Tri-Countries Bridge between Weil am Rhein, Germany and Hüningen, France

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Abstract

In the border triangle of southwest Germany, a new pedestrian bridge across the Rhine River was opened in March 2007. The slender arch bridge with a span of 230 m connects Germany and France near the border to Switzerland. This structure received the 2009 International Association for Bridge and Structural Engineering's Outstanding Structure Award.

Keywords: asymmetric; slender pedestrian arch bridge; main span 230 m; complex and carefully designed details.

Introduction

In July 2001, the city of Weil am Rhein and the Communaute de Communes des Trois Frontieres announced a competition to construct a pedestrian and cyclist bridge across the Rhine between Germany and France. The bridge was to be located near Basel, in the triangle of the three countries Germany, France and Switzerland.

The basic requirements of the Franco-German jury were the functionality/safety, ship impact, architectural quality/originality, cost, buildability and efficient use. The winning team got the project.

The basic requirement for the design of the bridge was a navigational clearance of 7,80 × 155 m. To reduce the risk of ship impact, an arch bridge design without piers in the Rhine was chosen.

Another basic concept in the design was the emphasis on the misalignment of the axis Hauptstraße/Rue de France and the correlation of views from Weil towards the tower in Hüningen. Owing to this correlation of views, the bridge was designed to be asymmetrical.

Main Bridge

A maximum longitudinal gradient of 4% was chosen to simplify access for people with disabilities. With the gradient and the navigational clearance of 7,80 × 155 m, the bridge has a total length of 248 m and a main span of 229,40 m (*Fig. 1*).

To achieve an elegant appearance, the height of the arch was minimized. The construction depth in the middle is 23 m between the arch and the abutments; and 14,90 m between the arch and the deck. Construction of this very slender arch was possible only by using steel. The light construction was continued on the bank region. The piers and the abutments disappeared in the water. The arch thrust had to be redirected at the abutments, and therefore, restraint members were required (*Fig. 2*).

Due to the restraint members, the system is combined between a tied arch and a real arch with restraint members.

The minimum width between the railings is more than 5 m, which provides enough space for pedestrians and cyclists to cross the river. Owing to the draft and the correlation of views, the cross-section is asymmetrical. The northern arch was built vertical and has two hexagonal steel box cross sections. The southern arch is inclined and was built with a circular hollow section. The northern side is the "strong side", while the southern arch is the "weak side" that leans on the northern one. The north side carries double the load of the south (*Fig. 3*).

Structural Analysis

For structural analysis, the system was modelled as a beam structure and the deck was modelled with finite elements. The main challenges were the slenderness/softness of the system and

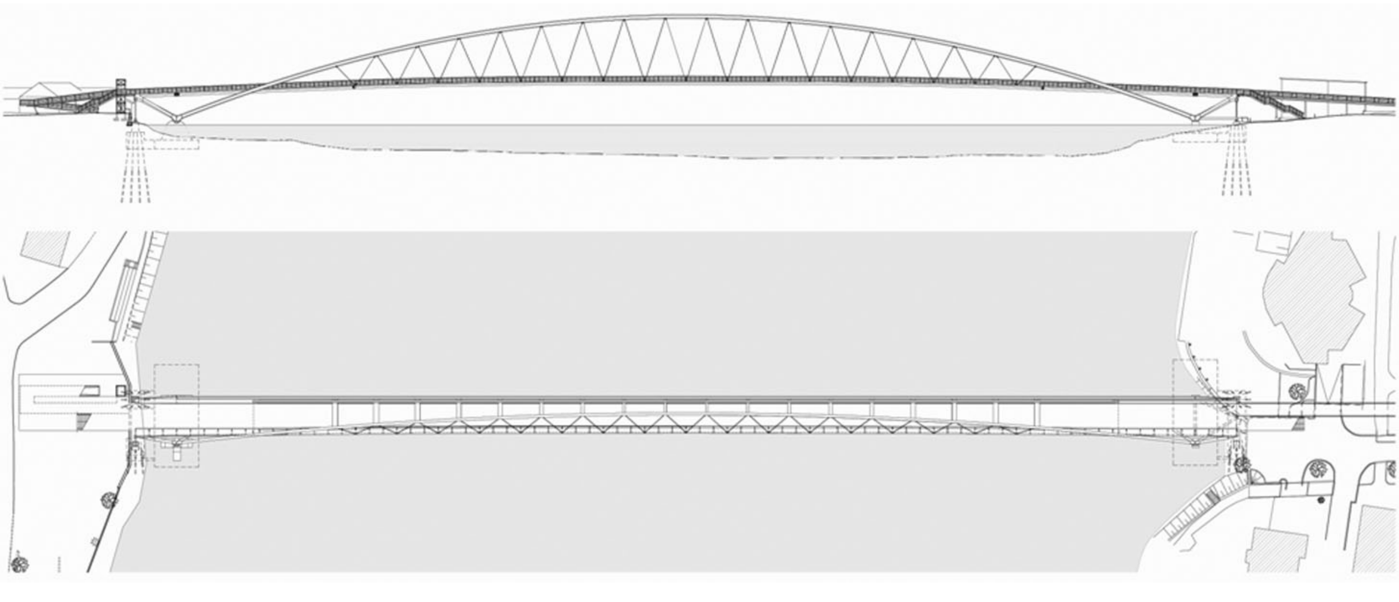

Fig. 1: Elevation and plan

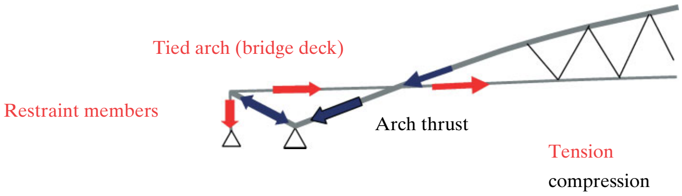

Fig. 2: System of the arch

the asymmetry resulting in horizontal forces also under dead loads.

The relevant design loads are the dead loads, wind loads and the live loads. The definition of realistic live loads for such a long pedestrian arch bridge is difficult. The Tri-Countries Bridge was designed for the full live load on half span according to the German Code DIN-Fachbericht 101 (*Fig. 4*).

The deflections for full live load are 1275 mm. Because of the very large deflections, the system is geometrically nonlinear. The system had to be analysed with second-order theory; the load cases could not be superposed and only load combinations had to be analysed.

The wind loads were calculated according to E-DIN (Eurocode) 1055-4:8/2002. With exact calculation, the wind tunnel tests could be confirmed. Exact calculation was essential to minimize the horizontal forces for the slender construction.

Hangers

The inclined locked coil rope hangers connect the orthotropic deck to the arch. To avoid buckling in the hangers, spiral strands were used. Connection between the arch and the deck is achieved with open swaged fittings. At the connection to the deck, open sockets were used to permit adjustment of the cable lengths (*Fig. 5*).

Connections and Bearings

The connections of the beams are carefully designed with regard to durability and aesthetics. To avoid gusset plates, the joints of the arches are built with cast steel nodes. The thickness varies according to the forces. The welding area between the beams and the cast steel nodes is outside the area with high forces.

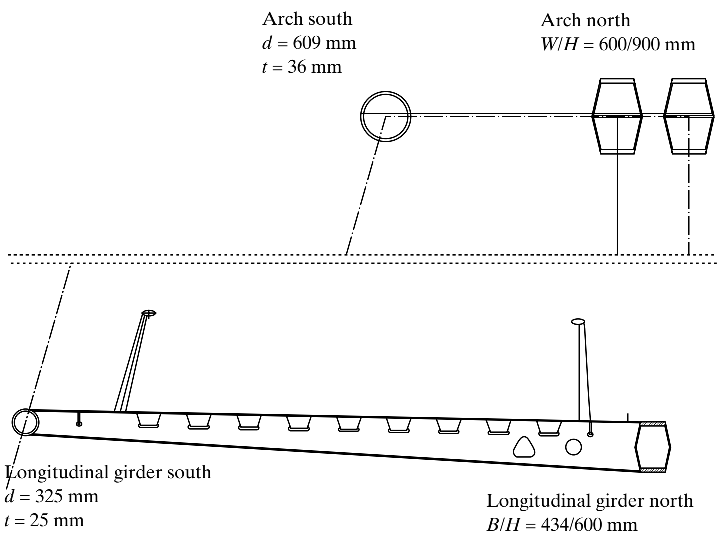

Fig. 3: Cross section

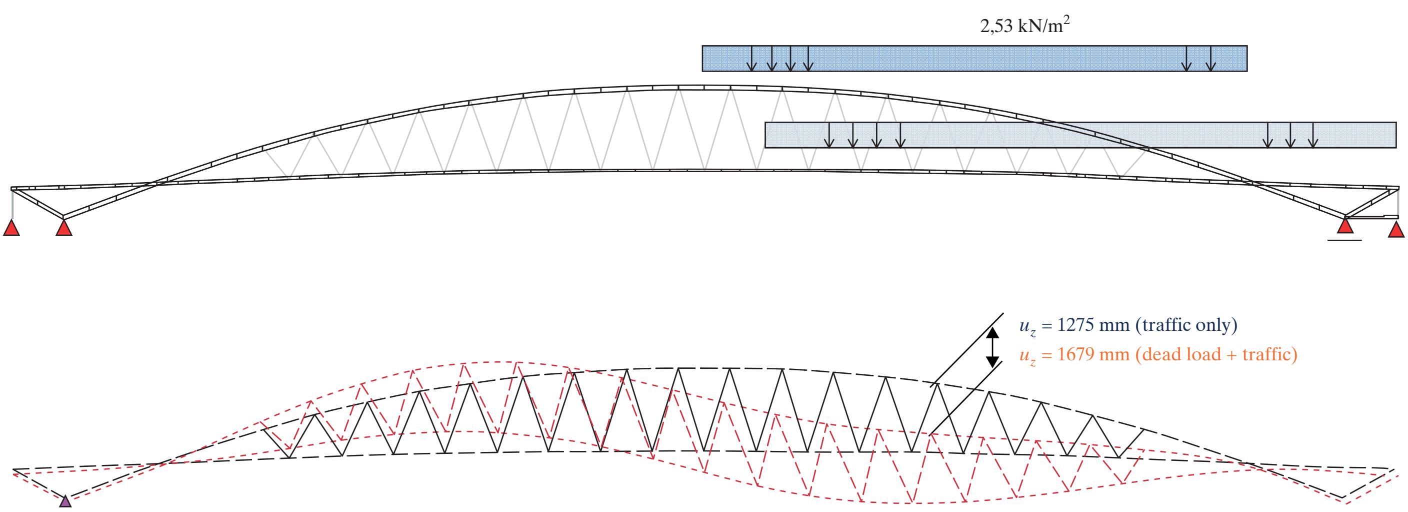

Fig. 4: Live load and associated deflections

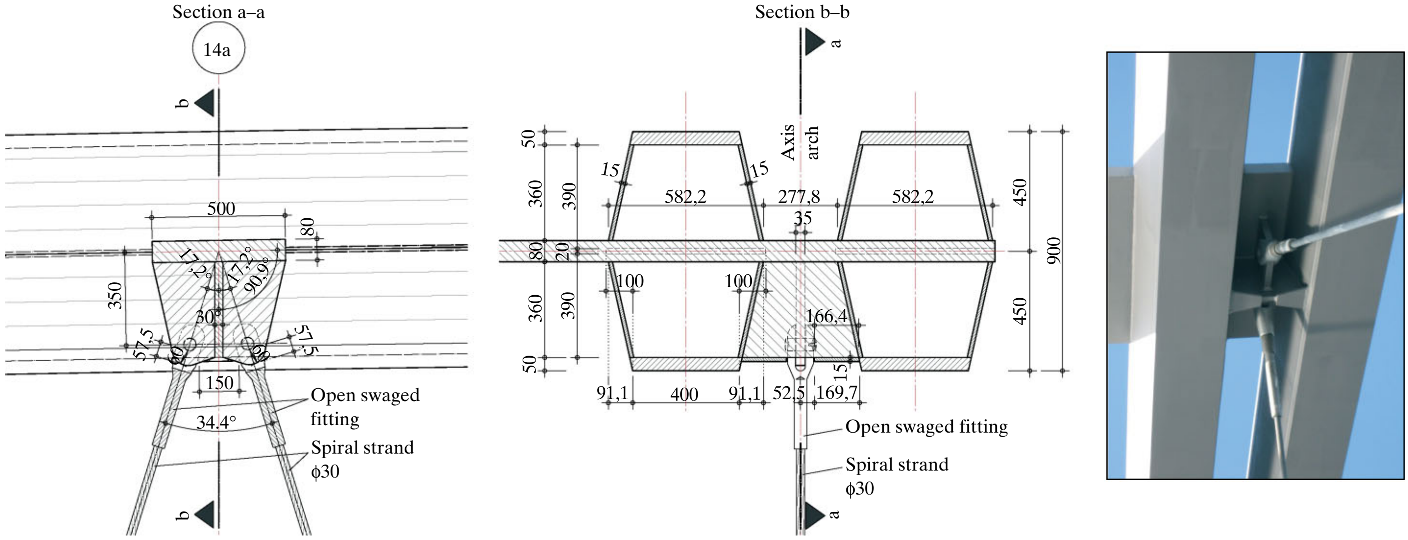

Fig. 5: Hangers (Units: mm)

Owing to the asymmetry of the system and the wind loads, there are high levels of horizontal forces at the bearings. The vertical bearing forces of the steel structure are relatively low. Therefore, the resultant force is not centred on the bearings. Typical supports with horizontal bearings cannot be used.

On the Hüningen side, the arch was fixed for longitudinal displacement. To get the forces to the abutment, three spherical bearings at the southern side and two at the northern side were necessary. All the spherical bearings are inclined. The bearings were of the form of spherical calottes and were all on the same spherical surface. The centre of the surface is the base of the arch, so that rotation is possible without restraining forces (*Fig. 6*).

On the Weil am Rhein side, the arch is free for longitudinal displacement but fixed for transverse forces. The maximum longitudinal displacement is about 500 mm. The structure that can handle the load and displacement transfer is a "drawbar", a structure with a pendulum. The pendulum is fixed to the abutment; horizontal load transfer is possible with a couple of forces (*Fig. 7*).

Fig. 6: Hüningen: fixed for longitudinal displacement

Fig. 7: Weil am Rhein: free for longitudinal displacement

Restraint Members, Foundation

The arch thrust is redirected at the abutments with restraint members. The tension members are steel plates, fixed with bolts at the end of the deck and on the abutment (*Fig. 8*).

Because of the use of restraint members, permanent soil anchors were required on both sides of the arches. The foundation soil is gravel–sand and in the deeper area it is mudstone. In the gravel–sand there is a raft foundation. To avoid a rotation of the foundation, the shear strength in the gravel is activated for load transfer of the horizontal forces.

Shop Assembly

Normally, the framework for the shop assembly is fabricated with positive camber (negative deflection). The system at the Tri-Countries Bridge is geometrically nonlinear. Therefore, the camber is a complex spatial form, which cannot be directly determined from the deflections. Calculation of the camber was done iteratively and by taking into account the geometrically nonlinear behaviour of the structure (second-order theory).

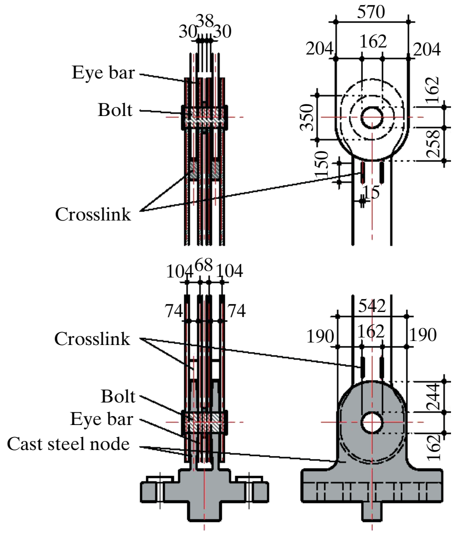

Fig. 8: Restraint members (Units: mm)

Owing to the asymmetry of the bridge cross section, there are horizontal displacements under dead load. Therefore, the bridge was assembled with horizontal and vertical camber.

In addition, the effect of the temporary cables during erection had to be considered. All the effects led to a complex camber. During shop assembly, the segments had to be supported in an inclined position, in order to achieve a vertical northern arch in the final permanent position under dead loads only.

Ramps

Ramps and stairs allow access to the main bridge from both sides. The ramps and the stairs are slender steel boxes with a maximum construction depth of 400 mm. The steel boxes are supported by tubes with 180 mm diameter.

For people with disabilities, the ramp on the French side is too steep, and therefore a lift was built.

The ramp at Weil am Rhein is supported with bracket pins on the main bridge (*Fig. 9*). At the end of the deck on the Weil am Rhein side is the free longitudinal displacement of the main bridge. Therefore, the bracket pins have a sliding surface. Because of the low construction depth, the bearings on the bracket pins are divided into horizontal and vertical bearings. The expansion joint between the ramp and the main bridge is made with sliding steel plates.

The railings with ropes are the same as on the main bridge. In the hand rail, lighting was integrated. Also, the same epoxy coating was used on the ramps and on the main bridge. The coating chosen was light grey in colour, DB 701.

Construction Stages

The bridge was pre-assembled at a pre-construction site 500 m from the erection site (*Fig. 10*). After welding the steel structure, the complete structure was subsequently floated in with heavy load transporters on pontoons. During the floating process, the Rhine River had to be closed for navigation for one day only. The bridge was turned in with cable winches from the pre-assembling area to the site.

Vibration Test

Before the opening of the bridge, vibration tests were performed to verify the dynamic calculation and to check its dynamic behaviour. About 1000 people from both communities walked in step across the bridge. Different speeds with different numbers of people were tested.

Differences between the test results and the dynamic analysis of the bridge were found at the third-mode shape. The damping of the Tri-Countries Bridge is very low (1%), but is in the usual range for a steel construction. The natural frequency of 1,0 Hz could be excited. The activated deck deflection has horizontal and vertical components. But the critical lateral vibrations are only activated when more than 500 people cross the bridge at a speed of at least 5,8 km/h. The probability of this happening is very low, and consequently the city councils decided not to install dampers.

Conclusion

The execution of the original idea of spanning the Rhine River with a single, asymmetric arch has been successful. The shape of the bridge is simple but expressive and strictly follows the optimal flow of forces (*Fig. 11*). The risk of ship impact is reduced. The asymmetric arch with a span of 230 m has the expected "originality", to the client's satisfaction. In spite of the technical challenges, complex details were designed carefully.

Fig. 9: Ramp Weil am Rhein

Fig. 10: Pre-assembling

Fig. 11: Tri-Countries Bridge at night

SEI Data Block

Owner:
City of Weil am Rhein and Communaute de Communes des Trois Frontieres

Competition, design:
Association between Feichtinger Architectes, Paris and Leonhardt, Andrä and Partner, Berlin

Detailed design calculation, supervison:
LAP, Berlin and Stuttgart

Detailed design drawings:
Max Bögl, Neumarkt

Shop drawings:
Stendess, Lovendegem, Belgium

Vibration test:
Büro Heilandt, Bochum and Dr Kovacs, Weinstadt

Checking engineer:
Prof. Dr -Ing. Kuhlmann, Stuttgart

Contractor (steelwork and concrete):
Max Bögl, Neumarkt

Dimensions:

Total length:	248 m
Span:	229,40 m
Bridge surface:	1500 m²
Total tonnage:	1020 t
Total costs (EUR millions):	9

Financing 50% France and 50% Germany

Co-financing from the European Union

Construction:	February 2006 to March 2007
Service date:	March 2007