Viaduct Tautendorf

Responsible management of existing structures

SSF Ingenieure

Preface

Up to now during expansion of motorway A9 the existing 4 lane bridges have been for the most part demolished and replaced by new structures in order to fit them to the new six lane cross-section. The singularity of the viaduct Tautendorf which in its clarity and structural refinement exudes industrial culture, persuaded client and planning engineer to retain this historic structure and to integrate it into the six lane widening.

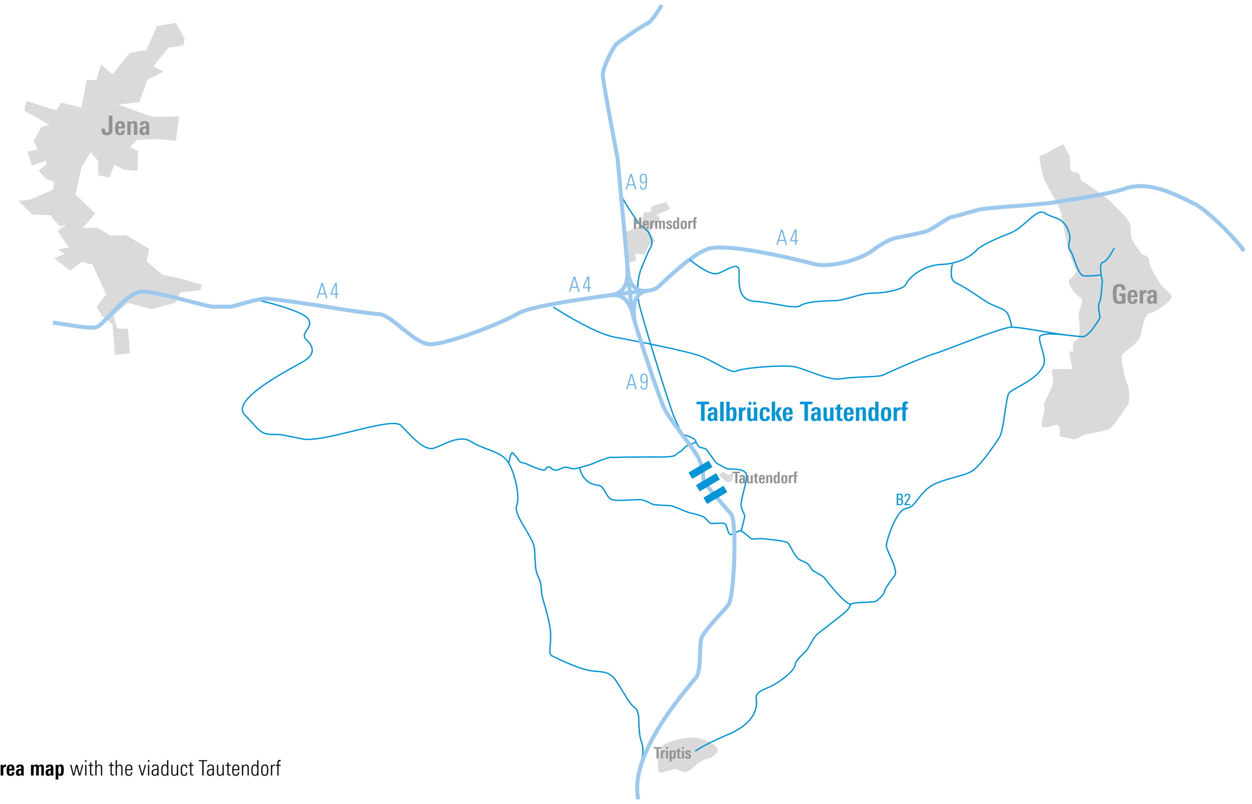
The project presented the challenge to keep carefully in mind aspects of maintenance and unrestricted usability of the old bridge, and at the same time to find a suitable approach which incorporates the historic structure efficiently and admits an economic solution for the new construction free of all extravagance compared to the rest of the motorway.

The old viaduct

The old viaduct Tautendorf had been completed during construction of the Reichsautobahn in 1937. It crosses over a river valley at an angle of approximately 45°, with a length of 249.8 m.
Symmetrically to the valley the spans are arranged at 46.6 m + 50.8 m + 55.0 m + 50.8 m + 46.6 m. There is one superstructure for each direction.
Special features of the bridge, in addition to the excellent detailing, are the supports of the superstructure at axes 20 to 50 which are formed as riveted steel portals and whose slenderness

Data and Facts	
Client	DEGES by order of the Free State of Thuringia
Spans	46.36 + 50.80 + 50.07 + 50.82 + 56.57 = 254.62 m
Width between railings	39.39 m
Bridge surface	9840 m
Construction costs	approx. 10 m euro
Services	object planning and structural engineering, preliminary and draft design, incl. preparation and evaluation of tenders

Partial view of the completed construction with abutment South



Area map with the viaduct Tautendorf

underlines the structure's finesse. In longitudinal direction they act with point rocker bearings as pendular support, connected in transversal direction by high girders to form a two-pinned frame. The portal frames carry a riveted steel girder made of 2.82 m high plate-girders at a distance of 8.31 m. Above it in a grid of 4.23 m, cross girders with a structural height of 1.08 m are arranged. In order to stiffen them against overturning, these girders are connected to the main girders' web like a frame. Cantilever beams are assembled on the outside in extension of the cross girders; these beams together with the vertical stiffeners mark the superstructure's appearance.

Secondary longitudinal girders INP 34 are linked to the cross girders and at the level of the lower chords of the cross girders are stabilizing bonds. The deck slab lies on the secondary girders without bonding agent, its load-bearing direction runs orthogonally to the longitudinal direction of the bridge.

Preliminary studies

Retention of an existing structure is only practical if planning of the new route can be accomplished without excessive effort, the condition of the structure is satisfactory and the load-bearing elements of the structure can carry today's traffic without the need of extensive reinforcement. Moreover, fatigue behaviour has to be studied precisely. Predictions as to the remaining fatigue life will have a considerable influence on any future utilization.

Planning documents of the viaduct Tautendorf were incomplete that is why essential constructional elements had to be measured on site. Taking of samples and technical analyses were necessary to identify building material and its properties. The result of the bridge's main examination in 1993 showed no relevant damage to the steel structure caused by corrosion. The primary load-bearing element was in good state. The deck slab, however, showed huge damage at the substance.

Design Principles and proposed solution

Examination of the existing structure with regard to route planning, structural condition and load-bearing capacity pointed towards a very favourable result regarding the capacity of the old bridge for future use.

First attempts to integrate the future regular cross-section of 35.5 into the existing structure could not be pursued as the steel con-

Picture credits: ediundsepp

Picture credits: SSF Ingenieure GmbH

1


3


2


4


1 **View** of the existing viaduct
2 **Detail** of the existing steel portal
3 **Setting** up additional top-chord
4 **Demolition** of concreted slap

General view east of the completed viaduct

struction of the superstructure as well as the portal frames had no load-bearing capacity left for carrying six new lanes. That is why further considerations were limited to the possibility that the two existing superstructures, coupled by a continuous deck slab which lies on all four main girders, only carry the lanes in direction of Berlin. For the lanes in direction of Nuremberg a new bridge is planned. As the existing viaduct with two separate superstructures for each direction will only carry the lanes in direction Berlin after the six-lane widening, an excessive width without function will remain after completion which, due to the structural conditions of the steel structure in connection with the existing design conditions, cannot be eliminated. To reduce these inoperable spaces of the superstructure and to achieve an economic dimension considering construction and follow-on costs as well as the desire to keep the old structure, the new superstructure's cross-section overlaps the old superstructure's cross-section by about 3.40 m.

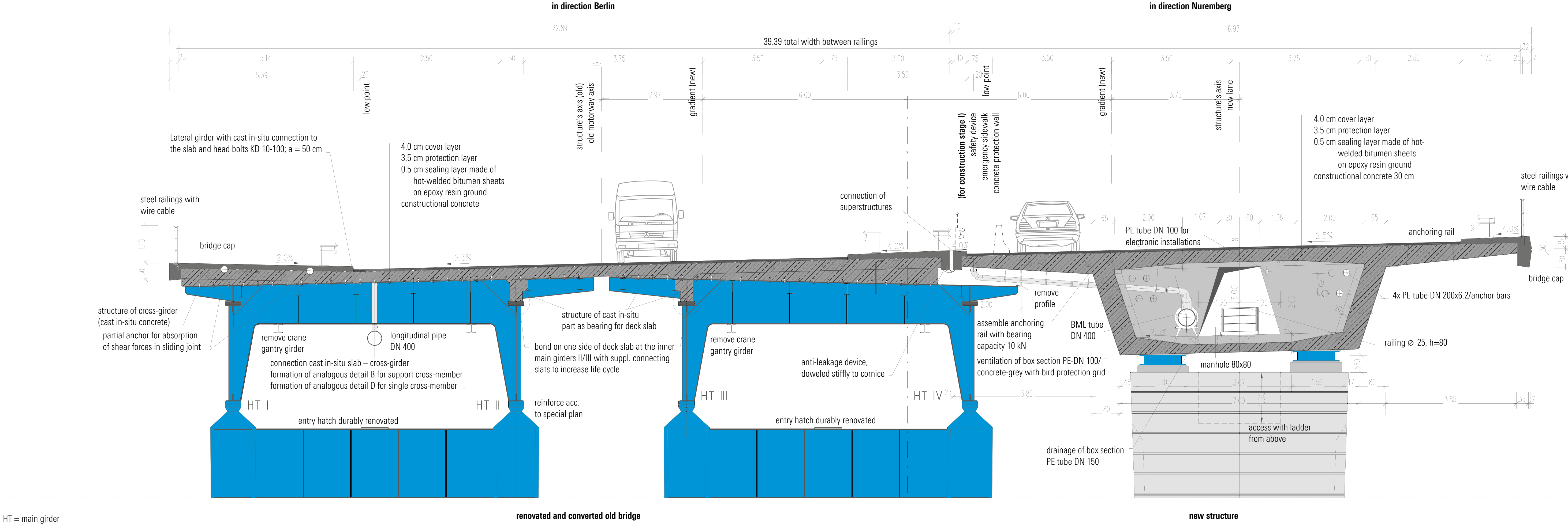
For the new bridge a variant had to be found that formed a harmonious unified whole with the existing structure. The straightness of the historic bridge is set beside a reinforced concrete box section. It seemed obvious to take up the well-proportioned span partitioning of the existing bridge for the crossing of the valley. Certain parameters of the existing pier portals are adapted for design of the new piers. The very detailed frame of the past is confronted with a pier form which takes up the negative slope of the old frame stanchions and shows a high structuring by forming horizontal grooves. The superstructure for the second lane is designed as externally pre-stressed, single-cell box section with a structural height of 3.0 m, constructed in sections on a falsework.

A deck that necessarily passes over both existing steel load-bearing structures to accommodate one of the two carriageways is subject to complicated geometrical and static load conditions. Two existing, separate steel structures designed with conventional cambers form now one coupled load-bearing structure with a crosswise slope. In longitudinal direction the deck spans the distance from one cross girder to the other.

Solution "Bond on one side of the deck slab"

The thickness of the new deck slab, spanning across both load-bearing structures, had to be optimized and adapted to the statically necessary dimension in view of the wedge-shaped joists above the cross girders that are required because of the crosswise slope and destined to reduce the weight of the structure. The concept of a continuous deck slab and wedge-shaped joists together with a continuous slab thickness of 0.30 m results in an augmentation of dead weight of only 6 percent compared to the existing

Cross section



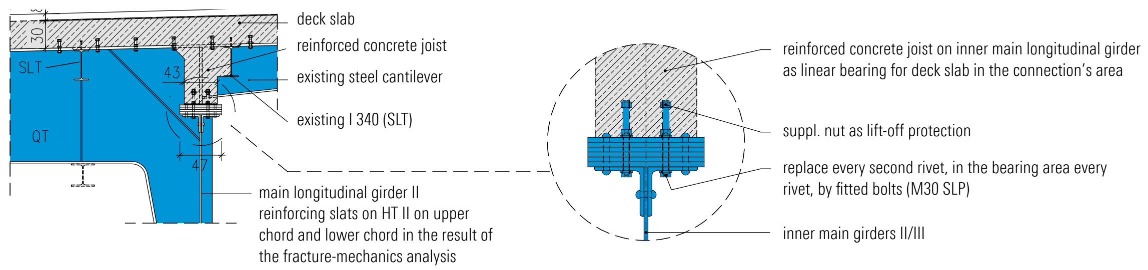
HT = main girder
M = outer diameter of thread
DN = nominal diameter
BML tube = sleeve-less drainage tube system
SLP = bearing type shear connectors without hole clearance
SLT = secondary longitudinal girder

structure. Loading caused by traffic had already been verified at the existing bridge to be uncritical. Traffic load acting on both old load-bearing structures is not relevant for dimensioning during demounting with only one carriageway. The load-bearing effect of the new deck slab with the wedge-shaped joists at the cross girders runs in longitudinal direction of the bridge from one cross girder to the other with a distance between the axes of 4.23 m. The deck slab links the two load-bearing steel structures to one another with a span of 5.0 m between the inner main girders. At the connection of the two superstructures, reinforced concrete joists are formed above the inner main girders to produce a transversal loading effect. In this way a line bearing support with clear static load paths is achieved when changing the bearing effect at the opposite side of the area between the main girders. A solution is chosen which implements direct bond on one side of the deck slab to the inner main girders II and III above the concrete joists which lie on the upper chords of the main girders. This solution does not disturb the view on the existing load-bearing structure; however, it is very advantageous for the static system as in the area of the inner main girders, carrying the right and middle lane, the highest stress amplitudes occur due to HGV traffic.
The concept of this load-bearing effect at the cross-section of the whole bridge achieved by bond on one side at the area of the inner main girders and the pure steel structure as well as the very distinctive stiffness differences between the outer main girders I and IV, which only contribute to calculations as steel load-bearing elements, and the bonded inner main girders II and III, necessitate supplementary examinations with relevant consideration of limiting cases.

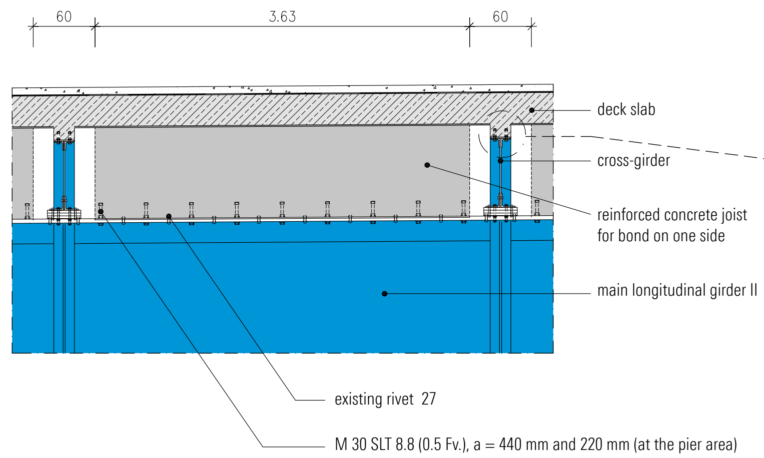
In addition to that, inspections of possible local overstrain due to displacement of the gravity line and the exact monitoring of deformation behaviour in longitudinal and transversal direction become obligatory. It is also indispensible to verify the transversal

Picture credits: SSF Ingenieure GmbH

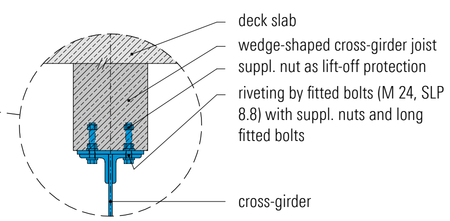
details of bond on one side at the area of the inner main girders II and III



main girder



cross-girder



bearing elements (cross-girders and deck slab) under additional considerations regarding different bearing directions in the area of the coupling and changes of internal forces due to the bond on one side of the main girders.

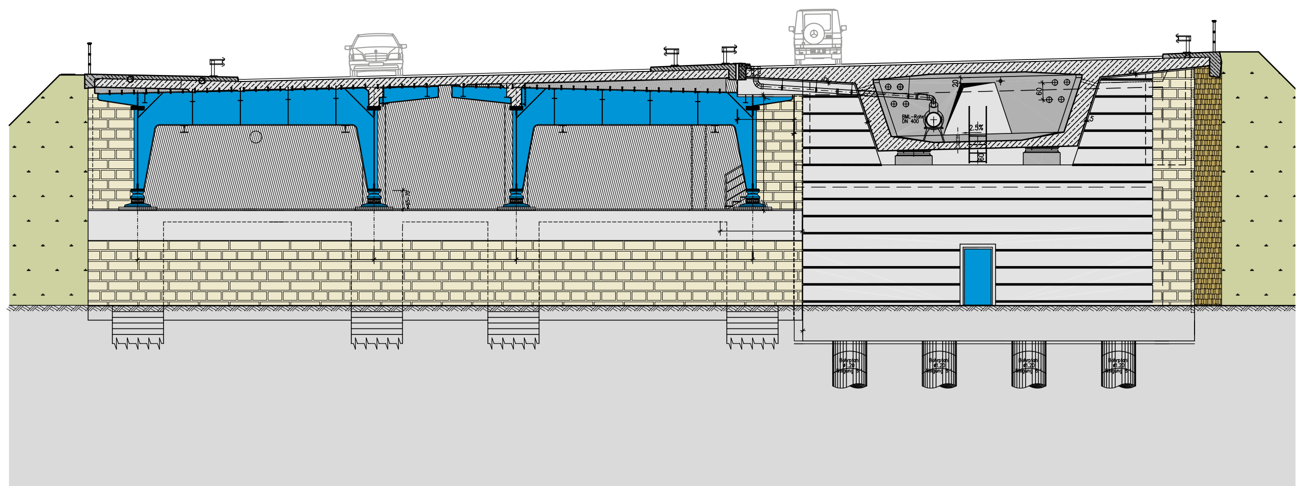
Stud shear connectors are excluded as bonding device for the one-sided bond in the area of the inner main girders as well as the cross-girder frame, as the old substance does not dispose of any welding aptitude. The bond is thus achieved by extra-long fitted bolts assembled into free rivet holes in the upper chords. About 7,000 bolts SLP-M22 and M30 of quality 8.8 are used with additional nuts at the thread ends as lift-off securing. The longitudinal bearing capacity in the area of the inner main girders (partial bond) and in transversal direction in the area of the cross-girders is dimensioned by applying an admitted value of an equivalent stud shear connector and verification of the calculated results by an in situ push-out test.

During verification at the steel bearing structure using admitted stresses and for reason of decreased yield strength (high percentage of nitrogen), the reduction factor 0.878 is applied which was identified during material analysis.

Fatigue Strength and Reinforcement

Whereas for new structures modern dimensioning procedures of bearing capacity, serviceability and fatigue strength can be used, the procedure of fatigue strength verification cannot be applied

View of the abutment South



Partial view of the abutment North with light-weight steel portal frames

Picture credits: SSF Ingenieure GmbH, Foto: Florian Schreiber Fotografie / SSF Ingenieure GmbH

for existing structures because of insufficient knowledge of the previously existing fatigue loads and pre-damages of the bridge and the large dispersion of fatigue strength.
That is why the procedure of fracture-mechanic analysis was introduced. The fatigue strength of the old structure is identified indirectly and results show how damage-tolerant the construction is when cracking occurs in the construction and which measures increase the robustness of the bridge.

This procedure starts from the supposition that the construction is fatigued to a point where fatigue damages are just at the limit of perceptibility. From such initial damages, the remaining service life is determined for the fatigue stress to be expected in future. A period of time is calculated between a fixed crack length and the breaking of the concerned slat. The start of the crack is defined at the edge of a rivet hole. The fixed crack length perceptible at inspection corresponds to the distance between rivet hole and edge of the rivet head (covered crack area) and to a crack length of 5 mm over the rivet head. The critical crack length, at which occur fast crack formation and failure of the examined structure, depends on the structure's toughness identified by fracture-mechanics tests as well as on the elements' geometry and stresses. Basis for all this is first of all the execution of general fatigue verifications according to Eurocode 3. The stress amplitudes for the fracture-mechanics analysis are defined on the basis of the fatigue load model and the frequency of the HGV-traffic distribution to the cross-section.

The inner main girder II underneath the lane (HGV-lane) which theoretically carries 83 % of the HGV-traffic, is subject to the highest load changes and stress amplitudes compared to the other main girders. The fracture-mechanics analysis resulted in the necessity for some cross-sections to undergo reinforcing measures in the area of the upper and lower chords by installing supplementary metal slats. The cross-sections of the inner main girder II to be reinforced are all in the transitional area from positive bending moment to negative bending moment that is where the load and the number of chord slats is low. The cross-sections of the reinforcing slats are chosen in such way that the period of crack growth until critical cracking time exceeds 6 years and the additional cross-section is able to absorb the liberated force in case of failure of an old slat. In total around 20 tons of supplementary slats are assembled. For the old slats of the inner main girder II underneath the middle lane as well as for the outer main girders I and IV, very low load changes were identified for reason of the low HGV traffic and the position underneath the caps and therefore much lower stress amplitudes so that these 3 main girders do not require any reinforcing measures to increase the life cycle.

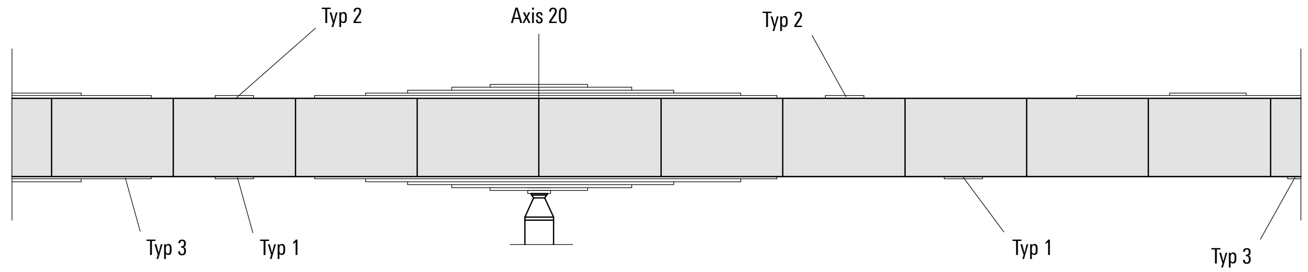
The new bridge

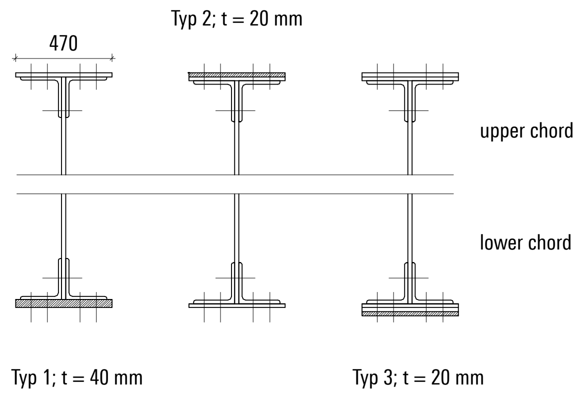
For the new bridge in direction to Nuremberg a solution had to be found that formed a harmonious unified whole with the existing structure. It seemed to suggest itself to take up the well-proportioned span partitioning of the existing bridge crossing the valley. Certain parameters of the existing pier portals of the old bridge were adapted for design of the new piers. The very detailed frame of the past is set beside a pier form which takes up the negative slope of the old frame stanchions and shows a high structuring by forming horizontal grooves.
This theme is again adapted for the bridge abutments' seats to express load distribution.
The wing walls move into line with the existing structure with travertine sheeting. The linearity of the historic bridge was confronted with a 3.0 m high reinforced concrete box section, externally prestressed and constructed in segments on a falsework.

Construction execution

Basis for the conversion and the general renovation of the existing bridge was the construction of the new bridge in close parallel position to the old superstructure. In order to overlap the new and the old superstructures as planned, the lane in direction Berlin had to be narrowed. After a construction period of 14 months the complete motorway traffic was diverted to the newly completed superstructure and the general renovation and conversion of the old bridge was started. The old deck slab was demolished by cutting segments which were then lifted off. The necessary additional slats, which were between 2.1 and 14.8 m long (quality St 52), were chosen in thickness (between 20 and 40 mm) and width (470 mm) in such way that in the girder no relevant stiffness deflections occur. The chord rivet was loosened and the additional slat assembled at an unstressed state under dead weight of the steel. Next, each additional slat was placed on the existing slat group and connected by fitted bolts in the existing rivet holes. The force-fitted connection of each additional slat with the old slat of the adjoining stronger cross-section was achieved by a connecting slat. The construction of the new deck slab with joists on the two inner main girders, wedge-shaped joists above the cross-girders and partially also on the secondary longitudinal girders placed high demands on the formwork workers. The deck slab was produced by pilgrim step method. To keep the gradient, deformation

view west of new bridge





Strenghtening of easterly inner main girder, additional chord on maingrider
View west on the newly constructed part

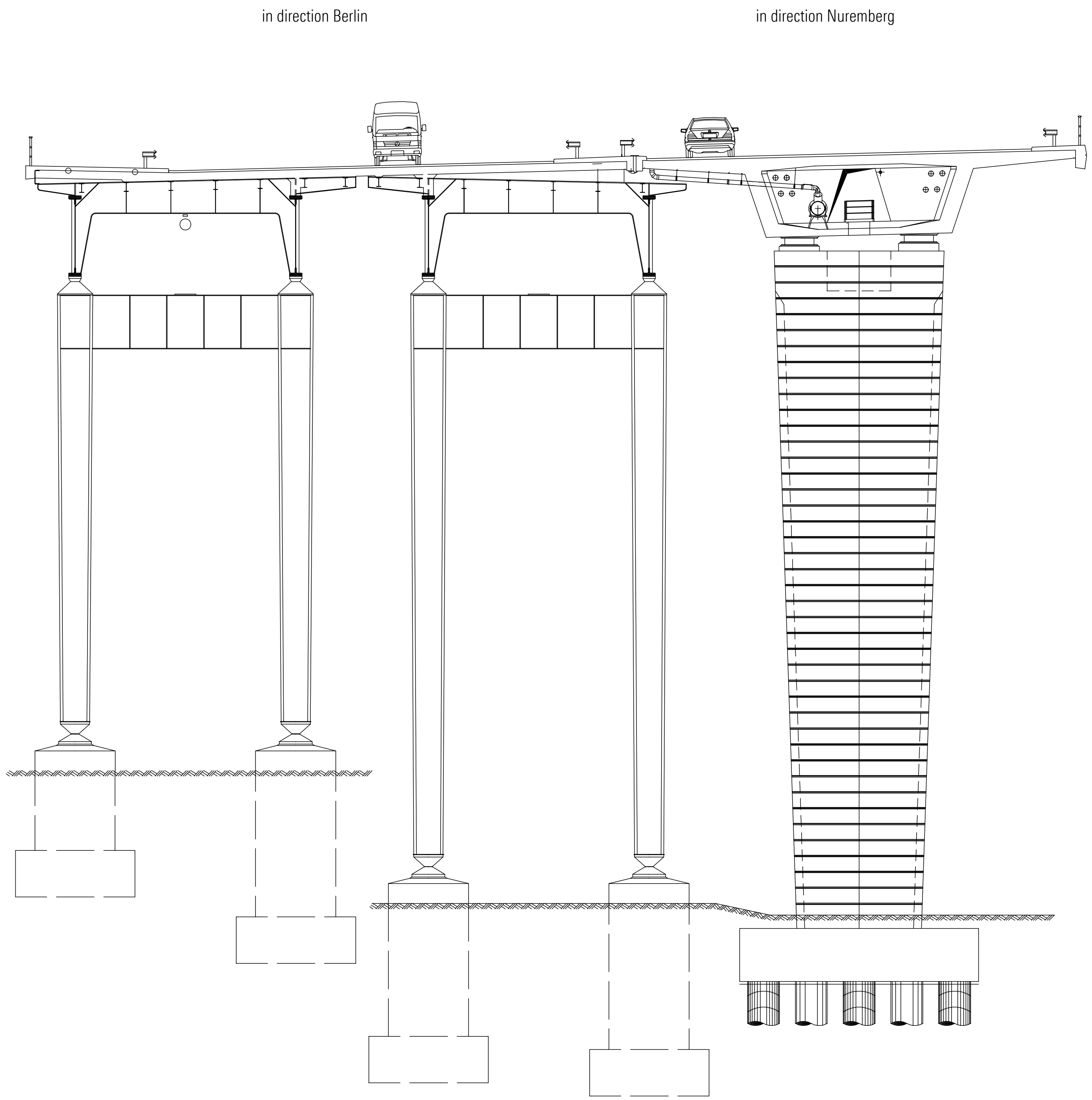
Picture credits: SSF Ingenieure GmbH, Foto: Florian Schreiber Fotografie / SSF Ingenieure GmbH

behaviour of the steel bearing structure was observed meticulously after each demolition and concreting step with a detailed measurement programme in order to determine the required superelevation values or to react immediately to differences. After 18 months of construction, the lane in direction Berlin was put into use on the coupled bearing structure.

Conclusion

The technical performance and foresight of preceding generations of engineers and architects, who left us excellent constructions, have to be acknowledged with respect. After 60 years of traffic and difficult maintenance conditions, the viaduct Tautendorf is subjected to another long-term life cycle and service thanks to a thorough renovation and conversion.

Retention of this masterpiece and its integration into the 6-lane widening of the federal motorway A9 is a visible expression of practically applied engineering culture and leaves no doubt that even under difficult technical and structural boundary conditions a respectful treatment of existing structures is possible. As client and planning engineer were marked with the mutual will to preserve a unique construction, a technically optimized, economically adequate and appealing solution between past and present had been found.



left: Viaduct Tautendorf, view from underneath
above: Cross section of new/existing viaduct with overlap

Picture credits: SSF Ingenieure GmbH, Foto: Florian Schreiber Fotografie / SSF Ingenieure GmbH

SSF Ingenieure

SSF Ingenieure AG
Consulting Engineers

Munich
Berlin
Halle
Cologne

www.ssf-ing.de