additional damping ratio for the structure and and optimal number of viscous damping wall with certain parameter conbinations.

The damping coefficient c and velocity exponent a are two main parameters of viscous damping wall and damping force $F=\mathrm{cv}^a$. There is certain different damping force with different parameter combinations and unit price of viscous dampig wall largely depends upon damping force and additional damping ratio largely depends on the parameter conbination, therefore parameter optimization with integrated optimal structure can both ensure the additional damping ratio and reduce the overall cost of integrated optimal structure. This is especially important for popularizing the use of viscous damping wall.

The main structure cost curve can get through the integrated optimal structural design for tall buildings with viscous damping walls and equipment cost curve can be gained in the Eq (2) using time history analysis method.

$$\varepsilon_a=\sum_j W_{cj}/\left(4\pi W_s\right) \tag{2}$$

Where: ε_a refers to additional damping ratio; W_{cj} refers to energy consumption in a reciprocating cycle with expected displacement of j-th energy dissipation equipment; W_{cj} refers to total strain energy of structure with energy dissipation equipment.

There are different overall costs with different parameter combinations and minimum overall cost corresponds to the optimal parameter of viscous damping wall and the corresponding optimal additional damping ratio and optimal number of viscous damping wall. Search the optimal parameter method based on the integrated optimal structural design for tall buildings with viscous damping walls was proposed for parameter optimization to minimize the structure overall cost with the optimization variable of parameters provided by the manufacturer, and the optimal parameters of viscous damping wall and corresponding optimal additional damping ratio for the structure and optimal number of viscous damping walls will be derived.

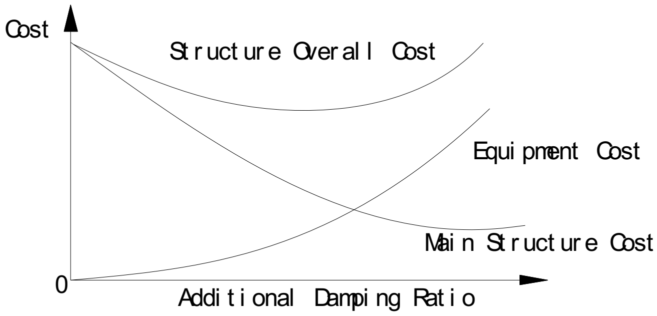

Fig 3: relation Curve

The specific process for the parameter optimization of viscous damping wall is: the first step is to gain the relationship between the optimized cost savings and additional damping ratio and the relation curve by the integrated optimal structural design; the second step is to get the relationship between the viscous damping wall cost and additional damping ratio and the relation curve by time-history analysis method with different parameter combinations; the third step is to get overall cost of integrated optimal structure with different parameter combinations; the fourth step is to compare the overall cost of integrated optimal structure with different parameter combinations to get minimum cost and corresponding optimal parameters of viscous damping wall, optimal additional damping ratio for the structure and optimal number of viscous damping wall.

3. Case study

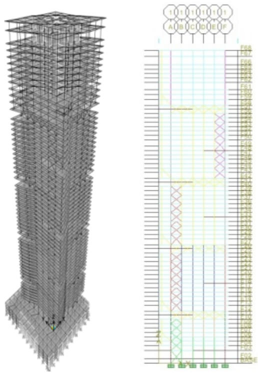

Fig.4: Three-Dimensional and Elevation Model

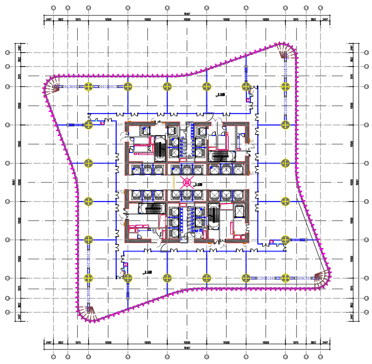

Fig.5: Plan View of Standard Story

As shown in Fig.6 and 7, belt truss frame core-wall structural system is applied a high-rise building with 300-meter and 68 floors. According to Chinese standard, the design characteristic period is 0.55s and the fortification intensity is 7 degree. The basic acceleration is 0.15g and Site class is III. The frame beams are made by sectional steel while the columns in the case are designed as SRC columns. The structure comprises of column braces on 1-58th floor and belt-trusses on the 11-12, 26-27, 41-42, and 57-58th floor. The damping ratio in the frequent earthquake is set to 4% and 5% for the moderate and rare earthquake.

Four parameters combinations provided by manufacturer were optimized in this paper and combinations are presented in table 1.

Table1: Four parameters combinations

Tonnage（t）	Parameters Combinations		Cost（10^4 yuan）
	C	*a*	
100	2348	0.45	6
150	3522	0.45	8
200	4000	0.45	11
300	5871	0.45	20

The first step for the parameters optimization of viscous damping wall is to gain the relationship between the optimized cost savings and additional damping ratio and the relation curve by the integrated optimal structural design. The result of four integrated optimization for original structure is presented in table 2 and the curve fitting of the results is depicted in Fig 6.

That optimized cost savings in table 2 is negative means this value is decreased cost relative to the original structure cost.

Table2: Results of Integrated Optimization for Original Structure

Additional Damping Ratio	Optimized Cost Savings
1.40%	-1307.41
4.20%	-2605.6
7.00%	-3648.67
11%	-4317.12

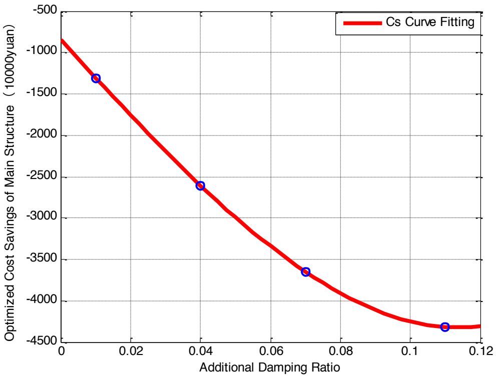

Fig.6: Relationship between the Optimized Cost Savings and Additional Damping Ratio

The second step is to get the relationship between the viscous damping wall cost and additional damping ratio and the relation curve by time-history analysis method with different parameter combinations. The additional damping ratio of structure with 66, 198, 264 and 396 viscous damping walls is respectively calculated as presented in table 3 and curve fitting of the data namely relation curve for the viscous damping wall cost and additional damping ratio is depicted in Fig 7.

Table3 Additional Damping Ratio

Additional Damping Ratio / Number		66	198	264	396
C=2348	Moderate Earthquake	1.63%	3.68%	5.62%	6.10%
	Frequent Earthquakes	2.69%	6.32%	9.42%	10.34%
C=3522	Moderate Earthquake	2.48%	5.72%	8.60%	9.38%
	Frequent Earthquakes	4.20%	9.58%	14.46%	15.94%
C=4000	Moderate Earthquake	2.85%	6.56%	9.72%	10.56%
	Frequent Earthquakes	4.82%	10.88%	16.66%	18.26%
C=5871	Moderate Earthquake	4.27%	9.68%	14.37%	15.71%
	Frequent Earthquakes	7.35%	16.51%	21.00%	21.74%

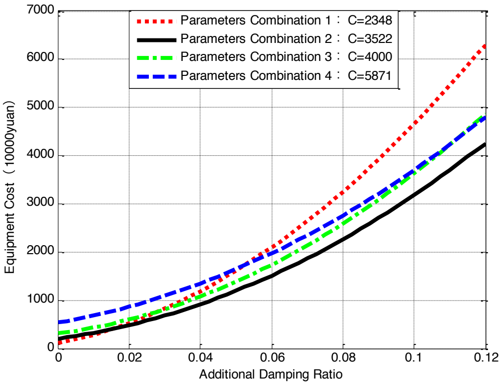

Fig.7: Relationship between Viscous Damping Wall Cost and Additional Damping Ratio

The third step is to get overall cost of integrated optimal structure with different parameter combinations, and the total cost curve will be plotted by adding the first two fitting curve together as depicted in Fig 8.

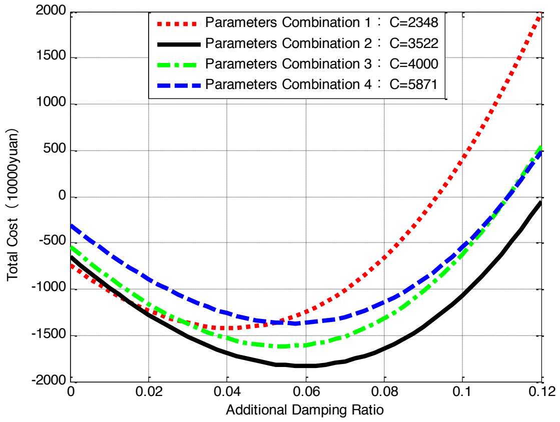

Fig.8: Total cost Curve under Four Parameter Combinations

The fourth step is to compare the overall cost of integrated optimal structure with different parameter combinations to get minimum cost and corresponding optimal parameters of viscous damping wall, optimal additional damping ratio for the structure and optimal number of viscous damping wall. The minimum value of the curve with four parameter combinations is calculated as presented in table4.

Table4: Minimum Value for the Curve under Four Parameter Combinations

Parameter C（a=0.45）	2348	3522	4000	5871
Single Equipment Cost （10000yuan）	6	8	11	20
Additional Damping Ratio	4.09%	5.91%	5.44%	5.70%
Minimum Total Cost（10000yuan）	-1420.5	-1830.4	-1617.1	-1368.6
Optimal Number	204	186	140	94

As presented in table4, when the damping coefficient c=3522 and velocity exponent a=0.45, the overall cost is minimal and corresponding optimal additional damping ratio for the structure is 5.91% and optimal number of viscous damping is 186.

4. Conclusion

Search the optimal parameter method based on the integrated optimal structural design for tall buildings with viscous damping walls was proposed for parameter optimization to minimize the structure overall cost with the optimization variable of parameters provided by the manufacturer, and the optimal parameters of viscous damping wall and corresponding optimal additional damping ratio for the structure and optimal number of viscous damping walls will be derived.

Main conclusions are as follows:

(1)There are different overall costs with different parameter combinations and minimum overall cost corresponds to optimal parameters of viscous damping wall and the corresponding optimal additional damping ratio and optimal number of optimal damping wall. when the damping coefficient c=3522 and velocity exponent a=0.45, the overall cost is minimal and corresponding optimal additional damping ratio for the structure is 5.91% and optimal number of viscous damping is 186 in the case study.

(2) Results show that the optimal parameters corresponding to the minimum total cost is not the biggest, and parameter or additional damping ratio is not the higher the better. Economy and effect should be taken into comprehensive consideration and parameter optimization can take a maximum of the economic effect viscous damping wall should have.

(3)Parameter optimization with integrated optimal structure can both ensure the additional damping ratio and reduce the overall cost of integrated optimal structure. This is especially important for popularizing the use of viscous damping wall.

(4) Parameter combinations provided by manufacturers are taken as optimization variables and the method proposed in this paper has high maneuverability which is practical and can promote the popularization and application of viscous damping wall.

5. Acknowledgements

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6. References

[1] Miyazaki, M., Arima, F., Kidata, Y., Hristov, I. Earthquake Response Control Design of Buildings Using Viscous Damping Walls. *Proceedings of First East Asia Pacific Conference, Bangkok*,1986. 1882~1891

[2] Arima, F., Miyazaki, M., Tanaka, H., ect. A Study on Buildings with Large Damping Using Viscous Damping Walls. *9th World Conference on Earthquake Engineering*. Tokyo-Kyoto:1988. 821-826

[3] M. Miyazaki, Y. Mitsusaka, Design of a building with 20% or greater damping, Proc. *10th World Conf. on Earthquake Engineering*, Madrid, 1992, pp. 4143~4148

[4] Fei, C., Weiqing, L., Shuguang, W., ect. The research of Energy dissipation design of Jin Bainian square with viscous damping walls. *Building Science*, 2008，24(9):56-59.

[5] Zhengcang Z., ect. Kagoshima airport terminal building a seismic reinforcement- three-dimensional elastoplastic analysis of structure adding viscous damping walls. *Building Structures*, 2000,(6) 20-23.

[6] Dongsheng D., Shuguang W., Weiqing, L. etc. Research and application of fluid viscous damping wall in high-rise structure [J]. *Journal of Building Structures*, 2010,31(9): 87-94

[7] Xi, Z., Xin, Z., and Yimin, Z. Optimal number of viscous damping walls for the seismic design of tall buildings [J]. *Building Structures*, 2014, 44(S2): 384-388.