

THE ERECTION OF ARCH BRIDGE OVER VISTULA RIVER IN TORUŃ

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SUMMARY

The erection procedure of the bridge was unique and individual, as the structural scale suggests. Generally, the assembly covered junction of arch elements on the assembly site near the Vistula river bank and the pontoon water transport of arch girders, which were settled on the arch abutments.

Keywords: *Steel arch bridge, floating erection, active geometry control.*

1. INTRODUCTION

The Toruń arch bridge erection has recently been one of the most outstanding events in engineering. In December 2013 the city of Toruń saw the largest arch bridge in Poland, given the name of gen. Elżbieta Zawacka. The arch bridge of two spans, each one 270 m long is a part of a Vistula River bridge passageway, of a total 3 km length of bridge structures. The new arch bridge was designed in the form of a steel structure, each of its spans consists of parabolic box girders and an orthotropic deck suspended by tubular hangers. The bridge static model is a hingeless arch without a tie, transporting the entire arch thrust onto supports.

Attention is paid to the bridge erection method, unique and individual for such a great structural scale. Generally, the assembly covered junction of arch elements on the assembly site near the Vistula river bank and the pontoon water transport of arch girders, which were settled on the arch abutments.

The client investor was Toruń Municipality, represented by the Municipal Road Authority of Toruń. The bridge was designed by PONT-PROJEKT design office, the general contractor was STRABAG.

2. DESIGN ASSUMPTIONS

The structure includes two arch spans, each one 270 m long. The arch rise equals 50 m. The arch cross-section is a hexagonal steel box 2,7 m wide and 3,5 m deep. The arch planes are inclined by a 10° angle (Fig. 1). Each span was braced between the arches by means of six joister beams. The deck is suspended from the arches by means of tubular hangers. The use of hangers of Ø219mm and Ø244 diameters led to the anticipated architectural and economic effect.

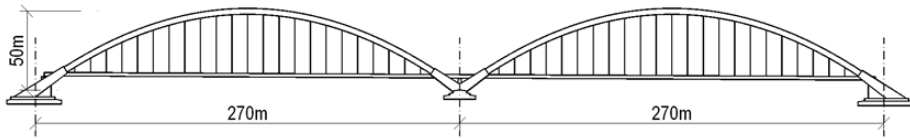


Fig. 1. Side view.

The deck is a steel grid structure with an orthotropic plate. The deck is 24 m wide (Fig. 2). The bridge supports are massive RC structures settled on RC prefabrication piles of dimensions 40 x 40 cm. The middle support is additionally settled on an artificial island located in the middle part of the river bed. The steel arches are anchored in RC abutments by means of steel bolts. The intention of the designed supports is to carry vertical loads and huge horizontal arch thrust.

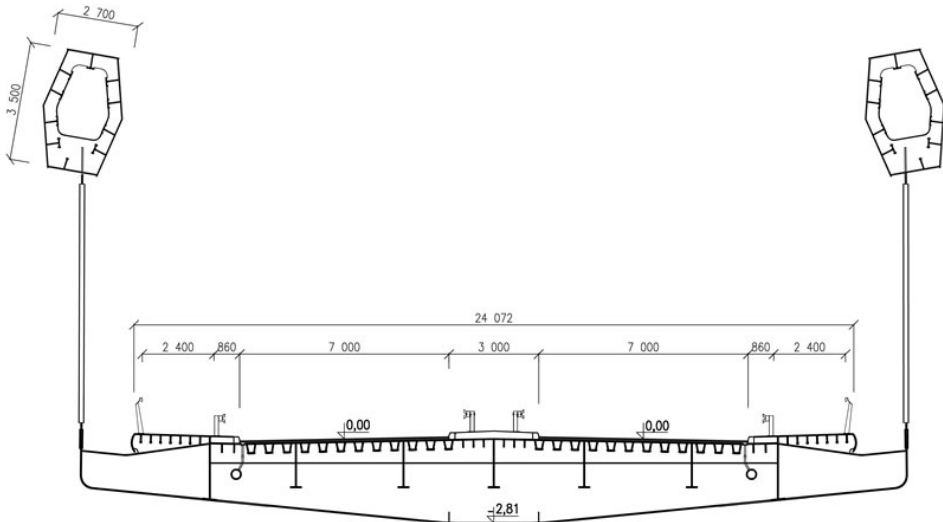


Fig. 2. Cross section.

The erection method assumed in the contract design was based on an assembly of arch girders without the use of formworks. This assembly procedure included in the contract design covered cantilever assembly of the sections, lifted and fastened to the previously erected sections, from the floating transportation means (Fig. 3). The deck assembly was similar to the arch procedure, in the water transport of an entire deck approximately 10 m long and its heavy lifting.

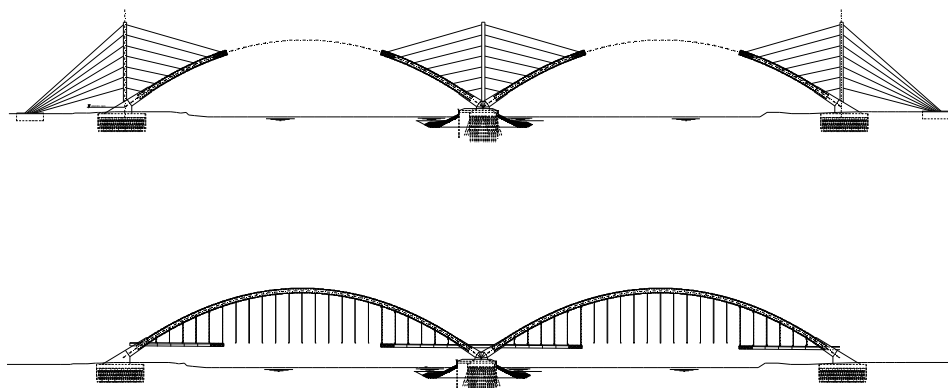


Fig. 3. Client proposal erection method.

3. PROPOSITION OF AN ASSEMBLY CONTRACTOR

The bridge design was completed assuming assembly of an arch not interfered by temporary supports in the river bed, according to the river authority regulations. The contract made it possible for the contractor to propose an alternative bridge erection method, without altering the structural assumptions of the bridge and navigation requirements (temporary supports) in the schedule of operations in the river. The contractor proposed an alternative arch assembly method - their complete erection on the assembly site near the bridge and water transport of two arch bays, each one of 2600 t, next settling them on concrete abutments. After concrete-filling of the arch starting sections in concrete abutments the entire arch girders, united on the assembly site near the bridge were floated to their erection site, supported on abutments. Finally, skop welds were made. General procedure of the deck assembly followed the design assumptions. The difference was the higher length of deck sections, equal to 30m. The contract requirement to make a navigable waterway during erection was fulfilled, meaning no assembly supports in the river bed while performing an assembly with the help of floating means, applying an alternative erection method.

4. ERECTION STAGES

The bridge assembly procedure was divided into 6 stages. The stages 1-5 covered arch girder assembly, the sixth was the deck assembly.

4.1. Support construction

The most demanding support elements are the RC arch abutments of huge dimensions and developed shapes, additionally sloped on a cantilever mode due to arch geometry. The interior of the abutments included a communication passage to make in individually shaped sliding formworks with a dedicated, hydraulically controlled supporting system (Fig. 4a, 4b).



Fig. 4. Arch beds of middle support (left) and arch beds of side support (right).

Concrete-laying procedure of the arch abutments was divided into steps (Fig.5). The last step was concrete-filling of arch girder starting sections (Fig.6), transferring giant loads from the arch to concrete. The steel-concrete load transfer was implemented by means of three systems: upper resisting ring, connecting bolts and the lower resisting ring. Performance of these elements was monitored by means of tensometers in the assembly course.

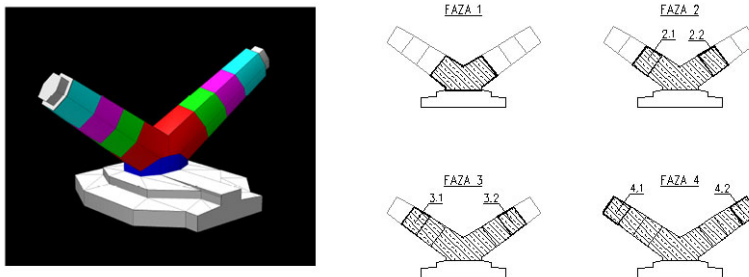


Fig. 5. Concreting stages of arch beds.

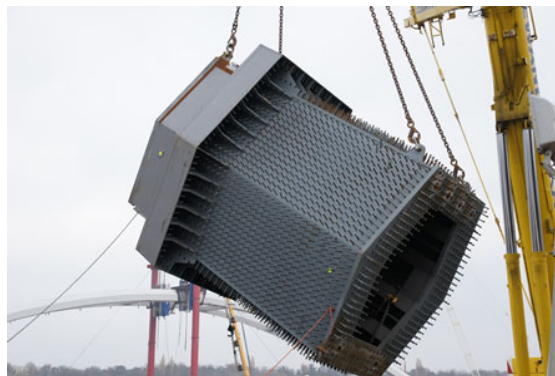


Fig. 6. Starter element of steel arch girder.

4.2. Assembly

4.2.1. Assembly arch

In order to assemble the steel structure of arch girders on assembly site was provided. This site was located near the end support of the bridge on the right bank of Vistula river, on the high water side. The site was intended to store and unite- assembly on formworks of a half-arch (Fig. 7), translation and lifting of a half-arch, making a joint in the arch midspan. There were two docks for the pontoons to enter on the assembly site, on the side of the river.



Fig. 7. Assembling half-parts of arch on temporary support.

4.2.2. Displacement

The arch halves were merged and shifted towards Vistula river on the axis of the assembly tower. Next both halves were shifted towards the assembly tower. Translation of the box arch produced large shear forces on supports. Thus internal and external box bracings were provided during the assembly (Fig. 8). The bracing was used to protect the box cross-section from excessive deformation.

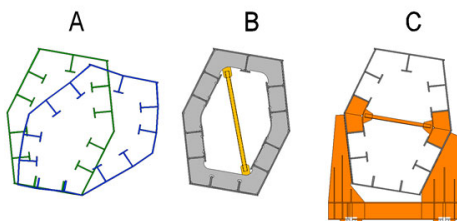


Fig. 8. Deformation protection - temporary stiffening.

4.2.3. Connection on the assembly tower

After shifting the arch halves were lifted due to their connection at the top. The lifting was performed with the use of the assembly tower (Fig.9). The tower included two columns and a spandrel beam. Four guy wires anchored to the tower spandrel beam and to subgrade anchoring system were designed to stabilize the tower. The anchors were made of steel bulkheads.



Fig. 9. Lifting tower – arch head joint.

Four hydraulic flow hoists of 500t load-carrying capacity were located on the tower spandrel beam (Fig.10). Due to lifting the arches were tied by the so-called hinge. It is a device connected from the top to both arch halves, equipped with loops to fasten the lifting cables. Due to the hinge both arch halves were tied by common bolts of cable anchoring systems. The relevant geometric collocation was done for the two halves to converge after lifting and provide a field joint at the arch top.

After fixing two arch halves by a hinge it was impossible to adjust one half with respect to another. The operation success was affected by a precise marking the hinge axis. All four bolts of cable anchorages had to be aligned precisely. The non-axial collocation could produce large forces in cables in the lifting operation, consequently- cable failure.

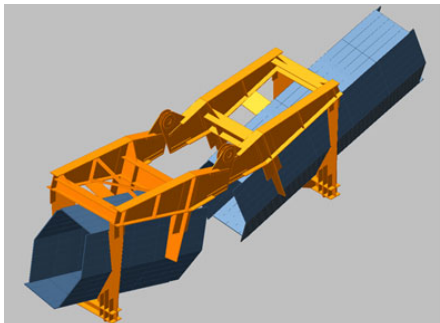


Fig. 10. Assembly hinge.

4.3. Water transport

The most complex operation of the arch assembly was water transport. This operation has supplemented by means of floating supports. They included: pontoons, towers and system of linear bracings. There were two towers connected by a soandrel beam on each pontoon. The towers allowed to freely lift and lower the spandrel beam. Arches were supported on the beam by means of specially designed support points (Fig. 11). After the floating supports carried the arches from the assembly tower and went out from the docks, the cross-beam has erected between pontoons.

The arches were translated at a low height above water level in order to achieve the highest safety factor possible. After the arch has located at the bridge axis it was lifted in order to let it settle on the abutments. The system control was assured by means of mooring ropes accompanied by tugboats. The total mass of floating system was 3000 t. The following assembly conditions were set as a computational results: limit wind speed equal 12 m/s, limit river water speed equal 2 m/s.

Prior to going out the floating structure was subjected to stability test. The real stability assessment of a floating structure has made by means of controlled sway. While floating permanent monitoring was made of wind and water speed and structural deflections. This allowed to implement appropriate safety procedures.



Fig. 11. Floating construction.

4.4. Arch supporting on abutments

The arches were supported on abutments by means of special design of plugs and sockets. The sockets were located in the transported arch structure while arch sections on supports were equipped by plugs (Fig. 12). The supporting points for the arch were adjusted to achieve a safe stress level corresponding to the allowable value of 200 MPa. The arch flexural action made the distance between its ends higher. After aligning the arch onto the bridge axis the arch were pulled to one another by means of a tie. Next the arches were lowered on the abutments, finally the tie has loosened.



Fig. 12. Structures guiding.

After the arches were supported on abutments their static model has hinged, contrary to the design assumptions- loosening the moments and breaking the arch axis. In order to achieve a proper arch geometry on field joints, the arches had to be ballasted (Fig. 13).

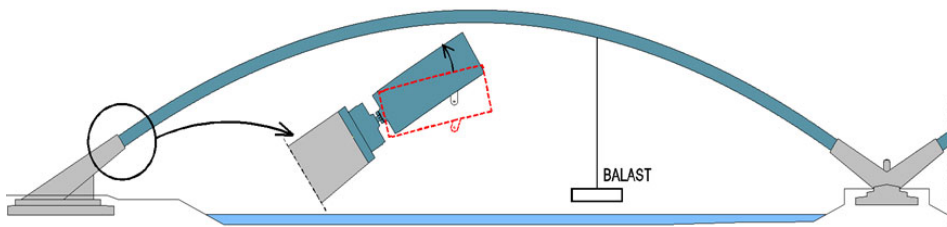


Fig. 13. Forced rotation with balast.

This operation covers loading of an arch structure in order to force desired rotations. Four ballasting operations were performed for a number of four abutments. Each ballasting cycle was followed by stabilization of a field joint to leave the forced deflection unchanged. This allowed to perform field joints of the arch with the abutments. The pontoons were applied as ballast. The pontoon was fastened to the arch and lifted upwards by means of ties. The desired weight was achieved by pouring an

appropriate amount of water into pontoons. The ballast weight was affected by a forced deflection magnitude and the temperature of the structure. The ballasts applied detected an appropriate 30t mass corresponding to a single arch branch. The arches were erected sequentially with a 1-month shift (Fig. 14).



Fig. 14. Placed on support first arch.

4.5. Deck erection

The deck has divided into 19 assembly units. At the end supports and on the island- the middle support the units were operated by a crane and settled on temporary supports. The remaining 16 units were assembled by means of pulling them from water (Fig. 15).

The stream bridge units were transported to the site on water in the 10m sections. They were united at the assembly site to larger, 30m units. They were pulled by means of cables suspended between hangers and deck brackets. The weight of a single lifted unit was 230 t. The arch and deck assembly was performed by means of the so-called active control system of assembly geometry. Appropriate measurement procedures were correlated with the dedicated analysis of deflections, stresses and forces in hangers. These operations led to an ongoing correctness check of building operations at every step of the procedure.

5. CONCLUSION

The erection of the greatest arch bridge in Poland is an incredible event of technology on the recent period. The applied assembly method is a world-scale achievement. The solutions of technology and organization with the help of inspection procedures on the construction site contributed to the designed final effect- a large-scale success.



Fig. 14. Lifting deck segment.

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