Study on Axial Compression Performance of GFRP Tube Reactive Power Concrete Composite Short Columns with Encased Steel

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Abstract: In order to study the axial compression performance of the GFRP tube reactive power concrete composite short column with encased steel, a finite element model of the composite short column was established. The constitutive models of steel, RPC and GFRP were selected. The element selection and contact method of each component were explained. The boundary condition and mesh division of the composite column were determined. Based on this, finite element verification analysis of 6 specimens was performed by ABAQUS. The load-displacement curves and the axial compression bearing capacity were obtained. By comparing with the test, the reasonability of the constitutive model and the finite element model of this kind of column is verified.

1. Introduction
In recent years, there have been many studies on confined RPC composite columns, steel tube confined steel concrete composite columns and FRP confined concrete composite columns. B. Zhang[1] carried out the axial compression test of six GFRP tube confined concrete short columns, and the influence of GFRP tube fiber winding angle and thickness on axial compression performance was explored. H. Ma[2] developed the axial compression test of 11 GFRP tubular recycled concrete composite short columns with encased steel, and the effect of steel ratio, slenderness ratio and strength of recycled concrete on axial compression performance was obtained. H. B. Li[3] carried out the axial compression test of three RPC composite columns with encased steel, and the influence of different RPC strength on axial compression performance and failure characteristics was explored. L.T. Pu[4] promoted three the axial compression performance test of the root-wrapped RPC column with encased steel, and the influence of RPC strength on the axial compression performance of the composite column was obtained. To investigate the influences of the concrete strength grade, the nominal slenderness ratio, the hoop coefficient and the flange width on the nonlinear stability capacity of
SHTCC column, finite element model[5] of 30 STHCC was established and the nonlinear buckling load formula was established. J. Ji[6] carried out axial compression experiment of 16 STHCC short column. The influences of the constraint effect coefficient, cubic concrete compressive strength, honeycombed web thickness and slenderness ratio on the axial compression bearing capacity of STHCC short columns and the stress mechanism were analyzed.

Although there is lots of research on RPC and FRP-confined concrete, there is little research on combining GFRP tube with RPC. GFRP tube RPC composite short columns with encased steel are proposed in this paper, and finite element model is established, at last, by comparing with test data the reasonability of finite element model is verified.

2. Finite Element Model

2.1. Material Constitutive Model

2.1.1. Constitutive Model for Steel. Double-broken line elastic-plastic constitutive model considering hardening was adopted for the constitutive model of the steel, as shown in figure 1.

![Steel constitutive model](image1.png)

2.1.2. Constitutive Model for RPC. The constitutive model of constrained concrete is adopted for RPC[10]. J.B. Mander[11], J.G. Teng[12], M. Pagoulatou[13] and L.H. Han[14] have successively given constitutive model (CM) in recent years. In addition, the non-constrained concrete constitutive model[15] is introduced for comparing with above constitutive model, and the constitutive curves are shown in figure 2. The load-displacement curves obtained by different constitutive model are shown in figure3, by comparing with the curve of experiment, it can be seen that the constitutive model of L.H. Han is reasonable as constitutive model of RPC.

![Comparison of different concrete constitutive model](image2.png)
2.1.3. Constitutive Model for GFRP. The constitutive model of GFRP is anisotropic. The parameters which need to be input in this paper adopt the experimental data of Y.X. Wang[16]. The specific parameters are shown in Table 1.

| $E_1$/MPa | $E_2$/MPa | $v_{12}$ | $G_{12}$/MPa | Horizontal($X_T$)/MPa | Vertical($X_C$)/MPa | Horizontal($X_T$)/MPa | Vertical($X_C$)/MPa |
|-----------|-----------|----------|--------------|------------------------|---------------------|------------------------|---------------------|
| 52000     | 8000      | 0.35     | 3000         | 795                    | 533                 | 43                     | 187                 |

2.2. Unit Selection and Contact Methods

The finite element model of GFRP tube RPC composite short column with encased steel was established by ABAQUS. The C3D8R element is selected for steel and RPC, and the S4 is adopted for GFRP tube. The hard contact is adopted between steel and RPC in the normal direction. The friction contact considering relative slip is adopted in the tangential direction, and the friction coefficient is determined as 0.5[17]. GFRP tube and RPC are connected by tie, and shell-solid coupling is adopted for the contact between plate and GFRP tube. The finite element model is shown in figure 4.

2.3. Boundary Conditions and Mesh Division

Reference points RP1 and RP2 are set at a distance of 10mm outside the upper and lower boundaries, then both are coupled with the upper and lower sections. The lower reference point is completely fixed and a vertical displacement is applied to the upper reference point. In figure 5, there are four mesh sizes of 10mm, 20mm, 40mm, and 80mm respectively. It can be seen that 40mm is more reasonable for mesh division.

Figure 3. Load-displacement curves of different constitutive model

Figure 4. Finite element model of GFRP tube RPC composite short column with encased steel
3. Finite Element Verification Analysis

The finite element verification analysis was carried out on 6 specimens by the above-mentioned method, and the axial load-displacement curves were obtained as shown in figure 6. By comparing with the test curves, it can be seen that the load-displacement curves obtained by the simulation and the experiment have good agreement, and the maximum error is 2.22%. The comparison of bearing capacity by simulation and experiment is shown in table 2. In addition, the stress diagram of the specimen CS-I100-C30 is shown in figure 7.

| Experiment | Specimen Number | $N_u^T$ /KN | $N_u^S$ /KN | $|N_u^S - N_u^T| / N_u^T \times 100\%$ |
|------------|-----------------|--------------|--------------|-------------------------------------|
| Q. Rong[7] | m-219-8         | 6210.24      | 6312.72      | 1.65                                |
|            | m-279-8         | 8235.29      | 8052.29      | 2.22                                |
| Y.B. He[8] | SC1             | 3995.27      | 4052.74      | 1.44                                |
|            | SC2             | 3891.51      | 3848.08      | 1.12                                |
| W.W. Yang[9]| C-C30          | 836.81       | 841.72       | 0.59                                |
|            | CS-I100-C30     | 975.92       | 975.56       | 0.04                                |
4. Conclusion

The following conclusions are drawn based on the above-mentioned finite element verification analysis:

(1) The RPC constitutive model, the bilinear constitutive model of steel and the anisotropic GFRP constitutive model are identified by finite element simulation analysis.

(2) A simulation method for GFRP tube RPC composite short column with encased steel is proposed. Suitable elements and contact method are selected, and boundary condition and meshing division are determined.

(3) 6 short composite columns were performed finite element verification analysis by ABAQUS. The bearing capacity is extracted and compared with the test data. The maximum error is 2.22%, which meets the engineering requirements.

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