Numerical Analysis of Axial Compression Performance of Concrete Filled Double Steel Tube Short Columns

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Abstract. For the purpose of obtaining the axial compressive performance of the concrete filled double steel tube (CFDST) short columns, four CFDST specimens were designed in this paper. Based on a simplified bilinear constitutive model for steel and a nonlinear constitutive model considering the hoop effect for concrete, and four short columns under axial compression were established by ABAQUS finite element (FE) software which can obtain the load-displacement curves and destructive forms, by compared with the existed experimental data the rationality of finite element model is verified. These can lay the foundation for further analysis of the extended parameters and seismic performance for composite columns.

1. Introduction

Concrete filled double steel tube (CFDST) short column which is formed by two concentric steel tube, an inner and an out, and concrete filling between the void of steel tube. The strength of the concrete can be equal or difference. Between the steel tube and concrete under axial compression there have an interaction, which is the core concrete is reinforced by the inner steel tube and the sandwich concrete reinforced by inner and outer steel tube, so that the core and sandwich concrete is in a three-direction stress state which significantly improve the bearing capacity of the whole system and greatly improve the plasticity and toughness. Due to the effect of concrete, which is delay or avoid premature local buckling and instability damage of the steel tube, and due to the effect of steel tube which can constraint the lateral deformation and improve the ultimate strength. Both of this assembly is take full advantage of the material properties. In addition, amongst the construction process of CFDST short column, steel tube can also be used as a template for pouring concrete. It can save the cost and speed up the construction progress.

There is a growing body of literature that research the prominent and distinctive characteristics of CFDST short column. As early as in the 1980s, J B Mander[1] studied the mechanical mechanism of concrete filled steel tube system, determined the failure stress of the members through the theory of energy balance, and proposed the stress-strain of confined concrete under various cross-section forms. ABAQUS finite element software was used to simulate the hollow double-tube concrete composite column by M Pagoulatou[2] and based on European norm, the calculation method of the bearing capacity of the members was proposed. Ekmekyapar[3] carried out an experimental study on the axial compression performance of 30 CFST short columns. The results show that the CFDST short columns greatly improve the bearing capacity, ductility and stiffness. L H Han[4] carried out a series of...
experiments on CFST axial compression short column specimens, the results show that the CFST has good ductility and load carrying capacity. Q Cai[5] compared the bearing capacity between concrete filled single and double steel tube short columns, and discussed the stress mechanism of concrete filled double steel tube short columns and the stress state of concrete and steel pipes under the limit state of bearing capacity. C Y Wan[6] carried out 7 concrete filled double steel tube short-column specimens, and gave the deformation form and bearing capacity calculation method of the composite columns. Based on the existing experimental data, ABAQUS FE software is used to simulate four specimens, the load-displacement relationship curves of them are obtained, at last the reasonability of the constitutive model is verified.

2. Finite element model

2.1. Constitutive model of Material

2.1.1. Constitutive model of Steel. The steel tube adopts the elastoplastic constitutive model, and the constitutive model is shown in figure 1, where $E_1$ is taken as 0.01 $E_s$[2]. The stress-strain curve consists of two parts: the elastic phase and the strengthening phase.

![Figure 1. Constitutive model of steel tube.](image1)

![Figure 2. Different constitutive models of concrete.](image2)

2.1.2. Constitutive model of Concrete. The CFDST short column is made up of inner and outer steel tubes, sandwich concrete and core concrete. The inner and outer steel tubes have certain restraining effects on the core and the sandwich concrete. This paper uses the combined hoop effect coefficient $\xi$ [7-8] to reflect the combined effect between the steel tubes and concrete. Different constitutive models of concrete are shown in figure 2. The constitutive model given by L H Han is shown as follows.

\[
\begin{align*}
\varepsilon &= \frac{A_k}{A} \left( \frac{A_{\alpha}f_{\alpha}}{A_{\alpha}f_{\alpha}} + \frac{A_{\sigma}f_{\sigma}}{A_{\sigma}f_{\sigma}} \right) \\
\varepsilon_0 &= \frac{A_{\phi}}{A_{\phi}} f_{\phi}
\end{align*}
\]

The uniaxial compressive stress-strain relationship of concrete is as follows:

\[
y = \begin{cases} 
2x - x^2 & (x \leq 1) \\
\frac{x}{\beta_x \cdot (x-1)^{(1.6 + 1.5)}} + x & (x > 1)
\end{cases}
\]
Where: $f_c$ is the ultimate compressive strength of ordinary concrete is the peak compressive strain, $\varepsilon_0$ is the peak compressive stress, $A_{c}, A_{s}$ are the cross-sectional area of the CFDST short column, the concrete cross-sectional area and the cross-sectional area of the steel tube. $f_y$ is the design value of the ultimate tensile strength of the steel tube, and $f_{ck}$ is the Standard value for ultimate tensile strength of the steel tube.

The uniaxial tensile stress-strain relationship of concrete is as follows:

$$
y = \begin{cases} 
1.2 \cdot x - 0.2 \cdot x^6 & (x \leq 1) \\
\frac{x}{0.31 \sigma_p^\gamma \cdot (x - 1)^{1/3} + x} & (x > 1)
\end{cases}
$$

Where, $\sigma_p$ is the peak tensile stress and $\varepsilon_p$ is the peak tensile strain, which is calculated as follows:

$$
\sigma_p = 0.26 \cdot (1.25 \cdot f_c)^{2/3}
$$

$$
\varepsilon_p = 43.1 \cdot \sigma_p (\mu e)
$$

2.2 Finite element model

2.2.1 Element selection and contact method. Based on the FE software ABAQUS, the FE model of CFDST short column is established. Both the steel tube and the concrete adopt the eight-node three-dimensional solid element (C3D8R). The interface contact model between steel tube and concrete is considered by the hard contact and tangential direction of the normal direction. It is composed of a frictional contact with respect to the bond slip.

2.2.2 Boundary conditions and meshing. The FE model sets a reference point 10 mm away from the upper and lower boundaries, and the reference point and the upper and lower boundaries are coupled to force the deformation to be consistent, thereby replacing the role of the platform pad. The lower reference point is a fixed constraint, the three-direction displacement and rotation at the bottom of the control column; the upper reference point adopts the displacement loading method, and the displacement deformation acts on the upper surface of the member through the reference point, and the loading displacement is 20 mm. Grid meshing of CFDST short column are shown in figure 3.

(a). Core concrete. (b). Inner steel tube. (c). Sandwich concrete. (d). Outer steel tube. (e).Column.

Figure 3. Grid meshing of CFDST short column.

2.3 Load-displacement curve and experiment verification

2.3.1 Comparison of two different concrete constitutive models. In this paper, two kinds of constitutive models proposed by M Pagoulatou[2] and L H Han[7] were used to simulate the experiment specimen CC1-SC1-OT1[3], and the load-displacement curve obtained by simulation is shown in figure 4. It can be seen from the comparison that it is more reasonable to simulate such components by using the constitutive model proposed by L H Han.
Figure 4. Load-displacement curve of CC1-SC1-OT1 under different concrete constitutive models.

Table 1. Experiment specimen parameters.

| Specimen     | h (mm) | $f'_c$ (MPa) | $D_i$ (mm) | $t_i$ (mm) | $f'_y$ (MPa) | $f'_o$ (MPa) | $D_o$ (mm) | $t_o$ (mm) | $f'_o$ (MPa) |
|--------------|--------|--------------|------------|------------|--------------|--------------|------------|------------|--------------|
| CC1-SC1-OT1  | 270    | 30.55        | 88.9       | 4.25       | 375          | 30.55        | 139.7      | 3.30       | 290          |
| CC2-SC1-OT2  | 270    | 68.09        | 88.9       | 4.25       | 375          | 30.55        | 139.7      | 5.87       | 355          |
| s7           | 880    | 51           | 102        | 8          | 331.3        | 51           | 219        | 8          | 325          |
| s24          | 880    | 90           | 89         | 4.5        | 392.5        | 90           | 219        | 6          | 312.5        |

A large number of experimental studies of such components have been carried out in the literature[3,4]. Based on the above constitutive model considering the hoop effect, the FEM is used to simulate the existing experiment specimens. The specific parameters are shown in table1. Four experiment specimens are simulated by the above modeling method. The simulation results are compared with the experiment curves as shown in figure5. There are good agreement not only in the damage location but also in the failure mode. It can be seen that the FEM is reasonable.
Figure 5. Comparison between the experiment data and FEM results.

Table 2. Comparative analysis of the bearing capacity for four specimens.

| Specimen   | $N_a$ (kN) | $N_t$ (kN) | $N_a/N_t$ |
|------------|-------------|-------------|------------|
| CC1-SC1-OT1| 1300.25     | 1355.26     | 0.95       |
| CC2-SC1-OT2| 1750.28     | 1570.95     | 1.11       |
| s7         | 5128.43     | 5225.16     | 0.98       |
| s24        | 5486.75     | 5501.28     | 0.99       |

Table 2 gives the comparison between the simulated value($N_a$) and the experimental value($N_t$) of the bearing capacity of the four specimens subjected to axial load. It can be seen that the results are in good agreement with the experimental data, and the maximum error is within the engineering allowable range.

3. Conclusion

In this paper, ABAQUS is used to introduce the FE modeling process of CFDST short columns. There are carried out simulation analysis of four existing experiment specimens. The results are in good agreement with the experimental data, and the constitutive model of the effect is reasonable, which lay the foundation for further establishing the calculation formula of the axial bearing capacity of the column.

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