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# Experimental study of web crippling behaviour of hollow flange channel beams under two flange load cases

Poologanathan Keerthan, Mahen Mahendran*, Edward Steau

*Science and Engineering Faculty, Queensland University of Technology, Brisbane, Australia*

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ABSTRACT

This paper presents the details of an experimental study of a cold-formed steel hollow flange channel beam known as LiteSteel beam (LSB) subject to web crippling under End Two Flange (ETF) and Interior Two Flange (ITF) load cases. The LSB sections with two rectangular hollow flanges are made using a simultaneous cold-forming and electric resistance welding process. Due to the geometry of the LSB, and its unique residual stress characteristics and initial geometric imperfections, much of the existing research for common cold-formed steel sections is not directly applicable to LSB. Experimental and numerical studies have been carried out to evaluate the behaviour and design of LSBs subject to pure bending, predominant shear and combined actions. To date, however, no investigation has been conducted on the web crippling behaviour and strength of LSB sections. Hence an experimental study was conducted to investigate the web crippling behaviour and capacities of LSBs. Twenty-eight web crippling tests were conducted under ETF and ITF load cases, and the ultimate web crippling capacities were compared with the predictions from the design equations in AS/NZS 4600 and AISI S100. This comparison showed that AS/NZS 4600 and AISI S100 web crippling design equations are unconservative for LSB sections under ETF and ITF load cases. Hence new equations were proposed to determine the web crippling capacities of LSBs based on experimental results. Suitable design rules were also developed under the direct strength method (DSM) format.



## 1. Introduction

Cold-formed steel (CFS) structural members are widely used in modern construction due to the many advantages they offer in comparison with conventional hot-rolled steel sections. They are usually thin-walled members with large width-to-thickness ratios. Lightweight, high strength and stiffness, accurate section dimensions, easy prefabrication and mass production are some of the qualities of cold-formed steel members that create cost savings in construction.

Since early 1990s, Australian manufacturing companies [1] have introduced innovative cold-formed hollow flange sections, and one of them known as LiteSteel beams (LSB) is shown in Fig. 1. The development of this hollow flange channel section was based on improving the structural efficiency by adopting torsionally rigid rectangular hollow flanges, minimising local buckling of plate elements by eliminating free edges, distributing material away from the neutral axis to afford greater bending stiffness than conventional cold-formed sections, and optimising manufacturing efficiency. The LSB sections were produced from a single steel strip using a combined dual electric resistance welding and automated continuous roll-forming process [1], primarily for use as floor joists and bearers in residential, industrial and commercial buildings. Table 1 shows the nominal dimensions of LSB sections.

The base steel used for LSB production has a yield strength of 380 MPa and a tensile strength of 490 MPa. However, due to cold-forming, the nominal yield strengths of the web and flange elements are 380 and 450 MPa, respectively [1]. The manufacturing process also introduces residual stresses and initial geometric imperfections which differ from those of common cold-formed and hot-rolled steel sections. Due to the geometry of the LSB, as well as its unique residual stress characteristics and initial geometric imperfections resultant of manufacturing processes, much of the existing research for common cold-formed steel sections is not likely to be directly applicable to the LSB.

Web bearing is a form of localised failure that occurs at points of transverse concentrated loading or supports of thin-walled steel beams (see Fig. 2) [2]. LSB joists and bearers that are unstiffened against this type of loading are also vulnerable to web bearing/crippling failures (see Fig. 3). The computation of the web bearing strength by means of theoretical analysis is quite complex as it involves many factors such as local yielding in the loading region, instability of the web element, and many others. Hence the current design rules in most cold-formed steel structures codes

* Corresponding author.
*E-mail address:* m.mahendran@qut.edu.au (M. Mahendran).

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are empirical in nature developed based on more than 1200 tests of conventional cold-formed steel sections such as C-, Z- and hat sections and built-up sections [3–8] for the four types of web crippling loading conditions shown in Fig. 4: End-One-Flange Loading (EOF), End-Two-Flange Loading (ETF), Interior-One-Flange Loading (IOF) and Interior-Two-Flange Loading (ITF). Since 2005, unified web bearing capacity equations have been developed that define specific web crippling coefficients for the key parameters influencing the web bearing capacity of C-, Z-, Hat and built-up sections, namely, clear web height to thickness ratio ($d_1/t_w$), inside bent radius to thickness ratio ($r_i/t_w$), bearing length to thickness ratio ($l_b/t_w$), in addition to web thickness ($t_w$) and yield stress ($f_y$). However, these capacity equations are not applicable to the Litesteel beams (LSB) due to the presence of two rectangular hollow flanges instead of the conventional flange plate elements. Effects of the presence of hollow flanges including the higher rotational restraint at the LSB web-flange juncture have been successfully included in the shear capacity design rules of LSBs [9–11]. However, such an approach has not been developed yet for the web crippling capacity of LSBs. Unlike other open cold-formed steel sections, LSBs will be subjected to web crippling and/or flange crushing failures.

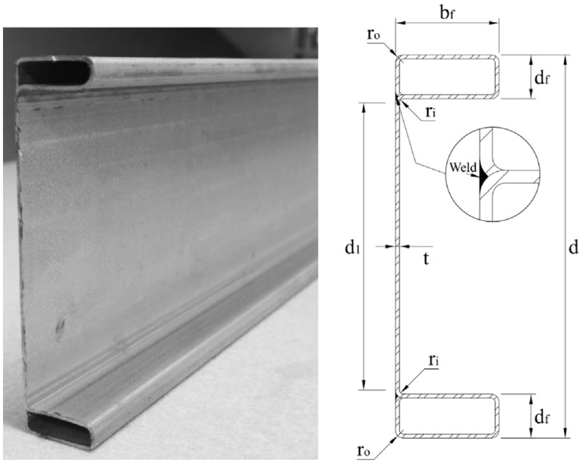


**Fig. 1.** LiteSteel beams [1].

**Table 1**
Nominal dimensions of LSB sections [1].

| LSB section | Depth (d) (mm) | Web and flange thicknesses ($t_w$ and $t_f$) (mm) | Flange width ($b_f$) (mm) |
|---|---|---|---|
| 300 × 75 × 3.0 | 300 | 3.00 | 75 |
| 300 × 75 × 2.5 | 300 | 2.50 | 75 |
| 300 × 60 × 2.0 | 300 | 2.00 | 60 |
| 250 × 75 × 3.0 | 250 | 3.00 | 75 |
| 250 × 75 × 2.5 | 250 | 2.50 | 75 |
| 250 × 60 × 2.0 | 250 | 2.00 | 60 |
| 200 × 60 × 2.5 | 200 | 2.50 | 60 |
| 200 × 60 × 2.0 | 200 | 2.00 | 60 |
| 200 × 45 × 1.6 | 200 | 1.60 | 45 |
| 150 × 45 × 2.0 | 150 | 2.00 | 45 |
| 150 × 45 × 1.6 | 150 | 1.60 | 45 |
| 125 × 45 × 2.0 | 125 | 2.00 | 45 |
| 125 × 45 × 1.6 | 125 | 1.60 | 45 |

*Note*: $d$, $b_f$, $d_f$=external dimensions (see Fig. 1).
Corner radii $r_o=2t_w$ mm, $r_i$=3.0 mm; and flange depth $d_f=b_f/3$.

Hollow flange channel sections such as LSBs can be used as flexural members in steel building systems, for example, floor joists and bearers. For them to be used as flexural members, their flexural, shear and web crippling capacities must be known. Recent research studies have investigated the flexural [12–15] and shear [9–11] behaviour and capacities of LSBs. However, no investigation has been conducted into the web crippling behaviour and strength of LSB sections. In this research web crippling behaviour and strength of LSBs under ETF and ITF load cases was investigated using an experimental study. This paper presents the details of this experimental study, and the results. Experimental web crippling capacities are compared with the predicted capacities using the current design rules. Currently the direct strength method (DSM) based design rules are not yet available for web crippling capacities. Suitable design rules are therefore developed under the DSM format in this paper.

## 2. Literature review

### 2.1. Web crippling test method

Many research studies have been undertaken to investigate the web crippling behaviour of cold-formed steel channel sections. The new AISI standard test method [16] presents the details of the suitable test procedures that should be adopted in web crippling studies. However, it is different to that used by past research studies [6,7] in relation to the specimen length and loading method used. The AISI standard test method [16] recommends the following test specimen lengths for the four loading cases shown in Fig. 4.

EOF loading : $L_{min} = 3d_1 +$ bearing plate lengths

IOF loading : $L_{min} = 3d_1 +$ bearing plate lengths

ETF loading : $L_{min} = 3d_1$

ITF loading : $L_{min} = 5d_1$

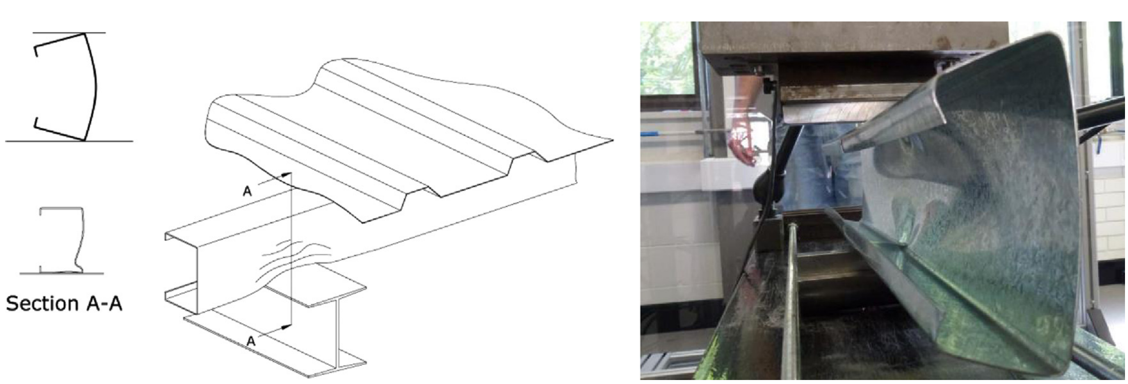


**Fig. 2.** Web crippling failure at a support [2].