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Comprehensive Performance of Special Shaped Concrete Filled Steel Tubular Columns

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Abstract

Concrete filled steel tube (CFST) is a composite member filled with concrete to steel tube, which has the advantages of high bearing capacity, good ductility and strong seismic capacity. It is widely used in long-span structures, bridge engineering and high-rise buildings. In recent years, people ' s requirements for building functions and basic living conditions are increasing day by day. The traditional rectangular cross-section column cannot meet the residents ' demand for architectural aesthetics and effective use area of houses because of its prominent column feet. The special-shaped column is one of the characteristic components in Chinese construction industry. It can hide the column limb in the wall, increase the flexibility and beauty of indoor layout, and has been widely used in residential buildings. This paper reviews the mechanical properties of concrete filled steel tubular special-shaped columns. The axial compression characteristics and ductility of high-strength concrete filled steel tubular special-shaped columns are reviewed. Combined with the shortcomings of the existing research, the future development direction and the problems still existing in the actual engineering are pointed out.

Keywords

Concrete Filled Steel Tubular Special-Shaped Columns; Mechanical Properties; Seismic Performance; Fire Resistance.

1. Introduction

Concrete filled steel tube (CFST) is a cast-in-place component composed of steel tube and plain concrete column. The bearing capacity of the whole component is greater than the sum of the bearing capacity of empty steel tube and concrete. According to the generalized Hooke ' s law of material mechanics, the strain value of any material element under unidirectional stress is greater than that under complex stress. In concrete filled steel tube, the core concrete is subjected to three-dimensional stress state, and the strain of each direction of the material element is smaller. The bearing capacity of concrete is significantly improved due to the decrease of transverse deformation caused by steel tube binding force. The expression of generalized Hooke ' s law is given by formula 1 :

$$\begin{aligned} \varepsilon_1 &= \sigma_1 / E - \mu(\sigma_2 / E + \sigma_3 / E) \\ \varepsilon_2 &= \sigma_2 / E - \mu(\sigma_1 / E + \sigma_3 / E) \\ \varepsilon 3 &= \sigma_3 / E - \mu(\sigma_1 / E + \sigma_2 / E) \end{aligned} \tag{1}$$

At present, the application forms of concrete filled steel tubular special-shaped columns mainly include T-shaped, L-shaped and cross-shaped. As a new type of pouring component, it is beneficial to the application of high strength concrete, and it is convenient to construct. It has

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the advantages of high bearing capacity, good plastic performance, good economic benefit, good seismic performance and good fire resistance[1].The seismic performance of shaped steel tube concrete column is much better than that of ordinary shaped reinforced concrete column[2]. Under the premise of the same structural bearing capacity and stiffness, the shaped steel tube concrete column can achieve smaller section. Therefore, the shaped steel tube concrete column structure is more and more widely used.

2. Mechanical Properties of Concrete-Filled Steel Tubular Special-Shaped Columns

At present, scholars ' research on the static performance of special-shaped columns mainly focuses on the bending performance, axial compression performance and eccentric compression performance. The research methods include establishing finite element model, experimental loading and theoretical calculation.

2.1. Flexural Behavior of Special Shaped Concrete Filled Steel Tubular Columns

Han and Zheng[3]. studied the deformation form and flexural bearing capacity of L-shaped concrete-filled steel tube. Under two finite element simulation conditions of axial compression and eccentric compression, they analyzed the influence of reinforcement ratio and steel tube wall thickness on the research results. The results showed that increasing the steel tube wall thickness had a greater impact on the flexural bearing capacity of special-shaped columns. Hao and Yu[4]. et al studied the special-shaped cross-section columns. Under the condition that the experimental and simulation data were consistent under axial compression, it was found that the specimens could work together well and have large ductility, but the connection plate did not damage when the ultimate bending load was reached. Therefore, considering the comprehensive safety and cost, the topology optimization of the special-shaped column was carried out and the recommended form of the connection plate was given.

2.2. Axial Compression Performance of Concrete Filled Steel Tubular Special-Shaped Columns

Wang and Zhou[5]. et al verified each other by comparing the finite element simulation analysis and five groups of L-shaped column experiments. They fully considered the axial compression experiment with three parameters affecting the axial compression performance, namely, the thickness of steel tube, the strength of steel and the slenderness ratio, and proposed the formula for calculating the axial compression strength and the stability bearing capacity. By observing the failure modes of the short column and the medium-long column specimens, they were mainly the strength failure and the instability failure, which were in good agreement with the finite element simulation results, verifying the accuracy and feasibility of the stability bearing capacity formula proposed by the axial compression strength. It is concluded that the concrete columns can work together well and have good axial compression performance. Yang and Zhang[6]. et al used the wall thickness and slenderness ratio of steel tube as the basic parameters to conduct axial compression tests on nine concrete-filled steel tube columns with cross section. They analyzed and compared the three factors that affect the bearing capacity, ductility and deformation capacity of special-shaped columns, including steel ratio of steel tube, stirrup coefficient and limb length, and summarized the influence of steel ratio of steel tube and limb length on the bearing capacity and ductility of specimens in different numerical ranges. It is concluded that with the increase of the thickness of the steel tube, the ultimate bearing capacity, local buckling and ductility of the component are also significantly improved, and reducing the slenderness ratio can increase the bearing capacity and bending stiffness, but also reduce the ductility of the specimen.

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2.3. Bias Behavior of Concrete Filled Steel Tubular Special-Shaped Columns

The eccentric compression performance of T-section square concrete filled steel tubular special-shaped columns was studied in Shandong Jianzhu University. Li and Zhou[7]. et al carried out the eccentric compression experiment with the three factors of specimen length, eccentricity and eccentric direction as the breakthrough point. By observing the eccentric compression deformation and broken ring phenomenon of nine special-shaped columns, it was found that the short column had no torsional deformation, and there was no cracking between the steel tubes and the end welds. The cooperative work was good, and the whole was characterized by strength failure. The state of the long column steel pipe is the same as that of the short column, and the whole is bending instability broken ring. The slenderness ratio and eccentricity have great influence on the ultimate bearing capacity. The eccentric compression performance is mainly determined by the eccentricity, and the influence of eccentric compression direction and specimen length is smaller. Cai and Zuo[8]. et al. carried out eccentric compression tests on L-shaped concrete-filled steel tubular special-shaped columns with eight constraint rods, and emphatically analyzed the eccentric compression performance of special-shaped columns under the three variables of constraint rod setting, load angle and eccentricity. Combined with the theoretical calculation of fiber model method, it is concluded that the constraint rod can effectively improve the experimental situation of steel tube buckling before yield, improve the problem that the constraint effect of square steel tube on concrete is smaller than that of circular steel tube due to the existence of negative angle, and enhance the ultimate bearing capacity of special-shaped columns under eccentric compression. The ductility is improved significantly, and the effect is more obvious with the increase of the number of constraint rods.

3. Seismic Resistance of Concrete Filled Steel Tubular Special-Shaped Columns

Wang and Yang[9]. et al designed three special-shaped columns with T-sections of reinforcement, ordinary steel tube and stiffened concrete-filled steel tube. Through the analysis and comparison of the experimental phenomena and failure state of the three special-shaped columns under low-axis reciprocating loading, it was found that the steel plate of the stiffened concrete-filled steel tube column had late bulging time, less number and lower height than that of the other two columns. At the end of loading, the integrity was good and the failure was light. The hysteresis curve is smoother and fuller, and the energy dissipation, initial stiffness, bearing capacity and ductility are more prominent.Based on the two factors of axial compression ratio and loading direction, Zhang and Shen[10]. et al carried out displacement control loading on concrete filled steel tubular column-steel beam frame structure. It is concluded that increasing the axial compression ratio can effectively improve the elastic stiffness and total energy consumption of the structure, and improving the horizontal displacement can also increase energy consumption. Among them, the axial compression ratio has the greatest influence.

4. Resistance of Concrete-Filled Steel Tubular Special-Shaped Columns

Yang and Liu[11]. et al designed two cross-shaped special-shaped columns to explore the factors affecting the fire resistance limit, and the two parameters of surface axial compression ratio and fireproof coating had the greatest influence. The greater the axial compression ratio, the smaller the fire resistance limit. The thicker the fireproof coating is, the longer the fire resistance limit is.Chen and Lei[12]. et al carried out the axial compression test on the L-shaped cross-section column after fire, and the deformation failure and bearing capacity of the column were consistent with the simulation results. The ultimate bearing capacity and ductility of L-shaped column are good, which proves the feasibility of fire prevention.Zhu and Sun[13]. et al calculated the bearing capacity of T-section column after fire by section superposition method, and verified each other with finite element simulation. After thermal coupling, structure and thermal analysis, it is concluded that the axial deformation of the column increases with the fire time, and the bearing capacity is mainly borne by the core concrete when the steel pipe exits the bearing work. Therefore, it is necessary to consider the conclusion of adding fire retardant coatings to the components.

5. Problems Still Need to be Further Studied for Concrete-Filled Steel Tubular Special-Shaped Columns

(1) The frequent occurrence of fire accidents often causes huge losses and casualties to human beings. Most of the fires spread locally. Timely control and extinguishment are of great significance to the maintenance and reinforcement of buildings after disasters. Column is the main component of the building structure under vertical load. Under the action of fire, many scholars have made research and proposed solutions to reduce the failure of steel tube caused by the rapid heating of steel tube surface and improve the fire resistance of concrete-filled steel tube columns. After the fire, there are few articles to summarize. The strength degradation, constitutive relationship and mechanical properties of concrete in steel tube also need further study.

(2) There are few researches on concrete filled steel tubular special-shaped columns and beam-slab joint columns, and there are few researches on integral frame structure and seismic shear wall structure. In view of the weakness that the weak zone of frame joint should be prone to damage, the experimental or theoretical research on single-layer or integral frame of concrete filled steel tubular special-shaped columns should be carried out in time to provide the basis for the promotion and development of such composite components.

(3) Most of the special-shaped concrete-filled steel tubular columns are outsourced concrete. For the fire, the rapid heating of the steel tube leads to the rapid degradation temperature of the steel tube, which makes the structure unpredictable damage. Timely solution to suppress the rapid heating of the outer surface of the steel tube has become the focus of future research.

(4) There are few studies on unequal limbs of CFST special-shaped columns. The failure modes and mechanical properties should be tested and studied under different cross-section forms, steel tube diameters and aspect ratios.

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