Response Spectrum Analysis of the Floorslab Isolating and Energy Dissipating Structural System

Qiaoling Xian, Fulin Zhou & Yaojian Long

Earthquake Egineering Research & Test Center, Guangzhou University, China

Email: xql@gzhu.edu.cn

SUMMARY:

The Floorslab Isolating and Energy Dissipating ('FIED' in brief) structural system is a new anti-seismic structural system for buildings. In this paper, to further investigate the damping effects of the FIED structural system, response spectrum analyses are carried out to the FIED structure as well as the traditional structure. By comparing the response spectra of the two structures, it is found that the stiffness and damping ratio of the isolation layer will affect the seismic reduction effect of the FIED structure. Smaller stiffness and larger damping ratio for the isolation layer will result in significant seismic reduction to the FIED structure. Besides, damping effect of the FIED structural system is remarkable when the natural period of the main structure T_1 is less than 3.0 second, and it becomes worse when T_1 is larger than 3.0 second.

Keywords: Floorslab, Isolation, Energy dissipation

1. INTRODUCTION

The Floorslab Isolating and Energy Dissipating ('FIED' in brief) structural system is shown in Figure 1.1. In the FIED system, the floorslabs are isolated to the beams with high damping materials, and gaps must be left between the floorslabs and the columns or walls. By this way, the vertical load transmitting route of this structural system is the same as that of the traditional structural system. However, when the building shakes in earthquake, the floorslab will move relatively to the main structure, and the high damping materials under the floorslab and inside the gaps can play the role of seismic isolation and energy dissipation to reduce the seismic reaction of the building. The FIED structural system has been proved to be effective in damping the seismic response of the building structure by some tests and analyses (Qiaoling Xian, et al, 2007,2008). In this paper, to further investigate the damping effects of the FIED structural system, response spectrum analyses are carried out to the FIED structure as well as the traditional structure.

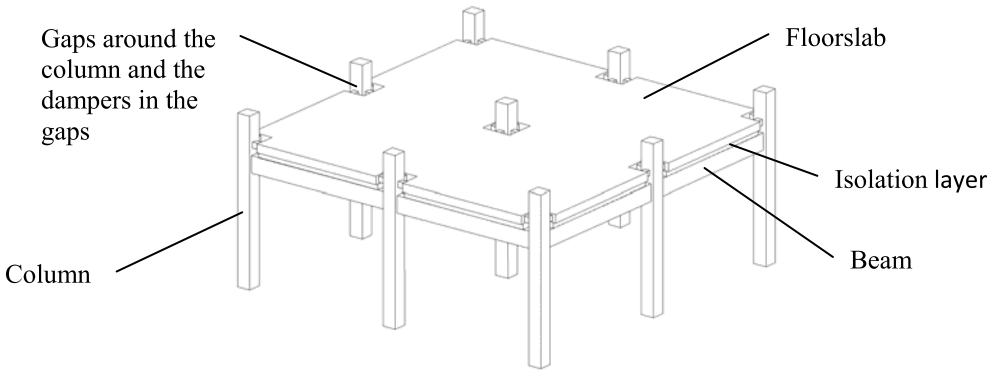
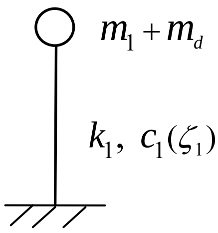


Figure 1.1 Schematic diagram of the FIED structural system

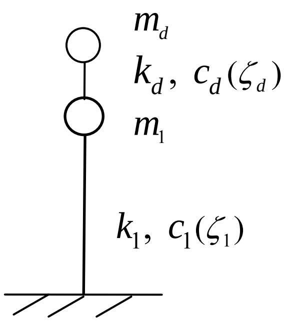
The response spectrum analyses are conducted by comparing the response spectra plots of the FIED structure to those of the traditional structure under the same earthquake excitation. A response spectrum plot of a SDF structure is obtained by picking the peak values of the response in a series of time history analysis when the natural period of the structure took different values.

2. ANALYTICAL MODELS

In order to compare the response spectrums of the traditional structure and the FIED structure, the analysis models are taken as in Figure 2.1.



(a) The Traditional Structure System



(b) The FIED Structure System

Figure 2.1 Calculation Models of the Two Structures

In Figure 2.1, m_1, k_1 and c_1 are the mass, stiffness and damping coefficient of the main structure (e.g. frame) respectively. m_d is the mass of the floor. k_d and c_d are the stiffness and damping coefficient of the isolation layer respectively. For the traditional structure shown as Figure 2.1(a), the differential equation under the earthquake excitation is:

$$(m_1+m_d)\ddot{x}+c_1\dot{x}+k_1x=-m\ddot{x}_g \tag{2.1}$$

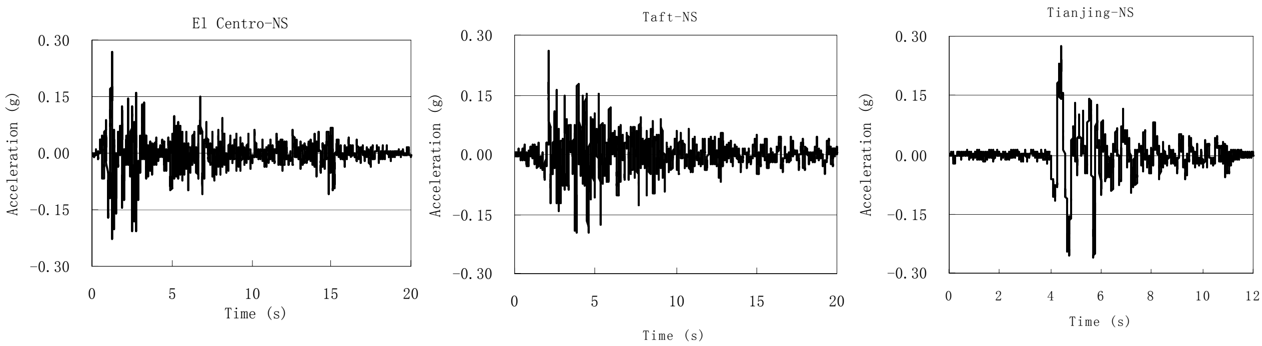
where x is the absolute displacement of the mass m_1+m_d, and $\ddot{x}_g$ is the ground acceleration. The differential equation of the FIED structure shown as Figure 2.1(b) is:

$$\begin{cases} m_1\ddot{x}_1+(c_1+c_d)\dot{x}_1+(k_1+k_d)x_1-c_d\dot{x}_d-k_dx_d=-m_1\ddot{x}_g \\ m_d\ddot{x}_d+c_d(\dot{x}_d-\dot{x}_1)+k_d(x_d-x_1)=-m_d\ddot{x}_g \end{cases} \tag{2.2}$$

in which x_1 is the absolute displacement of the mass m_1, and x_d is the absolute displacement of the mass m_d. Integrating the Eqn. 2.1 and 2.2 by numerical time-stepping method can give the seismic responses of the traditional structure and the FIED structure.

3. STRUCTURE PARAMETERS FOR THE SPECTRUM CALCULATION

The time history analysis programs have been coded in the Matlab platform for the traditional structure and the FIED structure in Figure 2.1. Large amount of time history analyses have been done to obtain the spectra of the two structures. The structure parameters are taken the same as those of the single storey frame model used for the shaking table test (Qiaoling Xian, et al, 2008). The mass of the main structure (i.e. frame) is $m_1=200kg$, and the mass of the floorslab (including the load of the floor) is $m_d = 1800kg$. The damp ratio of the main structure is $\zeta_1 = 2\%$. To calculate the spectra, consider the natural period of the main structure T_1 vary from 0.08 s to 5.0 s with an increment of 0.02 s. The stiffness of the main structure k_1 can be taken by $k_1 = 4\pi^2 m_1 / T_1^2$. The stiffness of the isolation layer under the floorslab k_d is taken as $0.01k_1$, $0.05k_1$, $0.1k_1$, $0.3k_1$ and $0.5\,k_1$ respectively. And the damping ratio of the isolation layer ζ_d is taken 2%, 4%, 6%, 8%, 10% respectively. Three typical real earthquake records: El Centro-NS, Taft-NS and Tianjing-NS are used as the input excitations to do the spectrum calculations. The acceleration time history curves of these records are shown in Figure 2.2.



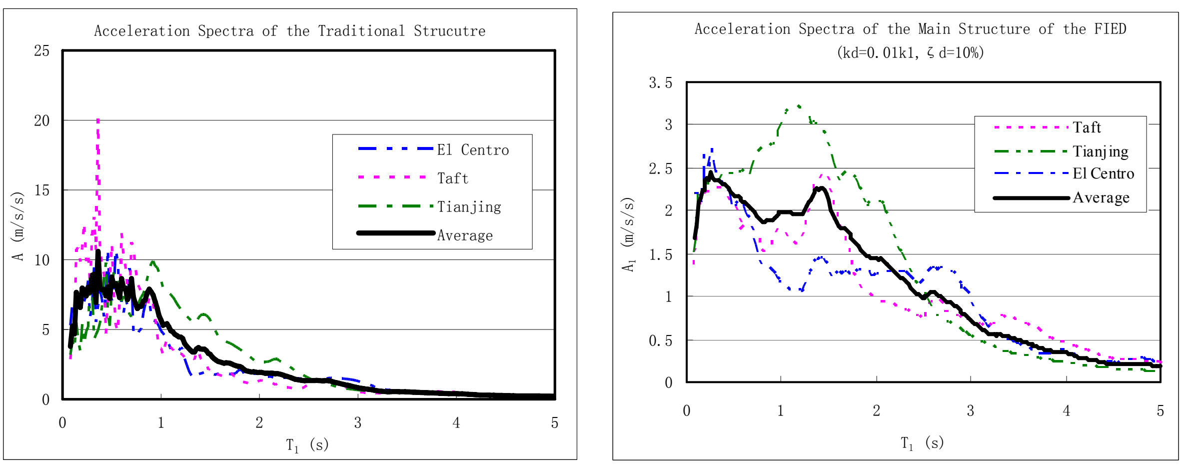
(a) El Centro-NS wave (b) Taft-NS wave (c) Tianjing-NS wave

Figure 2.2 Records utilized in the analyses

4. RESPONSE SPECTRUM ANALYSIS OF THE TWO STRUCTURAL SYSTEMS

The primary response spectra of the traditional structure under the three earthquake excitations, compared with those of the FIED structure when k_d takes $0.01\,k_1$ and ζ_d takes 10%, are shown in Figure 4.1. Because the response spectra vary greatly with the input earthquake excitations, for each case, the average response spectrum is calculated by the response spectra under the three earthquake inputs. Figure 4.1 gives the general impression that the peak values and most parts of the response spectra of the FIED structure are all smaller than those of the traditional structure.

In order to find the influence of the stiffness and damping ratio of the isolation layer to the response spectra of the FIED structure, five different values of the stiffness k_d as well as five different values of the damping ratio ζ_d have been considered respectively as stated before.



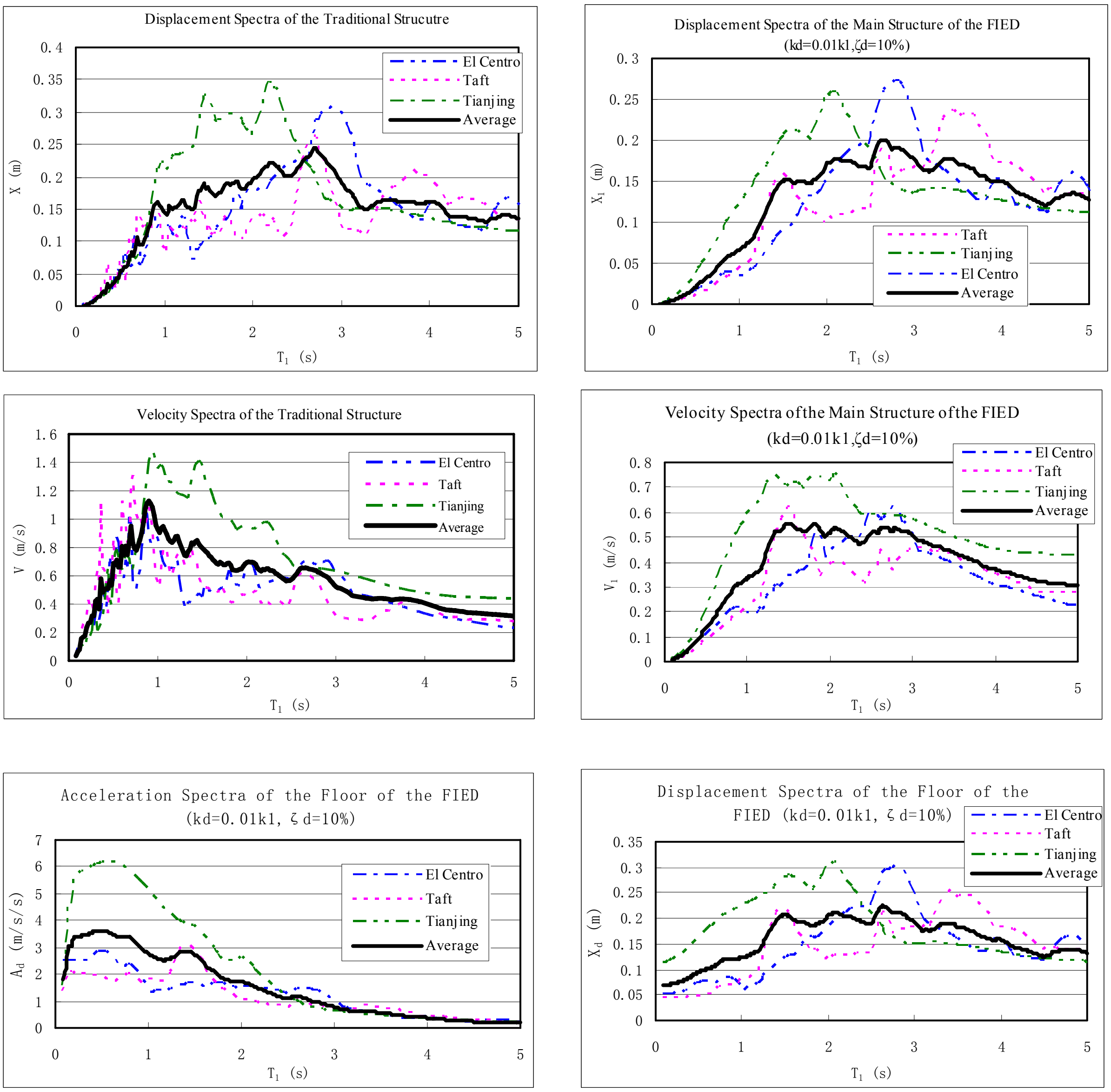


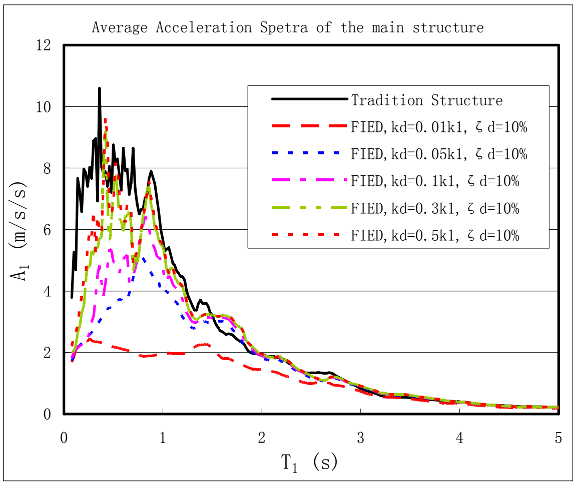
Figure 4.1 Response spectra of the traditional structure and the FIED structure when k_d=0.01k_1, ζ_d=10%

4.1 Influence of the stiffness of the isolation layer

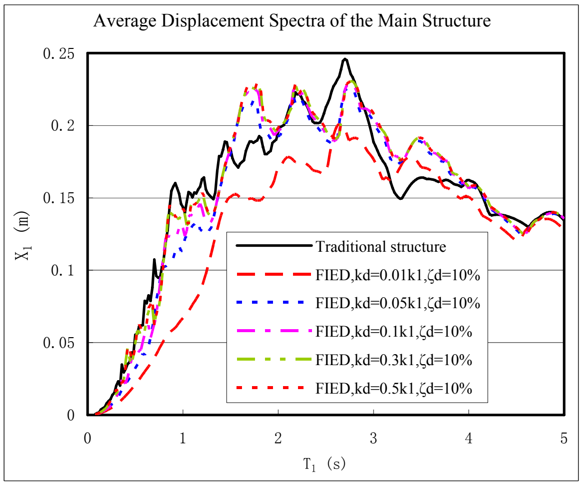
For the convenience of comparing the response spectra of the two structures, the average response spectrum curves of the FIED structure taking different values of k_d are plotted with the average response spectrum curve of the traditional structure. Figure 4.2 shows the average response spectra of the FIED structure when taking ζ_d equal to 10% and k_d equal to $0.01k_1$, $0.05k_1$, $0.1k_1$, $0.3k_1$ and $0.5k_1$ respectively. From Figure 4.2, it can be found that the seismic damping effect of the FIED structure reaches to the best when k_d takes to $0.01k_1$, and it becomes worse as k_d increases.

For the FIED structure with k_d=$0.01k_1$ and ζ_d=10%, Figure 4.2(a) to (d) show that the average acceleration, displacement and velocity spectrum of the main structure are all smaller than those of the traditional structure in the region of $T_1 \leqslant 3.0$ second, but are approximately the same in the region of 3.0 s$\leqslant T_1 \leqslant$5.0 s. The maximum reduction rate of the acceleration, displacement and velocity of the main structure reach to 77.9%, 62.5% and 72.3% respectively. The maximum reduction rate of the acceleration of the floor is 67%. In Figure 4.2(e), it is found that the average displacement spectrum of the floor is larger than that of the traditional structure in the region of $T_1 \leqslant 0.8$ second, but is approximately the same in the region of 0.8 s$\leqslant T_1 \leqslant$5.0 s. As for the average velocity spectrum of the floor, Figure 4.2(f) shows that the average velocity spectrum of the floor is larger than that of the traditional structure in the region of $T_1 \leqslant 0.5$ second, is smaller in the region of 0.5 s$\leqslant T_1 \leqslant$1.7 s, and is approximately the same in the region of 1.7 s$\leqslant T_1 \leqslant$5.0 s. Therefore when k_d =0.01 k_1 and ζ_d =10%, the damping effect of the FIED structure is significantly in the region of $T_1 \leqslant 3.0$ second.

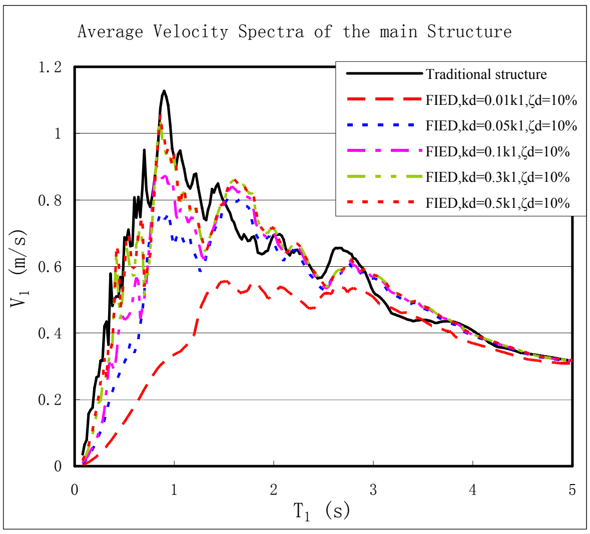
It can be found from Figure 4.2 (a) to (f) that the average response spectra of the FIED structure become larger with the increasing of k_d, especially when k_d >0.1 k_1. For the FIED structure with k_d =0.05 k_1 and 0.1 k_1, the average acceleration, displacement and velocity spectrum of the main structure, as well as the average acceleration of the floor, are all smaller than those of the traditional structure in the region of $T_1 \leqslant 1.5$ second, but are larger or smaller in the region of 1.5 s$\leqslant T_1 \leqslant$5.0 s. For the FIED structure with k_d =0.3 k_1 and 0.5 k_1, the average response spectra are vary around those of the traditional structure, which means the damping effect of the FIED structure is not good.



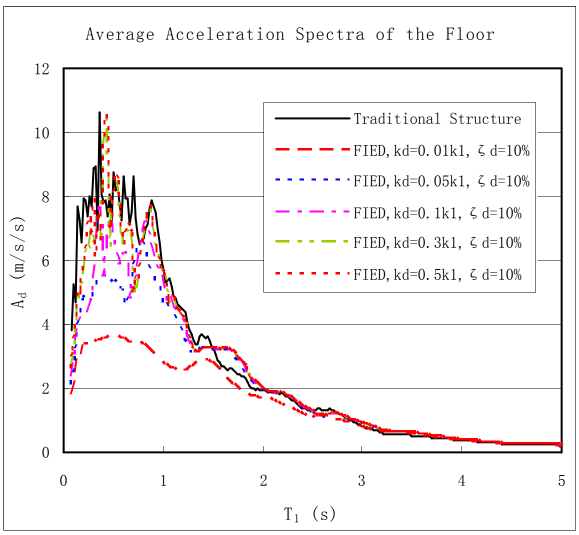
(a) Average acceleration spectra of the main structure



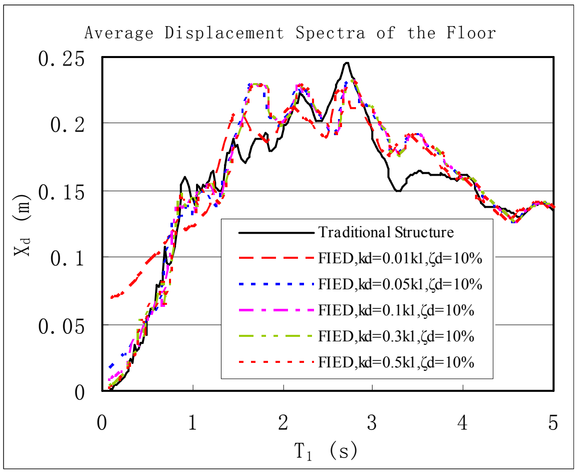
(b) Average displacement spectra of the main structure



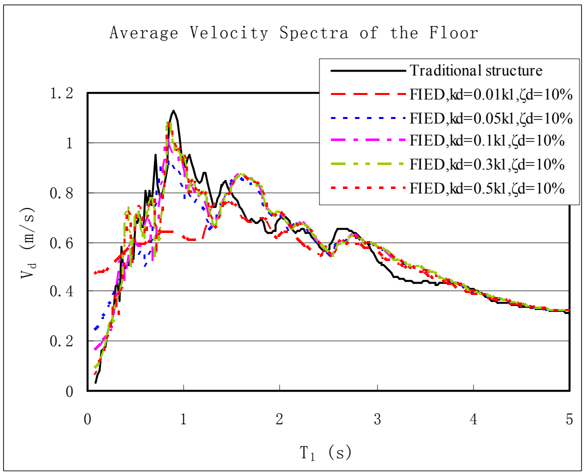
(c) Average velocity spectra of the main structure



(d) Average acceleration spectra of the floor



(e) Average displacement spectra of the floor

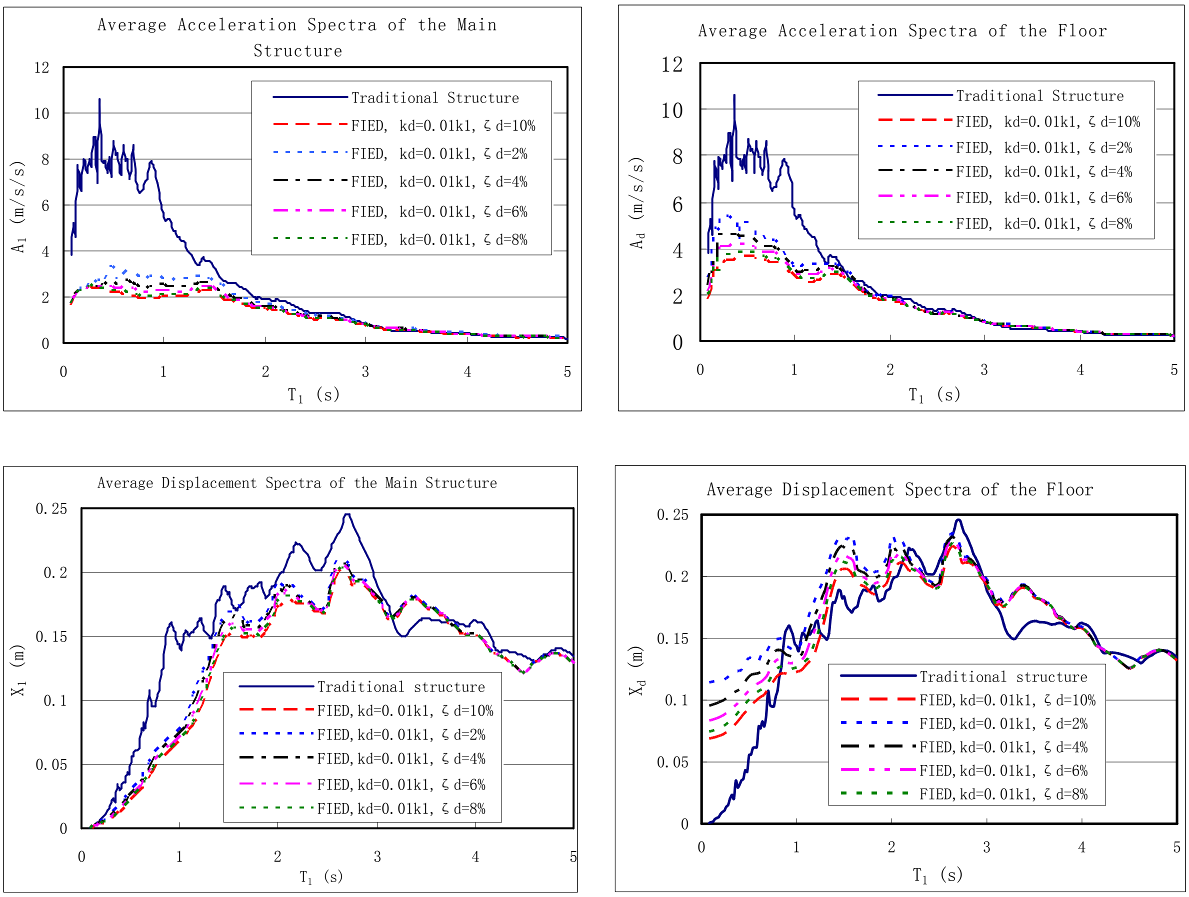


(f) Average velocity spectra of the floor

Figure 4.2 Average response spectra of the traditional structure and the FIED structure when ζ $_d$=10% and k_d takes five different values

4.2 Influence of the damping ratio of the isolation layer

To investigate the influence of the damping ratio of the isolation layer ζ_d to the damping effect of the FIED structure, we take k_d=0.01k_1 and ζ_d=2%, 4%, 6%, 8%, 10% respectively. The average response spectrum curves of the FIED structure having different ζ_d are plotted with the average response spectrum curves of the traditional structure in Figure 4.3.



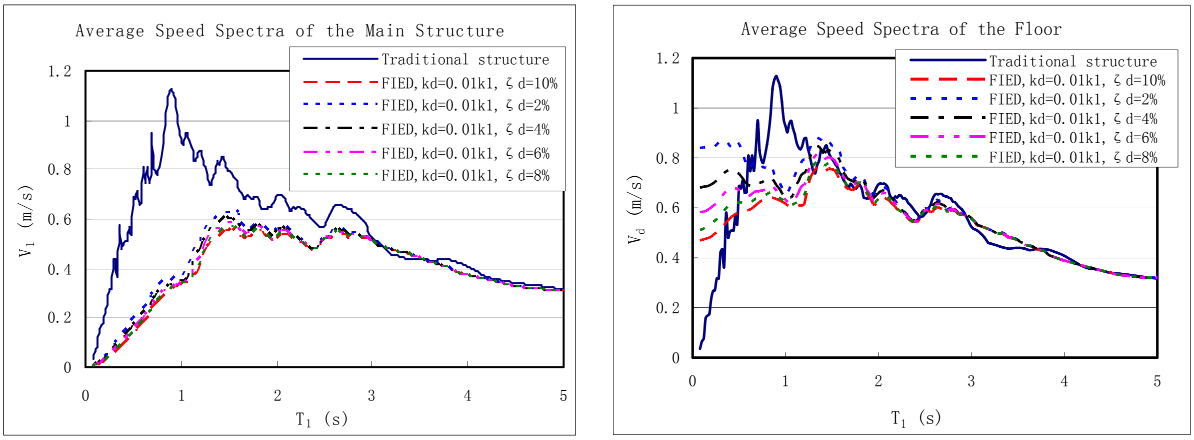


Figure 4.3 Average response spectra of the traditional structure and the FIED structure when k_d=0.01 k_1 and ζ_d takes five different values

Figure 4.3 shows that the seismic damping effect of the FIED structure reaches to the best when ζ_d takes 10%, and it becomes slightly worse as ζ_d decreases. When ζ_d =2%, the maximum reduction rate of the acceleration, displacement and velocity of the main structure reach to 74.5%, 58.1% and 69% respectively. The maximum reduction rate of the acceleration of the floor is 50.5%. That is to say, when the damping ratio ζ_d increases from 2% to 10%, the reduction rate of the average response increase about 3~4% for the main structure, and 16.5% for the floor. The increasing of damping ratio of the isolation layer contributes more to the seismic reduction of the floor than to the main structure.

5 CONCLUSIONS

The stiffness and damping ratio of the isolation layer will affect the seismic reduction effect of the FIED structure. The smaller the stiffness k_d and the larger the damping ratio ζ_d, the better seismic reduction effect will result. The seismic reduction effect of the FIED structure is more sensitive to the stiffness k_d than to the damping ratio ζ_d. To the analysis model, k_d =0.01 k_1 and ζ_d =10% result to the best seismic reduction effect. On the other hand, damping effect of the FIED structural system is remarkable when the natural period of the main structure T_1 is less than 3.0 second, and it becomes worse when T_1 is larger than 3.0 second.

AKCNOWLEDGEMENT
The authors gratefully acknowledge the support of this research by the National Natural Science Foundation of China under grant No. 90815027 and the Key Projects in the National Science & Technology Pillar Program during the Eleventh Five-Year Plan Period under grant No. 2009BAJ28B03.

REFERENCES

Qiaoling Xian, Fulin Zhou, Jian-an Liu, Yaojian Long. (2008). Study on Floorslab Isolating and Energy Dissipating (FIED) Structural system. *Proceedings of the 14th World Conference on Earthquake Engineering*. 11-0192.

Qiaoling Xian, Jian-an Liu, Fulin Zhou. (2007). Slab isolating and energy dissipating (SIED) structural system. *Journal of Earthquake Engineering and Engineering Vibration* 27:4,147-151. (in Chinese)

Qiaoling Xian, Jian-an Liu, Fulin Zhou. (2008). Shaking table test on the slab isolating and energy dissipating (SIED) structure. *Journal of Earthquake Engineering and Engineering Vibration* 28:3,145-151. (in Chinese)