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Finite element modeling of rivet fastened rectangular hollow flange channel beams subject to local buckling

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ABSTRACT

The innovative, rivet fastened Rectangular Hollow Flange Channel Beam (RHFCB) is a new type of cold-formed steel section, proposed as an extension to the widely researched hollow flange beams. The hollow flange beams have garnered much interest in the past due to the sections having capacities more typically associated with hot-rolled steel sections. This paper presents the details of finite element models developed to simulate fifteen back to back, four-point bending tests, previously carried out by the authors to investigate the section moment capacities of rivet fastened RHFCBs. The test specimens were laterally restrained to ensure predominant local buckling failures, commonly observed in short-span hollow flange beams. The developed finite element models were able to simulate the test results in terms of ultimate moment capacities, applied moment versus deflection graphs and deformation modes. In addition, elastic buckling analysis results based on the finite element models also agreed well with the results from Thin-Wall finite strip analyses. Upon validation, finite element modeling was extended to include a larger slenderness region in a parametric study. The ultimate moment capacities from the tests and finite element analyses were compared with currently available design standards: AS/NZS 4600, AS 4100 and AISI S100. The suitability of the Direct Strength Method was also investigated for the rivet fastened RHFCBs and a suitable modification was proposed.

1. Introduction

The use of cold-formed steel members in low rise building construction has increased significantly in recent times. It has been suggested that in the future more than 70% of steel buildings will be constructed using cold-formed steel. Cold-formed steel manufacturers have continuously utilized thin, high strength steels and new manufacturing technologies to develop advanced, lightweight sections that are more structurally efficient and cost-effective in order to improve the market share for cold-formed steel construction. Cold-forming process is simple, efficient, economical and environmentally friendly, and is capable of manufacturing very effective sections compared to hot-rolled, open steel sections. Over the years, the use of cold-formed steel structures in construction has increased rapidly, associated with a significant increase in their research [1–3].

Thin-walled cold-formed steel beams are susceptible to buckling effects that influence their load carrying capacity. In recent times, various efforts have been made in search for new cold-formed steel cross-sections that would increase the bending capacities. These included channel beams with double-box flanges [4–6] and thin-walled beams with open- and close-drop flanges [7,8]. Magnucka-Blandzi et al. [9] concluded that channel beams with double-box flanges and continuous web-flange joints are more buckling resistant than those with standard flat flanges. Sudhir Sastry et al. [10] extended the study of beams with drop flanges and found the performance of beams with extended open-drop flanges to be superior than those with close-drop flanges.

The widely researched Hollow Flange Beam (HFB) is an advanced cold-formed steel section introduced recently by Australian cold-formed steel manufacturers and researchers. In 2005, OneSteel Australian Tube Mills [11] introduced a type of HFB section, known as the LiteSteel beam (LSB), with its primary use as flexural members in residential and light commercial/industrial applications (Fig. 1). LSB is manufactured from a single strip of high-strength steel using a combined cold-forming and dual electric resistance welding process. The LSBs combine the stability of hot-rolled steel sections with the high strength to weight ratio of cold-formed steel sections, and are very efficient as structural beams since the hollow flanges are positioned away from the centre. In the past, the LSB has been highly researched due to its ability to provide capacities that are more typically associated with

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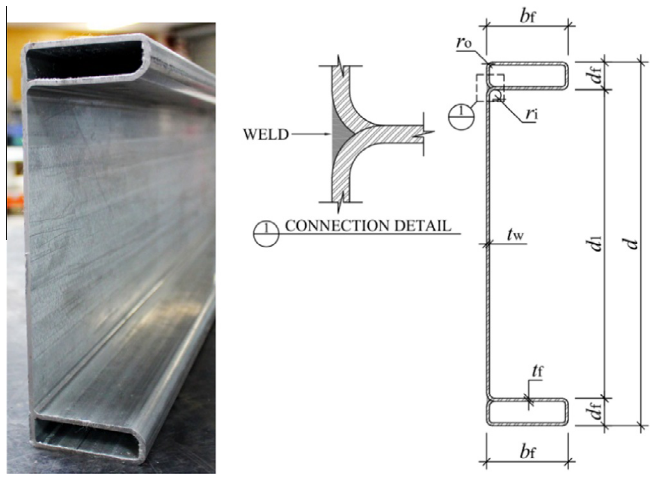

Fig. 1. LiteSteel beam.

hot-rolled, than cold-formed steel members [12–24]. However, the OATM discontinued LSB production in 2012, mostly due to the expensive manufacturing cost associated with the dual electric resistance welding process.

The LSB sections are efficient and attractive steel products, which can be used in floor and roof systems, as well as in modular building systems. Although the LSBs are no longer produced, there is a need to find an alternative manufacturing method to produce equivalent sections due to their popularity and demand among architects, engineers and builders. In this research study, an alternative manufacturing method has been proposed based on a combined cold-forming and rivet fastening process to produce an equivalent section, the rivet fastened Rectangular Hollow Flange Channel Beams (RHFCBs) (Fig. 2) thus eliminating the costly dual electric resistance welding process.

The rivet fastened RHFCB shown in Fig. 2 is a mono-symmetric section where the rectangular hollow flanges are cold-formed first and then connected to a web plate using inexpensive, self-pierce rivet fastening. Due to this simple and flexible manufacturing process, the designers can effectively choose different plate sizes, thicknesses and steel grades for web and flange elements to achieve the most efficient section for a given application. As an example, selecting a thicker web plate element is likely to eliminate or delay the unique lateral distortional buckling observed in hollow flange beams [25]. Unlike LSBs which come with only three hollow flange sizes (45 × 15 mm, 60 × 20 mm and 75 × 25 mm), the rivet fastened RHFCBs can be produced with many different flange sizes. In addition to these features, they have additional flange lips that are used for rivet fastening purposes, which may increase their moment capacities. Self-pierce riveting used in its manufacturing is carried out at ambient temperature, which translates to the likely absence of membrane residual stress normally induced by a welding process. The use of self-pierce riveting instead of the expensive welding process also means that the section can be manufactured at a reduced cost.

An experimental investigation was carried out at the Queensland University of Technology to investigate the section moment capacities of rivet fastened RHFCBs subject to local buckling effects. Fifteen tests were carried out on back to back RHFCBs with three different beam depths (150, 200 and 250 mm) and various thicknesses. The investigation also investigated the reduction in section moment capacity as rivet spacing increases (i.e. 50, 100 and 200 mm) [26]. However, limited investigation has been carried out on the flexural behavior and moment capacity of rivet fastened RHFCBs.

For the newly developed rivet fastened RHFCB sections to be used as flexural members, their moment capacities need to be fully investigated. In this research the flexural behavior and section moment capacity of rivet fastened RHFCBs was investigated using numerical studies. Finite element models (FEM) of rivet fastened RHFCBs were developed to investigate their nonlinear flexural behavior including their local buckling characteristics and section moment capacities. Available experimental data from Siahaan et al. [26] was utilized to evaluate the accuracy of the FEM.

This paper presents the details of the FEM of rivet fastened RHFCBs and the results. Both finite element analysis (FEA) and experimental results were then used to verify the adequacy of the current design rules in predicting the section moment capacities of rivet fastened RHFCBs. Appropriate improvements have been proposed for the design rules of section moment capacities of rivet fastened RHFCBs within the Direct Strength Method format.

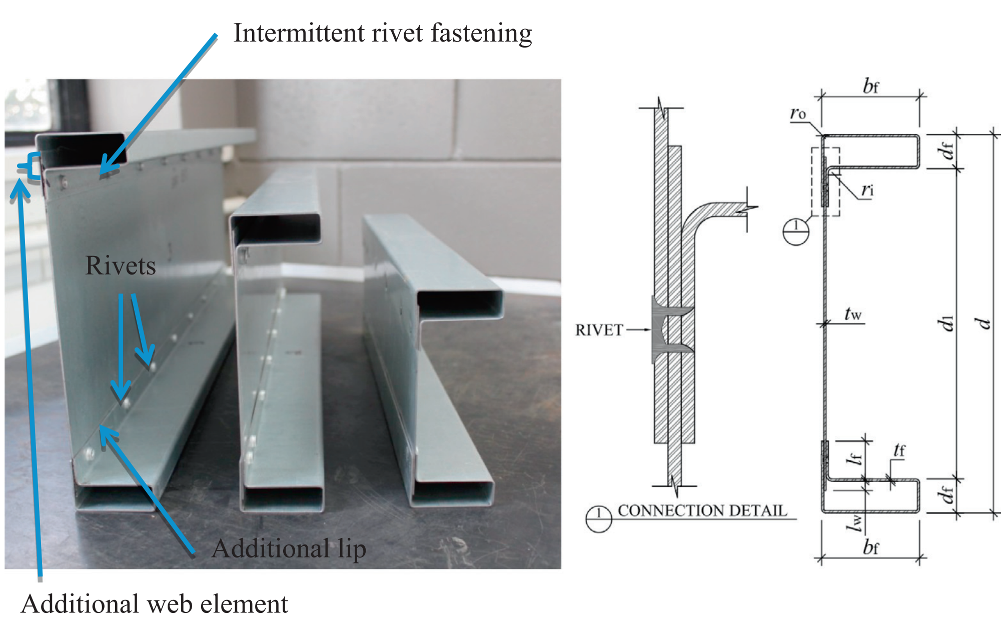

Fig. 2. Rivet fastened rectangular hollow flange channel beam.