Seismic performance analysis on GFRP reinforced concrete frame structure

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Abstract. At present, the research on FRP-reinforced concrete structures mainly focused on the performance of members at home and abroad, and there is less research on the overall seismic behavior of FRP-reinforced concrete frame structures. Based on the existing related research and the shaking table test, this paper studies the overall seismic performance of GFRP reinforced concrete frames. We excited the structure by inputting seismic waves through the computer, to make the frame model go through seven-degree multiple encounters earthquake damage, seven-degree fortifications earthquake damage, seven-degree rare encounters earthquake damage, eight-degree rare earthquake damage in turn, and recorded the acceleration and displacement responses of the structure. Acceleration data was analyzed by MATLAB software. And then used these data to analyze the seismic performance of the structure.

1. Introduction

Reinforced concrete structures have been widely used in building structures since their birth. However, the reinforced concrete structure has large defects. If it is in a harsh environment such as humidity, salt damage, chemical corrosion, etc., due to factors such as concrete carbonization and chloride ion corrosion, the steel bar will rust. The new fiber reinforced polymer (FRP), which has the characteristics of high tensile strength, light weight, good corrosion resistance, fatigue resistance, good insulation performance, and thermal insulation[1,2], can be used as a substitute for reinforcing steel. A new type of high-performance material, FRP bars can adapt to harsh environments, such as humid, salt-damaged marine and underground environments, and harsh chemical facilities. And it can effectively solve the problem of insufficient structural durability due to corrosion of steel bars. As a new type of composite material, FRP tendon is a perfection and supplement to traditional materials and has good development potential.

2. GFRP tendons mechanical properties

The properties of FRP tendons are related to factors such as the type and content of fibers, the bonding matrix, and surface treatment. In terms of mechanical properties, FRP bars with different fiber types are different. The comparative analysis of the performance index parameters of GFRP bars and ordinary bars is shown in Table 1[3,4,5].
### Table 1 Comparison of mechanical properties of ordinary steel bars and GFRP bars

| Material category | Density (g/cm³) | Tensile elastic modulus (GPa) | Ultimate tensile strength (MPa) | Yield Strength (MPa) | Ultimate elongation (%) |
|-------------------|----------------|-----------------------------|-------------------------------|---------------------|-------------------------|
| Ordinary steel    | 7.84           | 200                         | 490–600                       | 300–400             | >10                     |
| GFRP              | 1.25–2.15      | 35–70                       | 600–1600                      | /                   | 2.7–3.1                 |

From the chart data, it can be concluded that there is a large difference between GFRP bars and reinforcing bars. In the engineering, the performance characteristics of GFRP bars can be used to take advantage of them to make up for the lack of performance of the reinforcing bars.

### 3. Test plan

#### 3.1 Test model design

This experiment uses an earthquake simulation shaking table for testing. According to requirements, a prototype three-story, two-span prototype frame structure was designed in this experiment. The beam section size is 300×400mm, the column section size is 400×400mm, the plate thickness is 120mm, and the column distance is 4m. The total height is 9.75m. Beam-column longitudinal force bars are divided into GFRP bars, and the stirrups and steel bars in the plate are made of ordinary steel bars HRB335 and concrete strength grade C35. Other design parameters are shown in Table 2 below.

### Table 2 Design parameters of prototype frame structure

| category | Longitudinal beams | other materials | Ground motion parameters | Load | Seismic rating |
|----------|--------------------|-----------------|--------------------------|------|---------------|
| GFRP frame | GFRP               | C35 concrete    | 7degrees                 | Dead load 4.0KN/m² | Dead load 7.0KN/m² | Level 3 |
|          |                    | HRB335          | 0.1g                     | Dead load 2.5KN/m² | Live load 0.5KN/m² |

#### 3.2 Measuring point arrangement

Main measurement contents: acceleration of each floor, strain of GFRP bars and concrete; observation of the whole process of the structure from crack appearance, development to component yielding, and finally failure under the action of earthquakes at different levels; Observe the record and analyze its seismic performance. Based on the laboratory conditions, the model is equipped with 8 FRP tendon strain gauges and 8 concrete strain gauges, plus 32 acceleration sensors.

#### 3.3 Seismic action data

Relevant data were input for the 7 degree earthquake, 7 degree fortified earthquake action, 7 degree rare earthquake action and 8 degree rare earthquake action.

The peak acceleration of the input seismic wave during the Seven Degrees of Occurrence earthquake is 0.069g. The model was inputted with Taft unidirectional wave, El-Centro unidirectional wave, Lanzhou artificial wave and Wenchuan wave, Taft bidirectional wave and El-Centro bidirectional wave. Incentive, a total of six operating conditions.

The peak acceleration of the seismic wave input during the 7-degree fortification earthquake is 0.197g. Among them, unidirectional waves: Taft wave, El-Centro wave, Lanzhou artificial wave and Wenchuan wave, Taft bidirectional wave and El-Centro bidirectional wave. A total of eight operating conditions.

The peak acceleration input during the rare earthquake of 7 degrees is 0.433g. Among them, one-way waves: Taft wave, El-Centro wave, Lanzhou artificial wave and Wenchuan wave, Taft wave and El-Centro wave, two-way and three-way wave. A total of eight operating conditions.
The peak acceleration input during the octave rare earthquake is 0.788g. Among them, one-way waves: Taft wave, El-Centro wave, Lanzhou artificial wave and Wenchuan wave, Taft wave and El-Centro wave, two-way and three-way wave. A total of eight operating conditions.

4. Analysis of test results

The data collected through the shaking table test include signals measured by acceleration sensors and strain gauges. From a theoretical perspective, the acceleration signal can be integrated to obtain the displacement signal. In this paper, MATLAB software is used to program and process the data, and the model's natural frequency and natural period are obtained. By measuring the measured points at each measurement point, the acceleration data is eliminated by the trend term, smoothed and numerically integrated. Obtain the acceleration time history curve and displacement time history curve.

4.1 Seismic action data

Acceleration time history curve

Acceleration sensors placed on each layer of the model structure are used to collect the acceleration data of the model at each moment under different levels of earthquakes, and the acceleration time history curves of each floor are drawn. Due to space limitations, this paper gives the acceleration time history curve of the top layer under the action of some seismic waves. The acceleration time history curve of the top layer under the conditions of Taft unidirectional seismic wave under condition 1, condition 7, condition 15 and condition 23 are shown in Figure 1.

![Acceleration Time History Curves](image)

Figure 1: Time history curve of the top acceleration of the model under different levels

4.2 Displacement time history curve

The displacement time history curve of the model was obtained by MATLAB software using the frequency domain integration method. Figure 3.16 shows the time history curve of the top layer displacement of the model under the action of Taft unidirectional seismic wave. Figure 2 shows the time-history curves of the top layer displacement of the model under the action of Taft unidirectional seismic waves, take working condition 1, working condition 7, working condition 15, working condition 23 as examples.
5. Conclusion
(1) As the input seismic wave peak increases, the top acceleration peak of the model also increases, but the increase is different.

(2) During the test, the model underwent seven degrees of encounters, seven degrees of fortification, seven degrees of rare occurrences, and eight degrees of rare occurrences of earthquake damage in turn. The structure of the GFRP tendon model was damaged to varying degrees. Degradation, that is, the natural vibration period becomes longer, and the stiffness decreases.

(3) From the displacement response of the model structure at various stages, the displacement of the structural floor is small under the action of Taft wave and El-Centro wave; the displacement response of the model structure under the Wenchuan earthquake wave is the largest and the reaction is the most unfavorable, and the Lanzhou artificial wave is centered; it shows that there is a complex dependence and correlation between the floor displacement of the structure under the action of the seismic wave and the spectral characteristics of the input seismic wave and the structure itself.

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