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Lateral distortional buckling tests of a new hollow flange channel beam

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ABSTRACT

The LiteSteel beam (LSB) is a new hollow flange channel section developed by OneSteel Australian Tube Mills using their patented dual electric resistance welding and automated continuous roll-forming process. It has a unique geometry consisting of torsionally rigid rectangular hollow flanges and a relatively slender web. The LSBs are commonly used as flexural members in buildings. However, the LSB flexural members are subjected to lateral distortional buckling, which reduces their member moment capacities. Unlike the commonly observed lateral torsional buckling of steel beams, the lateral distortional buckling of LSBs is characterised by simultaneous lateral deflection, twist, and cross sectional change due to web distortion. An experimental study including more than 50 lateral buckling tests was therefore conducted to investigate the behaviour and strength of LSB flexural members. It included the available 13 LSB sections with spans ranging from 1200 to 4000 mm. Lateral buckling tests based on a quarter point loading were conducted using a special test rig designed to simulate the required simply supported and loading conditions accurately. Experimental moment capacities were compared with the predictions from the design rules in the Australian cold-formed steel structures standard. The new design rules in the standard were able to predict the moment capacities more accurately than previous design rules. This paper presents the details of lateral distortional buckling tests, in particular the features of the lateral buckling test rig, the results and the comparisons. It also includes the results of detailed studies into the mechanical properties and residual stresses of LSBs.

1. Introduction

The use of thin-walled, cold-formed high strength steel products in the building industry has significantly increased in recent years. With the availability of advanced roll-forming technologies and thin and high strength steels, cold-forming process has become efficient and economical, capable of producing a variety of efficient sections. Although cold-formed steel members are considered to be more cost efficient than hot-rolled steel members, they suffer from many complex buckling modes and their interactions because they are usually open slender sections that are either unsymmetric or singly symmetric. Therefore, advanced cold-formed steel sections, called the hollow flange sections, were introduced by OneSteel Australian Tube Mills (OATM) to replace the conventional cold-formed C- and Z-sections and smaller hot-rolled I- and channel sections [1,2].

The hollow flange sections (HFS) form a new group of cold-formed steel sections made of two torsionally rigid closed flanges and a slender web. Their unique geometry and light weight make them more efficient than hot-rolled steel members. The first HFS developed by OATM is known as hollow flange beam (HFB) as seen in Fig. 1. Although the HFB sections were discontinued by late 1990s, OATM has since improved their patented dual electric resistance welding and automated continuous roll-forming technologies and built a mill that is capable of producing a range of improved hollow flange sections (HFS) with varying web and flange sizes. The first of the improved HFS is the LiteSteel beam (LSB) shown in Fig. 2. The high strength steel material used for LSBs is a DuoSteel grade with nominal web and flange yield stresses of 380 and 450 MPa, respectively. Although the base steel has a yield stress of 380 MPa, the cold-forming process improves the yield stress of LSB flanges to 450 MPa. Currently there are 13 LSB sections with their depth in the range of 125–300 mm while their hollow flange width varies from 45 to 75 mm. The thickness of steel used is in the range of 1.6–3.0 mm. Table 1 shows the external dimensions of currently available LSB sections.

The LSBs are commonly used as flexural members, for example floor joists and bearers in residential, commercial and industrial buildings. When LSBs are used as flexural members, they are subjected to a relatively new lateral distortional buckling mode, which reduces their member moment capacities, particularly for intermediate spans. Unlike the commonly observed lateral torsional buckling of steel beams, the lateral distortional buckling of LSBs is characterised by simultaneous lateral deflection, twist and cross sectional change due to web distortion as shown in Fig. 3.

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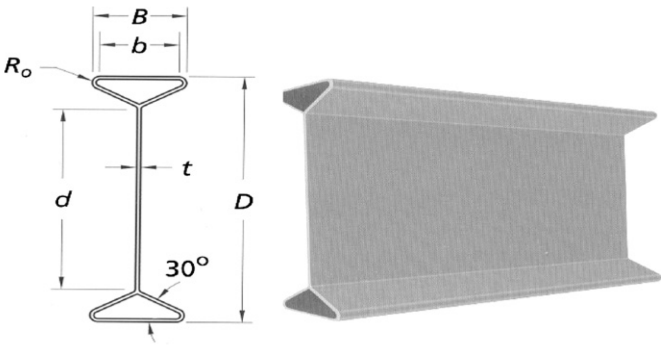

Fig. 1. Hollow flange beams.

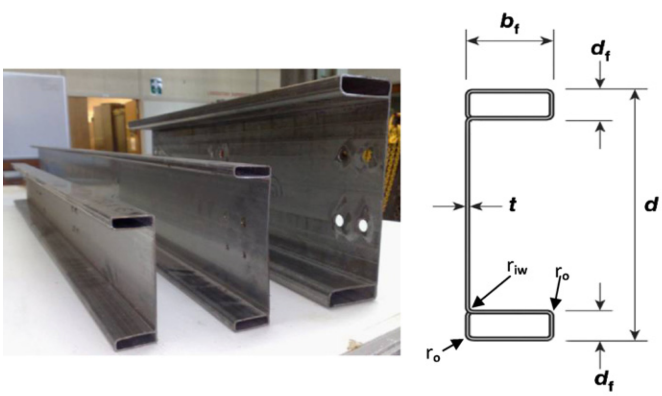

Fig. 2. LiteSteel beams.

Table 1
Details of currently available LSB sections.

Designation						Flange depth (mm)	Mass (kg/m)
d (mm)	×	b_f (mm)	×	*t* (mm)			
300	×	75	×	3.0	LSB	25.0	14.4
300	×	75	×	2.5	LSB	25.0	12.10
300	×	60	×	2.0	LSB	20.0	8.71
250	×	75	×	3.0	LSB	25.0	13.30
250	×	75	×	2.5	LSB	25.0	11.20
250	×	60	×	2.0	LSB	20.0	7.93
200	×	60	×	2.5	LSB	20.0	8.81
200	×	60	×	2.0	LSB	20.0	7.14
200	×	45	×	1.6	LSB	15.0	4.90
150	×	45	×	2.0	LSB	15.0	5.26
150	×	45	×	1.6	LSB	15.0	4.27
125	×	45	×	2.0	LSB	15.0	4.87
125	×	45	×	1.6	LSB	15.0	3.95

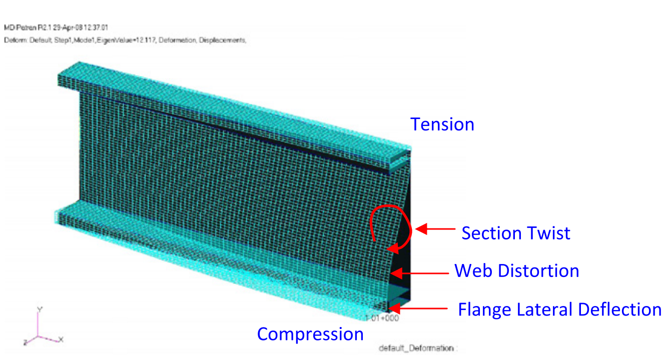

Fig. 3. Lateral distortional buckling of LSBs.

Elastic lateral buckling of channel section beams has been investigated and summarised in many books [3–6]. Effects of lateral distortional buckling on the strength behaviour of conventional I-sections were investigated first by Hancock et al. [7] and Bradford [8]. Elastic lateral distortional buckling of HFBs in uniform bending was investigated by Dempsey [1] using a finite strip method. Mahendran and Doan [9] investigated the experimental behaviour of HFBs whereas Avery et al. [10] continued this research using finite element analyses, and developed suitable design equations. Avery and Mahendran [11] investigated the use of web stiffeners to eliminate the lateral distortional buckling of HFBs. Pi and Trahair [12] also investigated the behaviour of HFBs using a nonlinear inelastic method to analyse the lateral distortional behaviour of HFBs. However, the ultimate strength behaviour of the new mono-symmetric LSB flexural members subject to lateral distortional buckling has not been investigated. Effects of mono-symmetric cross-section, web distortion, initial geometric imperfections, residual stresses and stress–strain characteristics on the lateral distortional behaviour of LSBs are not known. Therefore, a detailed experimental study was conducted to investigate the lateral distortional buckling behaviour of LSB flexural members.

More than 50 lateral buckling tests of LSBs with varying spans were conducted in this study. Simply supported beams were tested to failure using a quarter point loading method. A special test rig was used to simulate the ideal loading and support conditions required for lateral buckling tests. This paper describes the lateral buckling tests of LSBs, their results and comparisons with the predictions from the current design rules in AS/NZS 4600 [13]. It also includes the results of mechanical properties of steel, and initial imperfections and residual stresses of LSBs.

2. Experimental investigation

2.1. General

Two series of lateral buckling tests were carried out in this investigation. In the first series of more than 35 tests, test beams were only held via their web elements at the supports. This could have reduced their moment capacities due to the occurrence of local flange twist. Although this effect can be minimised or eliminated by plotting the test moment capacity results in a non-dimensional moment capacity format using the appropriate elastic lateral distortional buckling moments from numerical analyses, the use of ideal simply supported boundary conditions as required for the lateral buckling tests is desirable to eliminate such twisting. The first series of tests also did not include shorter spans. Further, the LSB manufacturers made some changes to the steels used in LSB sections, and also improved their manufacturing process. Hence it was decided to undertake a second series of 12 lateral buckling tests. Some of the tests in the second series considered the same spans used in the first series for comparison purposes while other tests considered shorter spans subject to lateral distortional buckling. In most of the tests in the second series improved simply supported conditions without local flange twist were used.

2.2. Test specimens

Test Series 1 included all the available 13 LSBs in order to investigate the effects of section geometry, thickness and yield stress of steel. Test beam span was varied from 1200 to 4000 mm to produce a large range of beam slenderness. Test Series 2 considered six LSBs with the same range of spans. Details of