Numerical Simulation Parametric Studies on Concrete-Filled Steel Tubular Columns

Lidong Zhao, Wanlin Cao and Taopin Ye
College of Architecture and Civil Engineering, Beijing University of Technology, Beijing 100124, China zhao2732@sina.com

Abstract. The finite element (FE) software is used to simulate concrete-filled steel tubular (CFST) columns. Based on the existing experimental data, the model is verified. The parameters studied include axial load ratio and shear span ratio, and the difference of seismic performance between circular CFST column and square CFST column under the condition of equal steel ratio is compared. The results show that with the decrease of axial load ratio, the hysteretic curve is plumper and the seismic performance is more stable. With the decrease of shear span ratio, the horizontal bearing capacity of the specimen increased significantly, but the cumulative damage effect was more significant. The simulation results also show that when the steel ratio is identical for circular and square CFST columns, the circular CFST column has superior seismic performance.

Keywords: Concrete-filled steel tubular (CFST) column, Finite element (FE), Axial load ratio, Shear span ratio, Steel ratio

1. Introduction
In recent years, China has witnessed the rapid development of super high-rise buildings. The amount of buildings taller than 600m keeps increasing. Because of its excellent seismic performance, CFST is widely used in super high-rise buildings, subway stations, Bridges and other structures. CFST combines the advantages of both steel and concrete, and its bearing capacity is greater than the sum of the two. Because of these advantages, CFST structure has been a hot spot of research among scholars all over the world.

In the field of finite element simulation, scholars from various countries have conducted corresponding researches. Tao and Wang [1] et al. proposed a refined finite element (FE) models to simulate CFST stub columns under axial compression. The dilation angle was calibrated against test data and a new hardening/softening function was developed. The proposed model was not only applicable to ordinary concrete, but also to high-strength concrete. Ouyang and Kwan [2] established a brand new FE model which took into account the lateral expansion of the confined concrete. The proposed model was compared with the experimental data, and the simulated value was in good agreement with the experimental value. Duarte and Silva [3] et al. proposed non-linear FE models of steel tubes filled with rubberized concrete (RuC). Compared with ordinary CFST columns, RuCFST columns had better ductility, but its bearing capacity and stiffness were slightly decreased. Talaeitaba and Halabian [4] et al. investigated concrete-filled double-skin tubular columns using extended FEM analysis. The parameters studied included FRP layers, diameter, hollow section ratio and material. The simulation results showed that when the number of layers was increased, the ultimate compressive strength of concrete increased significantly. The FE analysis of octagonal CFST short column was carried out by Hassanein [5]. The results showed that improving D/t ratio of octagonal CFST column...
can make the high strength concrete more economical. And a modified design model was suggested. Zheng and He [6] et al. conducted the quasi-static test of six circular double-skin CFST columns. The experimental results indicated that the hysteretic curve of each specimen is plump. Increasing axial load level can make the stiffness degradation faster. The displacement ductility decreased with increasing diameter-to-thickness ratio. Li and Zhang [7] conducted FE analysis of CFST column with inner I-Shaped CFRP profile under axial loading. The results showed that the bearing capacity increased with the increase of CFRP profile ratio.

In this paper, the FE model of CFST column is established and compared with the experimental data to verify the correctness of the model. The parameters studied include axial load ratio and shear span ratio. The difference of seismic performance between the circular CFST column and the square CFST column is studied. This research will provide reference value and design basis for engineering practice.

2. Specimen Design
The outer diameter of steel tube is \( D=508 \text{mm} \), and the wall thickness is \( t=9 \text{mm} \). The height of column is \( H=1270 \text{mm} \). The three-dimensional diagram of CFST column is shown in fig.1(a). The average concrete axial compressive strength is \( f_{c,m}=47.98 \text{ MPa} \), and the elastic modulus is \( E_c=33.5 \text{ GPa} \). The steel grade is Q345. The experiment was carried out on a large scale test machine of Beijing university of technology. The axial force applied by the specimen was 9180kN, and the test is based on a displacement loading procedure. Fig.1(b) shows the comparison of hysteretic curves of experimental and numerical simulation. The simulation results are in good agreement with the experimental results. Therefore, the relative parameters of the numerical model are verified.

![Figure 1. Specimen design and test results](image)

3. Finite Element Modeling
In this paper, ABAQUS software was used for numerical simulation analysis. The steel tube is based on shell element, and the concrete is based on solid element. The base is defined as a rigid body.

3.1. Constitutive Model of Material
The constitutive relation of steel is based on the bilinear model, as shown in fig.2(a). The actual values of yield load and yield strain are used. The Poisson ratio is 0.3, and the strengthening type is kinematic hardening. The core concrete is based on the stress-strain relational model proposed by Han [8], as shown in figs.2(b) and 2(c).
3.2. Interface Simulation
The contact between steel tube and concrete is defined as surface to surface contact. The normal direction is hard contact, the tangential friction behavior is the penalty function, and the friction coefficient is 0.4.

3.3. Loading Process
The displacement loading system was used in numerical simulation, as shown in fig.3. In order to conduct more accurate numerical simulation, the spacing between displacements decreases.
3.4. Parameter Analysis

3.4.1. Axial Load Ratio. The axial load ratio $n=N_0/N_u$, where $N_0$ is the vertical axial force applied to the top of the column in the FE simulation, $N_u$ is the compressive bearing capacity of the section. The value of $n$ in this paper is 0.3, 0.6 and 0.9. Fig. 4 shows the hysteretic curve of the specimens with different axial load ratios. With the increase of axial load ratio, the horizontal bearing capacity decreases gradually. The specimen with the lowest axial load ratio has the gentlest hysteretic curve descending section and slow bearing capacity degradation rate. When the axial load ratio is 0.9, the specimen shows poor deformation capacity. When the bearing capacity reaches the peak load, the horizontal force drops rapidly and the specimen is declared to be destroyed.

![Hysteretic curve](image)

Figure 4. Hysteretic curve
3.4.2. Shear Span Ratio. Fig. 5 shows the hysteretic curve of the specimens with different shear span ratios. Comparing the hysteretic curves of specimens with different shear span ratios, it can be seen that the bearing capacity increases significantly with the decrease of shear span ratio. The bearing capacity of specimens with shear span ratio of 2.0 was 78.10% higher than that of specimens with shear span ratio of 3.0, and 144.28% higher than that of specimens with shear span ratio of 4.0. For the specimens with smaller shear span ratio, the bearing capacity decreases rapidly after the curve reaches the peak load, showing poor ductility. The hysteretic curve of the specimen with a shear span ratio of 4.0 is relatively plump, the descending section of the curve is gentle, and the ductility is good.

3.5. Simulation Comparison of Square and Circular Steel Tube
To compare the seismic performances of a circular CFST column and a square CFST column under identical steel ratio, a model for a square CFST column with a 450mm side length and an 8mm thick wall is created, as shown in fig.6. The square section has the same steel consumption as circular section. The vertical axial force exerted by the square CFST column is also 9180kN.
A stress nephogram of the square CFST column when loading stops, as shown in Fig.7, shows that the bulge around the column base is severe, and there are two semi-wave bulges in the direction of height. Fig.8(b) shows a horizontal force-displacement hysteresis curve calculated from the finite element model for the square CFST column. Fig.8(c) is a comparison of the skeleton curves for the square CFST column and circular CFST column. The skeleton curve comparison results show that, compared to the circular CFST column, after the square CFST column reaches its peak load, the bearing capacity declines rapidly. The peak loads of concrete columns with the circular steel tube and square steel tube are 987.30MPa and 865.52MPa, respectively. The ductility coefficients are 3.69 and 1.87, respectively. The results show that, compared to the square CFST column, the circular CFST column has the following improvements: the bearing capacity improves by 14.07%, and the ductility coefficient improves by 97.33%. This means that the seismic performance of the circular section is superior to that of the square section.

![Figure 6. Sectional dimension(mm)](image)

![Figure 7. Stress nephogram](image)
4. Conclusion
Through the FE numerical simulation analysis, the following conclusions are obtained.

1) The hysteretic curve can be plumper by reducing the axial load ratio. When the axial load ratio reaches 0.9, the seismic performance of the specimen decreases significantly.

2) The horizontal bearing capacity of the members can be significantly increased by reducing the shear span ratio, but the cumulative damage effect is more significant. The hysteretic curve can be more full and ductility can be improved by increasing the shear span ratio.

3) Under the condition of identical steel ratio, the circular CFST column has superior seismic performance than the square CFST column.

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