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Section Moment Capacity Tests of Rivet-Fastened Rectangular Hollow Flange Channel Beams

R. Siahaan[1], P. Keerthan[2] and M.Mahendran[3]

Abstract

The rivet-fastened rectangular hollow flange channel beam (RHFCB) is a new cold-formed hollow section proposed as an alternative to welded hollow flange steel beams. It is a mono-symmetric channel section made by rivet fastening two torsionally rigid rectangular hollow flanges to a web plate. This method will allow the designers to develop optimum sections, with affordable rivet connection between the web and flange elements. The new rivet-fastened RHFCB has unique characteristics that are not encountered in conventional hot-rolled and cold-formed steel channel sections. Therefore an experimental study consisting of 15 section moment capacity tests was conducted with different rivet spacings to investigate the flexural behaviour and strength of rivet-fastened RHFCB members. The ultimate moment capacities from the tests were compared with the capacities predicted by the current design rules for steel structures, and their suitability to predict the section moment capacities of RHFCBs was investigated. The applicability of the Direct Strength Method based design rules was also investigated. This paper presents the details of this experimental study and the results.

Keywords: *Rectangular Hollow Flange Channel Beams, Cold-formed Steel Beams, Bending, Section Moment Capacity, Inelastic Reserve Bending Capacity, Direct Strength Method.*

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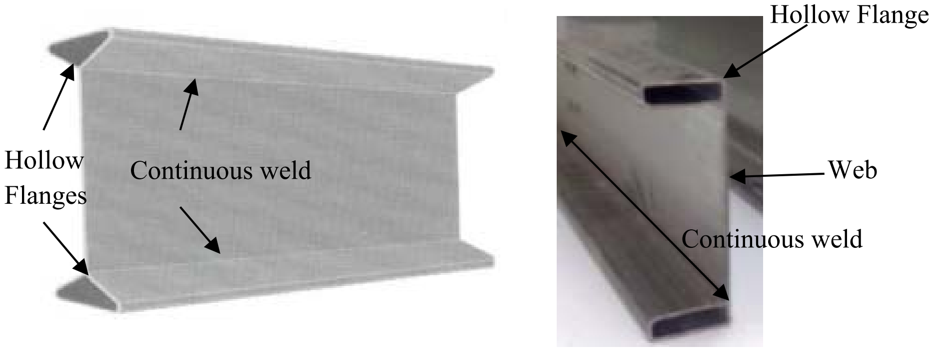
1. Introduction

In the past, hollow flange sections (HFS) including the Dogbone section (Figure 1a) and the LiteSteel Beam (LSB) (Figure 1b) have been widely used in residential, industrial and commercial buildings, mainly as flexural members, due to their improved structural performance and light weight. However, these HFSs are no longer manufactured today due to the expensive dual electric welding process used in their manufacturing process, as well as other factors.



(a) Dogbone Section (b) LSB Section

Figure 1: Hollow Flange Sections (HFS)

The rivet-fastened rectangular hollow flange channel beam (RHFCB) shown in Figure 2 is a new type of cold-formed HFS, proposed as an alternative to the welded HFS. The RHFCB is fabricated by intermittently rivet-fastening two cold-formed rectangular hollow flanges to a web plate. Unlike other conventional cold-formed sections, the HFS family including the rivet-fastened RHFCB, has no unsupported edges. Previous HFS beams are made from single strip of high strength steel through the use of combined cold-forming and dual electric resistance welding process. The rivet-fastened RHFCB uses the much more affordable rivet-fastening system and gives the flexibility of using different combinations of flange and web steel thickness and grades due to the way that it is being assembled. It also has additional lips, possibly contributing to additional strength.

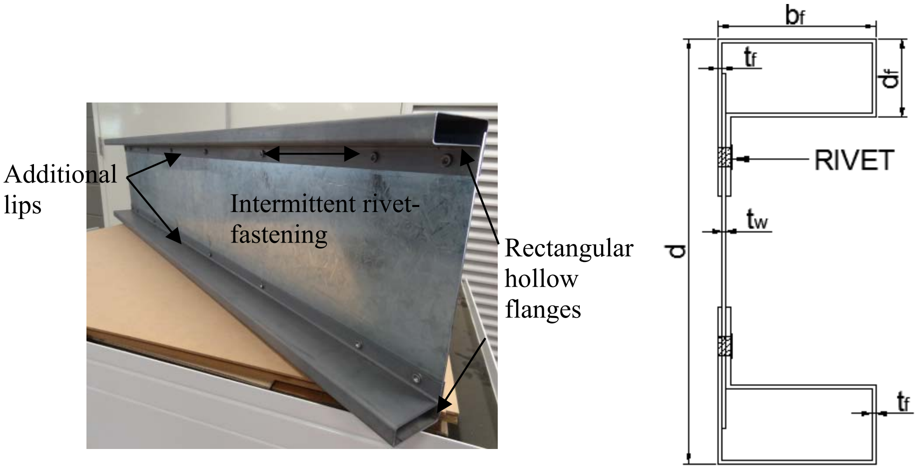


Figure 2: Rivet-Fastened Rectangular Hollow Flange Channel Beam

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 (Keerthan and Mahendran 2011; Anapayan et. al 2011a, 2011b). However, to date, no attempt has been made to investigate the behavior and strength of rivet-fastened RHFCBs. In this research, the section moment capacity of rivet-fastened RHFCBs was investigated using experimental studies. This paper presents the details of the section moment capacity tests of rivet-fastened RHFCBs, and the results. Experimental section moment capacities are compared with the predicted section moment capacities using the current design rules.

While there has been significant advancement in cold-formed steel structures, their adoption requires the support of suitable design code provisions. Currently, two design methods for cold-formed steel are available in the Australian/New Zealand Standard (AS/NZS 4600:2005) and the AISI S100. They are the Effective Width Method (EWM) and the Direct Strength Method (DSM). The DSM uses the elastic buckling load and the first yield load, requiring no iteration as in the EWM. Although the DSM was developed as an alternative approach, numerous research has been completed to extend its application. Yu and Schafer (2007) found that the DSM yields reasonable strength predictions for local and distortional buckling failures of C- and Z-section beams with a wide range of industry standard geometries and yield stresses of steel. Shifferaw and Schafer (2012) investigated the inelastic bending capacity of conventional open cold-formed steel members such as C- and Z-section beams and proposed suitable design rules for inelastic local, distortional, and lateral torsional buckling under the DSM format, which were subsequently added to the AISI S100 provision, to take advantage of the inelastic reserve strength for members that are stable enough to allow partial plastification of the cross-section. Anapayan et al. (2011a) carried out section moment capacity tests of 20 LSBs to investigate their behavior and strength as flexural members. Their findings revealed that compact and non-compact LSBs have higher inelastic bending capacities, with moment capacities greater than their first yield moments, compared to other cold-formed steel sections due to the presence of stiff rectangular hollow flanges. However, no design provision was proposed in the DSM format for HFS. This paper will use the section moment capacity test results of rivet-fastened RHFCBs to investigate the suitability of DSM based design rules.

2. Experimental Study

2.1 Test Specimens

Section moment capacity tests were carried out on 15 rivet-fastened RHFCBs, fabricated with various sizes of hollow flange and web elements that are rivet-fastened at different spacings: 50 mm, 100 mm, and 200 mm. Three different spacings were chosen to investigate its effect on the buckling and failure modes, and associated moment capacities. Table 1 presents the details of the RHFCB test specimens including their elastic section modulus values (Z) and compactness. The section classification of the available rivet-fastened RHFCB was determined first based on the Australian hot-rolled steel structures code AS 4100. It was based on the measured dimensions and yield stresses of base steel sheet. In Table 1, “C” denotes compact sections, which are not subjected to elastic local buckling effects and are likely to reach full plastic moment capacities. “NC” denotes non-compact sections, which are subjected to inelastic local buckling effects, with section moment capacities between their first yield and full plastic moment capacities. “S” denotes slender sections, subject to elastic local buckling effect with section moment capacities limited to their first yield moments.

Since the RHFCBs offer the flexibility of choosing different web and flange thickness, initial attempts were to develop all three types of compactness. However, due to the manufacturing limitation related to hollow flanges where the folding equipment can only fold steel sheets with a maximum thickness of 1.1 mm, all the flanges in these test series are slender and as a result, all sections are considered slender, overall.

Table1: Measured Dimensions of Tested Rivet-Fastened RHFCBs

Test No.	Rivet Spacing	RHFCB Sections d x b_f x d_f x t_f x t_w (mm)	Z (10^3 mm^3)	Flange Yield Stress (MPa)	Compactness		
					Flange	Web	Overall
1.	100	152x62x19x1.1x1.9	26.02	370	S	C	S
2.		201x62x19x1.1x1.9	39.60	370	S	NC	S
3.		250x62x19x1.1x1.9	54.81	370	S	S	S
4.		150x53x18x0.9*x1.4	18.90	-	S	S	S
5.		150x53x18x1.1x1.4	22.61	370	S	S	S
6.		201x53x18x0.9*x1.9	31.35	-	S	NC	S
7.		201x53x18x1.1x1.9	36.64	370	S	NC	S
8.		250x62x19x0.9*x1.9	48.22	-	S	S	S
9.		250x62x19x1.1x1.4	56.30	370	S	S	S
10.	50	152x62x19x1.1x1.9	26.02	370	S	C	S
11.		201x62x19x1.1x1.9	39.60	370	S	NC	S
12.		250x62x19x1.1x1.9	54.81	370	S	S	S
13.	200	152x62x19x1.1x1.9	26.02	370	S	C	S
14.		201x62x19x1.1x1.9	39.60	370	S	NC	S
15.		250x62x19x1.1x1.9	54.81	370	S	S	S

Note: d-depth, b_f-flange width, d_f-flange depth, t_f-flange thickness, t_w-web thickness, Z-elastic section modulus.

* Yield stress of 0.9 mm sheet is unavailable.

2.2 Test Set-Up

The section moment capacity tests were conducted using back to back RHFCB specimens to prevent twisting. A four point bending arrangement was used to simulate the critical central region of uniform bending moment and zero shear force. Figure 3 illustrates the schematic diagram of the test set-up where all the tested beams have the same length of 1200 mm. The distance between supports to loading point is 400 mm while the uniform bending moment region has a length of 300 mm. Such arrangement was selected to eliminate shear buckling failures.

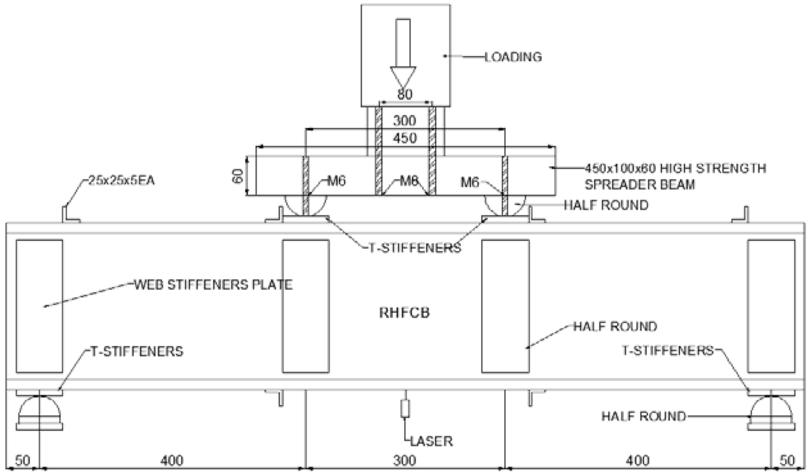


Figure 3: Schematic Diagram of Test Set-Up

Figure 4 shows the actual laboratory test set-up. The two, back to back, RHFCB specimens were connected with 10 mm thick web plate and T-shaped stiffeners at the loading and support locations using four M16 bolts. T-shaped stiffeners were used to support and transfer the loads to the web elements of test beams and thus avoided web crippling failures. Since this is a section moment capacity test, lateral buckling was prevented by using four straps at the compression flanges and two straps at the tension flanges to tie the beam together as shown in Figures 3 and 4. The use of straps to provide lateral restraint in a back to back section moment capacity test had previously been adopted by other researchers (Pham and Hancock 2013). An LVDT was placed underneath each beam specimen in the uniform bending moment region to measure the vertical deflection at md-span. The applied load and vertical deflections at mid-span were measured until post failure.

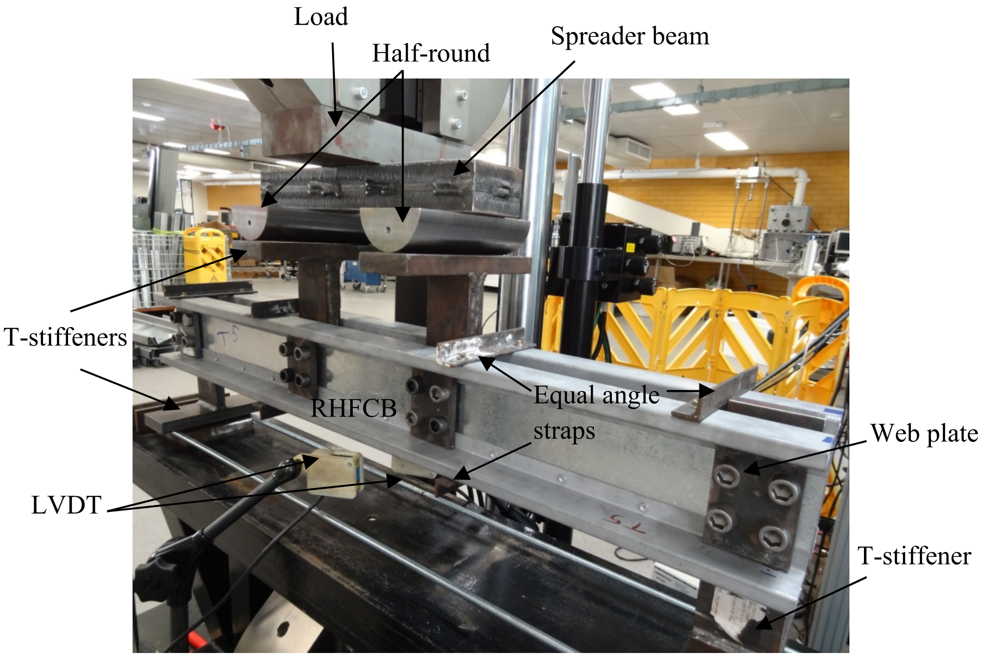


Figure 4: Laboratory Test Set-Up

3. Experimental Results

All the 15 rivet-fastened RHFCB test specimens failed by local buckling of the top compression flange at mid-span near the ultimate load. This is as expected as all of the flanges are classified as slender. Although the failure modes of all the rivet-fastened RHFCBs were similar, there were some differences in the way the failure occurred. 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 (400 mm). Generally, the moment versus deflection graphs of the section moment capacity tests were linear in the initial stage. Non-linearity commenced near the ultimate load. Figure 5 shows the applied moment-mid-span deflection curves for the test of 152x62x19x1.1x1.9 RHFCB with 100 mm rivet spacing while Figures 6 and 7 show the applied moment versus mid-span deflection curves for the tests of 201x53x18x0.9x1.9 with 100 mm rivet spacing and 250x62x19x1.1x1.9 RHFCB with 200 mm rivet spacing, respectively.

Anapayan et. al (2011a) reported one weld failure out of a total of 20 section moment capacity tests of LSBs. They subsequently concluded that the welding strength of LSBs is adequate. In this test, there was no rivet failure in all the fifteen tested specimens which indicate that the rivet strength of the new rivet-fastened RHFCBs is adequate.

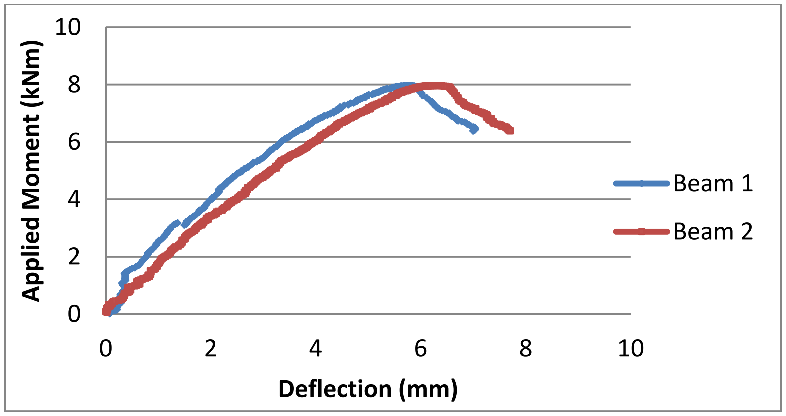


Figure 5: Applied Moment versus Mid-span Deflection Curves of 152x62x19x1.1x1.9 RHFCB, Rivet-Fastened at 100 mm Spacing

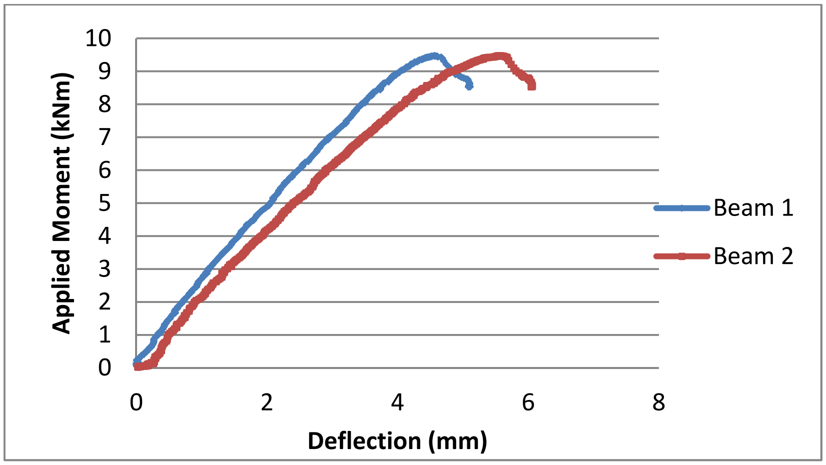


Figure 6: Applied Moment versus Mid-span Deflection of 201x53x18x0.9x1.9 RHFCB, Rivet-Fastened at 100 mm Spacing

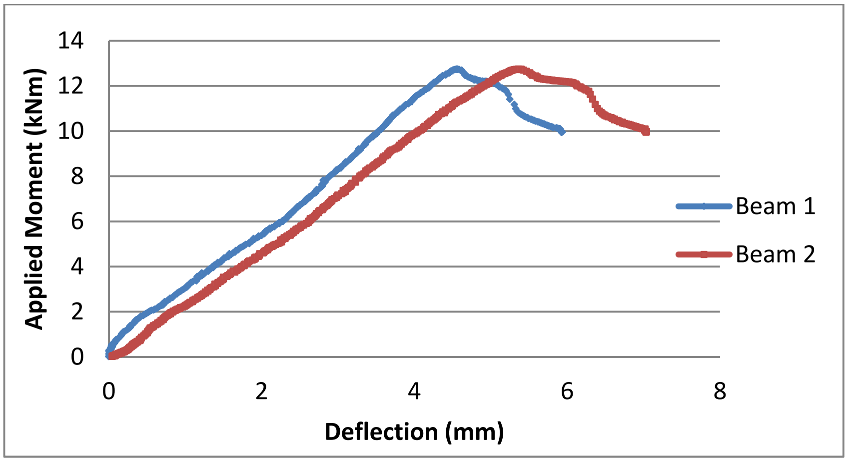


Figure 7: Applied Moment versus Mid-span Deflection Curves of 250x62x19x1.1x1.9 RHFCB, Rivet-Fastened at 200 mm Spacing

Table 2: Test Ultimate Moment Capacities and Comparison with AS/NZS 4600 and AS 4100 Predictions

Test No.	Rivet Spacing	RHFCB Sections $d \times b_f \times d_f \times t_f \times t_w$ (mm)	M_y (kNm)	Test M_u (kNm)	AS/NZS 4600		AS 4100	
					M_s (kNm)	M_u/M_s	M_s (kNm)	M_u/M_s
1.	100	152x62x19x1.1x1.9	9.63	7.97	7.16	1.11	5.82	1.37
2.		201x62x19x1.1x1.9	14.65	12.08	11.03	1.10	8.86	1.36
3.		250x62x19x1.1x1.9	20.28	14.88	15.50	0.96	12.27	1.21
4.		150x53x18x0.9*x1.4	-	5.32	-	-	-	-
5.		150x53x18x1.1x1.4	8.37	6.40	6.46	0.99	5.96	1.07
6.		201x53x18x0.9*x1.9	-	9.46	-	-	-	1.59
7.		201x53x18x1.1x1.9	13.56	11.36	10.69	1.06	9.65	1.18
8.		250x62x19x0.9*x1.9	-	11.98	-	-	-	-
9.		250x62x19x1.1x1.4	20.83	12.24	14.20	0.86	12.60	0.97
10.	50	152x62x19x1.1x1.9	9.63	8.45	7.16	1.18	5.82	1.45
11.		201x62x19x1.1x1.9	14.65	13.03	11.03	1.18	8.86	1.47
12.		250x62x19x1.1x1.9	20.28	16.27	15.50	1.05	12.27	1.33
13.	200	152x62x19x1.1x1.9	9.63	6.92	7.16	0.97	5.82	1.19
14.		201x62x19x1.1x1.9	14.65	10.30	11.03	0.93	8.86	1.16
15.		250x62x19x1.1x1.9	20.28	12.76	15.50	0.82	12.27	1.04

Note: M_u=ultimate moment, M_s=section moment, M_y= first yield moment.
* Yield stress data is unavailable for 0.9 mm thick beams

The ultimate moment capacities (M_u) obtained from the tests are given in Table 2. These capacities are then compared with the section's respective section moment capacities (M_s) calculated using the Australian cold-formed steel structures design standard (AS/NZS 4600) and the Australian hot-rolled steel structures standard (AS 4100) in Table 2, where M_y is the first yield moment.

It was observed during the experiment that there are two distinct web buckling modes. When web buckling occurs between two rivets, which is more common with large rivet spacings such as 100 mm and 200 mm, the web tends to buckle towards the outside of the beam (Figure 8). In contrast, when web buckling occurs at the rivet location (more common with 50 mm rivet spacing), the web tends to buckle towards the inside of the beam (Figure 9).

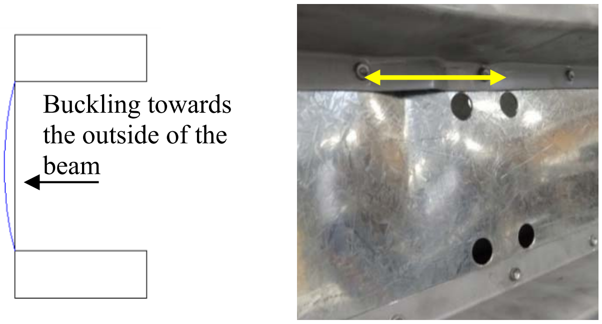


Figure 8: Web Buckling towards the Outside of the Beam, between Two Rivets, as found in 201x62x19x1.1x1.9 RHFCB with 100 mm Rivet Spacing

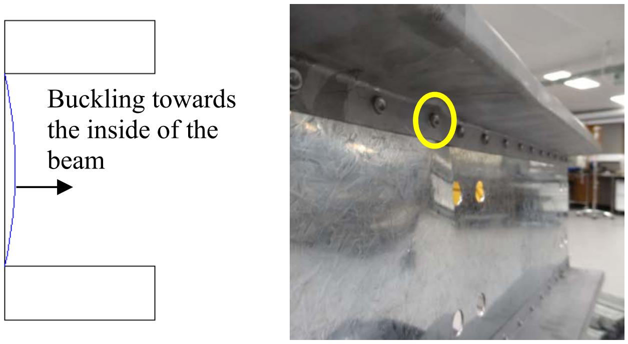


Figure 9: Web Buckling towards the Inside of the Beam, at Rivet Location, as found in 250x62x19x1.1x1.9 RHFCB with 50 mm Rivet Spacing

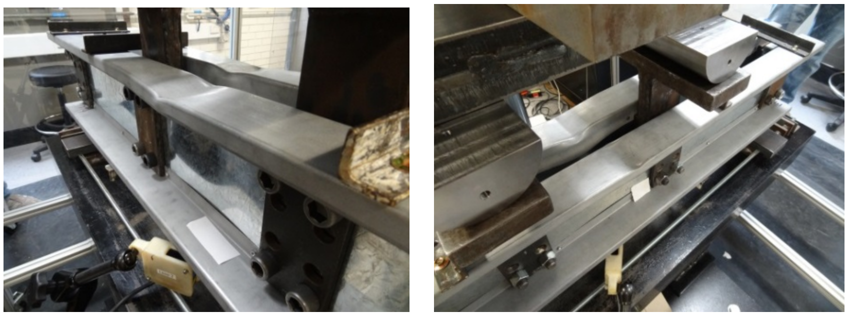
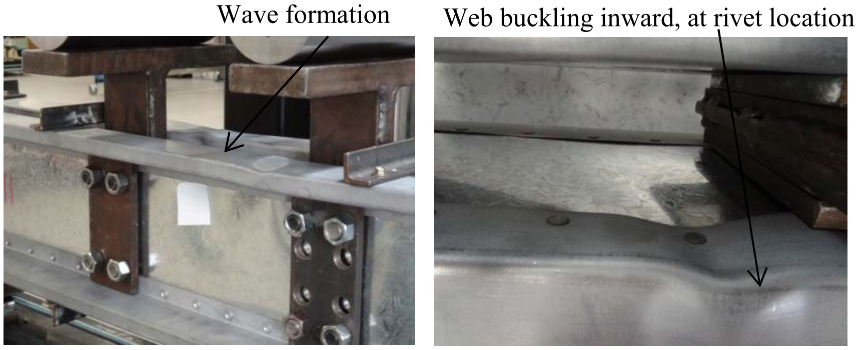


Figure 10: Typical Failure Mode of Rivet Fastened-RHFCBs



Wave formation

Web buckling inward, at rivet location

Figure 11: Failure Mode of 201x62x19x1.1x1.9 RHFCB with 50 mm Rivet Spacing

Web buckling between rivets, towards the outside of the beam

Figure 12: Failure Mode of 201x62x19x1.1x1.9 RHFCB with 100 mm Rivet Spacing

Figure 13: Failure Mode of 201x62x19x1.1x1.9 RHFCB with 200 mm Rivet Spacing

Figure 10 shows the typical failure mode of rivet fastened-RHFCBS while Figures 11 to 13 show the failure modes of 201x62x19x1.1x1.9 RHFCB with 50 mm, 100 mm and 200 mm rivet spacing, respectively. These figures show the dominant local flange buckling of the top flange and associated web buckling deformations. While local buckling of the outer compression flange was dominant, it was observed that the inner compression flange did not buckle before reaching the ultimate moment.


(a) 500 mm spacing (b) 100 mm spacing (c) 200 mm spacing

Figure 14: Separation between Lips and Web for 152x62x19x1.1x1.9 RHFCB with Varying Rivet Spacings

Figure 14 shows the separation between lips and web element for 152x62x19x1.1x1.9 RHFCB at different rivet spacings. When compared to Figures 11 to 13, it can be seen that separation between web and lip is more critical in sections with more slender webs. With increasing separation, reduction in moment capacities was observed. Table 3 shows the reduction of moment capacity values as rivet spacing increases, where the ultimate moment capacity at zero rivet spacing (welded) was obtained from finite element analysis using ABAQUS. Percentage strength reductions from being welded to rivet-fastened at different spacings were then calculated.

Table 3: Reduction of Ultimate Moment Capacity with Increased Rivet Spacing

Test No.	RHFCB Sections $d \times b_f \times d_f \times t_f \times t_w$ (mm)	Rivet Spacing	M_u (kNm)	% reduction
1.	152 x 62 x 19 x 1.1 x 1.9	0	8.64	-
		50	8.45	2.20
		100	7.97	7.75
		200	6.92	19.91
2.	201 x 62 x 19 x 1.1 x 1.9	0	13.96	-
		50	13.03	6.66
		100	12.08	13.47
		200	10.30	26.22
3.	250 x 62 x 19 x 1.1 x 1.9	0	17.32	-
		50	16.27	6.06
		100	14.88	14.09
		200	12.76	26.33

4. Comparisons of Section Moment Capacities with Predictions from the Current Design Rules

The section moment capacities (M_s) of all the 15 tested rivet-fastened RHFCBs were calculated based on the design method in AS/NZS 4600, which is identical to the North American Specification (AISI S100). They were also calculated using the Australian hot-rolled design standard (AS 4100) for comparison purposes. Since both AS/NZS 4600 and AS 4100 design standards do not have any provision for intermittently rivet-fastened beams, the calculated M_s values for the sections with different rivet spacing of 50 mm, 100 mm and 200 mm, are the same.

The AS/NZS 4600 design standard 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 (yield stress of flange) gives M_s. These M_s values are then compared with the failure moments (M_u) from tests as shown in Table 2. As seen in Table 2, AS/NZS 4600 predicts the section moment capacities of all rivet-fastened RHFCBs to be below their first yield moments (M_y) as they are all slender sections. AS/NZS 4600 is over-conservative in calculating the section moment capacities of 152x62x19x1.1x1.9 RHFCB, 201x62x19x1.1x1.9 RHFCB, and 250x62x19x1.1x1.9 RHFCB (Test Nos. 10, 11, and 12 respectively) which are all rivet-fastened at 50 mm with an average M_u/M_s ratio of 1.14. For sections with the same dimensions (Test Nos. 1, 2, and 3) but rivet-fastened at 100 mm spacing, AS/NZS 4600 predicted the capacities reasonably well with an average M_u/M_s ratio of 1.06. However, it over-predicted the M_s values for sections with the same dimensions (Test Nos. 13, 14, and 15) but rivet-fastened at 200 mm spacing with average M_u/M_s ratio of 0.91. These comparisons appear to indicate that AS/NZS 4600 design rules are able to predict the section moment capacities of intermittently rivet-fastened RHFCBs as long as the rivet spacing is small.

The section moment capacities (M_s) of the specimens were also calculated based on the design method in AS 4100 where the effective section modulus (Z_e) allows for the effects of local buckling. The section moment capacity is governed by the compactness of its plate elements. Here, the section modulus (Z) value was obtained from the finite strip analysis program THIN-WALL while the effective section modulus (Z_e) value was obtained by multiplying "Z" with the most slender element's ratio of λ_{ey}/λ_e if both flanges and web are slender. From the results in Table 2, it can be seen that the section moment capacities of all the 15 rivet-fastened RHFCBs predicted by AS 4100 are below their first yield moment (M_y) as all the sections are slender. However, when compared to AS/NZS 4600 design rules, AS 4100 design rules are over-conservative in predicting the section moment capacities of rivet-fastened RHFCBs.

Both AS 4100 and AS/NZS 4600 do not have any provision to allow for the effect of intermittent rivet fastening on M_s. Their design rules may still be adequate if the reduction in M_s due to intermittent rivet fastening is negligible. Table 3 shows the effect of rivet-fastening on the section moment capacity of RHFCB based on the test results for rivet spacings of 50, 100 and 200 mm, including finite element analysis results for zero spacing (continuously welded). Table 3 results show that on average the percentage reductions are 4.98, 11.77 and 24.2% for rivet spacings of 50, 100 and 200 mm respectively.

Based on these results, it appears that AS/NZS 4600 design rules can be used to predict the section moment capacity of rivet-fastened RHFCBs if the rivet spacing is 50 mm. However, based on the test observations relating to separation between web and flange elements (Figure 14) and the reduction of 11.77% for 100 mm rivet spacing, 100 mm rivet spacing may be acceptable and more practical for adoption. However, further research is needed to verify this.

5. Direct Strength Method

The Direct Strength Method (DSM) is an alternative procedure for determining the strength of cold-formed steel members. As found in Section 1.2.2.1.2.1 (Eqn. 1.2.2-8) in AISI S100, the section moment capacity (M_s) can be obtained from Equation 1.

$$\mathrm{M}_s = \left(\left(1 - 0.15\left(\frac{M_{ol}}{M_y}\right)^{0.4}\right)\left(\frac{M_{ol}}{M_y}\right)^{0.4}\right)M_y \tag{1}$$

where: M_s = section moment capacity, M_{ol} = elastic buckling moment, M_y= first yield moment.

For the inelastic region, the section moment capacity of sections symmetric about the axis of bending or sections with first yield in compression can be obtained from Section 1.2.2.1.2.1.2 (Eqn. 1.2.2-10) in AISI S100 by Equation 2.

$$M_s = M_y + (1 - \frac{1}{C_{yl}{}^2})(M_p - M_y) \tag{2}$$

where: M_s = section moment capacity, M_y= first yield moment, M_p=plastic moment, $C_{yl} = \sqrt{0.776/\lambda} \leq 3$

The section moment capacities of the rivet-fastened RHFCBs in DSM format were calculated and summarised in Table 4. In this method, M_{ol} can be obtained from FEA of rivet-fastened RHFCBs and thus it can predict M_s accurately for RHFCBs with varying rivet spacings. Figure 15 compares the test results with DSM predictions in a non-dimensional plot of M_s/M_y versus $\lambda = \sqrt{M_y/M_{ol}}$. This figure shows that the DSM predicts the M_s of rivet-fastened RHFCBs reasonably well. However, all the tested RHFCBs are slender and experimental results from this research alone are not sufficient to confirm the suitability of the DSM to predict the section moment capacity of rivet-fastened RHFCBs. Further research using both experiments and FEA are currently under way.

Table 4: Section Moment Capacities of Rivet-Fastened RHFCBs (DSM Format)

Test No.	Rivet Spacing (mm)	RHFCB Sections $d \times b_f \times d_f \times t_f \times t_w$ (mm)	M_{ol} (kNm)	$\lambda = \sqrt{\frac{M_y}{M_{ol}}}$	M_s/M_y
1.	100	152x62x19x1.1x1.9	7.19	1.16	0.83
2.		201x62x19x1.1x1.9	9.87	1.22	0.82
3.		250x62x19x1.1x1.9	12.92	1.25	0.73
4.		150x53x18x0.9*x1.4	-	-	-
5.		150x53x18x1.1x1.4	6.84	1.11	0.77
6.		201x53x18x0.9*x1.9	-	-	-
7.		201x53x18x1.1x1.9	9.94	1.17	0.84
8.		250x62x19x0.9*x1.9	-	-	-
9.		250x62x19x1.1x1.4	9.94	1.45	0.59
10	50	152x62x19x1.1x1.9	9.57	1.00	0.88
11.		201x62x19x1.1x1.9	14.87	0.99	0.89
12.		250x62x19x1.1x1.9	20.96	0.98	0.80
13.	200	152x62x19x1.1x1.9	6.29	1.24	0.72
14.		201x62x19x1.1x1.9	8.74	1.29	0.70
15.		250x62x19x1.1x1.9	11.53	1.33	0.63

Note: M_{ol}= elastic buckling moment from finite element analysis, M_s=section moment, M_y= first yield moment. * Yield stress data is not available.

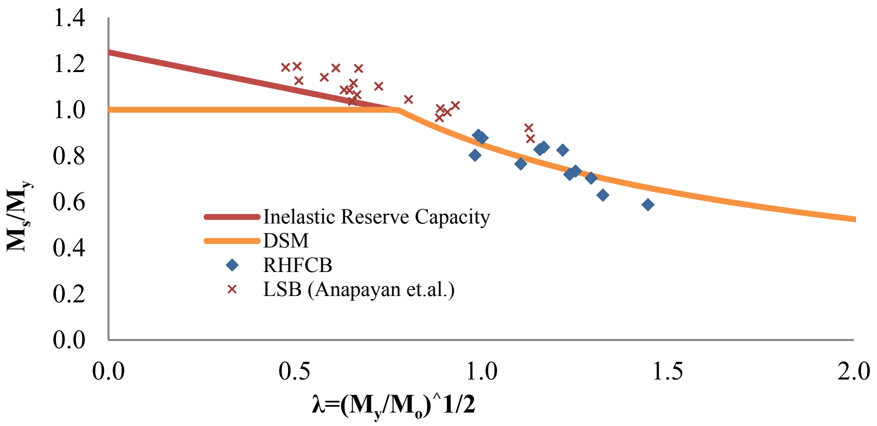


Figure 15. Direct Strength Method based Design

However, experimental section moment capacities of welded LSBs from Anapayan et. al (2011a) were also plotted in Figure 15 to assess the accuracy of DSM. The test M_s values were obtained from Anapayan et. al (2011a) while the

M_{ol} and λ values were calculated in this study. This comparison in Figure 15 further confirms the suitability of DSM based design rules in predicting the section moment capacities of welded and rivet-fastened HFS. As seen in Figure 15, compact and non-compact LSBs do have significant inelastic reserve bending capacity and that the DSM was conservative in predicting it. Therefore, further research through extensive finite element analysis and testing is needed, especially on compact and non-compact rivet-fastened RHFCBs.

6. Conclusions

This paper has presented the details of an experimental investigation of the section moment capacities of the new intermittently rivet-fastened rectangular hollow flange channel beams (RHFCB) and the results. Fifteen section moment capacity tests were conducted using a four point loading arrangement. Typical bending moment versus mid-span deflection curves and ultimate moment capacities from these tests are presented. The experimental study was intended to investigate the behavior of sections with different compactness: compact, non-compact, and slender, so as to also investigate their inelastic bending capacities. However, due to limitations in the manufacturing technology, only slender rivet-fastened RHFCBs were manufactured and tested.

Tests have shown that the section moment capacity of the rivet-fastened RHFCB reduced with increasing rivet spacing but is still acceptable up to 100 mm rivet spacing. It was found that using intermittent rivet spacing at 50 mm reduces the section moment capacity of the rivet-fastened RHFCB on average by about 5% due to the absence of continuous connection between the flanges and the web. At 100 mm rivet spacing, the section moment capacity reduced by about 12% while at 200 mm rivet spacing, it reduced by 24%. The effect of increasing rivet spacing on the capacity of rivet-fastened RHFCB was also found to be more critical in sections with more slender webs.

Comparison of ultimate moment capacities from tests with design capacity predictions from the current cold-formed and hot-rolled steel design standards showed that the cold-formed design standard is better in predicting the section moment capacities of rivet-fastened RHFCBs as long as the rivet spacing is small. At present, there is no provision for the effect of rivet-fastening in currently available standards and consequent capacity reduction as rivet spacing increases. It was found that the current DSM based design rules also predict the section moment capacities of slender, rivet-fastened RHFCBs reasonably well although further studies through finite element analysis is needed to investigate the applicability of the DSM to compact and non-compact rivet-fastened

RHFCBs. Effects of intermittent fastening on the moment capacity can be included using DSM based design rules.

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