Test Design and Finite Element Analysis of Shaking Table of Concrete Frame Structure Reinforced with CFRP Bars

Jianyue Wang1, Xinsheng Xu1*
1School of Civil Engineering and Architecture, University of Jinan, Jinan, Shandong, 250022, China
*Corresponding author’s e-mail: xinsheng_xu@163.com

Abstract. The shaking table test is an irreversible process for a nonlinear model structure. Therefore, how to choose ground motion and determine the input sequence are particularly important for the success of the shaking table test. In this paper, a 1/4 scale CFRP reinforced concrete frame structure specimen model is designed and made according to the similarity theory. By using the finite element analysis software SAP2000, the finite element model of CFRP reinforced concrete frame specimen is established. Four seismic waves are selected in the simulated shaking table test process, and the dynamic time history analysis of a total of 52 working conditions is carried out, including unidirectional, bidirectional and three-directional ground motion input, and the acceleration and displacement response of the structure are obtained. Taking story drift ratio as the evaluation index, the seismic performance of the structure is evaluated. This paper provides theoretical guidance for the subsequent shaking table test.

1. Introduction
Because FRP bars have excellent tensile properties, the research focus in the initial stage is mainly on the flexural behavior of concrete beams with FRP bars as tensile reinforcement[1-2]. There is little research on the overall seismic performance of FRP reinforced concrete frame structures. As an important means of seismic research, shaking table test can not only directly show the seismic performance of the structure and some weak links in design, but also verify some theoretical analysis models and numerical methods[3-4]. The experimental study on the shaking table test of FRP reinforced concrete frame structures is proposed in this paper. In order to ensure the success of the shaking table test, a 1/4 scale CFRP reinforced concrete frame structure specimen model is designed and fabricated according to the similarity theory. By using the finite element analysis software SAP2000, the finite element model of CFRP reinforced concrete frame specimens is established, and the shaking table test process is simulated, and the seismic performance of the structure is evaluated. This paper provides theoretical guidance for the subsequent shaking table test.

2. General situation of test design
2.1 Test model design
According to the experimental requirements, a prototype structure is designed, which is a three-story and two-span frame structure. The first layer is 3.75m, and the second layer is 3m, and the third layer is 3m. The total height of the building is 9.75m. According to the prototype structure size, shaking table size and other factors[5], the geometric similarity ratio of the model structure is 1/4, and the...
The average density similarity ratio is 1. According to the elastic modulus test, the elastic modulus similarity ratio of the model material is 1/2.02. Other similar relationships were determined by dimensional analysis. In order to satisfy the quality similarity between the model structure and the prototype structure, a uniform size iron block was arranged on the model structure, so the total weight of the model is 9.2t. According to the reinforcement area of the prototype structure, the reinforcement of the model structure is shown in figure 1.

2.2 Shaking table test scheme
For the model with nonlinear behavior, the shaking table test process is a damage accumulation and irreversible process, so it is not possible to select too many ground motions for shaking table test input.

According to the current seismic code, the number of seismic waves should be not less than two actual seismic records and one artificial simulated seismic acceleration record. Four seismic waves were selected in this experiment, namely EI-Centro Wave, Taft Wave, Wenchuan wave and Lanzhou artificial wave. When the shaking table test was carried out, the duration was compressed according to the time similarity coefficient, and the peak ground acceleration of ground motion was scaled according to different loading conditions. Before the seismic wave was input, the model structure had been scanned by white noise to measure the natural shaking period and damping characteristics of the structure. The peak ground acceleration of four seismic waves increased from 0.035g (frequently occurred earthquake with seismic intensity of 7 degree) to 0.4g (seldomly occurred earthquakes with seismic intensity of 8 degree), and the shaking direction had unidirection, bidirection and three-direction, a total of 52 working conditions. Three kinds of sensors were arranged in this experiment, namely acceleration sensor, displacement meter and strain gauge.

3. Finite element analysis results
The finite element model of CFRP reinforced concrete frame model structure was established by SAP2000. 52 load conditions were input one by one, the acceleration and displacement envelope diagram of the model structure were obtained by analyzing the model structure. The acceleration and displacement envelope diagram of the model structure under precautionary earthquake with seismic intensity of 8 degree were shown in figure 2 to figure 7. As can be seen from the figure:

1. Under the same acceleration amplitude, the displacement of the model structure was relatively minimum under the excitation of Taft wave, followed by EI-Centro wave, Lanzhou artificial wave. Wenchuan wave had the strongest earthquake response, and the floor displacement was the largest.

2. Under the same acceleration peak ground acceleration and the same seismic wave excitation, there is no significant difference in the maximum horizontal displacement of the model structure, regardless of whether the ground motion is bidirectional or three-directional input.
4. Evaluation of seismic performance based on displacement

In this paper, the seismic performance of FRP reinforced concrete frame structure model is evaluated according to the story drift ratio limit of reinforced concrete frame structure given in code for seismic design of buildings. Figure 8 shows the envelope diagram of the maximum story drift ratio of each floor under frequently occurred earthquake with seismic intensity of 7 degree to seldomly occurred earthquake with seismic intensity of 8 degree. Table 1 shows the seismic performance evaluation of structures under different seismic intensity.
Figure 8. Envelope diagram of story drift ratio
Table 1. Evaluation of seismic performance of structures.

| PGA/gal | El-Centro wave | Taft wave | Wenchuan wave | Lanzhou artificial wave | Overall merit |
|---------|----------------|-----------|---------------|------------------------|--------------|
| 69      | basically intact (including intact) | basically intact (including intact) | slight damage | basically intact (including intact) | basically intact (including intact) |
| 138     | basically intact (including intact) | basically intact (including intact) | moderate damage | slight damage | slight damage |
| 197     | basically intact (including intact) | basically intact (including intact) | severe damage | slight damage | slight damage |
| 300     | basically intact (including intact) | basically intact (including intact) | severe damage | moderate damage | moderate damage |
| 394     | slight damage | slight damage | severe damage | moderate damage | moderate damage |
| 591     | moderate damage | slight damage | collapse | severe damage | severe damage |
| 788     | moderate damage | moderate damage | collapse | severe damage | severe damage |

From the above chart, it can be seen that the first layer of the story drift ratio is the largest, indicating that the first layer deformation damage is large under the action of earthquake, which is the most easily damaged; under the action of Wenchuan seismic wave, the structure performance is stronger, and the damage is more serious than other waves. The comprehensive analysis shows that when the structure is affected by frequently occurred earthquake with seismic intensity of 7 degree, precautionary earthquake with seismic intensity of 7 degree and frequently occurred earthquake with seismic intensity of 8 degree, the seismic performance target of "undamaged under minor earthquake" is satisfied. When the structure is affected by precautionary earthquake with seismic intensity of 8 degree, the comprehensive evaluation of the structure is "moderate damage", which means that the structure "only needs general repair and can be used after taking reinforcement measures", to meet the seismic performance target of "repairable under moderate earthquake". When the seismic action reaches the seldomly occurred earthquake with seismic intensity of 8 degree, the comprehensive evaluation of the structure is "severe damage", but the structure also has certain deformation bearing capacity, so that the structure does not collapse, and basically meets the seismic performance goal of "no collapse under major earthquake".

5. Conclusions
In this paper, a 1/4 scale CFRP reinforced concrete frame model structure is designed. The finite element model of CFRP reinforced concrete frame structure is established, and the dynamic time history analysis is carried out. The following conclusions are drawn:

(1) According to the acceleration response, the maximum acceleration of each floor of the model structure is basically inverted triangle distribution, and the acceleration response of the top layer is the largest; under the same peak ground acceleration, the acceleration response caused by Wenchuan wave is the largest, which indicates that the maximum earthquake response of the model structure not only depends on the peak ground acceleration of ground motion, but also depends on the spectrum characteristics of seismic wave; the addition of vertical ground motion has little effect on the horizontal seismic action of the model structure in X and Y directions.

(2) From the displacement reaction, the floor displacement caused by Wenchuan wave is the largest at the same peak ground acceleration, followed by Lanzhou artificial wave, El-Centro wave, and the model structure floor displacement is the smallest under Taft wave excitation. It is explained that the
maximum reaction of the model structure is not only related to the peak ground acceleration of ground motion, but also related to the spectrum characteristics of seismic wave; under the action of the same seismic wave, the larger the peak ground acceleration, the greater the displacement reaction of the model structure, which indicates that the stiffness of the structure decreases gradually and the deformation increases gradually; the input of vertical ground motion has little effect on the horizontal displacement reaction of the structure.

(3) From the point of structural stiffness, the lateral stiffness of the first story column is the smallest, which is most prone to failure under earthquake action, so when the designer designs FRP reinforced concrete frame, the stiffness of the bottom column should be considered emphatically, and the stiffness of the bottom column should be strengthened by increasing the cross section of the bottom concrete column.

(4) From the point of story drift ratio, the maximum story drift ratio of the structure is mainly concentrated at the bottom, which indicates that the bottom layer of the structure is more prone to large deformation than any of the second and third floor under the action of seismic wave, and the bottom details of seismic design should be strengthened; under the action of different levels of seismic load, the structure has a strong reaction to the Wenchuan wave, and the damage is more serious than other waves.

(5) The shaking table test process is an inevitable process of damage accumulation, so the determination of ground motion input sequence is very important for the effectiveness of the test results. It is suggested that the excitation order of seismic wave at the same peak ground acceleration is as follows: Taft Wave, EI-Centro wave, Lanzhou artificial wave, Wenchuan wave.

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