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

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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.

![Schematic diagram of the FIED structural system](image-url)

**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.

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:

\[
(m_1 + m_d) \ddot{x} + c_1 \dot{x} + k_1 x = -m \ddot{g}
\]  

(2.1)

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

\[
\begin{align*}
(m_1 + m_d) \ddot{x}_1 + (c_1 + c_d) \dot{x}_1 + (k_1 + k_d) x_1 - c_d \dot{x}_d - k_d x_d &= -m \ddot{g} \\
m_d \ddot{x}_d + c_d (\dot{x}_d - \dot{x}_1) + k_d (x_d - x_1) &= -m_d \ddot{g}
\end{align*}
\]

(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 \( m_d = 1800 \text{kg} \). 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 \( k_1 = 4\pi^2m_1 / T_1^2 \). 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 \( 0.5k_1 \) respectively. And the damping ratio of the isolation layer \( \zeta_d \) 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.

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 \( \zeta_d \) 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 \( \zeta_d \) have been considered respectively as stated before.
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 $\zeta_d$ 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 $\zeta_d=10\%$, 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 $T_1 \leq 3.0$ second, but are approximately the same in the region of $3.0 s \leq T_1 \leq 5.0$ 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 $T_1 \leq 0.8$ second, but is approximately the same in the region of $0.8 \leq T_1 \leq 5.0$ 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 $T_1 \leq 0.5$ second, is smaller in the region of $0.5 \leq T_1 \leq 1.7$ s, and is approximately the same in the region of $1.7 \leq T_1 \leq 5.0$ s. Therefore when $k_d = 0.01 k_1$ and $\zeta_d = 10\%$, the damping effect of the FIED structure is significantly in the region of $T_1 \leq 3.0$ 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 $T_1 \leq 1.5$ second, but are larger or smaller in the region of $1.5 \leq T_1 \leq 5.0$ 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.
4.2 Influence of the damping ratio of the isolation layer

To investigate the influence of the damping ratio of the isolation layer $\zeta_d$ to the damping effect of the FIED structure, we take $k_d=0.01k_1$ and $\zeta_d=2\%, 4\%, 6\%, 8\%, 10\%$ respectively. The average response spectrum curves of the FIED structure having different $\zeta_d$ 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 $\zeta_d$ takes five different values

Figure 4.3 shows that the seismic damping effect of the FIED structure reaches to the best when $\zeta_d$ takes 10%, and it becomes slightly worse as $\zeta_d$ decreases. When $\zeta_d = 2\%$, 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 $\zeta_d$ 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 $\zeta_d$, 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 $\zeta_d$. To the analysis model, $k_d = 0.01 k_1$ and $\zeta_d = 10\%$ 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.

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