Design and construction of a semi-integral railway overpass using a Filler Beam Deck (WiB construction method)

Günter Seidl
University of Applied Sciences Potsdam

Design and construction of a semi-integral railway overpass using a Filler Beam Deck (WiB construction method)

Peter Kotz and Anton Braun[1],
Günter Seidl [2]

[1] SSF Ingenieure AG, Munich, Germany, pkotz@ssf-ing.de, abraun@ssf-ing.de
[2] SSF Ingenieure AG, Berlin, Germany, gseidl@ssf-ing.de

Abstract
An existing railway overpass in Dresden, built in 1898/99, didn't comply with the latest requirements. The structure will be replaced by a modern three-span-bridge using 'Filler Beam Deck' (WiB) construction method with two superstructures with double track lines. During construction the rail traffic, motor vehicles and tramway will be continuously in service. With respect to the present boundary conditions, the structure represents an innovative and extremely ambitious engineering task. Due to the sensitive urban environment, ambitious visual design requirements have to be fulfilled. The new railway bridge 'Großenhainer Straße' is an outstanding structure in respect of architectural and technical design as well as functionality.

Keywords: Railway bridge, semi-integral construction, filler beam deck

1 INTRODUCTION

The existing bridge dating from 1898/99 is a three-span welded trough bridge made of steel, consisting of four single-track trough structures, arched at the supports and abutments and with walkways on the outer superstructures.

The abutments are manufactured as evenly based gravity walls made of unreinforced concrete and partly faced with sandstone masonry. The intermediate supports consist of hinged supports made of cast iron or welded boxes and are also evenly shallow based.

Principal dimensions:

- total width of the superstructures: 21.20 m
- clearance widths: 16.20 m / 19.40 m / 16.20 m
- clearance height: 4.40 m – 4.65 m

The road overpass crosses at an angle of 64.85°.

Because of the four-track extension of the track with separation of the suburban railway lines and the long-distance railway lines, the planned increase for the line speed and the geometrical shortcomings as regards the cross-section of the roadway overpass, the present structure had to be replaced.
Beneath the bridge there are two double-track lanes, generous pedestrian areas and a double-track tramway that splits into two lines directly behind the structure.

The following requirements were made of the new structure:

- retention of the clearance dimensions of the bridge openings
- deck bridge with a continuous ballast track over all lines
- regulation dimensions for the roadway
- railway load models LM71, SW/2 and SW/0
- re-use of the existing abutments to the greatest extent possible
- the tracks run through at both ends of the structure without a gap between superstructure and embankment.
- construction executed in two sections
- railway, motor-vehicle and tram traffic to be maintained during construction.

Due to the sensitive urban situation and the intention to achieve a uniform design that is consistent with the nearby structures over the Hansastraße and the Friedensstraße, an accompanying architectural plan was to be created so as to produce a "family of bridges" formed by these three structures.

2 BOUNDARY CONDITIONS OF THE BRIDGE

Principal dimensions (Fig. 1):

- spans: 19.40 m + 22.10 m +19.40 m = 60.90 m
- skew: 64.85°
- total width of superstructure: 21.20 m

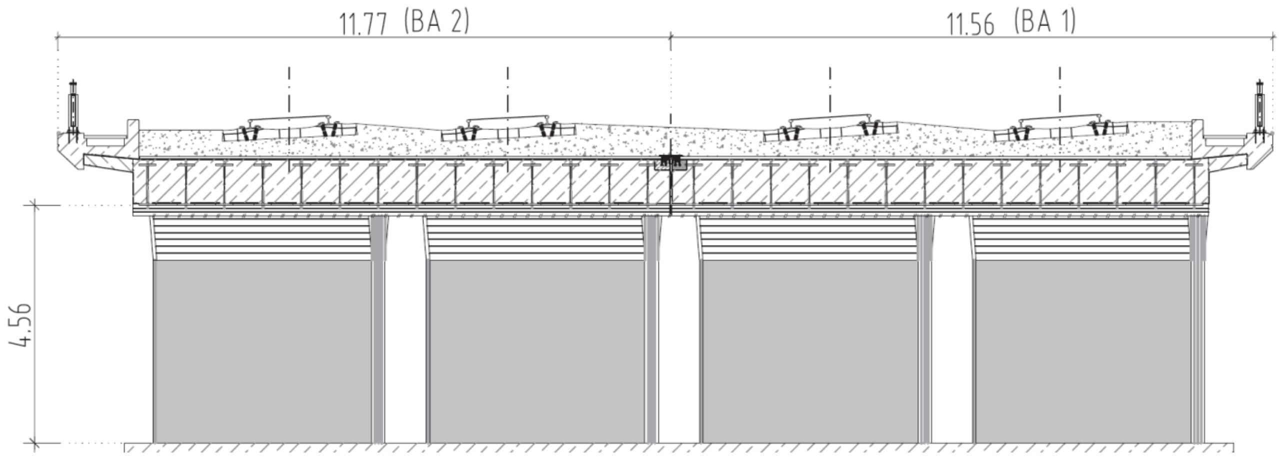

Fig. 1: Cross-section with the Filler Beam Deck

Abutments:
The existing abutments are retained to a large extent. New benchings with retaining walls are placed on top of them.

Supports:
Relatively narrow, reinforced concrete walls were designed, only 0.65 m thick, in part disintegrated. These must be designed as impact-resistant. They are evenly based on the existing foundations of the existing structure.

Superstructures:
Two structures each are provided for the long-distance railway and the suburban railway. Steel girder grids form the four deck bridges that pass over three spans. The superstructures of the oblique-angled existing structure feature vertical junctions. Service footpaths are attached to the outer superstructures.

Bridge bearing system:
There are longitudinal elastomeric bearings on the existing abutments. In order to distribute the longitudinal forces uniformly over the abutments, the longitudinal bearings are arranged alternatingly for each superstructure on the opposing abutment.

3 OPTIMIZED DESIGN FOR THE PROPOSAL

The optimized design basically consists of a construction design with a semi-integral support structure using a filler-beam deck (WiB) construction method. The footing foudation of the intermediate supports on the existing foundations was adopted by the design plan. The following list of keywords gives the features of the draft proposal:

- superstructures with filler-beam deck construction method (WiB)
- development of two double-track superstructures
- longitudinal support from the two rows of intermediate supports which are fixed into the superstructure
- transverse ends of the superstructures, following the crossing angle
- rows of intermediate supports based on the old foundations
- extensive re-use of the existing abutments with a new benching at its back

This achieves the following advantageous features:

- robust, deformation-resistant superstructure with low noise emissions
- minimization of longitudinal and transverse joints

- safe and deformation-resistant transfer of breaking forces into the foundation
- easy transition of the superstructure at the ends without rail expansion devices
- simulation to best advantage of the external appearance of the historic bridge
- advantages for maintenance because of fewer bearings and joints
- combination of the advantages of the framebridge with the filler beam deck method

3.1 Superstructure

Two double-track superstructures using the filler beam deck method (WiB) are built as continuous beams over three spans with spans of 18.90 m + 22.10 m + 18.90 m. In relation to the specified spans, a low construction height of only 0.88 m is available. Conversely, railway traffic demands considerable structural rigidity. The favourable statics system in the form of continuous beams and the filler beam deck construction method with its resistance to deformation (less deflective filler beam deck) represent an advantageous solution here.

3.2 Substructure

The pier discs in axes 20 and 30 are connected monolitically to the superstructure in order to transfer breaking loads. In this way, the existing abutments are relieved of horizontal forces.
On the abutments, just two elastomeric bearings per superstructure and axis are placed, one of them laterally fixed. Instead of the total of 32 bearings in the original design, the semi-integral construction method needs only eight bearings.
Because of the specifications of the design and the required visibility conditions for the tramway, the thickness of the piers was limited to 0.65 m. In order to avoid a “tunnel effect”, four individual pier walls per axis of approx. 4.25 m in length were arranged. The vault-like widening of the pier slabs at the transition to the superstructure makes it possible to make the loads flow from the superstructure into the pier slabs.
Both measures, inserting the piers into the superstructure and widening the piers at the transition, solve the problem of conducting the enormous braking and starting loads safely and with very little deformation through the very slender pier slabs into the foundation.
The existing abutments in axes 10 and 40 are retained. The shape of the new benchings with the projecting backfill faced toe wall is guaranteed. A shear-resistant connection with the existing structure is achieved by using bored, reinforced metal bars.

4 CONSTRUCTION DETAILING

4.1 Support foundation on large bored piles

Because of the tight situation with the tramway traffic in the area of the construction no lengthy interruptions in traffic were possible. There was no space available for this to execute the construction work in axis 20. Here it seemed expedient to work with a series of large bored piles and to lead off the braking and starting loads in axis 30 using pile supports (Fig. 2).
The single-row pile foundation in axis 20 possesses significantly less horizontal rigidity than the pile support in axis 30 with two rows of piles.
During construction, the rolled steel girders are supported on temporary frames. Each of the supporting frames at the pier axes is located in front of the structure axes on the pile cap plate. The frames at the support axes are supported with a surface foundation in front of the front wall.

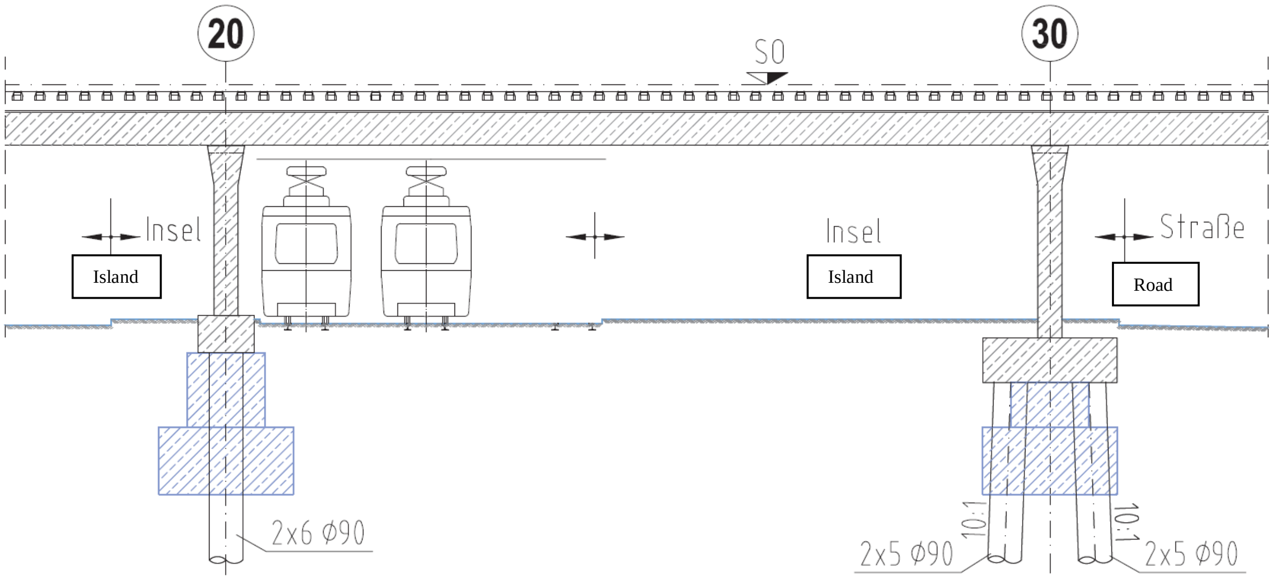

Fig. 2: Longitudinal section of the mid-span of the viaduct

4.2 Rolled steel girder joints

When designing the draft proposal it became clear that because of the great length of the rolled steel girders of 60.60 m welding joints need to be made.
In the course of work preparation, because of the restricted space of the construction site and the high quality demands for the manufacturing, the designing of workshop joints was judged to be the optimal solution. The arrangement of the joints had to be changed, placing them at points with the lowest possible static stress.

5 STRUCTURAL MODELLING

The structural calculation was done by finite element method. The superstructure, the piers and the pile cap plates were displayed as shell elements. In the static system, the bored piles were treated as bars and are connected to the system by rigid connections (Fig. 3).

One property of semi-integral structures is that the rigidity of the subsoil and foundations has a decisive influence on the dimensioning of the structure and thus it must be displayed realistically in the static model. A foundation had to be designed that on the one hand is of sufficient rigidity to absorb the loads from braking and starting forces and in addition meet the criteria for deformation for the live loads. At the same time, however, the rigidity may not be too high so that the constraining stress resultants caused by temperature, creep and shrinkage can be absorbed. An essential feature in the calculations for semi-integral structures with limit values for embedding is that because of load and constraining forces there is, in blanket terms, no "safe side". Altering the embedding can, for example, be favourable for the reinforcement of the piers but turn out to be unfavourable when verifying the superstructure. A corresponding range of input values must be taken into account in the static calculation.
With the pier foundation, the interaction between subsoil and structure was able to be taken into account in the calculation model. The bored piles were modelled in the system as elastically bedded bars taking into consideration the group effect and a pile footing spring that was led away from the resistance-settlement curve (Fig. 4). The bedding concepts defined in the soil survey were treated as limit values.
The concepts for embedding and the pile footing spring from the soil survey were entered into the calculation as lower limit values. As upper limit value for the pile embedding, the values from the soil survey were to be increased by a factor of five in the area of the existing foundations and below this by a factor of three. The spring rigidity of the pile footing spring was to be increased in the case of the upper limit by a factor of three. By applying upper and lower limit values for the embedding, any possible spread in the properties of the subsoil was considered.

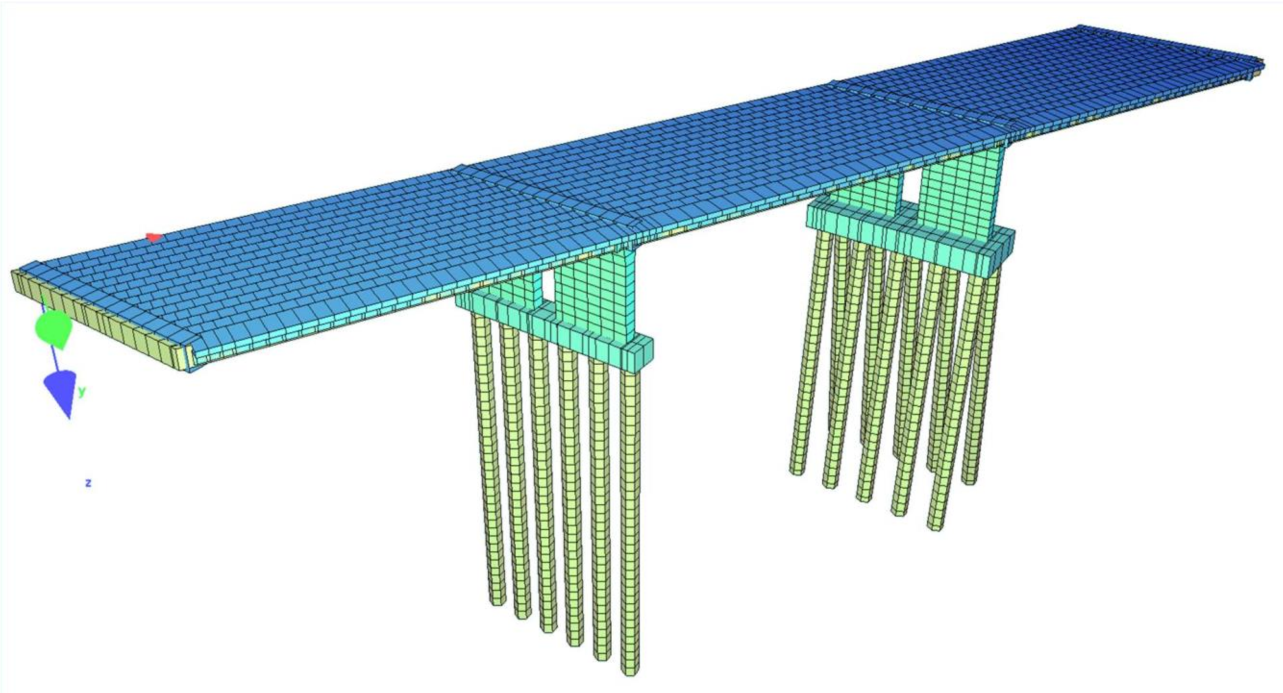

Fig. 3: Structural system of the bridge

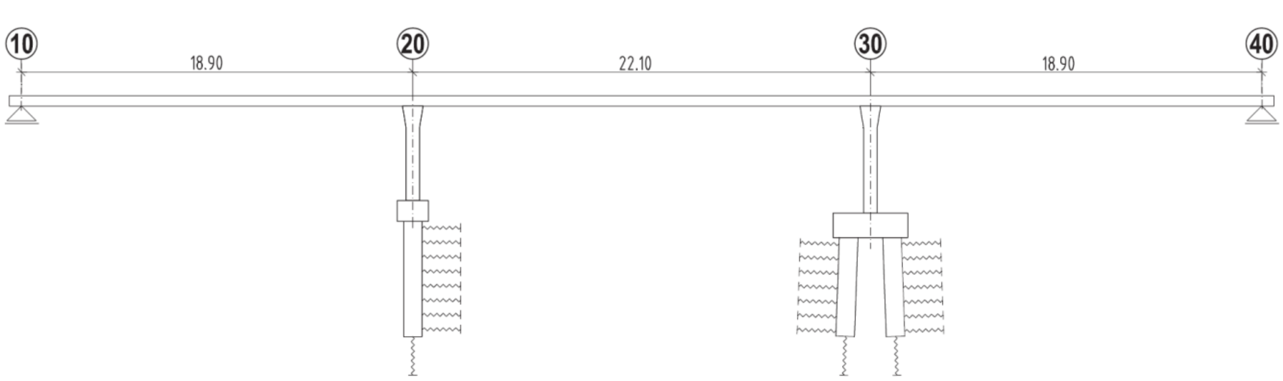

Fig. 4: Embedding of the piles

5.1 Detailing

In the detailed planning, special attention was given to the static and constructive design of the rigid connection between piers and superstructure. The flow of forces into the framework nodes was displayed on a truss-and-tie model that showed quite particularly the combined effect of the steel girders in combination with the concrete (Fig. 5).

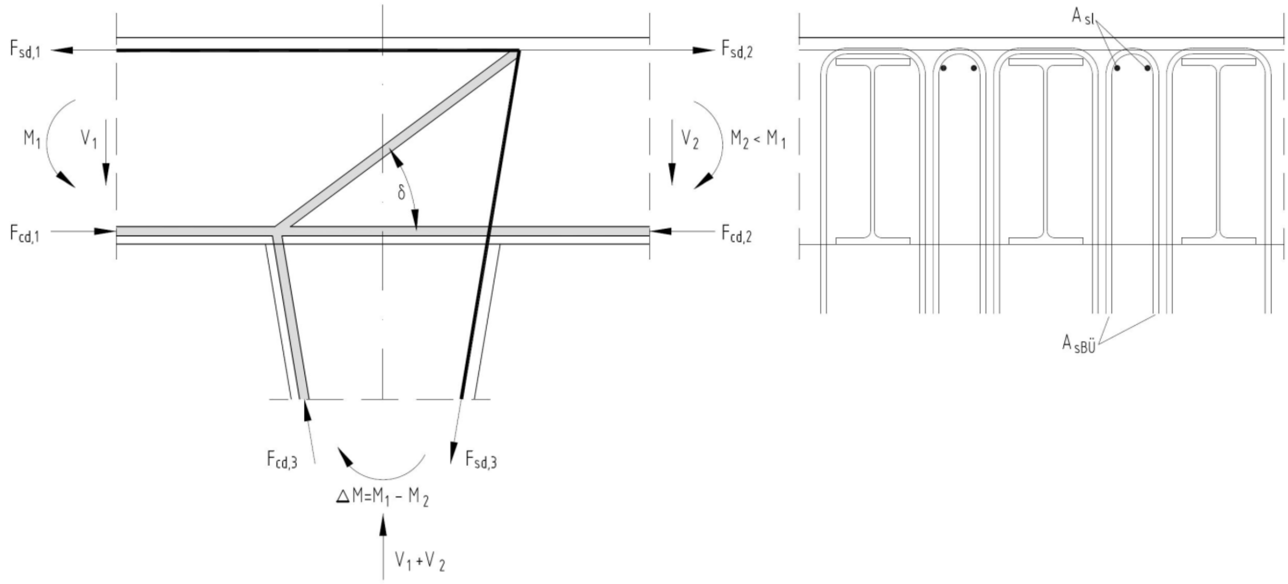

Fig. 5: Truss-and-tie model in the monolithic connection between pillar and superstructure

In comparison with standard semi-integral framework structures made of reinforced concrete, the geometrical and construction constraints also had to be overcome using the WiB construction method. With reinforced concrete frames, the required reinforcement of the frame corner can easily be led from the substructures into the superstructure. With a WiB superstructure with the same reinforcement guiding, this is possible only to a very limited extent.

Because of the vertical loading and the horizontal loads from braking and starting, bending moments occur over the supports, which must in part be led off into the piers and the foundation. The vertical tie rods were looped over the steel girders and guided as a longitudinal reinforcement in the superstructure (Fig. 6). This principle of reinforcement guiding using loops is also known from pre-stressed concrete frame bridges. The tie rod is not guided “around the corner”, so to speak, but rather it merely encircles the horizontal tie rod as a loop.

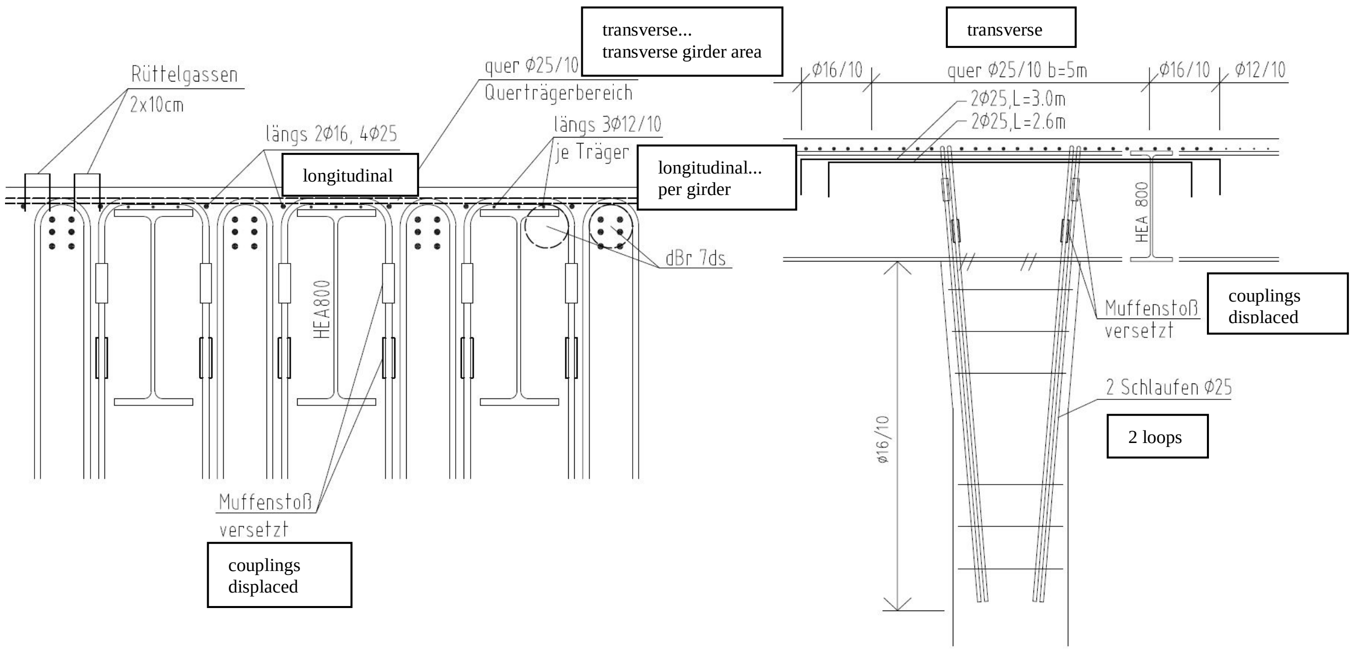

Fig. 6: Guiding of reinforcement at the support

The tolerance requirements for the incorporation of the reinforcement were very strict, since the loops were guided directly via the rolled steel girders. An additional difficulty was that all loops above the construction joint between pier and superstructure were pushed through using a muff coupling. This was necessary because the pier was to be concreted up to the lower edge of the superstructure, but could not be “threaded in” through loops encased in concrete. The vertical reinforcement between pier and superstructure is arranged between the steel girders in the case of a WiB superstructure. A spacing between the girders of only 0.67 m and the girder with of 30 cm result in a high degree of reinforcement that was taken into account in terms of design by using appropriate distances between bars and vibration passageways (Fig. 7).

Fig. 7: Connection over the support

The track stresses were verified by using upper and lower limit values for the foundation rigidities. In the case of sudden shock loading such as when braking and starting, the subsoil reacts with greater rigidity than is the case with slow deformations from temperature, creep and shrinkage. The decisive factor is the loading velocity. Accordingly, the values for embedding in the case of loads from braking and starting were able to be increased by a factor of two. In addition, it was shown that the piers in the support cap area in used stage I (= uncracked stage) stay in place. These boundary conditions are crucial for showing the deformations in accordance with DIN Technical Report 101 Appendix K. In this verification, the maximum longitudinal displacement from braking and starting is to be limited to 5 mm; otherwise it must be proven that the permissible values for the track stresses are adhered to. Proof of limitation of the longitudinal displacements and proof of the track stresses were able to be provided and installation of rail expansion devices avoided.

6 EXECUTION OF THE BRIDGE

In the area of pier axis 20, 12 vertical piles with a length of 18 m and a diameter of 90 cm were manufactured. In the area of pier axis 30, a pile support was required made of piles of a length of 15 m and an incline of 10:1.
Manufacture of the substructures was done to a great extent on the basis of standard construction methods and formwork systems. Because of central prefabrication of the formwork boards for the pier slabs at the works facility, work in the proximity of the tram lines was able to be minimized.

Manufacture of the abutments in two construction phases was made possible by an auxiliary wing in the construction axis and trench lining along the track. After completion of the 1st construction phase, this trench lining along the track merely has to be re-anchored to allow for it to function for the 2nd construction phase.

6.1 Frame corner manufacturer

Special emphasis had to be placed on the manufacturing of the frame corners between superstructure and pier slabs. Even the connecting support, which in future was to lie between the WiB girders, had to be calibrated by the surveyor for purposes of a smooth relocation of the steel girders, and also installed with millimetric precision. In addition to this, after placing the girders were to be encircled by reinforcement loops from the piers and thus linked into the pier reinforcement. This was done with reinforcement couplings. Because of the high degree of reinforcement of these connecting areas, it was also necessary to fit the upper areas of the piers by a haunched surface. The formation of the arches was coordinated at an early stage with the accompanying architectural planning.

6.2 Transport and relocation of the WiB girders

The manufacture and installation of the more than 60 m-long rolled steel girders for the superstructure construction constitute a novelty in railway bridge building. After a preparation period of more than one year, the 14 girders for the first construction phase were produced over the course of several months in a steelworks in Luxembourg and bolted together in seven pairs of girders. Previously, HEA 800 profile steel girders had never been manufactured in such excess length. Since it is not technically feasible to roll girders of this length, girders in lengths of 36.75 m and 23.85 m were welded and coated at the works facility using the highest standards of manufacturing and monitoring.
Next came the loading onto a special train of more than 500 m in length. The 80 cm-high pairs of girders were supported on the waggons with a free span of around 50 m. The steel girders rested on groups of three waggons each. Pivot bogies, on the first and third waggon respectively of each group of waggons, enabled the girders to lie completely flat during the journey, while the waggons can follow the course of the track.
The placement of these oversize steel girders was completed on the weekend with the aid of two mobile cranes.
Subsequently the girders were fitted with fibre-cement plates, the reinforcement layer that leads through the boreholes located in the steel girders was relocated and the lateral formwork of the superstructure was manufactured. To minimize compromising the road and tramway traffic only 30 hours were available in which to perform all this. The necessary construction-site agreements were therefore planned down to the last detail and optimized in advance with the project participants.

7 SUMMARY / OUTLOOK

For the construction of the replacement of the existing bridge in Dresden extremely difficult conditions have to be fulfilled. With the submitted design and realization the given targets will be reached

- Endurable structure
- Full satisfying functionality
- Advantageous design
- Securing the date of completion

This is the result of the successful cooperation of all involved members of the various teams. With the successful installation of the surplus rolled iron girders, the presently existing limits of functionality were exceeded, which was generally approved by engineering experts.