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Shear tests of rivet fastened rectangular hollow flange channel beams

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A R T I C L E I N F O

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A B S T R A C T

The intermittently rivet fastened Rectangular Hollow Flange Channel Beam (RHFCB) is a new cold-formed hollow section proposed as an alternative to welded hollow flange channel beams. It is a monosymmetric channel section made by intermittently rivet fastening two torsionally rigid rectangular hollow flanges to a web plate. This process enables the end users to choose an effective combination of different web and flange plate sizes to achieve optimum design capacities. Recent research studies focused mainly on the shear behaviour of the most commonly used lipped channel beam and welded hollow flange beam sections. However, the shear behaviour of rivet fastened RHFCB has not been investigated. Therefore a detailed experimental study involving 24 shear tests was undertaken to investigate the shear behaviour and capacities of rivet fastened RHFCBs. Simply supported test specimens of RHFCB with aspect ratios of 1.0 and 1.5 were loaded at mid-span until failure. Comparison of experimental shear capacities with corresponding predictions from the current Australian cold-formed steel design rules showed that the current design rules are very conservative for the shear design of rivet fastened RHFCBs. Significant improvements to web shear buckling occurred due to the presence of rectangular hollow flanges while considerable post-buckling strength was also observed. Such enhancements to the shear behaviour and capacity were achieved with a rivet spacing of 100 mm. Improved design rules were proposed for rivet fastened RHFCBs based on the current shear design equations in AISI S100 and the direct strength method. This paper presents the details of this experimental investigation and the results.

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 the steel buildings will be constructed using cold-formed steel. The cold-formed steel manufacturers have continuously utilised thin high strength steels and new manufacturing technologies to develop advanced light weight 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, which is capable of manufacturing very effective sections compared to the hot-rolled open steel sections. The Rectangular Hollow Flange Channel Beam (RHFCB) is one such advanced light weight section introduced recently by cold-formed steel manufacturers and researchers.

In 2005 OneSteel Australian Tube Mills [16] introduced the first RHFCB section, known as the LiteSteel beam (LSB) primarily for use as flexural members in residential and light commercial/industrial applications (see 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 sections with the high strength to weight ratio of cold-formed sections, and are very efficient as structural beams since they have the hollow flanges 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 hot-rolled, than cold-formed steel members ([3–6,8,9,11–13,21,22]). 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 recent times. In this research study, an alternative manufacturing method has been proposed based on a combined cold-forming and rivet fastening process to produce 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 the web plate using rivet fastening. Due to this simple and flexible manufacturing process, the designers can effectively choose different plate dimensions and thicknesses for web and flange elements to achieve the most efficient section to suit the clients' requirements. 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 [4]. Unlike for LSBs with only three hollow flanges

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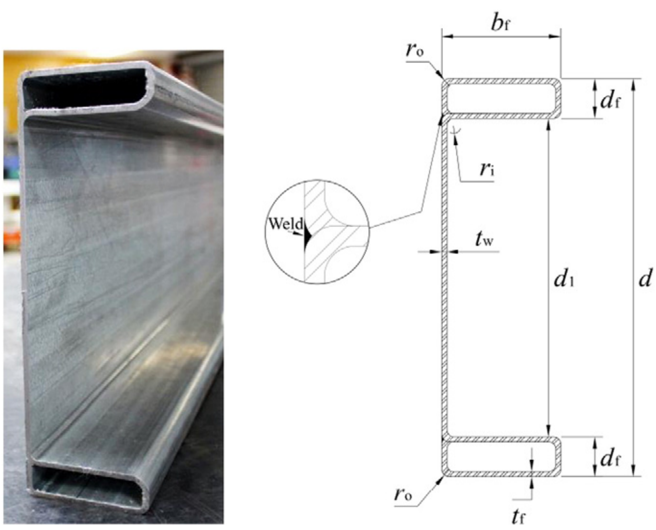

Fig. 1. LiteSteel beam [16].

(45 × 15 mm, 60 × 20 mm and 75 × 25 mm) the rivet fastened RHFCBs can be produced with many different hollow flange sizes. In addition to these features, they have additional flange lips that are used for rivet fastening, which may enhance their design capacities. However, limited investigation has been carried out on the structural behaviour and strength of rivet fastened RHFCBs.

For the newly developed rivet fastened RHFCB sections to be used as flexural members, their flexural and shear capacities need to be fully investigated. In this research the shear behaviour and capacity of rivet fastened RHFCB were investigated using experimental studies.

The web shear buckling design is based on the assumption that the web elements are simply supported, in which the effect of flange rigidity is neglected in conventional lipped channel beams (LCBs). LaBoube and Yu [15] calculated the ultimate strengths of LCBs by assuming that the web-flange joints are simply supported. However, Keerthan and Mahendran [7,8] found that there is considerable fixity at the web to flange juncture, in particular for welded hollow flange channel beams. They also showed the presence of significant post-buckling shear strength for welded hollow flange channel beams. However, intermittent rivet fastening instead of continuous welding of flanges to web elements may reduce these beneficial effects on the shear capacity. Hence this research investigated the shear capacities of rivet fastened RHFCBs. This paper presents the details of a series of primarily shear tests of rivet fastened RHFCBs, and the results. Experimental shear capacities are compared with the predicted shear capacities using the current design rules. Suitable design rules are then developed based on the current shear design equations in AISI S100 [2] and the direct strength method (DSM).

2. Shear capacities of lipped channel beams and hollow flange beams

In the past the shear buckling capacities of conventional lipped channel beams (LCBs) are computed by neglecting the effect of flange rigidity. LaBoube and Yu [15] investigated the shear strength of cold-formed steel LCBs by considering different web slenderness ratio, the edge support conditions provided by the flanges with varying flat width-to-thickness ratios and the mechanical properties of the steel. Based on their experimental studies a new set of design rules was proposed for the shear strength of cold-formed steel beams. These design rules were adopted in AISI S100 [1] and AS/NZS 4600 [24]. However, they were developed by assuming simply supported web elements, thus the rigidity offered by the flange elements to the web was ignored and the post-buckling shear strength was also not considered. The shear strength design capacity (V_v) equations are provided next.

$$V_v = V_y = 0.6 f_{yw} d_1 t_w \quad \text{for} \quad \frac{d_1}{t_w} \le \sqrt{\frac{Ek_v}{f_{yw}}} \tag{1}$$

$$V_v = V_i = 0.6 t_w^2 \sqrt{Ek_v f_{yw}} \quad \text{for} \quad \sqrt{\frac{Ek_v}{f_{yw}}} < \frac{d_1}{t_w} \le 1.508\sqrt{\frac{Ek_v}{f_{yw}}} \tag{2}$$

$$V_v = V_{cr} = \frac{k_v \pi^2 E t_w^3}{12(1-\nu^2) d_1} \quad \text{for} \quad \frac{d_1}{t_w} > 1.508\sqrt{\frac{Ek_v}{f_{yw}}} \tag{3}$$

where V_y = shear yield capacity, V_i = inelastic shear buckling capacity, V_{cr} = elastic shear buckling capacity, d_1 = depth of the flat portion of web measured along the plane of the web, t_w = web thickness, f_{yw} = web yield stress, E = Young's modulus, υ = Poisson's ratio and k_v is the elastic shear buckling coefficient, which is determined as follows.

For beams with transverse stiffeners

$$k_v = 5.34 + \frac{4}{(a/d_1)^2} \quad \text{for} \quad \frac{a}{d_1} \ge 1 \tag{4}$$

$$k_v = 4 + \frac{5.34}{(a/d_1)^2} \quad \text{for} \quad \frac{a}{d_1} < 1 \tag{5}$$

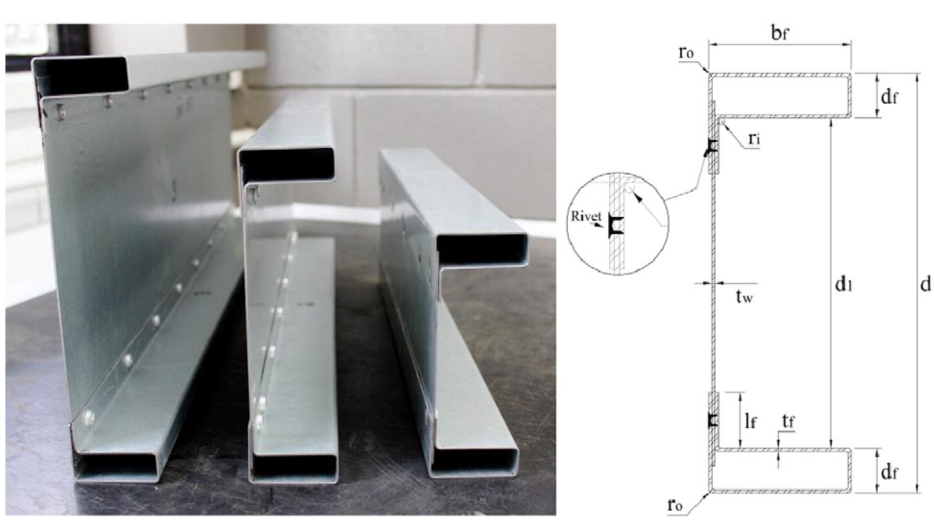

Fig. 2. Rivet fastened rectangular hollow flange channel beam (RHFCB).