Steel Castings in Architecture and Engineering

Hans Schober

Hans Schober, Dr.-Ing., is a senior engineer and partner with Schlaich Bergermann und Partner in Germany. His practice includes design and detailing of various pedestrian bridges, railway bridges, multi-story buildings and glass structures at home and abroad.

The second half of the 18th century saw the advent of widespread use of cast iron as a building material. However, its brittle quality made it safe only for structural elements under compression.

The world's first cast iron bridge built in Coalbrookdale, England (1777–1779) was reminiscent of stone arch bridges, but required less material due to the high compression strength.

In New York City's Soho, there are still a number of 19th-century buildings with cast iron supports, with the buildings' cast-iron façades carrying the loads.

The development of steel production technologies, the welding technique and rolled steel sections diminished the importance of cast structural elements. Nonetheless, the last few years have brought a reversal back to castings in structural engineering.

The new, low-alloy and low-carbon materials used in today's castings are a far cry from the traditional perception of cast steel as a brittle, porous, impossible-to-weld material to be used only under compression. This new material meets all quality requirements, such as strength, viscosity, weldability and corrosion resistance.

Cast steel permits beautiful, free-flowing forms as well as the manufacture of even the most complicated nodes with numerous HSS entering from any direction. It is possible to perfectly adapt the shape of the node and the wall thickness to the flow of forces from the entering HSS. Since the material characteristics of cast steel are not affected by the direction of stress, they are especially well suited for nodes stressed three-dimensionally.

With cast steel it is possible to create flowing forms without any sharp edges or leaps in the cross-section, thus avoiding stress concentrations and notch effects. This favorably affects fatigue behavior.

In cast steel nodes the welded seams between node and HSS can be placed away from the node core to the less stressed HSS and arranged there, perpendicular to the axis. This results in a simple, easily accessible, welded seam. This also avoids secondary stresses in the node due to welding.

The first cast iron bridge, Coalbrookdale, England (1777–1779).

Cast iron façade, Haughwout House, New York.

HSS cast steel node.

Roof for the 1972 Olympics in Munich, cast steel nodes for cable coupling. a) Roof; b) Foam model; c) Final installation of cable coupling.

Ice skating rink in Munich, 1985, steel casting for cable saddle

Left and above. Courtyard roof of Deutsche Bank, Berlin with cast stainless steel cable clamps

Water rolls off well-ventilated and rounded cast-steel nodes, reducing corrosion and improving accessibility for inspection and maintenance.

Steel castings possess technical advantages with regard to static and dynamic strength, accessibility of welded seams, simplicity of dimensioning, maintenance, and service life. In addition, their appearance inspires trust. These facts become more obvious as the number of tubes entering one node from different directions increases.

PERSONAL EXPERIENCE WITH CAST STEEL NODES

Cable-Net Structures

The cable-net roof for the 1972 Olympics in Munich, Germany caused a virtual renaissance for cast steel. A multitude of nodes had to be built as compact and as durable as possible for the coupling of locked coil cables, bundles of strands and HSS supports of various geometries. Even now, more than 30 years later, these cast steel elements are in mint condition without any flaws.

The ice skating rink in Munich, completed in 1985, profited from this previous experience.

Glass Structures

Glass structures usually require delicate, well-designed elements. The design generally calls for cast stainless steel with different finishes.

The pillow-type roof structure (courtyard roof) of the Deutsche Bank in Berlin vaults while the diagonal cable net swerves downwards. The vertical posts with the stainless steel balls at both ends rest in cast ladles, permitting random spatial angles to the grid shell and the cable net with a single element. The milled ball has a polished finish and the cast ladle is blast with glass spheres.

The roof of the Zeughaus in Berlin (Architect I. M. Pei) is a filigree shell. Diagonal cables transform the glazed quadrangles into triangles required for shells. Due to the complicated shape, cast steel GS 20 Mn 5 V is used for the million node.

In 1992 a very light cable net wall was developed for the Hotel Kempinski in Munich. The façade consists merely of a single-layer, plane, prestressed cable net with the glass panes intermittently attached to its nodes.

The cast stainless-steel mounting brackets are manufactured using ceramic moulds. They hold the glass panes at the four corners, requiring no drilling of the glass, and are clamped to the cables.

Since then, this minimized façade has been used several times, including the AOL Time Warner Building in New York City, although this application included different mounting brackets.

Cable net façade for the Hotel Kempinski in Munich with stainless cast steel corner patch plates and cable clamps.

Cable net wall for the AOL Time Warner Building in New York with stainless cast steel corner patch plates and cable clamps

Forked supports for the VW-Skoda plant in the Czech Republic.

Top and above. Courtyard roof of Zeughaus, Berlin with cast steel nodes

Buildings

In many cases technical aspects rather than aesthetic ones prompt us to use steel casting.

Cast steel nodes are particularly well suited for HSS structures with several HSS meeting in one point.

In the design competition for the assembly-shop roof of the VW-Skoda plant in the Czech Republic, forked supports with cast steel nodes prevailed due to their light appearance.

The roof of fair hall 13 in Hannover, Germany is a traditional spatial truss spanning a rectangle of 225m x 120m. Here at least five, but sometimes as many as nine bars of different diameters are combined in the nodes. Cast steel nodes are an excellent solution for this problem. In order to keep the expenses for the model to a minimum, a modular construction system was used to develop basic structures. Their various attachments for diagonals and strut joints permit any possible joining scenario.

Pedestrian Bridges

Cast steel nodes also find various applications in pedestrian bridges. They are used above all for the cable saddles on the masts and the cable clamps of the main cable. Examples of this application are the Max Eyth See bridge in Stuttgart, Germany and the pedestrian bridge in Bayreuth, Germany.

The Ripshorst bridge, curved in plan, is supported by a single steel arch. A hanging model was used to determine its geometry. Due to the spatial curved arch, numerous V-shaped vertical struts of different geometries have to be connected with the arch using cast steel nodes.

With castings, the welded seams can be placed away from the node care to a less stressed position.

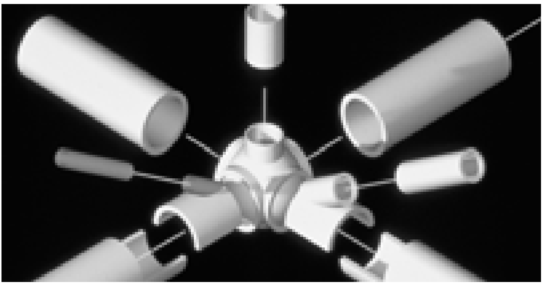
The module-type Expo-bridges in Hannover, carried by closely situated supports, rest on heavily rounded and defined cast steel elements.

There should be no reluctance to use rounded cast steel elements with stiffeners and varying wall thicknesses because in addition to structural and aesthetic benefits, their use can provide advantages for the casting process.

Highway Bridges

The Nesenbach highway bridge in Stuttgart rests on an HSS steel truss with a concrete slab and is supported by Y-supports. All nodes of the Y-supports and of the truss, including the connections to the concrete slab, are cast steel.

The Schattenring bridge in Stuttgart has its steel arch enter the concrete superstructure to optimize the arch rise. All HSS steel nodes, as well as the feet



Castings at the space truss of fair hall 13, Hannover, Germany 1998.

Above: Cast steel cable anchor for the Max Eyth See bridge near Stuttgart, Germany. *Below:* Pedestrian bridge in Bayreuth, Germany with cast steel cable clamps.

Railway bridge across the Humboldthafen.

and heads, are carefully designed cast steel elements.

Railway Bridges

In the heart of Berlin, near the government buildings, a new main train station, the Lehrter Bahnhof, is under construction.

At an elevation of approximately 10m, six tracks have to cross a distance of almost 1.000m, passing through the station and crossing the Humboldthafen basin attached to the river Spree.

At the center of the station building, all railway bridges are supported by forked-supports with an overall height of approximately 23m. They consist of four steel HSS with a diameter of 508mm each, dissolving into four three-dimensional forks at the top.

At the Humboldthafen the concrete superstructure is supported by a steel arch spanning 60m. The arch consists of thick-walled, seamless steel HSS with a wall-thickness of 100mm.

After intensive preliminary inspection, ensuring heat treatment and a final inspection in the work shop, the welded ends of the castings were machined. Proper machining and grove-weld backing is important under dynamic load because the quality of the weld root is a major factor in determining the fatigue category. It minimizes tolerances, facilitates the assessment (for ultrasonic testing) and provides controlled conditions.

For the Humboldthafen bridge, the weld ends were machined to compensate for the tolerances of the HSS and the casting.

The client, the Deutsche Bahn AG, made high demands as to the quality of the dynamically stressed castings. In addition to the limitation of carbon content, there was a strict limitation of the internal and external defects. Therefore, for all weld ends, defect acceptance level 1 applied. For any other area, defect acceptance level 2 according to DIN 1690 applied, though reducing the largest possible single defect and the largest possible total defect area to half of the stipulation in the code.

While there was no problem to meet defect acceptance level 1 for the weld ends, the foundry faced major problems meeting defect acceptance level 2, which could only be mastered with great efforts (if at all).

In the future it would be reasonable to adjust the quality requirements for the stresses in the casting, to define areas with different quality requirements, and to adapt the casting process.

For castings purely under static load, defect acceptance level 3 is sufficient, except for the weld ends.

All castings were submitted to a 100-percent surface crack inspection and to an ultrasonic inspection. In addition the quality inspector stipulated an x-ray test for 10 percent of the welded ends.

After being presented with all the contractor's test records, the quality inspector submitted the castings to another ultrasonic and surface crack inspection. He also examined the x-ray films of the contractor.

Defects could only be repaired with so-called shop welds after the consent of the client. For inadmissible defects, requests for allowances had to be submitted, which were either granted or dismissed after a lengthy procedure. In case of a dismissal, new castings had to be manufactured.

TESTS WITH CAST STEEL

Since this was the first application of cast steel nodes in modern railway bridge construction, the static and dynamic behavior of the cast steel welded to rolled steel had to be tested extensively. The following tests were conducted at the University of Karlsruhe.

Small specimen tests: Steel welded to cast steel plates with wall thicknesses of 25mm and 40mm.

Fatigue tests with cast steel HSS welded with a butt joint to rolled HSS with an outside diameter of 267mm and wall thickness of 20mm.

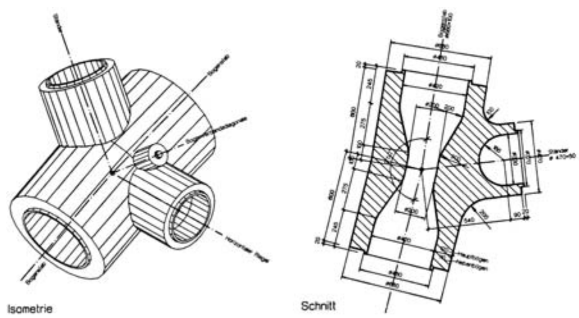
Tests with steel columns (full size testing): HSS with an outside diameter of 508-mm and 60-mm wall thickness, welded to cast steel nodes.

Fatigue tests with contact and butt joints (steel to cast steel) of the arch HSS: Thick-walled HSS with outside diameters of 660-mm and 100-mm wall thickness.

Diagnosis by sawing off the castings: Column foot with an outside diameter of 508mm, wall thickness 60mm. Arch node with an outside di-

Expo-bridge, Hannover, 1999.

Above and Above, right. Nesenbachtal bridge in Stuttgart, 1999.



Above, left: Schematic drawing of arch node. *Above, right:* Arch node with indicated defects.

ameter of 660mm, wall thickness 110mm.

Investigation of the mechanical properties of the castings in spatial directions.

Since the tests are published in [2] only the most relevant results will be given below.

The properties of GS 20 Mn 5 V derived from the static test are definitely comparable to that of ST 52 (S 355).

Both materials have a yield strength of around 360 N/mm², ultimate strength of about 550 N/mm² and elongation-at-fracture of about 30 percent, and they completely meet the standards.

The measurements of the absorbed energy also confirmed cast steel is a tough material.

Further tests with specimens showed virtually no dependency of the material properties on the stress directions (isotropic material) which is particularly relevant for three-dimensionally stressed nodes. At up to 200mm wall thickness, there was no distinct dependency on the thickness.

All the tests proved that welded connection between S 355 (St. 52-3) HSS and GS20Mn5V castings possess fatigue resistance corresponding to the welds.

This corresponds to a fatigue category $\Delta\sigma_c$ = 80N/mm² in the format of Eurocode EC3, valid without any further reductions for welded seams up to 60mm.

The weak-point of the fatigue strength was never the node itself but always the welded joint between the cast steel and the normal steel. ★

REFERENCES

[1] Schlaich, J., Schober, H.: Bahnbrücken am Lehrter Bahnhof in Berlin. Die Humboldthafenbrücke. Stahlbau 68 (1999; H. 6, S. 448-456)

[2] Schlaich, J., Schober, H.: Rohrknoten aus Stahlguss
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[3] Mang, S., Herion, S. : Guß im Bauwesen Stahlbau Kalender 2001; Ernst und Sohn

Above and below. Butt joint at HSS and machined weld ends