Sustainable High-Speed Railway Bridge Construction over the Danube-Tisa-Danube Canal

Construction of a Steel Trass Railway Bridge over the Danube-Tisa-Danube Canal Using the Launching Method with the Installation of Shock Transmitters

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Abstract As part of the project "Modernization, reconstruction, and construction of the railway Belgrade - Subotica state border (Kelebija)," a bridge designed for speeds of up to 200 km/h was constructed over the Danube-Tisa-Danube canal. The bridge, a two-track structure, features a truss continuous support on three spans totaling 154 meters (42+56+56). In the plan view, the bridge appears straight with straight abutments and skewed middle piers. The height between the top and bottom chord measures 9.0 meters, with a spacing of 12.5 meters between the main axes. The main girders are connected to cross beams at the bottom chord level and to wind bracing at the top chord level. The cross beams, composite members made from welded I-profiles and a concrete deck, provide additional support. The steel structure is supported on columns via spherical bearings. Due to operational requirements of the bridge, it became necessary to install a shock transmitter to absorb horizontal forces from braking, starting, and seismic activity. The bridge is supported by piles with a diameter of 1200 mm and lengths ranging from 20 to 23 meters.

To construct the middle pillars of the bridge, cofferdams were necessary in the canal. The steel structure was initially installed on the shore and then moved into its final position through longitudinal launching, facilitated by special temporary supports. The launching process involved the use of 12 sets of hydraulic presses and a launch grid beam to bridge the span during the structure's stretching.

This innovative construction method represents a new trend in bridge construction, demonstrating a commitment to sustainability throughout the project. The use of sustainable practices in both the design and construction phases ensures that the bridge aligns with modern environmental standards while providing essential infrastructure for the region.

1 Introduction

As a part of Design for Construction for the 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, a new bridge over the canal Savino Selo – Novi Sad has been designed. The canal Savino Selo – Novi Sad is an integral part of the system Danube-Tisa-Danube canal [1].

The high-speed rail system represents a unique, fast, innovative, and efficient mode of transport [2]. This Design for Construction of the bridge structure [3] was developed based on the approved Construction Permit Design, adopted technical parameters, traffic solutions, the existing condition of the railway, geodetic surveys, hydrotechnical designs, and geotechnical reports.

The designed structure in the technical documentation has been prepared in accordance with Serbian standards and applicable regulations, as well as the fundamental requirements of the Technical Specifications for Interoperability (TSI).

In addition to the engineering and design considerations, sustainability has been a key focus throughout the construction of the bridge. Measures were implemented to minimize environmental impact, including the use of materials and construction practices that promote resource efficiency.

Figure 1: Railway Bridge over Danube-Tisa-Danube canal

1.1 Percipients on the project:

Based on the agreement on economic and technical cooperation in the field of infrastructure between the Government of the Republic of Serbia and the Government of the People's Republic of China, a project for the modernization and reconstruction of the railway section from Novi Sad to Subotica and the state border (Kelebija) has been realized. Within the framework of this agreement, activities have been agreed upon that involve the engagement of Chinese companies in the design and construction phases of the afore mentioned infrastructure project.

The project investor is "Serbian Railway Infrastructure", while the project financier is the Ministry

of Construction, Transport and Infrastructure, Republic of Serbia.
The main designer of the project is CRDC (China Railway Design Corporation Ltd.) a renowned firm specializing in engineering design, responsible for developing all necessary technical solutions and plans related to the construction of the bridge.
The main contractor is the CRIC (China Railway International Corporation Ltd.) and CCCC (China Communication Construction Company Ltd.) Joint Venture, which brings its knowledge and resources to the realization of infrastructure projects.
The subcontractor for concrete works is the company CCECC (China Civil Engineering Construction Corporation Balkan) and China Railway Construction Corporation 11 group (CRCC11), which is responsible for all aspects related to the use of reinforced concrete, including preparation, installation, and quality control.
For the steel works, the subcontractors are CSCEC (China State Construction Engineering). In addition to the aforementioned foreign companies, domestic Serbian firms also participated in the drilling piles, the construction of formwork for the bridge's concrete elements, the installation of bridge equipment, and the execution of waterproofing works.
The Supervisor of all works is entrusted to the company PROJECT BIRO UTIBER DOO, Serbia, which provides expert control and supervision over all phases of construction.
This collaboration of various experts and companies contributes to the successful realization of the project, which will not only improve railway infrastructure but also contribute to sustainable development and economic efficiency of the entire transportation system.

2 Project overview

2.1 Layout

The design [3] encompasses a double-track bridge with a track gauge of 4.75 m. Structurally, the bridge is characterized as a continuous truss spanning three sections. In terms of plan view, the bridge is linear, featuring straight abutments and skewed intermediate piers. The angle that the bridge forms with the channel is 48 °. This configuration results in the main trusses being centrally symmetric relative to one another, with span lengths of 42 + 56 + 56 = 154 m.

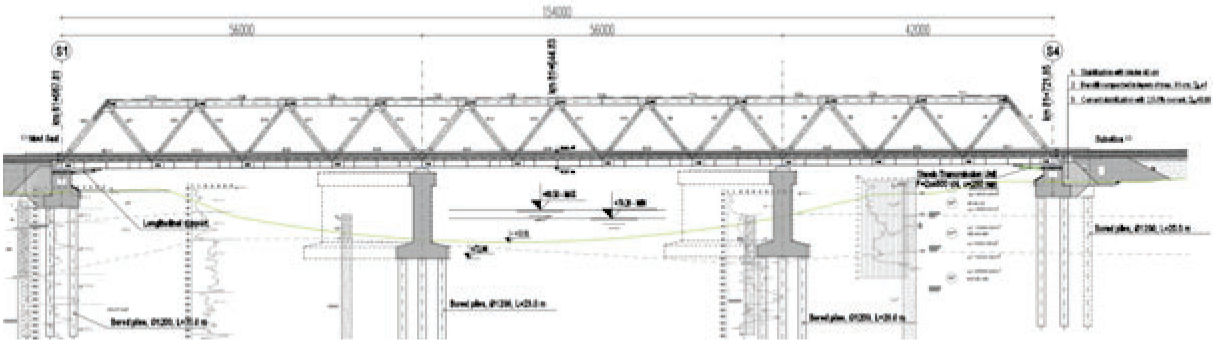

Figure 2: Longitudinal section

The vertical height between the top and bottom chords measures 9.0 m, while the spacing between the axes of the main trusses is 12.5 m. The trusses are composed of a top chord, a bottom chord, and diagonal members. The bottom chord experiences bending moments in addition to axial forces. Its cross-section is designed as a box section, with internal dimensions of 800 x 2000 mm. The top chord is formed as an open, hat-shaped section. All diagonal members are constructed with an open I-section, facilitating welded connections between the diagonals and the chords, allowing access for welding from both sides.

At the level of the bottom chord, the main girders are interconnected with cross beams, while at the level of the top chord, they are connected through wind bracing. The cross beams are composite elements, fabricated from welded I-profiles and a concrete deck with a thickness of 30 cm. The composite action is achieved through the use of headed stud shear connectors, which enhance the structural integrity and load distribution of the bridge system.

The concrete slab with edge parapets forms a ballast layer. The bridge has a drainage system consisting of gutters and drainage pipes placed below the concrete slab through special openings within the transverse girders. MMA waterproofing is applied over the concrete slab, on top of which an elastomeric mat for noise and vibration reduction is placed as protection. The bridge is equipped with revision paths 90 cm wide on both main girders.

The designed piles are 1200mm in diameter, with different lengths of 20m and 23m. The foundations of the abutments consist of 16 piles each, while the columns in the channel consist of 22 piles each.

The bridge employs spherical bearings, except for lateral supports along the bridge axis and longitudinal supports at the trusses. Additional bearings are strategically positioned in the track axes beneath the support cross girders to accommodate vertical deflections of the deck ends relative to the abutments. Although the forces generated by permanent loads in these bearings are minimal, they effectively prevent uplift forces during bridge exploitation. These bearings conform to the SRPS EN 1337 standard.

Furthermore, shock transmitters are installed at abutment S4, functioning as axial beams to mitigate instantaneous actions such as seismic events, braking, and traction forces. The primary purpose of these shock transmission units, as indicated in the structural calculations, is to limit longitudinal deformation of the deck slab to 5 mm due to braking and traction forces, in accordance with relevant standards.

2.2 Applied materials:

3 Construction of the bridge

3.1 Piles

Following the successful completion of static testing on the test piles, with favorable results obtained, the installation of permanent piles began. Total of 76 piles with a diameter of 1200 mm and lengths ranging from 20 m to 23 m were executed using the driving technique with full casing. Due to the elevation of the peninsula being significantly higher than the bottom elevation of the central beam of the intermediate columns, this necessitated the use of "blind drilling" to a depth of seven meters. A total of about 200 tons of reinforcement and 2500 m³ of concrete were installed in all the piles.

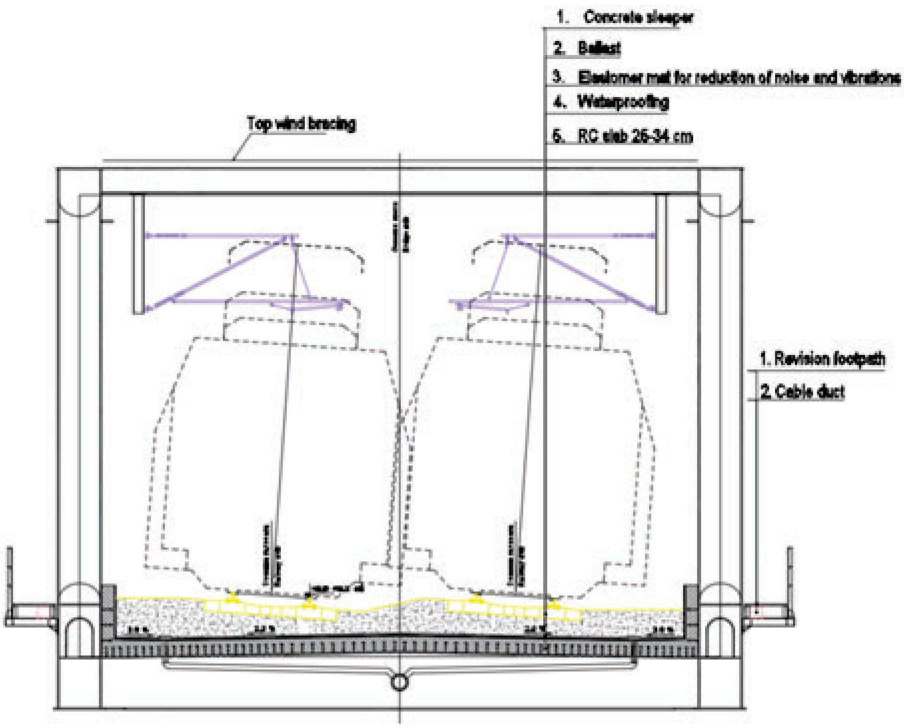

Figure 3: Typical cross section of bridge

Table 1

Element	Material	Comment
Main steel structure	S355	t≤20mm, S355J2+N+Z15; 20<t≤35mm S355J2+N+Z25 t> 35mm, S355K2+N+Z25
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
Bearings		According to: SRPS EN 1337
Shock-Transmission Units		According to: SRPS EN 15129:2018
Transition zone	Comb. of cement stabilization	According to: ZTVE-StB and UIC719

3.2 Cofferdam

The construction of two peninsulas on both sides of the canal was necessary for the installation of the middle columns, while adhering to the conditions of the Public Enterprise “Vode Vojvodine” for unobstructed navigation through the DTD canal.

After the formation of the peninsulas, the construction of piles began with drilling. Due to the elevation of the peninsula being significantly higher than the bottom elevation of the central beam of the intermediate columns, this necessitated the use of "blind drilling" to a depth of seven meters. After the piles were installed, the construction of the cofferdam began. The contruction of cofferdam is rectangular in shape with bracing frames at two levels, with dimensions at the base of 30.00 x 10.90 m, and Larsen piles VL 606 A of 16.0 m in length.

Figure 4: Construction site during the substruction work

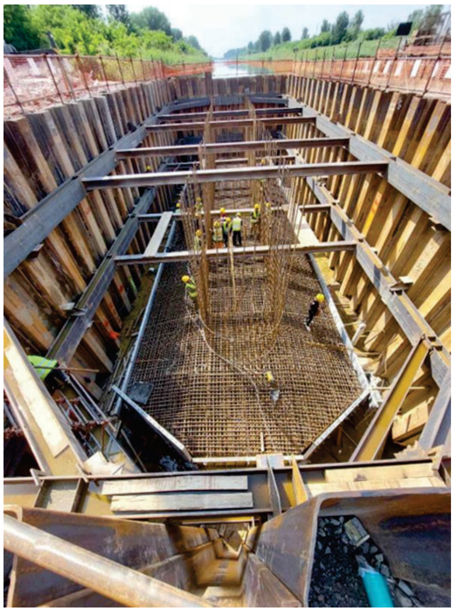

Figure 5: Reinforcement of the pile cap S2 in cofferdam.

3.3 Over piles, pillars and head beams

On the waterside, the execution of the pile caps, than abutments, and head beams began immediately after the piles were completed. For the execution of the elements in the canal (S2 and S3), the cofferdam had to be completed first. A calculation of the formwork and supporting scaffolding was done for all concrete elements, considering the dimensions of the elements. The works were carried out in parallel for S4 and S3, and shifted by one shift for S1 and S2 to utilize one complete set of formwork for the elements of the abutments and middle pillars. The total amount of concrete used for the over piles, pillars, and head beams beams was 3500 m3, while over 600 tons of reinforcement were installed.

Figure 6: Execution of the middle column S3 in the cofferdam

Figure 7: Execution of the abutment S4

3.4 Assembling steel structures

The steel structure with a complete anti-corrosion protection system was produced in China, specifically at the factory of China State Construction Engineering. It was transported by ship to the Port of Koper in Slovenia and subsequently delivered by road to the construction site in Serbia. After the delivery of the steel structure to the construction site, it was necessary to first initiate the consolidation of the structure on the ground and then the assembly of the entire bridge structure on temporary supports. Due to the limited transport conditions in terms of the dimensions of the structure, it was essential to form wind brace segments on the ground (in a star shape) and diagonal infill segments of the truss with an upper node (in a V shape). Once the segments were welded on the ground, they were lifted and mounted onto temporary supports using a crane.

Figure 8: Construction site

Figure 9: Steel structure on temporary supports

After the consolidation of the structural components on the ground, the elements were raised onto temporary supports on the bank and connected by welding. Once the complete bridge structure was assembled on the bank, the leading beam was mounted on the structure, and longitudinal shifting of the bridge into the designed position was executed. The assembly of the structure on the bank was conducted on the side of column S1 (with a smaller railway mileage).
The consolidation of the structure took place on the slopes of the embankment of the railway body, while the temporary supports for the assembly of the structure on the bank were constructed directly along the railway alignment.
The total weight of steel for this bridge was 1,200 tons, and it took 55 days to consolidate it on the assembly and launching.
For the pre-assembly of the steel structure at the construction site, the following machines were utilized: a crane truck with a capacity of 35 tons, a crane truck with a capacity of 80 tons, a crane truck with a capacity of 65 tons, a crane truck with a capacity of 55 tons, a lift truck with a height of 25 meters, and a platform trailer of 12 meters with a capacity of 20 tons.

3.5 Launching

According to Execution design Launching of the bridge at km 81+644 [4], the lounching process of the steel structure of the bridge was carried out: Initially, the complete assembly of the steel truss structure of the bridge was carried out on the shore (from axis L1 to axis S1); thus, the entire steel truss structure of the bridge could be installed in the designed position (from axis S1 to axis S4) using a lifting and sliding system.

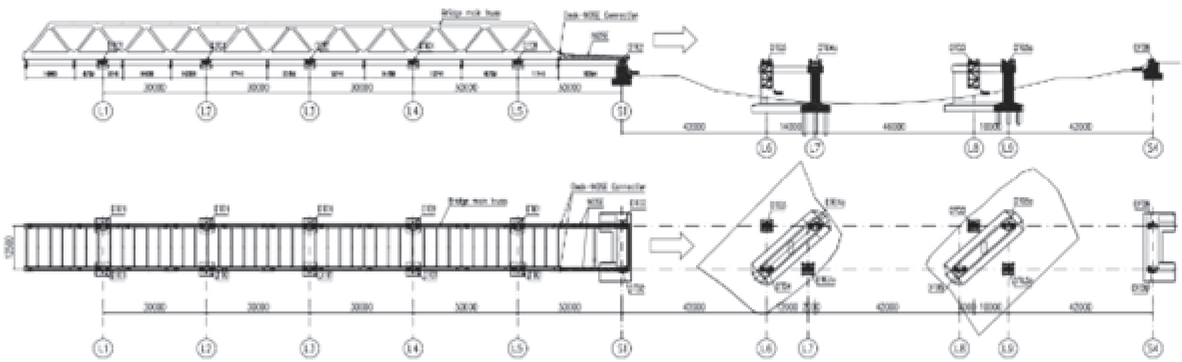

Figure 10: General layout of Bridge Incremental Launching Construction at Section km 81+644

In this project, 12 sets of longitudinal launching machines were positioned beneath the bottom chord of the truss, with a longitudinal spacing of 30 meters and a lateral spacing of 12.5 meters. During the longitudinal launching process, a leading beam with a length of 20 meters was placed in front of the steel structure. The leading beam was constructed from a two-dimensional triangular truss, spatially braced. With the assistance of the leading beam, the maximum cantilever portion of the steel truss (including the guide) was approximately 48 meters.

3.5.1 Hydraulic synchronous jacking technology - Hydraulic launching machine

According to the stress characteristics of the steel structure, a jacking press was applied that has three directions of movement, which enables the functions of longitudinal jacking, vertical movement, and lateral correction of the steel structure. A sketch of the working principle of the QLD100x2 launching machine.

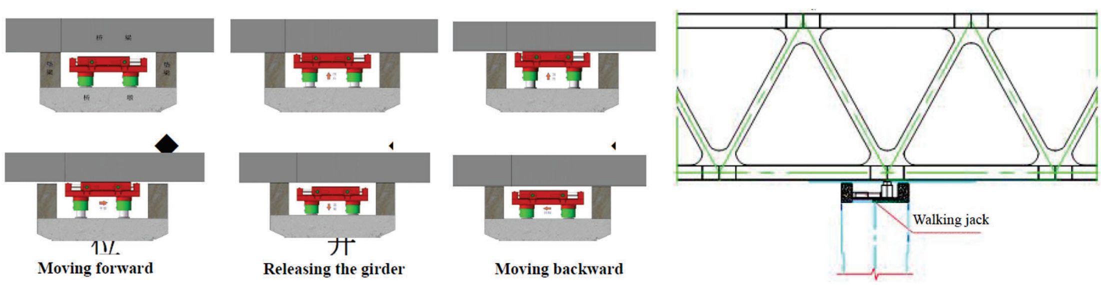

Figure 11: Sketch of the working principle of the QLD100x2 launching machine

During the movement operation, it was crucial to lift the vertical upper ram to facilitate the ascent of the steel beam away from its temporary support. At the same time, the horizontal press was activated to exert pressure on the vertical upper part, allowing it to move horizontally. When the maximum path of the horizontal press was reached, the vertical upper ram was lowered, allowing the beam body to settle back on the temporary support. After that, the vertical upper ram was retracted, and the vertical upper part was moved backward to return to its original position. This process was repeated, systematically moving the upper part of the beam until it reached the intended design position.

3.5.2 Calculation overview

The construction of the bridge using the incremental launching method at km 81+644.83 was realized in 12 key steps. The loads that were considered are as follows: Dead load, Live load (during the construction, live load $Q = 0.1kN/m^2$), and Wind load. According to the simulation analysis results of the construction stage, the diagram of the thrust reaction force in the most unfavorable working condition is as follows:

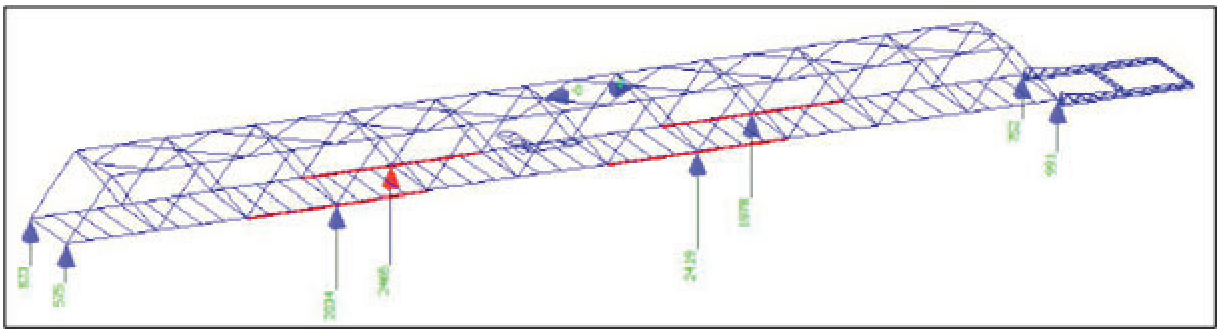

Figure 12: Diagram of the thrust reaction force in the most unfavorable working condition during the lunching

The max. jacking force of single point is 247t;
The rated vertical and horizontal jacking force of single jack is 400t and 100t respectively for walking jack (model QLD400) is used.
The safety storage coefficient of equipment: 400/247=1.6 (vertical) and 100/(247x0.1)=4 (horizontal)
The conclusion is that, according to the calculation for the adopted arrangement of temporary supports and the number of presses for launching the structure, the adopted launch presses have sufficient load-bearing capacity, which has been proven during the execution of the works.

3.5.3 Buckling calculation

During the launching bridge, some elements of the steel structure are under the loads that are different from the loads during the period of exploitation for which they were designed. This especially applies to the lower chord of the truss, which is loaded with compressive force, bending moments and a large concentrated force at the point of. After the buckling calculation, it was determined that it is necessary to strengthen the main box girder of the bridge with a 20mm thick reinforcement plate arranged every 1.167 meters.

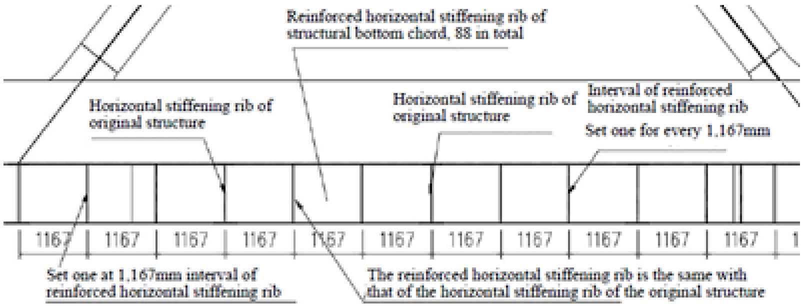

Figure 13: Drawing of main beam stiffening

3.5.4 Reinforcement slab

After the completion of the launching of the bridge's steel structure and the installation of the bearings, work commenced on the execution of the roadway slab. The formwork base was established. in accordance with the Formwork Design. Following the completion of the reinforcement cage, concrete was poured in phases due to the large surface area of the slab, with sections being poured in a staggered manner, separated by mesh. A total of 650 m^3 of concrete was utilized, while the surface area of the slab formwork amounted to 2000 m^2.
After the concrete slab is completed, a waterproofing protection based on methyl methacrylate (MMA) is applied, and over it, an elastomeric under ballast mat (UBM) is placed for noise and vibration reduction as protection.

3.6 Bearings and Shock transmitter

3.6.1 Bearings

This bridge has 16 bearings. The structure rests on five bearings at the abutments, while it relies on three bearings at the intermediate piers. All bearings, except for those in the longitudinal axis of the bridge, are spherical and movable in all directions. In the longitudinal axis of the bridge, all piers have guided bearings that are movable in the longitudinal direction of the bridge
After the longitudinal jacking of the bridge was completed, the installation of the bearings commenced. The bearings were mounted onto the steel structure of the bridge using bolts, following a geodetic control of the bridge's position. Subsequently, the bridge structure was lowered to the designed level using jacks that were positioned on the bridge's piers.
After completing the entire installation of the bearings, given that all bearings are movable, it was necessary to fix the bridge in both directions at pier S1, as well as to secure it in the longitudinal direction at pier S4, to facilitate the installation of longitudinal supports at pier S1 and shock transmitters at abutment S4.

3.6.2 Shock transmiters

The shock transmitter units are able to allow slow movements, like those given by thermal variations, creep and shrinkage without valuable resistance, and rigidly react to dynamic actions like those

Figure 14: Longitudinal support

Figure 15: Shock transmiter unit

due to braking or seismic events.
Before the installation of the STU (Shock Transmitter Unit), it was necessary to install longitudinal rigid supports on column S1. The structure of the longitudinal consists of a steel structure of a simple rod connected via bolts to the anchor plate on the abutment and the connecting plate on the steel structure. The anchors were installed in the bridge abutment prior to the concrete pouring of the bridge. The holes in the bottom chord of the bridge truss were formed on-site after the completion of geodetic measurements. It was delicate to carry out the drilling of these holes because the bottom chord of the truss has closely spaced stiffening plates to prevent buckling during the bridge lifting. After detailed measurements, the holes were successfully formed without damaging the stiffening plates. It remained to install the plates and secure them with bolts, which was successfully completed. After the installation of the longitudinal supports was finished, the installation of the shock transmitters commenced. At abutment S4, the anchors for the STU connection were installed before the column was concreted. The construction of the STU connection to the bridge's steel structure follows the same principle as the longitudinal support, with the addition that a sleeve is placed within the bolt holes to allow for the tolerance of the STU alignment. After placing the anchor plate on the abutment, drilling holes in the bottom chord of the truss, and securing the connecting plate with bolts to the structure, the STU was fixed by passing the bolts through the lugs of all elements. After the installation of longitudinal supports on S1 and shock transmitters on S4, the structure was released at the bearings on the S1 column.
Following the completion of the entire bridge and subsequent control geodetic measurements, it was determined that the structure was level according to the design specifications.

4 Bridge testing

After the completion of the entire bridge structure, including the ballast blanket and track, conditions were established for testing the bridge structure. The testing of the bridge under static and dynamic loading was conducted by the IMS (Institute for Materials of Serbia) in accordance with the Bridge Testing Program [5], which was approved by the Supervisory Team and the Bridge Designer. Upon completion of the tests, the bridge received an evaluation indicating that it is capable of bearing the loads specified in the project.

Figure 16: Photography at the time of bridge testing

5 Conclusion

The sustainability of the railway construction system in Serbia necessitates rapid execution dynamics, which this project has facilitated through its implementation methods. This mode of transport will enable sustainability in terms of cost-effectiveness, environmental considerations, and transport speed.

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