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Axial behaviour of concrete filled steel tube stub columns: a review

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Abstract

Concrete-filled steel tubular (CFST) columns are widely used in construction of high-rise buildings and peers of bridges to increase the lateral stiffness of the buildings, the axial load capacity, ductility, toughness, and resistance of corrosion of the columns. The CFST columns have much superior characteristics compared with traditionally reinforced concrete columns. The position of the concrete and steel tube in the cross-section of the CFST column is the most appropriate solution in terms of the strength and ductility. The steel tube, which is placed outside of the cross-section of the column, withstand the bending moment effectively. The concrete that is placed into the steel tube delay the local buckling of the steel tube and increase the axial load capacity of the column due to continually lateral confining. This paper presents a review on experimental results of the axial behavior of CFST columns performed by various researchers.

Keywords: *Concrete-filled steel tube columns; axial load capacity; ductility, toughness.*

1. Introduction

Concrete filled steel tube columns (CFST) are widely used in high-rise buildings, subway platforms and peers of bridges. CFST column members have superior properties compared to steel and reinforced concrete column members, which have equivalent properties. The placement of concrete and steel in CFST columns provides the optimum solution for the stiffness and rigidity of the CFST cross-section. Placing of the steel along the outermost periphery of the cross-section ensures that it is able to exhibit the most effective behavior under the bending moment and tensile stresses effects. At the same time, the bending stiffness of the steel tube section increases because the steel, which has a greater modulus of elasticity than the concrete, is placed farthest from the center of the section. Concrete, especially in rectangular and square CFST columns, delays the axial pressure loads as well as the buckling of the steel tube. When concrete core is encased by the steel tube, the strength and ductility capacities of CFST columns significantly increase. The most important features of CFST columns are that they have very high compressive strengths. In case of earthquake, the spalling of concrete of conventional reinforced concrete (RC) columns that is outside the concrete core encased by transverse reinforcement is not encountered in CFST columns. Furthermore, in CFST columns, there are no frequent reinforcement arrangement problems at joints in buildings that are seen in conventional RC columns, especially in earthquake areas.

The use of CFST columns (Fig. 1) is also economically beneficial. Since the steel tube acts as a mold in practice, labor and material costs are significantly reduced. As the reinforcement and mold work in traditional RC buildings take too much time, the middle and high-rise buildings built with the CFST members rise faster Matsui [1]. On the other hand, very simple beam-to-column joint details can be created by using CFST structural elements with rectangular or square cross-section. This saves the total cost of the structure and facilitates in the design phase. In addition, the steel tube and concrete naturally reinforce each other's behavior in the joints, therefore, this can diminish the labor and material costs in the joints. Furthermore, by using high strength concrete (HSC) in steel tube, it can be formed CFST columns with higher compressive strength than traditional RC columns Neogi and San [2]. Since smaller column sections can be obtained by using HSC, wider areas of use can be achieved in the architectural plan. With the use of smaller and lighter building frames, the building loads on the foundation are reduced, which reduces the base cost. The stated advantages mentioned above provide multi-purpose utilization of such building elements in modern building applications.

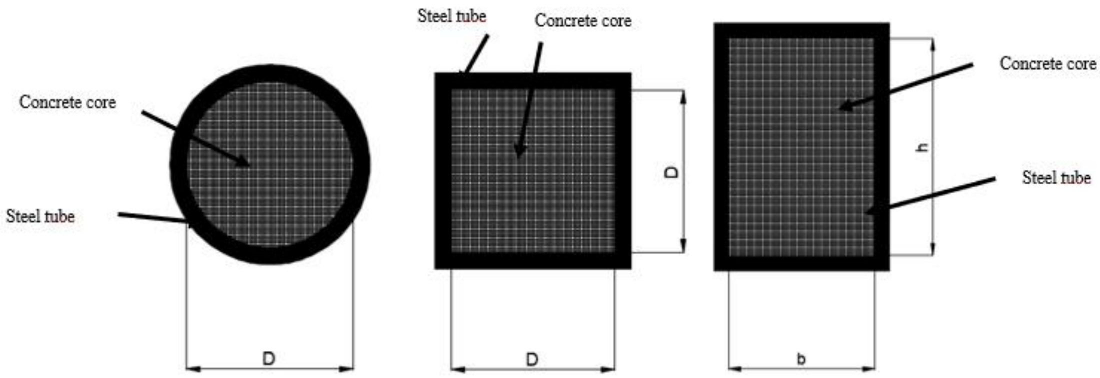

Fig. 1. The view of CFST columns a) Circular CFST columns b)square CFST columns c) Rectangular CFST columns.

One of the most important factors limiting the use of CFST structural elements is the limited knowledge about the behavior of CFST structural elements under various load effects. Many parameters complicate the analysis and sizing of the components of the CFST members. The CFST members consist of two materials with quite different stress-strain behavior. The interaction between these two materials also causes problems. It is quite difficult to determine the cross-sectional properties such as an elasticity modulus and inertial moment definition for the CFST cross-section with composed of steel and concrete. It is necessary to define in the regulations the definition of the energy dissipation mechanisms in the load effect of the CFST structural members. It is needed the determination of the parameters affecting the defined energy dissipation mechanisms, the use of the influence limits of these parameters in the analysis and dimensioning phase. The mechanism of energy dissipation in the load effect of the CFST structural members depends largely on the shape of the cross section, the diameter, the length of the member, the thickness of the steel tube wall, the strength of concrete and steel material. The bonding, wrapping of concrete, residual stress, creep, shrinkage and loading type affect the behavior of CFST structural members.

In recent years, numerous researchers have investigated the behavior of the CFST columns, beams, and beam-column joints under various loads effects. The researchers are also investigating issues such as bonding effect, stress-strain relationships, local buckling, sample size, and fire effect in order to create performance based earthquake regulations. In this study, some outstanding studies performed on CFST stub columns under axial compression by various researchers is briefly evaluated and discussed.

2. Review on CFST columns under axial compression

A large number of studies have been done by various researchers to investigate the axial load capacities of CFST columns with regard to cross-sectional shapes (circular, square, and rectangular), concrete strength (low, normal, and high), diameter-to-thickness ratio (D/t), length-to-diameter ratio (L/D), etc. Some of the earliest studies performed on CFST columns under axial compression have been done by Gardner and Jacobson [3] and Knowles and Park [4]. Gardner and Jacobson [3] examined 22 CFST columns with D/t ratios between 30 and 40. These tests results suggested that when the axial load reached to ultimate load, although the steel tube was at failure, but the concrete core was not failed. However, an increase in strain level of the steel tube was observed without local buckling, provided by the concrete stabilized the steel tube wall. Similarly, Knowles and Park [4] have investigated 12 circular and 7 square CFST columns with D/t ratios of 15, 22, and 59, and L/D ratios ranging from 2 to 21. The test results showed that the tangent modulus method accurately forecasted the axial load capacity for CFST columns with L/D ratios are higher than 11 but was slightly conservative for CFST ones with small slenderness ratios. This may be attributed to the increase of concrete strength resulting from triaxial confinement effects. However, this increase was only valid for circular tubes, not for CFST columns with square or rectangular shapes. Furthermore, it was observed that this increase in concrete strength occurred only in stub columns. The CFST columns with large L/D ratios shows weak composite section behavior and hence, failed by column buckling before reaching the strains reached to ultimate level.

Tomii et al. [5] examined almost 270 circular, octagonal, and square composite columns. The D/t ratios of CFST columns ranged from 19 to 75, and L/D ratios ranged from 2 to 9. The test results clearly showed that the post-yield behavior of the CFST columns can be characterized as either (1) strain-hardening; (2) perfectly plastic; or (3) degrading stiffness type. Although circular and many octagonal shapes were classified as either Type 1 or 2, some of the octagonal and all of the square cross-sections were categorized as Type 3. At high axial load levels, concrete confinement provided by the steel tube was observed in the circular and many octagonal cross sections due to strain-hardening characteristics for these specimens. On the contrary, square tubes provided very little confinement effect of the concrete core because the walls of the square tube withstand the concrete pressure by plate bending, instead of the membrane-type hoop stresses. Consequently, there was not seen an increase in the axial load capacities of the square CFST columns due to the triaxial compression effects.

Sakino et al. [6] tested 18 circular CFST columns with D/t ratios ranging between 18 and 192. In this investigation, three identical specimens were subjected to different load conditions. Axial load was applied to the concrete and the steel tube simultaneously for the first specimen group. The load was applied exclusively to the concrete core in the second specimen group, and the load application was similar to this in the third group except the inside tube wall was greased before casting the concrete. The test results showed that when the steel tube and the concrete core were loaded simultaneously, the steel tube provided no confinement effect until post-yield behavior of the CFST columns. In the only concrete loaded CFST specimens, some longitudinal stresses were observed and noted in the steel tube even for the columns with the greased wall. Although test results indicated that the axial stiffness of the concrete loaded only CFST columns were about half that of the other CFSTs tested, the concrete loaded only CFST columns have reached a greater yield and ultimate axial load capacity. Schineder [7] performed an experimental and analytical study on the behavior of short CFST columns under axial compression. 14 specimens, 3 circular, 5 square and 6 rectangular steel tube shapes, were tested to investigate the effect of the steel tube shape and wall thickness on the ultimate strength of the CFST columns. Confinement effect of the concrete core provided by the tube shape was also explained. The D/t ratios of CFST columns were between 17 < D/t < 50, and the L/D ratios of varied from 4 to 5. Experimental results indicated that circular steel tubes provide much more post-yield axial ductility than the square or rectangular steel tube sections. All circular tubes tested in this experimental study was classified as strain-hardening, while only the small D/t ratios, approximately D/t < 20 for this study, exhibited strain-hardening characteristics for the square or rectangular tubes. Furthermore, measured perimeter-to-longitudinal strains of the steel tube suggest significant confinement is not present for most tested specimens until the axial load reaches almost 92% of the yield strength of the CFST column. In addition, the square and rectangular steel tube walls, in most cases, did not provide significant confinement to the concrete core beyond the yield load of the CFST column. These authors have also observed that local wall buckling for the circular tubes occurred at an axial ductility of 10 or more, while local wall buckling of the square and rectangular tubes occurred at ductility between 2 and 8. Han [8] investigated the axial behavior of stub columns of concrete-filled rectangular hollow sections (RHS) subjected to axial load. A total of 24 RHS specimens were tested under axial compression. The main parameters varied in the tests are: (1) constraining factor (ξ) from 0.5 to 1.3, (2) tube width ratio (β) from 1.0 to 1.75. Experimental results indicated that the constraining factor (ξ) and the width ratio (β), to some extent, represent the composite action between steel tubes and concrete of the concrete-filled RHS columns. Generally, the higher is the constraining factor (ξ), the bigger is the strength index (SI), and the higher is the ductility index (DI). The bigger the width ratio (β), the smaller is the strength index (SI), and the lower is the ductility index (DI). Giakoumelis and Lam [9] examined 15 circular CFST columns with 30, 60 and 85 MPa concrete strength, and D/t ratio between 22.9 and 30.5. The specimens are separated as greased and non-greased specimens to investigate the bond effect on axial capacity and ductility of CFST columns. The results showed that the difference of the axial load capacity of greased and non-greased specimens can be ignored for 30 and 50 MPa concrete strength, while this difference can be significant (14%) for CFST columns with 85 MPa concrete strength. Ellobody et al. [10] examined the behavior and design of axially loaded CFST circular stub columns. The study was performed for a wide range of concrete cube strengths varied from 30 to 110 MPa. The (D/t) ratio of CFST columns ranged from 15 to 80. A three dimensional finite element (FE) model was developed to compare stress-strain relationships and axial load capacities of CFST columns. For this purpose, nonlinear material models for concrete and steel tubes were used in analyses. The results obtained from the FE analysis were verified against experimental test results. Gardner and Ashraf [11] have proposed the stress–strain behavior of structural carbon steel may be suitably accurately reflected for design purposes by an idealised elastic, perfectly-plastic material model; such material behavior lends itself to the concept of section classification. Tao et al. [12] have investigated some procedures given in the Australian bridge design standard AS 5100 (Standards Australia, 2004) for the design of concrete-filled steel tubular (CFST) columns, beams and beam-columns were presented and discussed in detail. A large number of test data from two currently available test databases (2194 test results altogether) was used to evaluate the applicability of AS 5100 design code in calculating the strength of CFST members. Some other existing design codes, such as the Japanese code AIJ (1997), American code AISC (2005), British bridge code BS 5400 (2005), Chinese code DBJ13-51-2003 (2003) and Eurocode 4 (2004), are also compared with the test results in this paper. From the comparisons, beneficial information was obtained for future possible revision of AS 5100 and for the suggestion that whether this model may be used for building construction. Soliman et al. [13] investigated experimentally the current design codes to evaluate the ultimate load behavior of concrete encased steel short columns. The design provisions for CFST columns from the Egyptian codes ECP203-2007 and ECP-SC-LRFD-2012, as well as, American Institute of Steel Construction, AISC-LRFD-2010, American Concrete Institute, ACI-318-2008, and British Standard BS-5400-5 was evaluated. Encased steel concrete columns have been examined experimentally to study the effect of concrete confinement and different types of encased steel sections such as steel pipe and plastic pipe, and wood sections. The axial load capacity of the tested CFST columns was compared with the values obtained from these design codes. The test results clearly showed that the confining effect provided by the steel tube to the concrete core was affected by the shape of the encased steel section. The tube-shaped steel section causes better confinement effect than other sections. Furthermore, it is obtained that the predictions of ECP- SC-LRFD-design code are more conservative than other design codes. Hoang et al. [14] examined numerically the behavior of circular CFST stub columns using various concrete strengths under concentric loading on the concrete core, which are based on the experimental tests of some researchers. ATENA-3D software was used to conduct the numerical analysis. To obtain good agreement between test results on CFST stub columns with normal strength concrete (NSC) and numerical results. It is obtained from the results that the numerical models in ATENA-3D successfully predict the behavior of CFST stub columns under loading on concrete core. Furthermore, ATENA-3D is enough reliable to perform numerical modeling of CFST columns with various concrete strengths.

3. Conclusions

Numerous experimental and analytical studies have been performed on CFST columns by various researchers mentioned above. The conclusions obtained from these studies can be summarized as below:

- The CFST structural members have higher ductility, strength, and energy dissipation capacities than equivalent steel and RC structural members.
- The confining effect exerted by the steel tube to the concrete core is higher for circular steel tubes than square and rectangular sections.
- When the diameter-to-thickness ratio of CFST columns is reduced, the axial load capacity and ductility can be increased.
- The bonding effect is much more effective for high strength concrete than low and normal strength concrete.
- The stress-strain relationships, axial load capacities, and the buckling of CFST columns can be represented by various finite element (FE) models developed by various researchers.
- The reliability of various design codes is not the same to predict the axial load capacities of CFST columns.

References

[1] Matsui C. Strength and deformation capacity of frames composed of wide flange beams and concrete filled square steel tubular columns. Proceedings of the Pacific Structural Steel Conference, Auckland, New Zealand, 4-8 August, 169-181; 1986.

[2] Neogi PK, Sen HK, Chapman JC. Concrete-filled tubular steel columns under eccentric loading. Journal of Structural Engineering ASCE 1969; 47(5): 187-195.

[3] Gardner NJ, Jacobson ER. Structural behavior of concrete filled steel tubes. ACI Structural Journal 1967; 64(7): 404-413.

[4] Knowles RB, Park R. Strength of concrete-filled steel tubular columns. Journal of the Structural Division ASCE 1969; 95(12): 2565-2587.

[5] Tomii M, Yoshimura K, Morishita Y. Experimental studies on concrete filled steel tubular stub columns under concentric loading. Proceedings of the International Colloquium on Stability of Structures under Static and Dynamic Loads 1977; 718-741.

[6] Sakino K, Tomii M, Watanabe K. Sustaining load capacity of plain concrete stub columns by circular steel tubes. Proceeding of the International Specialty Conference on Concrete Filled Steel Tubular Structures 1985; 112-118.

[7] Schneider SP. Axially loaded concrete-filled steel tubes. Journal of Structural Engineering ASCE 1998; 124(10): 1125-1138.

[8] Han L-H, Zhao X-L, Tao Z. Test and mechanics model for concrete-filled SHS stub columns, columns and beam-columns. Steel and Composite Structures 2001; 1(1): 51-74.

[9] Giakoumelis G, Lam D. Axial capacity of circular concrete-filled tube columns. Journal of Constructional Steel Research 2004; 60(7): 1049-1068.

[10] Ellobody E, Young B, Lam D. Behaviour of normal and high strength concrete-filled compact steel tube circular stub columns. Journal of Constructional Steel Research 2006; 62:706–71.

[11] Gardner L, Ashraf M. Structural design for non-linear metallic materials, Engineering Structures 2006; 28: 926–934.

[12] Tao Z, Brian UY, Han LH, He SH. Design of concrete-filled steel tubular members according to the Australian Standard AS 5100 Model and Calibration. Australian Journal of Structural Engineering 2015; 8(3): 197-214.

[13] Soliman KZ, Arafa AI, Elrakib TM. Review of design codes of concrete encased steel short columns under axial compression. HBRC Journal 2012; 9(2): 134-143.

[14] Hoang AL, Fehling E, Ismail M. Numerical modelling of circular concrete filled steel tube stub columns under concentric loading. Proceedings of the 4th International Symposium on Ultra-High Performance Concrete and High Performance Construction Materials; 2016.