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Experimental study of concrete filled cold-formed steel tubular stub columns

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ABSTRACT

An experimental programme was conducted to investigate the compressive behaviour of concrete-filled cold-formed steel tubular (CFCFST) stub columns with thicker tubes. A total of 30 CFCFST stub columns were tested. The cold-formed square hollow section (SHS) tubes included unstiffened sections and longitudinally inner-stiffened sections using different stiffening methods. Two tubular thicknesses of 6 mm and 10 mm were considered. The overall nominal dimension of the steel section was 200 × 200 mm, and the length of the stub columns was 600 mm. Normal concrete and self-consolidating concrete with a nominal compressive strength of 30 MPa were used to fill the cold-formed SHS steel tubes. The effects of the stiffeners on the rigidity, ductility, failure mode and average sectional strength of the CFCFST specimens were examined. The measured strengths of the CFCFST specimens were also compared with the predicted capacities using methods in various codes including AISC, BS5400, EC4, and DBJ and from a finite element (FE) analysis. Results demonstrate that the inner stiffeners affect the deformability, failure mode and overall strength of the stub columns with the 6 mm-thick tubes more significantly. The DBJ code method is comparatively the best in predicting the strength capacity. Using the validated FE model, an extended analysis has been conducted and this has provided further insight into the mechanical behaviour of the CFCFST specimens.

1. Introduction

Concrete-filled steel tubular (CFST) columns have been widely used in modern buildings and bridges because of their excellent structural properties such as high strength, high ductility, large energy absorption capacity, and high cost effectiveness. Square and rectangular CFST columns are increasingly used in structures for reasons of easy beam-to-column connection, high moment capacities, and aesthetic consideration. However, the general performance of square or rectangular CFST columns is not as good as their circular counterparts, and local buckling is more likely to occur in a square or rectangular tube [1]. Uy et al. [2,3] conducted studies to investigate the local buckling and post-local buckling behaviours of the CFST columns with welded square steel sections shown in Figs.1 (a) and (b). The nominal thickness of the steel tubes used in the above study was 3 mm and sectional width ranged from 120 mm to 300 mm. They found that the effect of local buckling on the compressive strength of the CFST columns was significant, and recommended that such effects be included in a modified rigid plastic analysis based on the methods of existing Australian and British standards [3] for cases where plate slenderness limits are large. Ge et al. [4,5], Kitada [6], Liu et al. [7] and Tao et al. [1,8,9–10] conducted experimental and numerical studies on thin-walled square and rectangular CFST columns where the steel walls were stiffened to improve their structural behaviour.

Typical steel box sections are built up by welding four plane plates, and the longitudinal stiffeners are usually welded on the plates with fillet welds as shown in Figs. 1 (c) [4], (d), (e) and (f) [1,8–10]. It is generally recognized, as evidenced in the aforementioned studies, that local buckling of steel tubes can be effectively delayed when stiffeners are provided, resulting in a marked increase in the sectional strength and relatively moderate increase in the ductility. However, local buckling or cracks along the welded corners were observed by Uy et al. [3] and Ge et al. [4] for some specimens. In fact, during the Mexico Valley earthquake, two buildings at the Pino Suarez station even collapsed completely due to cracks along welded corners and plate buckling of their steel box columns [6]. As an improved design, CFST columns with round corners similar to the section shown in Fig. 2 (a) was recommended [6].

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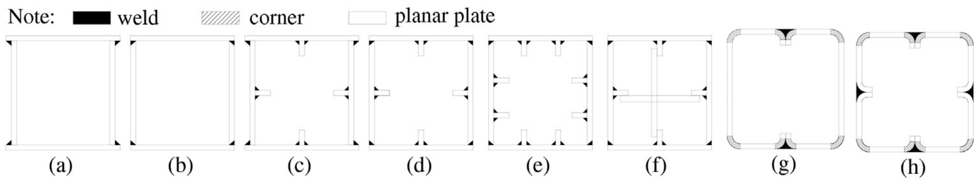

Fig. 1. Representative unstiffened and stiffened tubular sections of CFST columns from previous studies.

A steel section with round corners can be easily obtained using the cold-formed fabrication method. Nowadays, cold-formed steel components are also used extensively in buildings as both structural and non-structural members due to their superior performance of high strength-to-weight ratio resulted from the cold-formed process [11]. More recently, some extensive investigations into the structural performance of concrete-filled cold-formed steel (CFCFST) members have been reported. Chitawadagi et al. [12] conducted test studies on 27 cold-formed rectangular CFST columns with thickness ranged from 1.6 to 2.65 mm, and found that an increase in the wall thickness helps to postpone the local buckling failure and thus enhances the ultimate axial load carrying capacity. Zhang et al. [13,14] studied the static and dynamic structural behaviours of unstiffened and stiffened CFCFST columns with thickness of 1.25 to 1.48 mm. The stiffened steel sections were built up by welding cold-formed lipped angles and channels as shown in Figs.1 (g) and (f). It was also observed that the ultimate strength increased with the number of stiffeners, and the lips anchored with concrete very well until the specimens were damaged. Moreover, columns with more stiffeners have better ductility and energy dissipation capacity. Comparing the failure modes of thin-walled CFST columns with box sections reported in literatures, no cracks at the cold-formed corners were found.

However, the above studies have mainly been concerned with thin-walled cold-formed steel with thickness no greater than 3.0 mm. Young and Ellobody [15,16], Uy et al. [17] conducted series of experimental study on CFST columns with unstiffened cold-formed stainless steel tubes, and the maximum tubular thickness was 6 mm. With the advance of the cold-forming technology, nowadays cold-formed carbon steel sections with wall thickness even >20 mm are being produced and applied in structures. A number of studies [18–23] have been conducted to investigate into the structural behaviour of cold-formed square hollow section (SHS) and rectangular hollow section (RHS) tubes with tubular thickness ranging from 6 mm to 16 mm. The results indicate that thicker cold-formed corners and thicker plane plates both exhibit good structural behaviour. But research on the CFCFST columns with carbon steel tubes and wall thickness >6 mm, stiffened or not, is still very scarce.

The main objective of this study is to investigate the effect of the stiffener arrangements on the strength, stiffness and ductility of the CFCFST members with cold-formed carbon steel tubes having thicker walls. A total of 30 CFCFST stub columns using cold-formed carbon steel, with tubular thickness of 6 mm and 10 mm, were constructed and tested under axial compression. As composite compression members, the steel contribution ratio (δ) of the specimens falls well within the provision of Eurocode 4 [24]. Stiffened sections with different stiffener number and width were designed to investigate the effects of the stiffeners on the mechanical behaviours of the CFCFST columns. Normal concrete and self-consolidating concrete with nominal compression strength of 30 MPa were used to fill the steel tubes. The equivalent compressive strength, the normalised compressive strength ratio and the predicted capacities using various design codes, namely AISC [25], BS5400 [26], EC4 [24], and DBJ [27], were all analysed via ignoring the effect of the infilling concrete to the CFCFST specimens. FE model analysis has been conducted to produce complete axial load versus strain curve of the stiffened CFCFST members and provide further insight into the effect of the stiffeners.

2. Experimental programme

2.1. General

A typical stub column specimen configuration, with a length of 600 mm and a cross-section of 200 × 200 mm, was used in the CFCFST column tests. The parameters under investigation included: a) Two different tube thicknesses of 6 mm and 10 mm, with nominal yield strength of 345 MPa and 235 MPa, respectively. b) Three different types of concrete, namely normal concrete (CC), self-consolidating concrete mix-1 (SCC1) and self-consolidating concrete mix-2 (SCC2), that were used to fill the tubes. The nominal concrete compressive strength was chosen to be 30 MPa uniformly. c) Five different cross-section designs, including unstiffened and stiffened cross-sections with different arrangement of the stiffeners.

The detailed configurations of the tubular cross sections of the composite stub columns are shown in Fig. 2. Thus, totally 30 stub column specimens were fabricated and tested. These specimens were classified into 6 groups according to the two wall thicknesses and three types of concrete. Each group included five specimens of different cross section details. A summary of the 6 groups of the specimens is given in Table 1. The specimen labels in Table 1 are defined according to the section configuration, wall thickness, and the type of concrete. Take specimen “Pa-6-1” as an example, (1) “Pa” indicates section “a” as shown in Fig. 2 (a); the five sections are indicated by “Pa” to “Pe” sequentially, (2) the number “6” that follows indicates the thickness of the SHS tubes, “6” means 6 mm, and “10” means 10 mm, (3) the number “1” next indicates the type of concrete; “1” means normal concrete, “2” SCC1, and “3” SCC2.

Also listed in Table 1 are the measured parameters. B, t_1, and t_2 are the measured average total width of steel tube, average thickness of

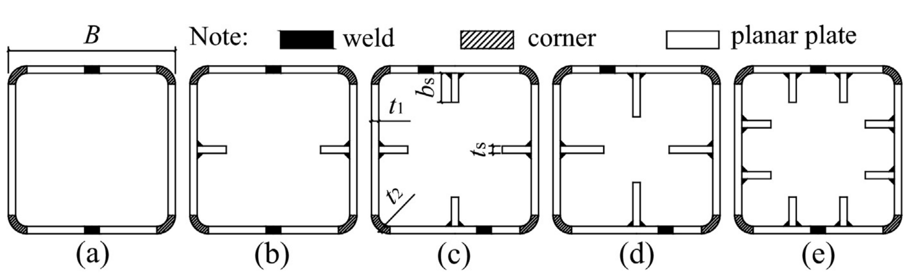

Fig. 2. Cold-formed steel tubular sections considered in this study.