Oct 26th, 12:00 AM

Increasing the Strength and Stiffness of Cold-formed Hollow Flange

Tim Wilkinson

Patrick Liu

Jester Magpayo

Huong Nguyen

Recommended Citation

Wilkinson, Tim; Liu, Patrick; Magpayo, Jester; and Nguyen, Huong, "Increasing the Strength and Stiffness of Cold-formed Hollow Flange" (2006). *International Specialty Conference on Cold-Formed Steel Structures*. 5.
https://scholarsmine.mst.edu/isccss/18iccfss/18iccfss-session2/5

Eighteenth International Specialty Conference on Cold-Formed Steel Structures
Orlando, Florida, U.S.A, October 26 & 27, 2006

Increasing the Strength and Stiffness of Cold-Formed Hollow Flange Channel Sections for Web Crippling

Tim Wilkinson[1], Patrick Liu[2], Jester Magpayo[2], Huong Nguyen[2]

Abstract

A new range of cold-formed channel sections has recently been manufactured with a unique hollow flange. The web crippling behaviour of these sections is notably different to plain channels due to the different rotational restraint provided to the web, and also the possibility of a flange crushing failure mode. This paper outlines an investigation into the strength of these new sections under the IOF (interior one flange) loading condition. Some novel methods of stiffening and strengthening the resistance to web crippling are outlined, and some methods of evaluating the strength enhancement are considered.

Introduction

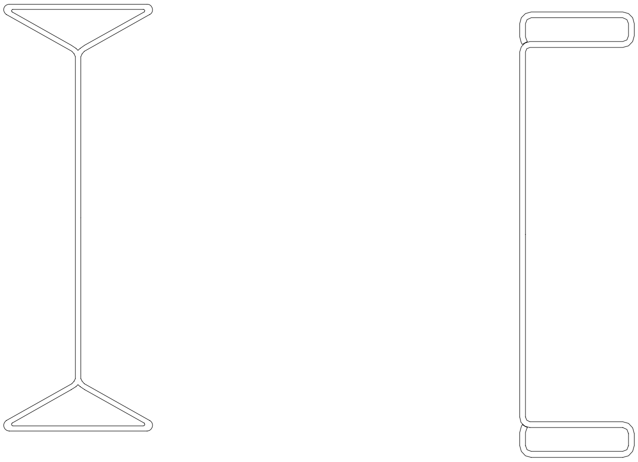
In structures, steel members are primarily chosen according to the properties of their cross-sections. Hot-rolled sections, such as the universal beam and channel, are efficient in bending, as the majority of the material is located away from the neutral axis of the section, but are torsionally weak, and have low resistance to flexural-torsional buckling. Hollow structural sections (HSS) are extremely stiff torsionally compared to open sections, but the distribution of the steel cross-section relative to its neutral axis is not as efficient as that of open sections.

Between early 1990 and mid 1995, Palmer Tube Mills Pty Ltd (PTM), now known as Smorgon Steel Tube Mills (SSTM) developed and refined a technique to roll-form steel strip and produce two simultaneous electrical resistance welds. This development resulted in the "Dogbone" Hollow Flange Beam (HFB) as shown in Figure 1a, which was the world's first cold rolled, fully Dual Electric Resistance Welded (DERW) structural beam, formed from a single high strength

---

[1] Lecturer, School of Civil Engineering, The University of Sydney, NSW, Australia.
[2] Former undergraduate students, School of Civil Engineering, The University of Sydney, NSW, Australia.

steel strip. The revolutionary cross sectional shape of the HFB had some unique failure modes such as flexural distortional buckling and bearing capacity failure. Research was required to investigate these failure modes before these sections could be used efficiently and safely. This research included analytical, experimental and numerical studies (Hancock et al (1994), Sully et al (1994), Pi and Trahair (1997), Avery et al (2000)). SSTM has recently introduced a new shape using this technology, the hollow flange channel, known as the LiteSteel™ Beam (LSB™), as shown in Figure 1b. This paper forms part of a project to investigate the behaviour of LSB.



Original Hollow Flange Beam

Hollow Flange Channel
LiteSteel Beam

Figure 1a & 1b: HFB & LSB Sections

Types of Bearing Loads

It was identified in initial investigations that the unique shape of the LSB would mean that experimental investigation of the bearing capacity would be required due to possible failure modes that were different to those experienced by plain channel sections. The bearing capacity of hot-rolled I-sections has been well researched, but cold-formed sections have specific problems related to their rounded corners, and hollow flange sections can fail by "crushing" of the hollow flange as well as a web crippling failure. In addition the hollow flange would apply different rotational restraint to the web and the load transfer mechanism into the web would be different to that of plain channels which would affect the web crippling capacity.

Four different types of bearing conditions are commonly specified depending on the nature of loading, and the location of the bearing load with respect to the ends of a typical beam. These are shown in Figure 2.

- IOF – interior one flange
- EOF – exterior one flange
- ITF – interior two flanges
- ETF – exterior two flanges

This report is concerned primarily with IOF loading. It was thought that this would be the most common type of bearing loading that LSB would be subjected to in flooring applications. In addition, the relative strengthening effects of the options considered were not expecting to be notably dependent on the type of bearing.

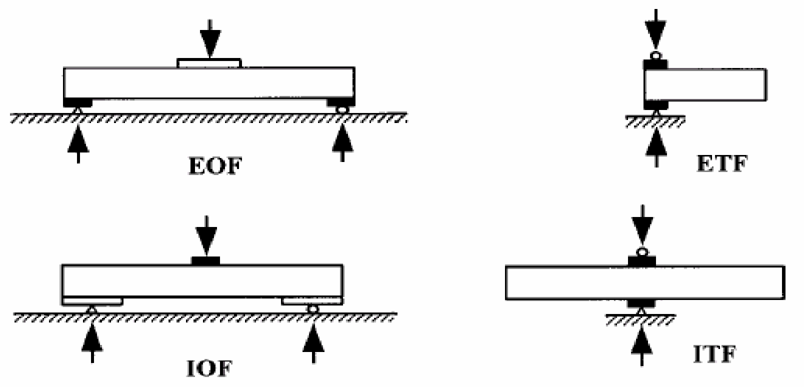


Figure 2: Definition of Bearing Types (from Young & Hancock 2001).

Initial Investigations

A comprehensive set of IOF and EOF bearing tests have been performed on LSB sections (Yang and Wilkinson 2005). The results were compared with the bearing strength equations in the then current Australian/New Zealand Standard AS/NZS 4600 (1996), and then draft and now current AS/NZS 4600 (2005). The 2005 edition was updated to reflect the universal bearing equation which has been used in the North American Specification for several years (Equation 1).

$$R_b = C t_w^2 f_y \sin\theta \{1- C_r\sqrt{(r_i/t_w)}\}\{1+ C_l\sqrt{(l_b/t_w)}\}\{1- C_w\sqrt{(d_1/t_w)}\} \quad (1)$$

The key conclusions of these tests were:

- All specimens failed by web crippling. The flange crushing failure mode was not observed until post-ultimate.
- The mean of the ratio of IOF test results to the AS/NZS 4600 (2005) predictions was 1.40.
- The mean of the ratio of EOF test results to the AS/NZS 4600 (2005) predictions was 1.43.

A multivariable non-linear regression analysis is currently being undertaken to determine a new set of co-efficients for use in the universal bearing formula that will better predict the strength of these sections in bearing.

Options for Stiffening and Strengthening the Web

The LSB is being initially designed for flooring applications, and hence bending and bearing are key design parameters. Analysis of common floor layouts and dimensions found that the spans were being limited by the bearing strength. Hence easy to install methods of stiffening the web were considered:

- Flat steel plate tek screwed to the toes of the hollow flanges with either 1 or 2 screws on each end (Figure 3).
- SHS (square hollow section) inserted into the web and tek screwed to the web by either 2 or 3 screws (Figure 4).
- Use of proprietary bracket products from the manufacturer Pryda (Figure 5).

Test Specimen Details

One specific size LSB was used for all tests: 200 × 45 × 1.6 LSB. These dimensions are defined in Figure 6. The actual measured thickness was slightly larger than the normal value of 1.6 mm and is included in the test results in Table 1. The nature of the forming process of the LSB imparts considerable cold work on the hollow flange portion of the section and relatively little on the web. The nominal material properties are f_{yw} = 380 MPa and f_{yf} = 450 MPa. Since the steel is cold-formed there is no distinct yield plateau, and hence the

0.2 % proof stress is used. A tensile coupon test of the web indicated that the actual yield stress was 418 MPa, 10 % higher than nominal. Full details on the material property tests are available in Liu (2005), Magpayo (2005) or Huong (2005). The measured thickness and yield stress is used in all calculations.

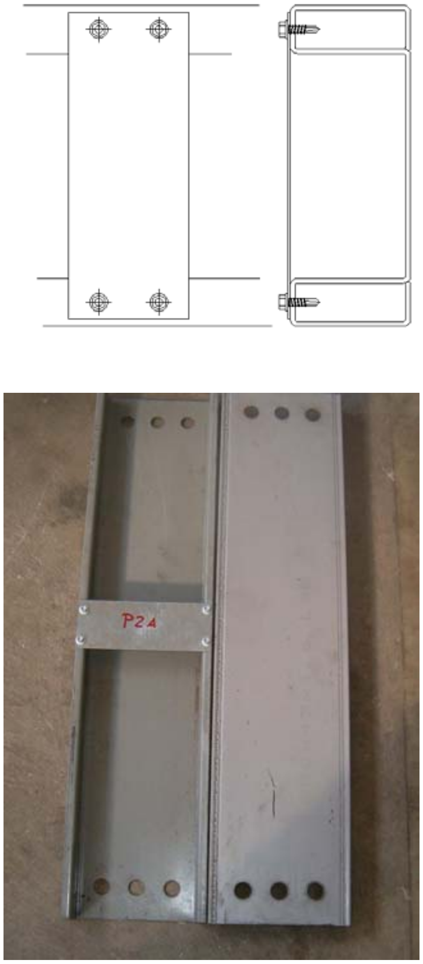


Figure 3: Plate stiffened option

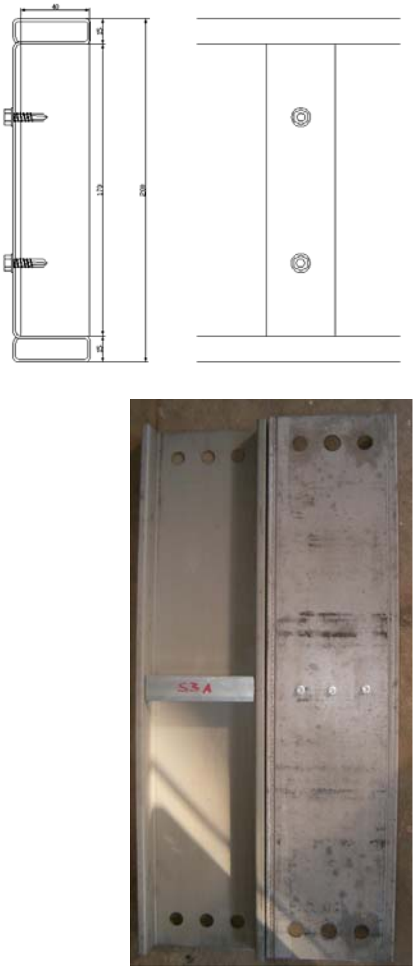


Figure 4: SHS stiffened option

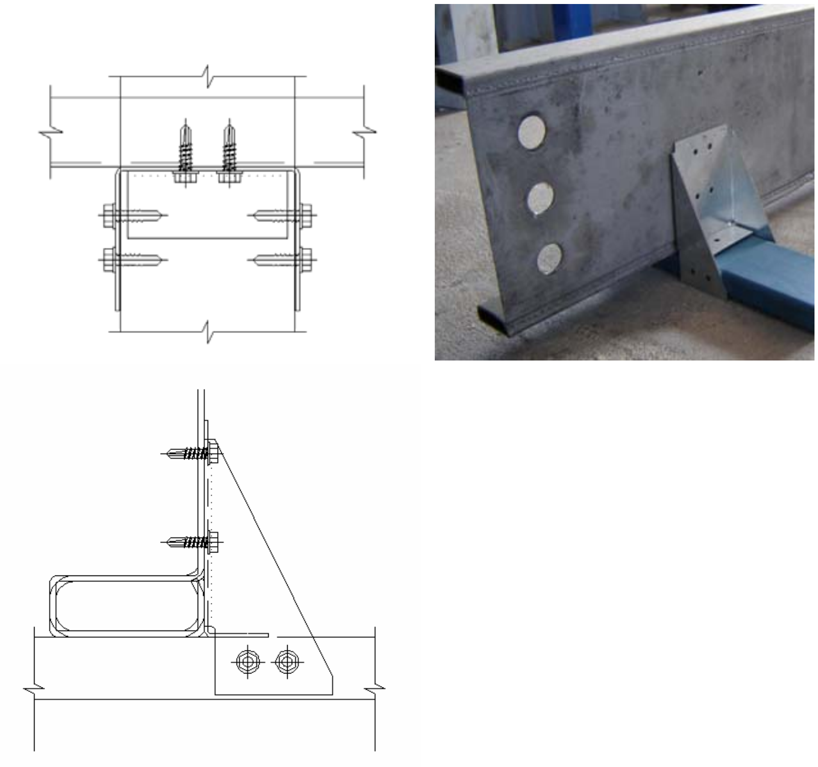


Figure 5: Bracket connection option

The flat plate had width 75 mm and thickness 1.5 mm. The SHS was 40 × 40 × 1.8 mm. The screw used were 12-14 manufactured by Buildex (12-14 denotes a screw gauge of 12 and 14 threads per inch).

Test Method

The bearing tests were performed in a 2000 kN capacity DARTEC testing machine, using a servo-controlled hydraulic ram. A diagram of the IOF test set-up is shown in Figure 7. The IOF bearing load was applied at the top flange at the centre of the beam with a stiff bearing lengths of 100 mm for the plate and SHS options. For the bracket connection, the stiff bearing length was 75 mm.

The stiffening components were located at mid-span, directly under the applied bearing load. A control test, without any stiffeners was also performed.

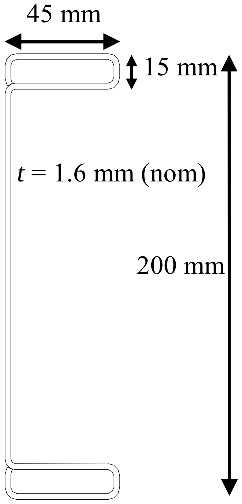


Figure 6: Section dimensions

The bearing load was applied directly through a steel block sitting on the top flange. The hydraulic ram moved at a constant stroke rate of 1.6 mm/min downwards. The LSBs were tested in pairs, back to back, with a small gap between them, to ensure that the loading arrangement was symmetric. At the supports, the LSB were bolted, through the webs, to a supporting block which was located between the two webs. The supporting blocks were on half rounds resting on greased Teflon pads which simulated a set of simple supports. The bolts were tightened to slightly beyond the "snug tight" condition, but well short of the full-tensioned condition.

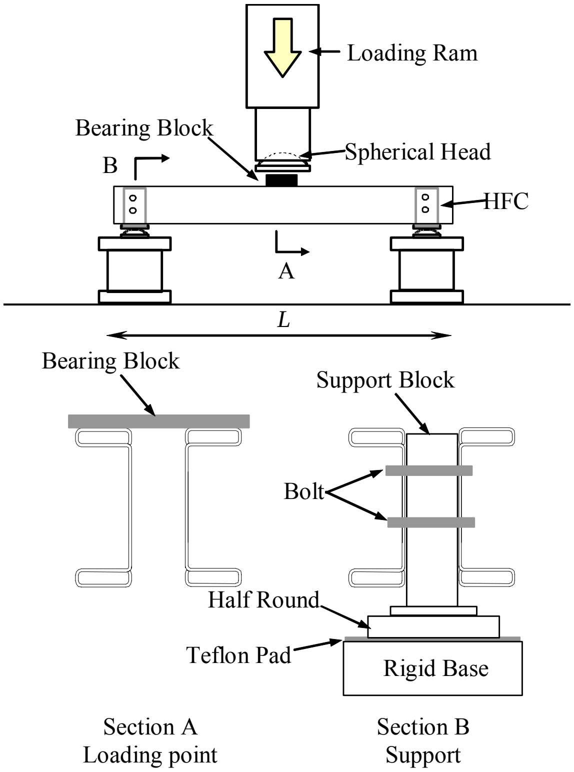


Figure 7: Diagrammatic Representation of IOF Test Procedure

Test Results

Maximum loads are reported in Table 1. Figure 8 shows the load-deformation curves. Figure 9 illustrates the failure mechanisms. All connections failed by some form of web crippling or flange crushing. Failure was not associated with moment or shear.

- The plain LSB experienced web crippling.
- For the SHS stiffened option, the majority of load was transferred via the SHS bearing between the inside faces of the hollow flanges. A flange crushing failure occurred, which was followed by some post ultimate web crippling which was restrained by the screws connected to the SHS.
- For the plate stiffened option, the plate experienced elastic member buckling due to its slenderness.

- The bracket option specimens experienced web crippling which was restrained to some degree by the bracket itself screwed to the LSB web.

ID	Configuration	R_{exp} (kN)	Percentage Increase
AS/NZS 4600	Plain	25.70	
	Plain (no stiffening)	35.16	
200I2AB100S16	SHS – 2 screws	62.82	78.6
200I2CD100S16	SHS – 2 screws	64.37	83.1
200I3AB100S16	SHS – 3 screws	61.47	74.8
200I3CD100S16	SHS – 3 screws	60.77	72.8
200I1AB100P16	Plate – 1 screw	38.70	10.1
200I1CD100P16	Plate – 1 screw	44.23	25.8
200I2AB100P16	Plate – 2 screws	44.01	25.2
200I2CD100P16	Plate – 2 screws	40.69	15.7
200I2AB75B16	Bracket – 2 screws	41.51	18.1
200I2CD75B16	Bracket – 2 screws	37.94	7.9
200I4AB75B16	Bracket – 4 screws	42.12	19.8
200I4CD75B16	Bracket – 4 screws	41.965	19.4

Table 1: Summary of maximum loads (experimental)

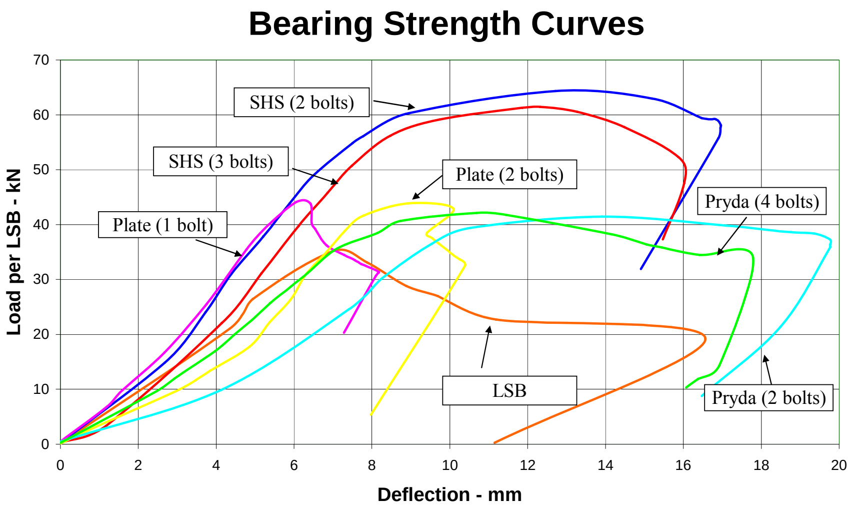
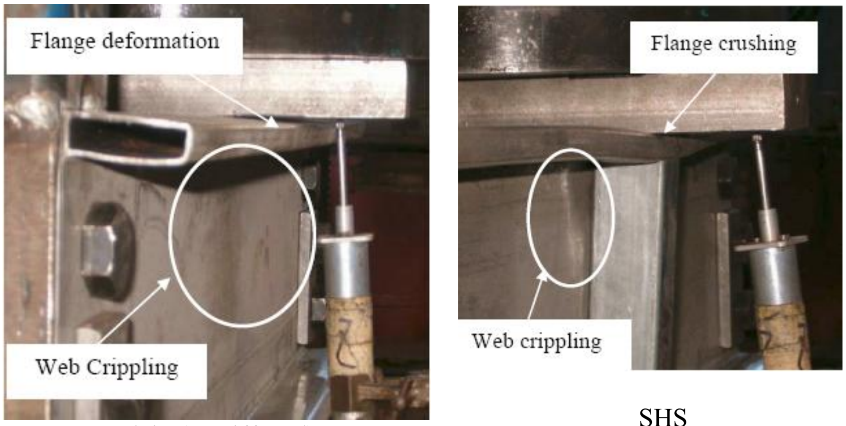
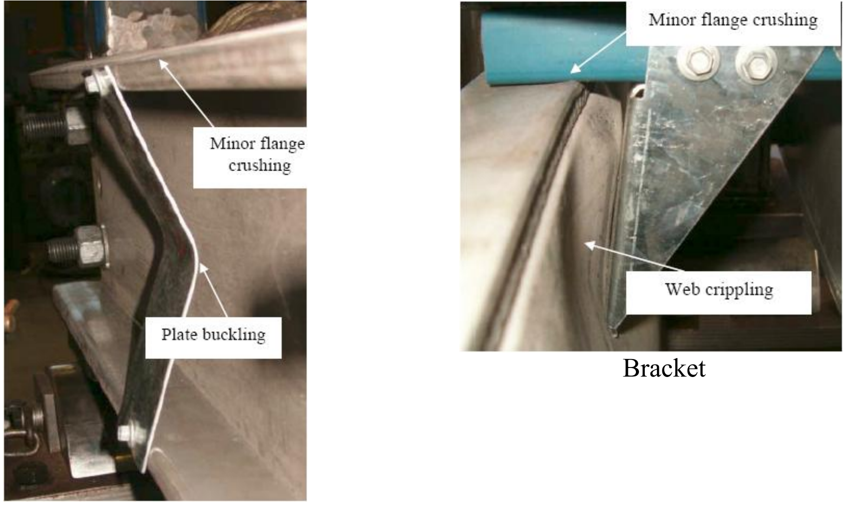


Figure 8: Load-deflection curves



Plain (unstiffened)

SHS



Bracket

Plate

Figure 8: Failure mechanisms

Discussion

The plain (unstiffened) specimen demonstrated 40 % higher capacity than the AS/NZS 4600 (2005) prediction, which was the same as increase previously reported by Yang and Wilkinson (2005).

The SHS stiffened approach showed an increase in capacity of approximately 75 % with little variability between the results. Having 2 or 3 screws connecting the SHS to the LSB appeared to have an insignificant effect on capacity. This method relies on direct bearing between the inside faces of the hollow flanges and essentially provides an alternative load path, by passing the web. It relies on having a reasonably tight fit of the SHS member into region between the flanges, though the flanges do rotate inwards to bear against the SHS if there is a small amount of initial gap. It might be possible to predict the strength of this option through the capacity or either the SHS in compression, or the punching shear/bearing of the SHS onto the hollow flange (most likely the controlling factor).

The plate stiffening method produced small increases in capacity ranging from 10 % to 25 %. This was controlled by elastic members buckling of the plate itself – since it was so slender. It is possible that the variability in the results might be due to initial imperfections in that slender plate. No clear conclusions can be drawn about the number of screws. It is possible that the strength of this option might be predicted by incorporating the buckling compression strength of the thin plate.

The bracket provided some restraint to the web of the LSB and the web crippling shape was altered by the presence of the bracket screwed to the web. The use of a reduced web *d*/*t* ratio in the bearing equation may be a possible method of predicting the strength of the specimen. The increase was on average 20 %.

Attempting to Evaluate Increased Strengths

SHS Stiffened connection

Several approaches were attempted to approximate the strength of this connection as outlined in Table 2.

Method	Prediction (kN)	Exp/Pred
Experiment (average)	62.3	
AS 4100 (1998) Clause 5.13.3, the bearing yield capacity of RHS	60.6	0.97
CIDECT (1994) punching shear of SHS to RHS T connection	43	1.44
AS 4100 (1998) Clause 6.2, squash capacity of SHS	120	0.52

Table 2: Prediction methods for SHS stiffened connection

Since the failure mode involved flange crushing and there was no evidence of distress in the SHS, it is not surprising that the SHS capacity greatly overpredicts the strength. The AS 4100 bearing yield equation seems to be a good predictor of strength, however this result should be considered with caution. The AS 4100 bearing yield and CIDECT punching shear models were based predominately on tests of SHS chords or RHS chords about the major axis. For this case the LSB flange is being treated as an RHS about the minor axis, with wide flange and almost non-existent web. These models may be inappropriate and it is possible that the close prediction is more a result of good chance.

Plate Stiffened Connection

Several approaches were attempted to approximate the strength of this connection as outlined in Table 3.

Method	Prediction (kN)	Exp/Pred
Experiment (average)	41.9	
Experimental result of unstiffened LSB plus Euler buckling of plate $\pi^2 EI/L^2$	37.4	0.90
AS 4100 (1998) bearing of RHS - Treat LSB plus the plate as a closed RHS	115	0.36

Table 3: Prediction methods for plate stiffened connection

Treating the LSB cross section combined with the plate joining the toes as a an equivalent closed RHS for bearing strength well exceeded the experimental result. Treating the plate as a web continuously attached to the “flange” does not reflect the concentrated load transfer through the screw(s) and the load dispersion mechanism is quite different. The Euler buckling strength of the plate alone is a very small 1.2 kN (compared to a yield load of about 50 kN), highlighting its extreme slenderness. The plate buckled before the ultimate load was reached – so the failure mode was still ultimately a web cripple. Even in its buckled shape the plate provide some rotational restraint to the flange, so it might be possible this connection strength could be predicted better by changes to the universal bearing equation – particularly the C_w term which relates to the web slenderness. However much more test data would be required to perform a reasonable analysis to calculate this.

Bracket connection

There was a small (but not insignificant) 20% increase in strength provided by the bracket. As was highlighted earlier, the web crippling shape was restrained by the screwed connections between the bracket and the web. As for the plate connection, it might be possible to model this by use of an adjusted web slenderness term, but more test data is required.

Conclusion

This paper has described IOF bearing tests of new range of cold-formed hollow flange channel sections, known as the LiteSteel Beam (LSB). Previous testing indicated the universal bearing equation was conservative (and analysis is currently underway to produce new co-efficients), but it was found that in certain practical applications that bearing capacity was governing design. Hence some simple and quick methods to stiffen the section were examined.

It was found that the most effective method of strengthening the section involved screwing an SHS section into the zone between the flanges. This removed the slender web from the load path and resulted in strength increases of approximately 75 %. The resulting strengths were reasonably well predicted by considering the flange crushing capacity of the hollow flanges, but further investigation is required to confirm if this is the appropriate model to use.

Appendix – References

Avery, P., Mahendran, M. and Nasir, A., (2000), “Flexural Capacity of Hollow Flange Beams”, Journal of Constructional Steel Research, Elsevier, Vol 53, No 2, pp 201-223.

Hancock, G. J., Sully, R. M., and Zhao, X-L., (1994), “Hollow Flange Beams and Rectangular Hollow Sections Under Combined Bending and Bearing”, Tubular Structures VI, Proceedings of the 6th International Symposium on Tubular Structures, Melbourne, Australia, Balkema (publ), Grundy, Holgate and Wong (eds.), pp 47 – 54.

Liu. P., (2005), “Bearing Capacity of LiteSteel Beams”, Thesis, Department of Civil Engineering, The University of Sydney, Australia.

Magpayo. J., (2005), “Bearing Capacity of LiteSteel Beams”, Thesis, Department of Civil Engineering, The University of Sydney, Australia.

Nguyen. H., (2005), "Bearing Capacity of LiteSteel Beams", Thesis, Department of Civil Engineering, The University of Sydney, Australia.

Pi, Y-L. and Trahair, N. S., (1997), "Lateral-Distortional Buckling of Hollow Flange Beams", *Journal of Structural Engineering*, ASCE, Vol. 123, No. 6, pp 695-702, June 1997.

Standards Australia (1998), Australian Standard AS 4100, Steel Structures, Standards Australia, Sydney, Australia.

Standards Australia/Standards New Zealand (1996), Australian/New Zealand Standard AS/NZS 4600 Cold-Formed Steel Structures, Standards Australia/Standards New Zealand, Sydney, Australia.

Standards Australia/Standards New Zealand (2005), Australian/New Zealand Standard AS/NZS 4600 Cold-Formed Steel Structures, Standards Australia/Standards New Zealand, Sydney, Australia.

Sully, R. M., and Hancock, G. J., (1994), "Hollow Flange Beams Under Combined Bending and Bearing", Proceedings, Australasian Structural Engineering Conference, Institute of Engineers, Australia, Sydney, Australia, September 1994, pp 1033 – 1038.

Yang D. and Wilkinson T., (2005), "LiteSteel Beams (LSB) Under Interior and End Bearing Forces", *Research Report No R849*, The Department of Civil Engineering, The University of Sydney, September 2005.

Young, B. and Hancock, G. J., (2001), "Design of Cold-Formed Channels Subjected to Web Crippling", Journal of Structural Engineering, American Society of Civil Engineers, Vol. 127, No. 10, October, 2001, pp 1137-1144.

Appendix – Notation

d_1	depth of the flat portion of a web measured along the plane of the web (mm)
l_b	actual length of bearing (mm)
L	total length of specimen (mm)
f_y	yield stress (MPa)
f_u	ultimate stress (MPa)
R_b	nominal capacity for concentrated load or reaction for on solid web connection top and bottom flanges (kN)
R_{max}	resulting limiting strengths (kN)
r_i	inside bend radius (mm)
t, t_w	thickness of a web (mm)