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Schuttebusbrug Zwolle

Design, Construction and Engineering

A striking part of the development of the Spoorzone in Zwolle is the new bus bridge. This bridge provides a completely free access route for buses only, without other traffic. It connects the new bus station on the south side of the railway yard with the intersection Rieteweg-Willemskade on the north side. Traveller comfort, optimisation of bus services and spatial qualities were decisive for the appearance of the bridge.
The bridge was festively opened on 9th of February 2019, when it was named the Schuttebus Bridge. The bridge is named after Herman Schutte, founder of the former bus transport and coach company Schutte Tours Zwolle. As per 17th of February, the bridge was included in the bus transport company's timetable.
The bridge has six supports, an abutment on both sides and four intermediate piers (Fig. 1). At the northern abutment, the bridge changes into an embankment with a length of 129 m. On the southern side, there is also an embankment with a length of approximately 60 m, which will connect to the new built bus station. The length of the bridge including the embankments is therefore approximately 435 m.

1 Introduction

1.1 Architectural design

A tender design was made based on the requirements from the call for tender. The type of bridge and the choice of materials were free to choose, but had to meet the functional and aspect requirements: a bus bridge with the smoothest possible line, which also offers optimum comfort to travellers.

A flowing line was achieved by minimising the number of supports and giving them a slender shape. The piers taper down from ground level to the top and have minimal dimensions at the top. The supports right next to the railway yard are placed eccentrically under the bridge to minimise the length of the main span. The piers underneath the approach bridges are also placed eccentric, but on the other side of the bridge axis.

By visually dividing the bridge into three horizontal layers, the construction height appears to be smaller than it actually is. The slenderness of the appearance is reinforced by the fact that the main supporting structure lies as far inward as possible. The steel main span and concrete approach bridges have been given a calm grey colour. The entire length of the superstructure is finished with edge elements made of curved aluminium panels fixed on top of concrete road barriers. Lane lighting has been integrated into the aluminium edge elements. The underside of the cantilever has been provided with bamboo panels attached to a steel substructure. This emphasises the landscape elements in the surroundings and connects the green embankments, giving the bridge a parklike appearance.

Source: jpv Delft

Fig. 1 View of superstructure in direction south

1.2 Optimization

Within the framework of optimisation, the supports at the ends of the midspan (supports 3 and 4) were shifted so the two central supports were symmetrical with respect to the intersection of the arcs in the centre span. In doing so, the supports were shifted towards the railway yard as much as possible while adhering to the previously specified system boundaries. In comparison to the above-mentioned length between the supports in the superstructure axis, the straight-line distance between the support points in the centre span is 80.23 m.

Both the slope on the north-west side and on the south-east side run almost parallel to the railway yard. The bridge structure, without intermediate supports in the railway yard, is therefore provided by an S-shaped, 82.13 m long central span in the superstructure axis. The radius of both opposing curves in this span is 50 m. This minimum radius was tested by means of a driving simulation of the buses crossing the bridge.

The radii from the centre field are continued in the adjacent fields with different lengths up to the connection of the approach bridges. The slope on the northwest side has a radius of 475 m in the bridge axis, the slope on the southeast side has a radius of 420 m.

The longitudinal decay of both slopes amounts to 5.3 %. The rounding of the top arch in the midspan is solved with a radius of 500 m. The structure bottom is rounded with a radius of 1390.62 m in the middle of the bridge. This rounding begins already in the approach bridges between supports 2 and 3 and 4 and 5, respectively.

The total length of the superstructure of 245.50 m between the abutment axes 1 and 6 resulted from the precondition that the underside of the structure at the abutment could not be lower than 5.25 m above sea level. There were no limiting conditions for the position of supports 2 and 5; they were classified according to the static requirements. The individual spans between the supports are 37.75 / 43.93 / 82.13 / 43.93 / 37.75 m.

2 Material and cross section

The S-shaped curved midspan could only be spanned by a very torsional rigid box girder. Due to the torsional moments as a result of the strong curvature, these could not be absorbed by the usual composite cross section with a slab made only of concrete. For this reason, the box girder section was closed at the top by a steel deck plate.

In both of the less curved approach bridges, the superstructure was designed as a fully posttensioned concrete box girder. Above supports 2 and 5, there are transverse girders in the box sections to absorb the bearing forces. The end cross girders at the abutments were widened to 9.88 m in order to be able to carry the torsional forces from the superstructure. In the construction phase, the inside of the prestressed concrete box girder was accessible via assembly openings for the expansion of the formwork and the application of the post-tensioning; in the final phase, these openings were closed with concrete.

The structure height of 2.60 m at the beginning of the approach bridges is increased to 2.98 m at the bottom near supports 3 and 4 and results in a structural height of 3.85 m in the centre of the mid span. The increase of the structural height in the centre of the main span makes sense from a static point of view, but was also a requirement of the architect who, for design reasons, wanted to combine the increase of the superstructure height towards the centre of the bridge with a decreasing width of the supporting box girder. This width decreases linear and symmetrical from 5.46 m at supports 2 and 5 to 3.66 m in the middle of the centre span.

The steel structure and the approach bridges are rigidly connected at about the moment zero point 11.635 m outside of supports 3 and 4 and form a continuous hybrid su-

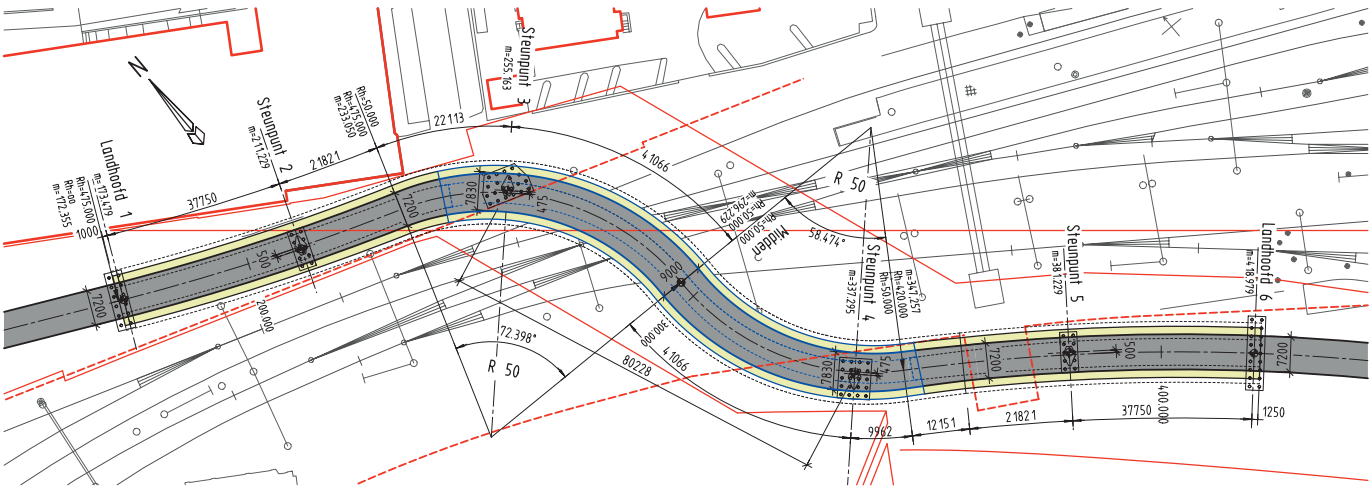


Fig. 2 Top view of superstructure

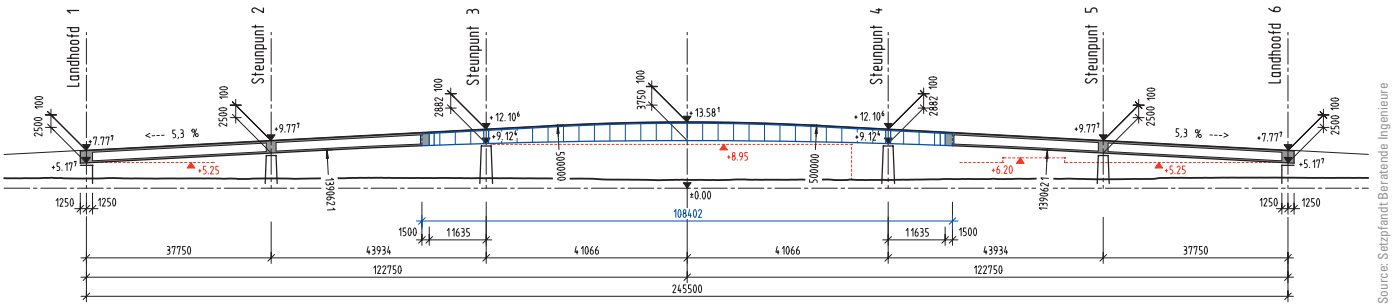


Fig. 3 Longitudinal section

perstructure. The steel superstructure lies almost entirely within the centrally symmetrical range of the centre span. Only the last 3.17 m up to the coupling joint with the northern approach bridge is already in the design curvature of the slope. The outer dimensions of the visible steel and concrete section at both coupling joints are identical, so that the material transition can only be recognised by the difference in colour and roughness of the materials.

2.1 Basic geometry of the cross sections

For reasons of driving comfort, the roadway width increases linearly from 7.60 m on the approach bridges from the middle between supports 2 and 3 and supports 4 and 5, respectively, to 9.00 m in the bridge section. The bituminous roadway structure including the seal has a thickness of 10 cm, below which there is a 20 cm thick concrete deck on top of the steel box girder. This deck which, also contributes in the composite section, essentially serves the drainage, to accommodate the conduits and the edge construction with barriers. The total external width of the bridge deck will thus increase from 10.23 m at the approach bridges to 12.23 m in the middle of the central span.

2.2 Steel cross section

The steel girder consists of an airtight welded box section. The plate thickness of the base plate is 65 mm in the centre and 70 mm at the supports, the plate thickness of the deck plate is 40 mm in the centre of the span and 50 mm at the supports. In the area of the moment zero points, the plate thicknesses are reduced. The web plates have a continuous thickness of 35 mm. S 355 was used for the entire steel construction of the box girder.

The box section is stiffened by means of transverse frames with a distance of 3.16 m measured in the superstructure axis. The cross frames consist of a continuous T-sections. Every second cross frame is additionally stiffened by a diagonal. These diagonals consist of tubes 244.5 × 16 and are required for the shape stability of the cross-section due to the strong torsional buckling. Since the torsional load in the final stage is mainly caused by the carriageway curvature, the diagonals are arranged in such a way that they obtain tensile forces from this load. The slope of the diagonals therefore varies in the centre of the bridge and at the moment zero points for the supports 3 and 4.

The longitudinal stiffening of the web and flange plates is provided by T-profiles welded inside. These profiles follow the curvature in the top view and are adapted to the different box section widths and box section heights by changing their distance and number. Since the longitudinal stresses in the T-profiles on the bottom and top plates cause considerable secondary forces due to the horizontal curvature, the flanges of the stiffeners are welded to the bodies of the cross frames.

The cross-members of the cantilevers have a T-section and always connect to the top of the crossframes in the inner side of the box girder. The deck plate of the cantilevers has a continuous thickness of 20 mm in the area of the road-

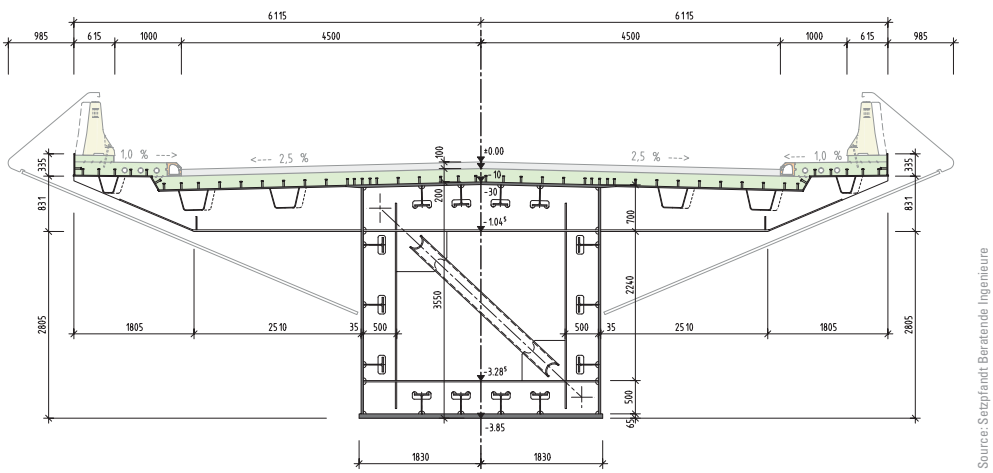


Fig. 4 Typical cross section

Tab. 1 Coating specifications

Layers	Primer	1st layer	2nd layer	3rd layer
Coating specifications	Metallisation Zn Al 85/15 (150 µm	Sigmacover (35 µm)	Sigmacover 280 (75 µm)	Sigmadur 1800 RAL 7004 (125 µm)

way, in the area outside the roadway the thickness decreases to 15 mm.

Since the outer side of the cantilevers had to be protected against corrosion, by means of zinc spraying, T profiles stiffening could not be foreseen here. The stiffening of the cantilevers was therefore performed with the usual trapezoidal profiles, which were adapted to the bridge curvature in polygonal sections.

The 20 cm thick concrete deck on top of the cover plate (C 35/45) is connected to the deck plate with studs in such a way that it carries longitudinally. In the transverse direction, the reinforced concrete slab takes over the transverse distribution of the traffic loads on the longitudinal stiffeners and reduces the deformations in the roadway and in the stiffeners.

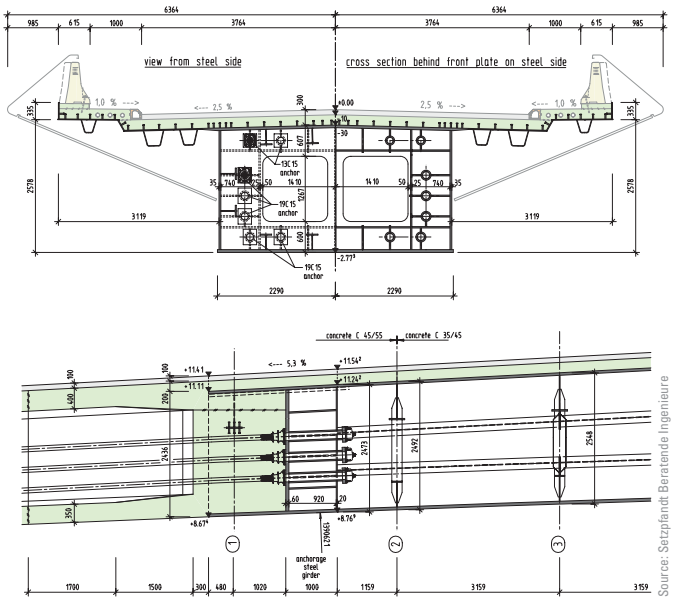


Fig. 5 Coupling joint

3 Coupling joints

The bending and torsion-resistant connection of the steel- and concrete box sections is effected by means of welded studs on the inside of the steel box and by continuing the tensioning elements from the posttensioned bridges in the steel construction. The welded studs take over the torsional and shear forces and the post-tensioning elements the horizontal and vertical bending moments.

The coupling area has a total length of 5.00 m, of which a length of 1.50 m is a solid concrete section. On the steel side, a 1.00 m long steel anchoring cross member is connected, in which the post-tensioning anchors were installed. This crossbeam absorbs the compressive forces of the posttensioned concrete and the tensile forces from the tensioning elements and transfers the resulting sectional forces to the steel section.

During the construction of the tensioned concrete superstructure, a 3.50 m long "coupling section" for the connection to the steel superstructure was left open. This coupling section was cast in two concrete steps after the steel construction had been installed. This required temporary auxiliary support structures under the approaches.

4 Bearing schedule in the final – and construction stage

4.1 Bearing layout

The superstructure is supported on spherical bearings at all axis. A part of the torsional forces in the superstructure are already dissipated by the vertical bearing forces at these points because of the existing layout of the bearings (they are not in a line and not central under the bridge axis). The torsional forces still present at abutments 1 and 6 are absorbed over the large spread of the bearings arranged there at both ends of the transverse girders, without any loosening of the bearings.

The longitudinal fixation for the entire superstructure is provided at abutment 6 by a centrally arranged bearing in the bridge axis. At this fixed point, the direction of movement of all other bearings in axes 1 to 6 is radially aligned. The transverse fixings of all the bearings are perpendicular to movement direction.

4.2 Supports during construction

In the construction stage after the steel superstructure has been installed, but before the connection to the post-tensioned concrete sections is made and before the bearings are connected to the steel superstructure, the steel box

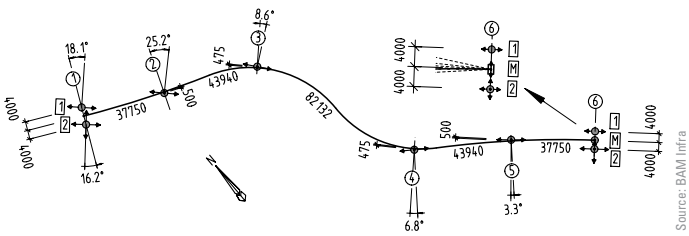
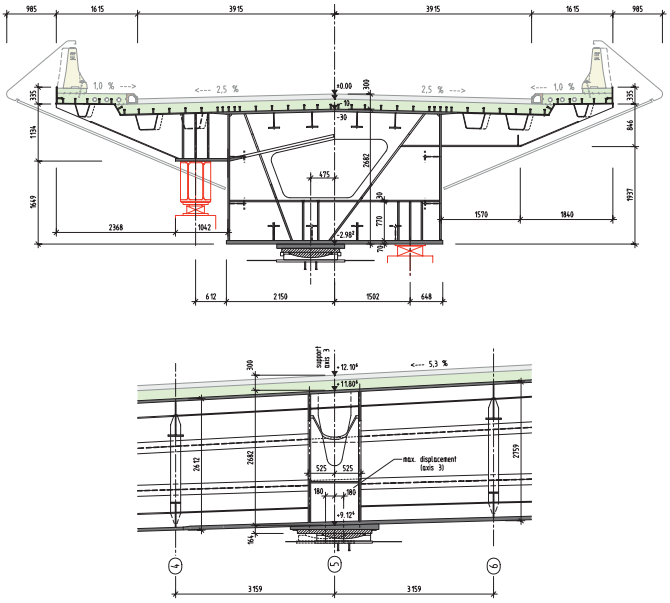


Fig. 6 Bearing schedule



Source: Setzpfandt Beratende Ingenieure

Fig. 7 Bearings and temporary supports in axis 3 and 4

girder is temporarily supported on an auxiliary support structure at the supports in axes 3 and 4. A transfer frame is fitted to transfer the loads from the spherical bearings into the box girder. This frame consists of two plates (t = 50 mm) at a distance of 1.00 m with inclined stiffeners in between. Due to the eccentric arrangement of the supports the jacking points are located on the inside and outside of the box to prevent the superstructure from tilting. On the outside, therefore, an extra bracket had to be attached, so that it would not be visible on completion. These support points on the superstructure can be used in the final phase as jacking points for a possible exchange of the supports.

5 Installation and transportation

The 110 m long central box girder was transported to the construction site in Zwolle in 10 sections by axle and assembled into a single girder at the preconstruction site. Because of the maximum width of 4.50 m, the transports took place at night. The maximum height of the box girder was 3.75 m, so a low-loader was needed to stay under the permitted height. The cantilevers were added 2 x 10 sections later. On small auxiliary supports with jacks, the sections were properly aligned and welded together.

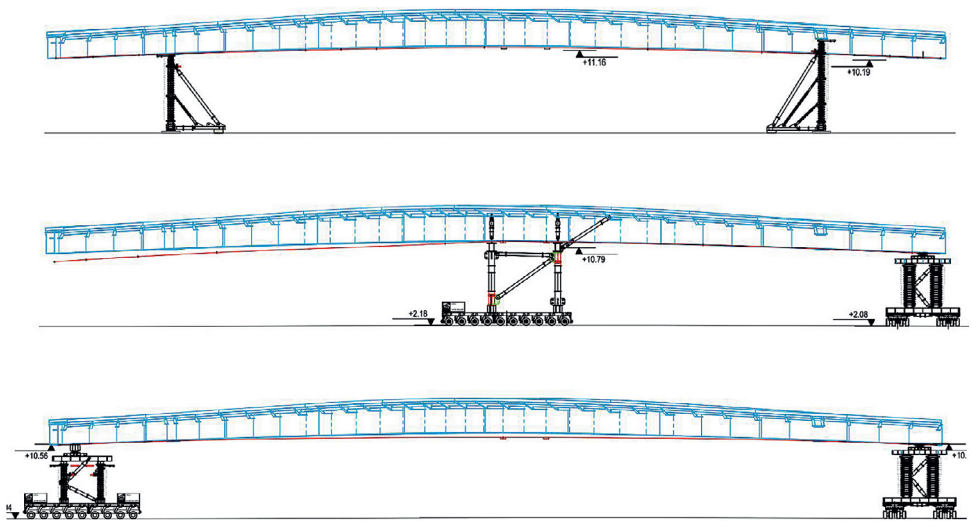
5.1 Jacking up the box girder

The bridge was jacked up in steps of 25 cm to a height of approximately 7.0 m by means of jack towers under the jacking points of the bridge at the position of the future bearing points. This height was necessary to be able to manoeuvre the bridge above the overhead wires, so that these did not had to be removed. The suspension of the overhead wires ensured that the train free period could be kept as short as possible to minimise disruption to train traffic.

5.2 Transportation

Now that the bridge was at the right height, the Self-Propelled-Modular-Transporter (SPMTs) with auxiliary supports could be driven under the bridge. The first group with 4 SPMTs was located approx. 10 m from the centre of the bridge and the rear group was under the end of the bridge. Between the two groups 300 tonnes of ballast was then placed, which shifted the centre of gravity of the bridge approx. 10 m, allowing for a cantilever of 60 m at the front. On top of the rear group of SPMTs, 120 tonnes of ballast were placed, which significantly increased the safety of the tipping stability. The ballast consisted of crane ballast.

After applying the ballast, the northern jacking tower could be unloaded, which caused the cantilever to deflect about 1 m. This deformation was also predicted in the engineering calculations. This load situation was normative



Source: Victor Buyck Steel Construction

Fig. 8 Transportation stages – lifting and SPMT setup

Source: Stefan Verkerk

Fig. 9 Cantilever ready for transportation

Source: Setzpfandt Beratende Ingenieure

Fig. 10 Bridge crossed the railway lines

for the steel box girder at the location of the central support.

The driving route across the construction site to the railway line was compacted with gravel and equipped with steel driving plates. The driving route was marked on the steel plates. During the night, the transport was driven to the railway line and parked on a specially constructed platform made of dragline mats. The cantilever reached so far that the railway was crossed.

A third set of SPMTs was waiting on the north side and was positioned under the cantilever. Two climbing towers with a turntable on top raised the cantilever. The turntable followed the angular rotation of the end of the cantilever as a result of the jacking. The 300 tonnes of counterweight were removed from the bridge and the middle group of SPMTs could be removed. The bridge was now supported at both ends, allowing the last 30 m to the auxiliary piers to be continued. Towards the end of the following day the bridge was placed on the two auxiliary pillars at axis 3 and 4, which temporarily fixed the bridge in the transverse and longitudinal direction.

6 Design calculations

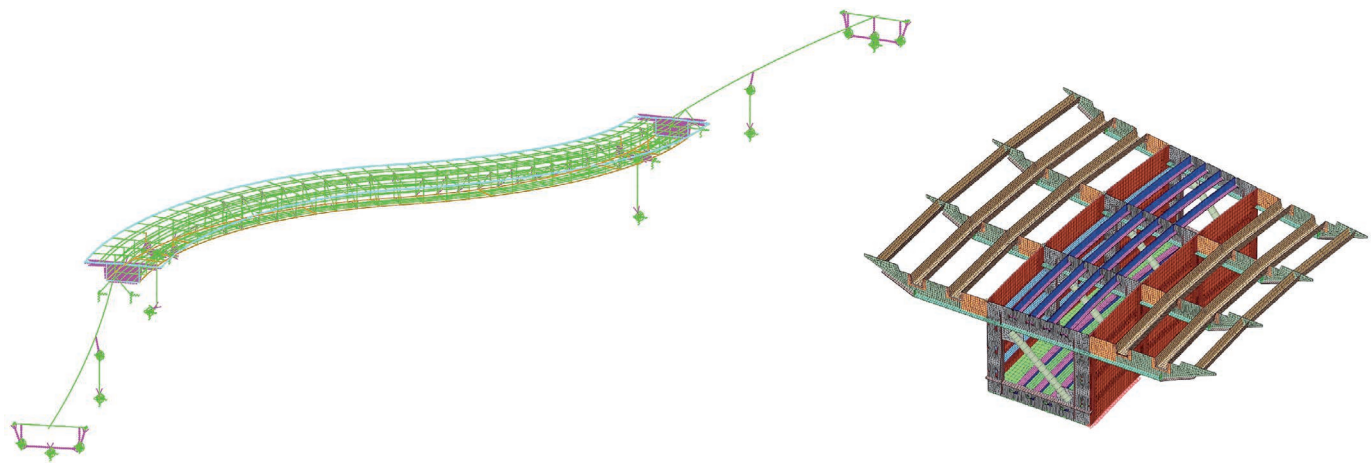
6.1 Global and local analyses

A global beam FE-model was used to determine the bearing reactions, deformations and global sectional forces. Later on the central steel girder was extended in the beam model with a FE-3D shell model, to analyse the deflections and force distribution due to torsion.

The crosssectional forces in the final phase were determined by also taking into account the construction stages from a previous phase with respect to the positions of auxiliary structures and temporary supports. Furthermore, 3D local models where used to study the transverse behaviour of the curved bridge sections, support sections and the connection joint with the concrete approaches.

6.2 Analyses during transportation

A separate calculation model was made to study the transportation of the bridge. Apart from the loads of the ±1.000 ton steel construction, the 420 tonnes of ballast special loads had to be taken into account



Source: Setzpfandt Beratende Ingenieure

Fig. 11 Integral beam with shell model and detailled FE-model

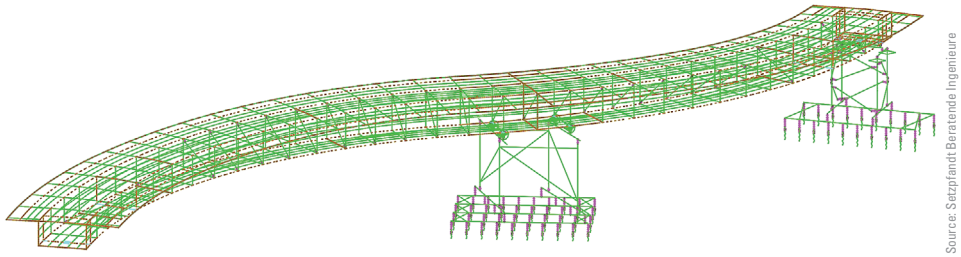


Fig. 12 FE-model during transportation

- inertia forces from braking (emergency braking);
- forces due to steering errors (longitudinal and transverse direction);
- Inaccuracies in the application of ballast and distribution of dead weight;
- Wind loads during start-up and higher wind loads at standstill;
- Skew of support structure;
- Subsidence and unevenness of the ground.

Special attention had to be paid to the fact that cantilever changed the direction of the torsion moment. The stiffened diagonals in the box would then no longer be loaded on tension, but on pressure. Local stiffeners where also needed to transfer the bearing forces into the box girder.

Data block

Client: Prorail B.V. Utrecht The Netherlands
Owner: Municipality of Zwolle
Architect: ipv Delft – creative engineers, Delft The Netherlands
Engineering team: BAM Infraconsult bv, Gouda The Netherlands
Setzpfandt Beratende Ingenieure GmbH & Co. KG, Weimar Germany
Contractor: BAM Infra Regional bv, Gouda The Netherlands
Victor Buyck Steel Construction NV, Eeklo Belgium

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