Terri Meyer Boake

Branching Out

BY TERRI MEYER BOAKE

Hollow steel castings help bring an exposed structural steel "tree" to life on a Canadian university campus.

TUBE-TO-TUBE CONNECTIONS, PARTICULARLY INVOLVING ROUND SECTIONS, ARE A POPULAR CHOICE WITH DESIGNERS. From the architect's perspective, round sections are desirable because of their clean appearance and their indifference to apparent orientation. Engineers like tubular members (HSS and steel pipe sections) for their efficiency; tubular structures provide a higher strength-to-weight ratio than wide-flange sections. And then there are the cost savings, thanks to a reduced surface area for paint or intumescent coatings.

Typically, when round sections have been selected, the inference is "Architecturally Exposed Structural Steel". But for all its benefits, this designation carries a complete set of additional baggage insofar as detailing, fabrication, erection, and finishing are concerned.

Fabricators must come up with connection details that are as clean and potentially seamless as envisioned by the architect; provide the strength and efficiency expected by the engineer; meet AESS requirements; and are able to be fabricated and erected in an economical manner.

Thankfully, fabrication methods have progressed significantly due to advances in computer numeric control (CNC) processes. But even if complex tube-to-tube connections can be made more accurately and more cleanly, they still exhibit geometric characteristics that may be too overwrought in appearance for some architectural applications.

Steel castings, however, can be used to solve complex tube-to-tube geometries while providing a solution that is potentially both technically and aesthetically superior. The use of castings to connect round tubular members is by no means new. But where numerous European buildings have employed castings, North American applications are rare.

Planting the Acorn

Because research institutions are known for helping to craft the future, perhaps it's fitting that one of the earliest casting applications on this continent is at a university. Phase one of the University of Guelph Science Complex in Guelph, Ontario, Canada is a 350,000-sq.-ft building with a triangular-shaped connecting atrium at its center, the focal point of which is a steel "tree" structure. Envisioning supporting structures as trees has its origins in the designs and load transfer mechanisms of Gothic cathedrals, which use compression to direct the forces through the stone pieces and into the foundations. In the case of the Science Complex atrium, the tree structure was to be fabricated from round tubular steel sections, prompting it to act more like a space frame. The upper branches of

Walters, Inc.

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The castings are prepped for connection to the tubes at Walters, Inc.'s fabrication shop (left). A top view of the casting, showing the beveled edge, collar, and alignment guide plates (right).

the tree carry the loads from the grid-like wide-flange framing system that supports the atrium roof, down through its tubular trunk to the concrete foundation below. This type of geometry, in its tree-like stretch, creates large eccentric forces that put significant moment stresses into the nodes connecting the branches.

The design of the nodes flowed from the architect's vision to create the tree-like exterior geometry. The wall thicknesses of the connectors were optimized to be both safe and economical, and the castings were determined to have superior performance characteristics if cast hollow (solid castings are sometimes preferred in seismic zones). It was deemed essential that if tested to failure, the node should be stronger than the tubular branches. In testing the node, short sections of pipe were added to the casting to simulate more closely the effect that the connection and transfer of the load to the branches would have on the material stresses.

Cast steel exhibits isotropic properties, making it quite suitable, in the case of these extremely eccentrically loaded nodes, for transferring forces through the connection in a reliable manner—i.e., being able to resist shear, moment, and torsional stresses. It accomplishes this by working the geometry as a function of variations in the wall thickness, independently of the finished form of the exterior. Unlike fabrications made from tubes or plates, the interior dimensions of the void in a casting do not have to match the exterior form of the object.

The steel specified for the tree casting had to meet ASTM A27 Grade 70/40, with a modified chemistry to ensure that it could be welded to the pipe branch with minimal preheating and would require no post-weld heat treatment (stress relieving). Although the casting would be shop welded and finished to one end of each branch/trunk, site welding would be required for the opposite end.

While site conditions would make both pre- and post-heating difficult, weldability was improved by specifying a lower carbon and silicon content, eliminating the need for preheating. The casting steel's minimum yield strength was to be 275 MPa. Instead of using regular HSS sections, pipe was selected for the project due to properties that were more closely aligned with those of the casting.

The key requirements included in the bid for the node fabrication included:

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The completed steel support tree is the centerpiece of the atrium at the University of Guelph Science Complex.

- Patterning, heat dissipation analysis, stress relieving, and all other activities inherent to the steel casting process.
- Surface finish comparable to that of the seamless steel pipe to which it would be attached. This was crucial to achieving an AESS 4 Category in terms of the ultimate high-gloss surface finish to be applied. (For more on Canadian AESS requirements, see "A Categorical Approach," 04/08, p. 43.)
- Non-destructive evaluation of each casting, including 100% ultrasonic testing as a minimum. Acceptance criteria to be as per CSA W59 Clause 11.
- Dimensional verification that the casting and machining complies to the drawings, with tolerances of +/- 3 mm (0.12 in.) on diameter of cast surface.

Growing the Tree

The erection of the tree began with its "trunk," which included a series of welded plates that created a flare at the base, increasing its diameter and connection to the foundation. The 610-mm-diameter (24-in.) steel pipe trunk branches initially into four 406-mm-diameter (16-in.) seamless steel pipe branches via the main casting. These in turn branch through the secondary castings to form fourteen 273-mm-diameter (8-in.) branches—two sets in clusters of three and four branches. Each of the upper 14 branches terminates in a hinge connector, where each supports the steel wide-flange roof beam grid. The project included five castings to resolve the various branching conditions. The main casting weighed about 1,080 kg (2,381 lb) and measured about 900 mm (3 ft) in height and 1,200 mm (4 ft) across. Its wall thickness varies but is in the range of 65 mm (2.55 in.). The secondary set of four castings that branch into three or four limbs weighed about 500 kg (1,102 lb), were 640 mm (2 ft) tall and 1,000 mm (3.3 ft) wide, and had a wall thickness of about 40 mm (1.6 in.).

A cage of temporary steel was erected around the base column to provide support for the branches as they were erected. Until the welding of the pipe-to-casting was complete, the branches could not be self-supporting. The temporary support framework also provided shoring for the wide-flange roof grid. This construction sequence was necessary in order to allow the upper branches to be erected last and to allow the slotted hinge connections to slide easily into the mates already in place on the underside of the wide-flange sections.

The pipe-to-casting connection relied on the addition of a sleeve, inserted inside the casting, as well as paired plates, also inside the casting, that would help gravity-guide the branch pipe sections into proper alignment during erection. Because the final finish on the members was to be high-gloss, great care was taken not to damage the members during erection. Canvas slings were used for lifting, and pads were placed in the V-shaped rests for the branches to ensure against damage. The fabrication of the end connectors was performed to a high level of precision, with all marks and welds being ground completely smooth prior to priming.

Ostensibly Seamless

What makes the final resolution of this particular project, and its tube-to-casting connections, unique is the way in which the transition between the elements was made to appear completely seamless. Multiple passes of welding were used to completely fill the V-shaped gap in the connection between the pipe and casting. This was subsequently ground completely smooth, prior to accepting the final finish. The extra effort to detail and fabricate this connection speaks for itself, as the resulting structure exhibits an elegance and lightness that uses this combination of HSS and castings to the best advantage. MSC

James Bowes

Airport Support

The European precedent for this particular tube-to-casting connection form can be found in the forest of steel trees that comprise the exposed structural system for Stuttgart (Germany) International Airport, Terminals 1 (1991) and 3 (2004). In this application, the main trunks have been fabricated from four round tubular steel columns rather than one. The cast steel nodes are detailed with a pronounced reveal at their top and bottom extremities, thereby accentuating the material and geometric differences of the systems.

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