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Section compression capacity of high strength cold-formed hollow flange channels

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ABSTRACT

Thin-walled cold-formed hollow flange channel (HFC) sections are increasingly becoming popular due to their potential benefits such as increase in buckling capacities provided by the presence of two torsionally rigid hollow flanges and the elimination of free edges. Past research studies of HFC sections were limited to their shear and bending capacities. This paper investigates their section compression capacities through a series of stub column tests, followed by finite element modelling of welded HFC columns. The developed finite element models were validated using experimental results, and then used to investigate the section compression capacity of HFCs made by welding rectangular sections to a steel plate or cold-forming and rivet/screw fastening to hollow flanges, where steel plates with different strengths and thicknesses were used as web and flange elements. Extensive structural performance data of HFC stub columns subject to local buckling was thus obtained covering the effects of varying slenderness of plate elements and the use of different strength steels for web and flange elements. Furthermore, the applicability of the available design rules such as effective width and direct strength methods to predict the compression capacity of such HFC sections was also evaluated. Suitable recommendations are then proposed to improve their accuracy. This study facilitates and advances the use of HFC sections as compression members.

1. Introduction

Cold-formed steel members are increasingly used in the residential and office buildings due to their advantages such as light weight and high strength to weight ratio. Their usage has led to ease of fabrication of structures, rapid constructability and reduced labour cost. However, these cold-formed steel members are generally open and thin-walled in nature, i.e., lipped and unlipped channel sections (Fig. 1), and hence they are prone to structural instability problems such as local, distortional and global buckling.

Previous researchers' attempts to delay some of the instability problems in open cold-formed steel members resulted in the development of hollow flange sections (Fig. 2). These hollow flange sections are made of two rigid closed hollow flanges and a slender web. The elimination of free edges and the reduced web length significantly increase the local buckling capacity while the closed rectangular flanges provide greater torsional rigidity, and eliminate distortional buckling effects. Hence, these sections have become an alternative wall stud section to the conventional lipped channel sections.

Hollow flange sections can also be produced in different shapes. Fig. 2(a) shows the doubly symmetric Hollow Flange Beam (HFB) used in the 1990s [1] while Fig. 2(b) shows the recently produced mono-symmetric hollow flange section, known as LiteSteel Beams (LSB). The HFB members were manufactured from a single strip of high strength steel using a simultaneous cold-forming and electric resistance welding process, and were introduced by OneSteel Australian Tube Mills (OATM) in the early 1990s. However, they were discontinued in 1997 due to the complicated manufacturing process involving electric resistance welding [2]. LSB is the recently invented hollow flange steel section developed by OATM using an improved dual electrical resistance welding process. This section has been extensively used in the Australian building industry since 2002, and is on average 40% lighter than the traditional hot-rolled structural sections of equivalent bending strength [3]. However, this section has also been discontinued in Australia, mostly due to the changes to OATM's business operations. Hence researchers at the Queensland University of Technology have proposed the use of screw or rivet fastening to produce such mono-symmetric hollow flange sections, referred to as hollow flange channel (HFC) sections in this paper.

The HFC sections can be made cost effectively using an intermittent screw or rivet fastening method as shown in Fig. 3(a). These built-up sections can be manufactured using the available cold-formed steel sheets in Australia. Importantly in these sections, steel plates of appropriate grade or thickness can be used as web and flange elements to produce the optimum sections. The HFC section can also be manufactured

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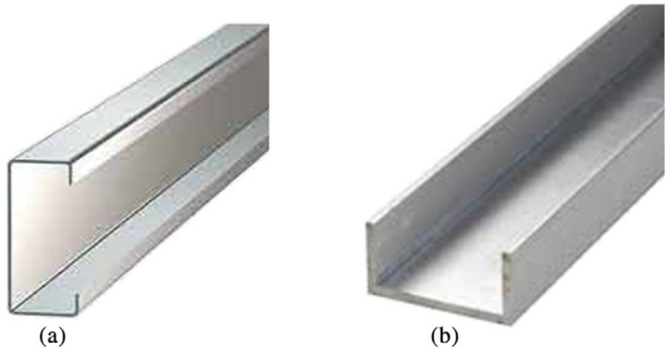

Fig. 1. Channel sections, (a) lipped channel section, (b) unlipped channel section.

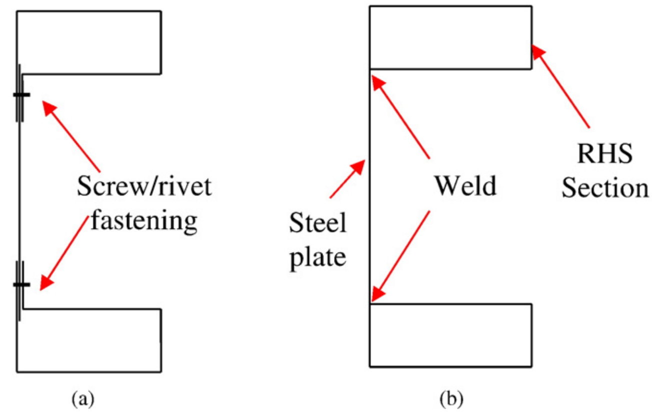

Fig. 3. Hollow flange channel sections, (a) screw/rivet fastened HFC section, (b) welded HFC section.

by welding two high strength cold-formed rectangular hollow sections (RHS) to a thicker web plate as shown in Fig. 3(b). Both these methods provide considerable improvements in comparison with LSBs for which the thickness cannot be changed while flange and web sizes are also restricted. Despite the shortcomings, the LSB section also belongs to the group of HFC sections. All of them have one identical characteristic in relation to the yield strengths of web and flange plate elements, i.e. they are different. The measured LSB flange and web yield strengths are about 540 and 420 MPa, respectively, due to the different levels of cold-working in LSBs, while in the other two HFC section (Fig. 3), they can be 700 and 300 MPa.

In the past, many detailed experimental and numerical studies [3–7] were undertaken on the behaviour of LSBs under the actions of bending, shear and torsion, but not in axial compression. In this study, a series of experiments was performed first to determine the section capacity of LSB compression members. The experimental results along with Yi and Wilkinson's [8] results were then used to validate the developed finite element models. The LSBs in Fig. 2 and the built-up HFC sections in Fig. 3 can have different web and flange yield strengths [9], but it is not known whether to use the minimum yield strength or the corresponding element yield strengths in their compression capacity calculations. Furthermore, the suitability of the available cold-formed design rules in the current standards based on the effective width and direct strength methods (DSM) need to be investigated for HFC sections including LSBs.

This paper focuses on the section capacity of HFC compression members subject to local buckling effects. Firstly it presents the experimental results and then illustrates the development and validation processes of the numerical models. Thereafter it presents a detailed numerical analysis based parametric study performed to evaluate the effects of different parameters on the compression capacities of HFC sections such as plate element slendernesses and the use of different types of steel (steel grade) for flange and web elements. Finally, the applicability of the effective width and DSM [10] based design rules in AS/NZS 4600 [11] and AISI S100 [12] in predicting the HFC section compression capacities was evaluated in this paper.

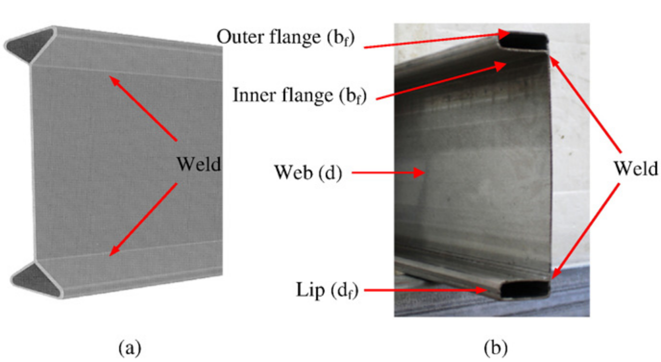

Fig. 2. Welded hollow flange sections, (a) Hollow Flange Beam, (b) LiteSteel Beam.

2. Experimental study

To obtain reliable structural performance data on the section capacity of HFC sections in compression, stub column tests were conducted using the welded HFC sections – LiteSteel Beams (LSBs). The stub column tests were conducted for two LSB sections, 150 × 45 × 15 × 1.6 LSB and 150 × 45 × 15 × 2.0 mm LSB, where the four numbers refer to the section depth d, flange width b_f, flange depth d_f and flange and web thickness t, respectively. The yield strengths of the web, inner flange and outer flange elements of these LSBs were also measured and are summarised in Table 1. Initially the half wave buckling length of the LSBs was found through elastic buckling analyses performed using a finite strip analysis program, THIN-WALL. The LSB stub column specimen length was selected as about three times the buckling half wave length. Fig. 4 shows the stub column test of LSB with the load acting on its geometric centroid.

In all the tests, local buckling of web element was observed first. Ultimately the LSB specimen failed by yielding of its web and flange elements. Fig. 5 shows the failure modes of the tested specimens where the local buckling of webs and the yielding of web and flange elements are clearly visible. Table 1 presents the measured ultimate failure loads. Yi and Wilkinson [8] also conducted an experimental investigation on the section compression capacity of LSB using stub column tests (Fig. 6). They tested different sized LSBs, and their results are also included in Table 1. Their test results were also used in this study to validate the developed finite element models (refer Section 3). Validated finite element models can be then used to perform an extensive parametric study to investigate the effects of different parameters on the section capacity of HFC compression members.

3. Finite element modelling

ABAQUS was used to analyse the welded HFC stub column models while MSC/PATRAN was used as pre- and post- processors to create the required input files and to visualise the failure modes and deflections. Elastic bifurcation buckling and non-linear analyses were performed. The thickness of the cold-formed and welded HFC/LSB stub column section is very small compared to its width and length, and hence conventional shell elements of S4 type were used to model it with finer mesh sizes of 4 mm × 4 mm. In regards to the boundary conditions, fixed MPC conditions were used at both ends of the column. The load was applied to the geometrical centroid of the section. At the loading point, all the rotational freedoms (4-R_x, 5-R_y and 6-R_z) and the translational freedoms along the 2-Uy and 3-Uz axes were fully