Road Bridge over the Sava River near Sremska Raca

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Abstract The bridge over the Sava river, near Sremska Raca, represents the end of the highway section from Kuzmin to Sremska Raca, which is about 18 km long. The total length of the bridge with approach structures is about 1300.0m. The main steel bridge structure is a continuous girder system on three spans L = 90.0 + 150.0 + 90.0 = 330.0m. The main girder is a single-celled box structure of trapezoidal cross section, which is characterized by constant height of 5000 mm. Assembly of the main bridge structure was carried out using the Incremental launching method.
The Design envisaged 4 expansion sections in each carriageway on the left bank of the Sava River (in Serbia) and two expansion sections in each carriageway on the right riverbank (in B&H). Total lenght of approach structures on boath sides of the Sava river amounts 539,50m+448,30m in the left carriageway, and 530,50m+448,30m in the right carriageway. Approach structures of the bridge over the Sava River were designed with two girder types. Precast prestressed reinforced concrete girders, 40.50 m long were designed for shorter spans at places where the Designer was not conditioned by obstacles and requirements. Prestressed box structures were designed in the revetment zone in Serbia and in the zone of curves and transition curves. All structures are designed as continuous structures with constant height.

1 Introduction

The Kuzmin – Sremska Rača highway section, approximately 18 km long, is designed as a part of the future highway to Bijeljina in the Republic of Srpska. This highly-ranked highway section will start in the vicinity of the existing "Kuzmin" interchange that enables connection to the state road, which passes through Kuzmin and Bosut settlements and continues to the present border crossing near Sremska Raca.
The studied highway section is composed of two traffic lanes, each 3.75 m wide (for both directions), emergency lanes, 2.50 m wide, verges 2 x (1.0 m + 0.5 m), central reserve, 4 m wide, and 1.50 m wide banks on both sides. The overall width of the standard cross section is 30,00 m. Limiting elements in plan and profile imply calculation of both minimum and maximum values foREr the layout, longitudinal profile, cross sections and sight distance based on design speed of 130 km/h.

2 Bridge over the Sava River – General Considerations

As already mentioned, a link between two countries will be enabled by building the bridge over the Sava River. On the right lane, the bridge will be 1312.60m long in total, and on the left lane the overall bridge length will be 1320.5 m. (Figure 1)

Figure 1: Bridge over the Sava River

Structural system of the central bridge structure carrying the steel construction is a three-span continuous girder (L = 90.0 + 150.0 + 90.0 = 330.0 m) with a single expansion joint. In the course of the bridge design development, special attention was paid to the fact that the existing railway/road bridge and new bridge are spaced at 60 m approximately and hence considered as one navigation span (from the aspect of safe navigation).
Accordingly, the navigation clearance of the new bridge (140 m) will be adjusted to the present bridge and in conformity with recommendations required for inland waterways, class Va (Decision of Sava Commission, No. 13/09 "Detailed Parameters for Waterway Classification on the Sava River"). It should also be noted that, pursuant to the Regulation on determination of international and interstate waterways (Article 2) and the Regulation on categorization of international and interstate waterways (Article 1), the Sava River, on the section covered by the Design, has the status of III category international waterway. Level of the bottom edge of the navigation span will be at 89.78 m asl minimum. Separate bridge structures, spaced at 15.50 m, are planned for each highway direction. The overall carriageway width on a single bridge structure is 11.50 m. A service footway, 0.75 m wide, is planned on the outer side of the highway. Together with safety barriers and guardrails, the single bridge is 14.75 m wide meaning that the entire bridge structure is 31.0 m wide in total (B= 14.75+1.50+14.75 = 31.0 m).

In the longitudianl direction, the bridge centerline is on tangent section. Reference level of the bridge on the left Sava bank is at grade of 1.70% while the reference level of the bridge on the right Sava bank is graded at 2.30%. Uniform crossfall of the main bridge deck of 2.5% towards outer curbs is in conformity with drainage requirements. Uniform crossfall of service footways is 4.0% towards curbs. In the left lane the crossfall of the road is variable from 6.00%, at the beginning, till 2.50% at the km 17+923.12. In the left lane, this transverse fall is towards the outer side of the structures. The right lane has a crossfall of 6.00%, at the beginning of the bridge (toward the inner edge of the structures) to 0.00% at km 17+891.79. From this station, the transverse slope changes to 2.50%, which is at the km 17+923.21. The transverse slope is towards the outer edges of the structures. This uniform (2.50%) transverse slope is also maintained on the approach structures on the right bank of the Sava river and it starts from km 17+923.12 in boath lanes.
The approach structures are to be implemented as pre-stressed concrete structures, with continuous girder system. Two types of girders have been adopted on the approach structures in both carriageways: box section (S1-S3, S3-S6 and S16-S21) and prefabricated girders (S6-S10; S10-S13 S21-S25). Spans of the continuous beam girders are different and they match the needs for overcoming the dike and the road on the Serbian side and the road and dike on the side of the Republic of Srpska.

3 Main Steel Structure

Steel structure of the central bridge section is designed as a standard orthotropic plate supported by a continuous girder with span lengths of L=90.0+150.0+90.0 m.

The main girder is a single-celled box structure of trapezoidal cross section, which is characterized by constant height of 5000 mm and aligned with the bridge centerline. At the carriageway level, inclined webs are spaced 8377 mm apart while at the bottom plate level, they are spaced at 6707mm. Figure 2)
The bridge deck and cantilever overhangs are 14 mm thick except in the zone of intermediate supports where the thickness is increased to 16 mm. Thickness of the bridge deck and cantilever overhangs is 22 mm above the intermediate support and this thickness remains constant for the next 24.0 m.

Longitudinal stiffeners of the bridge deck are shaped as water conduits of trapezoidal cross section, 300 mm high, 320 mm wide and 8 mm thick. They are situated at center-to-center spacing of 620 mm. Stiffeners at cantilever overhangs, under service footways, are vertical webs, 200 mm high and 14 mm thick. These webs are spaced at 300 mm.

Cross girders are spaced at 3.0 m apart and together with vertical stiffeners on vertical webs and transverse stiffeners on bottom slab (sole slab), they form a rigid frame system. Cross girder web is 800 mm high and 12 mm thick, with toe 300 x 16 in size. Cantilevers, 10 mm thick, are of variable height (from 810 mm to 450 mm) with toe 200 x 10 in size. Additional cross stiffeners (diagonal bracings) of tubular cross section are placed at every second cross girder (at every 6.0 m).

Solid diaphragms together with adequate stiffeners was placed above supports, in a box. Diaphragms have suitable openings to enable routing of telecommunication and electrical installations.

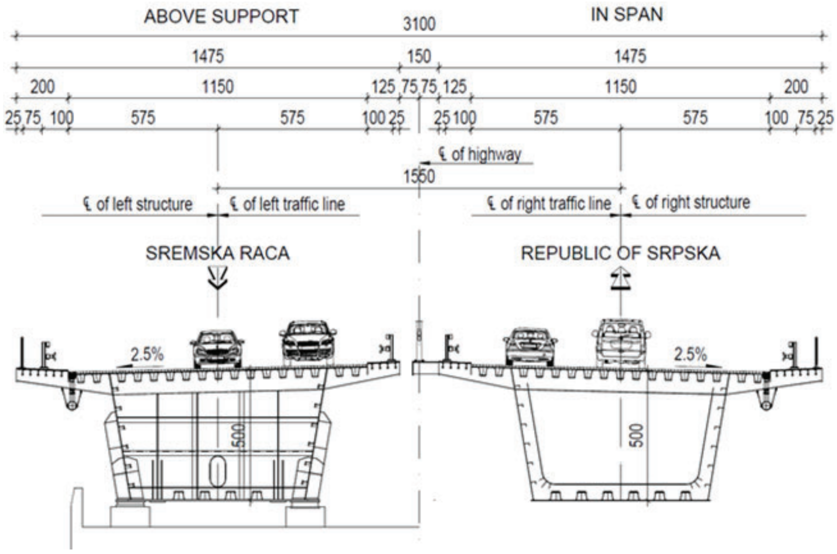

Figure 2: Cross section of main bridge structure

The box bottom plate, 6910 mm wide, is formed of sheet metal of variable thickness (from 20 mm to 45 mm) depending on static impacts. Stability of the plate is ensured by means of six longitudinal stiffeners of trapezoidal shape, 300 mm high and 420 mm wide. These trapezoidal stiffeners are 8 mm thick except in the area of 18.0 m around the intermediate support where thickness is increased to 10 mm.

Webs at the box are of variable thickness (from 14 mm to 20 mm), i.e. they are 30 mm thick in the area of intermediate support. Stability of vertical web is ensured using longitudinal stiffeners spaced at 760 mm apart. In addition, longitudinal stiffeners formed of angles L200 x 100 x 12 in size, will also apply. Openings at the web plate top was provided for ventilation purposes.

Elastic safety barrier was installed on either bridge side, 500 mm far from the pavement edge. Standard bridge gullies of sufficient capacity was installed for drainage purposes. Gullies was placed along the outer curbs.

Public lighting masts was planted in the central reserve and spaced at 30.0 m. Indoor lighting of the bridge structure will also be provided.

In addition, the adequate signs and signals for marking the navigation clearance will be placed under the central span to ensure safe traffic operations on the Sava River.

3.1 Structural Analysis

Static-deformation analysis of the structure was conducted using the relevant software based on the finite element analysis (SAP2000). Computation was performed in strict compliance with EN standards and National Annexes. Proves on limit bearing capacity and final serviceability were also carried out.

Basic loads included as follows:

1. Dead load of the steel structure together with other accompanying members (asphalt surfacing, waterproofing layer, elastic barriers and installations).
2. Traffic load:

- For road traffic: load model 1, braking and acceleration forces
- Pedestrian traffic
- Load required for fatigue analysis.

Additional loads included: temperature and wind loads.
Special attention was made to seismic load exposure.

The adequate cross section and geometry were determined for each node in linear model. In addition, interaction between steel deck and bottom plate (sole plate) was determined fully in accordance with the SRPS EN 1993-1-5:2013 Standard. Reduction of section geometry was performed in relation to its position along the girder. Stress state was calculated for such a determined sections. Unsymmetrical live load was observed so as maximum shearing stress in vertical webs can be calculated and equivalent stresses determined. Stability of vertical web and box sole plate to buckling was tested using the Dlubal PLATE-BUCKLING 08.18.01 program package.

3.2 Quality and Methodology

The whole steel construction wAS assembled of steel, grade S355 and S460, fully in accordance with the SRPS EN 10025:2011 Standard. Execution class for the structure is EXC4 (except the elements of the fence of pedestrian path, which are class EXC3). Forming of all elements in the workshop is was done by welding the steel sheets. Connections of vertical web, transverse girders and diaphragms shall be made using high strength bolts. These bolts shall have grade of 10.9 $\mu \geq$ 0.50, basic+dynamic load and will be designed to achieve full tightening force (100%) at faying joint provided that the difference between hole and bolt diameter is 0.3 < $\Delta d \leq$ 1 mm. Faying surfaces will be protected by metallization, i.e. by applying AlMg5 coat, 150 μm thick.

3.3 Bearings and anti Corrosion Protection

Neoprene – Teflon bearings was installed depending on reaction and expected displacement. Each bridge structure provided with eight bearings.
Anti-corrosion protection of steel construction was performed in strict compliance with recommendations stated in SRPS ISO 12944/2002, corrosivity class C5-I and service life of > 15 years. Epoxy/polyurethane paint, was apply in 4 coats having the total thickness of 320 μm. Inner sides of box cross sections (longitudinal stiffeners) made watertight and protected with a single 40 μm thick epoxy primer enriched with zinc.

3.4 Works on Structure Erection

Assembly was performed by pushing the structure on one side over the temporary teflon bearings using the "steel nose" and the temporary steel pier. The contractor for the construction of the bridge over the Sava is a Turkish company Taşyapı İnşaat Taahhüt Sanayi ve Ticaret A.Ş, and the subcontractor for the assembly of the steel structure was also Turkish company ENG Metal Yapı İnşaat Taahhüt Dış. Tic. AŞ. (Figure 3)

Figure 3: Assembly of the main bridge structure

4 Approach Structures

The Design envisioned 4 expansion sections in each carriageway on the left bank of the Sava River (in Serbia) and two expansion sections in each carriageway on the right riverbank (in B&H). Total lenght of approach structures on both sides of the Sava river amounts 539,50m+448,30m in the left carriageway, and 530,50m+448,30m in the right carriageway. Approach structures of the bridge over the Sava River were designed with two girder types: Precast girders, 40.50 m long were designed for shorter spans at places where the Designer was not conditioned by obstacles and requirements and prestressed box reinforced concrete girders in the revetment zone in Serbia and in the zone of curve and transition curve. All structures are designed as continuous structures with constant height. Arrangement of piers was dictated by requirements, terrain, and revetment positions on both sides of the Sava River.

4.1 Approach Structures Box Girders Structures

All bridge structures of this type, are continuous girders that rest on piers and support beams over bearings. Box cross section of the bridge with two webs was adopted for calculations. Cross section of box girders of structures has a constant height of 330 cm longitudinally. The constant height of cross section along the entire length of box approach structures was adopted to achieve a visual effect. (Figure 5)

Main box girder is prestressed and designed with concrete class C45/55 same as cross girders in spans and above supports. Top plate of the box girder has constant thickness of 35 cm and follows the carriageway crossfall. The main girder webs vary in thickness from 55 cm in span to 80 cm in the zone above supports. Bottom plate of the box girder also varies in thickness from 35 cm to 60 cm above piers. Top plate has 2.55 cm overhangs on both sides. These overhangs at both the cantilevers ends are 25 cm high. A space for installations and lighting cables shall be provided in footways.(Figure 4)

The box cross section of the main girder is stiffened with cross girders in spans and above all supports - in pier zones. Cross girders inside spans are 50 cm thick and those on middle piers are 120 cm thick. They shall be provided with openings for inspection of the main box girder interior.

Tendons in structures, formed of 19Ø15.7 mm strands with anchors and initial force Fpk=0.75xFp were designed for the main box girder prestressing. Permanent force in tendons was calculated by taking account of the following losses due to friction of tendons, insertion of wedge, elastic deformations, strain release in steel, and concrete contraction and creeping. All tendons of box girders S1-S3 and S3-S6, shall be prestressed symmetrically at both ends of bridge cross section.

The main girder shall be reinforced with ribbed bars B 500-b. Tendon casings shall have 100 mm inner diameter because the tendons will be installed prior to main girder casting process.

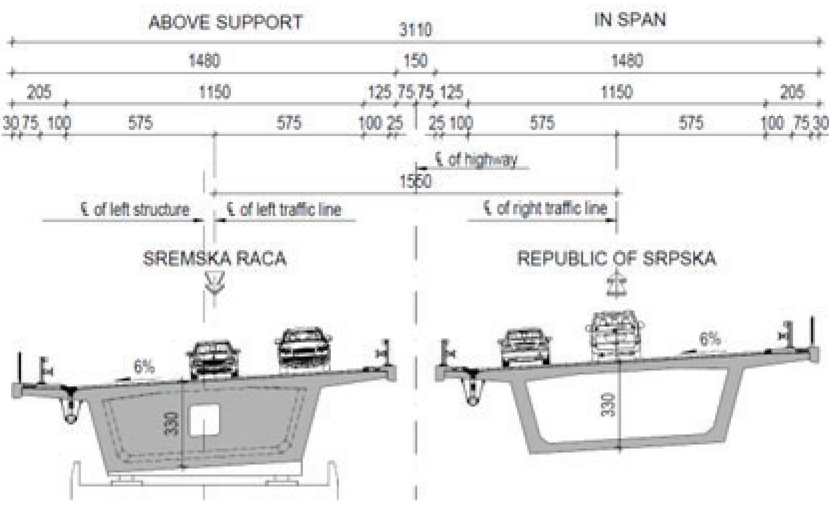

Figure 4: Cross section of box girder structure

The box girder, expansion section 7, between piers S16 and S21, in both carriageways will be constructed in phases applying “span-by-span” method, starting from pile S21 in both lanes.

Twenty prestressing tendons were formed of 25Ø15.7 mm, envisaged along the bridge, 50% of tendons, will be tensioned in one section in each phase. In the first phase, tendons will be tensioned from both ends while in phases 2-6, tendons they will be tensioned from one end. The structures will be erected in 5 phases. Strains and stresses in the structure shall be monitored during works. It should be pointed out that slightly wider box girder webs will be envisaged in extension zones. This is due to the need to accommodate extension anchors and tendons which are not planned to be extended in those sections.

Figure 5: Box girder structures

4.2 Approach Structures Precast Girders

Precast girders, 40.50 m long and 2.00 m high with 25 cm thick slab over them were adopted for the expansion structures S6-S10, S10-S13 and S21-S25 (both carriageways). Bridge structures of this type are continuous and hinged to support beams at middle piers, but in case of expansion sections 3 (S6-S10) and 7(S21-S25) the girders rest on piers over bearings, they are interconnected and made continuous by cross beams. Bridge structures (S10-S13) in both carriageways are continuous and rigidly connected to support beams at points of piers S11 and S12. They are longitudinally interconnected and made continuous by cross beams. (Figure 6)
Cross section of the structure consists of 6 precast prestressed girders, 40.50 m long and 200 cm high. Top flange of the girder is 175 cm wide, and bottom flange is 80 cm wide. The web thickness is 25 cm thick and by 150 cm long horizontal haunch crosses to T section above support. The girders are continuous with 25 cm thick reinforced concrete slab so that total height of the section is 225 cm with corresponding width of the slab. Cross girders, 30 cm, or 50 cm thick will be formed in spans and above piers and abutments. The slab above girders follows reference level crossfall along the structure. (Figure 7)
The precast girders and bridge deck will be integrated into a composite structure with the use of rebars protruding from girders. The structure is made continuous with 90-120 cm thick cross girders above middle piers. Girders in the structure and all other elements of supporting structure (reinforced concrete bridge deck and reinforced concrete cross girders) were designed of concrete class C40/50.

Tendons formed of 13Ø15.7 mm strands with anchors and initial force Fpk=0.75xFp were designed

Figure 6: Precast girders

for the main girder prestressing. It was assumed that each of precast prestressed girders will have 5 tendons. Permanent force in tendons was calculated by taking account of the following losses due to friction of tendons, insertion of wedge, elastic deformations (shortening), strain release in steel, andconcrete contraction and creeping.

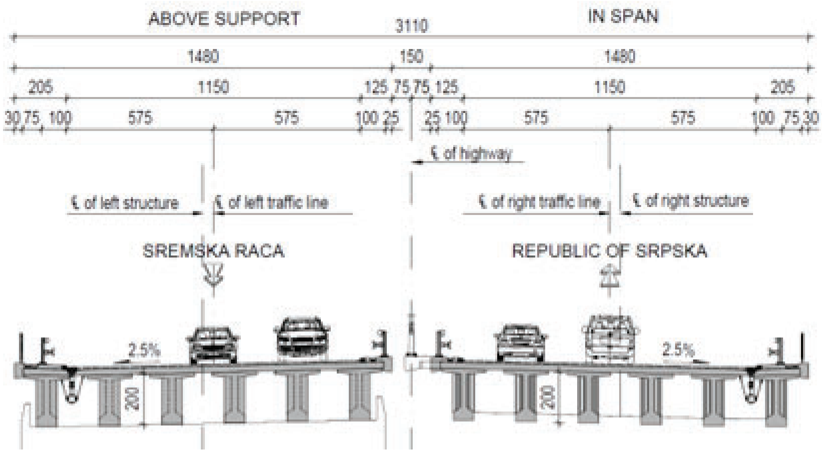

Figure 7: Cross section of precast girder

4.3 Piers/Abutments and Walls

Bridge structures rest on abutments and piers over pier caps, bearings, and support beams, excapt piers S11 and 12, which are rigidly connected to bearing beams . All support beams have both-sided overhangs in relation to shear wall. Support beams on dividing-expansion piers are wider because they support two concrete structures. Piers consist of reinforced concrete shear walls of constant cross section by height with semi-circular ends (80-90 cm radius), 770/160/180 cm in size. The radius of semi-circular ends and pier thickness are different along all approach structures. Dividing piers (S3,S6,S10 and S21) are 200 cm thick and have rectangular shape, with 20/20 cm chamfer edges. The piers height along the approach structures is different and ranges from 3,00m to 12,60m (left lane) and from 4,90m to 12,60m (right lane). On the right bank of the Sava river the piers vary from 4,50m to 8,50m in both carriageway lanes. The height of piers S14 and S15, of the main bridge structure is the same and it amounts 15,00m. The columns have sloping sides, as the piers S13 and S16, which are high 7,50m. (Figure 8)

Abutment S1 consists of wall panels of constant thickness with cross section of 1.40/14.10 m in size and enlargement at 85 cm height toward the support beam. The support beam for abutments is 1.00/2.45 m in size. Parallel wing walls, partly standing and partly hanging, are designed next to abutments. Since left and right carriageways are staggered, retaining walls are designed in the median. Outer wall side is vertical while the inner wall side is inclined at 10:1. These walls follow the highway gradient and they have nearly the same height. The wall foundation is restrained in the pile cap of abutment 1, and Ø1200 mm piles, 18.0 m long are designed under foundation. Top wall section is 50 cm thick. Abutment S25 also consists of shear walls of constant thickness with cross section of 1.40/14.10 m in size and enlargement at 85 cm height of the support beam. The support beam for abutments is 1.00/2.25 m in size.

Parallel wing walls, partly standing and partly hanging, are designed next to abutments. Cantilevers supporting footway and edge cornice are designed along the top edges of wing walls. The cantilevers vary in thickness from 30 cm to 25 cm in the median zone, while 120 cm long end cantilever under the outer footway vary in thickness from 35 cm to 25 cm. Transition slab will enable connection between the bridge and embankment. They will rest on pier over short element positioned at outer side of the parapet toward the embankment. Gravel wedges, properly tamped layer by layer, are envisaged behind the abutments S1 and S25. Lined embankment cones were designed next to abutments at the outer sides i.e., next to wider footways.

Figure 8: Piars of the main and access structure

4.4 Fundation

Because of geological soil composition the design envisaged deep foundations with foundation levels determined according to geomechanical reports, which can be corrected depending on the soil composition during excavation works. Foundations are designed on Ø1200 and Ø1500 mm reinforced concrete piles for all bridge piers/abutments.
A group of 6 reinforced concrete piles was designed on every pier for each carriageway on the bridge, except piers of the main steel structure and piers S18 and S19. Prior to construction, piles shall be subjected to load test. Piers rest on 10 cm thick blinding layer of plain concrete, class C12/15. This layer is differnet for the main structure and his piers, especially for piers S14 and S15, which are in the Sava river bed. Plain concrete in river Sava is class C20/25 thickness of 300 cm, according to the calculation of buoyancy force.