THE BIGGEST ARCH BRIDGE IN POLAND

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SUMMARY

Design and construction of bridge over Vistula River in Torun is the greatest arch bridge project of in Poland. The bridge of two 270 m length arch spans foundation laying on prefabricated piles and erected arch span girders on pontoons by water transport. During the realization of the bridge a few innovative material and construction solutions were applied.

Keywords: *Steel arch bridge, prefabricated piles, floating erection.*

1. INTRODUCTION

The Torun arch bridge erection has been recently one of the most outstanding events in engineering. In December 2013 the city of Torun opened 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 2 km length of bridge structures.

Fig. 1. *View of Torun bridge (fot. A. Zakrzewski).*

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

2. HISTORICAL VIEW

The town of Torun is one of the oldest municipalities in Poland, highly developed in the 13th century under Teutonic Order (1233). Torun developed dynamically and in the nineteenth century became the most important center of Pomerania.

Both present-day and historic image of a UNESCO-filed heritage town is monumental medieval architecture, with its vital complement – communication system. Torun is an important road junction of state roads nr 91, 15 and 80, providing road connections to Warsaw, Bydgoszcz, Olsztyn and Wroclaw. Multiple railway connections are present in Torun too.

It carries a vast archive of history, architecture and the tradition of building unique bridges. Vistula, the largest Polish river splits the town into two parts, thus leads to the erection of huge bridges. One of the longest timber bridges in Europe was built in the years 1497-1500 [1]. But in 1880 the bridge was destroyed by floe. In 1873 a steel 977 m long road-railway bridge (Fig. 2) was launched, modern at the times of erection.

Fig. 2. *Road-railway bridge - 1873 [2].*

During the Second World War the bridge was damaged (Fig. 3) and after a war it was reconstructed. In 1936 a new tram-road bridge 898 m long replaced the timber historical structure. The truss structure of spans was adapted from existing bridge in Kwidzyn located 100 km from Torun (Fig. 4).

Fig. 3. War damage – 1939 [2].

Fig. 4. Road bridge – 1936.

Urban development and the further need to join both sides of Vistula river was harmonized with the development of transit system of state roads crossing Torun. Two communication scopes – the local and the global ones, made a new Vistula crossing optimal and effective. Nowadays, after the new Vistula arch bridge is erected, Torun is equipped with four bridges, two municipal road passages, a single railway bridge and a suburban motorway bridge (Fig. 5). It is planed a new municipal road bridge located in the Waryński Street (no. 1 – Fig. 6)

Fig. 5. *Suburban motorway bridge (foto M. Nasieniewski).*

1 — Waryński Street road bridge planed
2 — railway bridge build in 1873 called Ernest Malinowski name
3 — roadway bridge build in 1873 called Józef Piłsudski name
4 — new roadway arch bridge called Elżbieta Zawacka name
5 — suburban motorway bridge

Fig. 6. *Bridges in Torun [3].*

Cohesiveness of historic reality of a 200-thousand habitat town and architecture of urban bridges is mirrored in the truss spans of arch upper chords. It is a perfect harmony of an arch shape, resembling the gothic vaults of historical building monuments.

A place of new bridge crossing with an arch bridge was localized not randomly. On one hand, the range of an obstacle which was Vistula River required a modern construction. On the other hand, novelty of the bridge construction and a long span had to fit to the historical structure of the city. This was the reason for placing the bridge distant from the old town. Both, environmental protection and aesthetics, played a key role in connecting modernity and history.

Despite of a modern bridge structure shape of an arch and parabolic chords of truss bridges is a memory of a monumental town underground and harmony of architecture in its time variation.

3. DESIGN

The design of Torun crossing was started in 2005 and lasted four years. The design of crossing was carry out by consortium polish company: ARCADIS, KONTRAKT, PONT-PROJEKT and DAMART. The bridge design was responsible PONT-PROJEKT. The scope of the design included conception, administrative and detail design.

Fig. 7. Torun crossing variants.

During the concept step, two localization variants were considered. One of them was "Trasa Nowomostowa" localized in direct neighbourhood of Old Town Torun (blue color), the other one was "Trasa Wschodnia" (red colour), localized 2 km to the west (upstream to the river). Figure 7 shows localization of both variants. The most important factors debated were communication and environment and based on them "Trasa Wschodnia" was chosen for the realization. The project consist of connection over 4 km long which includes 3km of bridge part where the main object is bridge over Vistula River.

The analysis of supports localization proceeded the choice of span range. Vistula river in Torun region is quite difficult river for shipping. Small depth of irregular Vistula River as well as sandbanks cause alteration in river current. Therefore the expected solution of water administration was a span as long as possible in a riverbed reaching more than 450 m. Based on a Municipal Road Authority of Torun suggestions which advised not to build support in a current of a river, a bridge with one 400 m arch span was analysed.

However this solution turned out to be unfavourable due to economical and esthetical reasons and finally two-spans arch bridge with a span of 270 m each was chosen as the best concept. Placing a middle support, the only one localized in a river, required a shipping analysis to define a river current which was variable during the last 20 years. Eventually the proposed support fulfils shipping requirements for a 100 × 9,4 m clearance of navigable channel in both spans This solution with a kind of artificial island took into account a potential current changes.

A new arch bridge was designed as a steel structure, each of its spans includes parabolic box girders and an orthotropic deck suspended by means of tubular hangers. The arch is modelled by a hingeless system without a tie, transferring all horizontal forces into supports with prefabricated piles 400 × 400 mm (Fig. 8a, 9).

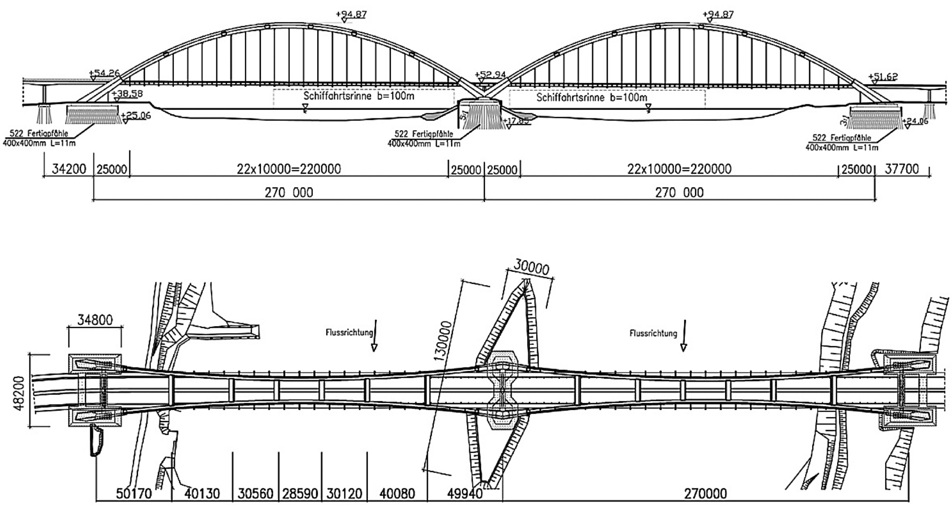

Fig. 8. *Side view (top), b) top view (bottom).*

Soil condition on the site is characteristic for the Vistula River bed in the area of Torun. The upper layer is made up of loose and medium-density sands. Below, at the depth of 5-8 m, there are silty sands, while at the depth of 20-25 m there is a thick layer of lignite silts.

Foundation side support of the bridge has 538 RC piles, 13 m long with 3:1 inclination. The central support has 395 RC piles, 21 m long with 5:1 inclination. Special structural system including precast piles was shaped for taking the inclinational reaction force from arch superstructure.

A significant issue in design of the bridge was the architectural analyses with looking for rewarding shape effect of superstructure and supports.

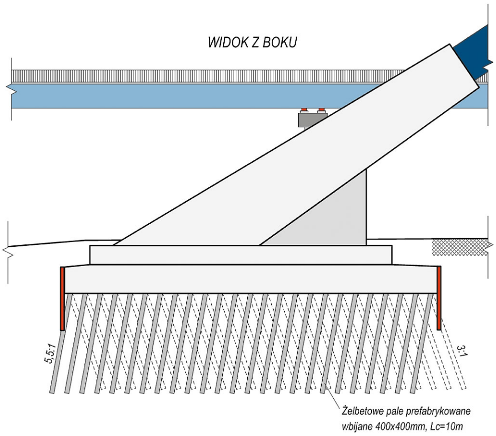

Fig. 9. *Side support model.*

The arch is modelled by a hingeless system without a tie, transferring all horizontal forces into supports. The structure includes two arch spans, each one 270 m long. The arch rise equals 50 m (Fig. 8). The width of the deck is 24 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. 10). Each span was braced between the arches by means of six jointer beams. The deck is suspended from the arches by means of tubular hangers. The use of hangers of Ø219 mm and Ø244 diameters led to the anticipated architectural and economic effect. The connections deck and hangers as hinge joint was design.

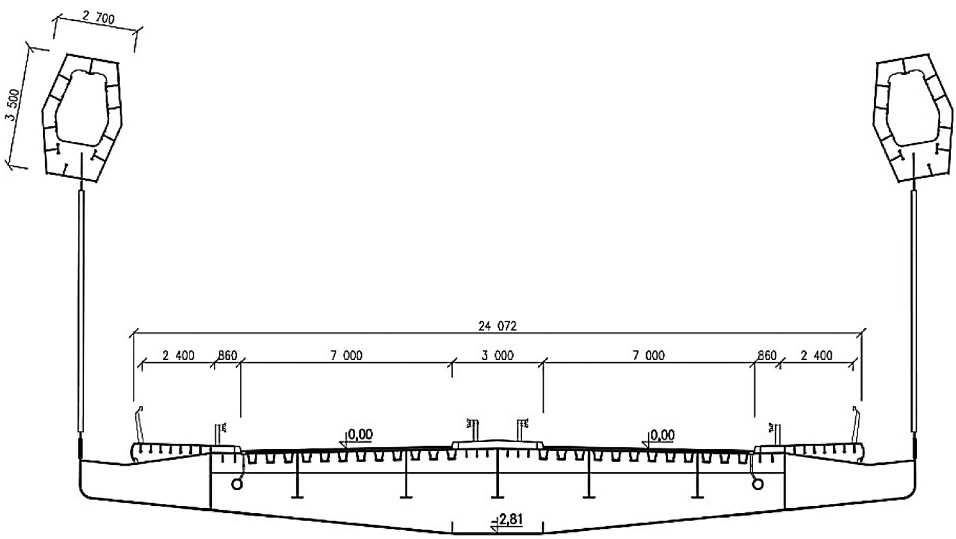

Fig. 10. *Cross section.*

The deck of bridge contains of longitudinal and traverse beams and orthotropic plate. The traverse arrangement transmit load from deck to arch was assume. The height of deck is 2,75 m (Fig. 10). The steel structure was made from S355 grade steel and connect by welding. Steel construction of bridge was prefabricated in three polish shipyards. The arch girders were divided into assembly elements of 10m length and 30 t weight. The deck was divided into erection sections dimensions 30 × 30 m.

Fig. 11. *Arch girder segment.*

The static and dynamical analysis was carried out with SOFISTIK and ROBOT software. The bridge was numerically modelled (Fig. 12) as an 3D integral structure made from arches, massive blocks of skewbacks and precast piles. Piles were modelled in the elastic ground. The calculation of the bridge was made by polish standards.

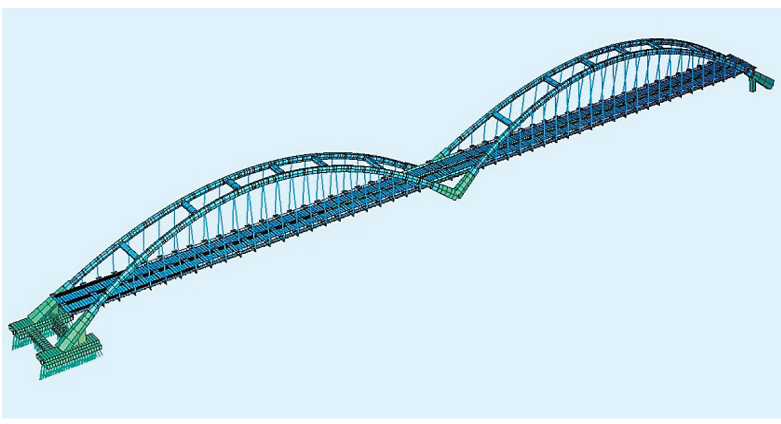

Fig. 12. *Computer model.*

The reaction characteristic force between steel and concrete on support is 46 500 kN. The forces in piles are from 1200 to 1400 kN. Sequential erection span by span arch causes asymmetrical horizontal action on middle support.

4. CONSTRUCTION

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

In order to assemble the steel structure of arch girders, an assembly site was provided. This site was located near the end of the support 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 (stage 1), translation (stage 2) and lifting of a half-arch and making a joint in the arch middle span (stage 3). There were two docks for the pontoons to enter on the assembly site, on the side of the river.

Fig. 13. *Assembly hinge.*

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. 14). The tower included two columns and a spandrel beam. After fixing two arch halves by a hinge (Fig. 13) it was impossible to adjust one half with respect to the other.

The most complex operation of arch erection was water transport (stage 4). This operation has supplemented by means of floating supports (Fig. 15). They included pontoons, towers and system of linear bracings. There were two towers connected by a spandrel beam on each pontoon. 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 erection operation was carried out by STRABAG. The technology documentations for water assembling and erection procedure made by PONT-PROJEKT.

The fifth erection stage of arches refered to place arch girders on support. The arches were supported on abutments by means of special design of plugs and sockets as a temprary construction. The sockets were loacted in the trnsported arch structure while arch sections on supports were equipped by plugs (Fig. 16). The plugs and sockets helped precisly place steel end of arch. Additionaly plugs and sockets provided unweight locally steel part to be joint by welding.

Fig. 14. *Lifting tower – arch head joint.*

Fig. 15. *Floating operation.*

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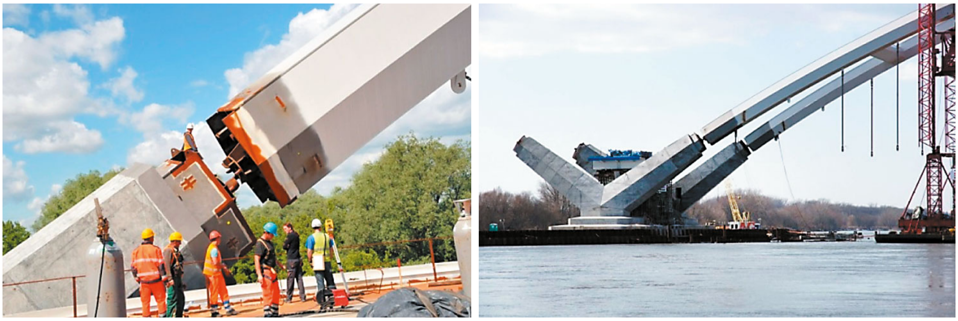

Fig. 16. *Placed on support first arch.*

Last sixth stage was erection of a deck. 16 sections each 30 m long and 230 t heavy ware floating under the bridge and heave lifted by cables suspended between hangers and deck crossing beam brackets (Fig. 17).

Fig. 17. *Deck heave lifting.*

5. CONTROL SYSTEMS AND MONITORING DURING ERECTION

While the erection was carried out observations and measurements of the behaviour of structural elements of the bridge were made. It covered an active system to control the assembly geometry and an assembly strain gauge monitoring. The experience in geometric control of building cable-stayed bridges was applied in the field of arch bridge construction.

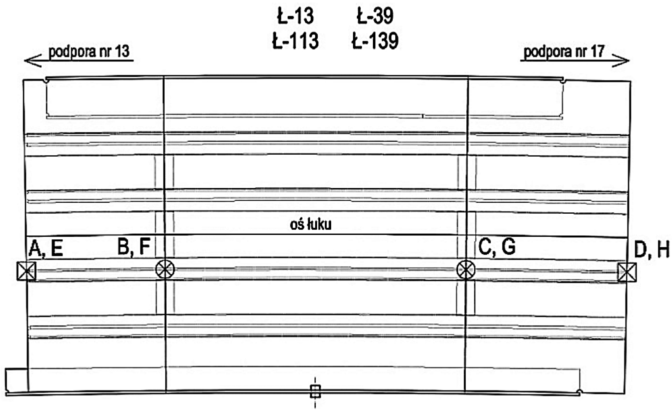

Fig. 18. *Benchmarks of arch section.*

Geometrical measurements were made by surveying services. A well-designed network of benchmarks on every bridge part and its synchronic work in the bridge structure domain made it possible to fabricate and precisely join hexagonal box sections (Fig. 18).

With this system it was possible to precisely determine the virtual axis of the arc. The benchmark system coordinated the geometry of segment contact and defined the relative position between section joins. The control system also allowed for the production of independent arch steel sections by three manufacturing companies not conducting the test assembly.

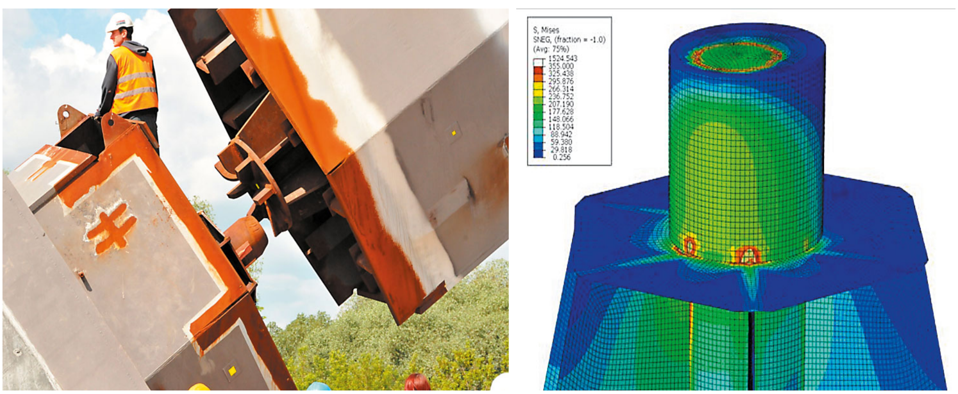

Fig. 19. *Assmbly "plug and socket".*

Moreover, the project assumed the monitoring of the stress control of the key elements of the bridge structure – steel and concrete connections in the headboards of the arch. The control procedure was based on strain gauge measurements, compared with the computational results conducted on advanced FEM models (Fig. 19).

Measurements were also used to assess the temporary support structural behaviour and to guide the arch during the erection (Fig. 20). Monitoring was provided by a team of Gdansk University of Technology [6], [7].

Fig. 20. *Steel arch anchorage.*

6. SUMMARY

Construction of the arched bridge in Toruń has recently become one of the greatest engineering events In Poland. The usage of floating erection method arch span is a unique world experience. Designed solutions of the foundation with prefabricated piles for such a large bridge are rare in the world. Technical solution and control procedures resulted in a bridge construction success.

Fig. 21. *Night view of Torun bridge (fot. M. Nasieniewski).*

Main data on the bridge:

- Total length of bridges – 2 300 m
- Length of tunnel – 400 m
- Arch span length – 270 m
- Total steel construction – 18 500 t
- Reinforcement steel – 7 900 t
- Concrete – 65 000 m^3
- Prefabricated piles – 49 000 m

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