Cast Steel Hardware

The Use of Cast Steel Fittings in Heavy Timber Construction

By David L. Kufferman, P.E.

The historic town of Kent, Connecticut, is a destination for those who seek the picturesque charms of its colonial architecture, as well as its discrete sense of urbane sophistication. A number of the original wood structures along Route 7, which serves as Kent's main street, are now occupied by art galleries and restaurants. Visitors stay overnight in fine old houses that have been converted into quietly luxurious bed-and-breakfasts. The popularity of the town has driven a local boom in low scale commercial development. The most successful of these projects have added interest to the town by respecting the scale of the old structures while avoiding phony 'Ye Olde Kent' theme park stylistic interpretations of the past.

Typical truss half sub-assemblies. Note symmetric geometry. ©Bridgeport Design Group

The 'Depot' building that is the subject of this article is part of one such development, located in a parcel of land behind the original row of wood buildings along Route 7. This building is a 6900 square foot store. It was important to the architects, Bridgeport Design Group, to maintain the feel of the place by conceiving the building in timber. The presence of other traditional heavy timber framed barns on the site intially suggested a similar approach to frame the roof structure. As the design evolved, it was decided that it was important to do something different with timber than traditional mortise-and-tenon joinery. The idea of using cast steel fittings to join the timber elements came to the fore.

Typical truss top chord end fitting. ©Bridgeport Design Group

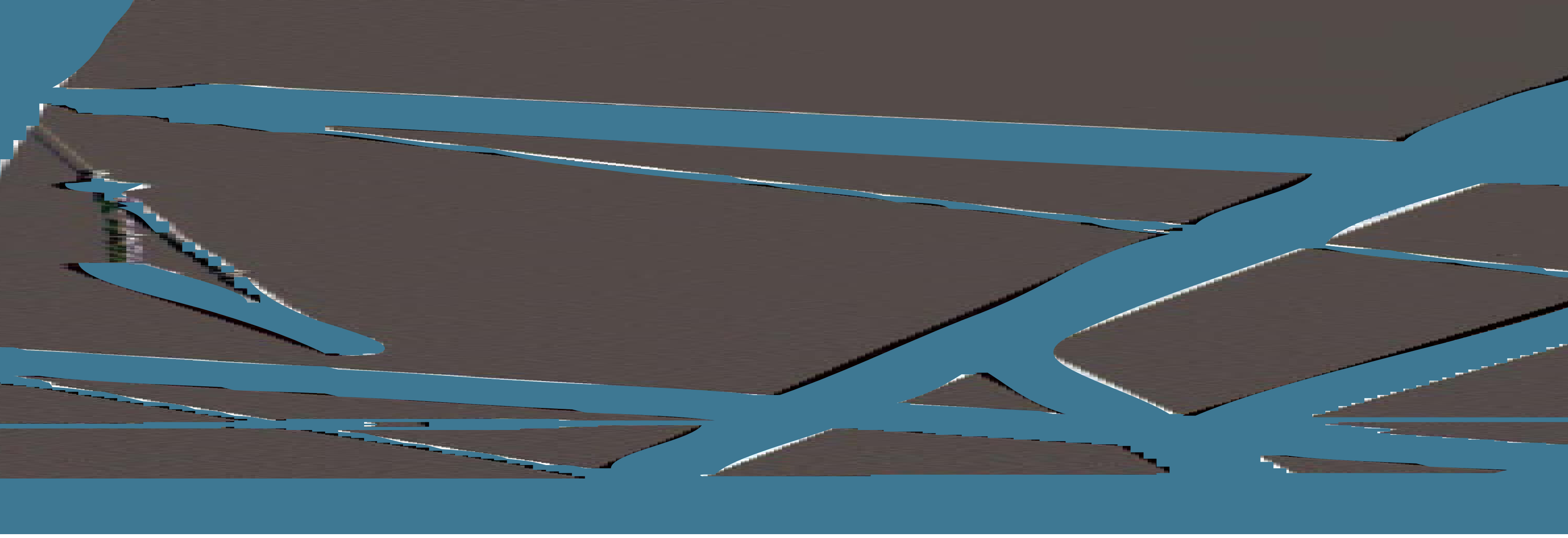
A Brief History

Beginning in the late 18th century, during the Industrial Revolution, cast iron, and later, cast steel, became widely used in construction. The first notable example was the Coalbrookdale bridge in England, which used detailing similar to mortise-and-tenon construction to connect the cast iron arch sections. In the mid 19th century, the Crystal Palace, also in England, took advantage of repetitive mass-produced cast iron elements to create a vast exhibition space. Toward the end of the 19th century, construction methodology adapted to the use of hot-rolled steel shapes, which became widely available and were much more economical to produce than large castings. Steel connections used hot-rolled plates and angles to join I-beams together with rivets. The use of steel castings became less frequent, mostly limited to its use for special connections such as arch bearings. As electric arc welding came into wide practice in the 20th century, many such connections that would previously had been cast could now be economically fabricated from steel plates, welded together. The use of cast steel in construction is therefore rare today, with some notable exceptions such as the Beaubourg Center in Paris from the 1970's. Cast steel is far from a lost art, however. Around 300 steel foundries in North America produce approximately 1.6 million tons of steel castings per year for use in railroad equipment and other kinds of heavy machinery.

Casting Process

While there are many techniques used in casting steel, all begin with the making of a pattern. The pattern looks like the final casting, with the addition of sprues, which create channels for the molten steel to flow into the mold, and risers, which create reservoirs of molten metal over sections of the casting which are expected to cool most slowly. The pattern can be a reusable wood, metal or plastic piece, or it can be wax or foam, which are lost in the casting process. For a relatively low production run, such as for this project, a wood or plastic pattern is often most economical. The advent of computer numeric controlled (CNC) milling equipment has greatly reduced the labor in the production of patterns molded from plastic.

Typical column head fitting. ©Bridgeport Design Group



The pattern is put into a box, and sand is rammed in. When the pattern is removed, its impression in the sand creates the mold. There are generally two such boxes, the bottom of which is called the drag, and the top one, the cope. If the casting is to contain internal voids or passages, then core boxes are used to create sand cores, which are also placed in the mold. Once the cope and drag are assembled, the molten steel can be poured in. After the metal has solidified, the casting can be removed. The sprues and risers must be removed, and other machining operations, which may be required, are performed to obtain the finished part. Heat treatment or other metallurgical processes may follow. The part should be subjected to an appropriate nondestructive testing procedure to ensure its soundness.

Advantages of Casting

For the architect, the advantage of using a casting for an exposed element is its potential for sculptural beauty. Almost any shape is possible, subject to the limitations of the specific casting process. A fabrication of welded plates can never approach the tactile quality of a casting. Castings do not have the problems of residual stresses or warping that can result from welding.

From an economic point of view, a cast part that is to be used repetitively can potentially be considerably less expensive than a welded fabrication, since the cost of a single pattern becomes less significant as the number of

Roof truss support fittings at 3 dimensional truss support.

casting cycles increase. In addition, the labor involved in casting a part is much less than welding a part up out of plates, especially when relatively complicated shapes are involved. The designer should be aware that such savings may be reduced by post-casting processes that may be required, such as heat treatment and machining.

Assembled roof trusses in place, showing supports. ©Bridgeport Design Group

Design for Casting

As thicker parts of the casting take longer to cool and solidify than thinner sections, there is a tendency for voids to form in thicker areas as the metal cools and shrinks. This problem is solved in the foundry by the use of risers, or reservoirs of molten metal, which are located over such thicker areas, and are purposely designed large enough to solidify last. The risers provide feed metal to keep such voids from forming. Still, there can be local inconsistencies in material properties in such thicker areas, and the riser must also be removed from the part. To reduce the likelihood of such problems, good practice is to design the casting with as uniform a thickness throughout as is practical. Fillet radii at T-junctions should be kept reasonably small to avoid the creation of thick zones, which might result in formation of voids.

To keep the cast part economical, it should be designed as simple to be cast. Ideally, the part should be conceived as two halves, each of which can be removed from the casting sand with no interference. Elements of the casting which are perpendicular to the parting plane must have a slight taper, or draft, to facilitate removal.

The design engineer should not feel intimidated by the many technical issues relating to the casting process, as this is the expertise of the foundryman. The responsibility of the design engineer is to size the part according to the allowable stress levels of the material, no different than it would be for a welded fabrication. Fairly simple parts can be engineered with hand calculations. More complex shapes are likely to require finite element analysis.

Specifications

For carbon steel castings that require up to 70 ksi tensile strength, the applicable standard is ASTM A27/A27M, *Standard Specification for Steel Castings, Carbon, for General Application*. For higher tensile stresses, the governing standard is ASTM A148/A148M, *Standard Specification for Steel Castings, High Strength, for Structural Purposes*. These standards specify types of heat treatment, chemical composition and tensile properties. There are other standards which cover other metals and alloys. In all cases, a tensile test is required for each heat. For high strength materials, a Charpy impact test may also be required. Testing methods are covered in ASTM A370, *Standard Test Methods and Definitions for Mechanical Testing of Steel Products*. The actual cast parts should be subject to an appropriate non-destructive testing procedure, such as magnetic particle, x-ray or ultrasound, in addition to close visual inspection, to ensure there are no cracks or voids.

An excellent reference for the design engineer is the *Steel Castings Handbook*, published by the Steel Founders' Society of America and ASM International, which covers all aspects of its subject in great detail.

Assembled roof trusses with purlins being installed. Note three cast fittings at ridge pin.

The 'Depot' Building

In plan, the 'Depot' building is essentially a rectangle, 122-feet long and 36 ½-feet wide, with another 36 ½-foot wide wing projecting 66-feet off one of its long sides, to form a sort of asymmetric 'T'. The roof structure over the selling floor was conceived as a series of trusses located on 12-foot centers, with a pin to pin span of 34 ½-feet. These trusses support 6x8 Douglas Fir purlins every 6 feet, which in turn support structural insulated panels (SIPs). The typical planar truss has 6x10 Douglas Fir rafter top chords, 1-inch diameter steel rod ties with clevis ends, and 5x5 Douglas Fir 'V' posts between them.

Under gravity loads, the timber top chord is naturally in compression, with the steel tie rods in tension. In order to avoid load reversals under wind uplift, the 10x10 columns were designed with fixed bases, making the overall structure redundant, so that the ties could be pretensioned against them. In this way, a level of tension is always maintained in the ties, even under uplift. Overall building stability under lateral loads is taken care of by the exterior walls, which were conventional 2x6 studs with plywood sheathing.

Completed store, open for use. ©Bridgeport Design Group

There are nine identical planar trusses, with a special three dimensional truss supporting the 36 ½-feet square section of roof where the wing crosses the main rectangle of the building plan. Each half of each typical planar truss is symmetric about an axis perpendicular to the midpoint of the top 6x10 Douglas Fir rafter chord, similar to a Fink truss. This means that the fittings at each end of each rafter chord have identical geometries, allowing four of the same fittings to be used for each typical truss. Other castings were used for the bases of the 'V' posts, for the 10x10 Douglas Fir column heads, and for the ridge beam connections. A total of 108 cast steel fittings were used in the building, using only five patterns. The timber elements are simply joined to the castings with bolts.

The casting material selected is a medium strength carbon steel equivalent to AISI 1522, quenched and tempered, having an ultimate tensile strength in excess of 72.5 ksi. This is a good general purpose grade of steel, being economical, easy to cast and to machine, readily weldable, and with good strength and ductility characteristics. The dimensions of the castings are such that stresses remained fairly low, so higher strength steel is unnecessary. Other 'one off', special connections were fabricated from welded ASTM A36 plate, since the cost of producing the pattern made less economic sense.

The pattern fabrication, casting and finishing operations were performed by the Gusstahl Lienen Foundry (GSL) in Germany. The patterns cost about $1200 each. The basic cost of the cast steel elements was about $3.10 per pound, including heat treatment and non-destructive testing. Including patterns, machining and other operations, the delivered cost of the castings worked out to about $21,700 or about $4.70 per pound in 2000.

Conclusion

The building is occupied by an outdoor sporting goods store. Since the building opened, many visitors have come in to the store, but not always to buy something. Many people come just to look at the architecture. The exposed structure is visually striking. The use of cast steel fittings to connect the timbers has added interest and refinement to the structure at a reasonable cost. Cast steel should be considered by the design engineer as a viable alternative to welded fabrications, not only for aesthetic reasons, but also for economy, especially when a particular part is used repetitively.▪

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The photographer for the Bridgeport Design Group photos is Keyvan Behpour, Kvon Photography, Bridgeport, CT. 203-336-3390. Mr. Behpour owns the photos jointly with Matthew Preston of Bridgeport Design Group.