Antiquated Structural Systems Series

Part 8

By D. Matthew Stuart, P.E., S.E., F. ASCE, SECB

This article is the eighth in a series that is intended to provide a resource of information to structural engineers for projects that involve the repair, restoration or adaptive reuse of older buildings for which no drawings exist.

The purpose of this series is to enable structural engineers to share their knowledge of existing structural systems that may no longer be in use, but are capable of being adapted or reanalyzed for safe reuse in the marketplace of today and the future.

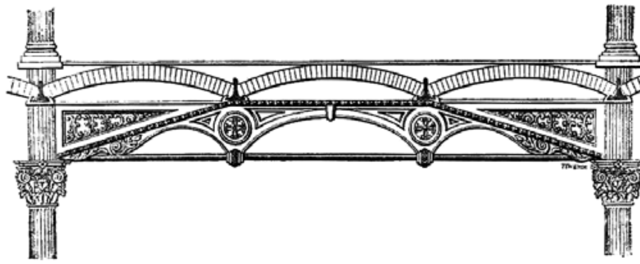

Figure 1a: Courtesy of Peabody Essex Museum.

Wrought and Cast Iron

Ferrous metals used in construction can be categorized into three principal iron-carbon alloys, based on approximate carbon content: wrought iron (0.020% to 0.035%), steel (0.06% to 2.00%) and cast iron (2% to 4%).

Wrought iron is almost pure iron and contains between 1% to 4% slag (iron silicate). The slag is not alloyed into the wrought iron, which gives the material its characteristic laminated (or layered) fibrous appearance. Wrought iron can also be distinguished from cast iron by its generally simpler forms and less uniform appearance.

Cast iron contains varying amounts of silicon, sulfur, manganese and phosphorus. Cast iron, while molten, is easily poured into sand molds, making it possible to create unlimited forms, which also results in mold lines, flaws and air holes. Cast iron elements are commonly bolted or screwed together, while wrought iron is either riveted or welded.

Wrought Iron

Wrought iron refers to ferrous metals that can be worked or "wrought" on an anvil, or shaped and forged in rolling machines. Wrought iron is tough and stringy, and has an elasticity that was conducive for use in bolts, beams and built-up girders. Wrought iron is also easily welded.

Until the mid-1800s, wrought iron in buildings was used primarily for tie rods, straps, nails, hardware or decorative railing and balconies. Around 1850, the structural use of wrought iron became more prevalent as rail beams, bulb-tees, channels and I-beams became commercially available.

When wrought iron was employed as tie rods, the material was typically used in conjunction with cast iron anchor plates shaped as stars, rosettes or an S. In built-up girders, wrought iron was also used in conjunction with cast iron. Initially, these composite built-up girders were constructed as bowstring trusses with an upper cast iron chord and a lower wrought iron tie rod (*Figures 1a* and *1b*). Later versions included perforated girders generally constructed with cast iron in the top three-quarters of the member and wrought iron in the bottom portion (*Figure 2*).

Figure 1b.

In 1854, the Trenton Iron Works manufactured the first rolled wrought iron beam in the U.S., a 7-inch-deep, bulb-tee rail beam. The following year, the Trenton Iron Works also manufactured the first I-beam in the U.S., the "Cooper beam", although I-beams had previously been rolled commercially in France in the 1840s. Prior to the development of the bulb-tee rail beam, wrought iron deck beams had been rolled for use in the shipbuilding industry, and prior to the development of the Cooper beam, channel beams had been manufactured. *Figure 3 (page 10)* shows the evolution of all of these rolled wrought iron sections.

Figure 2.

Rolled wrought iron beams continued to be used for several decades after the mid 1850s, even after structural steel became available. However, as the quality and quantity of available steel improved, the use of wrought iron gradually came to an end. In general, the use of wrought iron beam framing in conjunction with cast iron compression components lasted from the mid-1850s until the late 1890s.

The earliest known tabulation of wrought iron structural shapes was published by Carnegie Kloman and Company in 1873. The largest beam listed was a 15-inch-deep I-beam that weighed 67 pounds per foot. This publication is very rare, but an 1876 edition is available in the Library of Congress. The author was able to locate a digitized copy of the 1892 8th Edition of the *Wrought Iron and Steel Construction* manual (published by Pencoyd Iron Works of Philadelphia) on Google Book Search.

Material and design properties provided in the Pencoyd Iron Works manual indicate that the ultimate tensile strength of wrought iron was as high as

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50,000 psi. The allowable extreme fiber stress was indicated as 14,000 psi for wrought iron and 16,800 for steel. Limits for safe loads on wrought iron beams provided in the design tables include the character of the service load (i.e. static, fluctuating or impact) and extent of lateral support.

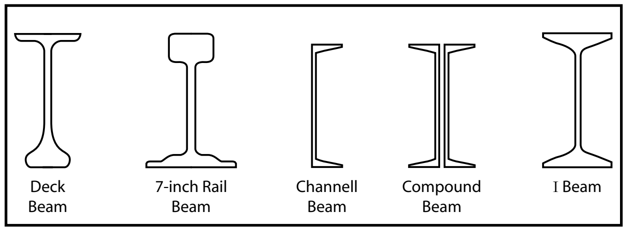

Figure 3.

Cast Iron

Cast iron is very hard and resists compression forces very well but, because of the carbon content, it is also very brittle. Because of this, cast iron was used primarily for the construction of columns and compression elements of composite wrought iron girders.

Shortly before the 1800s, cast iron was used for columns in multi-story, wood-framed factory buildings in England. Cast iron was used because of its strength and perceived fire resistance. The combination of cast iron columns and wood framing continued to be widely used for the next half century; however, by the mid-1800s, wrought iron beams began to replace wood.

Cast iron used for structural purposes during the 1800s typically had a compressive strength of 80,000 psi. Although there was no clearly defined yield point of the material, the tensile strength ranged between 10,000 and 15,000 psi. The brittleness of the material, in conjunction with its inherent manufacturing flaws, made cast iron highly susceptible to tensile failures; therefore, for most of the 1800s, cast iron was only used to resist compression forces.

In the mid-1800s, cast iron began to be used for the construction of the front façades of buildings (*Figure 4*). The cast iron façade was used for both decorative and structural purposes, as the adjacent floor framing was supported by the cast iron. Cast iron was also used in conjunction with masonry façades as exposed decorative/structural window and door lintels (*Figure 5*), as well as for balconies and verandas. Many of these types of exterior structures still exist today, thanks to ongoing painting and maintenance efforts.

Rolled Sheet and Corrugated Iron

The first sheet iron in the U.S. was rolled in Trenton, New Jersey in the late 1700s. Sheet iron was used as flooring and roofing material up until the end of the 1800s. Corrugation of sheet iron, patented in England in 1829, was first used in the U.S in the 1830s. Corrugated sheet iron was typically painted with pitch, which was later replaced by galvanizing.

Corrugated iron was also manufactured in arched sheets for floor construction. Typically, the ends of the arched sheets were supported by the bottom flanges of wrought iron I-beams, with concrete then cast on top of the sheets. This type of construction replaced brick arch floor construction, which had been used extensively with wrought iron I-beams previously.


Figure 4.

Building Construction Overview

The use of prefabricated cast iron façades, wrought iron beams and cast iron beam and column components served as a forerunner to the multi-story, steel-framed buildings of today. In addition, specialty wrought iron structures constructed in New York City in the mid 1850s, such as firewatch towers and gunshot manufacturing towers that employed drilled and socketed rock foundation anchors and infill masonry walls, served as a precursor to early steel skyscraper construction.

It is also interesting to note that the manufacturers of cast iron façades and other exposed components often identified the source of the material by either affixing foundry labels to the building or by using trademarks in the ornamentation of the decorative portions of the façade. This information can sometimes be used to assist in the structural evaluation of an existing building.

Deterioration

Iron oxidizes rapidly when exposed to moisture and air. The product of the oxidation process is rust. The minimum relative humidity to promote "rusting" is 65%, but humidity levels lower than this can cause oxidization in the presence of pollutants. In addition, if chlorides are present, the corrosion process can become accelerated. Once a film of rust starts to develop, the natural porosity of the corrosion byproduct tends to act as a reservoir for moisture, resulting in even further acceleration of the deterioration process.

Cast iron will develop a somewhat protective surface scale, which makes it slightly more resistant to corrosion than wrought iron; however, it is still recommended that cast iron be painted to prevent rusting. Iron can also be corroded by acids, magnesium and some sulfur compounds. Dissimilar metal galvanic corrosion can also occur between iron and copper, chromium, lead, stainless steel and brass. In general, wrought iron rusts more rapidly than cast iron. However, because of the slag content of wrought iron, the material is more resistant to progressive corrosion than cast iron.

Another type of deterioration common to cast iron is graphitization. This condition can occur in the presence of acidic precipitation or seawater. As the iron corrodes because of exposure to these types of environments, porous graphite residue is impregnated within the surface corrosion byproduct. The cast iron element retains its original appearance and shape, but becomes gradually weaker internally. Graphitization typically occurs when cast iron is not painted for extended periods or where the sealant has failed at the joints between adjoining components. This condition can be identified in the field by scraping the surface of the cast iron with a knife to see if deterioration of the iron is revealed beneath the surface.

Repair and Restoration

There are a number of methods available to remove paint and corrosion from cast and wrought iron, including manual scraping, chipping or wire brushing; low-pressure grit or sandblasting; flame cutting; and chemical removal.

Once any existing paint and corrosion have been removed, the most common method of protecting cast iron from further deterioration is to repaint the surface. Prior to repainting, it is first necessary to prepare or repair the surface. Proper preparation includes elimination of crevices or pockets that can collect moisture to prevent accelerated deterioration; removal or smoothing of sharp corners to prevent accelerated paint failure; hermetical sealing of hollow section to prevent moisture intrusion and freeze/thaw damage; filling of joints, cracks and bolt or screw holes with sealant to prevent moisture intrusion and freeze/thaw damage; and, following the paint manufacturer's specifications.

Figure 5.

In all cases, it is recommended that a test area be used to confirm that the selected cleaning, preparation and painting techniques are effective prior to attempting to remediate the entire restoration area. It is also recommended that sheltered areas such as eaves, where evaporation of moisture can be inhibited, be coated with additional layers of the selected paint or coating.

Additional protection and repair procedures can also include plating with metals, or cladding with plastic or epoxy. Sections or entire portions of a significantly deteriorated area may be replaced with glass fiber reinforced concrete (GFRC), fiber reinforced polyester (FRP) or aluminum.

If additional structural retrofitting is required as a part of an adaptive reuse project, the following remedial work should be avoided if at all possible: welding, burning of holes, the use of impact drills, high strength bolts, and filling of voids or posts with concrete.▪

*D. Matthew Stuart, P.E., S.E., F. ASCE, SECB is licensed in 20 states. Matt currently works as a Senior Project Manager at the main office of CMX located in New Jersey, and also serves as Adjunct Professor for the Masters of Structural Engineering Program at Lehigh University, Bethlehem, PA. Mr. Stuart may be contacted at **mstuart@CMXEngineering.com**.*

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