STUDY ON FLOORSLAB ISOLATING AND ENERGY DISSIPATING (FIED) STRUCTURE SYSTEM

Qiao-Ling XIAN[1], Fu-Lin ZHOU[1], Jian-an LIU[2], Yao-jian LONG[2]
[1]Professor, [2]Graduate Student, Earthquake Engineering Research & Test Center,
Guangzhou University, Guangzhou, China
Email:xql@gzhu.edu.cn

ABSTRACT:

The Floorslab Isolating and Energy Dissipating (FIED) structure system is a new kind of structure system for buildings, which has been applied for the China patent by the first author. In this structure system, the floorslabs are isolated to the beams with high damping materials, and gaps must be left between the floorslabs and the columns so that the floorslabs can move relatively to the main structure when the building vibrates horizontally. The high damping materials under the floorslabs and inside the gaps can play the roles of seismic isolation and energy dissipation during the earthquakes and reduce the seismic reaction of the building. To study the damping effect of this new structure system, we developed the motion equation of the FIED structure, and carried out a series of shaking table tests for a single storey steel frame model in both the FIED structure system and the traditional structure system. The research shows that the FIED structure system can control the seismic response of building structures more effectively than the traditional one.

KEYWORDS: floorslab, isolation, energy dissipation, structure system, shaking table test

1. INTRODUCTION

In the near decades, the seismic control methods and techniques for buildings have been developed rapidly (Soong and Dargush 1997). Base isolation, energy dissipation and tune mass damper are the main types of passive control. They have been proved to be very effective in seismic control of buildings. However, some disadvantages or limitations have been found in the use of these seismic control techniques to the buildings. For example, base isolation of rubber bearing is not very effective in the seismic reduction of the high and flexible structure. Tension will appear in the rubber bearings of base isolation when the base isolated high rise building undergoes severe earthquake. Most of the energy dissipation dampers depend on the inter-storey drift/velocity of a building to work. The larger the inter-storey drifts of the building, the more energy the dampers could dissipate. So the RC building structure usually would have been cracked when the energy dissipation dampers start working. The tune mass damper can only control one or several modes of the building, so the damping effect is not very obvious in the complex structure.

Starting with changing the traditional structure system, the authors tried to propose a new seismic control system for of buildings, to avoid the disadvantages of the present passive control methods and contribute to remarkable seismic reduction.

2. THE FLOORSLAB ISOLATING AND ENERGY DISSIPING (FIED) STRUCTURE SYSTEM

In the traditional structure system, floorslabs are fixed to the main structure (e.g. beams and columns of a frame).

The transmitting route of the vertical load is: floorslabs→beams→columns or walls→foundation.

In the new structure system proposed by this paper, the floorslabs are separated from the main structure. Seismic isolation layers are set between the floorslabs and beams, which could be made of high damping materials. Gaps must be left between the floorslabs and the columns or walls. Energy dissipation dampers or materials can also put into the gaps. By this way, the vertical load transmitting route of this structure system is the same as that of the traditional structure system. However, when the building shakes in earthquake, the floorslabs will move relatively to the main structure, which will drive the isolation layers under the floorslabs and the dampers inside the gaps dissipate the vibration energy of the building. This new structure system is characterized by the floorslab isolation and energy dissipation, so that is called the Floorslab Isolated and Energy Dissipated (FIED) structure system. Figure 1 illustrates this system.

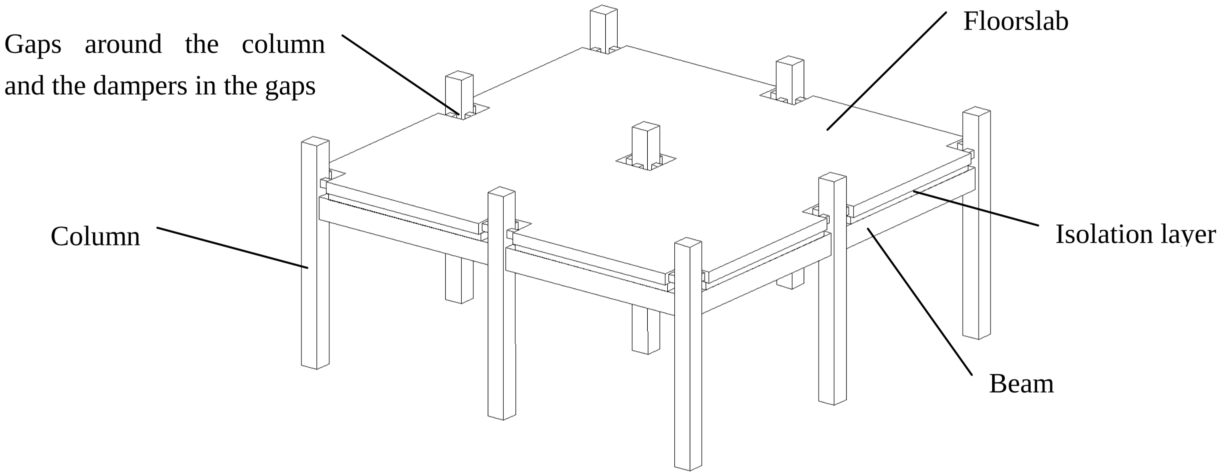
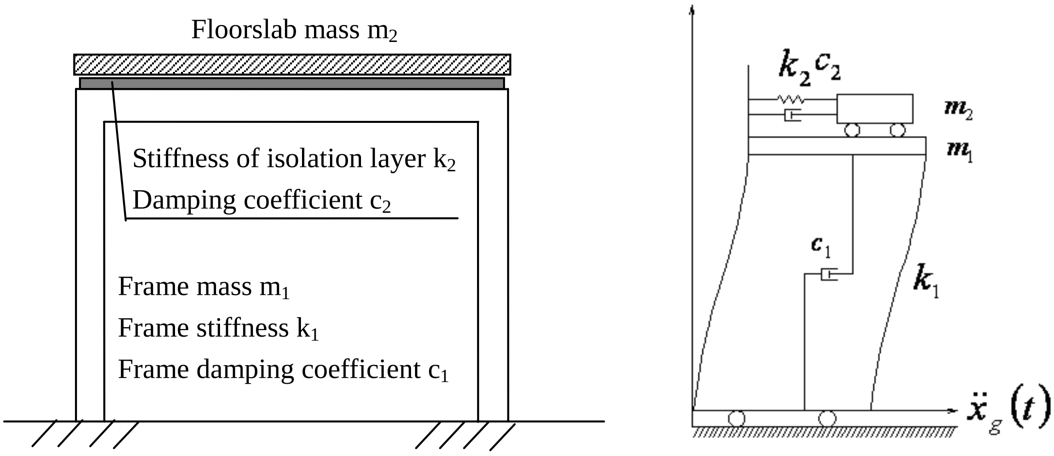


Fig. 1 Schematic diagram of the FIED structure system

Comparing to the present passive seismic control system, the FIED system has the following advantages:
(1) The vertical load acting on the isolation layer is only the dead load and live load on the floor, which can avoid many problems causing by large compression stress. The shear force and deformation of the isolation layer in earthquake is much smaller than that of the rubber bearing of the base isolation.
(2) Energy dissipating in the FIED structure system depends on the relative movement between the floorslabs and the main structure in earthquake and is sensitive to the deformation of the structure. Therefore, the FIED structure system fits for the building structures of either shear type or bend type. The damping effect is higher than the ordinary energy dissipation system which depends on the inter-storey drift/velocity of the structure.
(3) If the stiffness and the damping ratio of the isolation layer and the dampers are well chosen, the isolated floorslab can also have the function of tune mass damper to reach better damping effect, even though the mass of the floorslab can not be tuned in a large range.
(4) The isolating floorslabs can be flexibly arranged in a building structure, on each floor or some specified floors, in the form of the whole floorslab or only some parts of the floorslab. They can be set according to the analyses or optimization of the system to form something like the MTMD control system.

3. THE MOTION EQUATION OF THE FIED STRUCTURE



(a) Schematic diagram of the structure (b) Calculating model

Fig. 2 Schematic diagram and calculating model of the single storey FIED structure

Figure 2a shows a single storey FIED structure. The main structure (e.g. frame) has mass m_1, stiffness k_1 and damping coefficient c_1. The isolation layer set between the floorslab and the beams has stiffness k_2 and damping coefficient c_2. The mass of the floorslab is m_2. Figure 2b is the calculating modal of the single storey FIED structure subjected to earthquake-induced ground motion. The acceleration of the ground is denoted by $\ddot{x}_g$, the absolute displacement of the main structure by x_1,.and the absolute displacement of the floorslab by x_2. The equations of motion for the single storey FIED structure are:

$$m_1\ddot{x}_1+(c_1+c_2)\dot{x}_1+(k_1+k_2)x_1-c_2\dot{x}_2-k_2x_2=-m_1\ddot{x}_g \tag{1}$$

$$m_2\ddot{x}_2+c_2(\dot{x}_2-\dot{x}_1)+k_2(x_2-x_1)=-m_2\ddot{x}_g \tag{2}$$

Define the following parameters:

$$\mu=\frac{m_2}{m_1},\quad \omega_1=\sqrt{k_1/m_1},\quad \xi_1=c_1/(2m_1\omega_1),\quad \omega_2=\sqrt{k_2/m_2},\quad \xi_2=c_2/(2m_2\omega_2)$$

Let the relative displacement of the floorslab to the main structure be $x_d=x_2-x_1$. Substituting $x_2=x_1+x_d$ into the equation (1) and (2) gives:

$$\ddot{x}_1+2\xi_1\omega_1\dot{x}_1+\omega_1^2x_1-\mu\left(2\xi_2\dot{x}_d+\omega_2^2x_d\right)=-\ddot{x}_g(t) \tag{3}$$

$$\ddot{x}_1+\ddot{x}_d+2\xi_2\omega_2\dot{x}_d+\omega_2^2x_d=-\ddot{x}_g(t) \tag{4}$$

From equations (1) and (2) or equations (3) and (4) we can see that the differential equations of motion for the single storey FIED structure is the same as those for the single storey structure equipped with a tune mass damper. Stiffness ratio k_2/k_1, mass ratio m_2/m_1 and additional damping ratio ξ_2 are the main parameters affecting the structure performance.

4. SHAKING TABLE TEST OF THE SINGLE STOREY FIED STRUCTURE

To investigate the seismic behavior of the floorslab isolating and energy dissipating (FIED) structure, one steel frame modal has been made into traditional structure system and the FIED system respectively. Shaking table tests have been performed on the frame modal in each of the two structure systems.

The main structure used in the test is a single storey steel frame. The frame is 2.0m long, 1.2m wide and 1.0m height. The columns are made of angle iron L100×10 and beams channel iron C8. The floorslab, taken into account as accessory weight, is 300mm thick and made of reinforced concrete. The floorslab has an opening on each of the four corners and steel plates with screws embedded on the bottom and side faces. When the floorslab is screwed tightly with the beams, the traditional structure is formed. When isolation materials are set between the floorslab and beams, the FIED structure is formed.

Eight hollow rubber bearings, with 100mm external diameter, 50mm internal diameter and 80mm height, were used as the isolation layer when the frame modal is in the FIED structure system. Shear performance test had been done on these rubber bearings before they were installed in the frame modal. The test result is listed in Table 1.

Table 1 Equivalent stiffness and damping ratio of the rubber bearing

Controlled horizontal deformation of the rubber bearing	Equivalent stiffness (tf/cm)	Damping ratio（%）
50%	8.6515509E-02	5.57
100%	8.0384381E-02	4.38

In the shaking table tests, in addition to use the acceleration transducers on different height levels, a 3D force sensor was put under the bottom of each column to record the base forces of the column, and laser displacement transducers were used to obtain the horizontal displacements of the table, column foot, beam and floorslab. The shaking table test arrangements of the frame modal in the traditional structure system and the FIED structure system are shown in Fig. 3 and Fig.4 respectively.

Three earthquake records: El Centro-NS, Taft-EW and Tianjing-NS were used in the shaking table tests. The peak values of the input wave acceleration were tuned to 0.35m/s^2 (minor intensity of 7 degree seismic fortification in China Code) and 2.2 m/s^2 (severe intensity of 7 degree seismic fortification in China Code) respectively. To check the change of the dynamic characteristics of the frame modal, white noise was input before and after the test on each level of the acceleration peak value. The vibration direction was along the short side of the frame.

The dynamic characteristics of the frame modal were obtained by analyzing the reaction of the modal to the inputted white noise. Table 2 lists the dynamic characteristics of the frame modal in the two different structure systems. The data in Tab. 2 show that the fundamental period of the FIED structure modal is 2.5 times of that of the traditional structure modal, and the damping ratio of the FIED structure is about 2 times of that of the traditional structure. Longer fundamental period and bigger damping ratio usually will result in smaller seismic acceleration reaction. Besides, the fundamental period and the damping ratio of the frame modal in both structure systems only changed slightly before and after the severe intensity earthquake excitations, which means the frame modal remain in the static state after being input the severe earthquake excitations.

Fig.3 Photo of the frame modal in traditional system setting on the shaking table

Fig.4 Photo of the frame modal in the FIED structural system setting on the shaking table

Table 2 Dynamic characteristics of the frame modal in the two different structure systems

Circumstance	Traditional structure modal		The FIED structure modal	
	Period (s)	Damping ratio (%)	Period (s)	Damping ratio (%)
Before severe intensity earthquake excitations	0.0604	3.24	0.1524	6.52
After severe intensity earthquake excitations	0.0618	2.78	0.1495	6.68

For limited pages, this paper can only present the test results under the earthquake excitations at severe intensity. Seismic reduction ratio is used to describe the reduction of the seismic reaction of the FIED structure system to the traditional structure system, and is defined as follows:

$$\rho(\%)=\frac{R_T-R_F}{R_T} \qquad (5)$$

where ρ is the seismic reduction ratio, R_T is the seismic reaction of the traditional structure and R_F is the seismic reaction of the FIED structure.

In the traditional structure, because the floorslab is fixed to the frame, the acceleration at the top of the floorslab is approximately equal to the acceleration at the top of the frame. In the FIED structure, because the floorslab is isolated to the frame, the acceleration at the top of the floorslab is larger than the acceleration at the top of the frame. Therefore, the acceleration at the top of the floorslab of the traditional structure is used not only to compare with that of the FIED structure, but also to compare with the acceleration at the top of the frame of the FIED structure. Table 3 lists the acceleration peak values and amplification coefficients of the frame modal in two different structure systems under the three earthquake excitations at severe intensity. It can be seen from Tab. 3 that, for El-Centro, Taft and Tianjin inputs, the seismic reduction ratios of the acceleration at top of the frame are 33%~39%, 68%~78% and 42%~48% respectively. The seismic reduction ratios of the acceleration at top of the floorslab are 5%~27%, 59%~70% and 16%~42% respectively.

Table 3 Peak value and amplification coefficient of the acceleration (acceleration unit: g)

Earthquake records		Traditional structure			The FIED structure				
		Table	Top of floorslab	Floorslab /Table	Table	Top of frame	Top of floorslab	Frame /Table	Floorslab /Table
El Centro-NS	Max	0.3194	0.8155	2.55	0.3032	0.5201	0.7314	1.72	2.41
	Min	-0.2832	-0.9124	3.22	-0.2815	-0.5587	-0.6593	1.98	2.34
Taft-EW	Max	0.2551	1.4358	5.63	0.2987	0.3753	0.5118	1.26	1.71
	Min	-0.2522	-1.0657	4.23	-0.2834	-0.3848	-0.4899	1.36	1.73
Tianjin-NS	Max	0.2291	0.6173	2.69	0.2454	0.3822	0.5538	1.56	2.26
	Min	-0.2505	-0.8339	3.33	-0.2520	-0.4352	-0.4844	1.73	1.92

Figure 5 shows the acceleration time history curves of the frame modal in the two different structure systems under the excitation of the three earthquake inputs. The time history curves of the traditional structure are measured on the top of floorslab and those of the FIED structure are measured on the top of the frame. Even though the table input acceleration peak values relating to these time history curves have some differences, by comparing the time history curves of the two structures under the same earthquake input, it is found that the seismic reaction of the FIED structure is obviously smaller than that of the traditional structure. It can also be found that the order of the seismic reduction effect of the FIED structure system to the three input earthquake record is Taft, El Centro and Tianjin.

Table 4 Force peak values measured by the No. 1 three-dimensional force sensor (unit: kN)

Earthquake records		Traditional structure			The FIED structure		
		X direction	Y direction	Z direction	X direction	Y direction	Z direction
El Centro-NS	Max	2.7504	1.1871	6.6891	2.7117	0.0913	4.8841
	Min	-2.6628	-1.1401	-6.2113	-2.6574	-0.1522	-3.8754
Taft-EW	Max	3.6563	1.5745	9.0515	1.8295	0.1190	0.6901
	Min	-2.7796	-1.6520	-8.6003	-1.7861	-0.0803	-5.0168
Tianjin-NS	Max	2.7795	1.1816	6.2378	2.1064	0.1245	0.7963
	Min	-2.3642	-1.4500	-5.2823	-1.9218	-0.0664	-5.2026

Three-dimensional force sensor had been set under each foot of the frame column. To compare the seismic base shear of the frame modal in the two different structure systems under the three earthquake inputs, Tab. 4 lists the force peak values along three directions measured by the same force sensor (No.1 channel) at the same position of the two structure systems. The data in Tab.4 shows that when the earthquake inputs were in x direction, the forces in y direction are approximately half of the forces in x direction for the traditional structure, the forces in y direction are only 1/15 to 1/30 of the forces in x direction for the FIED structure, and the forces in x and z directions for the FIED structure are all smaller than those for the traditional structure. The average seismic reduction ratios of the forces along x, y and z direction for the three earthquake inputs are 22%, 92% and 48% respectively. Especially in the case of Taft input, the base forces in three directions for the FIED structure are far more less than those for the traditional structure. The test results demonstrate that the FIED structure system can remarkably reduce the seismic base shear of the structure.

Table 5 Displacement peak values measured by the laser displacement transducers (unit: mm)

Earthquake records		Traditional structure		The FIED structure		
		Table displacement	Inter-storey shift of the frame	Table displacement	Inter-storey shift of the frame	Shift of the floorslab to the top of frame
El Centro-NS	Max	23.052	2.644	26.7	3.292	14.8
	Min	-25.356	-2.676	-22.552	-2.592	-13.164
Taft-EW	Max	39.304	2.548	39.304	2.368	4.348
	Min	-39.076	-3.564	-39.076	-2.544	-2.624

For comparing the seismic displacement reaction of the frame modal in the two structure systems, displacements measured by the laser displacement transducers at different height levels of the frame modal have been analyzed, and the main results are listed in Tab.5. In the case of inputting Tianjin record, the displacement of the shaking table exceeded the capacity of the laser displacement transducer. Therefore, Tab. 5 has only the data obtained from the cases of El Centro and Taft. From Tab. 5, it can be found that the inter-storey shifts of the frame of the FIED structure are close to those of the traditional structure under El Centro input and smaller than those of the traditional structure under Taft input. In the FIED structure, having an isolation layer between the floorslab and beams of the frame, the shifts of the floorslab to the top of frame are somewhat large. The shifts of the floorslab to the top of frame under Taft input are much smaller than those under El Centro input.

5 CONCLUSIONS

The FIED structure system is our key innovation, which seismic reduction effect has been demonstrated by our shaking table tests. The test result shows that compared with the traditional structure, the seismic reduction effect of the FIED structure is as follows:

(1) The acceleration reduction ratio of the main structure (i.e. frame) reached to 36%~73%, average 54%. The acceleration reduction ratio of the floorslab was 10%~64%, average 34%.

(2) When the earthquake excitations were in x direction, the average reduction ratio of the base force along x, y and z direction was 22%, 92% and 48% respectively.

(3) The displacement reactions of the main structure of the FIED structure were close to those of the traditional structure. The displacement reactions of the floorslab of the FIED structure were larger than those of the traditional structure.

(4) The seismic reduction effect is significant with all of the three input earthquake records; the highest is with

Taft input, the second is with El Centro input.

In sum, the FIED structure system is rather effective in seismic damping and worth further studying.

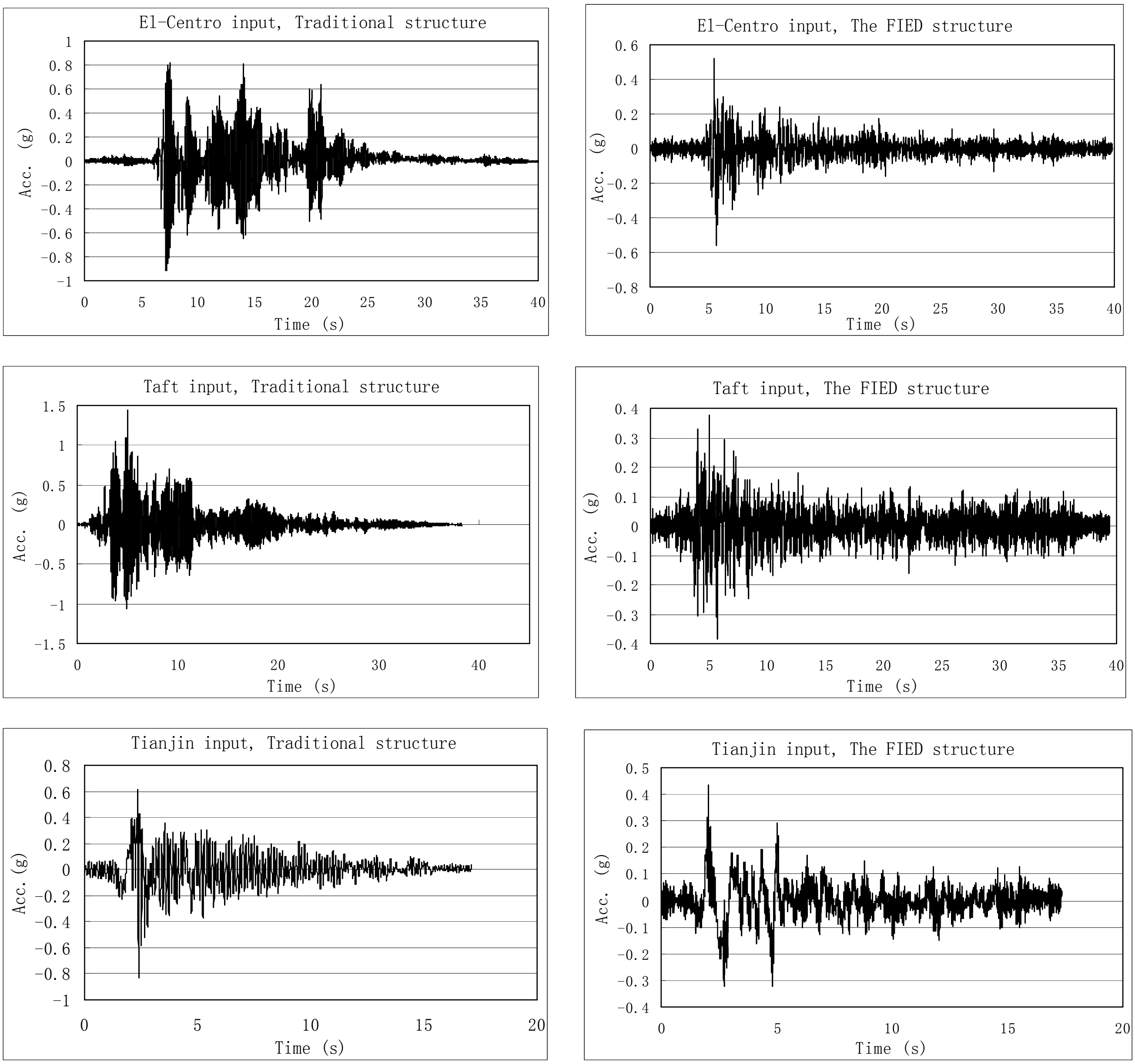


Fig. 5 Acceleration time history curves of the frame modal in the two structure systems

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