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INELASTIC BENDING CAPACITY OF LITESTEEL BEAMS

T. ANAPAYAN[1], M. MAHENDRAN[2], D. MAHAARACHCHI[3]

[1] *Queensland University of Technology, Brisbane, Australia <t.anapayan@qut.edu.aul>*
[2] *Queensland University of Technology, Brisbane, Australia, <m.mahendran@qut.edu.au>*
[3] *Queensland University of Technology, Brisbane, Australia, <d.mahaarachchi@robertbird.com.au>*

ABSTRACT

Australian manufacturers recently developed a new mono-symmetric cold-formed steel hollow flange channel section known as LiteSteel Beam. The innovative LSB sections with rectangular flanges are currently being used as floor joists and bearers in buildings. In order to assess their behaviour and section moment capacity including the presence of any inelastic reserve bending capacity, 20 section moment capacity tests were conducted in this study. Test results were compared with the section moment capacities predicted by the steel design codes. Although the current cold-formed steel design rules generally limit the section moment capacities to their first yield moments, test results showed that inelastic reserve bending capacity was present in the compact and non-compact LSB sections. The results have shown that suitable modifications to the current design rules are needed to allow the inclusion of available inelastic bending capacities of LSBs in design.

1. INTRODUCTION

Recently a new mono-symmetric cold-formed hollow flange section known as LiteSteel beam (LSB) was introduced by OneSteel Australian Tube Mills [1]. The LSB sections (Table 1) are made of two hollow flanges and a slender web using a patented dual electric resistance welding and roll-forming process. The high strength steel used is DuoSteel grade with nominal flange and web yield stresses of 450 and 380 MPa. The new LSBs are commonly used as flexural members such as floor bearers and joists. This research was conducted to assess their behaviour and section moment capacities including the presence of any inelastic reserve bending capacity. As seen in Table 1, many LSB sections are compact (C) and non-compact (NC) based on the plate slenderness calculations [2]. Unlike the conventional C- or Z-sections, these LSBs are not subjected to elastic local buckling effects and hence are likely to have considerable inelastic reserve bending capacities. Past research [3-5] has only addressed the plastic bending strength and behaviour of rectangular and square hollow sections. Therefore 20 section moment capacity tests were conducted on LSBs with short span and fully laterally restrained LSBs subject to local buckling and yielding effects. The presence of inelastic reserve bending capacity in LSBs was investigated since the current Australian and North American cold-formed steel structures design rules [6,7] limit the section moment capacities to first yield moments. This paper presents the details of this experimental study, the results and comparisons with design code predictions.

d	x	b_f	x	t		Compactness
300	x	75	x	3.0	LSB	NC
300	x	75	x	2.5	LSB	S
300	x	60	x	2.0	LSB	S
250	x	75	x	3.0	LSB	NC
250	x	75	x	2.5	LSB	NC
250	x	60	x	2.0	LSB	S
200	x	60	x	2.5	LSB	C
200	x	60	x	2.0	LSB	NC
200	x	45	x	1.6	LSB	S
150	x	45	x	2.0	LSB	C
150	x	45	x	1.6	LSB	NC
125	x	45	x	2.0	LSB	C
125	x	45	x	1.6	LSB	NC

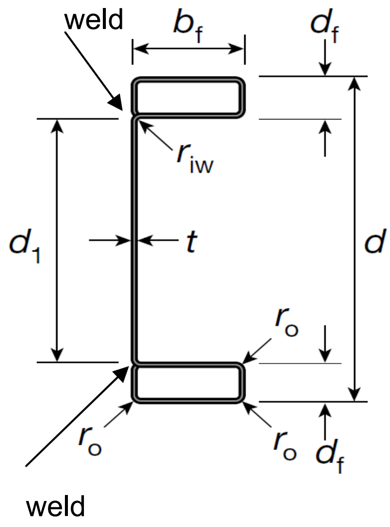


Table 1: Details of LSBs

2. EXPERIMENTAL STUDY

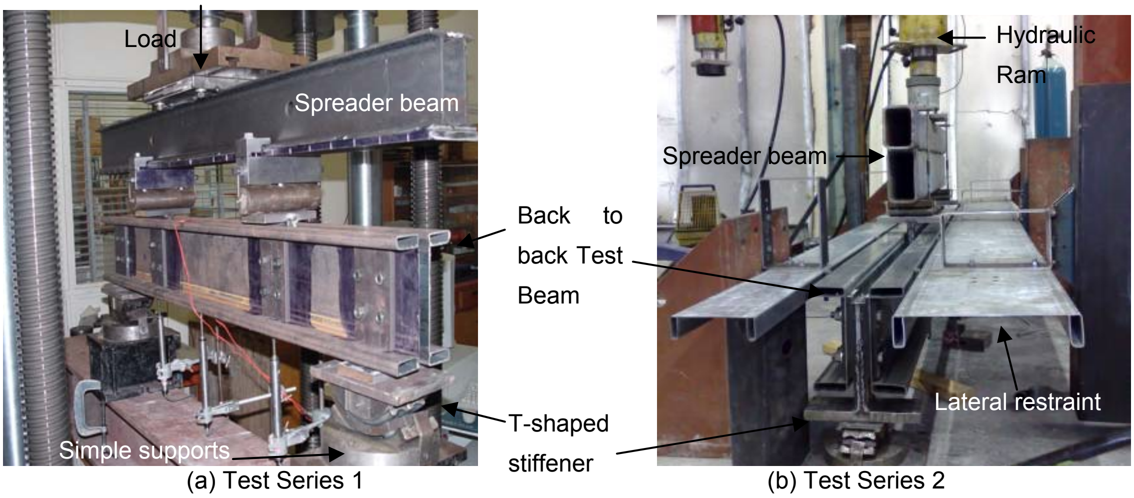
There were two series of tests in this experimental study. Test Series 1 included section moment capacity tests of the 13 available LSBs while Test Series 2 considered seven tests to verify the effects of the recently improved LSB manufacturing process. Table 2 presents the details of these test specimens including their elastic and plastic section modulus values (Z and S). Test beam dimensions and thicknesses were measured and the section properties including Z and S were calculated based on these measured values.

LSB Section	Test Series 1			Test Series 2		
	Z (10^3mm^3)	S (10^3mm^3)	Yield stress	Z (10^3mm^3)	S (10^3mm^3)	Yield stress
300x75x3.0LSB	173.90	203.19	528	174.7	209.6	497.8
300x75x2.5LSB	157.90	182.39	511			
300x60x2.0LSB	104.00	122.95	568	102.8	123.11	557.7
250x75x3.0LSB	132.80	154.99	506			
250x75x2.5LSB	120.90	139.83	525	120.1	141.87	552.2
250x60x2.0LSB	79.12	93.53	580	80.12	94.68	523.0
200x60x2.5LSB	70.34	82.43	496			
200x60x2.0LSB	56.17	65.71	473			
200x45x1.6LSB	36.14	43.04	478	40.15	47.87	536.9
150x45x2.0LSB	32.01	37.39	498	32.75	38.92	537.6
150x45x1.6LSB	25.12	30.34	540	26.71	31.49	557.8
125x45x2.0LSB	23.73	28.92	503			
125x45x1.6LSB	19.71	23.91	549			

Table 2: Details of Test Specimens

The mechanical properties of LSB plates were also measured using standard tensile coupon tests. The average yield stresses of the outside and inside flanges and web were 520, 465 and 412 MPa in Test Series 1 whereas they were 548, 494 and 448 MPa in Test Series 2. Table 2 includes the important outside flange yield stress for each test specimen in MPa. Flange elements had higher yield stresses and the lack of a yield plateau due to the higher cold-working in the flanges. However, the average percentage elongation at failure based on 50 mm gauge length was found to be 20, 27 and 31% for outside and inside flange and web elements, respectively. The average ultimate tensile stress to yield stress ratios of flange and web elements of LSBs varied from 1.08 (outside flange) to 1.25 (web). These results confirm that the steel used to make LSBs comply with the requirements in AS/NZS 4600 [6].

The section moment capacity tests were conducted using back to back LSB specimens under a four point bending arrangement as shown in Figure 1. The LSB specimens were tested by loading them symmetrically through a spreader beam by a testing machine in Test Series 1 and a hydraulic ram in Test Series 2. This four-point bending arrangement provided a central region of uniform bending moment and zero shear force. The two LSB specimens were connected with web plate and T-shaped stiffeners at the loading and support locations using M18 bolts as shown in Figure 1. T-shaped stiffeners were used to support and transfer the loads to the web elements of test beams and thus avoided web crippling failures and eccentric loading. Test spans varied from 1500 to 3300 mm (shorter spans for smaller LSBs). In most cases the loading points were located at third points. The applied load, vertical deflections and longitudinal flange strains at mid-span were measured until failure.



(a) Test Series 1 (b) Test Series 2

Figure 1. Test Set-up

3. EXPERIMENTAL RESULTS

Compact and non-compact LSB test specimens failed by local buckling of the top compression flange at mid-span near the peak load. Local web buckling was also observed soon after flange local buckling. Large flange deformations and yielding occurred at moments closer to the failure moment for compact sections. For non-compact sections, yielding and large flange deformations appeared to occur earlier while for slender sections, local web buckling occurred, which was followed by large flange deformations and yielding. There was no sudden unloading due to lateral deflection or insufficient material ductility. Elastic buckling of flanges was not observed. Typical failures of LSBs are shown in Figure 2.

Figure 2: Typical Failures of LSBs

The uniform moment between the loading points was calculated by multiplying the measured applied load and the distance between the support and the loading point. The moment versus mid-span deflection curves are given in [8]. It was found that for compact sections (150x45x2.0LSB), the moment versus deflection curve included a long horizontal plateau after the ultimate moment was reached while for slender sections (200x45x1.6LSB), the load decreased suddenly with deflection after failure. Strain measurements showed that compact LSBs reached high compressive and tensile longitudinal strains in their flanges at failure (>8000 microstrain) while slender LSBs were not able to reach such large strains.

The ultimate moment capacities (M_u) of LSBs in Test Series 1 and 2 are given in Tables 3 and 4. In these tables, their first yield and plastic moment capacities (M_y and M_p) are also given. They were calculated using the section properties based on their measured dimensions and nominal corners and the measured outer flange yield stresses in Table 2. The ultimate moment capacities from tests (M_u) are greater than M_y in most cases in Tables 3 and 4, which indicate that most of the LSBs have large inelastic reserve bending capacity.

LSB Section		M_y	M_p	M_p/M_y	M_s	M_u	M_u/M_s
300 x 75 x 3.0	NC	91.82	107.29	1.17	91.82	103.9	1.13
300 x 75 x 2.5	S	80.69	93.20	1.16	80.69	85.80	1.06
300 x 60 x2.0	S	59.07	69.83	1.18	59.07	52.40	0.89
250 x 75 x 3.0	NC	67.20	78.43	1.17	67.20	77.89	1.16
250 x 75 x 2.5	NC	63.47	73.41	1.16	63.47	71.49	1.13
250 x 60 x 2.0	S	45.89	54.25	1.18	45.89	47.33	1.03
200 x 60 x 2.5	C	34.89	40.89	1.17	34.89	52.47	1.50
200 x 60 x 2.0	NC	26.57	31.08	1.17	26.57	31.80	1.20
200 x 45 x 1.6	S	17.27	20.57	1.19	17.27	17.36	1.01
150 x 45 x 2.0	C	15.94	18.62	1.17	15.94	19.63	1.23
150 x 45 x 1.6	NC	13.56	16.38	1.21	13.56	14.94	1.10
125 x 45 x 2.0	C	11.94	14.55	1.22	11.94	14.38	1.20
125 x 45 x 1.6	NC	10.82	13.13	1.21	10.82	12.95	1.20

Table 3: Test Moment Capacities and Comparison with AS/NZS 4600 Predictions for Test Series 1

LSB Section		M_y	M_p	M_p/M_y	M_s	M_u	M_u/M_s
300 x 75 x 3.0	NC	86.97	104.34	1.20	86.97	93.00	1.07
300 x 60 x 2.0	S	57.33	68.66	1.20	57.33	53.36	0.93
250 x 75 x 2.5	NC	66.32	78.34	1.18	66.32	70.68	1.07
250 x 60 x 2.0	S	41.90	49.52	1.18	41.90	42.12	1.01
200 x 45 x 1.6	S	21.56	25.70	1.19	21.56	20.88	0.97
150 x 45 x 1.6	NC	17.61	20.92	1.19	17.61	20.20	1.15
150 x 45 x 2.0	C	14.90	17.56	1.18	14.90	16.18	1.09

Table 4: Test Moment Capacities and Comparison with AS/NZS 4600 Predictions for Test Series 2

4. COMPARISON OF SECTON MOMENT CAPACITIES WITH PREDICTIONS FROM THE CURRENT DESIGN RULES

The section moment capacities (M_s) of tested LSBs were calculated based on the design method in AS/NZS 4600 [6] and the North American Specification [7], which are identical. Their design method is based on the initiation of yielding in the extreme compression fibre. Effects of elastic local buckling are accounted for by using the effective widths of slender elements in compression in the effective section modulus (Z_e) calculation. The product of Z_e and f_y (the yield stress) gives M_s. The effective width was found to be equal to the actual width for all the elements of 13 LSB sections when their rounded corners were included. Hence the full section modulus (Z) based on measured dimensions and rounded corners was used to calculate M_s of LSBs, which is thus equal to the first yield moment M_y. These M_s values are compared with the failure moments (M_u) from tests in Tables 3 and 4.

As seen in these tables, the failure moments of all the test specimens exceeded the section moment capacities predicted by AS/NZS 4600 [6] except for 300x60x2.0 LSB. The average M_u/M_s ratio of compact (C) sections is 1.19 while it is 1.14 and 0.99 for non-compact (NC) and slender (S) sections, respectively. Since AS/NZS 4600 [6] does not allow the inelastic reserve bending capacity (limits to M_y), it leads to conservative predictions for compact and non-compact LSB sections. However, it was able to predict the capacities of slender LSBs reasonably well. As observed in the tests, there was considerable moment capacity beyond the first yield point for compact and non-compact sections. For compact sections, the average M_u/M_y ratio of 1.19 is very close to the average M_p/M_y ratio in Tables 3 and 4, which indicates that compact LSBs are capable of achieving their plastic moment capacities (M_p). The test results for the non-compact LSB sections as defined based on AS 4100 also indicate that their ultimate moment capacities are between their M_y and M_p.

AS/NZS 4600 allows the use of inelastic reserve capacity, but subject to four conditions. Currently available LSBs do not satisfy the first two conditions and thus inelastic reserve capacity was not included in the calculations. They are: the effect of cold-forming is not included in determining f_y; the ratio of the depth of the compressed portion of the web to its thickness does not exceed the slenderness ratio λ_1 defined as $1.11/(f_y/E)^{1/2}$. The first condition refers to the use of a higher yield strength of the corners due to cold-working. The section moment capacities of LSBs are based on a higher flange yield stress of 450 MPa that includes the benefit of significant cold-working of hollow flange elements, and not due to that of corners. The rectangular and square hollow sections (RHS, SHS) are manufactured using a similar method to that of LSBs, and their inelastic reserve bending capacities are calculated using AS 4100 [2] based on the increased yield stress enhanced by cold-working of their flange elements. Hence it is possible to use the available inelastic reserve capacity of LSBs as for RHS and SHS. The second condition relating to web slenderness appears to be too restrictive. The λ_1 value for LSB sections is only about 23.4, and was thus exceeded.

Tests showed that 300x60x2.0 LSB was unable to reach its first yield moment with M_u/M_s ratios of 0.89 and 0.93 as it is the most slender section with very deep web element (slender). These observations are as predicted by AS 4100 [2]. However, AS/NZS 4600 [6] predicted that 300x60x2.0 LSB will reach its first yield moment, ie. M_s is equal to $M_{y,}$ and hence the M_u/M_s ratio becomes less than 1.0 for 300x60x2.0 LSB. This implies that AS/NZS 4600 is unconservative in predicting the section moment capacities of some slender LSBs.

Based on the test results, it is concluded that AS/NZS 4600 [6] and NAS [7] design rules are conservative for compact and non-compact LSB sections while they predict the capacities of slender LSB sections reasonably well. Suitable modifications to their design rules are needed to allow the inclusion of the available inelastic reserve bending capacity in LSBs.

Eurocode 3 Part 1.3 design rules for cold-formed steel structures [9] were also considered. However, they only allow the basic yield strength to be used in the section moment capacity calculations, ie. 380 MPa instead of 450 MPa for LSBs. This led to lower predictions in comparison with test capacities of all the LSB sections. Test moment capacities were also compared with those predicted by AS 4100 [2]. These comparisons presented in [8] showed that AS 4100 design rules are more suited for predicting the section moment capacities of

T-
Shaped
Stiffeners

LSBs because they allow the inclusion of inelastic bending capacity. However, in principle, they cannot be used for LSBs as they are cold-formed steel sections.

Suitable design rules for the inelastic bending capacity of cold-formed steel beams were developed by Yener and Pekoz [10] based on the recommended ratio of compressive strain to yield strain (C_y) as a function of the b/t ratio of compression elements. These design rules were included in AS/NZS 4600 [6] and NAS [7], but could not be used for LSBs as most cold-formed steel sections do not usually meet the two conditions mentioned earlier. The presence of reduced inelastic bending capacity in cold-formed steel beams in comparison to hot-rolled steel beams is considered to be due to higher web to flange area, unsymmetric sections resulting in first yield occurring in the tension flange and the inability of cold-formed steel sections to sustain high compressive strains [10]. However, the LSBs despite being cold-formed, do not have the above shortcomings as they are not the conventional open cold-formed sections. The presence of rectangular hollow flanges eliminates the above problems and hence appears to lead to higher inelastic bending capacities for compact and non-compact LSB sections. Test results showed that compact LSB sections are able to sustain compressive strains equal to more than three times the yield strain. Hence it is feasible that the available inelastic bending capacities can be used for LSBs. Suitably modified design rules are needed for this purpose within the current cold-formed steel design codes. Further research is being undertaken using numerical studies to determine whether inelastic reserve bending capacities available in LSBs and other cold-formed steel sections can be included in design as for hot-rolled steel sections.

5. CONCLUSIONS

Section moment capacity tests of a new cold-formed hollow flange channel section known as LiteSteel beam were conducted in this study to assess their behaviour and moment capacities. This paper has described this study and presented the results including a comparison with design capacity predictions of current cold-formed steel codes. The section moment capacities of compact and non-compact LiteSteel beam sections were found to be greater than their first yield moments and thus the cold-formed steel codes are more conservative as they do not allow the use of available inelastic bending capacity. This research has shown that the available inelastic bending capacities in cold-formed LiteSteel beams can be included in design as for hot-rolled steel beams. Suitably modified design rules are needed within the cold-formed steel design codes for this purpose.

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