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Compression tests on cold-formed steel built-up box sections

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ABSTRACT

Built-up box sections are becoming increasingly popular as column members in cold-formed steel (CFS) structures; uses of such sections include CFS trusses, space frames, and portal frames. In this paper, the built-up box sections are fabricated by two identical lipped channel-sections connected at their flanges with self-drilling screws. This paper presents an experimental investigation on the axial capacity of CFS built-up box sections. Compression tests were conducted for different values of slenderness's covering stocky to slender columns. In total 8 built-up box columns were tested. For comparison, 8 single channel sections were also tested and reported herein. Prior to the compression tests, material properties and initial imperfections were measured for both the single channel and CFS built-up box sections. Load-axial shortening relationship, failure modes, and deformed shapes at failure are discussed for CFS built-up box columns. Test results show that all short columns failed through local buckling. However, for slender columns global buckling was observed. The experimental test results were also compared against the designed strength calculated in accordance with the AISI & AS/NZS. From the comparison, it was found that the AISI & AS/NZS are conservative by around 15-19% on average, while predicting the axial capacity of such CFS built-up slender columns.

1. INTRODUCTION

Structural applications for cold-formed steel (CFS) sections are increasing steadily and the use of CFS built-up box sections is becoming popular. This paper presents the results of 16 new experimental tests; of which 8 tests were conducted on CFS built-up box columns, whereas the remaining 8 tests were conducted on single channel sections. The cross-sectional details of the CFS built-up box section are shown

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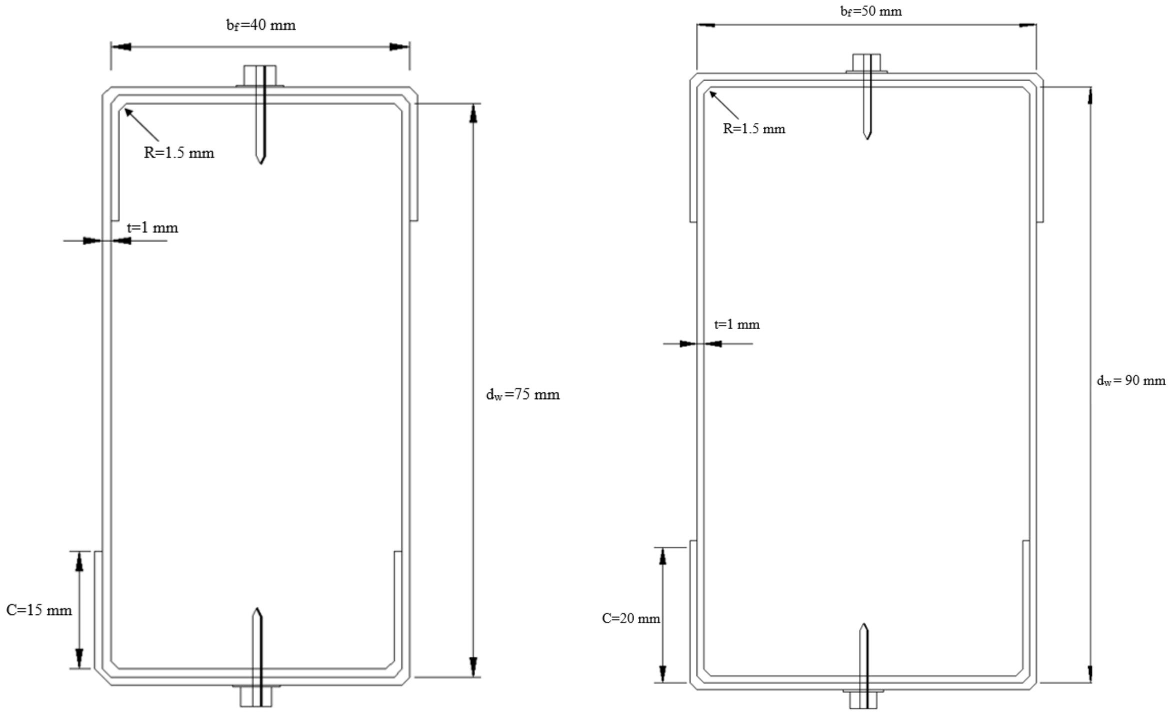
in Figure 1. As can be seen, the built-up box section is formed from two identical lipped channel-sections connected front-to-front by self-drilling screws. In such an arrangement, independent buckling of the individual channel-sections is prevented by the screws. Such CFS built-up box sections are used in CFS construction due to the advantages of high load-carrying capacity, stability, and higher moment of inertia, when compared to the back-to-back built-up CFS channel sections.



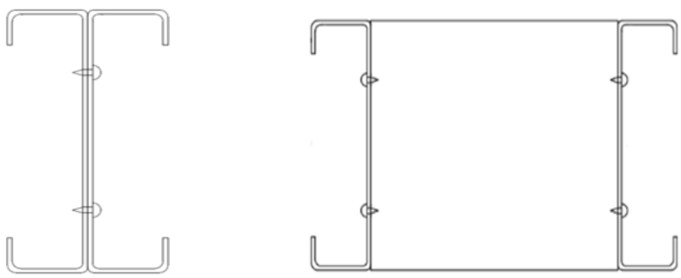
(a) B75 (b) B90

Fig. 1: Nominal cross-sections of CFS built-up box sections considered in this paper

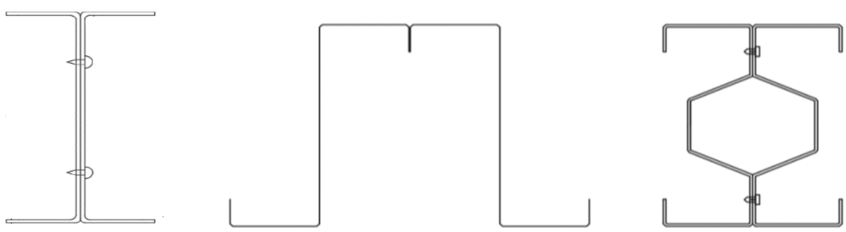
In the literature, no previous work has described any built-up box sections, composed of channels, connected front-to-front through bolts or screws, under axial compression. While Reyes *et al*. (2011) did describe experimental tests on front-to-front channels, these were welded. It was shown that if the seam weld spacing was less than or equal to 600 mm, a modified slenderness ratio could be used instead of the actual slenderness ratio for materials 1.5 mm and 2.0 mm thick. On the other hand, Li *et al.* (2016) conducted experimental and numerical investigations on flexural strength of CFS thin-walled beams with built-up box section which consists of nested C and U sections with the self-drilling screws. For U section beam bending about strong axis, the failure was more "local" than that of C section beams. Craveiro *et al.* (2016) presented an experimental investigation on the fire behaviour of compressed CFS columns with closed built-up cross sections. The investigation by Craveiro *et al.* (2016) suggested that an increase in the non-dimensional axial restraint ratio and column load levels lead to a decrease in critical temperatures.

Some literature is available for research on CFS built-up channels under axial compression, including recent work of the authors (Roy *et al*. 2018a, b, c, d, 2019a,b, c, d). Ting *et al*. (2018) studied the behaviour of CFS built-up channels, connected back-to-back under axial compression (Figure 2 (a)). To extend this work, Roy *et al*. (2018b) experimentally investigated the axial capacity of CFS built-up channels, connected back-to-back with a gap (Figure 2 (b)). Recently, Roy *et al.* (2018 a) presented a FE investigation on the axial capacity of CFS built-up un-lipped channels screwed back-to-back, concluding that AISI & AS/NZS can be un-conservative for stub columns (Figure 2(c)). Georgieva *et al.* (2012) investigated built-up zed-sections which were connected toe-to-toe (Figure 2(d)). Zhang and Young (2012) studied the compression capacity of built-up channels connected back-to-back with an opening (Figure 2(e)). It should be noted that most of the researchers as discussed above, focussed on the behaviour of back-to-back built-up channels because of the ease in connection between the back-to-back channels.

CFS built-up battened columns were investigated by Dabaon *et al.* (2015), they have concluded that the AISI & AS/NZS and the Eurocodes were un-conservative for columns undergoing local buckling, but the standards predicted the failure load safely for those built-up columns failed by global buckling. Stone and LaBoube (2005) considered stiffened flange and track channels connected back-to-back. Following on from this, Whittle *et al*. (2009) tested the axial capacity of built-up channels which were welded toe-to-toe. Also, Piyawat et al. (2013) investigated welded back-to-back built-up columns under compression. More recently, other researchers have also made some studies on CFS built-up columns: Fratamico *et al.* (2018) and Anbarasu *et al.* (2014) who investigated the axial strength of sheathed and bare built-up CFS columns and CFS built-up web stiffened batten columns, respectively. Recently, Dar *et al.* (2018) investigated the behaviour of laced built-up CFS columns, through experimental and numerical investigations.



(a) Ting *et al*. (2018)   (b) Roy *et al*. (2018b)



(c) Roy *et al.* (2018   (d) Georgieva *et al.* (2012)   (e) Zhang and Young (2012)

Fig. 2: Built-up cold-formed steel columns from literature

Current design guidelines as per the American Iron and Steel Institute AISI and Australia/New Zealand Standard AS/NZS (recommends the use of a modified slenderness approach to consider the spacing of fasteners while calculating the axial capacity of CFS built-up box sections. It is worth mentioning that the applicability and validity of the modified slenderness method, which has been adopted from the design of hot-rolled steel, has never been demonstrated for CFS built-up box sections.

In total, 16 experimental tests were conducted and reported; 8 of which were for single channel sections (C75) and the remaining 8 tests were for built-up box sections (B75). The nominal cross-sectional geometry of the CFS built-up box columns investigated in this paper is shown in Figure 1. Two different lengths were considered for experimental tests. The material properties and initial imperfections were measured for all test specimens. The effects of slenderness, fastener spacing, load-deflection, load-axial strain behaviour were observed and discussed in detail for different lengths of the columns.This paper has therefore presented an experimental investigation on axial capacity of the CFS built-up box sections.

2. EXPERIMENTAL INVESTIGATION

2.1 Test specimens

Cross-sectional details of the CFS single channel and built-up box sections considered in this paper: C75, and B75, are shown in Figure 1. As can be seen, B75 is the built-up box section from C75 channels. In this study, intermediate fasteners were used to connect the flanges of the front-to-front channels to form the built-up box section. In Figure 3, fastener spacing's for CFS built-up box sections of different lengths are shown. The dimensions of the built-up box sections and single channel sections are summarized in Table 1. The built-up columns were subdivided into two different column heights: short columns of 0.5 m height and slender columns of 1.5 m height. The reason behind choosing such lengths was to capture different buckling failure modes (Local, Distortional and Global buckling) (Ting *et al.* 2018, Roy *et al.* 2018 a, b) of the CFS built-up box sections. Pin-ended boundary conditions were applied for all single channel and built-up columns tested herein. In the test programme, longitudinal screw spacing of 100 mm was considered for all columns.

Table 1 Cross sectional dimensions of the test specimens

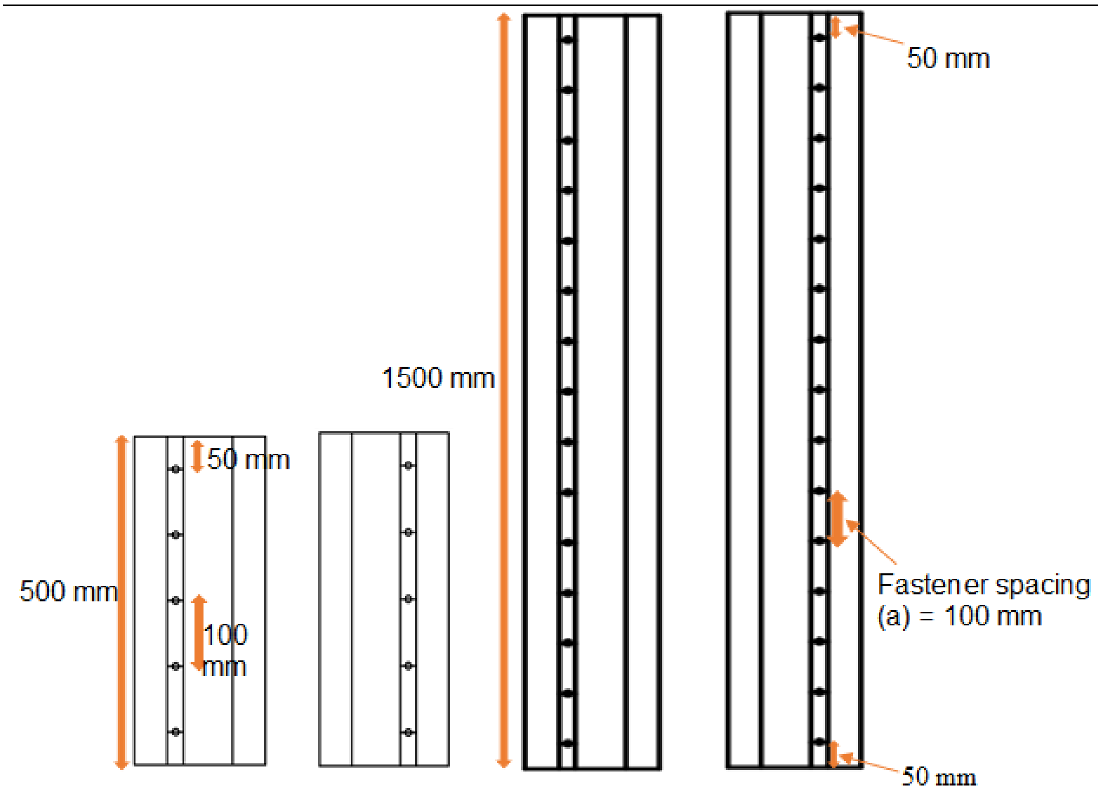
(a) C75 (Single lipped channel section)

Specimen	Web d_w (mm)	Flange b_f (mm)	Lip C (mm)	Length L (mm)	Radius R (mm)	Thickness t (mm)
Short						
C75- L500-1	75.0	38.1	14.0	500.2	1.5	1.0
C75- L500-2	76.1	40.0	14.1	501.1	1.5	1.0
C75- L500-3	75.4	39.4	15.2	503.2	1.5	1.0
C75- L500-4	74.8	39.4	15.6	499.7	1.5	1.0
Slender						
C75- L1500-1	76.3	41.2	15.4	1500.1	1.5	1.0
C75- L1500-2	74.7	40.6	14.7	1502.4	1.5	1.0

C75- L1500-3	75.4	39.7	16.1	1498.4	1.5	1.0
C75- L1500-4	74.8	39.2	15.8	1507.2	1.5	1.0

(b) B75 (Built-up box section)

Specimen	Web d_w (mm)	Flange b_f (mm)	Lip C (mm)	Length L (mm)	Radius R (mm)	Thickness t (mm)
Short						
B75- L500-1	76.1	39.8	15.1	500.4	1.5	1.0
B75- L500-2	75.2	38.5	14.2	498.7	1.5	1.0
B75- L500-3	74.7	41.6	14.8	499.6	1.5	1.0
B75- L500-4	77.2	40.2	14.2	502.4	1.5	1.0
Slender						
B75- L1500-1	77.4	41.2	14.4	1500.9	1.5	1.0
B75- L1500-2	76.4	40.6	14.6	1502.6	1.5	1.0
B75- L1500-3	75.4	39.7	15.3	1507.4	1.5	1.0
B75- L1500-4	75.2	38.7	15.1	1511.4	1.5	1.0



(i) Front facing (ii) Back facing (i) Front facing (ii) Back facing

(a) Short column (b) Slender column

Fig. 3: Fastener spacing– for the built-up box sections used in the experimental tests