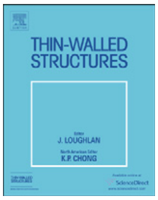
Thin-Walled Structures 56 (2012) 62–70

Contents lists available at SciVerse ScienceDirect

Thin-Walled Structures

journal homepage: www.elsevier.com/locate/tws



Compressive strength of circular concrete filled steel tube columns

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ARTICLE INFO

Article history:
Received 15 December 2011
Accepted 11 March 2012
Available online 13 April 2012

Keywords:
Concrete-filled steel tubes
Slenderness
Confinement
Overall buckling
Local buckling
Crushing
Yielding
Vertical deflection
Ductility

ABSTRACT

An experimental study was undertaken to investigate the behaviour of 24 concrete-filled steel tube (CFST) columns, loaded concentrically in compression to failure. Variables in the tests include the length, diameter, strength of the steel tubes and the strength of the concrete. The large slenderness ratio caused all composite columns in Series 1 to fail by overall flexural buckling. Although overall flexural buckling was also experienced in the composite columns of Series 2 tests, the stockier columns failed by crushing of the concrete and yielding of the steel tube. A comparison of the experimental results with the loads predicted by the South African code (SANS 10162-1) and Eurocode 4 (EC4) shows that the codes are conservative by 8.4% and 13.6%, respectively, for Series 1 tests, and 10.5 and 20.2%, respectively, for Series 2 tests. A plot of the compressive load versus the vertical deflection shows the composite columns to be fairly ductile.

1. Introduction

Concrete filled steel tube (CFST) columns are valuable structural members when compared with separate reinforced concrete columns or steel hollow columns. CFST columns combine the best characteristics of both steel and concrete materials, that is, they have high strength, high ductility, and high stiffness. These properties and the large energy absorption capacity ensure that composite columns are used in structures to resist seismic loads [1]. The steel tube acts as permanent formwork, and provides lateral confinement or lateral reinforcement to the concrete whilst local buckling which is normal a problem with thin-walled steel tube is delayed due to the presence of the concrete infill. This means that local buckling will occur at higher loads than what will happen with steel only. What is also important with these members is that the local buckling mode of the steel tube is modified since inward buckling, which is common with steel is prevented. Hence the wall of the steel tube tends to buckle outwards only. Furthermore, the column sizes can be reduced if composite columns are used resulting in increased floor spaces and lower costs.

When circular CFST columns are subjected to small axial loads, confinement can be neglected since the poisson's ratio for the concrete is smaller than that for steel [2–5]. The load causes the steel tube to expand faster than the concrete. As the load increases, the longitudinal strain of concrete also increases until it reaches a certain critical strain. At this point the lateral deformation of the concrete catches up with that of the steel tube. Any further increase in load causes the tensile hoop stress to develop in the steel tube, and the concrete core is subjected to triaxial compression [5]. The lateral stress generated by steel tube causes additional compressive resistance of concentrically loaded CFST columns to develop. This resistance is higher than the sum of the resistance of their components. Investigations by Brauns [6] also showed that the effect of confinement exists at high stress level when structural steel acts in tension and concrete in compression.

2. Selected literature review

The concept of lateral confinement is central to the behaviour of concrete filled composite columns and has been the focus of many researchers over the past 25 years. Previous research has shown that concrete confinement provided by the steel tube depends on parameters such as the diameter-to-thickness ratio, slenderness ratio (length-to-diameter ratio), shape of the cross-section, strength of the materials, eccentricity of the load and compaction method. Schneider [7] investigated the effect of the shape (3 circular, 5 square and 6 rectangular) and wall thickness of the steel tube on the compressive resistance of concentrically loaded short composite columns. Both steel tube and concrete core were loaded simultaneously. The results obtained showed that composite columns constructed from circular hollow sections offered better post yield concrete confinement, stiffness and

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http://dx.doi.org/10.1016/j.tws.2012.03.008

ductility compared to the rectangular and square hollow sections. Specimen with larger plate wall thickness had higher stiffness than those with smaller thickness. Similar results were also obtained by O'Shea and Bridge [8], Giakoumelis and Lam [9] and De Nardin and El Debs [10].

O'Shea and Bridge [8], and Giakoumelis and Lam [9] also studied the effects of the bond strength between the concrete and the steel tube of short circular and rectangular CFST columns with various concrete strengths under axial load. Both examined three loading conditions, namely, (1) simultaneous axial loading of the concrete and steel, (2) axial loading of the concrete only, (3) axial loading of the steel only [8] or loading the concrete and steel with a greased column [9]. The degree of confinement offered by a thin-walled circular steel tube to the internal concrete was found to be dependent upon the loading condition. The results obtained indicated that when the steel and concrete were loaded together, the steel tube offered little confinement. Increased strength due to confinement of high-strength concrete was obtained only if the concrete is loaded and the steel is not bonded to the concrete. Sakino et al. [5] attributed the strength improvement in short columns when the concrete and the steel are loaded simultaneously to be due to strain hardening of the steel instead of the confining effect.

Han and Yang [11], Han and Yao [12] and Han and Yao [13] performed tests to determine the influence of compaction methods of the concrete on the compressive resistance of concrete filled tubes. Tests showed that better compaction resulted in higher compression resistances. This investigation highlighted the importance of concrete compaction on the performance concretes filled tubes. Han and Yao [13], Han et al. [14], Lachemi et al. [15,16], and Yu et al. [17] studied short columns filled with self-consolidating concrete (SCC). SCC (also known as self compacting concrete) is highly flowable, non segregating concrete that can be placed without mechanical consolidation. The concrete cubic strength used in these studies ranged from 50 to 120 MPa. Tests results showed the behaviour of SCC filled steel tubular columns to be similar to composite columns with normal concrete, implying that the strength predictions used in existing design codes developed for normal concrete-filled columns could be used for SCC filled columns within the scope of tested concrete strength. However, the ductility for very high strength SCC filled steel tubes was found to be generally smaller than that for normal strength concrete filled steel tubes.

Zeghiche and Chaoui [18] and De Oliveira et al. [19] investigated the influence of column slenderness and concrete strength on the capacity on the behaviour of CFST columns. Increase in concrete strength resulted in an increase in the capacity of the CFST columns, however confinement was found to be more effective when the steel tube was filled with ordinary concrete, due to its higher deformation capacity in comparison with the high strength concrete. Shorter columns failed by crushing of the concrete and yielding of the steel whilst slender columns failed by overall instability. As expected, the load capacity decreased with increasing slenderness ratio of the column.

Despite the numerous publications about CFST columns covered in literature, most of this work focused on short composite columns, where local buckling is exhibited. This investigation is motivated by the need to explain the behaviour of composite columns over a wider range of column lengths and diameters, and verify the applicability of the formulas used in both SANS 10162-1 [20] and Eurocode 4 (EC4) [21] design codes. SANS 10162-1 is based on the Canadian Code, CAN/CSAS16.1-M01 [22]. The findings of these investigations are to be used to determine what adjustments, if any, should be made to the formulae in the respective codes.

3. Material properties

3.1. Steel

Since these investigations were undertaken at two different times and of different material properties, the first group of tests is referred as Series 1 and the second one as Series 2 (see Table 1). Structatube 300 steel was used for Series 1 tests and EN 10219-1-S355MH or simply S355 tube steel was used for Series 2 tests. Structatube 300 is Grade 300WA weldable steel tube that complies with SANS 1431 [23]. Structatube 300 tube has a minimum yield strength of 300 MPa and a minimum tensile strength of 450 MPa. EN 10219-1-S355MH or simply S355 Tube is a higher strength grade of steel tube and has a yield strength ranging from 355 to 475 MPa and a tensile strength ranging from 450 to 550 MPa.

In order to determine the material properties of the steel tubes, tensile tests were conducted on the steel coupons. These properties are necessary for determining the capacity of the CFST columns using the codes chosen. The tensile coupons were prepared and tested according to the guidelines provided by the British Standard BS 18 [24]. The coupons were tested in a 100 kN Instron tensile testing machine by applying a tensile load at a rate of 3 mm/min until failure. During testing a stress–strain curve was plotted by the computer, from which the yield and ultimate stresses of the steel were determined, as well as the modulus of elasticity (E). Table 1 shows the average material properties of the steel tubes. Note the substantial difference in the strength of the steel for the 2500 length column of 152.4 diameter. This tube was out of stock and was delivered at a later stage.

3.2. Concrete

Concrete cubes of dimension 100 × 100 × 100 mm were cast from the concrete batch that was prepared for the composite columns. The concrete mix design consisted of cement, 19 mm stone (coarse aggregates) and river sand (fine aggregate). The cubes were filled in two or three layers and compacted using

Table 1
Average material properties.

Series	Specimen	Steel tube			Concrete		
		f_y (MPa)	f_u (MPa)	E (GPa)	f_{cu} (MPa)	f'_{cu} (MPa)	E (GPa)
Series 1	S1-1	354.05	432.35	206.50	40.3	32.1	31.1
	S1-2	354.05	432.35	206.50			
	S1-3	354.05	432.35	206.50			
	S1-4	354.05	432.35	206.50			
	S1-5	345.20	430.40	209.00			
	S1-6	345.20	430.40	209.00			
	S1-7	345.20	430.40	209.00			
	S1-8	345.20	430.40	209.00			
	S1-9	361.95	457.85	208.05			
	S1-10	361.95	457.85	208.05			
	S1-11	361.95	457.85	208.05			
	S1-12	361.95	457.85	208.05			
Series 2	S2-1	488.20	549.60	206.70	30.9	25.6	28.27
	S2-2	488.20	549.60	206.70			
	S2-3	488.20	549.60	206.70			
	S2-4	394.30	480.20	206.70			
	S2-5	438.20	500.90	204.60			
	S2-6	438.20	500.90	204.60			
	S2-7	438.20	500.90	204.60			
	S2-8	430.30	480.15	201.60			
	S2-9	398.80	479.10	207.70			
	S2-10	398.80	479.10	207.70			
	S2-11	398.80	479.10	207.70			
	S2-12	392.20	470.80	206.80			