Finite Element Analysis of FRP Reinforced Concrete Frame Embedded with FRP Reinforced Plastic Joints

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Abstract. How to improve the ductility of FRP reinforced concrete frame is the key issue to solve the seismic safety of FRP reinforced concrete frame. Based on the force deformation process and failure characteristics of FRP reinforced concrete frame structure, a FRP reinforced plastic hinge connector was developed and applied to the concrete structure, which can introduce ductility into the FRP reinforced concrete frame structure to improve its seismic performance. Pushover analysis of FRP reinforced concrete frame structure model with FRP reinforced plastic hinge connector was carried out by SAP2000. The shear force-vertex displacement curves of the base under four lateral force loading modes and the variation of the interlayer displacement angle of the structures under rare conditions are obtained. The results of analysis show that the appearance of plastic hinges significantly improves the ductility of FRP reinforced concrete frames.

1. Introduction
The seismic design of the building structure was developed on the basis of a strong earthquake damage survey [1,2]. From the simple idea of seismic design, it was originally proposed by Japan in the early twentieth century [1], and it has been widely recognized internationally that the "small earthquake is not bad, the medium earthquake can be repaired and the earthquake does not fall". Buildings designed according to current seismic design codes can exhibit excellent seismic performance in earthquakes [3]. Although the "three-level" seismic fortification concept stipulates three standards, its boundary standards are relatively vague, and it is often difficult to grasp in actual design. In fact, the purpose of the current seismic design is mainly to protect human life [4,5], but because it does not control other damages well, it will cause huge property losses. Therefore, the performance-based seismic design has gradually gained people's attention and is considered to be the mainstream direction of seismic design in the future. The use of FRP bars instead of ordinary steel bars to reduce corrosion has become an effective solution. Pushover analysis has been widely used at home and abroad, but no one has applied it to the seismic performance of FRP reinforced concrete frame structures. In the analysis, it is very necessary to study the seismic performance of FRP reinforced concrete frame structures based on Pushover.

2. Specimen design
The design example of this paper is a five-layer 4×3 span FRP reinforced concrete frame structure with FRP bar plastic hinge connector. The total height is 18.9m, of which the first layer height is 4.5m and the standard layer height is 3.6m. The plate thickness is 100 mm, the beam cross-sectional...
dimension is 250 mm × 500 mm, and the column cross-sectional dimension is 400 mm × 400 mm. The floor plan of the frame structure is shown in Figure 1.

The design has a design life of 50 years, seismic fortification intensity of 8 degrees (0.20g), frame seismic rating of 2, site category II, and design earthquake grouping as the first group. The concrete strength grade is C30, and the tensile bars and the stirrups in the beam and the column are all made of FRP bars, and the tensile strength is HRB400. FRP bar plastic hinge connectors are implanted in the plastic hinge region of the beam and column, and HRBS400 is used for stainless steel. According to the seismic requirements, the range of the beam and column stirrup encryption zone is: 1400mm at the lower end of the bottom column, 500mm at the end of the column, and 600mm at the end of the beam.

Figure 1. Structural floor plan

3. Experimental method

The three-dimensional frame structure model of FRP ribs established in this paper, beam and column selection rod unit, cast-in-situ slab selection Shell (shell) unit; unit joints using joints for simulation. The 3D framework model was built using SAP2000 software, as shown in Figure 2. Define the constant live load and analysis conditions of the structure, automatically combine the loads according to the requirements of China's specifications, and then perform the operation analysis; finally check the calculation results to complete the reinforcement.

The SAP2000 is used to perform Pushover analysis on the structure. The horizontal lateral force distribution includes uniform distribution, inverted triangle distribution and lateral force distribution according to the first-order mode and node mass. Pushover analysis of FRP reinforced concrete frame structure with FRP bar plastic hinge connector was carried out by SAP2000. Gravity analysis was first carried out. Based on the analysis results, the horizontal load grading analysis was carried out. When the horizontal load push analysis is performed, the first and second lateral loading modes are used to load the structure, that is, the loading mode of the inverted triangle and the uniform loading mode. Which is?

1. Inverted triangle distribution in the X direction: gravity load + first mode (horizontal)
2. Inverse triangle distribution in the Y direction: gravity load + second vibration mode (longitudinal)
3. Uniform distribution in the X direction: gravity load + acceleration in the X direction (lateral)
4. Uniform distribution in the Y direction: gravity load + acceleration in the Y direction (longitudinal)
4. Experimental phenomena and analysis

4.1 Bottom shear force-vertex displacement curve

As can be seen from the above figure:

1. In the same nappe direction, the trend of the Pushover curve formed by the inverted triangular distribution and the uniform distribution is basically similar, except that the values of the base shear force and the vertex displacement corresponding to different nappe steps are the difference. However, in different push-over directions, the development trend of the push-pull curve in the X direction is relatively flat, while the push-over curve in the Y direction has a relatively obvious turning point.
(2) The deformation of the FRP reinforced concrete frame structure with FRP bar plastic hinge connector is gradually changed from the elastic phase to the elastoplastic phase. The FRP bar plastic hinge connector is used to introduce the ductility into the FRP reinforced concrete frame structure.

(3) Comparing the structures under the four load modes, the inverted triangular distribution has large shearing force and small apex displacement, indicating that the ductility of the structure is poor under its action. However, the base shear force and the vertex displacement uniformly distributed in the X and Y directions are relatively stable, which indicates that the structure has better ductility under the uniform lateral force.

4.2 Structural interlayer displacement angle

![Figure 4. Inter-layer displacement angle of the structure under rare conditions](image)

According to the interlayer displacement angle curve of the X direction and the Y direction of the figure, it can be concluded that:

(1) The maximum displacement angle in the X direction is 1/52, and the maximum displacement angle in the Y direction is 1/51, which is in line with the requirements of the displacement angle of the frame structure in the "Code for Seismic Design of Buildings".

(2) Under the four lateral force load modes, the weak layer of the structure basically appears in the second layer of the structure at first, but with the increase of the number of push steps, the nappe force gradually increases, and the structure is weak. The layers change and appear on the first layer of the structure. This is consistent with the response of the frame structure in actual earthquakes.

4.3 Structural plastic hinge analysis

Most of the plastic hinges that appear in the structural beam are in the IO (immediate use) phase, with only a small portion being in the LS (life safety) phase. The plastic hinges of the columns appear only on layers 1-2. They are both in the IO (Immediate Use) phase and less than the LS (Life Safety) state. It can be seen that the FRP reinforced concrete frame structure with plastic FRP ribs has a plastic
hinge at the beam end and the column end, which makes the structure ductile and prevents brittle failure of the frame structure.

5. Conclusions

(1) Selection of lateral forces. By comparing the Pushover curves of the structure in the four load modes, the base shear force and the vertex displacement in the X direction are slightly larger than the Y direction. Moreover, the uniform distribution in the Y direction is smaller with respect to the inverted triangular distribution when the change in the shear force of the base is the same. Therefore, from the overall point of view, the undercut triangle has a large shear force and a small apex displacement, indicating that the ductility of the structure is poor under its action. However, the base shear force and the vertex displacement uniformly distributed in the X and Y directions are relatively stable, which indicates that the structure has better ductility under the uniform lateral force. Therefore, when selecting a model of lateral force, a uniformly distributed lateral force model in the X direction should be preferred.

(2) The displacement angle between the structural layers. In this paper, the structure is subjected to Pushover analysis by using the lateral force distribution of different modes and different directions, and the maximum value of the inter-layer displacement angle all appear in the first layer. It is indicated that the first layer is a weak layer of the frame structure. Moreover, the value is larger than the interlayer displacement angle obtained by the vibration mode decomposition reaction spectrum method and the bottom shear force method. And they all meet the requirements of China's norms.

(3) Plastic hinges. When the structure reaches the performance point, the appearance stage of the plastic hinge is all less than the LS (life safety) stage. Therefore, the structure can meet the requirements of "the big earthquake does not fall." And during the napping process, most of the plastic hinges that appear in the structural beam are in the IO (immediate use) phase, and only a small portion is in the LS (life safety) phase. The plastic hinges of the columns appear only on layers 1-2. They are both in the IO (Immediate Use) phase and less than the LS (Life Safety) state. This shows that the safety performance of the structure can be guaranteed. And the appearance of plastic hinges compensates for the lack of ductility of pure FRP reinforced concrete frames.

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