Design and Construction of the Löwenbrücke in Bamberg

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The Löwenbrücke crosses the Main-Danube Canal in the city of Bamberg / Germany where an existing 3 span (27 m – 44 m – 27 m) steel bridge built in 1946 to 1949 had to be replaced to provide full load bearing capacity and clearance for shipping on the canal.

To find a solution that would fulfil both the functional requirements of the parties involved and the aesthetic needs of the medieval city under the present, complex boundary conditions, extensive investigations on possible bridge systems were performed during pre-design phase, including a symmetric and a non-symmetric cable stayed superstructure, an arch bridge, a portal bridge, a truss bridge and a classical suspension bridge. The results of pre-design were evaluated under economic (both construction and maintenance), technical, functional and aesthetic aspects. Best overall performance was found for the symmetric cable stayed bridge.

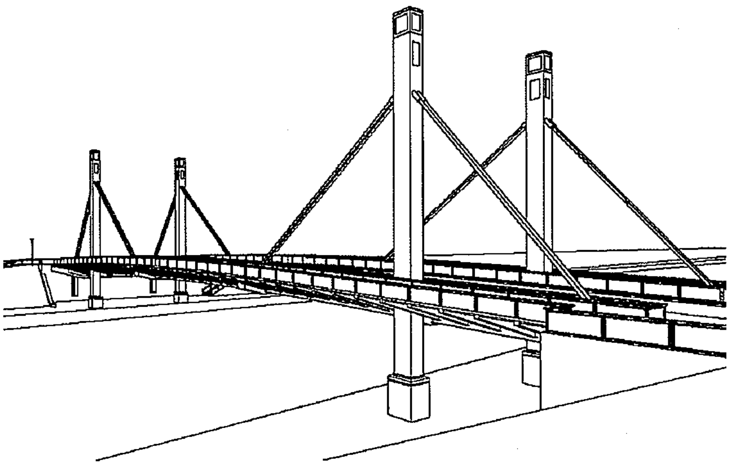

Figure 1: Isometric view

The load bearing structure of the selected solution consists of a composite bridge deck, four pylons and eight sets of two tensile members each. The span is 15 m – 75 m – 15 m. In longitudinal direction, three air-tight hollow box girders connected to a grid by hollow box cross beams are arranged.

The two footways are separated from the main bridge, resting on cantilever beams welded to the outer hollow box girders of the main bridge. The resulting width between railings for the footways, two bicycle and three traffic lanes is 2,50 m +14,05 m + 2,50 m. The steel pylons have a total height of 20 m above street level and are placed in the gap between main bridge and footways. Tensile members are made of solid steel with rectangular cross section and compact, hammer-shaped end pieces. Due to unfavourable span ratio, tension forces must be anchored at the abutments via pendulum supports.

The construction sequence was planned under the demand that shipping on the waterway could only be interrupted for very limited periods. Temporary supports were installed on top of the piers of the existing bridge. Erection of the steel structure started with the side spans and mid spans up to these supports. The remaining parts of the mid-span girders were installed as full length pre-fabricated segments.

The bridge deck with an overall thickness of 35 cm was cast on a lost formwork of semi precast elements to avoid erection and removal of formwork above the water. To minimize shrinkage stresses, it was intended to use a concrete mix with reduced shrinkage. However, site execution showed the problem of transferring the laboratory mix design to the site under realistic weather conditions.

The bridge has been opened to traffic on 27th of march 2009.

Figure 2: The Löwenbrücke in (almost) final state

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Abstract:

The Löwenbrücke crosses the Main-Danube Canal in the city of Bamberg / Germany. The existing steel bridge built in 1946 to 1949 had to be replaced, as it did not provide full clearance (width and height) for shipping on the canal and had reached the end of its service life, requiring extensive repair.

The new bridge had to be designed under complex boundary conditions. Required clearance for shipping on the canal together with the predefined street level only permitted a very limited construction height of less than 2 m for a centre span length of approx. 75 m. In addition, layout had to be carefully adapted to the architectural environment of the historic city.

In a first step, a number of different solutions were investigated. Evaluation of the concepts under functional, architectural, economic and technical aspects showed best performance for the symmetric cable stayed composite bridge.

Keywords: Composite bridge, cable stayed bridge, construction sequence

1 Introduction

The Löwenbrücke crosses the Main-Danube Canal in the city of Bamberg / Germany that has a long tradition in bridge construction (even the medieval town hall was built on a bridge in the 14th century).

The existing bridge was a simple 3 span (27 m – 44 m – 27 m) steel construction with two piers inside the Canal. It was built in 1946 to 1949 with the limited resources of the post-war era. By the year 2000, it had reached the end of its service life and showed the full range of typical damage, including severe corrosion to the load bearing structure, a loss of functionality of the roller bearings and the expansion joints, corrosion to railings etc. Immediate and extensive repair was required.

This investment could not be justified, as the provided clearance below the bridge (width x height = 42,0 m x 5,4 m) fell short of the minimum requirements for the waterway (width x height = 72,0 m x 6,4 m). The bridge represented a needle's eye for shipping and had already suffered some minor ship impacts on the superstructure. In the hypothetical case of a full ship impact on the piers, these would not have been able to withstand and a loss of the entire bridge would have been the consequence.

Figure 1: The old Löwenbrücke in 2007

To overcome these functional and safety deficiencies, it was commonly decided by local authorities and the Canal administration to replace the existing bridge in an extensive program including also two other bridges in the city of Bamberg (the Luitpold Brücke and the Kettenbrücke) within a period of six years. As these three bridges are vital parts of the municipal infrastructure, the construction periods had to be well coordinated to minimize the impact on inner city traffic.

2 Conceptual studies in pre-design

One of the main challenges was to find a solution that would fulfil both the functional requirements of the parties involved and the aesthetic needs of a medieval city.

The functional requirements were defined mainly by the waterway. The required clearance results in a centre span of approx. 75 m that is almost twice the span of the existing bridge. However, existing street level could only be raised to a very limited extent. The available height for the load bearing structure below street level was only about 2 m. In addition, existing neighbouring buildings only allowed short side spans so that the structure would have to work as a single span beam in principal.

For the given situation, bridges with a load bearing structure above the street level are the obvious solution, though a classical deck or portal bridge would still be possible,

On the other hand, layout had to be carefully adapted to the architectural environment of the historic city of Bamberg that is part of the UNESCO cultural world heritage list. The bridge marks the transition from the inner city to industrially and commercially dominated areas, but is visible from large distances and represents a landmark in the overall appearance of the city.

In pre-design, extensive investigations on possible bridge systems were performed in cooperation with Schultz-Brauns & Reinhart architects and discussed with local authorities, see figure 2.

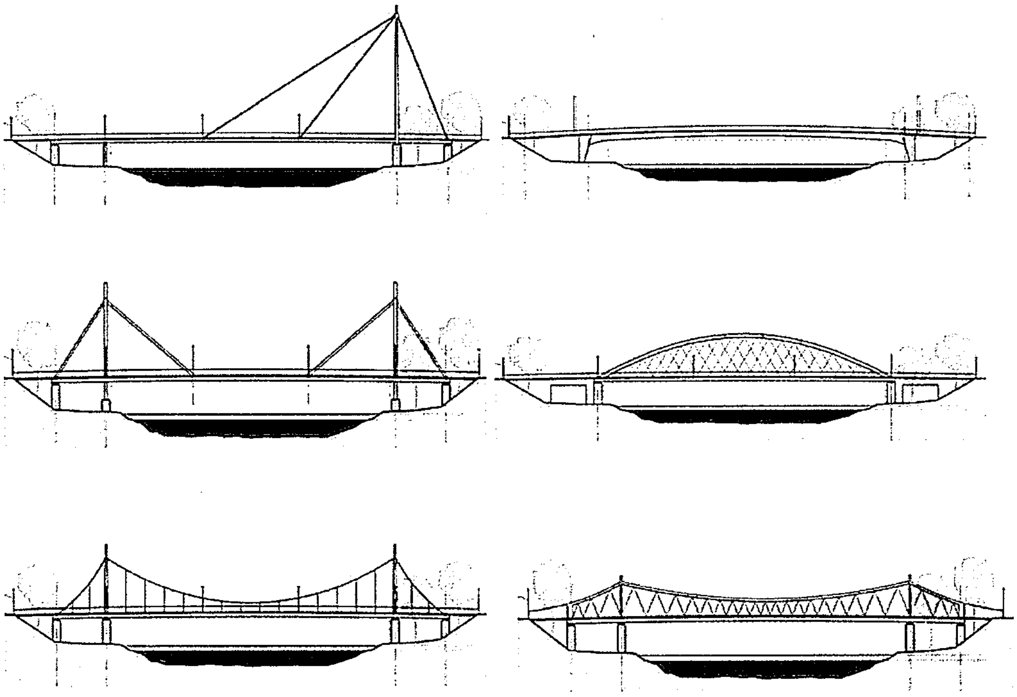

Figure 2: Conceptual study in pre-design

The results of pre-design were evaluated under economic (both construction and maintenance), technical, functional and aesthetic aspects.

Solutions A and C – a non-symmetric cable stayed bridge and a suspension bridge – are not appropriate (technically and aesthetically) or economic for the present medium span situation.

Solution B – a symmetric cable stayed bridge – harmonizes well with the environment and represents a visible, but not too dominant landmark. A good, optical balance of spans and pylon height can be reached. Technically, the support of the main span by the cables allows a slender bridge deck, but large tensile forces must be anchored to the substructure at the end supports. Construction and maintenance costs are moderately increased.

Solution D – a composite deck bridge – is aesthetically rather unspectacular and has no landmark effect. The problem of unbalanced spans is avoided by a single span frame system with very massive abutments. It is a standard construction and therefore the most economic system both in erection and maintenance, but reaches the technical limits of constructability for the present geometric boundary conditions (span and slenderness). Street level must be lifted to provide the required height for the load bearing structure.

The arch bridge E overcomes the problems of unbalanced spans by a single span construction with massive abutments similar to D. Optical appearance and integration are good, but user quality on the footways along the canals is reduced by tunnelling the abutments. To minimize the impact on shipping during construction, the fully pre-assembled steel structure could be moved in via the waterway. However, only limited space is available for pre assembly of the arch on the construction site. Maintenance costs for renewal of corrosion protection are increased by the large and irregular steel surface.

The truss bridge solution F suffers from the bad span ratio both technically and aesthetically. The optical appearance is very technical and too dominant. For the construction sequence and maintenance costs, the results are the same as for the arch bridge.

Best overall performance was found for solutions B and D. On this basis, local authorities decided for the symmetric cable stayed bridge (B in fig. 2). The main reason for the decision was the architectural integration into the semi-urban environment.

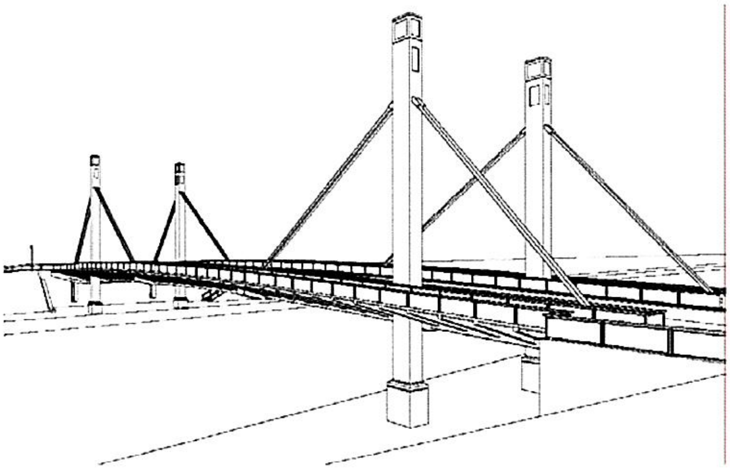

Figure 3: Isometric view

3 Structural concept

The load bearing structure consists of a composite bridge deck, four pylons and eight sets of two tensile members each. The span is 15 m – 75 m – 15 m.

In longitudinal direction, three hollow box girders are provided that are connected to a grid by hollow box cross beams in the axes of the pylons, the anchoring points of the tensile members and the abutments. All box girders are air-tight for corrosion protection in final state. Steel class is mainly S355J2G3. For some limited areas with load concentrations (e.g. anchoring regions of tensile members), steel S420NL with thickness up to 100 mm is used.

One special feature of the design are the two footways separated from the main bridge for enhanced traffic safety and user comfort and a lighter overall appearance of the otherwise rather wide and heavy bridge deck (fig. 4). The footways are continuous steel beams with an orthotropic steel deck resting on cantilever beams welded to the outer hollow box girders of the main bridge. The symmetric part of the cantilever moment from both sides is balanced by small transverse steel beams connecting the bottom flanges of the cantilevers.

The resulting width between railings for the footways, two bicycle and three traffic lanes is 2,50 m +14,05 m + 2,50 m.

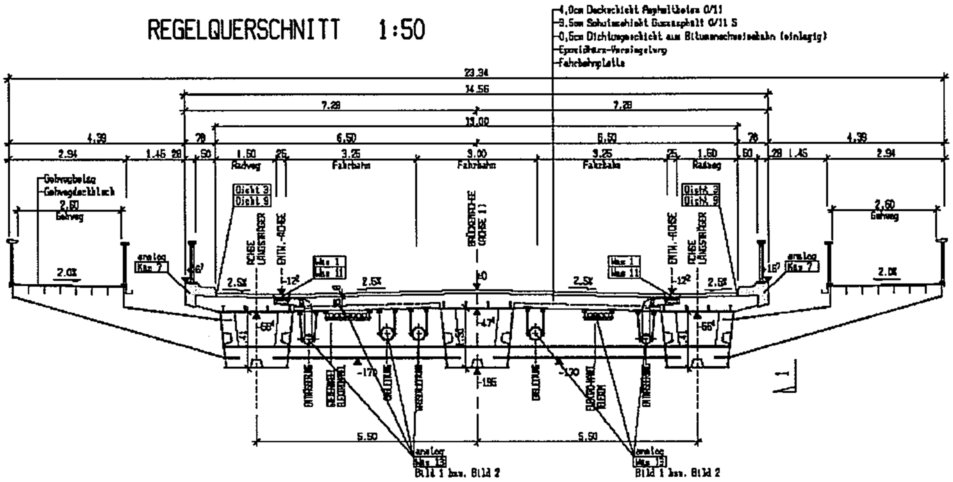

Figure 4: Cross section

The steel pylons have a height of 15 m above street level plus additional 5 m for functional and architectural lighting. The pylons are placed in the gap between main bridge and footways. As they are located outside the highest water level suited for shipping, no ship impact on the substructure must be considered. The foundation consists of 6 inclined piles Ø120 cm per pylon. The pile caps are connected by an underground cross beam to increase lateral stiffness of the pylon frames.

In the concept studies, tensile members were multistrand stay cables. A detail investigation of the anchoring region showed that available space for anchoring of the cables in the pylon head was critical. Therefore, it was decided to use solid steel tensile members (S355NL) with a rectangular cross section 180 mm x 145 mm (welded from two strips 90 mm x 145 mm). For anchoring of tensile forces, compact hammer-shaped end pieces are arranged. As the thickness of end pieces (220 mm) falls out of the application range of German bridge design code *DIN Fachbericht 103*, investigations on fracture toughness [1] and an approval (*Zustimmung im Einzelfall*) were required.

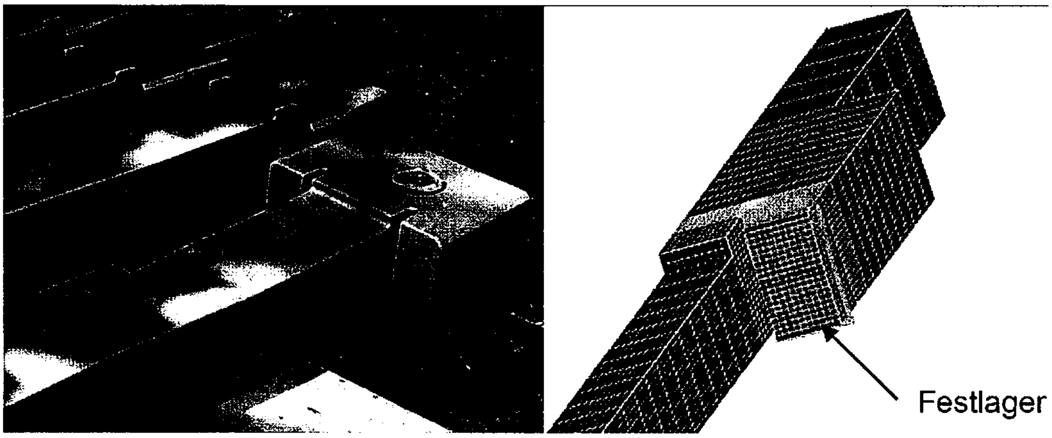

Figure 5: Anchor heads of tensile members, BE model [1]

Due to unfavourable span ratio, large tension forces must be anchored at bridge ends. This is achieved via pendulum supports that provide the required longitudinal deformation capacity by a bolt connection. The pendulums are placed in recesses in the front side of the abutments. They are visible in final state and visualize the flow of forces in the structure. Apart from this, no bearings are required.

Uplifting forces are balanced by the dead weight of the massive abutments.

Figure 6: Installation of end cross beams with pendulum anchoring

4 Construction sequence

The construction sequence was planned under the demand that shipping on the waterway could only be interrupted for very limited periods. For the given structural system, a free cantilever construction would be the standard solution. This was considerably simplified by the fact that temporary supports could be installed on top of the piers of the old bridge at moderate cost.

Erection of the steel structure started with the pylons, the side spans, the mid-span girders up to the construction joints at the temporary supports and the tension members. The remaining parts of the mid-span girders with a length of approximately 25 m were installed as full length pre-fabricated segments. These were moved in on the water and lifted into place hydraulically.

After welding of all steel parts, temporary supports were released, and tension members were pre-stressed in order to achieve a well defined initial state of stress. Pre-stressing forces were applied by an internal thread in the anchor head of the tension members.

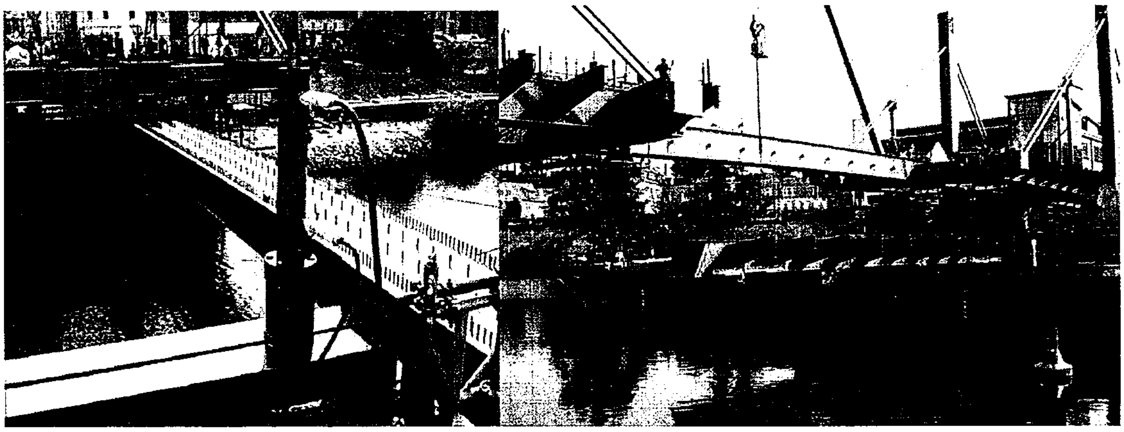

Figure 7: Lifting of the mid span segments

During the pre-stressing process, considerable deviations between computed and actually measured deformations were observed. Re-checking of calculations and a sensitivity analysis for possible influences did not give a satisfactory explanation for this. From the fact that these deviations are not symmetric in spite of an almost perfectly symmetric bridge it was concluded that the only possible explanation are some unintentionally imposed deformations during the previous construction phases (e.g. settlement of the temporary supports). Neither safety nor clearance of the bridge are impaired by this.

5 Reinforced concrete bridge deck

The bridge deck with an overall thickness of 35 cm was cast in three steps. Erection and removal of formwork above the water was avoided by casting the concrete deck on a lost formwork of semi precast elements spanning between the steel girders. Only limited formwork was required for the edges of the slab that could easily be placed on the already installed cantilever beams for the footways.

To minimize shrinkage stresses in steel and concrete, it was intended to use a concrete mix with optimized shrinkage behaviour. Limiting values of final shrinkage equal to 0,25 ‰ were prescribed to the concrete supplier. These values could be confirmed in shrinkage tests. However, the discrepancy between laboratory and site conditions became obvious during casting of the deck. Due to heavy rain, considerable amounts of water accumulated in the formwork and certainly had a strong influence on the actual concrete mix. One may seriously doubt that the laboratory tests are representative for this site concrete.

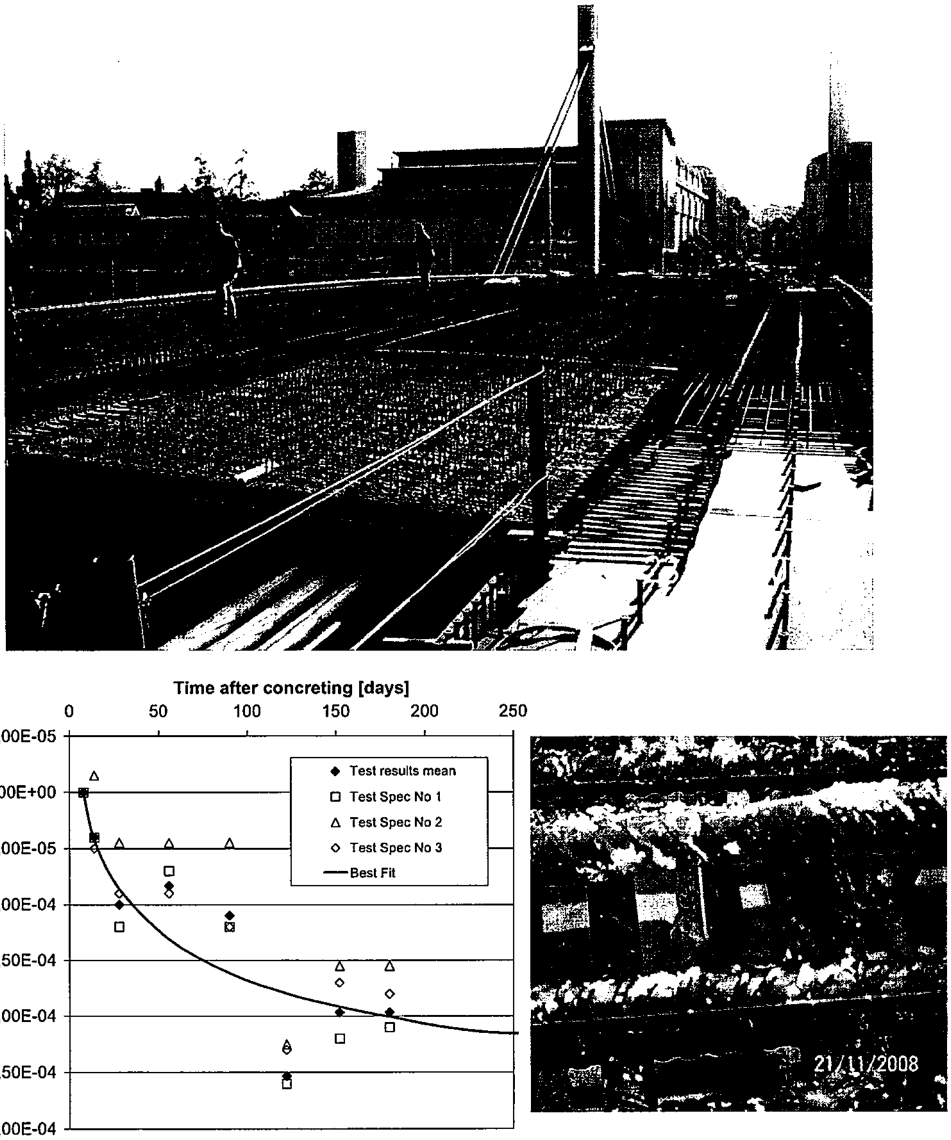

Figure 8:Concrete deck: Lost formwork, result of shrinkage tests, effect of heavy rain during casting

After casting of the slab, the external footways were placed on the already installed cantilever beams.

The bridge has been opened to traffic on 27th of march 2009. Currently, some remaining works (completion of corrosion protection etc.) are going on.

Figure 9: The Löwenbrücke in (almost) final state

6 References

[1] Nachweis der erforderlichen Materialzähigkeit von Hammerköpfen. Gutachten Prof. Feldmann RWTH Aachen / Prof. Sedlacek und Partner, Aachen

[2] DIN Fachbericht 103 – Stahlbrücken (03/2003)

Bridge owner:	City of Bamberg, represented by Entsorgungs- und Baubetrieb (EBB)
Architectural Consultant:	Schultz-Brauns & Reinhart, München
Checking Engineers:	Dr.-Ing. B. Brandt, Rieger + Brandt, Nürnberg
	Dr.-Ing. H. Schroeter, Schroeter und Kneidl, Weiden Opf.
Construction Company:	ARGE Löwenbrücke (Glass Ingenieurbau GmbH/Leipzig, Echterhoff Bau GmbH/Dessau, Plauen Stahl Technologie GmbH/Plauen)