Seismic responses analysis of the parallel composite isolated structure

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Abstract: Taking a practical engineering as an example, the state space method was used to calculate the maximum displacement, the maximum shear response, and the hysteretic time-history response of parallel composite isolated structure subjected to different characteristics of earthquake ground motions. The results show that parallel composite isolated structure can give full play to advantages of different types of isolated bearings and effectively reduce the seismic responses of the superstructure; different characteristics of earthquake ground motions have important effects on seismic responses of parallel composite isolated structure. Those results can provide some guidance for the design of parallel composite isolated structure.

1 Introduction

Parallel composite isolated structure is a kind of combined isolated structure supported by both laminated rubber bearings and sliding friction isolated bearings in parallel. It can make full use of advantages of rubber bearings. Rubber bearings can provide enough elastic restoring force, reduce the structural stiffness and prolong the period, and friction sliding bearings have low cost, high damping, and good performance of energy dissipation. And meanwhile, the composite isolated bearings can overcome the disadvantages of rubber bearings with high price and friction sliding bearings which cannot return automatically. Therefore, it has been concerned by many scholars in recent years [1-6].

In practical engineerings, the earthquake ground motion that structure encounters is unknown, and different characteristics of earthquake ground motions have important influences on the response of parallel composite isolated structure. Based on the author's previous studies[7], the state space method was used to calculate the maximum displacement response and shear response, and the hysteretic time-history response of parallel composite isolated structure subjected to different characteristics of earthquake ground motions, which can provide some references for the design of parallel composite isolated structure.

2 Theoretical model of parallel composite isolated structure

The calculation model of parallel composite isolated structure is shown in figure 1, using story shear model; only concerning elastic response of the structure, the motion differential equation of the structure subjected to the horizontal earthquake ground motion is as follows [8]:

$$[M]\{\ddot{X}(t)\}+[C]\{\dot{X}(t)\}+[K]\{X(t)\}=-[M]\{\delta\}\ddot{x}_g(t)-\{F\} \tag{1}$$

$$\{F\}=\left[\lambda\cdot\mu\cdot\sum_{i=0}^{n}M_i\cdot g\cdot \mathrm{sgn}(\dot{x}_0) \quad 0 \quad \cdots \quad 0\right]^T \tag{2}$$

where $[M]$, $[C]$ and $[K]$ are mass, damping and stiffness matrix of parallel composite respectively; $\{X(t)\}$, $\{\dot{X}(t)\}$ and $\{\ddot{X}(t)\}$ are displacement, velocity and acceleration column vector relative to the ground; $\ddot{x}_g(t)$ is earthquake ground motion acceleration; $\{\delta\}$ is unit column vector; $\{F\}$ is sliding friction column vector; μ is the friction coefficient of friction sliding bearing, $0\le\mu\le1$; λ is the friction bearing ratio, $0\le\lambda\le1$; sgn is a sign function, $\dot{x}_0$ is the acceleration of isolated layer.

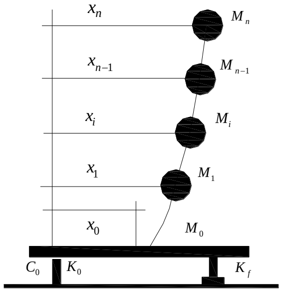


Figure 1. Calculation model

3 The state space method for analysis of seismic response

Time history analysis method is a commonly used method in the analysis of seismic response, which uses numerical integration method to solve the displacement, velocity and acceleration responses of structure step by step at every moment. This paper analyzes and calculates seismic time history responses of parallel composite isolated structure with state space method. For the second-order motion differential equation (1), take $Z(t)$ as state vector of multi-degrees-of-freedom structure.

$$Z(t)=\begin{pmatrix} z_1(t) \\ z_2(t) \end{pmatrix} \tag{2}$$

$$z_1(t)=\{X(t)\}$$
$$z_2(t)=\{\dot{X}(t)\} \tag{3}$$

Obviously,

$$\dot{z}_1(t)=z_2(t) \tag{4}$$

From formula (1), we can get

$$\{\ddot{X}(t)\}=-[M]^{-1}[C]\{\dot{X}(t)\}-[M]^{-1}[K]\{X(t)\}+[M]^{-1}P(t) \tag{5}$$

Substitute formula (3) into formula (5), we can get

$$\dot{z}_2(t)=-[M]^{-1}[C]z_2(t)-[M]^{-1}Kz_1(t)+[M]^{-1}P(t) \tag{6}$$

The formula (4) and (6) can be expressed in matrix, so the state equation of multi-degrees-of-freedom structure can be written as

$$\dot{Z}(t)=AZ(t)+B\{P(t)\} \tag{7}$$

where,

$$A=\begin{bmatrix} 0 & I_n \\ -[M]^{-1}[K] & -[M]^{-1}[C] \end{bmatrix}; B=\begin{bmatrix} 0 \\ [M]^{-1} \end{bmatrix};$$
$$P(t)=-[M]\{\delta\}\ddot{x}_g(t)-\{F\} \tag{8}$$

where I_n is a n identity matrix.

Displacement response can be obtained by the following formula

$$\{X(t)\}=[I_n \quad 0]\begin{pmatrix} z_1(t) \\ z_2(t) \end{pmatrix} \tag{9}$$

The velocity and acceleration responses can be worked out when we get displacement response of structure.

4 Examples

4.1 Calculation parameters

The example is a six-story reinforced concrete frame structure with parallel composite isolated bearings. The mass and shear stiffness of each layer are shown in Table 1, in which floor No.1 is isolated layer [12]. In order to analyze and discuss conveniently, if there are no special introductions in the later chapters, the friction bearing ratio λ of parallel composite isolated structure takes 0.3; friction coefficient μ takes 0.1; time step is 0.02s; Rayleigh damping is used to calculate structural damping matrix.

According to the clause explanation 12.1.3.3 of “code of aseismic design of buildings”(GB 50011-2010): Design characteristic periods of type I, II, III sites are all relatively shorter in most parts of our country, thus isolated buildings can be constructed except type IV sites. Therefore, this paper selects respectively Qian’an wave, Northridge wave and EI Centro wave to input calculation model (shown in table 2), then carries out the seismic response research of parallel composite isolated subjected to different characteristics earthquake ground motion, and the calculated results are shown in Figure 2 to Figure 5.

Table 1 Parameters of structure

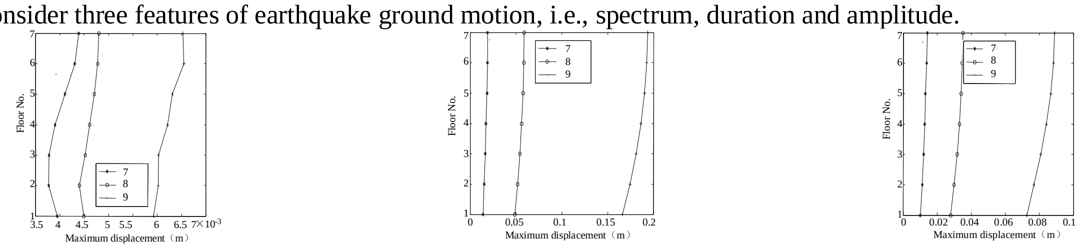
Floor No.	1	2	3	4	5	6	7
Mass/ton	510	586	586	586	586	586	400
Shear stiffness/kN/mm	60	1200	1200	1200	1200	1200	1200
damping ratio ξ	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table 2 Earthquake ground motion characteristics

Earthquake ground motion record	Time	Peak time /s	Direction	Acceleration peak value/cm/s^2	Duration/s	Characteristic period/s	Site classification
Qian'an	1976	4.29	NS	132.39	22.02	0.10	I
Northridge	1994	4.20	NS	825.9	29.2	0.22	II
El Centro	1940	2.12	NS	341.7	53.74	0.54	III

4.2 Seismic responses of parallel composite isolated structure

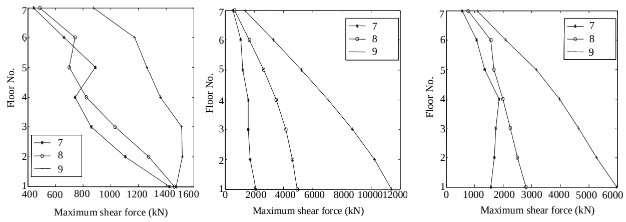
As can be seen from figure 2, the maximum displacement responses almost have the same law, the displacement of isolated layer is the maximum, superstructure interlayer displacement is lesser, different from the top-down "amplified shaking type" displacement responses of traditional aseismic structure, the maximum displacement of parallel composite isolated structure is "overall translational type", which reduces displacement responses of superstructure effectively, thus making superstructure still in elastic state in strong earthquake and ensuring the safety of the superstructure. But from figure 2(a) we can see that the deformation of superstructure subjected to Qian'an earthquake ground motion is more inhomogeneous relative to that of Northridge and EI Centro, which may cause the excessively big interlayer displacement angle of superstructure. One possible reason for it may be that Qian'an wave is near field wave. Besides, present research suggested that the closer the characteristic period of site to the natural vibration period of structure is, the stronger the response of structure has. But as can be seen from figure 2(b) and figure 2(c), the maximum displacement response of parallel composite isolated subjected to EI Centro earthquake ground motion applicable to site III is not the biggest, yet the maximum displacement subjected to Northridge earthquake ground motion applicable to site II obtains the maximum. The possible reason may be the pulse wave characteristics of Northridge earthquake ground motion. The above analysis results reflect complex effect of earthquake ground motion characteristics on seismic responses of parallel composite isolated structure. More research work should be done to consider three features of earthquake ground motion, i.e., spectrum, duration and amplitude.



(a)Qian'an (b) Northridge (c) El Centro

Figure 2. The maximum displacement response curve

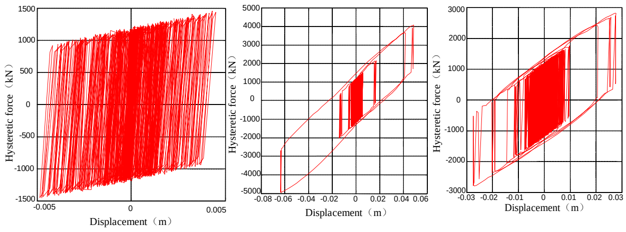
As can be seen from figure 3, the maximum shear response of the structure overall presents a decline trend from bottom to top under different earthquake ground motions, and reduce speed increase along with the increase of acceleration peak value, which is favorable for the superstructure. But from figure 3, in the case of 7 degree fortification, the maximum shear responses of parallel composite isolated structure all have an obvious inflection point at the forth floor of structure, whose values are $741.6kN$,$1588.9kN$ and $1858.6kN$ respectively, which reflects the acceleration amplitude of earthquake ground motion has a certain effect on the maximum shear response of parallel composite isolated structure.



(a)Qian'an (b) Northridge (c) El Centro

Figure 3 The maximum shear response curve

Figure 4 is the hysteretic time history response curve of parallel composite isolated structure subjected to different characteristics of earthquake ground motions. Due to limited space, this paper only gives the calculated results subjected to 8 degree fortification intensity earthquake. From figure 4, hysteretic curve subjected to different earthquake ground motions are similar in shape, but different in slope steep degree of curve before and after sliding, which shows a very good hysteretic characteristics. The hysteretic loops is full and the capacity for energy dissipation is excellent, which means seismic response will be reduced significantly, thus can prevent superstructure from damage or destruction effectively.



(a)Qian’an (b) Northridge (c) El Centro

Figure 4. Hysteretic curve

5 Conclusions

(1) Different earthquake ground motions have important effects on seismic response of parallel composite isolated structure, from the standpoint of the maximum displacement response, maximum shear response, and hysteretic behavior, the seismic isolated performance of parallel composite isolated structure can be fully reflected.

(2) Parallel composite isolated structure can give full play to the advantages of different kinds of isolated bearings. It can form a reasonable isolated layer through appropriate combination, which can work cooperatively subjected to earthquake action, and it can effectively reduce the seismic response of the superstructure. So it is a kind of isolated structure worthy of in-depth study.

Acknowledgements

The research was sponsored by the Key Program of the Hebei Education Department (Grant No. ZD2015073 and ZD2016038) and the Scientific Key Program of Hebei GEO University (Grant No. KAG201607). China and Australia cooperation research projects (16394507D); Hebei overseas training project for excellent experts.

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