Numerical Research on Axial Compression Behavior of L-shaped Steel Reinforced Concrete Short Columns

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Abstract: To investigate the axial compression performance of L-shaped steel reinforced concrete short column, thirteen specimens were designed with different steel ratio, different shear-span ratio, different strength grade of concrete, different stirrup ratio. By choosing reasonable material constitutive model, the finite element model of existing test specimens were established with the help of finite element software ABAUQS. Compared the existing test results, the simulation data was in good agreement with the test results, the rationality of finite element modeling method was verified. Based on this, the axial load-displacement curves of thirteen specimens under the axial compression were obtained, and the change regularity of axial load capacity, elastic stage stiffness and ductility with the main parameters were studied.

1. Introduction
With the rapid development of urbanization and the rapid increase of urban population, super high-rise buildings and long-span bridges are rising rapidly, so normal reinforced concrete columns not only form fat columns, occupy too much building space and easily form convex edges inside, but also consume lots of building materials in the system. So specially shaped columns are widely used in new buildings. As we know, the stress of frame corner column is complex, so it is good to use L-shaped steel reinforced concrete short column with equal limbs. Based on the conventional L-shaped reinforced concrete column, steel is added to the inside to form L-shaped steel reinforced concrete special-shaped column [1-3], so the section size of frame column can be decreased. This kind of composite column can not only increase the ultimate bearing capacity, but also improve the seismic performance of the structure [4-5]. However, there are few studies on this kind of special-shaped composite columns now. By choosing the reasonable material nonlinear constitutive model, the finite element model of L-shaped steel reinforced concrete special-shaped column is established. By making simulation analysis of L-shaped steel reinforced concrete short columns, the load-displacement curves are obtained. Compared with the existing test data, the rationality of finite element model is verified in this paper. It lays a further foundation for establishing the ultimate bearing capacity calculation formula of this kind of special-shaped short columns [6].
2. Design of specimens
To study the mechanical behavior of L-shaped steel reinforced concrete short columns with equal limbs under axial compression, thirteen specimens were designed with shear-span ratio (λ), steel ratio (ρₐ), strength grade of concrete (fₑ), stirrup ratio (ρᵥ) and longitudinal reinforcement ratio (ρₛ). h stands for clear height of columns. The normal section and elevation of specimen Z-2 are shown in figure 1. The specific parameters of the specimens are shown in table 1.

![Elevation](image1)
![Right section](image2)
![Side elevation](image3)

Figure 1. Sketch of specimen Z-2.

| Specimen | h/mm | λ | t/mm | ρₐ % | fₑ Mpa | ρᵥ % | ρₛ % |
|----------|------|---|------|------|--------|------|------|
| Z-1      | 800  | 1.6| 4    | 5.4  | 60     | 0.5  | 1.44 |
| Z-2      | 800  | 1.6| 6    | 8.2  | 60     | 0.5  | 1.44 |
| Z-3      | 800  | 1.6| 8    | 11.1 | 60     | 0.5  | 1.44 |
| Z-4      | 800  | 1.6| 10   | 14.0 | 60     | 0.5  | 1.44 |
| Z-5      | 400  | 0.8| 6    | 8.2  | 60     | 0.5  | 1.44 |
| Z-6      | 600  | 1.2| 6    | 8.2  | 60     | 0.5  | 1.44 |
| Z-7      | 1000 | 2  | 6    | 8.2  | 60     | 0.5  | 1.44 |
| Z-8      | 800  | 1.6| 6    | 8.2  | 40     | 0.5  | 1.44 |
| Z-9      | 800  | 1.6| 6    | 8.2  | 50     | 0.5  | 1.44 |
| Z-10     | 800  | 1.6| 6    | 8.2  | 70     | 0.5  | 1.44 |
| Z-11     | 800  | 1.6| 6    | 8.2  | 60     | 0.5  | 0.79 |
| Z-12     | 800  | 1.6| 6    | 8.2  | 60     | 0.5  | 1.11 |
| Z-13     | 800  | 1.6| 6    | 8.2  | 60     | 0.5  | 1.77 |

3. Finite element model and test verification

3.1 Constitutive model of steel bar and section steel
Bilinear ideal elastic-plastic model is used in the constitutive model of steel, which is shown in figure 2. Its elastic modulus and poison’s ratio are 1.9 x 10⁹ Pa and 0.3.

![Constitutive model of steel](image4)

Figure 2. Constitutive model of steel.
3.2 Constitutive model of concrete

3.2.1 Constitutive model of concrete in Design Code for Concrete Structures (GB50001-2010). The following constitutive relations can be used for concrete materials: isotropic hardening model, Kinematic hardening model. Isotropic hardening model is used in this paper. The stress-strain relationship of concrete under uniaxial compression refers to the stress-strain curve of concrete under uniaxial compression proposed in the standard GB50001-2010. The stress-strain relationship used is as follows:

\[ \sigma = (1 - d_c)E\varepsilon \]

(1)

\[ d_c = \begin{cases} 
1 - \frac{\rho_n n}{n - 1 + x^n} & (x < 1) \\
1 - \frac{\rho_1}{\alpha_n (x - 1)^2 + x} & (x > 1)
\end{cases} \]

(2)

Where: \( \rho_c = f_{co} / E_{co} ; \ n = E_{co} / (E_{co} - f_{co}) ; \ x = \varepsilon / \varepsilon_{co} ; \ \alpha_n \) is the parameters of descent segment, which is equal to 3.0; \( d_c \) is the parameters of single shaft damage evolution.

3.2.2 Constitutive model of concrete confined by stirrups. J R Qian [7] and other scholars selected twenty-four confined concrete columns for axial compression test. Combined with the research results at home and abroad, the constitutive model of confined concrete with stirrups is put forward, which is shown in figure 3, the expression of axial compressive strength is:

\[ f_{col} = (1 + 1.79\lambda_c) f_{co} \]

(3)

The peak strain expression corresponding to \( f_{col} \) is as follows:

\[ \varepsilon_{col} = (1 + 3.5\lambda_c) \times 0.0018 \]

(4)

The skeleton curve expression of stirrup confined concrete constitutive model is as follows:

\[ \sigma = \begin{cases} 
f_{col} \left[ a\frac{\varepsilon}{\varepsilon_{col}} + (3 - 2a)\left(\frac{\varepsilon}{\varepsilon_{col}}\right)^2 + (a - 2)\left(\frac{\varepsilon}{\varepsilon_{col}}\right)^3 \right] & (0 \leq \varepsilon \leq \varepsilon_{col}) 
of_{col} \left[ \frac{\varepsilon}{\varepsilon_{col}} (1 - 0.87\lambda_c^{0.2}) T \left(\frac{\varepsilon}{\varepsilon_{col}} - 1\right)^2 + \left(\frac{\varepsilon}{\varepsilon_{col}}\right)^3 \right]^{-1} & (\varepsilon > \varepsilon_{col})
\end{cases} \]

(5)

Where: \( a \) is the parameter of ascending section, which is 2.4-0.01\( f_{co} ; f_{co} \) is the cubic compressive strength of concrete; \( T \) is the parameter of descending, which is 0.132\( f_{cu}^{0.785-0.905} \).

3.3 Finite Element Model

The longitudinal reinforcement and stirrups of composite columns are embedded in concrete. For the loading end cushion plate, the displacement in X and Y directions is limited, while for the other end, the displacement in X, Y and Z directions are limited. The vertical load is applied to the position of the section center. The 3D solid model of column is shown in figure 4.
3.4 Verification of finite element model test

3.4.1 Verification of finite element simulation results for specimens. To prove the rationality of finite element analysis, a simulation analysis of the test specimens are carried out [8]. The axial load-displacement curves of specimens are drawn in figure 5. The simulation data is in good agreement with the test results. So it is feasible to carry out axial compression analysis of L-shaped steel reinforced concrete special-shaped short columns by using the modeling method.

![Figure 5. Comparison of load-displacement curves of columns.](image)

4. Numerical analysis of extended parameters

In this paper, the axial compression performance of columns with the main parameters of $\rho$, $\lambda$, $f_c$ and $\rho_s$ is simulated and analyzed. The finite element stress diagrams of the specimens and the load-displacement curves of the columns under different control parameters are obtained.

4.1 Comparison of axial compression behavior of L-shaped steel reinforced concrete special-shaped short columns under different control parameters

4.1.1 Steel ratio. The load-displacement curves of columns with different steel ratios are shown in figure 6. With the increase of the steel ratio, the descent segment of load-displacement curve of specimens tends to gentle inclined. The longitudinal deformation of the specimens is larger, the ductility is better.

![Figure 6. Different steel ratios.](image)

4.1.2 Shear-span ratio. The load-displacement curves of columns with different shear-span ratios are shown in figure 7. When the load is less, the various materials of the column are in the elastic stage, the load-displacement curve increases linearly. As the load increases constantly, the load increases less than longitudinal displacement, so the load-displacement curve grows nonlinearly. When the displacement loads on the columns reach 5.75 mm, 7.09 mm, 9.16 mm and 14.25 mm respectively, the load reaches its limit value.

4.1.3 Strength grade of concrete. The load-displacement curves of columns with different strength grade of concrete are shown in figure 8. With the increase of strength grade of concrete, the bearing capacity of columns under axial compression increases constantly, but its corresponding strain values have
inconspicuous change.

![Figure 8. Different strength grades of concrete.](image1)

![Figure 9. Different stirrup ratios.](image2)

4.1.4 Stirrup ratio. The load-displacement curves of columns with different stirrup ratios are shown in figure 9. With the increase of stirrup ratio, the bearing capacity of columns under axial compression increases continuously, the elastic stiffness changes little in the initial stage, and the ductility of columns increases. The effect of stirrup ratio on the bearing capacity and ductility of columns under axial compression is significant.

5. Conclusion
The paper presents a simulation analysis involving 13 axially loaded L-shaped steel reinforced concrete special-shaped short columns. The rationality and practicability of the finite element modeling method in this paper are verified. The finite element simulation results are obtained. By analyzing and comparing the effects of various parameters on L-shaped steel reinforced concrete special-shaped short columns, it can be seen that the steel ratio, shear span ratio, concrete strength grade and stirrup ratio are important indexes affecting the axial compression behavior of columns.

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