ENGINEERING ADVANCES IN COLD-FORMED STEEL HOLLOW-FLANGE LONG SPAN BEAMS

Geoff Fletcher[1]

Martin Holland[2]

[1]LiteSteel Technologies
31 National Drive, Lyndhurst VIC 3803
gfletcher@litesteel.com

[2]Structerre
1 Erindale Rd, Balcatta WA 6021
mholland@structerre.com.au

ABSTRACT

Cold-formed steel beam sections remain an economic structural option in many applications given the cost & other advantages in their manufacture, efficiencies in section properties and material properties, and ease of handling, fabrication and connections – all relative to hot-rolled steel. However, they have not commonly been associated with high-load beam applications due to potential for localised instability in open sections necessitating additional stiffening elements or substitution by heavier sections. The development of hollow-flange sections has raised the upper limit of bending performance for cold-formed steel members and now recent innovation in relatively simple, high-capacity moment connections has further added to the suitability of these for high-load applications as a competitive alternative to hot-rolled sections.

Case study details are given for an application of hollow-flange Long Span Beam in portal frame construction to be sited in Region D cyclonic conditions, including performance testing of innovative moment connections.

Other developing applications include high-efficiency fabricated trusses, structural plan bracing, and fixed-ended purlin connections.

These developments have largely been the result of critical engineering study of design and construction aspects in the use of steel to maximise the structural performance while minimising the construction limitations typically associated with steel.

BACKGROUND TO HOLLOW-FLANGE BEAM TECHNOLOGY

Hollow-flange beam technology has evolved as manufacturing methods have advanced to allow commercially viable supply of beam product to industry. The testing of such beams (typically mill-produced by cold-forming strip from coil and welding the free edges back onto the strip) has shown that analysis and modelling of hollow-flange beam performance by current design standards (AS4100 Steel Structures, AS4600 Cold-formed Steel Structures) is not reliable. Not surprisingly, given the advances and investment required for development, proving and commercialisation, the intellectual property in this technology is privately owned and patented (and is Australian). The current available beam form in industry was presented at a previous ASEC conference in 2 papers by Mahaarachchi & Mahendran (2005) and another by Yang & Wilkinson (2005) and it has a similar form to a parallel-flange channel except the flanges are hollow and with a maximum steel thickness of 3mm.

All structural beam applications consider the interaction of load intensity & distribution with span, section & material properties to produce typical beam responses of bending, shear & bearing stresses and deflection, all of which become greater as span increases. For many open sections (having free edges) and all thin-walled sections it is common for local buckling instability in and near compression flanges to limit overall section capacity. That is, they are non-compact. A further 2 papers by Mahaarachchi & Mahendran (2006) presented buckling behaviour results of hollow-flange Long Span Beam upon which moment-span capacity values were derived. Wilkinson et al (2006) also considered the web behaviour in bending and bearing modes.

This paper refers to "Long Span Beams" merely to indicate combination of higher values of compressive bending stress with effective length (Le) exceeding, say, 20 x section depth (d) wherein the hollow-flange Long Span Beam performs more efficiently than hot-rolled or cold-formed sections considering the rate of capacity loss as Le increases. This greater efficiency of capacity in strength and stiffness as a function of steel mass and its current commercial viability is the result of engineered improvements in cross section efficiency, material properties, and manufacturing processes.

Technology drivers

The currently available hollow-flange Long Span Beam (Fig.1) improves upon problems encountered with a forerunner which had hollow triangular flanges separated by a central web. These improvements relate to structural efficiency of the section, manufacturing efficiency to reduce cost of supply, and construction efficiency for the end-users / builders.

Regarding an **efficient section** in beam action, the advantages of hollow flanges over other similar open sections (eg. Cee, Zed) are indicated by the much higher Torsion Constant (J) and a higher proportion of section area located in the flanges. Strength-to-mass and Stiffness-to-mass ratios exceed those possible with hot-rolled sections. The section strength of the flanges is also manipulated upwards by the manufacturing process.

Regarding **efficient manufacture**, the current section (Fig.1) commences with grade 380MPa strip from which circular lobes are rolled at the sides & welded. These lobes are then cold-worked further to form the rectangular hollow flanges with an improved yield strength of 450MPa. It is more reliable to manufacture from lower strength feed which results in lower rates of commissioning stock (set-up wastage).

Regarding **efficient construction**, this is now aided rather than hindered by section geometry, as was the case with the superseded triangular flange variant. The section now resembles a conventional parallel-flange channel presenting more accessible & orthogonal surfaces for connections. The maximum strip thickness of 3mm not only affords mass reduction but allows for connections with self-drilling screws, in addition to other operations such as powersaw cutting, nailing, drilling, bolting and welding.

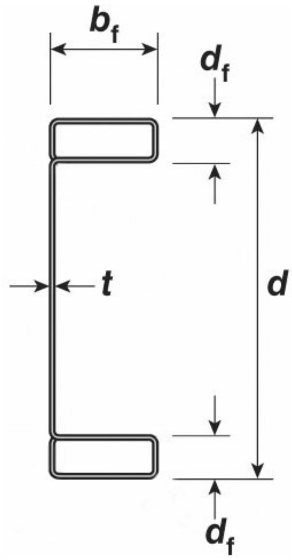

Fig.1 : Generic section of hollow-flange Long Span Beam

Innovation and Incentives for Engineering

It is usually the case that successful innovation needs to be led by demand from industry rather than academic research retrospectively looking for an application need to fill. Indeed, much research is funded from industry sources based on market demand which sets the direction of the research from the outset. This alone can justify the costs of necessary research and development to innovate successfully. In the case of hollow-flange Long Span Beam the development brief was simple – improve the beam cross section to optimise beam performance with respect to strength and stiffness from a given mass of steel, and deliver a steel beam not dependent on detailed fabrication off-site for connections.

The regulatory network around Intellectual Property is an aid to the process of innovation development and for hollow-flange Long Span Beam patents apply to the IP created in the section geometry (derived by theoretical & testing analysis) and in the manufacturing process itself (Dual Electric Resistance Welding), both requiring significant investment and managed risk to develop and verify. Detailed specifications relating to these patents are readily accessible in the public domain.

The main application example below focussed on modular high-capacity beam-to-beam connections required to enable the use of hollow-flange Long Span Beam in portal frame construction on-site in remote areas where dependence on specialised plant and trades was to be minimised.

APPLICATION INNOVATIONS

Full Moment Portal Frame Connections

A recent application of hollow-flange Long Span Beam sections in high-load & extreme conditions has been for the Gorgon Project on Barrow Island in Western Australia. Central facilities buildings in the accommodation complex were designed in modular form around a portal frame nominally 14m wide x 3.5m high with interior column (Fig.2).

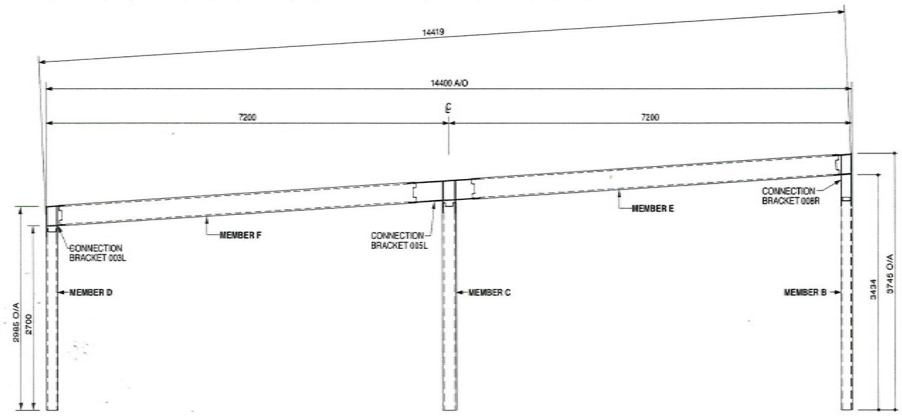

Fig.2 : Portal frame with hollow-flange Long Span Beam and connectors

In addition to extreme wind loadings (Region D) and related severe exposure to aggressive atmosphere the design also needed to allow for containerising of components and construction with minimal mechanised input. The suitability of hollow-flange Long Span Beam sections for column and rafter members was augmented by the development of specialised moment connections using a multiple of conventional self-drilling metal screws, as a quick and site-flexible alternative to more traditional methods of welding or bolting. A typical LH exterior column / rafter connector bracket (Fig.3) shows the main elements of pre-drilled flat bar-to-flange (x 2) and web stiffener for each connection point.

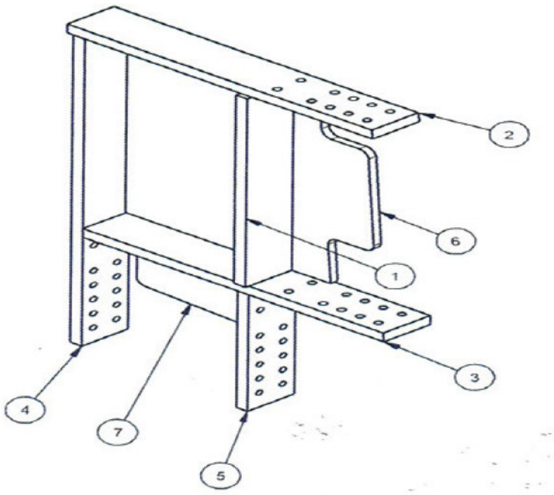

Fig.3 : Detail of hollow-flange Long Span Beam portal knee connector

Appropriate design principles were applied but since this was clearly further innovative engineering in the innovative field of hollow-flange Long Span Beam structures it was necessary to prove connection performance via load testing. For this particular connector Fig.4 shows a full scale test in progress during which a peak moment around 40kNm was applied and satisfactorily ductile and load-sharing behaviour was evident.

Fig.4 : Load testing of Long Span Beam portal frame knee connection

Note the self-drilling screws passing through the flange to work in double shear. There is scope to further improve the joint design by eliminating altogether any potential for initial slip arising from fixing through clearance holes, as can be a factor with bolted connections. The other nodal connectors including column bases were similarly designed and tested in order to verify the required capacity of the proposed solution, which is now being constructed.

Another related application (re moment connection) also being considered is for a similar flange and web connector attached to a precast wall panel to allow a fixed-end moment connection to permit hollow-flange Long Span Beam sections for roof or upper floor support even lighter than if simply supported.

High Performance Trusses

Hollow-flange Long Span Beam has also been used as top and bottom chord elements in fabricated trusses. Buckling of the compression chord in a truss is a critical performance limit. The Long Span Beam section is laid over so that bending about its own major axis contributes to the out-of-plane bending strength in the truss in addition to the section’s inherent efficiency as a closed section under column action. Web diagonal members are other cold-formed sections either welded or metal screwed to the

Long Span Beam chords to produce zero-slip connections for optimised deflection performance.

Structure Bracing

Extending the performance benefits noted with fabricated trusses another new application which exploits the advantages of the hollow-flange Long Span Beam is that of plan bracing in steel framed structures, primarily where superior strut action is required compared to other cold-formed options. Again the hollow-flange Long Span Beam is laid over (toes down) and screwed through the web into the bottom flange of crossing purlins.

CONCLUSIONS

The evolution of cold-formed hollow-flange beam technology as genuine Australian engineering innovation has recently focussed more on the necessary co-requisites of connections to widen the scope of suitable applications. Whereas cold-formed sections and metal screwed connections may have traditionally been associated with light-weight applications, the current form of hollow-flange Long Span Beam represents the most efficient configuration of steel material possible considering structural performance, manufacturing reliability and ease of construction including allowance for on-site flexibility. A range of high-capacity moment connections has been designed to be assembled on site using self-drilling metal screws and has been tested to prove capacity for incorporation into cyclonic region-sited portal frames. Other recent applications include fabricated trusses and structure plan bracing to improve upon previous limitations for cold-formed beam sections.

REFERENCES

Mahaarachchi, D. and Mahendran, M. (2005), "Experimental Study of LiteSteel Beam Sections", Proceedings of Australian Structural Engineering Conference, Newcastle, Australia, September.

Mahaarachchi, D. and Mahendran, M. (2005), "Finite Element and Analysis and Design of LiteSteel Beam Sections", Proceedings of Australian Structural Engineering Conference, Newcastle, Australia, September.

Mahaarachchi, D. and Mahendran, M. (2006), "Section Moment Capacity of a New Cold-formed Hollow Flange Channel Section", Proceedings of 18th International Specialty Conference, Recent Research and Developments in Cold-Formed Steel Design and Construction, Orlando, Florida, USA, October.

Mahaarachchi, D. and Mahendran, M. (2006), "Lateral Distortional Buckling Behaviour of a New Cold-formed Hollow Flange Channel Section", Proceedings of 18th International Specialty Conference, Recent Research and Developments in Cold-Formed Steel Design and Construction, Orlando, Florida, USA, October.

Yang, D. and Wilkinson, T. (2005), "Bearing Tests of LiteSteel Beams (LSB)", Proceedings of Australian Structural Engineering Conference, Newcastle, Australia, September.

Wilkinson, T., Liu, P., Magpayo, J. and Nguyen, H. (2006), "Increasing the Strength and Stiffness of Cold-Formed Hollow Flange Channel Sections for Web Crippling", Proceedings of 18th International Specialty Conference, Recent Research and Developments in Cold-Formed Steel Design and Construction, Orlando, Florida, USA, October.