Thin-Walled Structures 120 (2017) 91–104

Contents lists available at ScienceDirect

Thin-Walled Structures

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

Full length article

Axial compressive behaviour of concrete-filled double-tube stub columns with stiffeners

Zhi-Bin Wang[a,b], Zhong Tao[b,*], Qing Yu[c]

[a] *College of Civil Engineering, Fuzhou University, Fuzhou, Fujian Province 350108, China*
[b] *Centre for Infrastructure Engineering, Western Sydney University, Penrith, NSW 2751, Australia*
[c] *Department of Construction Management, Tsinghua University, Beijing 100084, China*

ARTICLE INFO

Keywords:
Concrete-filled double-tube columns
Stiffeners
Axial compressive strength
Ductility
Finite element analysis
Superposition mode

ABSTRACT

Concrete-filled double-tube (CFDT) columns, which are a new type of composite columns, have high fire resistance and the potential to be widely used in high-rise buildings. It is expected that the amount of steel used in a regular CFDT column will be relatively high due to the use of double tubes. To reduce the steel consumption, a thin-walled steel tube with longitudinal stiffeners may be adopted for the outer tube in a CFDT column. This paper studies the behaviour of concrete-filled stiffened double-tube (CFSDT) stub columns under axial compression. Tests on 12 CFSDT stub columns and two reference columns were carried out accordingly, and the test results confirm that the stiffened columns have high strength and good deformation capacity. A finite element model was developed to analyse the interaction between the steel tubes and concrete. Based on further parametric studies, a superposition model was proposed to predict the axial compressive strength of CFSDT stub columns.

1. Introduction

Due to their great advantages, such as high strength, favourable ductility and good seismic behaviour, concrete-filled steel tubular (CFST) columns have been widely used in the construction of high-rise buildings [1]. With the advancement of high strength steel and concrete, the cross-sectional dimensions of CFST columns are becoming increasingly smaller, which poses a risk to their fire resistance. Accordingly, the so-called “concrete-filled double-tube” (CFDT) columns shown in Fig. 1(a) and (b) have been proposed by Liew and Xiong [2,3] aiming to improve the fire resistance of CFST columns with high strength concrete, since the inner circular CFST can be protected by the outer concrete. Meanwhile, the ductility of the columns can also be enhanced. Generally speaking, if the cross-sectional areas are the same, a square CFDT column shown in Fig. 1(b) would have higher flexural stiffness than the circular column shown in Fig. 1(a). Meanwhile, a square column is easier to connect with the beam. Therefore, this paper will focus on the study of square CFDT columns shown in Fig. 1(b).

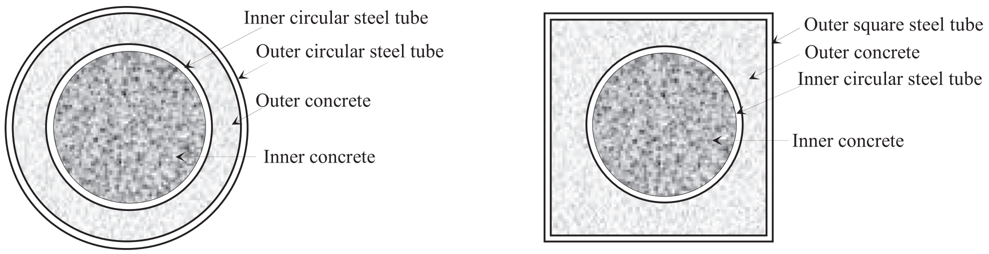
Due to the use of double tubes, it is expected that the steel ratio in a CFDT column will be relatively high [2,4–6]. For example, a typical CFDT test specimen S3-2-1 in [2] had an outer circular tube of 219 × 10 mm and an inner circular tube of 114 × 6.3 mm. Therefore, the steel ratio (total cross-sectional area of steel in the column divided by the cross-sectional area of concrete) for this specimen is as high as 30%, which highlights the need to reduce the cost and steel consumption in CFDT columns. To realise this goal, a viable solution is to use stiffened thin-walled tubes as the outer tubes in CFDT columns. The stiffening can be achieved either by using welded stiffeners [Fig. 1(c)] or cold-formed stiffeners [Fig. 1(d)]. Since using cold-formed steel sections can reduce the welding costs, they are adopted in this paper to fabricate the so-called “concrete-filled stiffened double-tube” (CFSDT) columns, as shown in Fig. 1(e). Previous studies by the authors and other researchers [7–15] have proved the effectiveness of stiffeners in enhancing the performance of thin-walled square tubes by delaying local buckling.

Liew and Xiong [2] and Wan and Zha [4] tested a series of circular CFDT stub columns under axial compression. In order to improve the corrosion resistance, Chang et al. [16] and Hassanein et al. [17] studied the axial compressive behaviour of circular CFDT stub columns consisting of a stainless steel outer tube and a carbon steel inner tube. These studies in [2,4,16,17] proved that circular CFDT stub columns exhibit high strength and good ductility. Qian et al. [18] focused on the seismic behaviour of square CFDT columns. They found that the lateral force – displacement hysteretic loops of all square CFDT columns were plump and stable. They recommended the use of this type of composite columns in earthquake-prone zones. Romero et al. [5] and Espinos et al.

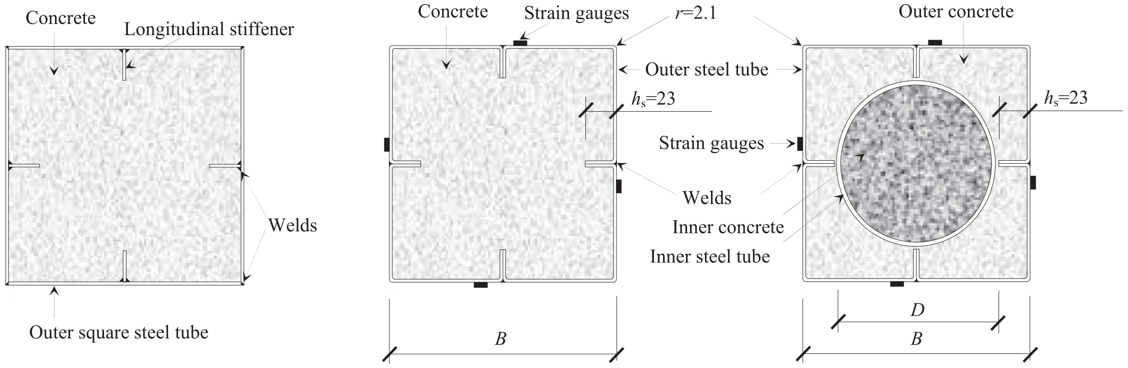
---

[*] Corresponding author.
E-mail address: z.tao@westernsydney.edu.au (Z. Tao).

http://dx.doi.org/10.1016/j.tws.2017.08.025
Received 19 April 2017; Received in revised form 5 August 2017; Accepted 22 August 2017



(a) Circular CFDT (b) Square CFDT



(c) CFST with welded stiffeners (d) CFST with cold-formed stiffeners (e) CFSDT

Fig. 1. Various composite columns (unit: mm).

[19] studied fire resistance of circular CFDT columns and circular concrete-filled double skin tubular columns (the inner tube was not filled with concrete) through experiments. In addition, Espinos et al. [20] investigated fire resistance of circular CFDT columns using finite element method. They concluded that the inner steel tube was effectively protected by the outer concrete and increasing the inner steel tube thickness led to a significant increase in the fire resistance of those composite columns. Romero et al. [6] and Wan and Zha [4] studied the behaviour of slender circular CFDT columns under axial compression. Compared with normal CFST columns or concrete-filled double skin tubular columns without inner concrete, CFDT columns exhibited higher strength.

The first author has conducted some preliminary experimental research on one CFSDT member, one thin-walled CFST counterpart (without an inner tube) and one concrete-filled double skin tubular counterpart under pure bending [21]. Longitudinal stiffeners were provided for the outer steel tubes of these members, and the cross-sectional configuration of the CFSDT member is the same as that shown in Fig. 1(e). Compared with the reference thin-walled CFST counterpart without the inner tube, the flexural strength and stiffness of the CFSDT specimen were improved by 32.5% and 2.8%, respectively. In addition, compared with the reference concrete-filled double skin tubular member, the flexural strength and stiffness of the CFSDT specimen were improved by 5.9% and 5.1%, respectively. It indicates that the inner steel tube had a high influence on the flexural strength but only a moderate influence on the stiffness of the composite member. Wang et al. [21] also found that all components in the CFSDT member worked together very well throughout the test and no obvious slip between them was found. Meanwhile, no fracture of the outer steel tube was observed and the beam failed due to excessive bending deformation.

So far, no research has been undertaken to study the axial compressive behaviour of CFSDT stub columns with stiffeners. This paper presents the results of a total of 14 tests of stub columns under axial compression. A finite element (FE) model is then developed to simulate the CFSDT stub columns. Based on further parametric studies, a superposition model is proposed to predict the load-carrying capacities of CFSDT stub columns.

2. Experimental investigation

2.1. General

A total of 14 stub columns were prepared and tested, including 12 CFSDT stub columns and 2 thin-walled CFST counterparts. The corresponding cross-sections are exhibited in Fig. 1(e) and (d), respectively, where D is the overall diameter of the inner circular tube; B is the overall width of the outer steel tube; r is the outer radius of the corners of the lipped angles used in fabricating the outer steel tube; and h_s is the height of the longitudinal stiffeners. The main experimental parameters are: (1) presence of the inner steel tube or not; (2) cylinder strength of the inner core concrete $f_{c,i}'$ (42.1 and 69.8 MPa); (3) diameter-to-thickness ratio of the inner steel tube D/t_i (29.2, 37.1 and 70.4); and (4) D/B ratio of the cross-section (0.57, 0.68 and 0.70).

The height (L) and cross-sectional width (B) of all stub columns were 600 and 200 mm, respectively. The outer steel tubes of all the columns had a same thickness (t_o) of 2.01 mm. Therefore, the corresponding width-to-thickness ratio of the steel plates in the square tube $[b/t_o = (B-2\,t_o)/t_o]$ is equal to 97.5 if the steel plate is not stiffened. This ratio is significantly higher than the limitation of b/t_o specified by Uy [8] for square CFST columns in Eq. (1):

$$\frac{b}{t_0} = \alpha\sqrt{\frac{k\pi^2 E_s}{12(1-\upsilon_s^2)f_{y,o}}} = 58.6 \tag{1}$$

where b is the clear width of the steel plate between the faces of the supporting plate elements; α is the reduction factor accounting for initial imperfections, which may be taken as 0.651 according to AS4100 [22]; E_s and υ_s are the elastic modulus and Poisson's ratio of the steel tube, which are usually taken as 200,000 MPa and 0.3 respectively; $f_{y,o}$ is the yield stress of the outer square steel tube (in the current study $f_{y,o}$