conference preview

STEEL CASTINGS IN ARCHITECTURE: DO YOU KNOW HOW TO DESIGN THEM?

Knowing the basics of steel castings can go a long way toward helping you incorporate them into a project.

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ALL STEEL IS CAST.

The ability to melt and cast steel was critical to the industrial revolution and has helped create the modern infrastructure of today's world. Some steel is cast as a simple ingot and then rolled in a mill to its final shape. In modern mini-mills, steel scrap is melted in electric arc furnaces and continuously cast into a bar for rolling into structural shapes like wide-flanges. When it comes to structural steel castings, they are made in the same type of furnace and from the same scrap, but from there they are poured into molds and made directly into the final shapes for specific products.

Where rolled products like wide-flange shapes offer advantages in terms of strength, standardization and efficiency in both cost and design, steel castings provide enhanced flexibility of geometry and the ability to achieve custom shapes. And while steel castings can provide any geometry imaginable, their advantages are even more rewarding to engineers and architects who understand the casting process and the ins and outs of incorporating them into a design.

Castings in Codes

With steel castings, design freedom is greatly enhanced. However, a consequence of geometric freedom is that the typical construct of the AISC *Specification for Structural Steel Buildings* (ANSI/AISC 360)—i.e., prescriptive, closed-form equations for structural member capacity based on sectional analysis—cannot always be applied. Sectional analysis works well for long, slender elements like beams, braces and columns. However, steel castings are typically used at connection points and, given their nonuniform shaping and proportions, they are usually more appropriately considered "disturbed region" structural bodies. As such, the 2D CAD platforms and frame-based structural analysis tools often employed by structural design firms are inadequate for casting design. Rather, 3D solid modelling coupled with finite element analysis is necessary to develop and communicate the casting's geometry and to assess the internal stresses within the bodies of steel castings. From there, engineering judgement, together with a sufficient understanding of casting manufacturing and the structural efficacy of cast steel, is necessary to determine whether a casting's design is adequate.

Castings are addressed in the *Boiler and Pressure Vessel Code* (B&PVC), which was developed by the American Society of Mechanical Engineers (ASME) in response to several serious boiler explosions in Massachusetts. ASME published the first edition of the ASME Boiler Code in 1915 to avoid these explosions. The B&PVC is constantly updated to give guidance on materials and design properties for pressure vessels, and steel castings are included in this code with other steel products like steel pipes, plates and forgings. For the most common alloy (carbon steel), castings are designed using the same properties as rolled products or forgings and must also be qualified for welding per B&PVC, Section IX. Castings designed under this code can be designed assuming the same mechanical properties allowed for rolled shapes of the same alloy grade and welded with the same



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▲ A universal pin connector with an architectural taper.

▲ Custom cast steel nodes for an AESS application.

procedure. In addition, AWS recognizes steel casting grades as being compatible in welding with other alloys in the same group, though AWS does not list any cast steel grades as prequalified base metals in AWS D1.1: *Structural Welding Code*.

One important issue that is not well covered in existing design guides or codes for castings is the fact that the structural efficacy of cast steel material is a function of not only the material's chemistry, heat-treatment, thickness and shape, but also its soundness. The quality of cast steel material is assured through the stipulation of non-destructive examination criteria, which establishes the maximum allowable indication size as identified by various testing techniques (visual, liquid dye penetrant, magnetic particle, ultrasonic and radiographic). There is a correlation between indication size and a material's structural performance, but this correlation is not well understood by those without experience in the destructive structural testing of steel castings.

From a commercial and contractual perspective, to enable a steel foundry to quote on and produce castings, shop drawing-level casting drawings are required, along with a casting production specification that outlines foundry qualifications, quality control and assurance, material grade, non-destructive examination requirements for both the first article and production components, surface quality requirements, dimensional tolerances and machining requirements (if any).

Castings in Construction

There are two types of castings that are specified in building construction: standardized and custom-designed. Standardized castings are more commonly thought of as products than as castings and are offered by various manufacturers. There are a variety of standardized castings available for a wide range of uses, from connectors that simplify and lower the cost of seismic-resistant construction—like the AISC 358-listed (*Prequalified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications*) Kaiser Bolted Brackets for special moment resisting frames or the ICC-listed Cast Connex high-strength connectors for special concentric braced frames—to those intended for architecturally exposed structural steel (like Cast Connex universal pin connectors or architectural tapers) to those used in conjunction with steel rods and cables (such as those provided by Ronstan and others).

Overall, standardized castings are easily specified. Because they are standardized, their geometries and their strength capacities are typically tabulated by the product supplier, and the products themselves are readily available. Most product suppliers also offer CAD assets and specification language, the provision of which simplifies the specification of these components in contract documents. Furthermore, as the products are supplied by known manufacturers, fabricators pursuing a project where the components have been specified know whom to contact for pricing during bidding and are able to leverage the supplier's technical support teams should questions arise during fabrication or erection.

Conversely, custom-designed castings must be conceived, engineered, detailed and manufactured on a project-by-project basis. There are a number of commercial and technical barriers to a more widespread use of custom castings in the building construction industry, one being a lack of design guidance for castings for use in building structures.

For these reasons, in nearly all successful modern implementations of custom-designed steel castings in building construction, the structural engineer of record has delegated the engineering and detailing of the castings to the casting supplier. In these cases, contract documents clearly call for the use of a casting, show the casting's general configuration and out-and-out dimensions and also indicate the loading that the casting must be engineered to resist. A specification that clearly dictates the structural and architectural performance requirements of the castings, and which clarifies the roles and responsibilities of the casting supplier and the steel fabricator, should also be provided. This then leaves development of the detailed casting shop drawings and the production specification (including the stipulation of material grade, non-destructive testing, dimensional tolerances, etc.) to the casting supplier.

An additional recommendation for structural engineers interested in incorporating castings into a design is to speak with a casting supplier in advance of specification. The supplier's input into the general configuration can produce a buildable, cost-

A closeup of a single turnbuckle casting on the San Ysidro Land Port of Entry project.

effective solution. Experienced casting suppliers can offer insight on how the freedom of geometry offered by castings can best be leveraged to address design or constructability challenges and assist the design team in understanding the value and economy—as well as attractiveness—that castings can offer to the project as a whole.

Successful Implementation

The recently constructed Northbound Primary Inspection Canopy at the San Ysidro Land Port of Entry successfully implemented numerous castings both of the standardized and customized variety. The thin-profiled ETFE (ethylene tetrafluoroethylene) canopy is supported by a network of 57 cables and three steel and concrete masts.

The sockets at the ends of each cable are themselves steel castings; each socket was part of the cable assembly provided by the cable supplier. Thus, there are no less than 114 standardized castings incorporated into the project.

One of the most unique and challenging connections occurs on each side of each mast, where five cables, ranging in diameter from 2¾ in. to 4 in., intersect and splay off in different trajectories, all at a point in midair approximately 15 ft to the side and 20 ft above the canopy plane. Several early concepts were sketched for these connections, which were dubbed "the nodes." These initial concepts considered steel plates welded together with pinned end fittings, but none proved elegant or easy to conceive due to the unique trajectories of the intersecting cables, thus fortify-

Castings 101

Steel castings are made by tooling forming a cavity in a chemically bonded sand mold. This tooling must be extracted from the mold when the chemical binder sets, which requires a modest draft angle around 1% from the mold surface. This draft can be removed from the resulting casting by subsequent machining but is a factor in the production process. Features that require "backdraft" or internal cavities can be made by producing a core, which is a separate sand piece that forms the desired feature. While cored features add cost to castings (the cores must be tooled, produced and set in the mold), the ability to make complex internal passages is a major advantage when it comes to intricate designs. A casting's design must also compensate for the shrinkage of the alloy during solidification to avoid center-line porosity in isolated thick sections.

Tooling for a universal pin connector casting.

ing the decision to use custom steel castings for the connections.

This decision was made very early in the design process, which proved vital to the successful implementation of the castings. For starters, it allowed the design team plenty of time to consult with steel casting suppliers as well as engineers that specialize in designing castings. During these consultations, proposed geometries and forces were shared by the design team to ensure that the proposed design concept could be constructed as conceived. Other topics of discussion included appropriate material specifications, non-destructive testing, mock-ups and corrosion protection to further validate that the desired structural and aesthetic aspects could be achieved.

The early decision also allowed the general contractor time to perform early budgeting work for the nodes, as well as provided ample time and information to factor bid award, design, manufacturing, shipping and installation of the castings into the construction schedule. ■


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The Northbound Primary Inspection Canopy at the San Ysidro Land Port of Entry uses more than 100 standardized castings.

This article is a preview of Session E14: "Steel Castings in Architecture—Do you Know how to Design them?" at NASCC: The Steel Conference, taking place March 22–24 in San Antonio. Learn more about the conference at ***www.aisc.org/nascc****.*