Finite Element Analysis of Dynamic Behavior of CFRP Reinforced Concrete Frame

Haoyu Zhang¹, Xinsheng Xu¹*

¹School of Civil Engineering and Architecture, University of Jinan, 336Nanxinzhuan West Road, Jinan 250022, Shandong, China
*Corresponding author’s e-mail: xinsheng_xu@163.com

Abstract. At present, the research on the performance of CFRP reinforced concrete structures at home and abroad mainly focuses on the ductility of individual members, especially FRP reinforced beams and columns, while the research on the ductility and seismic performance of FRP reinforced concrete frame structures is relatively less. Firstly, the finite element model of the shaking table test scale model of CFRP reinforced concrete frame structure is established by using SAP2000 finite element analysis software. Then, the non-linear dynamic time-history load condition is defined for the model, and the dynamic elastic-plastic time-history analysis is carried out to obtain the acceleration response and displacement response of the model under different levels of earthquake. The results show that the CFRP reinforced concrete frame structure is damaged and its stiffness deteriorates seriously. The lateral deformation of the structure is mainly caused by the bending deformation of the beam and column, while the lateral displacement of the column caused by the axial deformation is relatively small.

1. Introduction

The finite element model of CFRP reinforced concrete frame structure is established by SAP2000. The model uses frame elements to simulate beam and column members, thick shells in shell elements to simulate model floor slabs, steel bars to simulate stirrups to use Kinematic model, concrete to use default Takeda plastic model, CFRP bars to simulate using user-defined linear elastic constitutive relationship, and the integration method to select linear direct integration method.

2. Model building

According to the test requirements, a prototype structure is designed, which is a three-storey and two-span "Tian" frame structure. The first storey is 3.75m high, the second and third storeys are 3M high, and the total building height is 9.75m. Column section size 400 mm *400 mm, beam section size 300 mm *400 mm, floor thickness 120 mm. The beam-column longitudinal reinforcement of the prototype structure CFRP reinforcement, and the stirrups and the distributed reinforcement of the floor are all made of ordinary reinforcement, and the concrete strength grade is C35. After defining the non-linear properties, the behaviour of beam and column members can be well simulated. The thickness of floor and reinforcement are increased to make rigid slabs and the shells in the surface element library are selected. The element is used to simulate the mechanical behaviour of rigid floor slabs and roof slabs, and the column bottom is defined as a fixed-end constraint to simulate the rigid base of the model structure.
3. Seismic Performance Analysis of CFRP Concrete Frame Structures

3.1 Acceleration Response Analysis
By processing and analyzing the acceleration data, the maximum acceleration response of each layer of the model under different levels of earthquake can be obtained. By dividing the peak acceleration of each layer by the peak acceleration input from the mesa, the acceleration amplification coefficients of each layer can be obtained. The change trend of the acceleration amplification coefficients can reflect the damage of the structure. Based on the data, the envelope graphs of the peak acceleration and the amplification factor of each layer of the model under different levels of earthquake action are drawn, as shown in figs. 1-3.

(a) Acceleration peak  (b) Acceleration transmissibility
Figure 1. Envelope diagram of acceleration peak and acceleration amplification factor of the model under Taft one-way seismic wave

(a) Acceleration peak  (b) Acceleration transmissibility
Figure 2. Envelope diagram of model acceleration peak and acceleration amplification factor under the action of El Centro one-way seismic wave
The following conclusions can be drawn from the analysis of the above figs:

1. When the same acceleration is input to the structure, the acceleration response caused by Taft wave and El Centro wave is approximately a straight line, while the floor acceleration response envelope caused by Wenchuan wave shows an obvious inverted triangular distribution from top to bottom. Among the three seismic waves, the floor acceleration response caused by Wenchuan wave is the largest, which shows that the acceleration response of the structure depends not only on the acceleration peak input. The value is also influenced by the spectrum characteristics of seismic waves. With the increase of the peak acceleration of the input seismic wave, the acceleration amplification coefficient of the model decreases, which indicates that with the increase of the peak acceleration, the frame has irrecoverable residual deformation and the structure has different degrees of damage.

2. The maximum acceleration response of the model appears on the top floor of the frame, and the acceleration amplification factor of the top floor of the frame is the largest. When the peak acceleration of the input seismic wave is 0.069g and 0.197g, the acceleration amplification coefficient of the model varies greatly along the floor. When the input of 0.433g and 0.788g Wenchuan wave, the trend of the increase of the acceleration amplification coefficient slows down greatly, which indicates that the damage of the bottom floor of the frame is serious and the stiffness of the structure is damaged, which affects the upward transmission of seismic action.

3.2 Displacement response analysis

Through dynamic elastic-plastic time history analysis, the displacement time history curves of each floor of the CEFP frame under different levels of earthquake can be obtained. Figure 3.19 shows the displacement time history curves of the top floor of the model under 7-degree multiple occurrence (working condition 1), 7-degree fortification (working condition 7), 7-degree rare occurrence (working condition 15), 8-degree rare occurrence (working condition 23) Taft unidirectional seismic wave. It can be seen from the figure that under the action of 0.069g Taft seismic wave, the maximum displacement response of the top layer of the model appears at 6.1s, and the peak displacement is 0.4mm; under the action of 0.197g Taft wave, the maximum displacement response of the top layer of the model also appears at 6.1s, and the peak displacement is 1.6mm; under the action of 0.433g Taft wave, the maximum displacement response of the top layer of the model appears a little earlier, and at 5.8s, the peak displacement reaches 4.6. When the peak value of the input ground motion acceleration reaches 0.788g, the maximum displacement response of the top layer of the model also appears at 5.8s, and the peak displacement reaches 10.3mm.
4. Conclusion

(1) With the increase of input peak value, the displacement response of CFRP model increases gradually. When 0.069g and 0.197g acceleration peak value acts, the floor displacement increases gently. When 0.433g and 0.788g acceleration peak value acts, the floor displacement increases significantly, which indicates that the structure is damaged, the stiffness degradation is serious, and the deformation increases.

(2) CFRP model is a symmetrical "Tian" type structure. Its lateral stiffness in the X direction is the same as that in the Y direction. However, compared with the maximum relative displacement responses in the X direction and Y direction of the model, it can be found that the displacement in the X direction of the structure is obviously larger than that in the Y direction, mainly because the energy of the seismic wave input in the Y direction is less than that in the X direction, so the displacement response in the Y direction is also smaller than that in the X direction.

(3) From the floor displacement envelope diagram of CFRP model, it can be seen that the inter-story displacement of the structure decreases gradually from bottom to top, i.e. shear-type deformation. It shows that the lateral deformation of the structure is mainly the bending deformation of the beam and column, and the lateral displacement of the column caused by the axial deformation is relatively small, so the whole structure presents shear-type lateral displacement.

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