Railway Bridges over Dunav-Tisa-Dunav (DTD) Channel as part of the High-Speed Railway Design Belgrade-Budapest, Section Novi Sad-Subotica-State Border

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Abstract As part of the design of the Belgrade-Budapest high-speed railway project, the design of the section Novi Sad-Subotica-State border with a length of 108 km was completed. The railway is designed for a maximum speed up to 200 km/h. The route of the Novi Sad - Subotica - State border high-speed railway crosses the Danube-Tisa-Danube canal (DTD) in several places. The most significant bridges over the canal are:

- **The bridge at km 81+644** is a continuous steel truss bridge on three spans of 42.0+56.0+56.0 m.

- **The bridge at km 0+796** is a continuous girder on three spans of 27.6+82.8+27.6 m. The end span sections are box girders, while the middle span is designed as a steel truss.

- **The bridge at km 110+351** is a simply supported beam, steel truss bridge with a span of 63.0 m.

- **The bridge at km 117+151** with a total length of 1463 m is the longest bridge on the alignment. There are a total of 43 piers. Majority of structures are prestressed concrete beams L=31.5 m, box girder section. 8 spans are steel trusses of span L=48.75 m. The designs of all structures were done according to Eurocode, UIC and RIL recommendations.

The Design for Building Permit was completed during 2021, the Design for Construction (DFC) [1] in the first half of 2022. The works started in July 2022 and new line opening is expected by the end of 2024.

1 General

As part of the design of the Belgrade-Budapest high-speed railway project, the design of the section Novi Sad-Subotica-State border with a length of 108 km was completed. The double-track railway line is designed for a maximum speed up to 200 km/h. The route of the Novi Sad - Subotica - State border high-speed railway crosses the Danube-Tisa-Danube canal (DTD) in several places. The most significant bridges over canal DTD are presented in this paper.

1.1 Bridge at km 81+644

1.1.1 Introduction

As a part of reconstruction and modernization of the railway line Belgrade-Subotica state border (Kelebija), part Novi Sad - Subotica state border (Kelebija) for the design speed up to 200 km/h, at the chainage km 81+644.83, new bridge over the canal Savino Selo – Novi Sad has been designed. General layout of the bridge is presented in Figure 1.

Figure 1: Bridge at km 81+644 – General layout

1.1.2 Description of the bridge

Design foresees two track bridge with track distance od 4.75 m. Structurally, the bridge represents continuous truss over three spans. Respect to plan view the bridge is straight with straight abutments and skewed middle piers. With this arrangement the main trusses are central symmetric to each other with spans 42+56+56=154 m.

Height between top and bottom chord is 9.0 m. Spacing between axes of main trusses are 12.5 m, and they are made of top chord, bottom chord and diagonals. Bottom chord are subjected to bending moments with the axial forces. Cross section of bottom chord is box section. Inner dimensions of bottom chord are 800x2000 mm. Top chord is formed as open – hat like section. All diagonals are with open I section, which allows execution of welded connections between diagonals and chords (approach to the weld from both sides). In bottom chord level, main girders are connected with cross beams and in top chord level they are connected with wind bracing. Cross beams are composite members made from welded I profile and concrete deck with thickness of 30 cm. Composite section is provided by the usage of head stud shear connectors. Typical cross section of the bridge is presented in Figure 2.

The railway tracks in the bridge zone are in the curve with radius of 2000 m, while the alignment is slightly rising. With described layout solution the following is achieved:

- Required waterway $>$ 27.7 m
- Waterway height $>$ 6.0 m
- Clearance between ground bottom edge of the bridge structure at abutment S1 $>$ 3.5 m
- Possibility of erection on the shore and launching into the final position.
- Reinforced concrete deck slab with the edge parapets forms a ballast bed.
- The bridge has drainage system. It consists of gullies and drainage pipes placed below deck slab through special holes within transverse girders.
- Sprayed Methyl Methacrylate (MMA) waterproofing is performed over the deck slab, over which an elastomeric mat for noise and vibration reduction is placed as protection.
- Bridge is equipped with revision paths 90 cm wide on both main girders.
- Bored piles Ø1200 and 20.0-23.0 m long are designed.

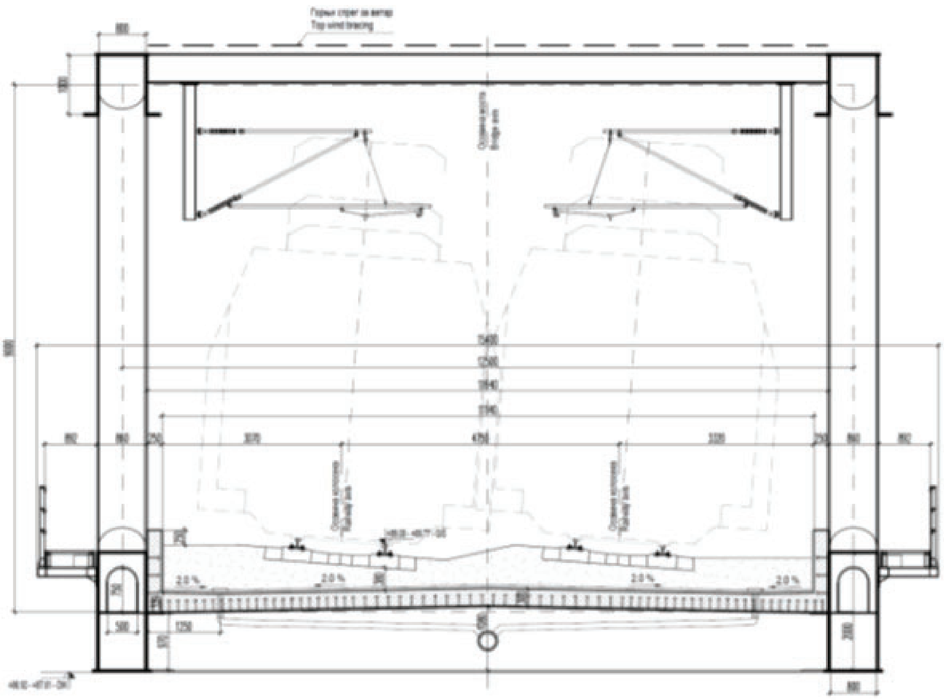

Figure 2: Bridge at km 81+644 – Typical cross section

1.1.3 Bearings

Except lateral supports in the bridge axis and longitudinal supports at the trusses all other bearings are adopted as spherical bearings with following arrangement presented in Figure 3.:

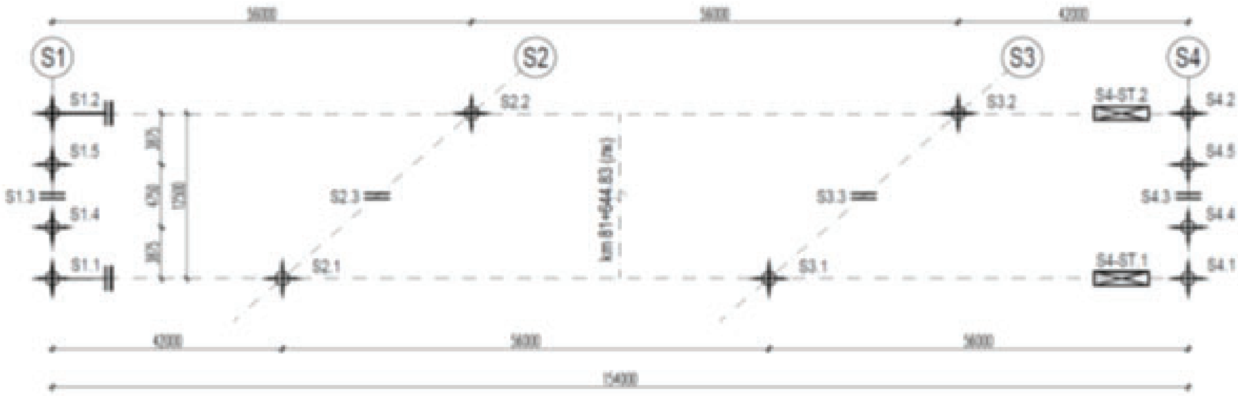

Figure 3: Bridge at km 81+644 – Bearings layout

Additional bearings are placed in the track axes below support cross girders to satisfy vertical deflections of the deck ends in relation to the abutment. Forces, due to permanent load, that occur in these bearings are not great, yet they prevent any possibility of uplift forces in the exploitation of the bridge.

Additionally at abutment S4 shock transmitters are installed acting as axial beams for instantaneous actions such as seismic and breaking and traction forces. Main reason for installation of shock-transmission units is shown within structural calculation and it becomes from limitation of longitudinal deformation of the deck slab to 5 mm due to braking and traction forces.

1.2 Bridge at km 110+351

1.2.1 General

As a part of reconstruction and modernization of the railway line Belgrade-Subotica state border (Kelebija), part Novi Sad - Subotica state border (Kelebija) for the design speed up to 200 km/h, at the chainage km 110+351.21, new bridge over the canal Becej-Bogojevo has been designed. General layout of the bridge is presented in Figure 4.

Figure 4: Bridge at km 110+351 – General layout

1.2.2 Description of the bridge

Design foresees two track bridge that crosses the river in the single span. Structurally, the bridge represents truss simply supported beam with 63.0 m span. Height between top and bottom chord is 8.69 m. Spacing between axis of Main is 10.48 m, and they are made of top chord, bottom chord and diagonals. Bottom chord are subjected to bending moments beside tension. Cross section of bottom chord is box section. Inner dimensions of bottom chord are 800x1400 mm. Top chord is formed as open – hat like section. All diagonals are with open I section, which allows execution of welded connections between diagonals and chords (approach to the weld from both sides). In bottom chord level, main girders are connected with cross beams and in top chord level they are connected with wind bracing. Cross beams are composite members made from welded I profile and concrete deck with thickness 30 cm. Composite section is provided by the usage of head stud shear connectors. The railway tracks in the bridge zone are straight, with the alignment in slight slope toward to abutment S2.

With described layout solution the following is achieved: Required waterway >14.4 m, Waterway height >6.0 m, Clearance between ground under the bridge and bridge itself >3.5 m, Possibility of erection on the shore and launching into the final position. Tracks are at the axis distance of 4.5 m. Reinforced concrete deck slab with the edge parapets form a ballast bed. The bridge has drainage system. It consists of gullies and drainage pipes placed below deck slab through special holes within transverse girders. Sprayed MMA waterproofing is performed over the deck slab, over which an elastomeric mat for noise and vibration reduction is placed as protection. Bridge is equipped with revision paths 87 cm wide on both main girders. Bored piles Ø1200 mm and 17 m long are designed. Typical cross section of the bridge is presented in Figure 2.

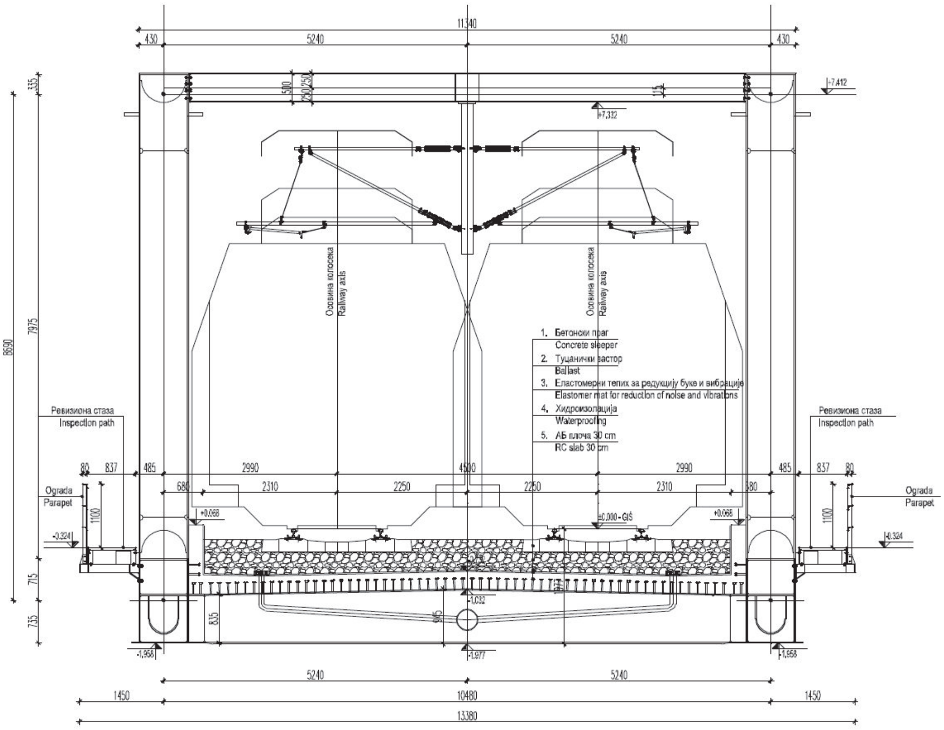

Figure 5: Bridge at km 110+351 – General layout

1.2.3 Bearings

Additional bearings are placed in the track axes below support cross girders to satisfy vertical deflections of the deck ends in relation to the abutment. These bearings should be installed upon erection of the steel structure and before casting of composite deck slab. Forces, due to mass of the concrete slab, that occur in these bearings are not great, yet they prevent any possibility of uplift forces in the exploitation of the bridge.

1.3 Bridge at km 117+151

1.3.1 General

As part of the reconstruction and modernization of the railway Belgrade-Subotica state border (Kelebija), part Novi Sad - Subotica state border (Kelebija), at the chainage km 155+155.43 in Vrbas, a new viaduct was designed. The total length of the viaduct is 1416.81 m, and it is designed for a maximum speed of up to 200 km/h.

The project provides a double-tracked viaduct with a centre-to-centre spacing of 4.5 m between tracks. The structural system consists of simply-supported girders in the longitudinal direction, with an alternating configuration for the bearings, i.e.alternating between fixed-free. The simply-supported girders consist of prestressed, reinforced concrete box sections. Steel trusses are also provided for longer spans. All piers consist of reinforced concrete sections rigidly connected to pile caps.

The horizontal alignment lies on a curve with R = 5000 m. The prestressed concrete spans follow the radius of the horizontal curve, while the steel trusses are constructed as straight structures. With respect to the horizontal curve, the steel structures are laid out following a ratio of 1/2-1/2. General layout of the bridge is presented in Figure 6.

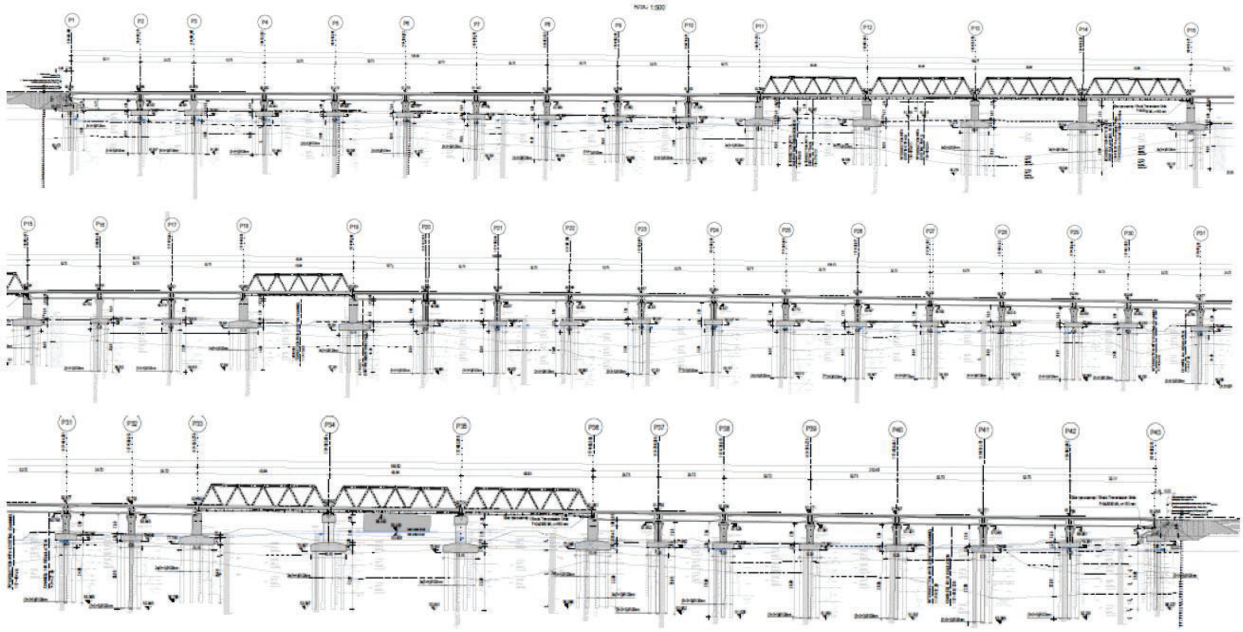

Figure 6: Bridge at km 117+155 – Longitudinal section

1.3.2 Description of the steel structure

A total of eight spans are bridged by steel structures. All structures are identical truss-type structures with tracks on the lower belt. Their spans are 48,750 m. They are arranged in three groups; the first group is a series of four structures on columns from P11 to P15, the second is a single-span structure on columns P18 and P19, and the third group consists of a series of three span structures on columns P33 to P36.

The static height of the truss structure is h = 8.9 m. The main girders of the bridge are on a span of 10.7 m, and they consist of upper belts, lower belts and diagonal sections. It is characteristic of the lower belts that, in addition to axial forces, they are also exposed to bending moments. The cross section of the lower belt is formed as a box - passable. The internal dimensions of the lower belt are 800x1500 mm. The upper belt is shaped like an open - tophat-shaped cross-section. All diagonals are adopted with an open and cross section, which allows the execution of welded diagonal connections for belt bars (access to the welded connection on both sides). The main girders are connected at the level of the lower belt by cross beams, while the upper girders are connected by a wind coupling. Cross beams are welded rods and cross-sections connected with a reinforced concrete pavement slab 30 cm thick. Composite action is achieved through the use of shear studs.

The reinforced concrete slab forms a bed for accommodating the ballast and track.
The structure is equipped with a drainage system. The system consists of drains and drainage pipes that are located beneath the deck slab and pass through designated openings in the cross beams.
Typical cross section of the bridge is presented in Figure 7.
MMA spray waterproofing is applied over the deck slab, upon which an elastomeric overlay (ballast mat) is placed for noise and vibration reduction.
The structure is equipped with 90 cm-wide inspection paths on both girders.

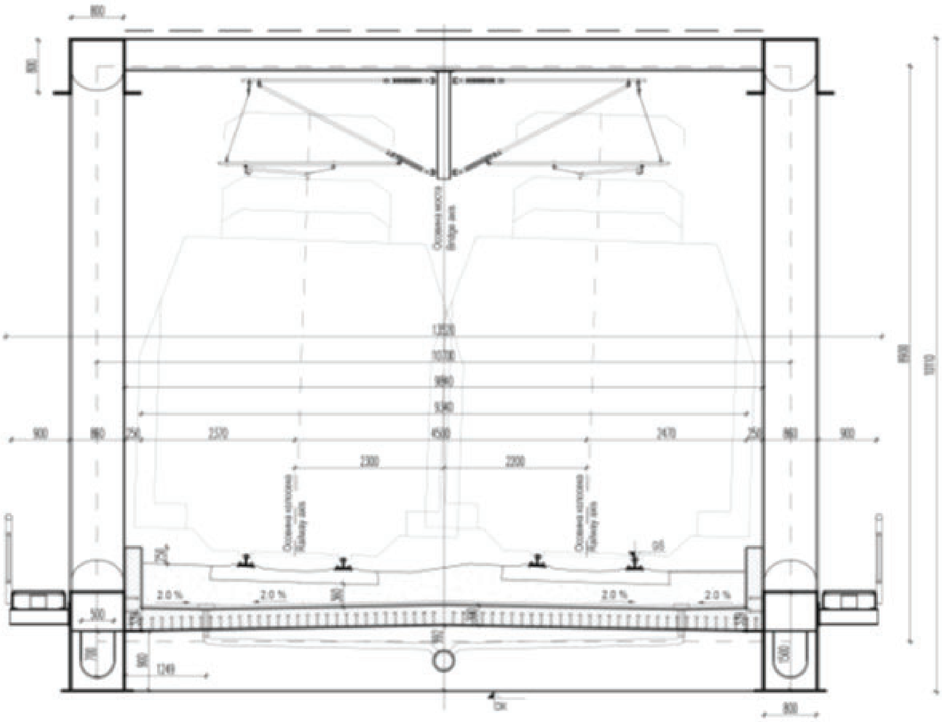

Figure 7: Bridge at km 117+155 – Typical cross section of steel structure

1.3.3 Description of the concrete structure

Structural elements
The superstructure consists of a cast-in-place box girder section with cantilevers at each end. The reinforced concrete structure will be prestressed by means of post-tensioning.

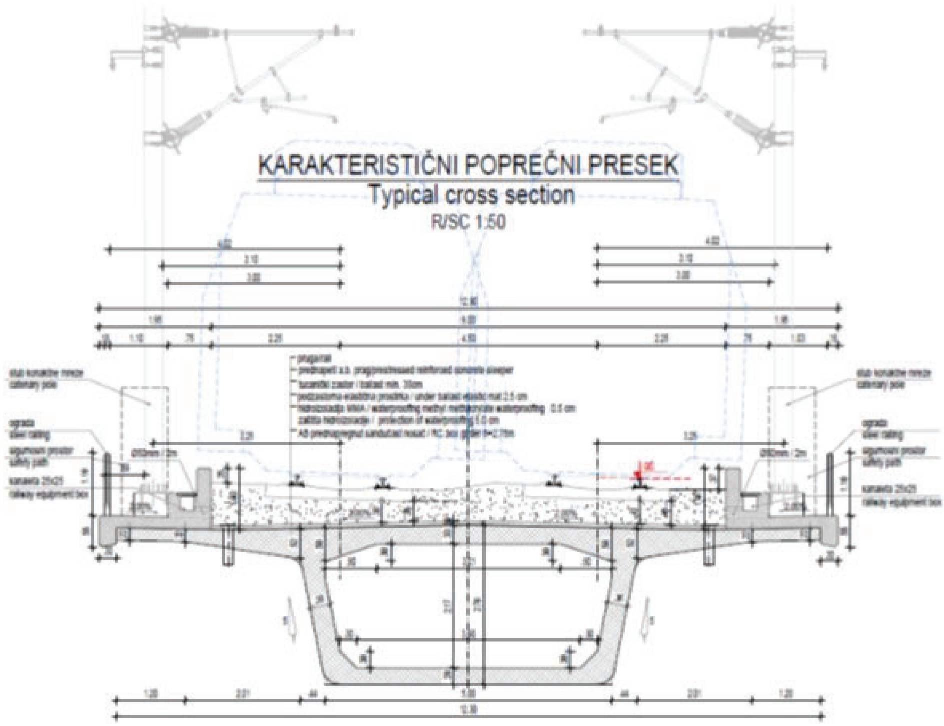

Figure 8: Bridge at km 117+155 – Typical cross section of concrete structure

Superstructure
The superstructure consists of a box girder section. The minimum thicknesses of the top and bottom slabs (flanges) are 33 and 28 cm, respectively, while the webs are 36 cm-thick. Cantilever lengths are 3.2 m each, which together with the slab provides for a total width of 12.30 m. The cross section height is h = 2.8 m. The superstructure is prestressed. Considering that the bridge consists of a system of simply-supported girders, the superstructure is supported on bearings at each pier. Typical cross section of concrete structure is presented in Figure 8.

Substructure
Abutments are conventional reinforced concrete, with stems 2.20 m-thick and 2.00 m tall, while ballast walls are 3.30 m tall. Pile caps at abutments are 2.20 m-thick and 6.00 m-wide. Bearings are provided at the top of each abutment stem. Based on the information provided from the “Report on geotechnical conditions,” the bridge will be founded on piles. Piles will consist of Ø120 circular cross sections.

1.4 Bridge at km 0+796

1.4.1 General

As part of the reconstruction and modernization of the railway Belgrade-Subotica state border (Kelebija), part Novi Sad - Subotica state border (Kelebija), at the chainage km 0+796.33, a new bridge over the canal was designed Savino Selo - Novi Sad. Before the construction of the new bridge can begin, the old bridge, located at the same location, must be demolished. This bridge is designed for a designed speed of up to 80 km/h because it is not on the high-speed track.
Design foresees two track bridge that crosses the river in the three spans. Unfavorable angle between bridge and canal $\approx 45°$ had a big influence on forming a bridge structure layout in preliminary design stage. General layout of the bridge is presented in Figure 9.

1.4.2 Description of the bridge

Structurally, the bridge represents continuous beam with 27.6+82.8+27.6 m spans. One of main characteristics of this bridge is a significant difference between middle and approach spans in means of length, but also in the means of rigidity of main girders. Main girders in the middle span are lattice structures with structural height of 9.5 m, and in the same time approach spans are box girders which look like extension of bottom chord of middle span and have a total height ≈ 2.15 m. With chosen piers and abutment schedule required waterway width is provided and foundations of existing bridge are avoided as much as possible. With significant differences in spans rigidity, uplift forces on abutments S1 and S4 are avoided.

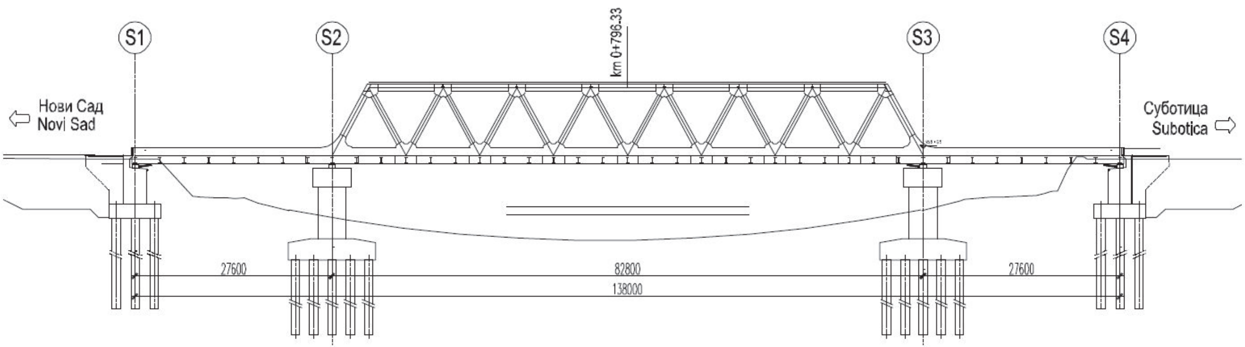

Figure 9: Bridge at km 0+796 – General layout

Structural height of lattice main girder in the middle span is 9.5 m. Spacing between axis of Main is 10.91 m, and they are made of top chord, bottom chord and diagonals. Bottom chord are subjected to bending moments beside tension. Cross section of bottom chord is box section - passable. Inner dimensions of bottom chord are 900x2100 mm. Top chord is formed as open – hat like section. All diagonals except end ones (D1 and D16) are with open I section, which allows execution of welded connections between diagonals and chords (approach to the weld from both sides). End diagonals D1 and D16 are formed as passable box section with bolted connection with bottom chord (high strength preloaded (HV) bolts are used) and welded connection to the upper chords. In bottom chord level, main girders of middle span are connected with cross beams and in top chord level they are connected with wind bracing. Typical cross section in span 2 is presented in Figure 11.

Main girders of approach spans are formed in the same way as bottom chord of middle span. Cross beams, all except once above piers and abutments, are composite members made from welded I profile and concrete deck with thickness 30 cm. Composite section is provided by the usage of head stud shear connectors. Steel part of cross beams above piers and abutments are adopted with higher bearing capacity than others, formed as hat like sections, so the temporary supports for different erection stages can be placed under them. Under cross beams on S1 and S4 permanent bearings in track axis are foreseen. Typical cross section in spans 1 and 3 is presented in Figure 10.

The railway tracks in the bridge zone are straight, with the alignment with slopes toward to abutments S1 and S4. Vertical curve reaches its higher spot in pier S3 area.

With described layout solution the following is achieved:
Required waterway > 27.7 m; Waterway height >6.0 m; Clearance between ground under the bridge and bridge itself >3.5 m Tracks are at the axis distance of 4.75 m. Reinforced concrete deck slab with the edge parapets form a ballast bed. The bridge has drainage system. It consists of gullies and drainage pipes placed below deck slab through special holes within transverse girders. Sprayed MMA waterproofing is performed over the deck slab, over which an elastomeric mat for noise and vibration reduction is placed as protection. Bridge is equipped with revision paths 87 cm wide on both main girders. Bored piles Ø1200 mm and 16 m long are designed at abutments S1 and S4, and L= 22 m at piers S2 and S3.

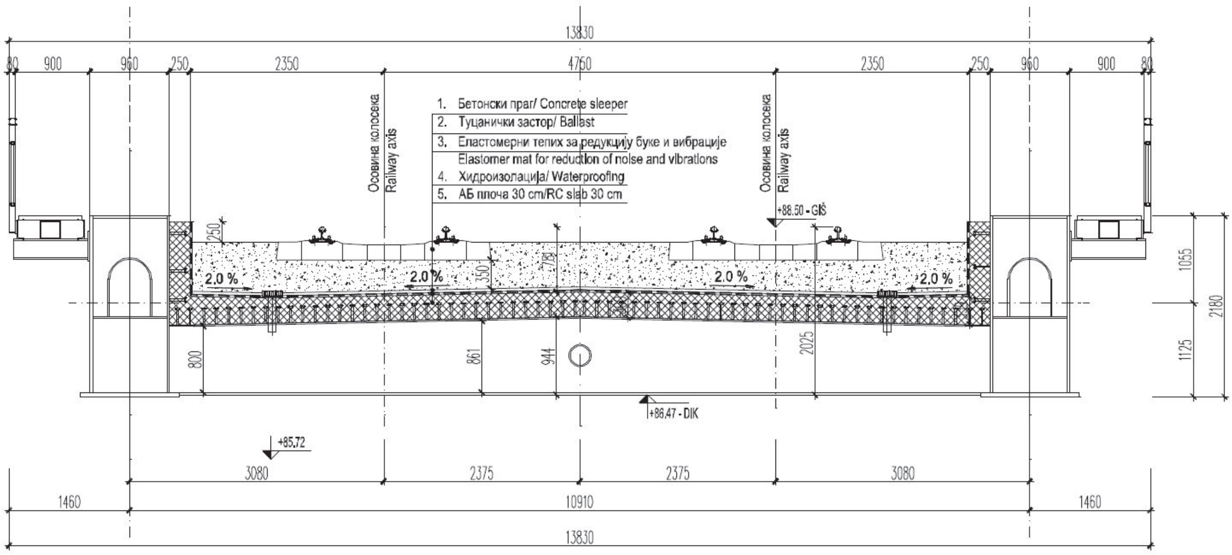

Figure 10: Bridge at km 0+796 – Typical cross section in spans 1 and 3

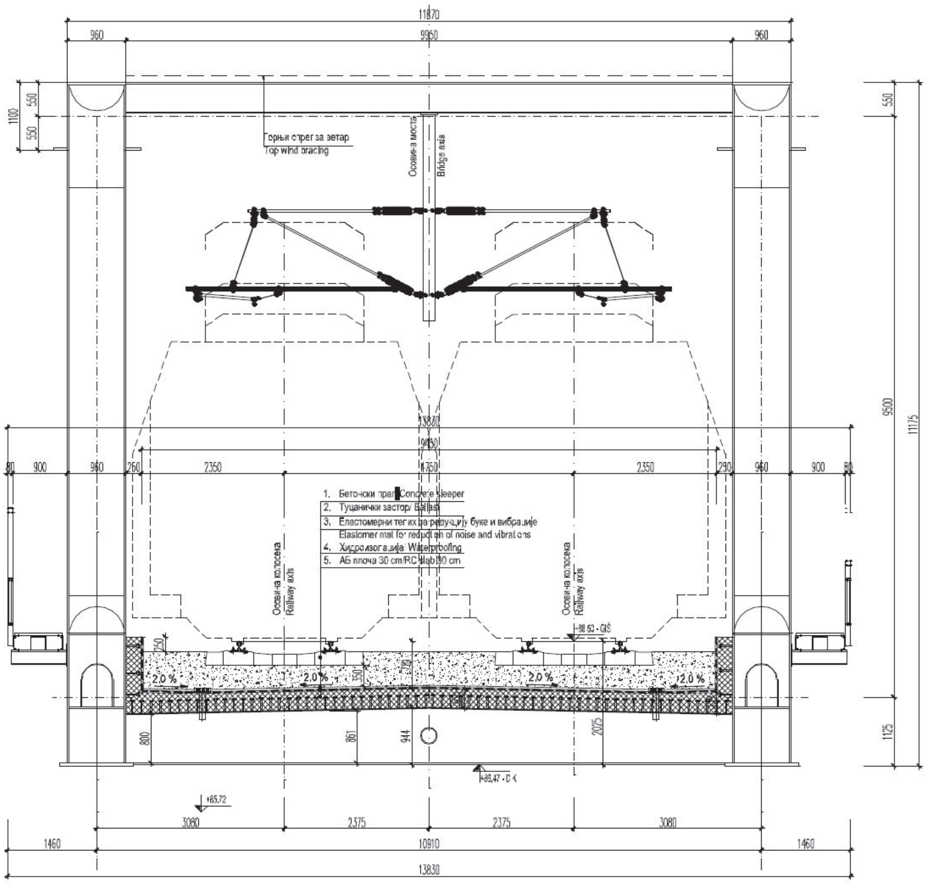

Figure 11: Bridge at km 0+796 – Typical cross section in span 2

1.4.3 Bearings

Spherical bearings are adopted. On abutments S1 and S4 and pier S3 beside bearings shock transmitters are predicted. The main purpose of this devices is to resist longitudinal, horizontal forces due to fast loads, and in the same time to allow displacements, which develop in longer time periods (i.e. temperature displacements). In this manner it is achieved that all piers and abutments participate in resistance to horizontal forces coming from braking, traction and earthquake, with less than 5 mm of longitudinal deflection of any spot of deck due to braking and traction. This limitation value is request of valid standards. Horizontal displacement of bridge structure without shock transmission units (STU) and with various bearings schedules are analyzed within structural analysis, and those results indicate that usage of STU is necessary.

Additional bearings are placed in the track axes below support cross girders to satisfy vertical deflections of the deck ends in relation to the abutment. These bearings should be installed upon erection of the steel structure and before casting of composite deck slab. Forces, due to mass of the concrete slab, that occur in these bearings are not great, yet they prevent any possibility of uplift forces in the exploitation of the bridge.

2 Structural calculation

The structural calculation has been performed using the software package "TOWER" developed by "RADIMPEX", Belgrade. The structure was analyzed in a few three-dimensional finite element (FE) models.
Load analysis was performed according to valid Serbian standards - SRPS EN 1991-1-1:2012 [3] and their national annexes.
The design considered the following loads: Self-weight of the structure; Dead load, weights of track elements; Horizontal soil pressures determined in accordance with the provisions of the standard SRPS EN 1997-1:2017 [4]; Shrinkage of concrete - Railway traffic loads in accordance with the standard SRPS EN 1991-2:2012 [5], Chapter 6. Vertical traffic load: Load schemes LM71 and SW/2 were used for analysis of railway traffic actions on normal track lines (SRPS EN 1991-2:2012 [5], 6.3.2). Dynamic coefficient Φ3 for load scheme LM71 according to SRPS EN 1991-2:2012 [5], 6.4.5.2:
The load scheme "unloaded trains", for stability control in case there is a train with unloaded wagons on the structure, according to chapter 6.3.4 of SRPS EN 1991-2:2012 [5], adopted as a vertical uniformly distributed load qkv = 10.0 kN/m.
Equivalent traffic load for calculation of earth pressures on abutments according to chapter 6.3.6.4 of SRPS EN 1991-2:2012 [5]. Horizontal traffic load: Centrifugal force (SRPS EN 1991-2:2012 [5], 6.5.1); Nosing force (SRPS EN 1991-2:2012 [5], 6.5.2); Traction and braking forces (SRPS EN 1991-2:2012 [5], 6.5.3).
Loads due to temperature effects (SRPS EN 1991-1-5:2012 [6] and SRPS EN 1991-1-5 / NA:2017 [6]); Wind load (SRPS EN 1991-1-4:2012 [7] and SRPS EN 1991-1-4 / NA:2017 [7]); Seismic load (SRPS EN 1998-1:2015 [8], SRPS EN 1998-2:2012 [9] and SRPS EN 1998-5:2012 [10])
Load combinations for the control of the ultimate limit states and servisibility limit states are adopted in accordance with SRPS EN 1990:2012 [2] and SRPS EN 1990/NA:2012/1:2020.
Track-bridge interaction was performed for all 4 bridges presented in this paper.

3 Applied materials for steel bridges

Table 1: Applied materials for steel bridges

Element	Material	Comment
Main steel structure	S355	Additional class descriptions are defined in the graphic and numerical documentation
Piles	C30/37	Exposure class: XC2, V-I
Piles and pile caps	C30/37	Exposure class: XC2, XA1, V-I
Abutments and piers	C30/37	Exposure class: XC4, XD1, XF1, XA1, V-II, MS-S2
RC deck slab and pedestals	C35/45	Exposure class: XC4, XD1, XF1, V-II
Studs	SD1	According to: ISO13918:2007
Reinforcement	B500B	Applies for all concrete elements
Shock-Transmission Units		According to: SRPS EN 15129:2018

Behind abutments, gravel wedges are formed as a combination of cement stabilization on top of granulated gravel made in 30 cm thick layers, with compaction to the designed modulus of stiffness. For the formation of gravel wedges in front of and behind the bridge, recommendations from UIC 719:2008 [12] were used.

4 Conclusion

In the period from 2021 to 2022, design for construction permits and design for construction for the double-track railway Novi Sad-Subotica-State border (bridges, underpasses, overpasses and galleries - a total of 56 structures) were completed.
The designer for all structures is a company China Railway Design Corporation (CRDC) - a subsidiary in Belgrade.
Construction works began in mid-2022. The steel structure for all the bridges was manufactured in China and delivered to the construction site, where assembly was carried out.
Completion of all works on the construction of the double-track railway Novi Sad - Subotica - State border is expected to be by the end of 2024.

5 References

[1] DFC – Design for Construction, , China Railway Design Corporation – Belgrade branch, Serbia (November 2021.) Book 2/1.1.5 Design for bridge at km 000+796.33; Book 2/1.1.6 Design for bridge at km 081+644.83; Book 2/1.1.20 Design for bridge at km 110+351.21; 2/1.1.23 Design for bridge at km 117+155.43

[2] SRPS EN 1990:2012- Basis of structural design and SRPS EN 1990/NA:2012/1:2020 - Basis of structural design — National Annex— Amendment 1

[3] SRPS EN 1991-1-1:2012: Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings

[4] SRPS EN 1997-1:2017: Eurocode 7: Geotechnical design - Part 1: General rules

[5] SRPS EN 1991-2:2012: Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges

[6] SRPS EN 1991-1-5:2012: Eurocode 1: Actions on structures - Part 1-5: General actions - Thermal actions and SRPS EN 1991-1-5/NA:2017: Eurocode 1: Actions on structures - Part 1-5: General actions - Thermal actions — National Annex

[7] SRPS EN 1991-1-4:2012: Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions and SRPS EN 1991-1-4/NA:2017:Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions — National Annex

[8] SRPS EN 1998-1:2015: Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings.

[9] SRPS EN 1998-2:2012: Eurocode 8 - Design of structures for earthquake resistance - Part 2: Bridges

[10] SRPS EN 1998-5:2012: Eurocode 8: Design of structures for earthquake resistance Part 5: Foundations, retaining structures and geotechnical aspects

[11] SRPS EN 1990:2012: Eurocode - Basis of structural design and SRPS EN 1990/NA:2012: Eurocode - Basis of structural design - National Annex

[12] UIC Code 719, 2008: Earthworks and track bed for railway lines