Mechanical Behavior of L-Shaped Concrete Filled Steel Tubular Columns under Axial Compression

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Abstract. L-shaped concrete-filled steel tubular column (CFST) has the advantages such as high bearing capacity, good ductility and high utilization rate of internal space of the building, thus avoiding the occurrence of column shearing in the indoor use space. In engineering application, the axial bearing capacity of CFST is very important for the stability of structure, and is an extremely significant mechanical performance index. Finite element (FE) models are established to calculate the load-deformation curves and the calculated results are verified by the experiments. On this basis of FE models, the parameters of wide-to-limb ratio, steel yield strength, concrete cylinder strength and steel thickness are analyzed. It indicates that the calculation method of axial bearing capacity based on superposition theory is basically suitable for L-shaped concrete filled stub column structure in the ranges of the parameters.

Keywords: CFST; L-shaped; column; axial compression; ultimate strength.

1. Introduction

As early as 1879, concrete-filled steel tubular was applied to the piers of severn railway bridge in Britain. In the former Soviet union, the axial and bias properties of concrete-filled steel tubes have also been studied in depth. Moreover, scholars from the United States, Australia, Japan and other countries have studied and applied the main high-strength concrete filled steel tube in engineering. In China, the research on concrete-filled steel tube mainly focuses on the concrete-filled steel tube structure with rectangular section and circular section. It is an internal filled concrete-filled steel tube structure filled with plain concrete. On the basis of previous studies, this paper selects a reasonable constitutive relationship between steel and core concrete, and uses the finite element analysis program Abaqus to establish a three-dimensional nonlinear finite element analysis model of L-shaped concrete-filled steel tubular stub column under axial compression. The load-deformation relationship of the axial compression test members of L-shaped concrete-filled steel tube stub column in this paper’s references is checked and calculated. The calculated results are in good agreement with the experimental results. Based on this model, 34 examples of axial compression calculation of L-shaped concrete-filled steel tubes are analyzed, and the calculation results show that the bearing capacity calculation method based on the superposition theory proposed in literature [1] is basically applicable to L-shaped concrete-filled steel tubes. However, in the perspective of safety, it is recommended to multiply the relevant safety factor on the bases of superposition theory. The calculation formula is shown in formula 1.

\[ N_\mu = f_c A_c + f_y A_s \] (1)
2. Finite element calculation

2.1 Establishment of finite element model

Establishing an appropriate 3d nonlinear finite element model is the key to accurately and effectively analyze the mechanical properties of concrete-filled steel tubular composite structures. The stress-strain relation is the physical relation of engineering structural materials and the macroscopic behavior expression of its internal microscopic mechanism. In this paper, the finite element calculation model adopts the constitutive relation model proposed in literature [2], where the L-shaped section correction is equivalent to the rectangular section of equal length and width. The steel pipe adopts the shell element (S4R) with four-node reduction integral format, and the Simpson integral with 9 points in the direction of shell element thickness. Core concrete is a three-dimensional solid element (C3D8R) with an eight-node reduced integral scheme. Figure 1 shows the division of steel tube and core concrete elements in a typical L-shaped concrete-filled steel tube column. This model adopts the interface model proposed in literature [3], which is composed of interface normal contact and tangential bonding slip. Relative sliding occurs between interfaces. Friction penalty formula allowing elastic sliding is adopted in the calculation, in which the interface model coefficient between steel tube and core concrete is set as 0.6.

![Steel mesh division](image1)

![Concrete mesh division](image2)

Figure 1. Grid diagram

2.2 Verification of finite element model

In order to verify the reliability and accuracy of finite element calculation results, some axial compression specimens in literature [4] and literature [5] were simulated. The comparison between the finite element calculation curve of mean longitudinal strain relation and the experiment is shown in figure 2 and figure 3. As you can see from figure 2 and figure 3, the variation trend of the finite element calculation curve is similar to the experimental curve. Therefore, the finite element calculation results have certain reliability and accuracy. The calculation results of bearing capacity are summarized in table 1 and table 2.

| No. | Specimen number | Specimen length(mm) | $D_0 \times B_0 \times t_0$ (mm) | Stiffener | $f_y$ (MPa) | $f_{cu}$ (MPa) | $N_e$ (kN) | $N_{fe}$ (kN) | $N_e / N_{fe}$ |
|-----|----------------|---------------------|--------------------------|-----------|------------|-------------|-----------|-------------|---------------|
| 1   | LRA-1          | 900                 | 300×150×5                | 45×28×4   | 320        | 53.1        | 4891      | 4628        | 0.946         |
| 2   | LRA-2          | 900                 | 300×150×5                | 45×28×4   | 320        | 53.1        | 4875      | 4628        | 0.949         |
| 3   | LRB            | 900                 | 300×150×6                | 45×28×4   | 300        | 53.1        | 4852      | 4905.3      | 1.011         |
| 4   | LRC            | 900                 | 300×100×6                | 45×28×4   | 300        | 53.1        | 4059      | 3698.9      | 0.911         |

Note: $R$ means specimens with stiffener. $N_e$ means Actual carrying capacity. $N_{fe}$ means bearing capacity of Finite element calculation. Mean of $N_{fe} / N_e$ is equal to 0.954 and the mean square error is equal to 0.0416.
3. Parameter analysis

In multi-storey and high-rise commercial and residential buildings, the width of L-shaped concrete-filled steel tubular column is taken as the thickness of the wall, generally 200mm. In this paper, a total of 34 specimens were designed in an equal proportion of 1:1. The section details of the specimens are shown in Figure 4. The limb width B of the specimen was set at 200mm, the section...
aspect ratio D/B was set at 2, 2.5 and 3, the steel tube thickness was set at 20mm, 25mm and 30mm, the steel yield strength fy was set at 200MPa, 400mpa, 600mpa and 800mpa, and the axial compressive strength f'c of the concrete cylinder was set at 20 mpa, 40mpa, 60mpa, 80mpa and 110mpa, respectively. The calculation results of axial compression bearing capacity are shown in table 3. Figure 5 is a typical axial compressive stress-strain curve of l-shaped concrete-filled steel tube. As shown in figure 5, the axial load of CFST column comes from the superposition of the axial force provided by steel tube and inner concrete. What’s more, the restraint effect of steel tube on core concrete is the key factor to improve the axial bearing capacity of concrete-filled steel tube. Compared with rectangular concrete-filled steel tubes of equal length and width, the restraint effect of steel tubes on core concrete in L-shaped concrete-filled steel tubes is obviously weaker than that of rectangular concrete-filled steel tubes, which is caused by the fact that steel tubes at the middle and negative corners of L-shaped concrete-filled steel tubes are subject to compression and bending deformation earlier than those at the positive corners, failing to form a better hoop effect. The axial bearing capacity of CFST short columns calculated according to formula 1 is slightly higher than that calculated by finite element simulation. Therefore, in the perspective of safety, the calculation of axial bearing capacity of L-shaped concrete-filled steel tube is suggested to be based on the superposition theory which were multiplied by the relevant safety factor in practical engineering application. That is, the modified superposition theory calculation method. The calculation formula is shown in formula (2).

\[ N_{\mu} = \varphi (f_c A_c + f_y A_s) \]  

(2)

![Figure 4. Section of L-Shaped CFST](image)

![Figure 5. N-ε curves for a typical L-Shaped CFST](image)

| NO. | D/B | fy (MPa) | fc' (MPa) | t (mm) | Ns (kN) | Ne (kN) | Nu (kN) | Ne (kN) | Nu (kN) | Ne (kN) |Nu/Ne |
|-----|-----|----------|-----------|--------|---------|---------|---------|---------|---------|---------|------|
| L1  | 2.5 | 200      | 200       | 25     | 9500    | 2250    | 11750   | 11585.7 | 8982.61 | 2556.91 | 1.014181 |
| L2  | 2.5 | 200      | 50        | 25     | 9500    | 5625    | 15125   | 14921.9 | 9059.46 | 5699.51 | 1.013611 |
| L3  | 2.5 | 200      | 80        | 25     | 9500    | 9000    | 18500   | 18245.7 | 9113.17 | 8830.56 | 1.013938 |
| L4  | 2.5 | 200      | 50        | 25     | 9500    | 12375   | 21875   | 21495.8 | 9161.3 | 12050.1 | 1.017641 |
| L5  | 2.5 | 200      | 80        | 25     | 9500    | 25500   | 34875   | 34315.4 | 17382.2 | 16933.2 | 1.017461 |
| L6  | 2.5 | 200      | 50        | 25     | 9500    | 5625    | 24662   | 24171.7 | 17839.6 | 6096.16 | 1.018753 |
| L7  | 2.5 | 200      | 80        | 25     | 9500    | 9000    | 28000   | 27448.1 | 17869.4 | 9264.19 | 1.020107 |
| L8  | 2.5 | 200      | 50        | 25     | 9500    | 12375   | 31375   | 30778.2 | 18120.2 | 12385 | 1.02536 |
| L9  | 2.5 | 200      | 80        | 25     | 9500    | 25500   | 34875   | 34315.4 | 17382.2 | 16933.2 | 1.017461 |
| L10 | 2.5 | 600      | 20        | 25     | 28500   | 2250    | 30750   | 30778.2 | 26681 | 3733.73 | 0.999084 |
| L11 | 2.5 | 600      | 50        | 25     | 28500   | 5625    | 34125   | 33472.6 | 26205.2 | 6813.83 | 1.019491 |
| L12 | 2.5 | 600      | 80        | 25     | 28500   | 9000    | 37500   | 36688.7 | 26436.6 | 9829.28 | 1.022671 |
| L13 | 2.5 | 600      | 50        | 25     | 28500   | 12375   | 40875   | 39938.2 | 26706.4 | 12804 | 1.023456 |
| L14 | 2.5 | 600      | 80        | 25     | 28500   | 40875   | 44250   | 44638.4 | 28236.8 | 14215.6 | 1.025186 |
| L15 | 2.5 | 600      | 50        | 25     | 28500   | 74250   | 50625   | 50275.5 | 29955.6 | 12329.9 | 1.025754 |
| L16 | 2.5 | 600      | 80        | 25     | 28500   | 108750  | 55075   | 54757.1 | 30427.6 | 13329.5 | 1.026311 |
| L17 | 2   | 200      | 20        | 20     | 6080    | 1792    | 7872    | 7797.7 | 5745.34 | 2033.02 | 1.009528 |
| L   | Nc   | Ns   | Nu   | Nse  | Nsc  | Ne   |
|-----|------|------|------|------|------|------|
| L18 | 2    | 200  | 50  | 20   | 6080 | 4480 | 10560| 10452.7 | 5796.98 | 5479.57 | 1.010265 |
| L19 | 2    | 200  | 110 | 20   | 6080 | 9856 | 13952| 13801.5 | 11231.8 | 2435.93 | 1.010905 |
| L20 | 2    | 400  | 20  | 20   | 12160| 1792 | 16640| 16398.8 | 11405.4 | 4864.09 | 1.014708 |
| L21 | 2    | 400  | 50  | 20   | 12160| 4480 | 16640| 16398.8 | 11405.4 | 4864.09 | 1.014708 |
| L22 | 2    | 400  | 110 | 20   | 12160| 9856 | 22016| 21544.1 | 11599.7 | 9902.54 | 1.021904 |
| L23 | 2    | 800  | 20  | 20   | 24320| 1792 | 26112| 26337.7 | 22559.9 | 3303.76 | 0.991431 |
| L24 | 2    | 800  | 50  | 20   | 24320| 4480 | 28800| 28360.4 | 22057.2 | 5983.12 | 1.0155  |
| L25 | 2    | 800  | 110 | 20   | 24320| 9856 | 34176| 33362.1 | 22161.4 | 10891.3 | 1.024396 |
| L26 | 3    | 200  | 20  | 30   | 13680| 13680| 16312| 16010.2 | 12938.9 | 3013.61 | 1.01885 |
| L27 | 3    | 200  | 50  | 30   | 13680| 13680| 20260| 19867.1 | 13029.4 | 6685.5  | 1.019776 |
| L28 | 3    | 200  | 110 | 30   | 13680| 13680| 28156| 27345.9 | 13134.7 | 14062.5 | 1.026247 |
| L29 | 3    | 400  | 20  | 30   | 27360| 27360| 32992| 32610.1 | 26213.9 | 3741.55 | 1.012898 |
| L30 | 3    | 400  | 50  | 30   | 27360| 27360| 33940| 33172.7 | 25711.2 | 7176.76 | 1.02313 |
| L31 | 3    | 400  | 110 | 30   | 27360| 27360| 41836| 40603.7 | 26057.6 | 14476.4 | 1.030349 |
| L32 | 3    | 800  | 20  | 30   | 54720| 54720| 61300| 59826  | 50208.4 | 8961.23 | 1.024638 |
| L33 | 3    | 800  | 50  | 30   | 54720| 54720| 69196| 67017.6 | 50307.5 | 16227.2 | 1.032505 |

Note: Nc is axial bearing capacity of core concrete, Ns is axial bearing capacity of steel tube, Nu is axial bearing capacity of steel tube concrete, Nse is axial bearing capacity of steel tube calculated by finite element method, Nsc is axial bearing capacity of core concrete calculated by finite element method, Ne is axial bearing capacity of concrete tube calculated by finite element method.

### 4. Conclusion

CFST has become an important development direction of structural engineering discipline and achieving good economic benefits and architectural effects. So far, the calculation method of axial bearing capacity of concrete filled steel tube column is not perfect. According to the calculation results in this paper, the calculation result of axial bearing capacity of L-shaped concrete-filled steel tube column based on the superposition theory is slightly larger. If a reasonable and economical safety factor can be determined on the basis of superposition theory, it will provide a good design basis for future engineering designers.

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