ROAD ARCH BRIDGE OVER THE ODRA RIVER

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SUMMARY

In the paper authors presented general overview on the new-built road bridge over the Odra river in Cisek – Bierawa. Overall parameters of the bridge are indicated. Authors described also assumptions for finite elements calculations – calculations were carried out with standard approach according to PN-S standards, as well as with nonlinear approach including buckling analysis, nonlinear analysis of 2-nd order with geometric imperfections. Also erection's stages are shortly presented as in this kind of structures way of object's realization reflects on its static capacity and cannot be omitted in design. The paper presents entire design procedure in technical aspects, beginning from assumptions, then design procedures, construction stages and final result of realization with first load tests description.

Keywords: *Arch bridge, steel arch, FE analysis, static calculation, construction stages, nonlinear analysis.*

1. INTRODUCTION

At the place of crossing of county road 1404O with the Odra river, between Cisek and Bierawa towns in Opole voivodship, had been used since 1983 a six-span temporary bridge with overall length of 162 m. The construction system of the bridge was MD-33 military folding bridge. Spans of the bridge were supported on solid concrete walled pillars and massive abutments. Traffic flow was realized on two lanes 2 x 3.0 = 6.0 m width road. Deck surface was made out of timber transversal girders. Pedestrian traffic was not allowed, but sidewalks, each of 0.75 m width, were situated both-sided only for maintenance services. Static system of the bridge was 4-span continuous beam 4 x 33.23 m with cantilevers and 2 side-spans supported on a cantilevers from one side and on abutments on the second side. Length of side spans is 12.80 m. In cross section of the bridge there are 4 steel girders of I-beam cross section, which are restrained in horizontal and vertical planes with steel bracings made out of hollow sections. In side spans height of main girders is variable, while girders in 4 inside spans are of constant height.

Because of a constantly deteriorating technical condition of the bridge there were introduced more and more severe limits of allowable traffic loads. Recently limits reached 3.5 t of allowable car weight and max. 20 km/h for its velocity. Independently on a bad technical condition of the bridge it could be stated that a period of safe lifetime of the temporary bridge was over. The bridge was under exploitation for over 30 years, while the law regulations stated maximum period of exploitation for temporary bridges for 20 years. Technical and safety and maintenance conditions forced a necessity of erecting a new structure in the same place.

Basic technical parameters of the existing bridge were:

- Theoretical length 2x12.80 + 4x33.23 = 158.52 m,
- Total length (till end of abutments wings) 162.15 m,
- Width of traffic lanes 2x3.00 = 6.00 m,
- Width of service sidewalks 2x0.75 = 1.50 m,
- Width of the deck (between railings) 2x3.00 + 2x0.75 = 7.50 m,
- Width of the bridge 7.66 m,
- Construction height 1.60 m,
- Railing height 1.05 m.

Fig. 1. *General view on temporary bridge from the left bank of the Odra river.*

Fig. 2. *General view on temporary bridge from surface layer level (on the left) and from the bottom side (on the right).*

2. DESIGN OF THE NEW BRIDGE

2.1. Assumptions and parameters

Design works were done by design office PROMOST Wrocław Sp. z o.o. Sp. k. The new bridge was designed on A load class according to PN-85/S-10030 [1].

Basic technical parameters of the new bridge are:

- Theoretical length (in axis of traffic lanes)
  24.27 + 93.50 + 27.00 + 19.50 = 164.27 m,
- Total length (till end of abutments wings) 180.65 m,
- Width of traffic lanes 2x3.50 = 7.00 m,
- Width of pedestrian and cyclists path 3.00 m,
- Width of the deck (between railings)
  0.24 + 0.50 + 2x3.50 + 0.50 + 0.39 + 3.00 = 11.63 m,
- Width of the bridge 12.75 m,
- Construction height 1.89 m,
- Railing height 1.20 m.

The static system of the new-build bridge is a 4-span continuous, steel – concrete composite beam with the main span with arch with tie-beam construction. Construction of a side-spans and tie-beams in an arch span is made as a steel grid connected with concrete deck. Two main girders are steel welded box-sections and they are jointed with plated-girder cross-beams. Main girders are designed with constant height of 1.38 m and transversal spacing of 8.18 m. Optimization of girder's cross-sections according to internal forces envelopes is made by variable thickness of flanges and webs. Height of girders with concrete deck depends on cross-section and is of 1.73 to 1.78 m. Mid-span and support cross-beams (excluding arch support cross-beams) are designed as welded I-beams with constant height in mid-span and linear variable height in cross-beam – main girder connection zones. Support cross beams are designed with taking into account future possibility of lifting entire bridge in order to e.g. change bearings. Thus, in area near main girders their height is equal to height of girders and is constant. Cross beam's web is additionally stiffened with transversal stiffeners. At the ends of arch span cross beams are designed as box girders. Boxed cross-section of a support cross beams in an arch span is a necessity taking into account that because of chosen static system cross beams are bended in two directions, and are under tension and torsion at the same time. This cross beams are also designed for lifting procedure of entire bridge, having ribbed their interior in an appropriate way. Spacing of mid-span cross beams is constant only within one span and varies for every span from 4.83 to 5.40 m. In a support zone of an arch span a diagonal tie-beams are designed with I-beam cross-section. This tie-beams connect support cross sections of arches with main girders. Every cross-beams and main girders are connected with concrete deck by use of headed studs.

General drawings showing a bride are presented in Fig. 3, 4 and 5.

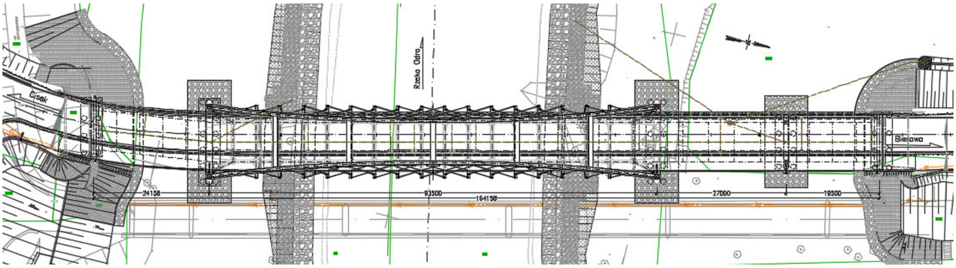

Fig. 3. *Top view on a new-designed bridge.*

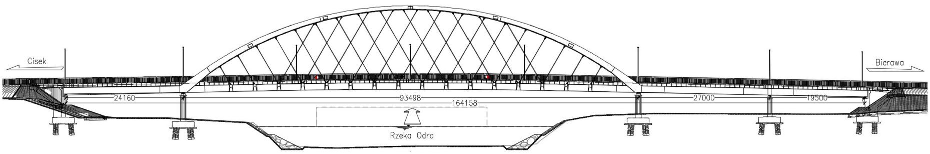

Fig. 4. *Side view on a new-designed bridge.*

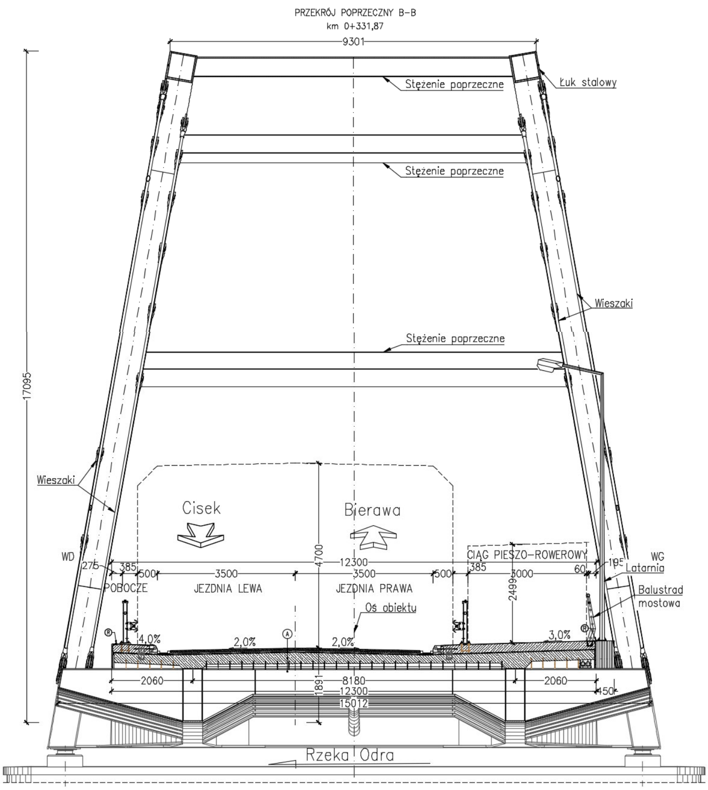

Fig. 5. *Cross section of a new-designed bridge in a mid-span of arch span.*

2.2. Arch span

The main arch span is 93.50 m long and 16.00 m height measuring between axis of an arch and of a main girder in a mid-span. Height of an arch is then approx.. 1/6 of its length. Two steel arches are designed, each of boxed cross-section, both connected to each other with 5 transversal, boxed in cross-section, top bracings. Planes of arches are in inclination of 10 deg. out of vertical and supported at the concrete pillars outside of plane of the concrete deck. Thus widths of pedestrian, cyclist and traffic lanes are not disturbed throughout entire bridge length. Width of each arch box girder is constant and is of 0.70 m, but its height is variable from 0.70 m in a mid-span to 1.80 m in a support zone. Entire steel superstructure is welded out of steel grades S355J2+N, S355J2+N+Z15 and S460NL, depending on elements.

Fig. 6. *General view on new-build bridge from level of a surface.*

Fig. 7. *General view on new-build bridge from level of terrain.*

2.3. Technology of realization

In the technical design it was assumed that the steel girders, together with already welded cross beams, will be launched longitudinally from one bank of the river, but the last single side span from opposite river bank will be erected be means of cranes. It is because of a curvature of this span, what makes launching more complicated, as well as because of easy access to terrain below considered side span. For every side spans it was assumed to build one temporary support and for the main span – two temporary supports in the river. Assembly of steel arches was made with use of two temporary towers erected in axis of two temporary supports in the river. Beside of that regular scaffoldings were erected to make possible construction works on arches elevation, like welding the transversal bracings, painting etc.

Fig. 8. *Bridge erection – stage of arches assembling. Temporary supports and towers.*

Suspension of steel deck structure (main girders and cross beams) in the main arch span was designed by means of solid circular system hangers connected to 16 cantilevers (for the single tie-beam), which were situated on extension of the cross beams (in spacing of 4.92 m). Hangers were connected to cantilevers and arches by means of bolts with possibility of prestressing force regulation (with Roman screw). Hanger bars diameter was of 72 mm, and were made out of steel with minimal yield strength of 520 MPa, ultimate strength of 660 MPa and minimal elongation of 19 %.

Corrosion protection of steel structure is made out of metallic coatings and the top layer of paintings. Box sections of main girders, support cross beams of arch span, cross beam’s cantilevers and arches with their transversal bracings were subjected to be filled with nitrogen.

New concrete slab is designed out of C40/50 concrete with total thickness of 22 – 29 cm, with rebar out of BSt500 steel. Concrete deck is connected with main girders and cross beams with headed studs.

Spans of the bridge are supported on concrete solid pillars and solid abutments by means of spherical bearings. New supports are made out of C30/37 concrete with rebar out of BSt500 steel. Behind the abutments approach slabs with length of 5.20 m and thickness of 0.35 m are designed.

Foundations are designed on large diameter piles drilled in steel removable conduit pipe. In pillars supporting arch span there are piles with diameter of 1.20 m and length of 12.00 m, in the rest of pillars of diameter and length of 1.00 m and 8.00 – 14.00 m, respectively. Because of various geotechnical conditions at both river banks and fact, that piles bases were found in different soil layers, there were injection below piles bases needed to minimize the risk of unequal foundation settlements.

In order to make possible future inspections of technical condition and conservations of elements in the main span below concrete deck, it was assumed that hand-propelled inspection trolley will be set up. Guideway of the trolley was suspended to cross beams.

2.4. Static calculations

Static calculations were carried out in Autodesk Robot Structural Analysis Professional with finite element analysis. Bridge was firstly reflected in FEA as e1p2 object (flat beam model) as preliminary model for simplified calculation and cross sections dimensioning, and then as e1+2p3 as an exact reflection of bridge geometry (spatial beam and plate model). Analysis and dimensioning was made according to PN-91/S-10042 [2], PN-82/S-10052 [3]. Independently from abovementioned standard analysis entire bridge was cross-checked with use of buckling, nonlinear and second order analysis taking into account initial imperfections of arches. Of course construction stages were taken into account and stress states in all bridge members from one stage were saved and taken as initial one for analysis of the next construction / exploitation stage.

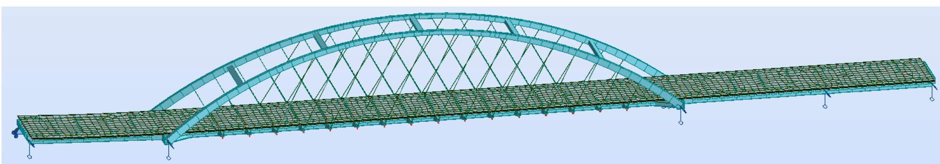

Fig. 9. *FE model with concrete deck – stage of bridge exploitation.*

Because of complicated 3D geometry of the bridge, especially arches inclination from vertical plane towards bridge axis, net system of hangers, the side span inclination in the horizontal plane (necessity to fit bridge geometry to road layout) and necessity of taking into account the vertical road alignments in design of steel superstructure, a 3D CAD model of steel structure was prepared. It reflected all technical solutions and showed all details, e.g. division of steel structure onto assembly elements, variation of width of girders flanges, thickness of their flanges and webs influencing necessity of beveling / chamfering. This detailed modelling process allowed to avoid drawing errors as well as solving many design problems at early stage of creation the bridge geometry.

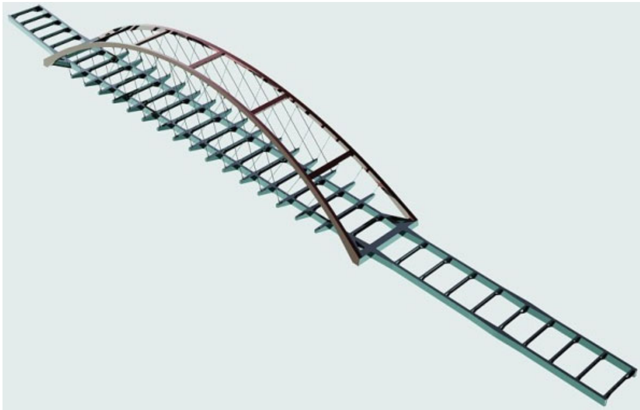

Fig. 10. *Axonometry view of steel superstructure (3D).*

3. REALIZATION OF BRIDGE

The general reconstruction of the considered bridge was made in 2014, and the general contractor was BANIMEX Sp. Z o.o. from Będzin. All task was co-financed by European Union in frame of founds from European Fund of Regional Development for Opole voivodship for 2007-2013 titled: "Inwestujemy w Twoją przyszłość".

4. TRIAL LOAD TEST

In August 2014 a trial load tests were conducted and the bridge carried both static and dynamic tests. In frame of static tests all spans, one by one, were loaded with 7 lorries with total weight of 36.3 to 38.9 t each. Deflections of side spans and both deflection and strains for main arch span were measured. During dynamic tests lorries were crossing the bridge with different velocity. Also schemes with breaking forces or with crossing with trial threshold were carried out. Deflections, strains and accelerations were measured. The bridge load response was in line with expectations. Elastic deflections were 80 – 102 % of these calculated, while permanent deflections were 0 – 8 % of total ones. After test no damages could been observed and the bridge was open to free traffic flow.

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