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Utilizations of Steel-Reinforced Concrete-Filled Steel Tubular (SRCFST) Constructions

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Abstract. In recent times, there has been a significant amount of research dedicated to traditional concrete-filled steel tubular (CFST) structures. This research has been broad and includes both practical testing and theoretical analysis. As of late, scholars have redirected their attention toward introducing innovations in the domain of steel-concrete composite systems. This piece delves into investigations involving experiments and simulations, as well as the underlying mechanisms and interplays of constraints. The focus is on rectangular columns made of Steel-Reinforced Concrete Filled Square Tubular (SRCFST), subjected to combined compression and torsion forces. By building upon previous investigations, the article not only provides a summary but also evaluates the pathways that research on SRCFST columns has taken. Additionally, it offers a glimpse into the potential directions for future studies. This comprehensive strategy not only serves as a point of reference for upcoming research endeavors but also furnishes practical insights for their real-world implementation.

1 Introduction

As an important load-bearing member, the load on the column is also increasing, which requires it to have higher bearing capacity and better ductility to meet the development needs of modern buildings. Opting for the conventional reinforced concrete structure would result in excessively large component section sizes, leading to an inefficient utilization of building space. Over the past few decades, concrete-filled steel tubes (CFST) have found extensive application in various construction contexts, including building structures and bridges, even in regions prone to seismic activity[1]. Beyond the typical concrete-filled steel tube configurations, concrete-filled steel tubular composite columns manifest in four distinct forms: Concrete-filled double skin tubes (CFDST), Concrete-encased CFST, CFST with additional reinforcement, and Stiffened CFST, as depicted in Figure 1 [2]. Each of these configurations exhibits distinct behaviors and involves varied steel contributions to the overall structural properties.

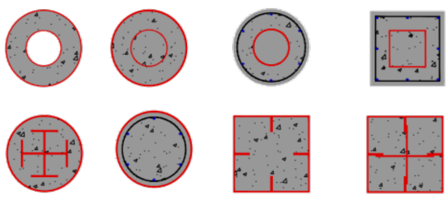

Fig. 1. Concrete-filled steel tubular composite column

2 Classification and Advantages of SRCFST

Currently, two research approaches exist for steel-reinforced concrete-filled steel tubular (SRCFST) composite structural columns, classified based on the positioning of the steel pipe. Wang[3] introduced a novel heavy-load composite column, referred to as the steel-reinforced concrete-filled steel tube composite column. This type of composite column emerges as a result of the study conducted on SRC columns and CFST columns.

Concrete-filled steel tubes (CFST) have gained significant prominence in recent decades due to their inherent advantages. The external steel tube contributes to the structural properties by means of axial reinforcement and confining actions. Furthermore, the external steel tube can serve as a permanent formwork, thereby obviating the need for conventional formwork efforts. Nevertheless, CFST does exhibit a drawback in terms of its susceptibility to local buckling. This area for potential improvement has been substantially addressed through the development of steel-reinforced concrete-filled steel tubular (SRCFST) members.

Sectional steel components significantly enhance column capacities without altering column profiles. In contrast to traditional reinforced concrete, Concrete-Filled Steel Tubular (CFST) structures eliminate the requirement for formwork, thereby offering the advantage of reduced construction time and costs. The

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inclusion of steel sections greatly contributes to the augmentation of load-bearing capacity, lateral displacement ratio, ductility, prevention of local steel shell buckling, and energy absorption capacity.

Both the steel frame and steel tube jointly confine the concrete interior, resulting in a state of three- or two-way compression within the core region. This effect substantially elevates the ultimate compressive strain and ultimate compressive strength of the concrete. In comparison to conventional carbon steel, steel-reinforced concrete boasts several advantages, including simplified structural configurations, convenient construction, reduced section dimensions, exceptional ductility, high load-bearing capacity, and the ability to effectively address a wide array of modern building requirements[4-7].

3 Background of experimental investigations and Finite element (FE) analysis on SFCFST members

3.1. Axial Compressive Loading

In recent years, extensive experimental studies and theoretical analyses on the mechanical properties of SRCFST columns have been undertaken by scholars. A substantial body of literature has been published, specifically focusing on axial compression tests conducted on SRCFST columns.

Wang et al.[8] conducted a comprehensive experimental investigation involving 13 composite columns. The outcomes of these experiments showcased that this novel composite column design possesses remarkable loading capacity and excellent ductility. Additionally, it facilitates a reduction in the cross-sectional size of the column, consequently enhancing the available space within the building. The findings further revealed that by determining the relative aspect ratio (λ) of the combined columns, coupled with the cross-sectional configuration of the SRCFST column, the calculation equations (Equation 1 and Equation 2) suitable for this combined column were derived[9].

$$N_u = \varphi(A_c f_c + 2A_t f_t + A_s f_s) \tag{1}$$

$$\varphi = \begin{cases} 1 & \lambda \le 0.2 \\ \dfrac{1}{2\lambda^2}\left[\begin{array}{c} 1+0.281\sqrt{\lambda^2-0.04}+\lambda^2- \\ \sqrt{1+0.281\left(\sqrt{\lambda^2-0.04}+\lambda^2\right)^2-4\lambda^2} \end{array}\right] & \lambda > 0.2 \end{cases} \tag{2}$$

The embedding of sectional steel within the steel tube-concrete column was observed to retard the propagation of shear diagonal cracks in the concrete[10]. The load-bearing capacity and ductility of these components exhibited a decrease with the length-thin ratio, while they increased with higher shape steel ratios. Notably, alterations in the confinement factor had a pronounced impact on both the load-bearing capacity and ductility of the composite column.

As the length-thin ratio increased, the influence of initial defects on the composite column's load-bearing capacity became progressively more significant. Component damage transitioned from material strength deterioration in shorter columns to inelastic bending instability damage. When the length-thin ratio surpassed a certain critical value, elastic instability damage would manifest within the column.

Xu et al[11] introduced the concept of the steel-reinforced concrete-filled steel tubular column. They conducted experiments on three axially compressed composite columns with varying steel ratios to demonstrate the collaborative functionality of the inner steel core concrete and the outer concrete under vertical loads. The experimental results revealed a direct correlation: higher steel content led to increased load-carrying capacity and ductility of the members.

Based on theoretical analyses, the bearing capacity of the SRCFST column can be calculated using the following equation (3).

$$N_u = A_s f_s + \psi \cdot A_c f_c + A_t f_t (1 + 1.8\xi) \tag{3}$$

Under certain conditions, the SRCFST column exhibits superior fire resistance compared to CFST. The progression of damage in a fire scenario can be categorized into three distinct stages: the initial warming phase of expansion, the axial compression stage, and the ultimate destruction stage. During these stages, the core concrete shoulders the majority of the load-bearing responsibility. However, as temperatures rise, the collaborative efficacy between the steel tube and concrete, as well as between the concrete and steel section, diminishes.

Drawing from pertinent research findings in CFST structures, Deng et al.[12] treated the SRCFST column as a composite entity and highlighted that the primary factor influencing the axial compression bearing capacity of the composite column is the restraint index. By integrating this insight with the axial compression formula for CFST columns, the authors presented a formula for calculating the restraint index.

3.2. The Effect of Fire

Notably, the fire load ratio, length-thin ratio, steel tube steel ratio, and the thickness of the fire protection layer exert a considerable influence on the fire resistance threshold of the component [13]. It's worth noting that when the thickness of the fire protection layer surpasses 7mm, the impact of the length-to-thinness ratio on the fire resistance threshold becomes negligible[14].

In 2013, Lv et al.[15] performed a finite element analysis investigating the typical temperature field and its distribution characteristics across sections of steel pipe-concrete columns exposed to fire. The outcomes revealed that as the overall temperature of the fire-exposed members increased, material damage escalated, ultimately leading to a less favorable fire resistance scenario for square steel tube columns. Interestingly, the temperature field across the column cross-section exhibited biaxial symmetry in cases of composite two-surface and four-surface fires. Consequently, the material strength field, temperature strain, and temperature stress also exhibited biaxial symmetry, with the stress mechanism of the column mirroring that of the normal temperature condition (as illustrated in Figure 2).

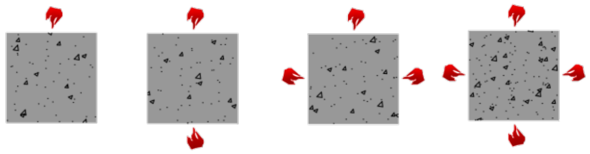

Fig. 2. Different fire conditions

3.3. Other Experiments

Shear tests were conducted on 20 Type I and cross-sectional type SRCFST members by Shi Y L et al. [16]. The study revealed commendable ductility and shear resistance in these components. The incorporation of embedded section steel played a beneficial role in impeding the expansion of core concrete cracks. As the bending moment increased, the damage mode shifted from being shear-dominated to flexure-dominated. Consequently, a simplified predictive formula for shear-bearing capacity was formulated.

In a separate study, the structural behavior of 22 circular steel tube concrete (SRCFST) columns subjected to coupled compression and bending with preloading effects was analyzed using finite element models[17]. While the load-deflection curves for SRCFST columns with I-beams and cross sections under different preloading methods were similar, the ultimate strength exhibited a slight reduction. The key parameters influencing the ultimate strength influence coefficient (kp) were identified as preloading ratio, load eccentricity, and length slenderness. Consequently, Jia et al. formulated design equations (Equation 4 and Equation 5) for the ultimate strength of SRCFST compression-bending components, considering the effect of preloading.

$$V_0 = \gamma_v A_t \tau_{scy} + 0.6t \cdot h \cdot f_{sy} + 1.5 f_s A_s \tag{4}$$

$$\gamma_v = 0.97 + 0.2\ln(\xi) \tag{5}$$

4 Conclusions and Perspective

Note that this paper focuses on the innovative research and application progress of SRCFST column in recent years. The followings can be summarised from the aforementioned:

1. Embedding steel into CFST columns can enhance the load-bearing capacity of members, improve the ductility of members, enhance the deformation capacity, inhibit the local buckling of steel tube, improve the fire resistance and slow down the development of cracks

2. Load ratio, non-uniform fire conditions and external steel cross-section and fire resistance are closely related, fire resistance with the fire load ratio and the increase in the length of the thin ratio and significantly reduced, the higher steel content of the component fire performance.

Based on the above summary and discussion in this paper, the following suggestions for future research on SRCFST column are proposed:

The existing research focuses on various aspects like strength capacity, failure mode, axial shortening, strain variations of the steel tubes and concrete cores, etc. It is necessary to research the connection mode and connection effect of novel beam-column nodes, space truss structural system and high performance sustainable material hybrid system with whole life cycle performance evaluation.

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