The Balsberg Viaduct of the new light rail network to Zurich-Airport

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Summary

This paper reports on the key structure for the new light rail network in the area of Zurich-Airport – the Balsberg Viaduct. The project was published for total contractor submission in October 2005 based on a highly detailed preliminary project. The contract was awarded to a local joint venture team comprising two contractors (Marti AG / Stutz AG) and two civil engineering consultancies (Synaxis AG / Henauer Gugler AG). The paper comments on the several optimizations to the preliminary project made by the winning team. The challenges presented by the local soil conditions and the particularly restraining construction site conditions are also described. The Balsberg Viaduct is currently the major bridge project under construction in Switzerland. The viaduct will play a key role in bringing people closer to Zurich Airport – and thereby bringing Zurich and Swiss people closer to the world.

Keywords: Viaduct, concrete bridges, light rail, pile foundation, soil conditions, construction site conditions, pre-stressing, box girder, monolithic structure, total contractor submission.

1. Introduction

The area around and including Zurich Airport, is steadily growing. Located in the Glatt valley near Zurich, the area is home to many national and international firms that have their headquarters and production facilities close to the airport. Public transport to the airport and its surrounding region is currently provided by the Swiss Federal Railways, Zurich's local commuter rail network as well as local buses, taxis and hotel shuttle services. In order to increase the capacity of the public transportation system, it was decided to build a new set of light rail lines to Zurich Airport and surroundings in the Glatt valley – the new network of the "Glattalbahn". These new lines will be built in several stages and the tender for each stage was submitted in a separate lot.

Within the direct extension line from Zurich-City to the airport, the Balsberg Viaduct may be considered the key structure. This viaduct – passing the name-giving former headquarters of Swissair at Balsberg – has a total length of almost 870 m. After the total contractor's optimization, it consists of four box girder bridges with lengths of 72 m, 146 m, 154 m and 104 m, a high-level station approx. 66 m long, a T-beam bridge of 94 m length, two approach ramps with 94 m and 138 m length, and two pedestrian bridges of 19 m and 28 m length, ending at the station.

The Balsberg Viaduct was published for total contractor submission in October 2005. The contract was awarded to a local joint venture team; several other teams from Switzerland, Germany and Austria also tendered for the contract. The paper highlights the optimizations made to the preliminary project in terms of expansion joint layout, pile foundation and structural details.

2. The total contractor submission project for the Balsberg Viaduct

The longitudinal section including the soil model, pile foundations and expansion joint layout ("Dilatation") is shown in Fig. 1, in two parts due to the length of the structure. The following sections describe the originally proposed structural layout and their main features. The interface between the total contractor for the main structure and the total contractor for the track work is defined by the protection mortar above the sealing.

Along with the given alignment of the light rail and the high-level station, the structure has to consider several additional constraints such as under-passing roads and accesses to industrial areas and parking, denoted in minimum heights in red color in Fig. 1.

2.1 General structural layout and expansion joints

Except for the part denoted "Brücke Rampe Balsberg", all substructures of the viaduct have a fixing point for longitudinal elongation, denoted "Festes Lager". Those points are formed by pier sections with double width. These piers are also structurally responsible for the transfer of longitudinal forces into the foundation. The transfer of horizontal break and acceleration forces from the slab track into the superstructure of the viaduct is provided by shear corbels located at the end of every expansion section, also see Fig. 2. Along with the given layout of the expansion joints (allowing optimization during tender), the mechanical construction of the joint was prescribed as well.

Except for the fixing points for elongations being monolithically connected to the superstructure, all pier heads were assumed to have bearings. However, it was already proposed in the submission project to check the possibility of monolithically connecting the other pier heads as well.

2.2 Elements of superstructure

2.2.1 Main viaduct – box-girder bridges

For the parts denoted "Brücke Werft Balsberg" and "Brücke Werft Borddienst" in Fig. 1 – corresponding to the main part of the viaduct – box-girder sections were proposed. A typical cross-section is shown in Fig. 2, along with the detail of the edge beam. For the longest span of 37.12 m in the part "Brücke Werft Balsberg" crossing a local major road ("Flughofstrasse"), a box-girder section with 0.4 m more box height was proposed in the tender drawings. The box-girders must be post-tensioned with electrically fully isolated tendons, in order to allow electro-magnetic resistance

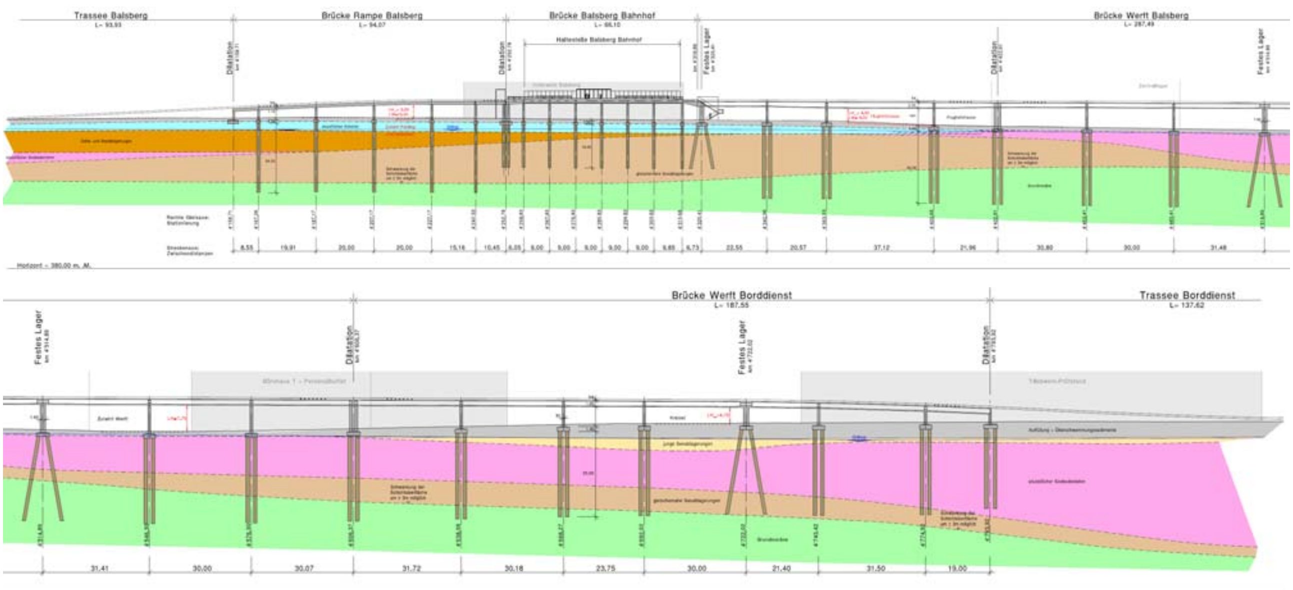

Fig. 1 Longitudinal section with soil information, as submitted for total contractor tender.

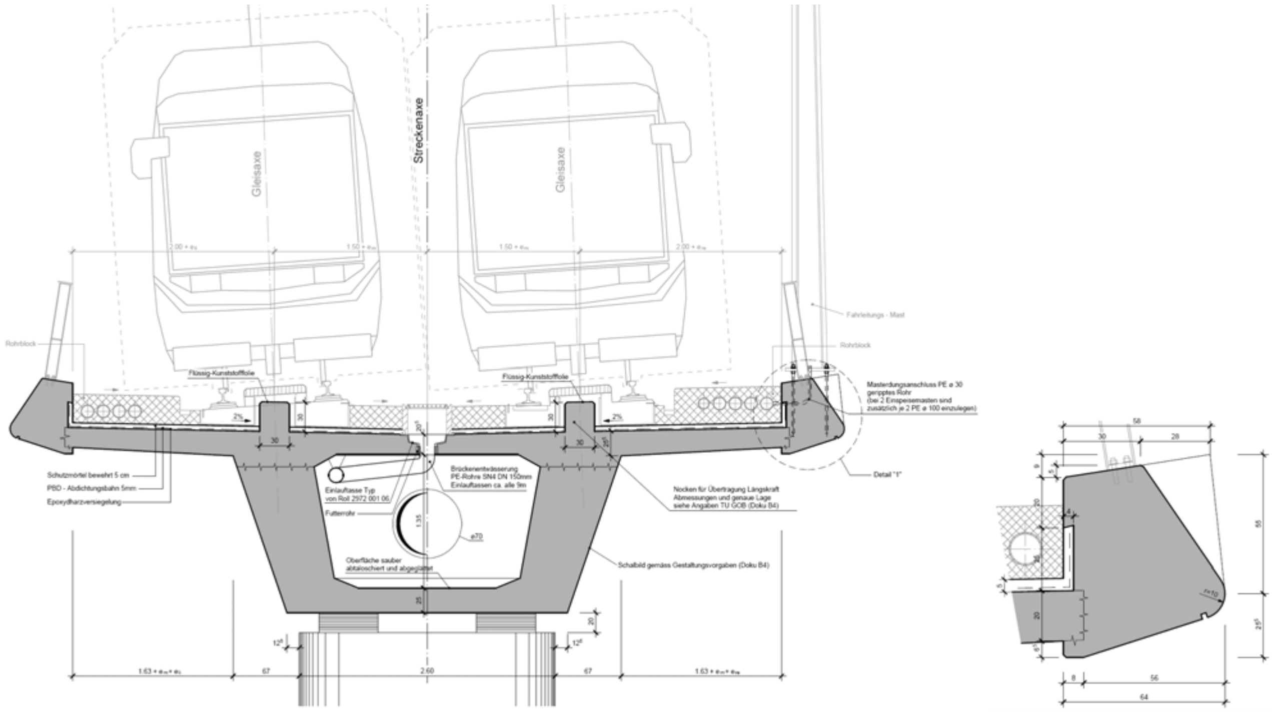

Fig. 2 Typical cross-section of box-girder bridges and detail of edge beam, as submitted for total contractor tender.

measurements to supervise the durability of the tendons. All sections have to be fully pre-stressed for service loads, only allowing tensile stresses in the outmost fibers of the cross-section smaller than 70% of the average tensile strength of the concrete ($\sigma_{ct} \leq 0.7 \cdot f_{ctm}$); a value which corresponds to the 5%-fractile of concrete tensile strength according to the current Swiss code SIA 262 (2003).

Attention may be paid to the shape of the edge beam of the deck – this shape will be provided to all bridges and overpasses of the light rail network as a distinctive mark of the new transportation network.

2.2.2 High-level station and pedestrian bridges

Fig. 3 shows typical sections through the high-level station ("Brücke Bahnhof Balsberg") and the adjoining pedestrian bridges ("Fussgängerbrücken"). All structural elements are made of reinforced concrete, except the post-tensioned pedestrian bridge over the adjacent street ("Flughofstrasse").

The architectural layout of the station itself is also part of the architectural design standard as a distinctive mark for the new light rail network "Glattalbahn", similarly to the edge beams of the superstructures shown in Fig. 2. This rail stop design is already provided in the lots that have been executed up to now.

2.2.3 Approach ramp bridge

Fig. 4 (upper) shows the cross-section of the approach ramp bridge. The T-beam must also be fully post-tensioned for service loads with electrically isolated tendons. The short piers of the approach ramp bridge are monolithically connected to the superstructure.

2.2.4 Approach ramps

The approach ramps are U-shaped sections of reinforced concrete with a total height of up to 5.2 m and variable thickness of side walls and bottom slab, as shown in Fig. 4 (lower). The 'caissons' are filled with layered and compacted gravel material and provided with a compacted foundation layer for the light rail track with prescribed minimum stiffnesses for all layers.

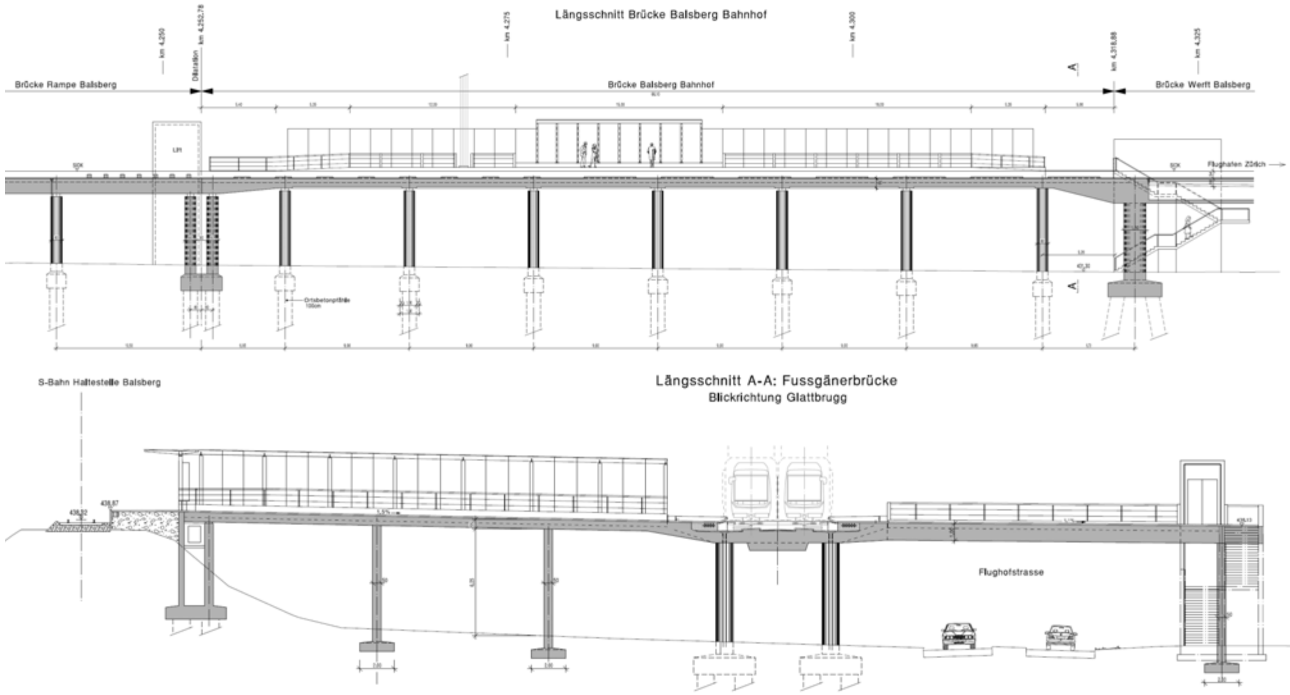

Fig. 3 Typical section of high-level stations and pedestrian bridges, as submitted for total contractor tender.

2.3 Foundations and soil conditions

2.3.1 Pile foundations

As shown in Fig. 1, all parts of the viaduct are founded on piles. In the structural design for the submission project, only the foundation of the highest loaded piers was investigated and the same layout of piles with a diameter D = 1.0 m was applied for all piers. For the piers with horizontal load transfer, inclined piles were proposed.

2.3.2 Soil

Above a compact base moraine in up to 30 m depth (green layer in Fig. 1) with high bearing capacity and stiffness, several layers of soil can be found containing higher or smaller amounts of clay or other soft soil components. These parts of the soil show a considerably lower bearing capacity and stiffness but allow certain mantle friction resistance for the boring piles. However, the brown layer in Fig. 1 denoted "gletschernahe Seeablagerungen" (representing layers of delta material from the retracting glaciers) already exhibits reasonable bearing capacity and stiffness properties for piles with significant tip resistance.

3. Technical optimizations by the joint venture team

The following drawings and explanations represent the project status of the tendered project. The project has been further developed in the meantime.

3.1 Longitudinal structural layout – expansion joints

The first concept optimized during tender was the layout of the expansion joints in order to reduce the number of expensive mechanical expansion joints with usually intensive maintenance. Fig. 5 shows the structural layout submitted by the total contractor, exhibiting several general advantages:

- Harmonized expansion lengths, reducing the number of expansion joints and allowing the application of the same type of mechanical expansion device in all joints,

- A floating superstructure, eliminating the necessity of accessible abutment chambers,
- Eliminating the piers with double width – architecturally deemed inappropriate – for the transfer of horizontal loads from the floating superstructure, leading to optimized actions on the architecturally sized piers and a calmer overall appearance,
- Monolithic pier head joints eliminating the requirement of bearings. The disadvantage with bearings in concrete structures that bearing friction often is not exceeded due to the high dead loads, leading to unconsidered loadings on the piers, is also eliminated. The pier heads next to the expansion joints are provided with concrete hinges in order to reduce restraint actions in the piers.
- Increasing redundancy of the subsystems by monolithic joints.

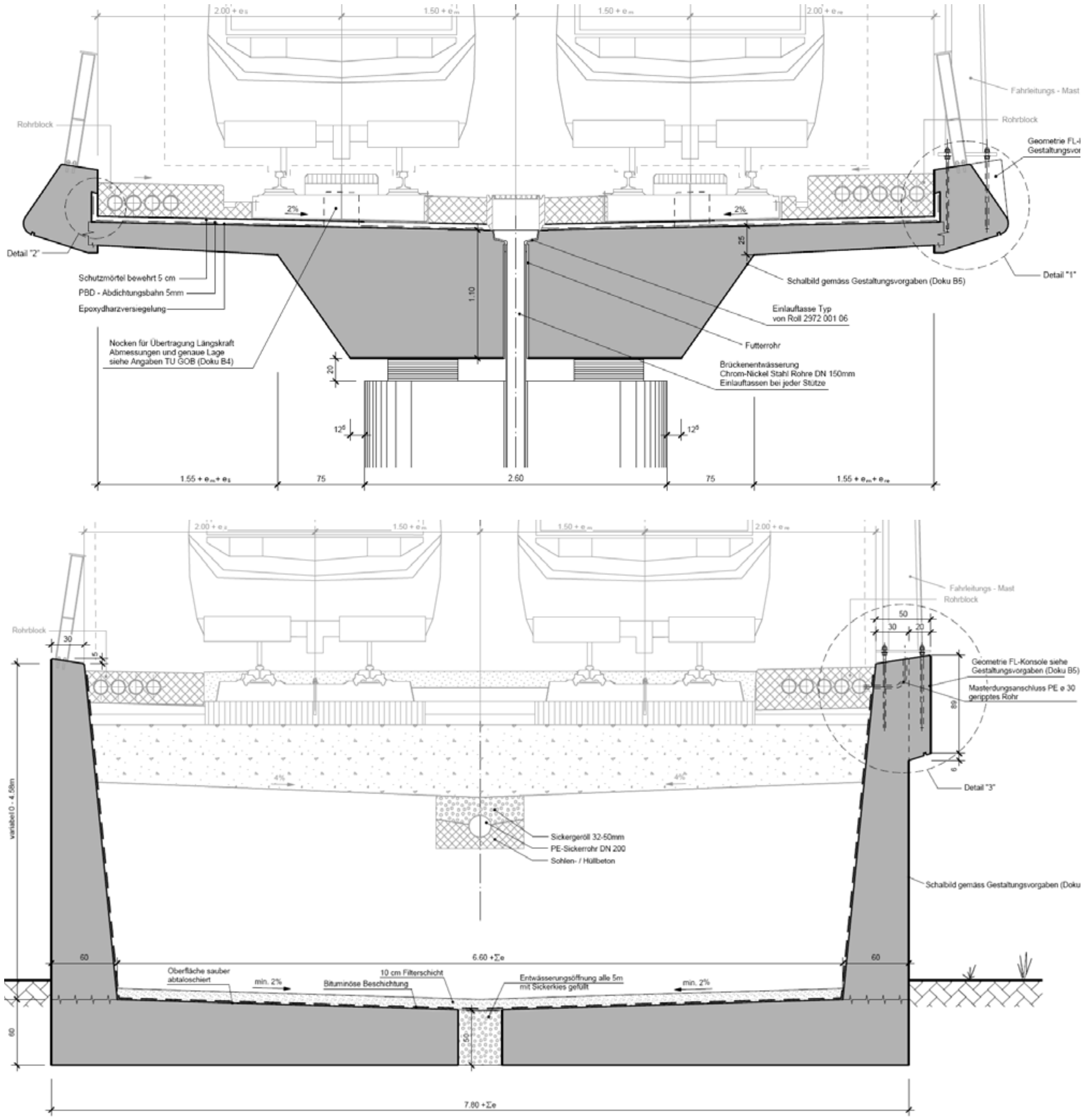

Fig. 4 Cross-section of approach ramp bridge (upper) and of approach ramps (lower), as submitted for total contractor tender.

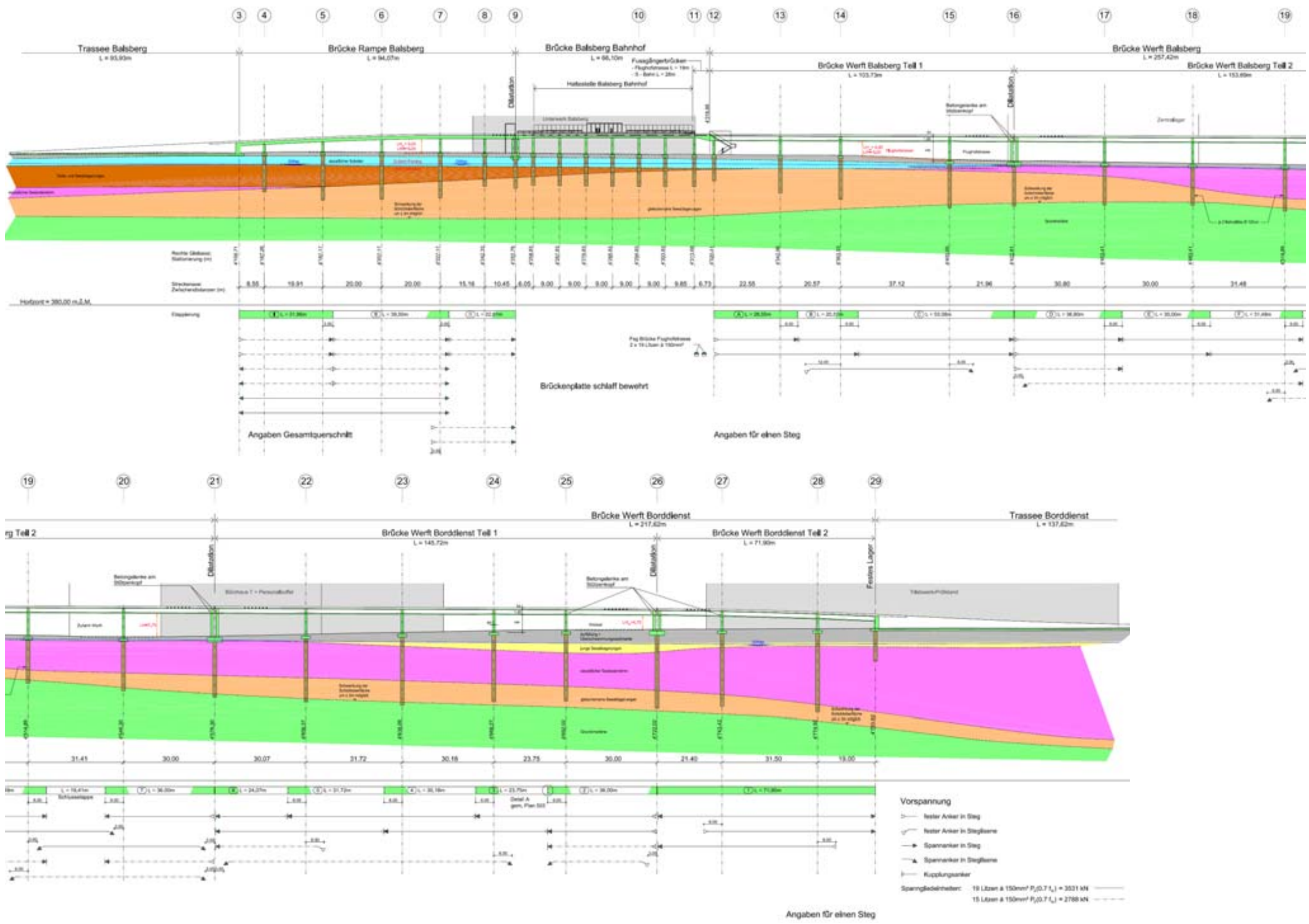

Fig. 5 Longitudinal section with layout of expansion joints, prestressing and pile foundation, as submitted by total contractor.

It is believed that all these optimizations led to a considerably decreased number of structural elements with high maintenance and thereby to significantly lower life-cycle-costs.

3.2 Elements of superstructure

3.2.1 Main viaduct – box-girder bridges

A further point of focus in the optimization process conducted by the joint venture team consisted in checking the optimization potential of the cross-section. A solution with a double T-beam section was investigated as well but led to the conclusion that several disadvantages existed (appearance, execution, costs). It was therefore decided to proceed with a box-girder section.

Preliminary investigations during tender showed that the increased height of the box girder in the longest span of the part denoted “Brücke Werft Balsberg Teil 1” in Fig. 5 is not necessary and can be balanced by increased pre-stressing force. It was furthermore decided to prefabricate the edge beams in segments of 3 m. The analysis of execution options for the superstructure resulted in the application of the span-to-span method as shown in Fig. 5 by the means of formwork girders below the box girders. The tendons are made of subsequently drawn-in strands and the ducts are coupled on site, see Fig. 6. These changes result in several advantages:

- Slender appearance of the viaduct in the long span, also providing increased height for the under-passing road,
- Optimized surfaces of the concrete edge beams with high optical quality and durability,

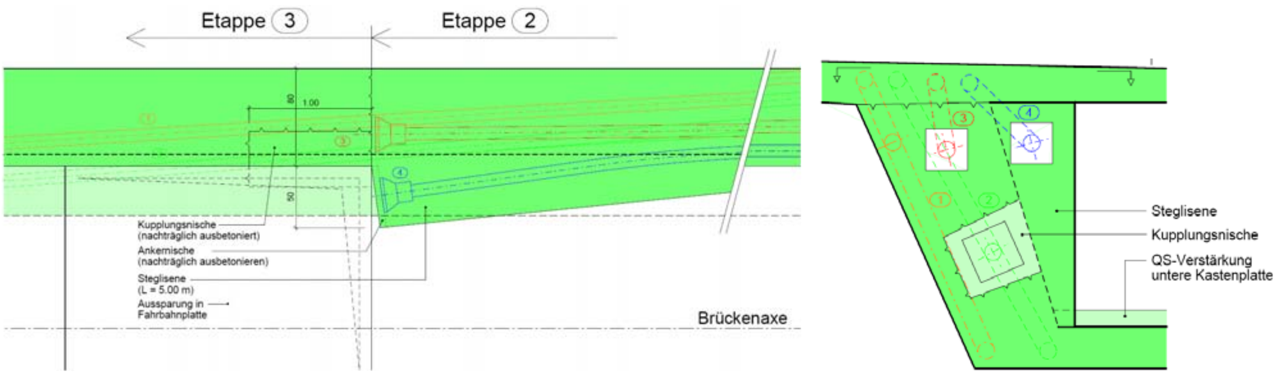

Fig. 6 Deatil of tendon anchorage – horizontal section (left) and cross-section (right).

- Optimized conditions for execution with constant girder height and no necessity of intermediate supports of the formwork girders; this allows for repetitive effects, thereby leading to high safety for dead lines and guaranteed quality,
- Minimized impact on the traffic below the viaduct (to be assured at all times),
- Post-tensioning layout in accordance with optimized expansion joint layout, allowing fully pre-stressed sections also during execution stages; staggered coupling of the tendons in order to omit coupling joints with decreased durability; durable and reliable embedment of anchorages in structural concrete. Due to on-site coupling of the ducts, faults in the ducts during execution of other works can also be omitted.

3.2.2 High-level station and pedestrian approaches

These structures allowed only for minor optimizations. The joint venture team only proposed the replacement of the abutment chamber in the rail dam by a simple pier founded on a boring pile and monolithically connected to the superstructure.

During later project phases (after tender) the spans of the plate for the high-level station were increased by 1.5 m, thereby eliminating the relocation of existing utility pipes, facilitating execution and further increasing architectural quality.

3.2.3 Approach ramp bridge

For this part of the viaduct, the optimizations proposed by the joint venture team were similar to the ones for the box-girder sections:

- Monolithic joints of piers and superstructure eliminating abutment chambers, thereby allowing facilitated application of sealing membranes, increasing static redundancy of the superstructure and minimizing life-cycle costs,
- Prefabricated edge-beams of the section for optimized quality and durability,
- Using the concrete slabs of the slab track of the rails to reduce differential settlement in the filling of the approach ramps.

3.2.4 Approach ramps

The shape of the approach ramps was adopted by the joint venture team, but also optimized in several points:

- Staggered thicknesses of bottom slab and walls as well as execution lengths optimized for shrinkage and provided with sealing tapes in the wall joints, leading to decreased material quantities and increased durability,

- Separation of the U-shaped section in two L-sections in the parts with low height, leading to optimized material quantities and increased execution speed,
- Application of geo-textiles between filling and slab track foundation layer and around the drainage pipe to prevent congestion.

All these measures lead to lower execution and life-cycle costs due to increased durability and decreased maintenance.

3.3 Foundations

Beside the general structural layout, the foundations offered the greatest potential for optimization in the opinion of the joint venture team. Along with optimized and thereby considerably decreased lengths of the drilled piles in accordance with the provided soil information, the joint venture team proposed to apply two drilled concrete piles D = 1.2 m per pier instead of four piles D = 1.0 m, leading to further advantages:

- increased execution speed due to less vehicle movements, hence lower execution costs,
- increased specific area for mantle friction and tip resistance as well as resistance for horizontal loads, thereby optimizing the collaboration of piles and superstructure,
- reduced impact on ground water, thereby increasing environmental protection,
- use of pile caps as foundations of formwork girders, leading to reduced execution costs.

4. Dates

The foundation works are in progress since December 2006. All the works for the concrete structures must be finished by December 31st, 2007, for the continuation by the track contractor.

5. Conclusions

The focus of the joint venture team in the optimization of the tendered viaduct was clearly on:

- Minimum maintenance: minimum number of bearings and expansion joints, consequent drainage of cross-sections and longitudinal subsystems; application of additional protection measures for durability where appropriate and effective.
- Maximum robustness: high redundancy due to monolithic joints; ductility by provision of minimum reinforcement; application of durable materials.
- Minimum risk: detailed planning and execution schedules of the submission project leading to minimized risks for execution and costs; close co-operation with major sub-contractor already during tender stage; application of approved products and execution methods.

It is believed that the strict and early focus on these criteria led to the optimization of the relevant parts of the Balsberg Viaduct in terms of material quantities, execution risks and life-cycle costs. In addition with the early and narrow collaboration of all members of the joint venture team, it is believed that this process resulted in winning the total contractor submission.

6. Acknowledgements

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