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Review Article

ADVANCEMENTS IN CONCRETE FILLED STEEL TUBULAR (CFST) COLUMNS - A REVIEW

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Concrete-filled steel tubes are gaining increasing prominence in a variety of engineering structures, with the principal cross-section shapes being square, rectangular and circular hollow sections. The study about the behavior and the characteristics of CFST columns is the prime need of the hour. This review paper outlines the important contributions on CFST columns contributed in the recent years. This paper presents the innovative experimental investigations conducted on CFST columns and the load deflection response characteristics of columns are also addressed. A comprehensive summary of various analytical and numerical studies on modeling of CFST members is portrayed in this paper. The design specifications and standards by AIJ, Eurocode-4, ANSI/AISC and AIK are addressed.

Keywords: Concrete-filled steel tubes, Experimental investigations, Analytical and numerical studies, Design standards

INTRODUCTION

Concrete filled steel columns have seen an increased usage in building structures throughout the world. A well-designed and properly detailed composite column is a structural element that will highlight the synergistic behavior of its constituent materials, including the high cross-sectional stiffness, high compressive strength, and fire resistance of the concrete and the large ductility, high tensile resistance, high strength-to-stiffness ratio, and lightweight construction associated with steel. The Concrete-Filled Steel Tube (CFST) column system has many advantages compared with the ordinary steel or the reinforced concrete system. The main advantage is the interaction between the steel tube and concrete. The local buckling of the steel tube is delayed by the restraint of the concrete, and the strength of concrete is increased by the confining effect of the steel tube. In addition, once construction complexities are addressed (i.e., the interdisciplinary coordination between steel and concrete workers and forming of the beam-column connection), more advantages can be obtained from composite columns through speedier construction, formwork savings, reduced loads on foundations, increased useful space, and lower

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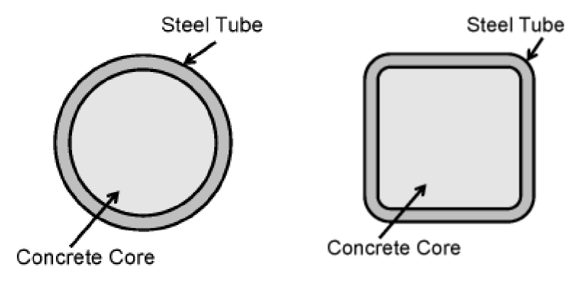
construction and maintenance costs. Some of the common cross sections of CFST columns are shown in Figure 1.

Figure 1: Common Cross-Sections of CFST Columns



RESEARCH ON CFST COLUMNS

Lin-Hai Han *et al.* (2010) demonstrated six tests on Reinforced Concrete (RC) beam to concrete-filled steel tubular (CFST) column planar frames subjected to ISO-834 standard fire. The test parameters integrated the level of axial load in the CFST column, the load level in the RC beam and the beam-to-column linear rotational restraint ratio. From the experiments, it was noted that, higher beam load level and column axial load level lead to lower fire resistance of the frames. A lower beam-to-column linear rotational restraint ratio can slightly enhance the fire performance of the frame, but its influence on the fire resistance seems to be limited.

Huiling Zhao *et al.* (2010) simulated the nonlinear behavior of composite structural connections consisting of steel concrete composite beams and Concrete-Filled Steel Tubular (CFST) columns. The model proposed for CFST columns adopts fiber-based stress strain relations that enable the consideration of strength and ductility for confined concrete and local buckling of the steel tube. The flexibility of the composite-beam-to-CFST-column connection is modeled as a panel zone. It was demonstrated that the proposed simplified technique was an effective approach to simulate the overall response of the composite subassembly.

Perea (2010) conducted a comprehensive experimental research program on CFTs that consisted of tests on 18 full-scale slender specimens. These specimens were the longest and the most slender CFT specimens tested to date. The specimens were tested under a series of unique loadings that included buckling, combinations of different axial and transverse loads (both uniaxial and biaxial), and torsional load histories. The description of this test series and its main experimental results with respect to buckling were the subject of this paper.

Fei-Yu Liao *et al.* (2011) investigated the influence of gap on the failure mode, ultimate strength and flexural stiffness of the CFST specimens. The paper presented the influence of the gap on the compressive and flexural behavior of CFST members. A total of 21 specimens were tested. The main parameters considered for the study were the gap type and gap ratio.

Seong-Hui Lee *et al.* (2011) estimated the behavior of a circular CFST column under eccentric loading. An experimental test and fiber element analysis on 11 circular stub CFST column specimens were conducted. The parameters considered were high strength steel and concrete diameter to thickness ratio and eccentric distance. The results from the experimental tests and fiber element analysis were compared with AISC (2005), Eurocode

4 (1994) and KBCS (2009) to verify the suitability of the analysis in the codes. The ductility of the circular CFST columns using lower strength 30 MPa concrete is higher than the ductility of circular CFST columns using higher strength 60 MPa concrete up to a diameter thickness ratio of 80. From the analysis results, it is considered that AISC and KBCS show good agreement for the circular CFST column under eccentric loading.

Qing Quan Liang (2011) analyzed high strength circular CFST slender beam-columns. The paper presented a new numerical model for predicting the nonlinear inelastic behavior of high strength circular CFST slender beam-columns under axial load and bending. The numerical model accounts for confinement effects on the concrete core, circular steel tubes and incorporates initial geometric imperfections of beam-columns. Axial load – moment – curvature relationships obtained from the fiber element analysis of column cross-sections were utilized and the equilibrium states in the inelastic stability analysis of slender beam-columns were determined. The computer program implementing the numerical model was an excellent computer simulation tool that can be used to investigate the fundamental behavior of high strength circular CFST slender beam-columns.

Qing Quan Liang (2011) presented the verification and applications of a new numerical model developed for the nonlinear inelastic analysis of high strength circular CFST slender beam-columns under axial load and bending. The accuracy of the numerical model was examined by comparing the predicted ultimate strengths and load-deflection responses of circular CFST slender beam-columns with corresponding experimental results. Excellent agreement between computational and experimental results was obtained. The parametric studies reported in this paper provided benchmark numerical results that are extremely useful for validating other nonlinear inelastic analysis techniques.

Vipulkumar Ishvarbhai Patel *et al.* (2012) carried out experimental and numerical research on full-scale high strength thin-walled rectangular steel slender tubes filled with high strength concrete. Experimental ultimate strengths and load-deflection responses of CFST slender beam-columns were tested by independent researchers and used to verify the accuracy of the numerical model. The verified numerical model was then utilized to investigate the effects of local buckling, column slenderness ratio, and depth-to-thickness ratio, loading eccentricity ratio, concrete compressive strengths and steel yield strengths on the behavior of high strength thin-walled CFST slender beam-columns.

Yu-Feng An *et al.* (2012) studied the of behavior and design principles on very slender thin-walled CFST columns. A Finite Element Analysis (FEA) was developed to carry out the behavior of compressive columns. The FEA model was then used to perform mechanism analysis on very slender circular CFST columns. Parametric studies were conducted and the ultimate strengths from tested results and design codes were compared and discussed. The reliability analysis method was used to calibrate the existing design formulas given in DBJ/T13-51- 2010, ANSI/AISC 360-05 and Eurocode – 4.

Qing Quan Liang *et al.* (2012) presented a new multiscale numerical model for simulating the structural performance of biaxially loaded high-strength rectangular CFST slender beam-columns accounting for progressive local buckling, initial geometric imperfections, high strength materials and second order effects. The inelastic behavior of column cross-sections was figured at the mesoscale level by the fiber element method. Macroscale models were developed to simulate the load-deflection responses and strength envelopes of thin walled CFST slender beam-columns. New computational algorithms based on the Müller's method were developed iteratively to adjust the depth and orientation of the neutral axis and the curvature at the column's ends to obtain nonlinear solutions. The computer program that implements the multiscale numerical model developed was an efficient simulation and design tool that can be used to determine the structural performance of biaxially loaded high strength rectangular CFST slender beam-columns made of compact, non-compact or slender steel sections.

Vipulkumar Ishvarbhai Patel *et al.* (2012) presented a novel numerical model for simulating the behavior of high strength thin-walled rectangular CFST slender beam-columns under axial load and uniaxial bending. The numerical model for pin-ended CFST slender beam columns with equal end eccentricities and single curvature bending was developed based on fiber element formulations. It was inferred from the torsion moment-rotation angle hysteretic curves that the CFST columns under cyclic torsion and low compression – torsion load have high energy dissipation capacity.

Nie Jian-guo *et al.* (2012) conducted experimental study on seismic behavior of concrete filled steel tube columns under pure torsion and compression – torsion cyclic load. Based on the test results and literatures available, the torsion mechanism of CFST columns was preliminarily analyzed.

Fei-Yu Liao *et al.* (2013) performed a nonlinear analysis of CFST stub columns with a circumferential gap or spherical-cap gap under axial compression. Gap between the steel tube and concrete core can be considered as a kind of initial concrete imperfection in CFST structures. A nonlinear finite element model was developed, where the nonlinear material behavior and the effect of gap on the interface behavior of the concrete and steel tube were incorporated. A regression analysis was performed based on the results and a simplified formula was proposed to estimate the effect of spherical-cap gaps on the ultimate strength of CFST stub columns and the accuracy of the predictions was verified by the finite element results.

Ganesh Prabhu *et al.* (2013) investigated experimentally and analytically Carbon Fibre Reinforced Polymer (CFRP) strips composites in strengthening of CFST members under compression. CFRP fabrics was used as horizontal strips (lateral ties) with several other parameters such as the number of layers, width and spacing of strips. Experimental results revealed that external wrapping of CFRP strips provides restraint against the lateral deformation effectively and delays the local buckling of steel tube. The proposed analytical model for predicting the load bearing capacity of CFRP confined CFST columns was able to capture the results accurately. It was found that external strengthening of CFST columns using normal modulus CFRP strips was a quite effective technique to increase the load carrying capacity and stiffness of the CFST section.

Xiushu Qu *et al.* (2013) investigated the behavior of rectangular CFST columns subjected to eccentric loading. A total of 17 rectangular CFST columns uniaxial and biaxial bending tests were carried out. Parameters considered that concrete compressive strength, steel strength, cross-sectional proportion and eccentricity. The relationship between the strength index and ductility, subject to the constraining factors, as well as the eccentricity ratio, were studied.

Chao Hou *et al.* (2013) presented a FEA on concrete filled steel tubular (CFST) members with square sections under both loading and chloride corrosion. The FEA model was then used to perform mechanism analysis on the CFST stub columns and beams subjected to loading and chloride corrosion. Theoretical analysis was done using the FEA modeling. It was obtained that CFST stub columns and beams under corrosion behaved in a relatively ductile manner. Chloride corrosion was found to have significant effects on the mechanical behavior of both CFST stub columns and beams.

Xiushu Qu (2013) carried out Load-reversed push-out tests on 6 rectangular CFST columns. The paper investigated the nature of the bond between the concrete in fill and the steel tube, the contribution of each bond stress component (i.e., chemical adhesion, microlocking and macrolocking) and the development of macrolocking within four half-cycles of loading. The concept of a critical shear force transfer length was introduced, and its implications on practical design discussed. The critical interface length to ensure full shear transfer was studied, and design recommendations were provided.

Portolés (2013) conducted tests on slender circular tubular columns filled with normal, high, and ultra-high strength concrete for plain, bar reinforced and steel fiber reinforced columns. These columns were reinforced and subjected to both concentric and eccentric axial load. The experimental ultimate load of each test was compared with the design loads from Eurocode 4, accurate for the eccentrically loaded tests. It is also worth noting that for slender members an improvement in ductility is easily obtained with eccentricity, but not with concrete strength or type of infill.

Lin-Hai Han *et al.* (2014) investigated the behavior of concrete-encased CFST stub columns under axial compression. A FEA) modeling was developed to analyze the behavior of the composite columns. The material nonlinearity and the interaction between concrete and steel tube were considered. The load versus deformation relations of the concrete-encased CFST stub columns was presented. The differences of concrete-encased CFST columns, conventional CFST and RC columns were portrayed. A formula was proposed to predict the ultimate strength of the composite stub columns.

Xiao-Gang Liu (2014) had done experiments on composite connections consisting of steel girders framing into CFST beam-columns. The test results were compared with the calculation results of the AIJ specification. The AIJ specification is less accurate when the concrete compression strength f_c exceeds 70 MPa or the steel tensile yield strength f_y exceeds 450 MPa.

CONCLUSION

This paper focused on the recent advancements in CFST columns. In recent years, there has been a trend towards the development of advanced analysis methods suitable for design of CFST columns. Over the past several decades, a wide range of research has been conducted on the monotonic and cyclic behavior of circular and rectangular concrete filled steel tube columns. An extensive work can be done in CFST columns subjects to blast loading and fire exposure.

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