The New Bechlingen Viaduct in the Course of the Motorway A 45

Nicholas Schramm [1] ✉, *Stephan Sonnabend* [1], *Peter Wagner* [2]
✉ e-mail: nicholas.schramm@buechting-streit.de
[1] Büchting + Streit AG, Munich, Germany
[2] Adam Hörnig Baugesellschaft mbH & Co. KG, Aschaffenburg, Germany

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Abstract Due to deficits identified during the recalculation of the Bechlingen viaduct on the A 45 the two substructures of the existing arch bridge had to be replaced by a new construction. For this purpose, the existing bridge structure was dismantled with the help of a demolition scaffolding. The new bridge structure consists of a geometrically complex three-span continuous girder system in prestressed concrete construction with two separate superstructures. The very wide cross-section required in the course of the six-lane expansion is designed as a two-cell prestressed concrete box girder with internal and external prestressing. Due to the section-by-section production on a scaffolding which was ground supported or suspended from the joints and the concreting of the cross-section in four sections, the interaction between the structure and shoring with regard to the load-bearing behavior had to be investigated in detail. This contribution deals with special features of the design and construction of the new bridge structure as well as the demolition of the existing bridge.

1 Introduction and Project Overview

The Bechlingen viaduct is located between Dortmund and Giessen along the A45 federal motorway. The existing bridge structure with two separate superstructures, built in 1972, is an arch bridge in concrete construction with an arch span of 92.60 m and a length of 179.20 m, which crosses the A 45 federal motorway at operating km 5+261.076 to 5+440.276 km. The A 45 motorway crosses the valley of the Bechlinger Bach, the L3376 and three service roads. The viaduct is located near a district of Aßlar called Bechlingen, in the Lahn-Dill district of central Hesse/Germany (cf. Figure 1).

Due to the sharp increase in traffic loads and the high proportion of heavy goods vehicles, the existing bridge structures of the Bechlingen viaduct are no longer suitable for the future, meaning that the two separate superstructures need to be replaced. In future, the A 45 federal motorway is to be widened to 6 lanes in the area of the bridge. Figure 2 shows a photo of the existing partial

Figure 1: Location of the Bechlingen viaduct on the motorway A45 © B+S AG

structure (superstructure for the carriageway in the direction Dortmund, in the background) and the new bridge being built (superstructure for the carriageway in the direction Hanau, in the foreground).

Figure 2: Bechlingen viaduct: Erection of the shoring for the new construction of the substructure for the carriageway in the direction Hanau and the existing arch bridge of the substructure for the carriageway in the direction Dortmund © Adam Hörnig

The existing bridge superstructures made of prestressed concrete, including the piers and abutments, will be completely dismantled and replaced by two new bridge structures made of prestressed concrete. Firstly, the viaduct travelling in the direction of Hanau will be dismantled and rebuilt, while traffic will be guided 4+0 on the superstructure travelling in the direction of Dortmund. Traffic will then be diverted onto the new superstructure travelling in the direction of Hanau with a 4+0 traffic flow and the second section of the structure will be dismantled and rebuilt.
The A45 motorway runs in a straight line for approx. 60 m in the area of the structure and for approx. 120 m in the transition curve (left-hand curve) with $R \approx 1{,}000$ m at the end of the bridge. The gradient of the viaduct lies in a trough curve, whereby the longitudinal gradient in the construction area varies between approx. 0.55 % and approx. 1.15 %. In the area of the structure, the gradient of the BAB A45 motorway is approx. 31 m above the valley floor.

2 Demolishing of the existing bridge structure

To dismantle the existing structure, the superstructure was first lightened by removing the decking, waterproofing and caps without damaging the transverse tendons, including the railings, crash barriers and restraint systems. The entire superstructure was then scaffolded and dismantled on the demolition scaffolding. The superstructure was not dismantled in the opposite direction to construction, but in a similar sequence to construction. The dismantling was started above the arch apex and continued symmetrically in the direction of the abutment in order to avoid eccentric loads on the arch that would exceed its load-bearing capacity.
To dismantle the superstructure, the shoring was pressed against the superstructure and this was divided into corresponding sections by several cuts in the transverse and longitudinal direction. These elements were then lifted out using a mobile crane (cf. Figure 3). As the longitudinal anchorage point of the existing structure was close to the arch apex, additional temporary longitudinal anchorages were realised at the abutments by welding the expansion joint elements together in order to be able to absorb longitudinal forces during the dismantling.

The arch and the pillars on it were also cut into manageable elements and lifted out step by step from the centre of the arch using a mobile crane (cf. Figure 4). In order to secure the arch elements in position during the demolition process, plug-in beams were used towards the supporting structure of the arch. The piers were conventionally demolished from below using a longfront excavator.

The L3376 road underneath the structure was secured by protective scaffolding during the demolition, which meant that road traffic could be maintained during the construction work. The auxiliary foundations of the demolition support scaffolding were positioned in such a way that they could also be partially used for the new construction.
The demolition was planned by the engineering company MKP GmbH and carried out by Moß Abbruch-Erdbau-Recycling GmbH & Co KG as a subcontractor of Adam Hörnig Baugesellschaft mbH & Co KG.

Figure 3: Demolition of the existing structure: demolition support scaffolding and excavation of the carriageway slab elements © Adam Hoernig

Figure 4: Lifting out the cut-out arch elements using a mobile crane © Adam Hoernig

3 Construction of the new Bechlingen vidaduct

3.1 Superstructure

The replacement construction of the Bechlingen viaduct is being realised as a 3-span prestressed concrete superstructure with spans of 54.60 m in the two edge spans and 70.00 m in the central span (cf. Figure 5). The total length of the bridge structure in the motorway axis is 179.20 m. The lower edge of the cross-section follows a parabolic course, whereby the cross-section heights vary between 3.30 m at the end of the edge spans and in the centre of the main span and 5.10 m in the pier axes.

Due to the requirements for maintaining the stopping sight distances, the two superstructures cannot be routed in parallel and each directional carriageway must be routed independently in the construction area. The carriageway in the direction Dortmund follows a clothoid (A = 491.191) with a longitudinal gradient of approx. 1.1 % and has variable transverse gradients between 2.6 and 5.2 %. The carriageway in the direction Hanau follows a constant radius (R = 2,900 m at the inner edge of the centre cap) and has a longitudinal gradient of approx. 1.25 % and a variable transverse gradient of approx. 2.6 to 5.1 %. The width of both superstructures is constant and the transverse inclination of both superstructures is in the same direction. The cantilever arm lengths also vary due to the variable transverse inclination of the superstructure.

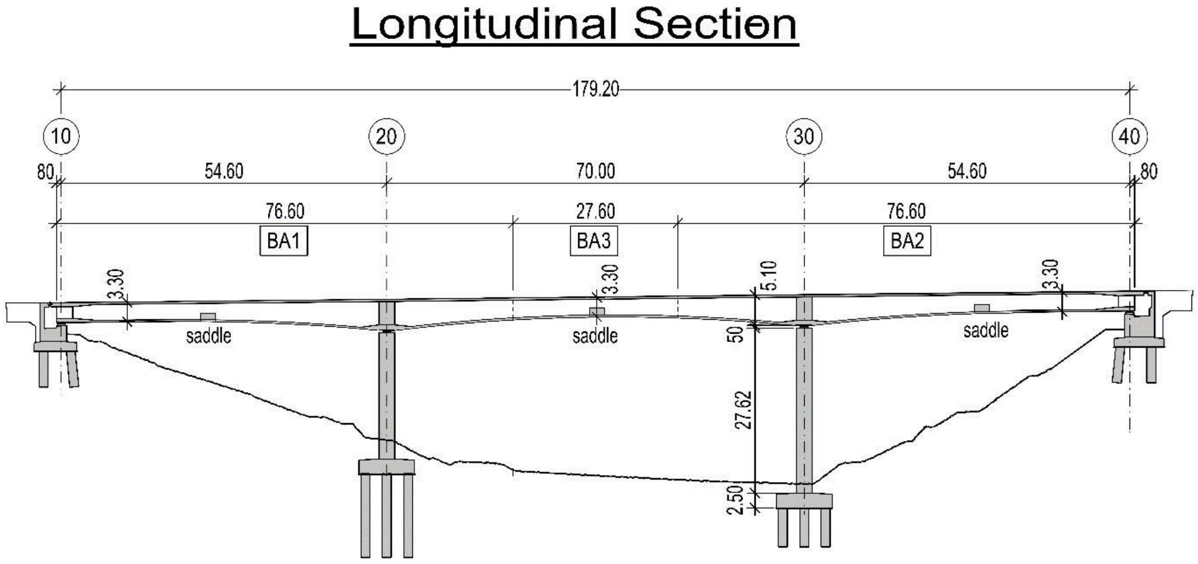

Figure 5: Longitudinal section of the TB Bechlingen with division of the construction sections © B+S AG

Contrary to the invitation to tender, which envisaged an asymmetrical position of the construction joints to divide the bridge into three construction sections, the two construction joints were moved symmetrically into the main span in the area of the moment zero points as part of the execution planning. As a result, construction sections 1 and 2 (BA 1 and BA 2) are geometrically almost identical and the same ground-supported shoring can be used for both (cf. Figure 6). The scaffolding supports could be partially supported on the pile head plates of the new pier foundations and on the abutments. This meant that only two additional auxiliary foundations were required for construction phases 1 and 2, which could also be used for the dismantling. Subsequently, construction section 3 (BA 3) can be realised using a shoring with coupling joint suspension (cf. Figure 7). By symmetrising the position of the construction joints, it was also possible to optimise the tendon guidance.

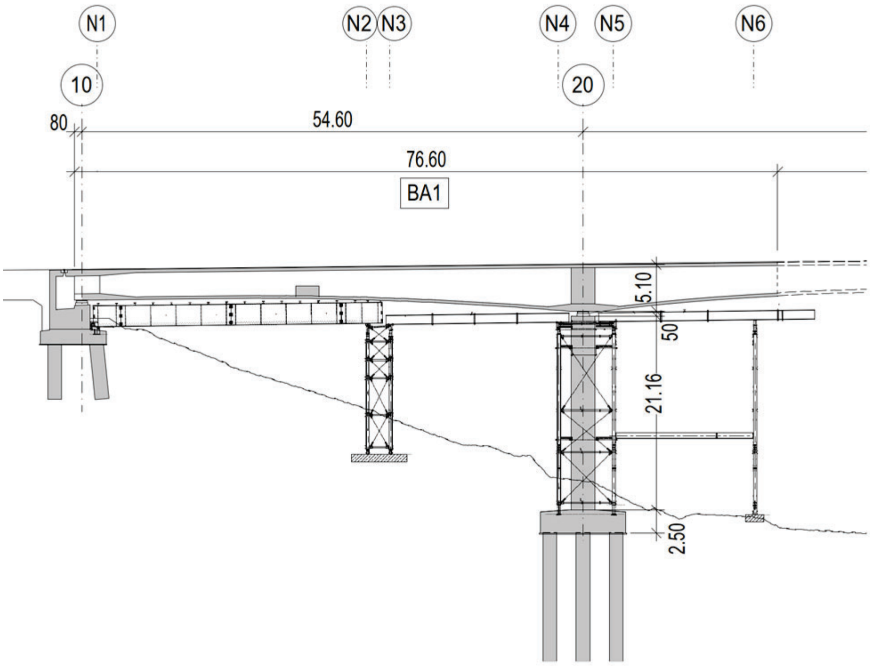

Figure 6: Shoring for BA 1 (BA 2 analogue) © B+S AG / RöRo Traggerüste GmbH & Co. KG

The superstructure cross-section is designed as a two-cell longitudinally prestressed concrete box girder (see standard cross-section of the Hanau carriageway in Figure 8) in mixed construction with external and internal prestressing. The construction material used is concrete C 45/55. For the superstructure of the Hanau carriageway, the total cross-section width (between the outer edges of the caps) is 20.507 metres. For the Dortmund carriageway, the maximum cross-section width is only 18.50 m, whereby the 2.00 m smaller cross-section width compared to the Hanau carriageway is achieved by reducing the cantilever arm lengths by 1.00 m in each case. Thanks to the arrangement of a central web, it was possible to avoid a transverse prestressing for the comparatively wide superstructure cross-section. In the future, it is to be expected that a classic single-cell box girder with transverse prestressing can be used again for similar, correspondingly wide cross-sections, after unbonded transverse tendons with plastic ducts are approved or favoured again in the course of the imminent introduction of BEM-ING Part 1 in Germany. This is not the case at the moment.

Solid diaphragms with thicknesses of 2.75 m at the abutments and 2.60 m in the pier axes, which are monolithically integrated into the webs and the carriageway slab, are used as cross girders. Due to the variable transverse inclination of the cross-section and the variable construction height, the web heights vary in the longitudinal direction. To absorb the inclined main compressive stresses, the web thicknesses must be increased from 45 cm for the outer webs and 40 cm for the centre web in the field to 55 cm for the outer webs and 50 cm for the centre web in the pier axes. The floor slab

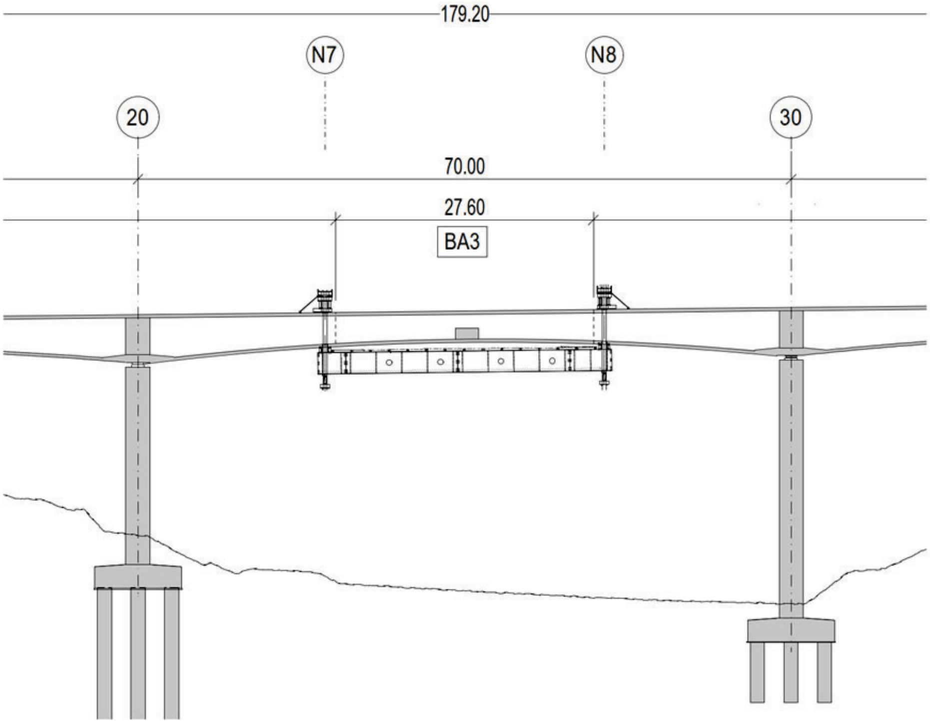

Figure 7: Shoring for BA 3 © B+S AG / RöRo Traggerüste GmbH & Co. KG

thickness also varies from a minimum of 30 cm in the field area up to 80 cm on the pier axes. Solid end cross beams are formed at the end supports. For this reason, the carriageway slab and the floor slab of the box girder are cambered close to the end support axes 10 and 40. The parameters mentioned above, which vary along the axis of the structure, result in an extremely demanding structure in terms of geometry.

For practical construction reasons, additional construction joints were provided between the floor slab and the webs, contrary to the tender. Otherwise, an elaborate suspension of the formwork would have been necessary for the centre web. The cross-section was therefore constructed in four sections. Firstly, the bottom slab was constructed and provided with partial prestressing in order to be able to absorb the concreting loads from the webs without cracking. The outer webs were then concreted and the centre web was constructed. In the next step, the trough was prestressed and the carriageway slab was constructed. Once all three construction sections had been completed, the external prestressing was applied.

The design of the cross-section as a two-cell box girder results in special load transfer characteristics that must be taken into account in the design. For example, the cross-section undergoes profile deformation, particularly with highly eccentric live loads, which leads to the individual webs participating unevenly in the load transfer. An asymmetrical load generally leads to longitudinal bending, torsion and profile deformation (cf. Figure 9), whereby their respective proportions depend on several factors such as the torsional and bending stiffness or the distance to cross beams.

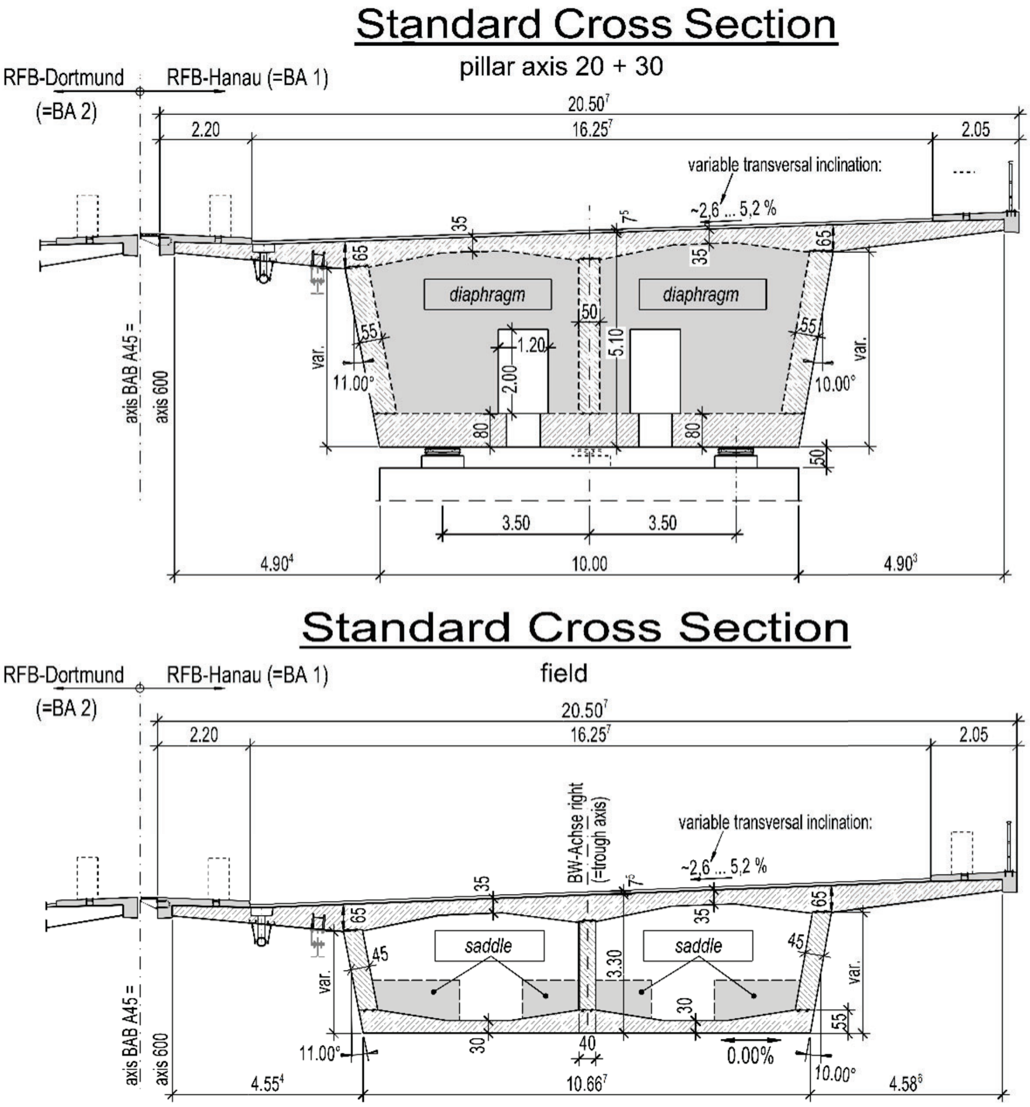

Figure 8: Standard cross-section in the field (top) and pillar axes (bottom) for the superstructure of the Hanau carriageway © B+S AG

According to the tender, this effect had to be taken into account for the decompression check, the longitudinal stresses in the fatigue check and for the shear force design in the longitudinal direction. It was agreed with the client that the internal forces for the corresponding verifications would be determined using the single-rod model and that the corresponding load increase factors would be applied for the design. The load increase factors were calculated as part of an additional analysis on the folded structure. This showed that the outer webs generally experience greater loads than those on the single-rod model due to profile deformation. The load increase factor was determined to be 1.09 for actions due to dead weight and additional loads. A factor of 1.47 was obtained for UDL traffic loads and a factor of 1.35 for TS traffic loads in the most unfavourable section in the longitudinal direction of the structure.

Figure 10 shows a view of BA 1 and BA 2 being completed and the shoring for the construction of BA 3 being erected.

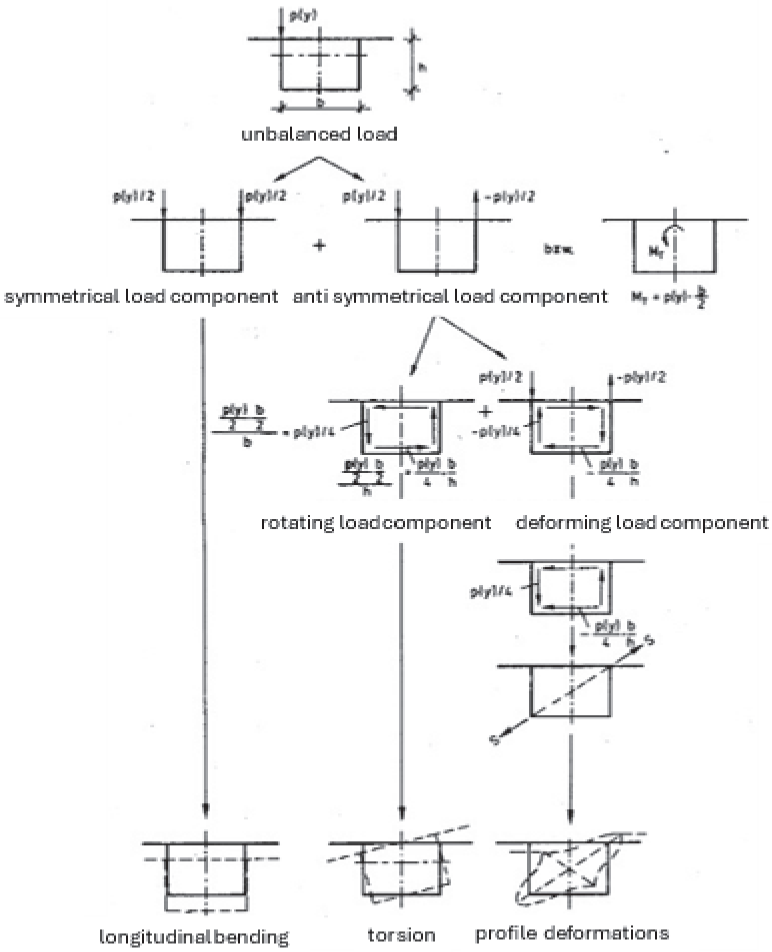

Figure 9: Breakdown of an asymmetrical load on a single-cell box girder into the components for longitudinal bending, torsion and profile deformation; Source: Dissertation, Grossert 1989: “Investigations into the load-bearing behaviour of solid bridges with a two-cell box cross-section”

The prestressing of the structure in the longitudinal direction is carried out internally with 6-22 tendons (St 1660/1860, Pmax = 4752 kN) with subsequent bonding in the chords as well as external garland-shaped bondless wire EX60 tendons (St 1570/1770, Pmax = 3117 kN) in the box girder. Up to 20 internal 6-22 tendons were provided in the bottom slab and 11 internal 6-22 tendons above the pier axes in the carriageway slab. Eight EX60 wire tendons are used as external prestressing. The internal bonded tendons are prestressed on one side at the corresponding pilaster strips in the bottom slab and on the ceiling pilaster strips in the carriageway slab. The internal tendons in the span area of the main span are subsequently pulled in, as these are routed across the construction section boundaries. All other internal tendons are installed directly as prefabricated tendons.

For a possible subsequent retrofitting of a noise barrier, the load approach of a 4.5 m high noise barrier was taken into account for the design of the superstructure.

Figure 10: View of BA 1 + BA 2 and preparation of the shoring for construction of BA 3 © Adam Hörnig

3.2 Bearing System and expansion joints

Figure 11 shows the bearing system of the Bechlingen viaduct. Due to the height of the loads and displacements to be transferred, spherical bearings are used. To avoid constraints from the curvature of the structure in groundview as far as possible, the bearings are placed tangentially. There is a transversely fixed bearing in each axis, which means that the superstructure is supported in a statically determinate manner in the transverse direction. The longitudinal fixing point is located at the abutment in axis 10. Contrary to the tender, two longitudinally fixed bearings were provided in axis 10 in order to avoid costly temporary longitudinal fixings for the condition of the bearing replacement. The longitudinally fixed bearings were each designed for 70 % of the total horizontal force in the longitudinal direction of the bridge. Due to the low vertical load in the abutment axis, correspondingly complex anchoring constructions had to be provided for the longitudinally fixed bearings in order to be able to transfer the high horizontal loads. It should be noted that, from the point of view of the authors of this article, the arrangement of the longitudinally fixed bearings in the pier axes is always preferable due to the higher superimposed loads. As a result, complex anchoring constructions can generally be avoided. In axis 40, a finger expansion joint with a calculated dilatation of the superstructure of approx. 230 mm was provided. Due to the limited absorbable deformations of the finger expansion joint in the transverse direction, a transversely fixed guide bearing arranged in the centre under the superstructure must be provided at the finger expansion joint abutment in direction Hanau in axis 40. Furthermore, the maximum permissible vertical height offset of the fingers of 5 mm in accordance with TL/TP-FÜ (German standard) was verified by calculation.

In order to ensure longitudinal restraint in the construction phase for construction section 2, a temporary longitudinal restraint was provided in the form of at approx. 45° inclined bars between the pier head and the supporting cross girder. This will be cut through and dismantled when the

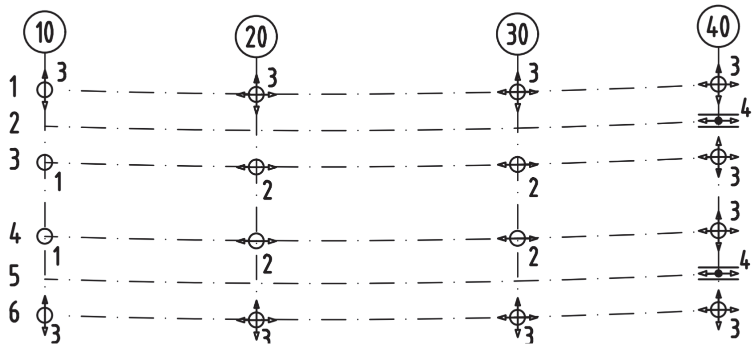

Figure 11: Overview sketch of the bearing system © B+S AG

gap is closed, for which the final longitudinal restraint in axis 10 will then be available. Figure 12 shows the design of the temporary longitudinal restraint in axis 30. Alternatively, a temporary longitudinal restraint in the form of presses with a correspondingly high shear load-bearing capacity (usually 8 % of the vertical superimposed load) would also have been conceivable. However, the building company favoured the design with inclined bars.

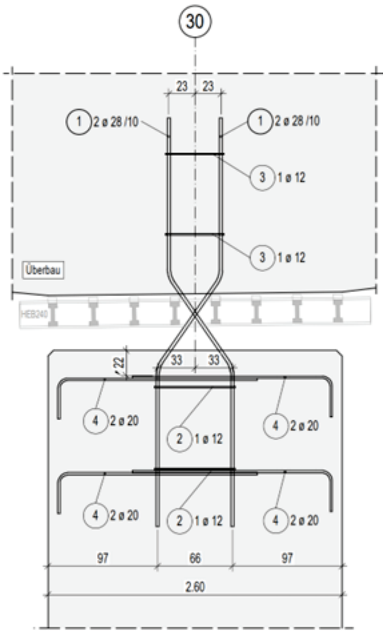

Figure 12: Formation of the temporary longitudinal restraint in axis 20 © B+S AG

3.3 Substructures

Appropriate shoring first had to be planned for the construction of the substructures. In the area of the pier foundations, the slopes, which were up to approx. 40° steep, were secured or shored with nail walls. These had to be dimensioned for heavy demolition equipment, such as a 160 tonne long front excavator, above the shoring. The stability of the existing transoms as part of the shoring wall could be proven without further measures.

Both the abutments and the piers of both superstructures are founded with large bored piles d = 150 cm deep. In the course of execution, it became apparent that the assumed rock horizon (diabase rock) was significantly higher in places than assumed and the rock strengths were so high that no significant drilling progress could be achieved. Against this background, individual bored piles were shortened in consultation with the geotechnical expert in the course of execution.

At the base, the piers have a rectangular full cross-section measuring 2.60 m x 6.00 m, which widens from 6.00 m to 10.00 m at the pier head in the transverse direction of the structure. The widening occurs on the upper 9.03 m of all piers, with the last 0.65 m having a constant width of 10.00 m. The cup-shaped widening results in a strong tension band in the pier head, which had to be covered by a correspondingly large reinforcement cross-section. In order to avoid cracking from this tension band effect in the comparatively thin walls of the inspection pit of the pier head, vertical separation joints were provided in these walls in agreement with the client, contrary to the tender.

The box-shaped abutments are constructed separately and are separated by an expansion joint in accordance with German Standard RIZ Fug 1 over the entire height of the abutment. To reduce the required minimum reinforcement due to expansion restraint, four dummy joints were provided in accordance with German Standard RIZ Fug 2. The abutments each have a maintenance walkway for structural maintenance. In order to be able to demolish the second substructure (carriageway Dortmund) and construct the new abutment of the new replacement structure in its shadow, the abutments of the 1st construction phase (carriageway Hanau) will receive an auxiliary wing along the joint axis of the separating space joint.

3.4 Special features of production on shoring

The construction of the superstructure on ground-supported shoring (BA 1 and BA 2) or suspended from the coupling joints (BA 3) resulted in a number of special features that had to be taken into account during planning and execution. In particular, the interaction between the shoring and the bridge superstructure was taken into account by applying the respective effective structural stiffnesses. In order to take into account the springback of the shoring in the calculations and to be able to carry out the most realistic deformation calculations possible to determine the required deflections, the longitudinal girders with their corresponding stiffnesses were included in the modelling of the superstructure. The couplings between the superstructure and the supporting structure were modelled with non-linear springs, taking into account the tensile failure, using the SOFiSTiK program package (cf. Figure 13).

The required superelevation was determined taking into account the shoring stiffness and the summation of the construction stages. In order to be able to compensate for potential deviations between calculated and actual deformations in the course of cross-section construction, control measurements were carried out after concreting the floor slab and webs. The required superelevation was set using superelevation moulds in the superstructure formwork.

To close the gap during the construction of the last construction phase 3, compression pieces in the form of six HEB 100 steel girders with a length of 900 mm each are installed in the floor slab in a

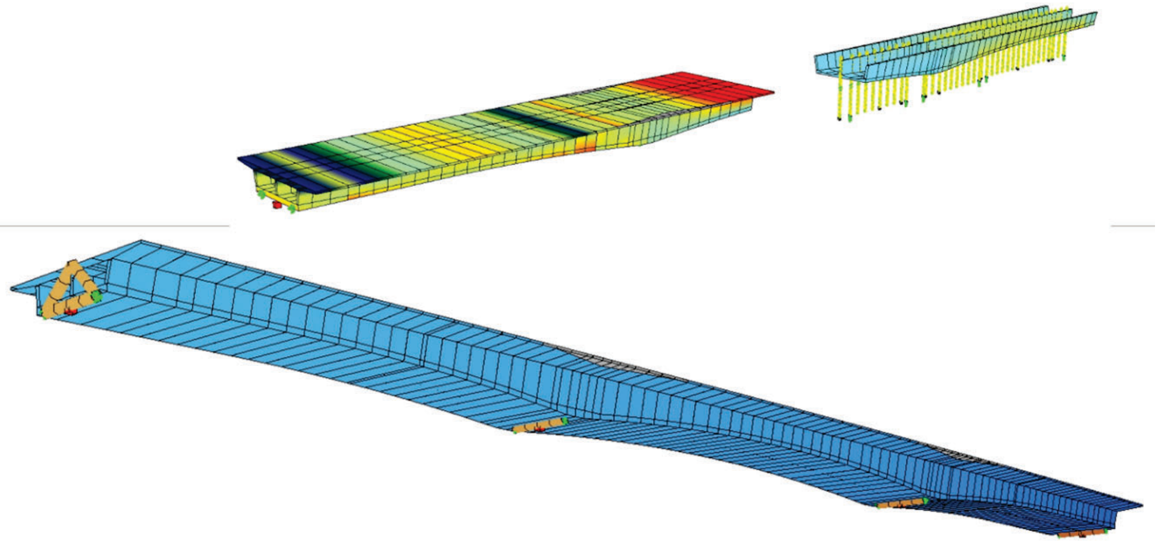

Figure 13: Calculation model of the Bechlingen viaduct; top: Construction stage with partial cross-sections and taking into account the supporting structure stiffnesses; bottom: Structure in its final state © B+S AG

force-fit manner (cf. Figure 14). Four of the floor slab tendons in the centre span are then tensioned against the compression pieces and at the same time the temporary longitudinal restraint in axis 30 is released. With this procedure, cracking due to constraining forces caused by the two longitudinal anchor points present in the construction stage can be avoided.

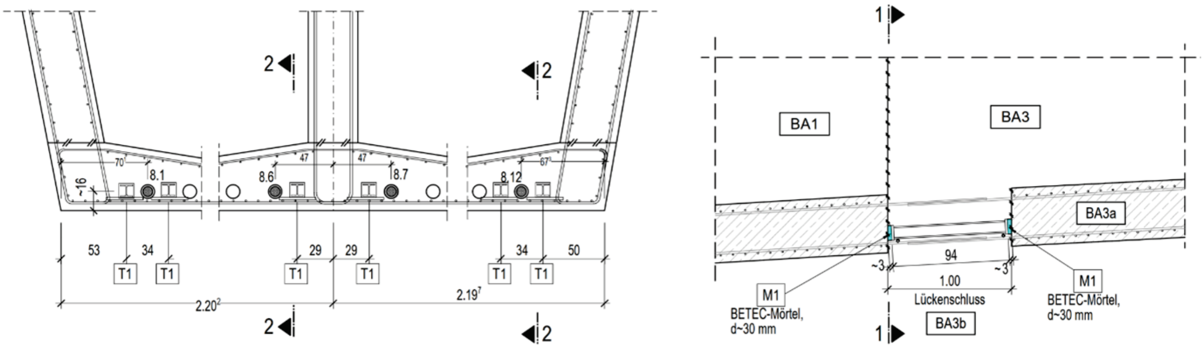

Figure 14: Pressure pieces in the floor slab to close the gap © B+S AG

The shoring work was carried out by the company RöRo Traggerüste GmbH & Co.

4 Summary and outlook

In this article, a prestressed concrete bridge with a two-cell box girder in mixed construction with construction on falsework was presented. It was shown that the specified gradient and the design of the very wide cross-section as a two-cell box girder resulted in a technically demanding structure that presented corresponding challenges both in terms of planning and construction. For future bridge structures with similarly wide cross-sections of more than 20 m, it is to be expected that the imminent introduction of BEM ING Part 1 in Germany will allow them to be designed as single-cell box girders with transverse prestressing in the carriageway slab.

Thanks to the excellent cooperation of all those actively involved in the project, the Bechlingen viaduct on the A45 motorway is another modern and visually successful structure.