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DESIGN AND CONSTRUCTION

THE BRIDGE OVER THE WILDE GERA VALLEY THE LONGEST-SPANNING ROAD ARCH BRIDGE IN GERMANY

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Abstract: *With the construction of the new highway A71 between Thuringia and Bavaria the deep valley of the "Wilde Gera" at the location of the ridge of the Thuringian Forest is crossed in a height 110m above the valley. The original conceptional design was a beam bridge. The alternative proposal "Arch Bridge" was chosen by the client for its special aesthetical design. The foundation works at the location of the disposal site in the valley could be avoided. Therefore relocation of the disposal site became obsolete. Special protection works for the existing train tracks and the country road L2149 could also be avoided. The span of the arch is 252 m. The total length of the bridge is 552 m and has not been modified. The superstructure consists of a single-piece steel composite cross-section, which carries the deck slab for both carriageways with a width of 26.5m.*

1 INTRODUCTION

As one of the traffic network projects for the German reunification, the Autobahn A71/A73 connects Thuringia with Bavaria and provides the Thuringian Forest and the region around Suhl and Meiningen with highway access. The highway crosses the ridge of the Thuringian Forest between Ilmenau and Zella-Mehlis. Just before the Rennsteig Tunnel, one of the longest sections on the ridge, the Autobahn crosses the Wilde Gera valley. The depth of the valley requires a height of roughly 110 m. Additional obstacles in the valley consist of the road between Gräfenroda and Gehlberg and the railroad line Erfurt-Suhl

2 ORIGINAL DESIGN

The design favoured originally by the authorities was a girder bridge as shown in Figure 1. The girder depth was 5 m in the centre spans and 4 m and 3.79 m at the abutments. The span lengths were 90 + 108 + 114 + 78 + 60 = 552m.

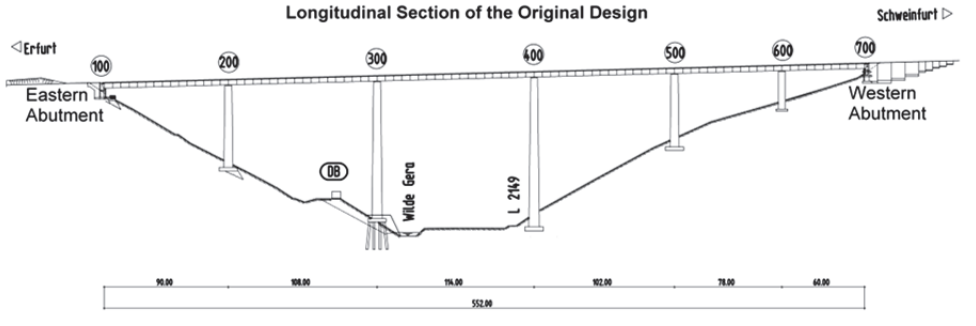

Figure 1: Original Design

A special feature was a single composite girder. This superstructure type was first proposed for the Wilde Gera Bridge and has been used on other bridges at the same highway afterwards.

The positioning of the piers also required the relocation of a trash dump site and the re-routing of the Wilde Gera creek as well as construction of a pier in the railroad embankment.

3 ALTERNATIVE DESIGN PROPOSAL

Jointly with the construction company Adam Hörnig an alternative arch bridge design was proposed, and submitted to DEGES, the owner's representative, during the tendering process (Figure 2). A single composite girder proved to be advantageous for the economy of the arch proposal. An alternative with two arch bridges and separate superstructures for each road direction would have been too costly. Since the bridge crosses the valley obliquely, two parallel arches would have posed aesthetic problems. The main advantages of the alternative proposal besides its aesthetic qualities, is that all of the obstacles in the valley could be spanned in one go with the single arch. No relocation of former waste disposals was required, the course of the Wilde Gera remained unchanged and the railroad embankment was unaffected.

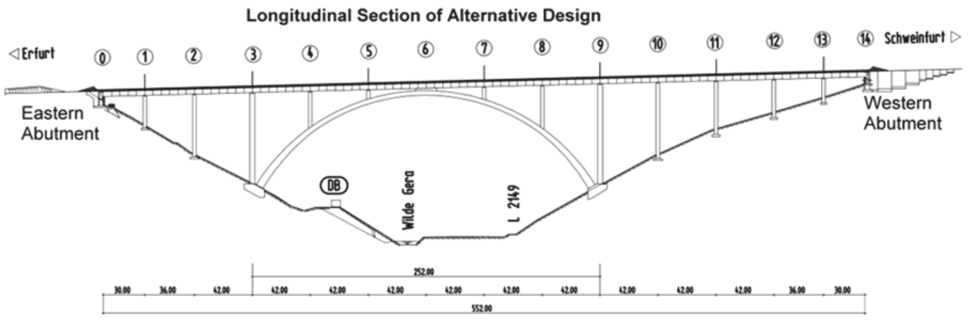

Figure 2: Alternative Design Proposal

To achieve an “arch-friendly” design, some geometric boundary conditions from the original design had to be modified:

1) The radius of curvature in plane was increased from 5200 to 7800 meters in order to decrease the eccentricity of the piers on the straight arch. Increasing the radius further or even straightening out the alignment was not possible, as the nearby Schwarzbach Valley Bridge had already been awarded. Thus the possible changes in alignment were limited.
2) The entire bridge structure was moved 3 meters to the West to fit the arch symmetrically into the valley. Thus both arch springings are at the same height level, which improves the aesthetics further.
3) The span lengths of the superstructure are 30 + 36 + 10 x 42 + 36 +30 = 552 meters, while the total length remains the same.

To clear the railroad embankment sufficiently and to have good rock conditions for the foundations at the springings, the arch span of 6 x 42 = 252 meters proved to be optimal. Though it was not specifically intended, this turned out to be the longest-spanning arch bridge in Germany at that time, today it is the longest-spanning road arch bridge.

4 ABUTMENTS

Hollow, U-shaped abutments were used at both ends of the bridge. Steel doors allow maintenance personnel to enter the hollow parts. The front bench wall is 0.5 meters thick except for at the bearing locations, where it widens to 1.2 meters. Because of the steep slope at the western abutment, special landscaping measures had to be done there. The slope also has an influence on the lengths of the wing walls and the footing levels. The southern wing wall of the western abutment is prolonged over 65 meters by a cantilever retaining wall with stepped footings. The height of the wall varies between 17 and 2 meters.

5 PIERS

All piers have a hollow box section. The standard dimensions are 2.5 by 9 meters, the piers on the springings have outer dimensions of 3.5 by 9 meters (Figure 3). The walls are 30 and 40 cm thick, respectively. All pier heads are dimensioned to allow the positioning of jacks next to the bearings to be able to jack up the superstructure.

The entire structure is an ideal living space for bats, so that all piers were equipped with a 10 cm high opening above the maintenance doors. The drainage pipes usually made of UPVC were done in rough, unglazed clay to allow a better ultrasound transmission. For the same reason, the access areas around the abutments and piers were laid out with stone or gravel packing. The usual bird protection measures were omitted completely:

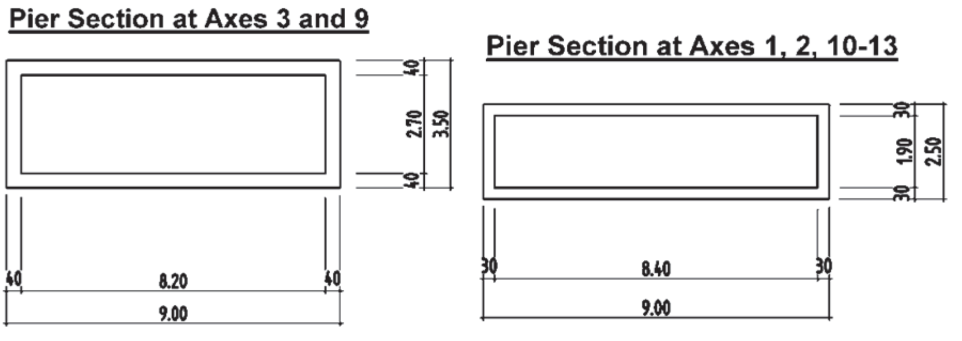

Figure 3: Pier Sections

6 FOUNDATIONS

The top rock layer in this area of the Thuringian Forest is mainly a 650 m deep section of quartz prophyr rock covered on the slopes by thin layers of earth and weathered rock. In the valley, thicker layers of clayey materials and gravel are found. According to DIN 4149 the area is located in Earthquake Zone 0, which does not require any seismic analysis. As suitable rock was close to the ground surface, flat footings were used at all abutments, piers and the springings. Some foundations were stepped in the lateral direction; unsuitable rock or soil layers were replaced with blinding concrete grade C15. The foundations at the springings are up to 6 meters thick and have a surface dimension of 17 by 14.5 meters. This results in a concrete volume of roughly 1300 m^3 at each end of the arch.

7 STAYED CONSTRUCTION OF THE ARCH

The arch was designed as a two-cell hollow box section with an outer web thickness of 40 cm and 30 cm for the inner web. The top and bottom flanges are each 35 cm thick. The depth of the section varies from 5.5 meters at the springings to 3.3 meters at the crown (Figure 4). A solid section would certainly have been easier to build in terms of reinforcing and concreting, but the higher dead weight would have required more stays.

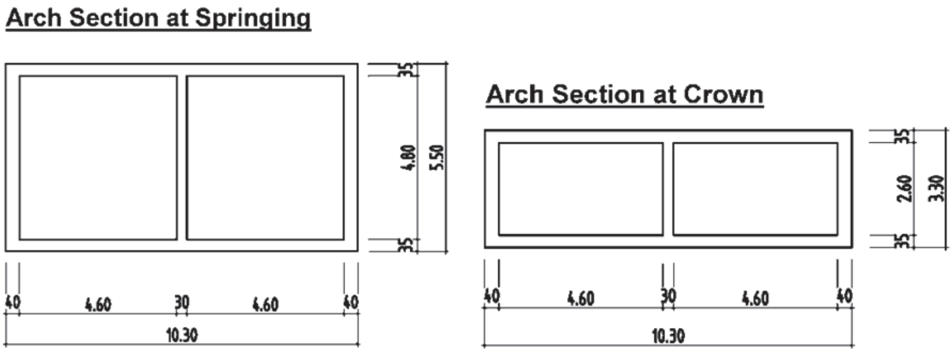

Figure 4: Arch Sections

During structural analysis, the shape of the arch was optimised to keep the bending moments in the completed arch to a minimum. If only the arch's dead load was considered, the line of thrust would have been a purely parabolic shape, but the piers introduce concentrated loads at their points of support and modify the line of thrust. The "kinks" were smoothened out and the final shape is visually close to a parabola.

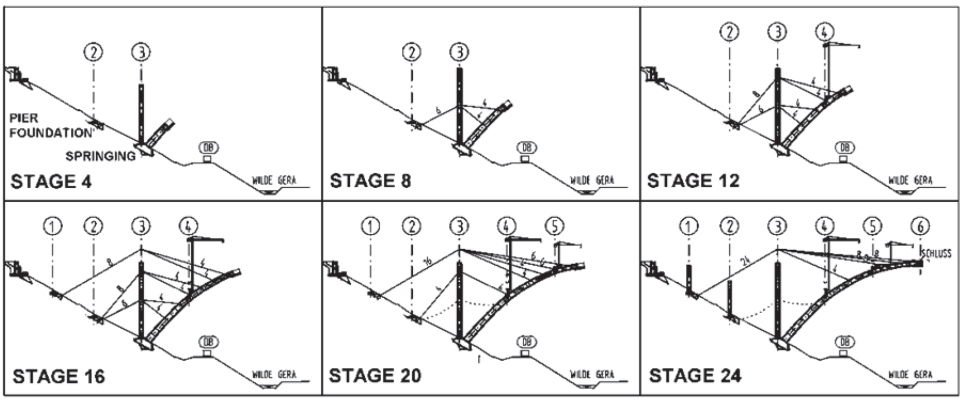

Figure 5: Stages of construction for one half of the arch

Each half of the arch was constructed in 24 stages while cantilevering out from the springings (Figure 5). Construction of both halves was done simultaneously. Then a 25th stage was cast to complete the arch. The first stage at each springing was 7 meters long in order to be able to mount the climbing formwork. All other stages consisted of 6 meter long, straight sections. Otherwise the curvature would have been different for each section. Despite this, the polygonal arch shape remains hardly perceptible to the eye.

A climbing formwork system was used to cast each arch segment. The formwork was mounted to the previously cast segment so that its own weight and the concreting loads were transferred back to the cantilever. To reduce the effective cantilever length, the arch was back-stayed using cables that were connected to pier foundations and deviated at the

piers over the springings. An initial concept of using temporary piers near axes 4 and 8 was abandoned as this might have caused a cave-in of the railroad embankment.
The stay cables, covered with a temporary anti-corrosive coating, were composed of prestressing tendons of the type VT 12-150 provided by VBF. Though each had an allowable prestressing force of 1752 kN, they were only stressed to a maximum of about 1500 kN. Starting at the 13th stage of each half, additional temporary pylons were placed on the piers at the springings to ensure a sufficient angling of the very top stays (Figure 7).

Figure 6: Anchoring of the cable stays at one of the footings

Figure 7: Temporary pylon on pier top of pier at arch springing

Near axes 4, 5, 7 and 8, where the piers later rest on the arch, cranes were mounted for the construction of the arch itself, see Figure 8. These had to be considered in the structural analysis, especially for the deformation calculations.
In order to anchor the stays, rock anchors were used in axes 1 and 2 as well as 10 and 11 (Figure 6). Within each foundation, stay and rock anchors were overlapped to transfer the forces. The stays themselves were connected using coupling anchors. For the rock anchors DYWIDAG AS 6815 anchors with an allowable force of 2009 kN were used. All of them were tested using stressing abutments at 1.25 times the allowable force before being accepted for use. They were then released to 70 % of the force before being re-stressed to the full allowable load to ensure an even distribution of forces on all anchors. In addition, three anchors per slope were tested at 1.5 times the force against failure.
After casting the 24th section of each half of the arch, and before casting the final section, a steel compression beam was introduced in between the halves. Afterwards the stays were released just enough to exert sufficient compression on the beam for covering the temperature differences during the casting of the final joint (Figure 8). The hardening concrete would not have been able to sustain these temperature loads or a temperature differential in the arch. Afterwards most of the stays were removed except for those which were necessary for the construction of the superstructure.

Figure 8: Arch just before the two halves were joined

The structural analysis of the arch, especially during the construction stages, was very complex. The detailed design was performed in accordance to DIN 1045. Additionally, the prestressing forces in each cable were adjusted so that a specially defined allowable tensile stress in the arch cross-section was not exceeded during construction. This allowable stress was limited to 3.8 MPa, which is roughly equivalent to the tensile strength of the concrete. This ensured that the deformations were calculated on a nearly uncracked system. With the testing of the concrete cube strength, the E-Modulus was determined, as well. Part of the duties of the concrete manufacturer was to ensure that during the entire construction of the arch this value remained constant. In case of changes in the concrete mixture the manufacturer had to provide the new E-modulus so that the deflection calculations could be revised. The computer model was calibrated based on the first four stages which were not back-stayed. Good correlation between the measurements and the calculation supported the accuracy of this method. Additionally, accurate knowledge of the stiffness distribution in the arch was necessary, since the influences of the cable planes on each other depended on the arch stiffness. Analysis of the completed arch was done on an overall system including the superstructure, piers, arch and foundation. The static and dynamic analyses were performed using the SOFiSTiK analysis package. During the construction stages, arch, piers at the springings, stays and earth anchors were considered in a single model. Variations in wind gust strength and resulting longitudinal and lateral oscillations of the cantilevering arch sections were computed in an analysis using to the Davenport spectral method. Then the results were integrated into the detailed design of the arch.

8 SUPERSTRUCTURE

A composite section was used for the bridge superstructure. It consists of a trapezoidal steel trough with exterior support struts for a concrete deck slab with a total width between handrails of 26.5 meters for two lanes of traffic in each direction. The depth of the superstructure of 3.7 meters is governed by the angle of struts (Figure 9). Because the concrete slab was considered a “wearing part”, the design included the potential replacement of the slab in 14 meters wide sections, while traffic is re-routed on the remaining part of the slab.

Manufactured at the steel plant in Plauen, the various segments of the superstructure were transported to the site by lorry. Because of clearance constraints in the narrow village roads of the Thuringian Forest, the segments had to be relatively small. With a maximum allowable length of 24 meters, the trough section was separated into two parts along the centreline. This resulted in segments that were 5.30 m wide, 3.35 m high and 21 m long. The exterior struts were transported separately to the site.

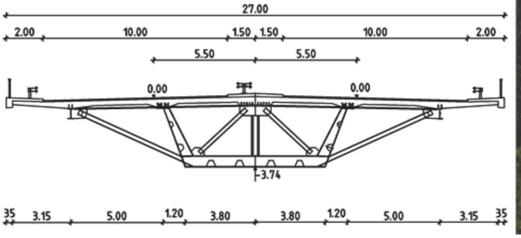

Figure 9: Cross section of the superstructure

Figure 10: Completed Bridge

All segments were mounted behind the western abutment on an 80 m long yard. Three segments were mounted, levelled and finally welded together. Then additional corrosion protection was added at the welds and wherever else necessary. A final coat of paint was applied after the deck slab was concreted. After the mounting of 63 meter long segments, the steel superstructure was launched onto the piers using sliding bearings roughly 2 meters long.

Once the steel parts of superstructure had all been launched and the bearings replaced, the deck slab was cast in-situ. Two formwork units were used starting at either end of the bridge at different points in time so that they would meet roughly in the middle of the arch. Thus unequal loading of the arch was mostly avoided, although part of the stays were re-activated to counteract the remaining asymmetries.

9 CONCLUSION

The structure has been completed (Figure 10) and the Thüringer Wald Autobahn has been completed as well. The bridge over the Wilde Gera Valley as part of these Highway is a very elegant, but just as a robust structure.

The structure received the First German Bridge Award.