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Study on Influence of the Vibration Reduction effect of Viscous Dampers Considering Soil-Structure Dynamic Interaction

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ABSTRACT. Based on the rigid ground assumption, the model of frame structure and the structure with viscous dampers were established. By contrasting the structural dynamic responses, the performance of viscous dampers was analyzed. Two corresponding models were built up as soil-structure dynamic interaction was taken into consideration and the performance of the viscous dampers in this condition was analyzed as well. The results showed that soil-structure interaction (SSI) could reduce the effect of viscous dampers and it is necessary to consider SSI in the design of energy dissipation devices such as viscous dampers.

KEYWORDS: *soil-structure interaction, frame structure, energy dissipation, linear viscous damper, damping effect*

1. INTRODUCTION

The study of Soil Structure Interaction (SSI) could go back to the year of 1904, when Lamb analyzed the vibration problem of elastic foundation. The work on the SSI has almost experienced the following stages: The basic theory in 1950s to 1960s is the preparation stage (e.g. Amold et al. 1955). The study on analysis method of SSI is in the mid-1960s to the mid-1980s (e.g. Chopra et al. 1969, Iguehi et al. 1981). A further study has been concentrated on SSI since mid-1980s (e.g. Karabalis et al. 1986, Ahmad et al. 1988, Wolf et al. 1994, Dionisio et al. 1998, Lu et al. 2005, Eduardo 2010, Hooman Torabi et al. 2014, Pierfrancesco et al. 2015, Trombetta et al. 2015). Passive control has several advantages: simple structure, lower cost, easier maintenance and so on. Passive control includes three styles: base isolation, shock absorption and energy dissipation. Energy dissipation has wider applications and adapted to new buildings and existing buildings. Viscous damper is a kind of damper that has no stiffness and is related to velocity.

This study built up finite element model of frame structure on soft soil ground using ANSYS program. Dynamic response of structure with and without viscous dampers was analyzed under the two cases of rigid foundation and considering SSI. The influence of SSI on the damping effect of viscous dampers was obtained.

2. GENERAL SITUATION

A 10-story building is cast-in-place reinforced concrete frame structure. The plane layout of standard floor and pile foundation are shown in Fig. 2.1 and Fig. 2.2. The floor height is 3.6m. The section size of the column is 550mm×550mm and the beam is 300mm×500mm. The thickness of floor slab is 120mm. The dead load of standard floor is 5.0kN/m^2, including floor slab self-weight and the live load is 2.0kN/m^2. The raft thickness of the piled raft foundation is 1000mm. The elevation of the top of the raft is ±0.00. The superstructure and foundation use C35 concrete. The site soil is Shanghai soft soil. The site belongs to Ⅳ class. The intensity of earthquake resistance of buildings is 8. The designed basic earthquake acceleration is 0.2g.

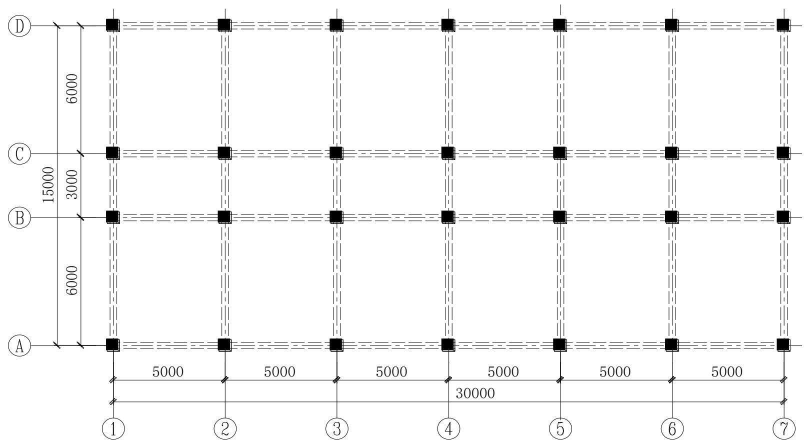


Figure 2.1 The floor plan of standard floor

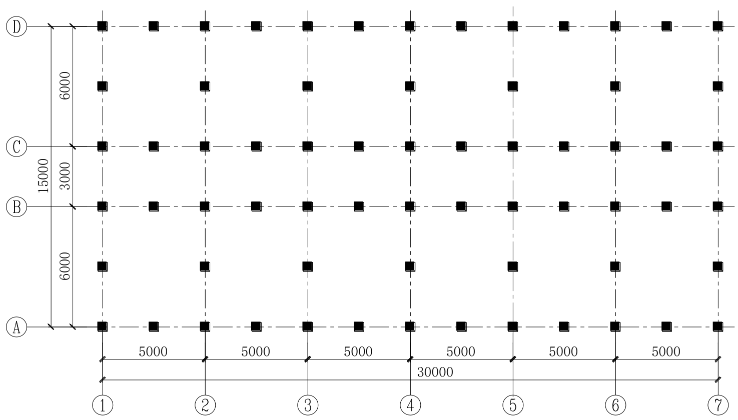


Figure 2.2 The layout of pile foundation

The input seismic waves are SHW1 wave and SHW2 wave, which have 65s and 30s wave length respectively. The time interval of the discrete acceleration of the two waves is 0.02s. Fig. 2.3 and Fig. 2.4 are acceleration time-history curves and their Fourier's spectrum. According to the principal of seismic wave shorting, SHW1 wave and SHW2 wave are shorten to 36s and 30s respectively in the analysis.

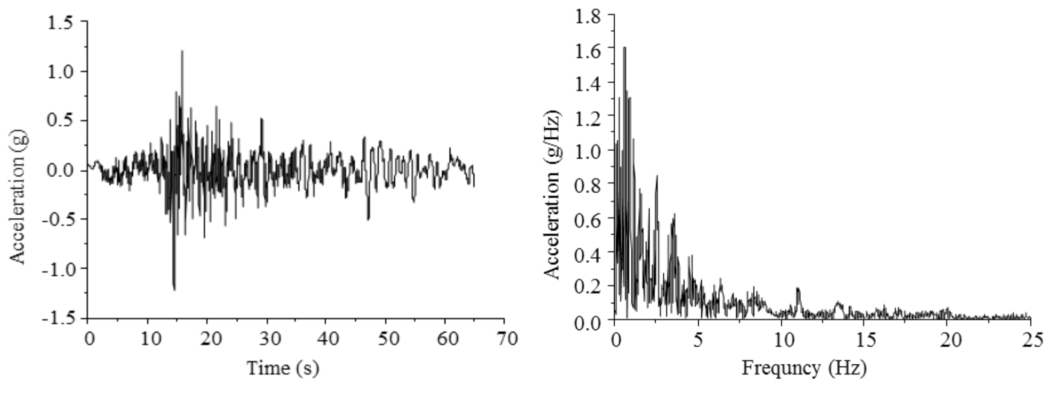


Figure 2.3 Acceleration time-history and corresponding Fourier spectra of SHW1 wave

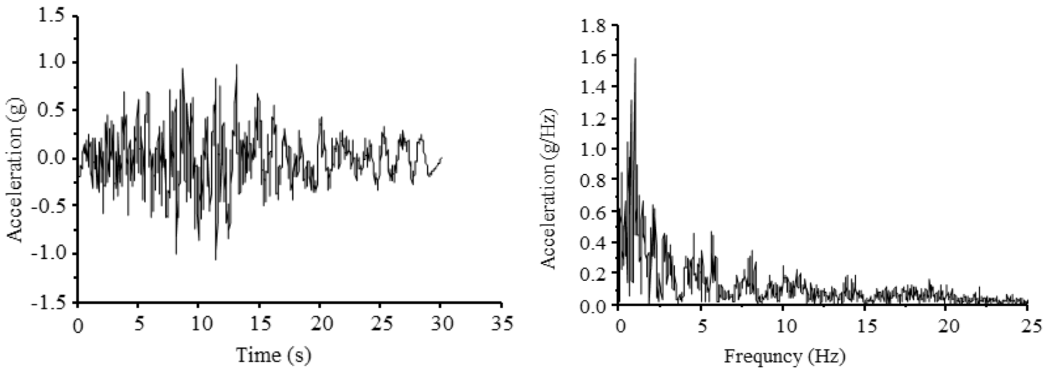


Figure 2.4 Acceleration time-history and corresponding Fourier spectra of SHW2 wave

Equivalent linearization model is adopted as soil constitutive models. Soil skeleton curve of Davidenkov model is used in the soil-structure interaction system.

Three models that the soil longitudinal size is 5 times of the structure longitudinal size and the boundary is free are built up. The model that the soil lateral size is 20 times of the structure lateral size and the boundary is viscoelastic can well simulate the infinite field of half space by comparing and analyzing. So the model is adopted in this paper.

Four same viscous dampers which the damping coefficient is $3.65\times10^{6}\ N \cdot s / m$ are set up in each story. The layout of the dampers in the floor plan is showed in Fig. 2.5. In the elevation, the dampers are set up in each story and adopted braced style.

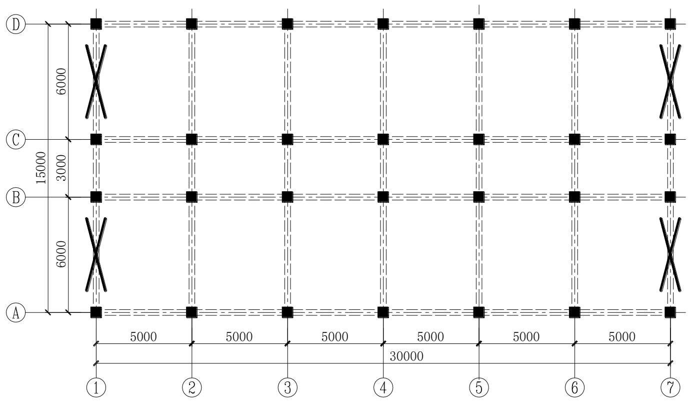


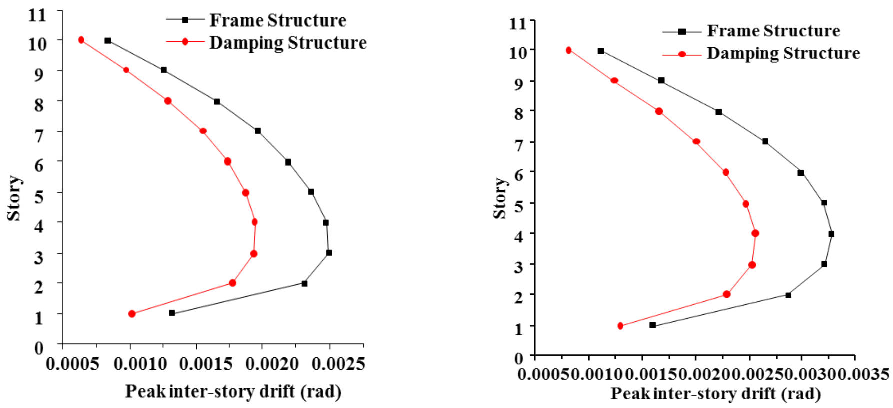
Figure 2.5 The floor plan of viscous damper
Note: “X” expresses viscous damper in the span

3. Damping Effect of Viscous Damper Under the Assumption of Rigid Foundation

3.1. Inter-story Drift of Structure

As shown in Fig. 3.1, the damping rate of peak inter-story drift increases first then decreases with the rise of floor under the SHW1 wave, while increases gradually under the SHW2 wave. This indicates that the inter-story drift varying with floor is related to the selected seismic waves.

Seen from Tab. 3.1, the mean damping rate of peak inter-story drifts are 22.73% and 23.09% respectively under the two waves. Although viscous dampers play a better role in damping effect, the inter-story drifts still fail to meet the standardized requirements 1/550 after setting the dampers. That is because the inter-story drifts of original frame structure are big.



(a) SHW1 wave (b) SHW2 wave

Figure 3.1 Peak curves of inter-story drift

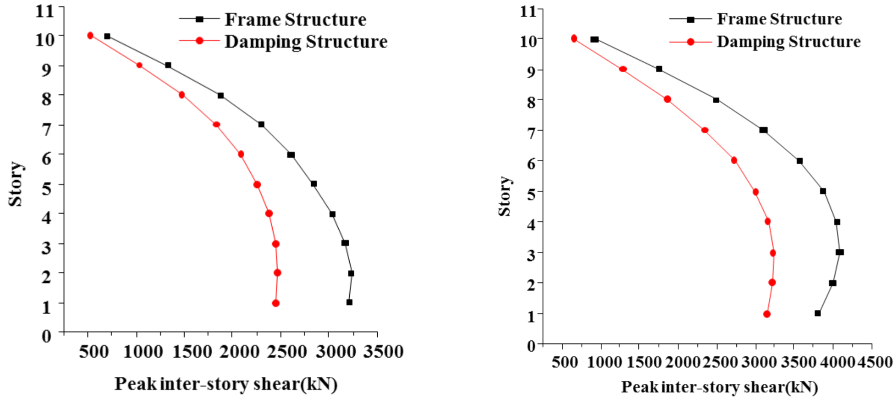
Table 3.1 Peak value of inter-story drift and damping rate (Unite: rad)

Story	SHW1 Wave			SHW2 Wave		
	Frame Structure	Damping System	Damping Rate（%）	Frame Structure	Damping System	Damping Rate（%）
1	1/755	1/986	21.81	1/626	1/774	19.38
2	1/433	1/564	22.58	1/349	1/437	19.93
3	1/401	1/516	23.25	1/312	1/396	20.94
4	1/404	1/515	24.09	1/305	1/391	21.95
5	1/423	1/535	24.19	1/313	1/405	22.81
6	1/457	1/576	23.70	1/335	1/438	23.75
7	1/508	1/644	22.82	1/377	1/498	24.15
8	1/605	1/776	21.95	1/452	1/605	25.34
9	1/795	1/1029	21.35	1/598	1/809	25.75
10	1/1200	1/1572	21.58	1/902	1/1233	26.93

3.2. Inter-story Shear of Structure

The peak inter-story shear of each floor is calculated according to the shear at each column base of frame structure.

As shown in Fig. 3.2, the damping rate of peak inter-story shear decreases first then increases with the rise of floor under the SHW1 wave, while increases gradually under the SHW2 wave. It is because the viscous dampers do not change the stiffness of structure that the seismic forces acting on the structure will not be changed. So the damping effects of inter-story shear depend on the ratio of the horizontal component of damping force and the total inter-layer shear.



(a) SHW1 wave (b) SHW2 wave

Figure 3.2 Peak curves of inter-story shear

Table 3.2 Peak value of inter-story shear and damping rate (Unite: kN）

Story	SHW1 Wave			SHW2 Wave		
	Frame Structure	Damping System	Damping Rate（%）	Frame Structure	Damping System	Damping Rate（%）
1	3212.88	2452.36	23.67	3807.33	3156.45	17.10
2	3234.23	2468.36	23.68	4001.12	3213.14	19.69
3	3171.09	2449.50	22.76	4090.60	3230.59	21.02
4	3035.63	2384.28	21.46	4053.96	3163.33	21.97
5	2841.26	2255.18	20.63	3882.25	2997.13	22.80
6	2606.64	2087.98	19.90	3567.13	2724.46	23.62
7	2304.58	1828.59	20.65	3103.36	2342.34	24.52
8	1875.23	1473.51	21.42	2499.79	1859.38	25.62
9	1331.63	1034.31	22.33	1760.27	1289.60	26.74
10	696.75	524.08	24.78	916.21	650.60	28.99

Seen from Tab. 3.2, the mean damping rate of peak inter-story drifts are 22.13% and 23.21% respectively under the two waves. There appears to be little difference between the two values. As dampers could not change the stiffness of structure, the seismic force acting on the structure could not vary regardless of dampers.

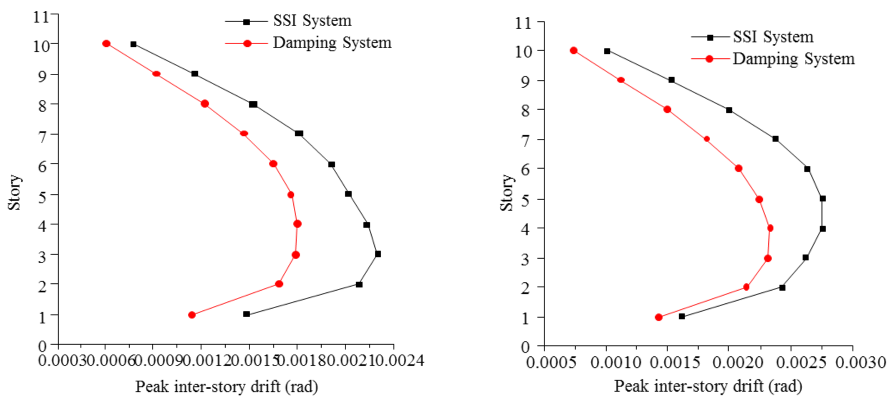
4. Damping Effect Analysis of Viscous Dampers Considering SSI Effects

4.1. Inter-story Drift of Structure

Inter-story drift of structure is not entirely caused by the elastic deformation of the vertical members after considering SSI effect, which is similar to floor displacement. The whole swing of structure can produce the jump of displacements between the floors, but in general, it is not the inter-story drift of structure. The displacement caused by structural deformation of vertical members is called “stress inter-story displacement” and the rest are “non-stress story displacement”.

Seen from Fig. 4.1, the peak inter-story drift of structure is still bigger in the middle floors considering SSI effect. The maximum inter-story drift is in the third and fourth layers respectively under the two waves. Moreover, the peak inter-story drift of SHW2 wave is bigger than that of SHW1 wave, which is consistent with the results under the assumption of rigid foundation.

It can be seen from Tab. 4.1 that the damping rate of peak inter-story drift decreases first and increases later with the rise of floor under SHW1 wave and increases gradually under SHW2 wave. The mean damping rate is 20.38% and 19.17% respectively of the two waves. The damping rate of the lower part of the floor is small and the upper part of the floor increases obviously.



(a) SHW1 wave (b) SHW2 wave

Figure 4.1 Peak curves of inter-story drift

Table 4.1 Peak value of inter-story drift and damping rate (Unite: rad)

Story	SHW1 Wave			SHW2 Wave		
	SSI System	Damping System	Damping Rate（%）	SSI System	Damping System	Damping Rate（%）
1	1/675	1/878	23.08	1/621	1/699	11.21
2	1/458	1/594	22.90	1/413	1/468	11.70
3	1/435	1/561	22.37	1/381	1/432	11.76
4	1/448	1/556	19.43	1/363	1/430	15.44
5	1/472	1/569	16.93	1/365	1/446	18.65
6	1/498	1/607	17.98	1/380	1/483	21.31
7	1/553	1/683	19.05	1/421	1/550	23.39
8	1/658	1/822	19.93	1/500	1/667	25.00
9	1/863	1/1091	20.86	1/655	1/889	26.36
10	1/1300	1/1651	21.30	1/986	1/1348	26.85

Table 4.2 Comparison with inter-story drift and damping rate before and after considering SSI effect

Structure/System	SHW1 Wave		SHW2 Wave	
	Peak Inter-story Drift	Mean Damping Rate	Peak Inter-story Drift	Mean Damping Rate
Frame Structure (rigid foundation)	1/401	—	1/305	—
Damping Structure (rigid foundation)	1/515	22.73%	1/391	23.09%
SSI System	1/435	—	1/363	—
Damping System (considering SSI)	1/556	20.38%	1/430	19.17%

Some main points can be summed up from Tab. 4.2:

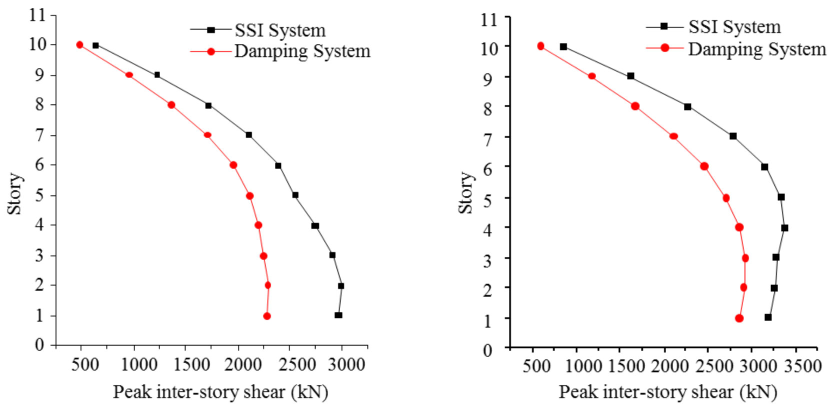
(1) The distribution of inter-story drift does not change but the value of inter-story drift changes when considering SSI effect. The shapes of the distribution of inter-story drift varying with the floor do not change basically whether considering SSI effect or not. Where the floor the maximum inter-story drifts does not change as well. Inter-story drift of structure without dampers decreases to some extent considering SSI effect under both waves.

(2) Although the damping rate of inter-story drift decreases considering SSI effect, the inter-story drift of SSI vibration-reducing system is still smaller than the corresponding value of rigid foundation vibration-reducing system.

4.2. Inter-story Shear of Structure

The peak inter-story shear of structure decreases with the rise of the floor, which can be seen from Fig. 4.2, the curve of inter-story shear is unsmoothed at the bottom of the floor in the case of unsetting viscous dampers, while the curve becomes smooth in the case of setting viscous dampers.

Seen from the Tab.4.3, the damping rate of peak inter-story shear decreases first and increases later with the rise of the floor under the SHW1 wave, while the rate increases gradually under the SHW2 wave. The mean damping rate is 20.99% and 19.71% respectively under the two waves. There is little difference between the two values but big difference between the damping rates of each floor. This is related to the trend that damping rate vary with the floor.



(a) SHW1 wave (b) SHW2 wave

Figure 4.2 Peak curves of inter-story shear

Table 4.3 Peak value of inter-story shear and damping rate (Unite: kN）

Story	SHW1 Wave			SHW2 Wave		
	SSI System	Damping System	Damping Rate（%）	SSI System	Damping System	Damping Rate（%）
1	2973.81	2288.74	23.04	3182.26	2850.30	10.43
2	2998.12	2294.26	23.48	3264.71	2905.41	11.01
3	2918.03	2249.60	22.91	3282.89	2920.36	11.04
4	2742.36	2202.27	19.69	3371.67	2858.91	15.21
5	2553.31	2121.90	16.90	3335.25	2705.42	18.88
6	2392.46	1958.30	18.15	3141.36	2455.94	21.82
7	2112.88	1707.73	19.18	2788.92	2106.66	24.46
8	1721.98	1370.31	20.42	2274.04	1675.72	26.31
9	1224.78	959.34	21.67	1621.68	1174.30	27.59
10	642.20	484.99	24.48	852.01	593.32	30.36

The results of the inter-story shear in this section are compared with that under rigid condition. Several conclusions can be drawn:

(1) The value of inter-story shear changes considering SSI effect. To the structure without viscous damper, the peak base inter-story shear is 3212.88kN and 3807.33kN respectively under the two waves without considering SSI effect, while the shear is 2973.81kN and 3182.26kN respectively under the two waves considering SSI effect. It can be seen that the shear decreases. Furthermore, to the structure with viscous damper, the peak base inter-story shear also decreases to some extent influenced by the SSI effect.

(2) The damping rate of inter-story shear has changed considering SSI effect. The mean damping rate of inter-story shear is reduced from 22.13% to 20.99% under SHW1 wave. Although the mean damping rate of inter-story shear decreases considering SSI effect, the peak inter-story shear of SSI vibration-reducing system is smaller than that of rigid foundation vibration-reducing system. The damping effect of SSI effect compensates for the reducing effect of viscous dampers.

(3) The range of variation of damping rate is larger, which indicates that SSI effect has made damping rate of each floor uneven.

5. CONCLUSIONS

The models of a frame structure and the models of structure with viscous dampers with the assumption of rigid foundation and considering SSI effect were established by ANSYS program. Some conclusions can be gotten by analyzing floor displacements, inter-story shift, inter-story shear and the damping force:

(1) As SSI effect could change the frequency and damping ratio, the seismic response is reduced to different degree considering SSI effect, which has damping effect in a sense.

(2) The mean damping rates of inter-story shift and inter-story shear are lower considering SSI effect. And the decreasing degree is related to seismic excitation.

(3) The seismic response of vibration-reducing system considering SSI effect is lower than that of rigid foundation system. So it indicates that vibration-reducing effect of SSI makes up the decreasing vibration-reducing effect of viscous dampers. It is conservative to the design of structure and viscous dampers.

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