Finite Element Analysis of Dynamic Behavior of GFRP Reinforced Concrete Frame

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Abstract. In order to promote the rapid development of FRP reinforced concrete structure engineering application, it is very important to study the failure mechanism and seismic performance of FRP reinforced concrete frame structure. In this paper, a 1/4 scale specimen model of GFRP reinforced concrete structure is designed and manufactured according to similarity theory. The finite element model of the shaking table test specimen of GFRP reinforced concrete frame structure is established by using SAP2000 finite element analysis software. The validity of the finite element model is verified by comparing the natural vibration period with the first six modes. Then, the model is defined as a non-linear dynamic time-history load condition, and the dynamic elastic-plastic time-history analysis is carried out to obtain the dynamic performance indexes of the model under different levels of earthquake, such as acceleration response, inter-story displacement angle and floor shear force.

1. Introduction
The dynamic elastic-plastic time history analysis of the platform vibrator test model of GFRP reinforced concrete frame is carried out by SAP2000 finite element analysis software. The natural vibration period, frequency, acceleration response, displacement response and floor shear force of the first several modes are analyzed, and the seismic performance of GFRP reinforced concrete frame structure is evaluated.

2. Model building
Due to the limitation of the size of the platform vibrator table and the effective bearing capacity, the model structure of the scale is usually adopted for the test object. At present, there are relatively few engineering examples of FRP reinforced concrete frame structure, so a prototype structure is designed according to the test requirements. It is a three-storey two-span "Tian" shaped frame structure with a floor height of 3.75m, two-storey and three-storey height of 3m, and the total height of the building 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 GFRP reinforcement, and the stirrups and the distributed reinforcement of the floor are all made of ordinary reinforcement, and the concrete strength grade is C35.

3. Seismic Performance Analysis of GFRP Concrete Frame Structures

3.1 Acceleration Response Analysis
Through dynamic elastic-plastic time history analysis, the acceleration time history curves of each floor under different levels of earthquake can be obtained. By processing and analysing 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. Because of space limitation, only the acceleration peak value and the acceleration amplification coefficient in the X direction of the model are given. Based on the data obtained, the envelope graphs of the acceleration peak value and the acceleration amplification coefficient of each layer of the model under different levels of earthquake action are drawn, as shown in figs. 3.1-3.4.

Figure 3.1 Envelope diagram of acceleration peak and acceleration amplification factor of the model under Taft one-way seismic wave

Figure 3.2 Envelope diagram of model acceleration peak and acceleration amplification factor under the action of El Centro one-way seismic wave

Figure 3.3 Envelope diagram of acceleration peak and acceleration amplification factor of Lanzhou artificial wave
The following conclusions can be drawn from the analysis of the above charts:

1. When the same peak acceleration is input to the model structure, the distribution of acceleration response along the floor caused by different seismic waveforms is different. The floor acceleration response caused by Taft wave and El Centro wave is approximately a straight line, while the floor acceleration response envelope caused by Lanzhou artificial wave and Wenchuan wave presents an obvious inverse triangular distribution from top to bottom. The acceleration response of the floor caused by Wenchuan wave is the largest among the four seismic waves, which shows that the acceleration response of the structure depends not only on the peak value of the acceleration input, but also on the influence of the spectrum characteristics of the seismic wave.

2. 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.

3. The maximum acceleration response of the model appears on the top floor of the frame, and the acceleration amplification coefficient increases gradually with the increase of the floor, and the acceleration amplification coefficient of the top floor of the frame is the largest. When the peak acceleration of input seismic wave is 0.069g and 0.197g, the acceleration amplification coefficient of the model varies greatly along the floor. When Lanzhou artificial wave and Wenchuan wave of 0.433g and 0.788g are input, the increasing trend of acceleration amplification coefficient is greatly slowed down, 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 Floor displacement envelope diagram

(a) Seven-degree fortification 0.069g  
(b) Seven-degree fortification 0.197g

Figure 3.5 Envelope of Maximum Relative Displacement of Floor under Different Level Earthquakes

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

3.3 Inter-layer Displacement Angle Analysis

![Figure 3.6 Envelope diagram of the maximum interlayer displacement angle of the model floor under different acceleration peaks](image)

From the chart, it can be seen that the maximum interlayer displacement angle of the model structure occurs in the first floor, that is, the largest interlayer displacement of the first floor, which also shows that the lateral displacement of FRP reinforced concrete structure is mainly shear deformation. With the increase of the peak acceleration, the inter-story displacement angle of the structure increases gradually. When the input peak acceleration reaches 0.788g, the model shows obvious first-floor weak layer state. This is because the first-floor height is higher than the other two layers. It can be seen that increasing the first-floor height is easy to form the first-floor weak layer.

3.4 Floor Maximum Shear Analysis

By multiplying the maximum acceleration of each floor by the mass of the corresponding floor, the inertia force of each floor can be obtained. The maximum shear envelope of the floor can be obtained by accumulating the inertia force of each floor upward. According to the data, the maximum shear envelope diagram of the floor under different acceleration peaks is drawn, as shown in Figure 3.6. From the figure, it can be seen that the maximum shear envelope of the model floor increases with the increase of the peak acceleration, and the maximum shear envelope of the structure floor basically presents a linear distribution from top to bottom, indicating that the distribution of the structure mass along the height is relatively uniform.

![Figure 3.7 Maximum Shear Envelope Diagram of Model Floor under Different Acceleration Peaks](image)

4. Conclusion

(1) When the same acceleration peak acts, the maximum acceleration response of the model appears on the top of the frame, and the acceleration amplification factor also increases with the increase of the floor. The acceleration amplification factor of the top layer of the frame is the largest; with the peak value of the input seismic wave acceleration. The increase of the model's acceleration amplification factor shows a decreasing trend, indicating that the frame produces irreversible residual deformation as
the peak value of the seismic wave increases.

(2) When one-way, two-way and three-way seismic waves are input to the same seismic wave, the structural displacement response under two-way and three-way seismic waves is obviously larger than that under one-way seismic waves. The displacement response caused by three-way seismic input is not different from that caused by two-way seismic input, which indicates that the vertical seismic action has little effect on the horizontal displacement.

(3) From the floor displacement envelope diagram of the model, it can be seen that the inter-story displacement of the GFRP reinforced concrete frame structure decreases gradually from bottom to top, i.e. shear 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 lateral displacement.

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References
[1] Lv XL, Li PZ and Chen YQ. (2010) Complete data of shaking table model test for 12-storey reinforced concrete standard frame. R.
[2] Lu.CQ. (2013) Shaking table test and simulation comparative analysis of reinforced concrete frame structures with different performance. D. Chongqing University.
[3] Xue JY, Hu ZB, Liu ZQ. (2017)Shaking table test of SRC special-shaped column space frame structure model. J. Journal of Architectural Structure, 38 (2): 74-82.
[4] Lu XZ, Qing Jiang, Miao ZW, et al.(2015) Elasto-plastic analysis of earthquake resistance of buildings (second edition). M. China Construction Industry Press.
[5] Li JY. (2017) Shaking table test design and seismic performance analysis. FRP reinforced concrete frame structure. D.