Experimental Verification on Finite Element Model of Composite Columns with Concrete Filled Steel Tube Flange

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Abstract: In order to study mechanical performance of composite columns with concrete-filled steel tube flange subjected to the eccentric compression, the finite element model of this kind of composite columns is established by using ABAQUS finite element software. In this paper, the reasonable material constitutive and finite element modelling method are selected to carry out numerical simulation analysis of concrete-filled steel tubular composite columns and concrete-filled square steel tubular columns. The load vertical displacement curves, load lateral deflection curves and failure modes are obtained, which are in good agreement with the existing test data. The rationality of material constitutive and finite element modelling is verified, which lays a foundation for further establishing the calculation formula of eccentric compression bearing capacity of this kind of column.

1. Introduction

The composite column with concrete-filled steel tube (CFST) flange is a new type of composite column formed by connecting two rectangular CFST flanges with honeycomb steel webs, as shown in figure 1. The core concrete can effectively delay and prevent the local buckling of steel tube and the instability failure of the specimen. At the same time, the steel tube plays a restraint role on the core concrete. The core concrete is in the three-dimensional compression state under the action of steel tube, which can effectively improve the compressive strength and resistance to deformation of the core concrete. The honeycomb steel webs can reduce the dead weight of the structure and connect the two legs as a whole to carry the load together, so as to effectively improve the bearing capacity and deformation resistance of composite columns. The ultimate bearing capacity, ductility and stability bearing capacity of this kind of composite column will be much better than those of ordinary CFST column and honeycomb column[1].

Experts and scholars at home and abroad have done a lot of research on concrete-filled steel tubular column and honeycomb column. G. Balaji[2] applied low-speed axial load on square hollow aluminium column and honeycomb aluminium column, and established solid model by using finite...
element software. The experimental data and numerical simulation results are in good agreement. M. Ahmed[3] established a model of uniaxial local bending and global buckling behaviour of high-strength concrete-filled square steel tubular slender beams and columns (DCFST) under axial compression, and obtained the interaction curve of CFDST slender beams under eccentric loading. S. Jayaganesh[4] studied the mechanical properties of six CFST columns under local axial compression, and gave the calculation formula of axial compression bearing capacity. At present, the research of composite column with CFST flange is mainly focused on the axial compression and stability performance, but the research on the eccentric compression performance of this kind of column is less. In this paper, the finite element models of CFST flange composite column and concrete-filled square steel tube(CFT) column are established by using ABAQUS finite element software with reasonable material constitutive model and finite element modelling method. Through the numerical simulation analysis of CFST flange and CFT column, the load vertical displacement curves, load lateral deflection curves and failure modes of specimens are obtained respectively. Compared with the existing test results, the rationality of the finite element modelling in this paper is verified.

![Figure 1. The honeycomb composite column with CFST flange](image)

2. Finite element modeling and experimental verification

2.1. Material constitutive model

2.1.1. Steel. The ideal elastic-plastic constitutive model is adopted for the constitutive model of steel, as shown in figure 2.

![Figure 2. Constitutive model of steel](image)

2.1.2. Concrete. The constitutive model of confined concrete proposed by L.H. Han [5] is adopted. The stress-strain curve of concrete under compression is as follows:
\[
y = \begin{cases} 
2x - x^2 & (x \leq 1) \\
\frac{x}{\beta_0(x-1)^{\frac{1.6}{x^2}} + x} & (x > 1)
\end{cases}
\]  
(1)

Among them: \( x = \varepsilon / \varepsilon_0 \); \( y = \sigma / \sigma_0 \); \( \sigma_0 = f_c \); \( \varepsilon_0 = (1300 + 12.5f_c)10^{-6} + 800\xi^{0.2} \cdot 10^{-6} \).

The stress-strain curve of concrete under tension is as follows:

\[
y = \begin{cases} 
1.2x - 0.2x^6 & (x \leq 1) \\
\frac{x}{0.31\sigma_p^2(x-1)^{1.7} + x} & (x > 1)
\end{cases}
\]  
(2)

Among them: \( x = \varepsilon_c / \varepsilon_p \); \( y = \sigma_c / \sigma_p \); \( \sigma_p = 0.26 \times (1.25f_c)^{2/3}; \varepsilon_p = 43.1\sigma_p \). The physical meaning for each variable is referred in literature[5].

2.2. Establishment of finite element model

The full-scale 3D solid geometric model of CFST column is established by ABAQUS finite element software, as shown in figure 3. Eight node three-dimensional solid element (C3D8R) is used for rectangular steel tube, honeycomb steel web and concrete. The hard contact in the normal direction and the friction contact in the tangent direction are combined between the steel tube and concrete, and the friction coefficient \( \mu \) is 0.25. Two reference points RP1 and RP2 are set at the load action position outside the two ends of the specimen, and the reference points are coupled with the two end faces of the column. The displacement load in the member direction \( (U_x=U_y=UR_x=UR_y=0) \) is applied at the upper end of the column, and the fixed boundary condition \( (U_x=U_y=UR_x=UR_y=0) \) is applied at the lower end.

![Finite element model of specimen](image)

3. Finite element model verification

3.1. Verification of axial compression test

In the early stage, the research group carried out the axial compression performance test of this kind of column[6]. Using the above material constitutive model, the numerical simulation analysis was carried out on three axial compression test specimens of this kind of composite column, and the vertical load vertical displacement whole process curve and failure mode of the column were obtained, and compared with the existing test results, as shown in figure 4 and figure 5. Through the comparison, it can be seen that the finite element simulation curve is in good agreement with the test curve, and the
maximum error between the simulation value ($N_a$) and the test value ($N_t$) is 2.87%, which meets the engineering accuracy requirements. From figure 4, figure 5 and table 1, it can be seen that the material constitutive model used in this paper is reasonable.

![Figure 4. Comparison between simulation and test curves for composite columns with CFST flanges](image)

| Specimen number | $h_w \times h_1 \times h_2 \times t_1 \times t_2$ (mm) | $L$ /mm | $f_{cuk}$ /MPa | $N_a$ /kN | $N_t$ /kN | $\frac{N_a - N_t}{N_t \times 100\%}$ |
|-----------------|--------------------------------------------------|--------|---------------|----------|----------|----------------------------------|
| HCC-1           | 100×50×100×3.8×0.6 | 370    | 40            | 1193.87  | 1182.15  | 0.99                             |
| HCC-2           | 100×50×100×2.3×0.6 | 370    | 50            | 1037.13  | 1067.75  | 2.87                             |
| HCC-3           | 100×50×100×2.3×0.6 | 370    | 60            | 1168.35  | 1173.69  | 0.45                             |

3.2 Boundary condition verification

Based on the material constitutive model and finite element modeling method mentioned above, three existing concrete-filled square steel tubular specimens under eccentric compression in reference[7] are simulated by finite element method, and the vertical load mid span lateral deflection curve and failure mode of the specimens are obtained, which are compared with the test results, as shown in figure 6 and figure 7. The maximum error between the simulated value ($N_a$) and the experimental value ($N_t$) is 5.24%, which meets the engineering accuracy requirements. It can be seen from figure 6, figure 7 and
table 2 that the boundary constraint conditions proposed in this paper are reasonable.

| Specimen number | \( L / \text{mm} \) | \( e / \text{mm} \) | \( f_{\text{uk}} / \text{MPa} \) | \( f_{\gamma} / \text{MPa} \) | \( N_t / \text{kN} \) | \( N_a / \text{kN} \) | \( \frac{N_t - N_a}{N_a} \times 100\% \) |
|-----------------|-----------------|----------------|-----------------|-----------------|----------------|----------------|-----------------|
| SC40-150-0.2    | 1180            | 13.0           | 43.2            | 488.4           | 2470           | 2576.11        | 4.30            |
| SC40-180-0.2    | 1180            | 18.5           | 43.2            | 488.4           | 2660           | 2520.53        | 5.24            |
| SC50-200-0.2    | 1180            | 19.0           | 55.3            | 488.4           | 2625           | 2608.31        | 0.64            |

Figure 6. Comparison between simulated curves and experimental curves for CFT columns

Figure 7. Comparison of simulated and experimental failure modes for CFT columns

4.Conclusion
In this paper, based on the finite element software ABAQUS, the axial and eccentric compression performance of composite columns with concrete-filled steel tube flange and concrete-filled square steel tube columns are simulated and analyzed respectively. By selecting reasonable material constitutive model and finite element modeling method, the load vertical displacement curve, load lateral deflection curve and failure mode of specimens are obtained respectively, and compared with the existing test results, the results show that the two methods are effective. The maximum error is 5.24%. It can be seen that the reliability of the finite element model established in this paper lays a foundation for the study of the eccentric bearing capacity of composite columns with concrete-filled steel tube flanges.

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