Slender lines shape the future in steel-bridge engineering

Neckar Bridge in perfect form thanks to LP plates from Dillinger

The new Neckar Bridge is both an iconic introduction to Stuttgart and, simultaneously, a pioneering engineering achievement. The four-track railway bridge over the River Neckar has its innovative design as a steel-sail bridge with a span of nearly 80 metres to thank for this acclaim. Thick steel plates combining an extremely demanding functionality with filigree aesthetics at the same time were used for its steel sails. Longitudinally profiled (LP) plates supplied by Dillinger, the world's technological leader for tailor-made heavy plates, domiciled in Dillingen/Saar, made a definitive contribution to the overall result. With a carefully selected variably adjustable thickness across plate length, they permit optimum matching of the plate profile with the stress pattern.

The design of the new Neckar Bridge originates from the renowned independent engineering consultancy schlaich bergermann partner (sbp), of Stuttgart. Founded in 1980, the consultancy, now with a total of 190 employees, earns some 40 percent of its turnover from bridge engineering projects. The inception of the consultancy's history is marked by the design of Munich's Olympic stadium roof, the starting point for many subsequent lightweight structures. With the Second Hooghly River Bridge in India, sbp designed in the 1980s the cable-stayed bridge with, at that time, the world's largest span. The sbp design for the cable-net roof of the Mercedes-Benz Arena in Stuttgart also ushered in the start of the success story of this roof pattern. Innumerable construction projects around the entire world bear witness to the consultancy's power of engineering innovation; sbp is now globally represented - in New York, São Paulo, Shanghai, Paris, Berlin and Madrid – in addition to the parent organisation in Stuttgart. The company has received the highest distinction in bridge engineering, the German Bridge Design Prize, no less than five times. This award, donated by the German Association of Consulting Engineers (VBI) and the Federal Chamber of Engineers, is presented in recognition of the most elegant, most innovative and, simultaneously, most sustainable new or modernised bridge structures. And the new Neckar Bridge may well be on track to continue this series! Being part of the Stuttgart 21 infrastructure project, within the scope of which Stuttgart's main station is undergoing reconstruction and the associated railway complex reconfigured, the new bridge is also an element of the Paris-Munich-Budapest main line. Its location derives from the largely underground redesign of the existing rail routing on the Neckar, a sensitive choke point. As a result of the conversion of the existing terminal station into a low-level through station, the track route now takes on a new orientation, at 90° to the original layout. This is also the reason for the replacement of the existing bridge over the Neckar with a new structure for the city's urban rapid transit rail system (the "S-Bahn") and for long-distance rail traffic. At a length of 345 and a width of 25 metres, the new four-track railway bridge over the Neckar has spans of 77 and 74 metres. At its highest point, it is located 15 metres above the river's normal water level. On the west side, the bridge superstructure divides, entering at this point two separate tunnels: for the S-Bahn, the tracks lead to the new underground station, while long-distance rail traffic reaches the new main station via the second tunnel.

Steel sails replace cables

The new Neckar Bridge consists of a seven-span continuous beam. Striking steel sails identify the two main spans, above the river. Four spans are suspended by steel sails and tension ties-chords on nine steels masts. sbp developed a longitudinal support structure consisting of three hollow-box steel girders for the steel-reinforced concrete composite structure. This is immovably carried on three rows of main piers in the longitudinal direction at the outer sides and at the middle of the superstructure and is supported by the steel sails. In this way, the slender new supports absorb the enormous horizontal braking forces which can occur on this four-track railway bridge. The sbp engineers' aim was to achieve a visually lightweight and transparent bridge design despite the span of nearly 80 metres and the loads and forces imposed by a four-track railway. The precondition for this was a top support structure featuring tension ties, which run downwards from masts. Unlike cable-stayed bridges of similar design, sbp instead selected not cables but an arrangement of steel plates, thus interpreting anew the model of a classical self-anchored suspension, or tension ties-chord, bridge with rigid tension ties. Groups of plates consisting of two vertical plates joined to surrounding end plates form the tension ties and mastheads of all the sails. Following the principle of the inversion of an arched support structure, sbp resolved the tension ties into sails. Philipp Wenger, Technical Director at sbp, explains the underlying concept: "In the arch, the vertical forces from the substructure are transmitted via the arch tangents in the form of compressive forces. If this principle is inverted, the arch tangents become tension ties loaded purely by tensile forces." He adds: "For this reason, a relatively thin cross-section expanding in a slight trumpet-shape at the bottom, converging in a taper in the upward direction and then becoming increasingly thicker, was selected for this inverse arch." This means that the maximum stress ratio in the entire sail is equal, as a result of the differing thicknesses of the steel plates throughout the entire length. In all, a total of eighteen half-sails of identical geometry were welded together to create the nine sails that distinguish this bridge. The sails bear the forces exerted largely in the form of a membrane and have been produced using plates of thicknesses varying across the sail surface.

Bespoke tailoring in LP plates

For every tension ties structure of the two outer girders, two wedge-shaped LP plates, the thickness of which increases from 35 millimetres to 90 millimetres, were welded together to plate groups. These were then longitudinally joined to 10.5-metre long elements with a thickness of 70 to 180 millimetres. For the central, significantly more heavily stressed sails, plate groups of up to 250 millimetres in thickness and consisting of the higher-strength grades S460ML and S460QL were needed. Since the LP plates could be supplied only in normalised delivery condition (S460NL, for example), recourse was made to milled-to-shape plates for these tension ties. The use of LP plates was a virtually obvious step for sbp for the tension ties spanned visually like a sail canvas for load transmission and with a cross-section tapering downward. "We were aware, of course, that these plates would be a possible solution to implement variable thicknesses and also exhaustively exploit potential cost benefits", remembers Frank Schächner, Administrative Director at sbp. "The invitation to tender had, as always, to be product-neutral", he adds. The contractor commissioned by Deutsche Bahn for the construction of the new bridge, Max Bögl, of Neumark, nonetheless selected these very special plate profiles supplied by Dillinger. Thanks to their variably adjustable thickness in the longitudinal direction during the rolling process, LP plates permit optimum adaptation of the plate profile to structural-analysis, design and production-related needs. Featured in Dillinger's product range since 1983 and continuously refined and further developed since then, such plates now possess references throughout Europe for their successful use in bridge and surface civil engineering. Their potentials for specific profile-creation have also proven their worth for the design of extremely long rotor blades for wind turbines. Available in all cases from Dillinger as single bevel, double bevel or multiple bevel variants, LP plates eliminate the need for the otherwise unavoidable cost-intensive and time-consuming machining and welding together of series of smaller individual plates. That reduces not only material usage but also the weights needing to be transported and installed. By economising on welds, they in addition reduce not only production and inspection times, but also welding costs. Despite their complex production and the associated higher overheads, the bottom line is, nonetheless, cost-savings of up to 10 percent. Fewer welds and the ability of positioning them in less stressed areas assure in addition safer designs that are significantly less susceptible to metal fatigue.

Not concrete - innovative steel!

In the construction of the new Neckar Bridge, a further aspect spoke more generally for the use of Dillinger heavy plate. The bridge is located in Stuttgart's mineral spa protection zone: Bad Cannstatt is, after Budapest, Europe's most important mineral-water spa, yielding 44 million litres each day. The new bridge is located in the core zone of the geological strata bearing the artesian (confined) mineral water at very high pressure. In order to preclude any damage to the confining bed and therefore leakage of mineral water, the project had to be prevented from disturbing the natural pressure conditions prevailing here. Correspondingly severe restrictions were therefore imposed during the foundation and construction periods. For this reason, the longitudinal support structure was also implemented – contrary to the original planning – using steel rather than concrete. This made it possible to reduce the bridge's deadweight by a good 20 percent, with the result that significantly less weight needed to be diverted into the ground of the site. Europe's leading producer of heavy plate, Dillinger, supplied a total of 1,600 tonnes of steel to Max Bögl – in the form, in particular, of special steels in large plate thicknesses and formats. Of this quantity, 169 tonnes were accounted for by LP plates of structural steels grades S355J2+N, S355N and S355NL for the tension ties. Primarily thermomechanically (TM) rolled steel, including more than 30 tonnes of heavy, extremely large-format plates of grade S460ML, was used for the longitudinal and transverse beams, the masthead plates and the non-variable-thickness components of the sails. The large formats of these TM plates made it possible to significantly reduce the number of welds necessary and, additionally, to save weight, thanks to the higher strength of this steel. At the same time, its low carbon equivalent assured excellent working properties, weldability and toughness, with the result that it contributed just as much to the safety of the design as to the cost-effectiveness of the project.

The critical masthead connection

A great challenge to design and production was presented by the fixing of the vertical masthead slabs, up to 250 millimetre in thickness and consisting of S460QL, to the masthead plates. Thanks to the pattern of forces flowing between the sails and the masts, the mastheads, to which the tension ties connect on both sides, were particularly critical points. Plate thickness and the high-strength fine-grained structural steel supplied by Dillinger necessitated not only agreement in individual cases but also special approval by German Railways, since the rail authority's codes and standards permitted only a maximum plate thickness of 100 millimetres. For the sbp experts it was therefore essential to prove the necessary fatigue strength of these heavily loaded welds by means, inter alia, of extensive structural and Charpy V-notch energy tests on finite-element volumetric models. For the circumferential butt weld completed low-notch on this basis, the large-format plates were firstly preheated to nearly 500° C and carefully protected against cooling throughout the complex welding process. In Philipp Wenger's view, the new Neckar Bridge is of exemplary character for modern steel-bridge engineering: "The combination of such high mechanical strength, thicknesses and shaping of the steels to boost properties for the same stress levels has never before occurred in this form." In his estimation "… comparable plates with thicknesses of up to 250 millimetres have never yet been used in such quantities and using such preparation and installation methods, even abroad." For Frank Schächner, too, the future-orientated advantages of the new knowledge gained for steel-bridge engineering are readily apparent: "Thanks to the selection of an efficient support structure, paired with the use of high-strength steels, the Neckar Bridge represents a new dimension in sustainability and cost-efficiency."

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More information :
AG der Dillinger Hüttenwerke
Dr. Tobias Lehnert
66748 Dillingen/Saar
Germany
Telephone: +49 6831 47 3612
Telefax: +49 6831 47 3089
e-mail: tobias.lehnert@dillinger.biz
www.dillinger.de

Text freely reproducible, copy please to :
impetus.PR
Ursula Herrling-Tusch
Vaalser Straße 259
D-52074 Aachen
Germany
Telephone: +49 (0) 241/189 25-10
Telefax: +49 (0) 241/189 25-29
e-mail: herrling-tusch@impetus-pr.de
www.impetus-pr.de