

LONG SPAN POST-TENSIONED BOX GIRDER BRIDGE IN BRATISLAVA

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ABSTRACT.

The paper describes an analysis and detailed design of the 470 m long D4 motorway bridge in the Slovak capital Bratislava. This bridge is a part of 2 932.50 m long D4 motorway crossing of the Danube River and its surrounding areas. The 210 m long main span of the post-tensioned three span box girder bridge is the longest span which has ever been built in Slovakia. The Ministry of Transportation and Construction of the Slovak Republic requirement was to cross all future rowing tracks by a single span. The depth of the cross section varies from 4.39 m at span to 13.09 m at piers. 35 m wide cross section carries 4-lane carriageway, median, sidewalk and cycling path. The central part of carriageway is built by the balanced cantilever method. The overhangs carrying outer lanes are built by wing traveller machine and supported by the precast struts. The bridge is currently under construction as a part of PPP project of Bratislava ring road (the motorway D4 Bratislava, Jarovce - Bratislava, Ivanka north section).

KEYWORDS: Balanced cantilever, box girder, main span.

1. INTRODUCTION

The bridge is a part of the southeast Bratislava ring road - D4 motorway, running between the Jarovce interchange in the south and Ivanka, north interchange in the east of Bratislava. D4 motorway Bratislava, Jarovce - Ivanka, north connects the motorway D2 (south) and the motorway D1 (east). This 22.59 km long motorway section is a part of the running PPP project consisting of 58.13 km long D4 motorway and R7 expressway, 14 interchanges and 122 bridges.

To avoid the European and national protected areas and to protect the Danube River habitats as much as possible, the D4 motorway crossing the Danube, required to build the 2 932.50 m long bridge structure which passes over the right bank seepage channel, the Danube branch - Jarovce, the future rowing tracks, the Danube, the Danube branch - Biskupice and the left bank seepage channel.

The bridge structure consists of 4 bridges divided by the expansion joints. The first structure above the right bank seepage channel and the Danube branch - Jarovce is 782.5 m long, the second one which is subject of this paper, above the future rowing tracks is 470 m long, the third one crossing the Danube itself is 430 m long and the fourth bridge spanning above the Danube branch - Biskupice, the left bank seepage channel and floodplains is 1250 m long (see Fig.1).

The design meets the minimal vertical and horizontal clearance requirements of 4 m (above a reference level of 132.20 m.n.m.) and 200 m respectively, at the future rowing tracks crossing. The horizontal clear-

ance of 150 m and vertical clearance of 10 m above the above mentioned reference level were required at crossing of the Danube. The bridge articulation, the type of foundation, the shape of substructure and superstructure were proposed by the concessionaire and accepted by the Slovak Ministry of Transportation and Construction in the public procurement.

The bridge carries 4-lanes and paved central reserve of D4 motorway, which is a category D25.50/100 (width/design speed). The distance between the guardrails is 26.0 m on the bridge structure. The 3 m wide sidewalk is on the left side and 3 m wide cycling path on the right side of the bridge. Pavement cross-fall is positive on both sides from a motorway centre line. Straight section of the D4 motorway runs on the bridge.

2. BRIDGE DESCRIPTION

After taking into account the area nature and conditions and meeting the Client's requirements the bridge has been designed as a 470.0 m long continuous three-span box girder structure of post-tensioned concrete with the spans lengths 127.5 + 210.0 + 127.5 m. The bridge is resting on deep foundations. The bridge construction method, with the main span's length of 210 m, is the balanced cantilever construction method.

In cross section the superstructure is formed by a single-cell core of the section with top slab's cantilevers (overhangs) on both sides which are supported in the transverse direction with precast steel-

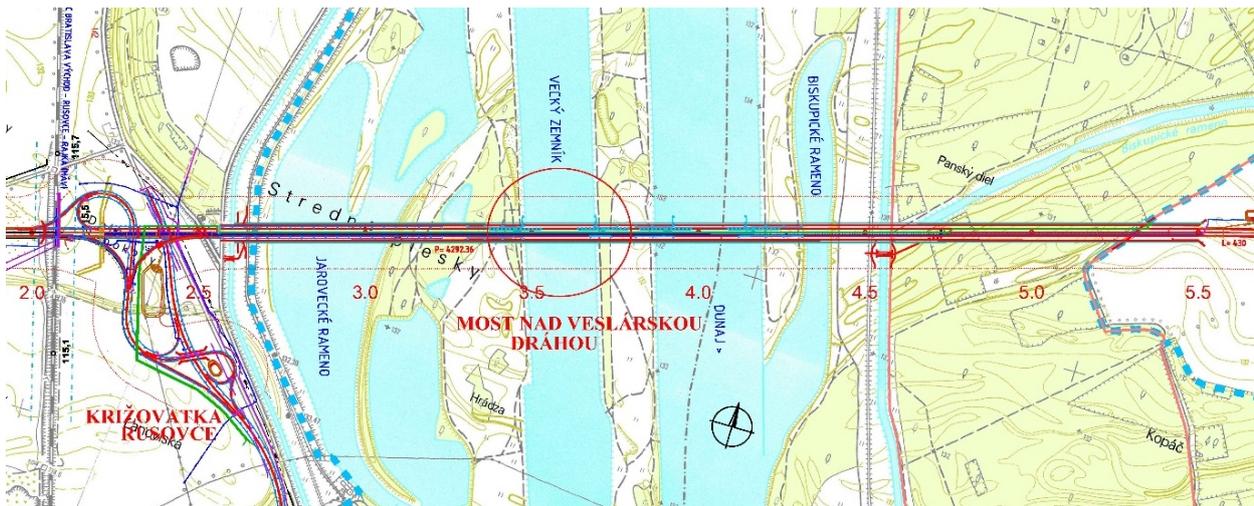


FIGURE 1. Bridges crossing the Danube and its branches.

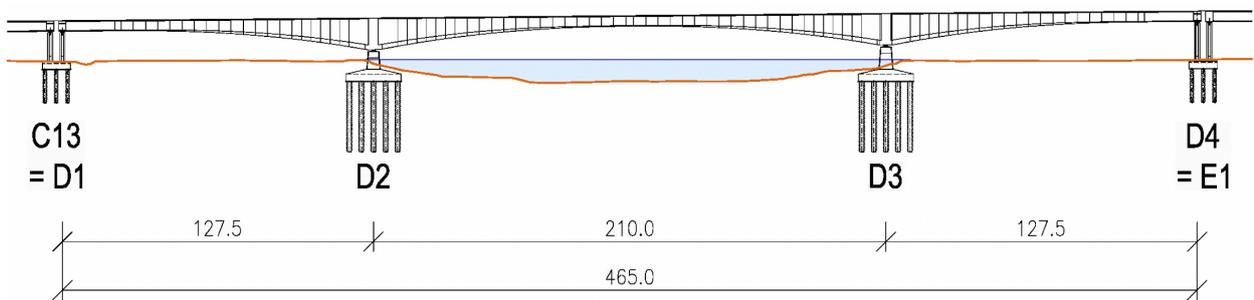


FIGURE 2. B Longitudinal section.

concrete braces set in the section’s core. The superstructure is prestressed in longitudinal as well as transversal direction of class C50/60 post-tensioned concrete.

The box girder core section’s depth varies from 4.30 m in midspan and at the abutments up to 13.0 m at piers. The superstructure top slab’s width is constant, 34.50 m, along the whole length. The superstructure is placed on steel bearings with the placement on fixed bearing on pier D2.

The bridge substructure is formed by a common bridge’s pier supporting the structure above the Danube branch - Jarovce, two intermediate piers and an end pier (abutment) common with the bridge over the Danube river. The common piers are designed as pairs of column stems with the dimensions 3.15 × 2.10 m. Each pair of piers’ stems supporting one of the adjacent bridges is interconnected in the bottom part with a dwarf wall, the parameters of which were optimised in order to enable, by its rigidity, the transmission of seismic effects. The joint piers are resting on deep foundations, on 20.0 m long large-diameter piles with the diameter of 1.200 m.

The intermediate piers are designed as pairs of skew piers’ stems embedded in 5.0 m high footing. The piers stems’ upper part is interconnected in transverse direction by means of 2.5m high stiff section with a frame effect. There is a pair of bearings

on pier’s cap. The intermediate piers are resting on deep foundations, on 29.0 m long large-diameter piles with the diameter of 1.800 m.

3. CONSTRUCTION SEQUENCE

When preparing the bridge design the designer has proposed the piers foundations to be situated in Veľký Zemník water body bank’s slope. The method and the sequence at the construction of piers foundations has been designed so as to eliminate in the maximum possible extent the action of groundwater and the action of water from the Danube’s riverbed.

The substructure foundations are designed to be constructed in pits protected with interlocking sheet-pile walls strutted with steel shielding box. The piles were bored from the terrain level from artificially made jutting of fill material at the level of river’s reference water level. The length of pier foundation pit’s protection walls is 13.0 m, with the strutting in wall’s upper level. The pit’s bottom is grouted by means of jet grouting. The sealing with 3.50 m thick injection-grouted subgrade in combination with completed bored piles resists the water’s buoyancy forces. The jet grouting was carried out by drill rig from the pile-construction platform’s level. There were intermediate piles with temporary props constructed in pits which are providing for the superstructure’s stability during the construction.

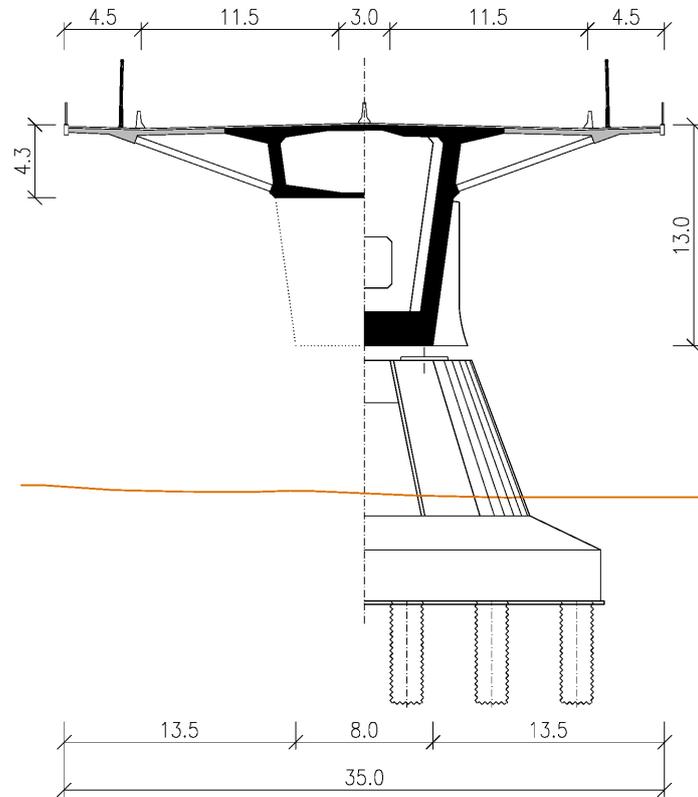


FIGURE 3. Cross-section in midspan and at piers.

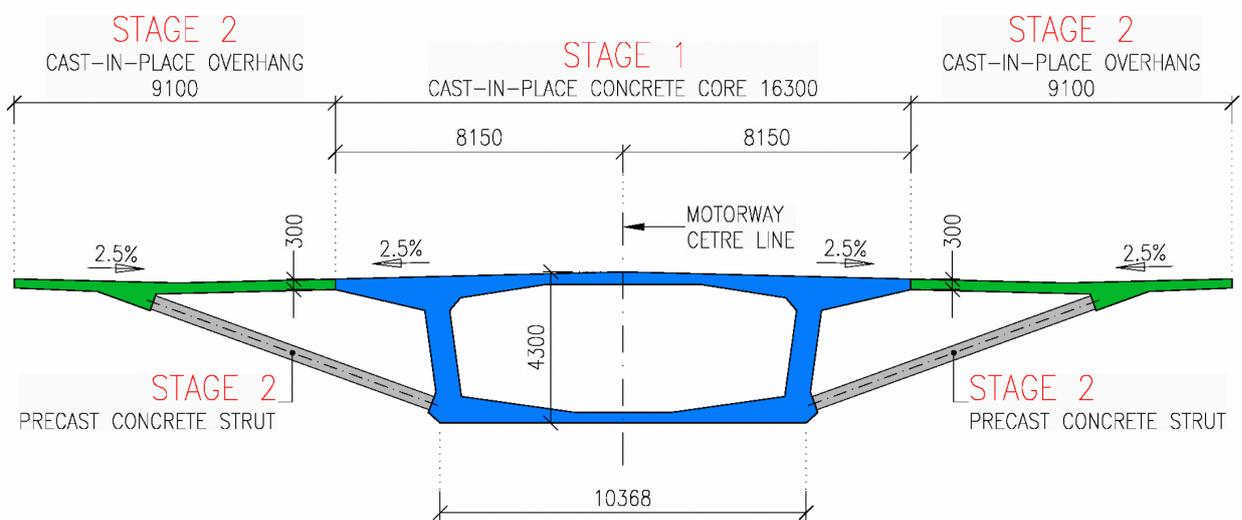


FIGURE 4. Deck cross-section construction stages.

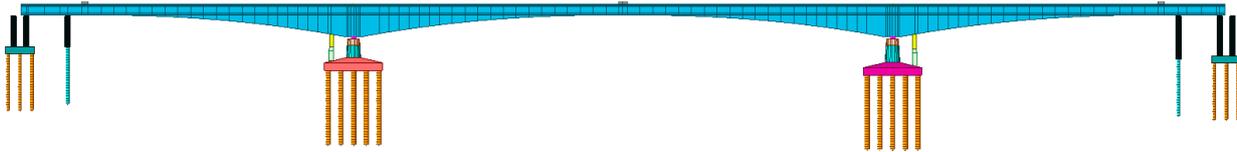


FIGURE 5. Global analysis model.

The superstructure construction is proposed in two stages. The section core formed by box-section girder with outer overhangs is constructed in stage one to which the deck slab's outer overhangs supported with precast steel-concrete braces will be connected in stage two. The box-section core is constructed from two starting sections by segments symmetrically because of the piers axis. The temporary props are situated at the end spans. The props are leant to piers foundations with anchoring the joint gap by means of prestressing bars. The starting section is anchored through temporary prop to the foundations by means of unbonded tendons. The temporary prop's side is connected with piers' stems by means of steel braces. The number of segments of balanced cantilever's overhang is 20. Because of the used form traveller's (mobile concreting carriage) loading capacity the length of 6 highest segments is 3.9 m, the length of remaining 14 segments is 5 m. Upon completing the concreting of each segment the section is prestressed by using a group of prestressing tendons situated in the slab. The section core at bridge's end spans is executed on temporary supporting scaffolding with temporary bracing by means of scaffolding prop in the vicinity of jointing segment. Uniting the balanced cantilevers to form one unit by means of in-situ concreting will be performed first at the end spans and then at the middle span. Upon completing the box girder's core section the prestressing of bonded tendons situated in core's bottom slab will be performed along the whole bridge's length.

After removing the casting form travellers the travellers for concreting the second stage of bridge superstructure will be assembled at the end span on both sides of the core. Using the form traveller the precast steel-concrete braces will be positioned and the deck slab's outer overhanging cantilevers will be concreted. Following the top slab's concreting and hardening the top slab will be prestressed in the transverse direction. In order to minimise the tensile stresses in section's core and in deck slabs cantilevers the whole section in bridge's longitudinal direction will be post-tensioned by means of tendons situated in top and bottom slab of section's core, anchored in anchor blocks (blisters). The diameter of longitudinal prestressing bonded tendons is 15.7 mm, with the number of strands being 31 pieces. The diameter of transversal prestressing bonded tendons, with using the flat plastic tendon ducts, is 15.7 mm, with the number of strands being 4 pieces, alternatively 12 pcs above the end diaphragms.

4. BRIDGE ANALYSIS AND DESIGN

The bridge, with its span of 210 m and the corresponding dimensions, with the used construction method, has required, when preparing the design and at the assessment, a special approach with the need to analyse the possibility of occurrence of risk construction details. There were various analysis models created for this purpose, in order to achieve as faithful behaviour of structure as possible.

The bridge's structure has been analysed by using the MIDAS Civil program system.

The structure's global model has been prepared of beam elements (Figure 5), together with the substructure and piles. This model expresses the detailed construction sequence in two stages, progressive prestressing of longitudinal tendons in a number of stages and an impact of shrinkage and creep of concrete. For the very model it was necessary to enter as concisely as possible the subgrade for the bridge foundations construction. The subgrade's reaction is modelled by means of springs' rigidity along piles' length, which express the composition of subsoil in foundation level and subgrade's deformations when subjected to load. The different subgrade stiffness were verified by the company BGG by means of a special geotechnical software and the results of geotechnical monitoring. The structure has been assessed in the construction stages during balanced cantilever construction of bridge superstructure and in the final stage of the bridge use.

For the analysis of transverse direction, in addition to the global model, a shell element (top slab, web, bottom slab) model of bridge's part (Figure 6) was used, which included also the prestressing of deck slab in transverse direction. To check the details subject to extreme stresses, where cracks can occur, a truss analogy together with the calculation on the model of volumetric elements (Figure 7) has been used.

4.1. THE STRUCTURE DESIGN AND ASSESSMENT DURING THE CONSTRUCTION- STABILITY SUPPORTING OF BALANCED CANTILEVER

During the construction of balanced cantilevers their stability shall be provided for by means of a temporary pier situated situated 8.6 m from piers D2 and D3 axis towards the end span. Temporary piers are connected with the balanced cantilever by means of prestressing tendons which are anchored in auxiliary diaphragm in balanced cantilever's box. The analy-

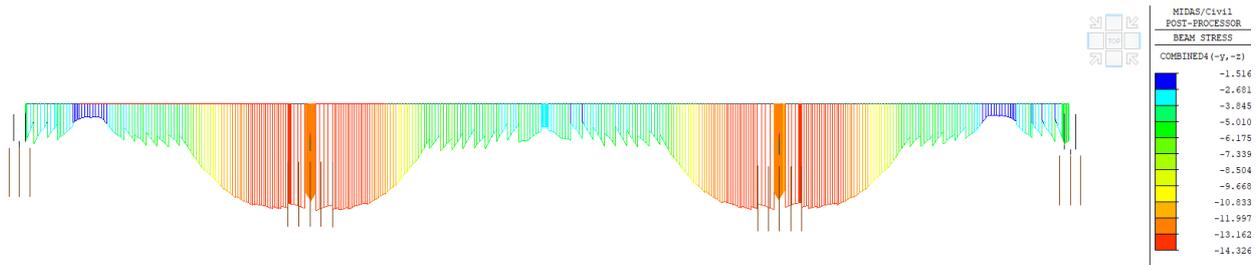


FIGURE 9. Sample of stress distribution in the bottom of deck (MPa) at time T=100y - frequent combination.

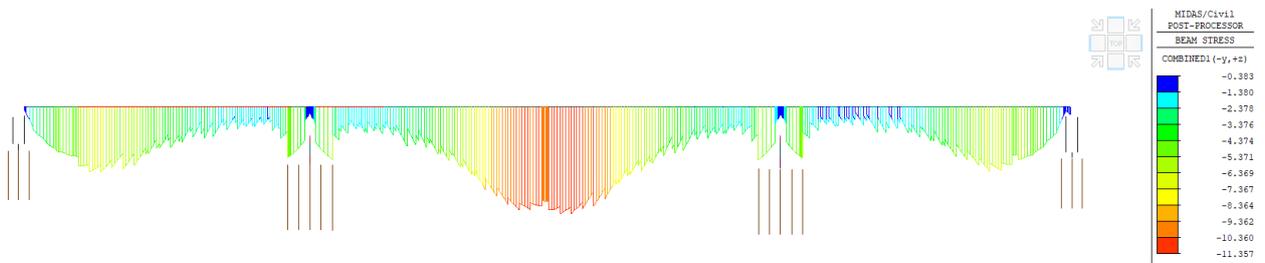


FIGURE 10. Sample of stress distribution in the top of deck (MPa) at time T=100y - quasi-permanent combination.

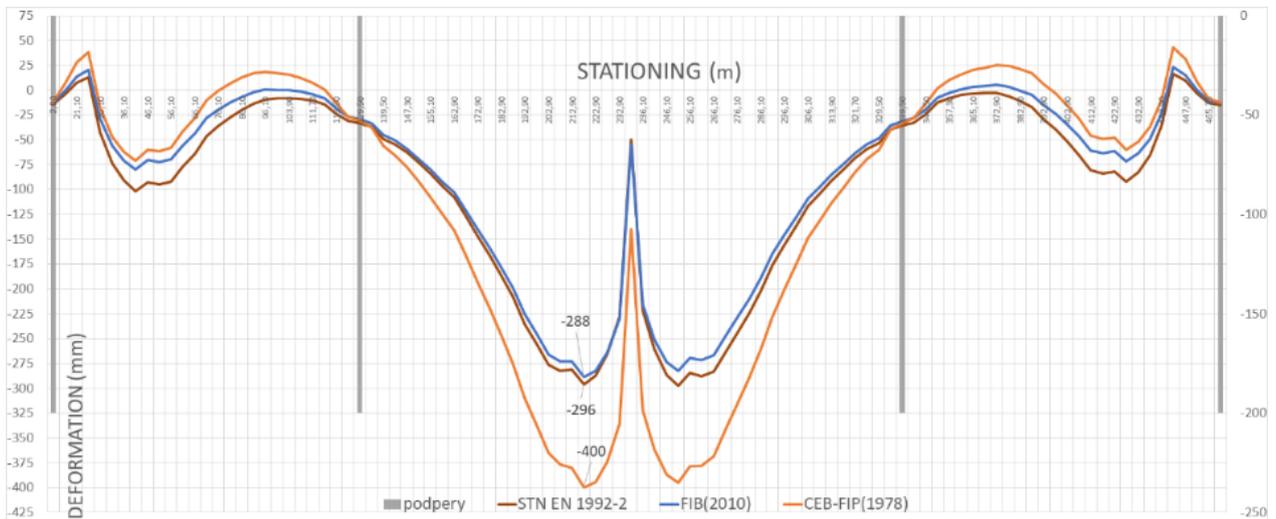


FIGURE 11. Deflections for different creep and shrinkage functions.

longitudinal shear, torsion as well as the local effects occurred due to prestressing tendons anchoring.

5. SUPERSTRUCTURE CAMBER CALCULATIONS

The global beam element model was prepared to calculate the camber using MIDAS CIVIL. The construction stages and pile settlement (modelled by springs) were taken into the account. In general, the calculated camber depends on these two variables: creep and shrinkage functions and accuracy of the FEM model (1D, 3D, type of elements, cracks and so on). The following creep and shrinkage functions were considered to get the camber prediction as accurate as possible:

- STN EN 1992, Appendix B (Eurocode)
- CEB-FIP Model Code 1978

- FIB Model Code 2010

The calculated deflections using different creep and shrinkage functions gave significantly different results, e.g. the max deflection for CEB-FIP Model Code 1978 was 400 mm and for FIB Model Code (2010) was 288 mm, i.e. the difference was 112 mm using the same type of the model. To find out the proper combination of the FEM model and creep and shrinkage functions, we used the calculated and measured deflections of the existing bridge of the similar type of superstructure and span.

The camber was checked by using combined FEM model created from beam elements (a top and bottom slab of the 16.3 m wide concrete core) and plate elements (the concrete core walls and overhangs). The FIB Model Code 2010 was used for creep, shrinkage and prestressing steel relaxation ($r_{1000} = 2.5\%$, mean development). The combined FEM model en-



FIGURE 12. Balanced cantilever under construction at pier D2.

abled to take into the account the shear creep deformation in the concrete core walls and shear-lag effect of the overhangs. The simplified crack prediction in the concrete core walls and overhangs was taken into the account either. The unfavourable deviations of actions and prestressing from mean values in accordance with STN EN 1990, STN EN 1991-1-1 a STN EN 1992-2 were considered for the final camber deflections.

The main span camber deflections obtained using above described combined model with the crack prediction and creep and shrinkage from the FIB Model Code 2010 were almost identical to the results obtained from the beam model and creep and shrinkage from the CEB-FIP Model Code 1978.

6. CONCLUSIONS

The bridge construction commenced in November 2018. At the time of writing, 5 segments of balanced cantilever at the D2 pier and 3 segments of balanced cantilever at the D3 pier have been built. So far, the camber calculations are in accordance with the measured box girder core deflections. Accurate camber calculations are key to the success of the construction of long span bridges built by the balanced cantilever method. The construction of superstructure should be finished in the fall of 2020. After the completion, the 210 m long span is going to be the longest span in Slovakia built by the balanced cantilever method.