STEEL ARCH BRIDGE WITH A REINFORCED CONCRETE COMPOSITE SLAB PLATFORM - CASE STUDY

J. Ukleja

Opole University of Technology, Faculty of Civil Engineering and Architecture, Opole, POLAND.

e-mail: j.ukleja@po.opole.pl

SUMMARY

The discussed bridge is a single-span structure consisting of steel arches and a suspended deck having the form of a reinforced concrete composite slab integrated with steel crossbars. The primary structural components of the bridge are two hinge-less arches set on bearings resting on reinforced concrete abutments. The arches are tensioned by tie beams suspended from the arches using hangers, and those tie beams also support the deck. The analysis of the structure of the bridge enabled the selection and optimisation of the sections and consideration of the interaction resulting from the integration of the deck with the steel crossbars. The results of that analysis enabled the development of a bridge construction method with consideration of all arch erection stages and loads from other structural members and utilities. An important issue was how to ensure that the structure has the correct, linear shape after and during erection.

Keywords: *Road bridge, steel arch with tie-beam, suspended reinforced concrete slab, composite slab with steel crossbars.*

1. INTRODUCTION

Steel arch bridges are increasingly used for road and rail traffic – this applies both to reinforced concrete bridges and steel bridges: [1], [2] and [8–13]. The discussed bridge is a mixed structure consisting of steel arches and a suspended deck having the form of a reinforced concrete composite slab integrated with steel crossbars.

1.1. Description of the situation before the construction of the bridge

The discussed bridge is an important passage across the Koszarawa River passing across Sporyska street in the town of Żywiec. The previous bridge was deconstructed because it did not have the required parameters and was in poor condition. Originally, it was a multi-span bridge supported on two abutments and several pillars across the river. The structure of the spans was scrapped, the piers were demolished, and the abutments were reconstructed and reinforced so that they could be used as supports for the new, single-span structure.

1.2. Parameters of the new structure

The parameters of the new bridge were adjusted to the road requirements based on the requirements for communal roads of class Z (service roads). Consequently, the technical parameters of the bridge have been established as follows: span length L = 70.0 m, traffic load class A (vehicle 80kN), carriageway width: 7.0 m + 2 x0.5 m protective zone and walkways on both sides with a width of 2 x 1.5 m. The structure of the bridge consists of an arch span set on bearings supported on reinforced concrete abutments. The static arrangement of the bridge structure consists of two hinge-less steel arches with I-shaped tie beams suspended from the arches using hangers. Those tie beams also support the deck. The deck structure consists of steel I-shaped crossbars integrated with a reinforced concrete deck slab, supported on I-shaped tie beams suspended from the arches of the bridge structure. The reinforced concrete deck slab composite with the crossbars and tie beams ensures the lateral stiffness of the bridge, without the need for additional diagonal braces in the deck.

2. STATIC AND STRENGTH CALCULATIONS

2.1. Input data for calculations

2.1.1. Permanent loads (Fig. 1c and d):

a) dead load of deck slab concrete after setting,
b) g'_1 – deck slab load per linear metre of the crossbar,
c) g^{ch}_1 – sidewalk slab load,
d) dead load of the steel structure,
e) g_p – dead load of the crossbar without the composite deck,
f) dead load of the pavement under the arches – g'_3,
g) dead load of the pavement on the carriageway – g'_5,
h) The carriageway pavement consisted of the following parts: 3 cm wearing layer, 4 cm binder layer, 3 cm protective layer, 1 cm bituminous sealing layer and 1 to 8 cm levelling layer,
i) dead load of the pavement on the sidewalks g'_4, consisting of the following: 0.5 cm wearing-sealing course (resin layer) and 1 cm levelling layer.

2.1.2. Traffic loads (Fig. 1a and b)

Traffic load class A has been adopted as per [5], which corresponds to standard usable load of vehicles K = 800 kN (200 kN axle load and 100 kN wheel load) and evenly distributed road traffic load $q = 4.0\ kN/m^2$. The loads considered in the Base Case include the following:

- load factor for road traffic $\gamma_f = 1.50$ and for crowd loading $\gamma_f = 1.3$,
- dynamic factor $\phi = 1.35 - 0.005 \cdot L = 1.00$,

a) Road traffic loading q ($\phi = 1$),
b) Vehicle loading K as per [5] has been replaced with a load evenly distributed over a rectangular surface with a size of $3.80 \cdot 4.70$ m referred to as q_K,
c) Crowd loading – q_t,

d) For crowd loading, the dynamic factor has been neglected as per [5].

e) For the calculations of the main girders and supports, crowd loading Q_t has been adopted as the node force per hanger.

f) Loads from utilities on the bridge – the water supply pipeline has been considered – q_w.

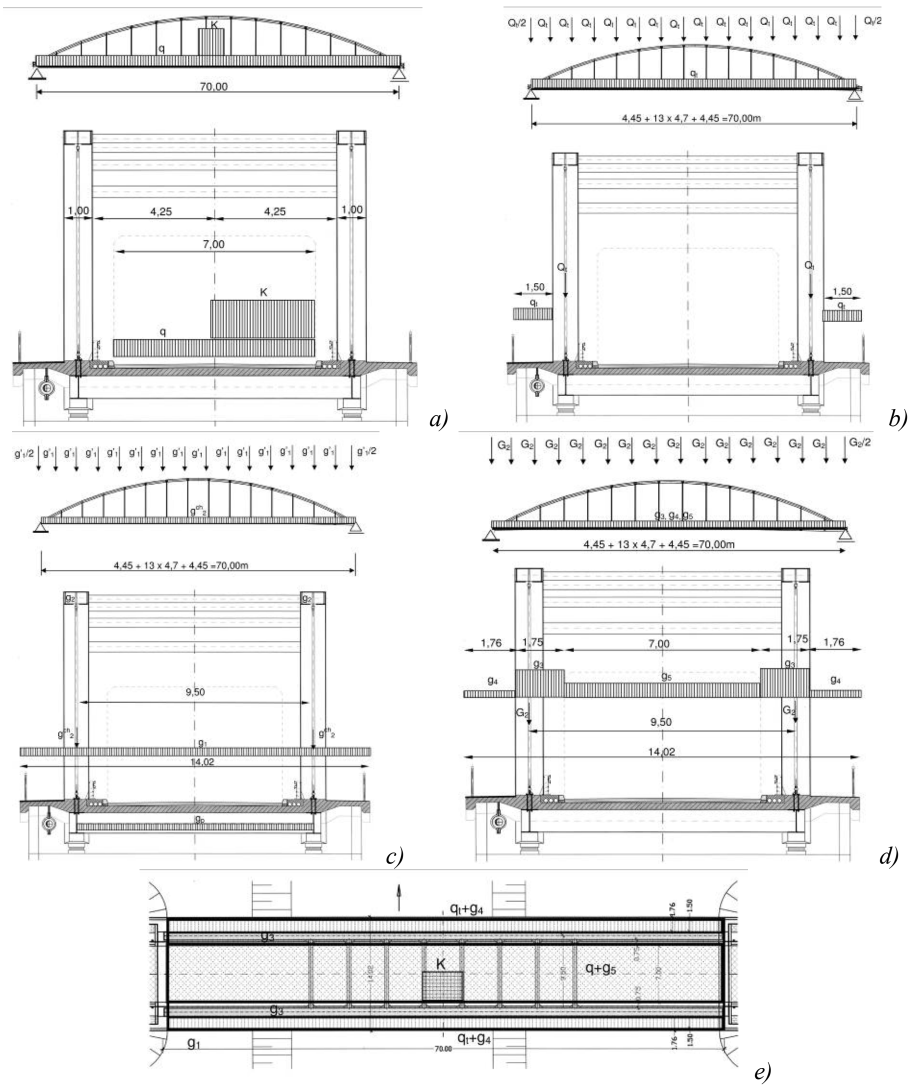

***Fig. 1.** Bridge load diagrams: a) road traffic loading; b) crowd loading; c) dead load of the structure; d) dead load of the pavement; e) total simultaneous load as per diagrams in items a, b, c and d.*

3. CALCULATIONS PROCESS

The computational model (Fig. 2) was a three-dimensional steel structure accurately representing bar and arch sections. The reinforced concrete components of the deck slab have been considered after conversion of their composite section into equivalent steel sections (Fig. 3).

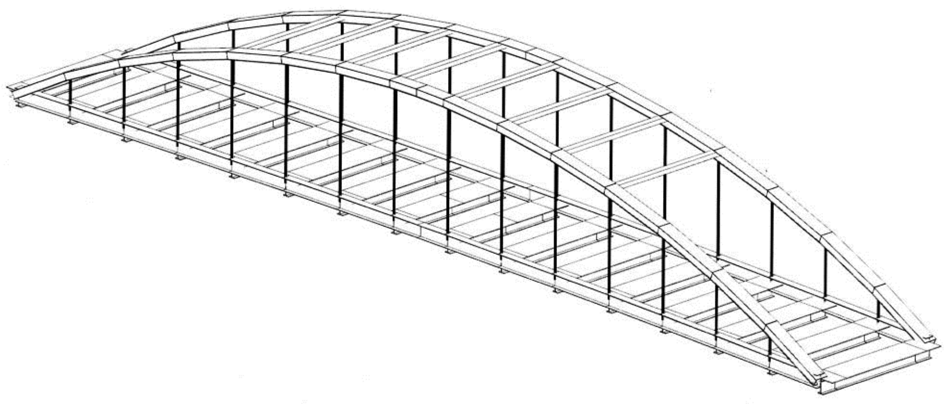

Fig. 2. *Established computational model.*

The numerical analysis of the structure of the bridge carried out in the Autodesk Robot Structural Analysis software enabled the selection and optimisation of suitable sections and material used to construct the bridge and consideration of the interaction resulting from the integration of the deck with the steel crossbars. The structural arrangement of the model was recreated as accurately as possible with consideration of the actual loading conditions of the bridge structure.

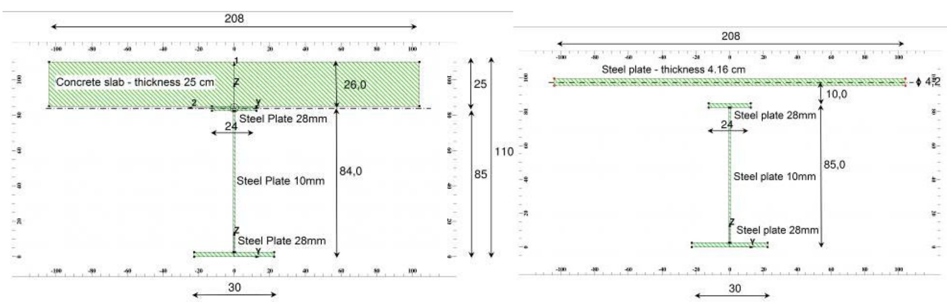

Fig. 3. *Bridge load diagrams. Real section (left). Real section converted into a steel section (right).*

The results of the analysis are presented in tables 1 and 2. Those results enabled the development of the bridge construction method with consideration of all stages of the erection of arches, other structural members and utilities such as large-diameter pipelines suspended from the bridge structure. An important issue in the discussed case was how to ensure the target shape of the carriageway pavement and sidewalks. Due to the circular longitudinal section of the pavement and its constant cross-section, it was necessary to adjust the height of each hanger. Since the hangers could not be adjusted after the deck slab was cast, it was necessary to perform accurate numerical calculations of deflections for the actual loads and design loads (with or without consideration of load factors). That issue had a significant impact on the correct use of the drainage and the shape of the designed large-diameter water pipeline suspended under the bridge.

Table 1. *Forces and stresses in the steel arch structure after integration deck slab with crossbars.*

Component of bridge structure	N_{max} [kN]	Q_{max} [kN]	M_{max} [kNm]	σ_{max} [MPa]	σ_{min} [MPa]
arch	11,051.88	254.42	1929.16	275.48	36.72
tie beam	-9899.19	-269.46	1859.75	-63.85	-271.00
hanger	-805.95	-20.65	-	-137.00	-99.18
crossbar	-3.80	666.39	1454.82	47.75	-47.74
brace	6.10	-9.04	10.48	4.95	-4.92

Table 2. *Maximum deflections of span structure.*

Load type	Load factor	Deflection (cm)
Total load (fig. 1 e)	yes	23.3
Dead load of the bridge (figs. 1 c and d)	no	11.2
Live loads (K, q, q_t)	yes	8.5

In addition to the strength analysis of the structure carried out based on [3], [4], [6] and [7], it was important to ensure that the structure was given a suitable shape during erection, so that its correct linear shape could be achieved without the need for the adjustment of the hangers between the arch and the tie beam. In order to maintain the assumed loading conditions of the deck slab, it was necessary to consider the upward deflection of the steel structure during deck slab casting.

3.1. Bridge construction

A view of the erected bridge is presented in figs. 4 and 5, and the major stages of bridge construction and construction details are depicted in figs. 6 to 13.

Fig. 4. *View of the underside of the structure on the upstream side.*

Fig. 5. *Bridge structure on the downstream side.*

Fig. 6. *Formation of arches, tie beams and hangers.*

Fig. 7. *Steel structure assembly phase.*

Fig. 8. *Detail depicting the connection of the arch with the tie beam and crossbar.*

Fig. 9. *Formwork prepared for the composite deck slab.*

Fig. 10. *Formwork for the cantilever sidewalk slab.*

Fig. 11. *Arrangement of ducts for various utilities in the sidewalk cover.*

Fig. 12. *Grillage consisting of tie beams, crossbars and the sidewalk slab.*

Fig. 13. *Stormwater drainage from the roadway and sidewalk.*

4. DISCUSSION

The design of the was prepared based on the input parameters of the bridge listed in chapter 2.1.1. Standard static calculations enabled the determination of extreme stresses in the individual members and deflections of the structure. This referred to the target condition upon completion of the bridge. However, the intermediate stages of erection could lead to irreversible deformations of the structure. The shape of the structure was adjusted primarily using hangers and hold down bolts. However, after the deck slab was cast, adjustment became impossible. According to the bridge erection method, the deck slab formwork would be supported directly on the assembled steel structure consisting of arches complete with braces, crossbars, tie beams and hangers. If the slab was cast incorrectly, there was a risk of deformation because the entire structure was subject to deflection with wet, unset concrete. The second difficulty was the fact that, once the concrete cementation, the adjustment of hangers would not be possible. That is why it was crucial to calculate and estimate the real deflections (not the design deflections which take in to account the factors) of the individual nodes of the structure. If temporary intermediate supports were used, they should also be considered in the calculations.

The results of the calculations for the operating phase were verified in the discussed case by the tests carried out during the bridge load test. The presented case demonstrates that the procedure adopted during the bridge design phase was correct, as confirmed by the thoroughly planned performance of the works, with consideration of all erection phases. The applied erection methods, confirmed by the preceding static analysis, were verified with good result during the construction of the bridge.

5. CONCLUSIONS

The discussed arch bridge is a structure combining the advantages of steel structures and composite structures (constructed of reinforced concrete and steel). The static calculations were carried out for the individual construction stages and various stages of operation. This enabled the monitoring of structure deflections, correction of the structure during erection and estimation of its shape upon completion of the construction. This was important because it would be impossible to correct the hanger length after the deck slab was cement. Also, the fact that the slab was composite with the crossbars enabled the optimum use of its strength, at the same time reducing the dead load of the deck. The primary advantages of that solution are as follows:

a) relatively low weight of the bridge structure and deck owing to the use of a reinforced concrete slab integrated with steel grillage;

b) no need to use braces and diagonals at the level of the tie beam and crossbars owing to the integration with the deck slab;

c) uncomplicated assembly of the steel structure, which is subsequently used to support the formwork when the deck slab is cast;

d) slender, neat-looking shape of the bridge merging well with the surrounding landscape.

The disadvantages of that solution include the complicated computational analysis at the design stage and during the preparation of the construction method and the need to carefully monitor the individual construction stages.

The bridge constructed using that method was finalist in the competition for the best project modernization in 2010 organised by the President of the Republic of Poland.

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