Design and Construction of Bridges on Morava Corridor

Dusko Bobera [1] ✉, *Predrag Bakic* [1], *Isidora Gavrilovic-Bukvic* [1], *Goran V. Milutinovic* [1], *Marko Lekovic* [1]
✉ e-mail: dusko.bobera@dbinzenjering.rs
[1] DB Inzenjering, Belgrade, Serbia
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Abstract Morava Corridor Motorway Project is a 112 km dual-carriageway motorway currently under construction in Serbia, with a design speed of 130 km/h, from Pojate and the A1 (the North-South motorway in central Serbia) through Kruševac and up into Preljina in the north of Čačak. The project runs east/west in the West Morava River valley and is seen as a key enabler of the economic corridor to the industrial city of Kruševac and its ultimate international connections to Bosnia, Montenegro and Macedonia. It consists of 78 bridges, 26 overpasses, and 11 underpasses. With the length of the motorway and the number of structures currently under construction, this is one of the largest construction projects currently in Serbia. In this paper, experiences during design and construction of these bridges has been presented. First, design approaches (such as strut-and-tie method for design of pile caps and pier caps) has been discussed, and construction aspects of the project have been reviewed. The motorway is located in seismically active region, with peak ground acceleration up to 0.2g. Precast construction was used for the majority of structures, which enable fast and efficient construction. Pretensioning of the concrete beams has been applied on almost all bridges, which is the type of the prestressing extremely rare in Serbia, where posttensioning is always used in bridge construction. By pretensioning, large number of beams were produced in timely manner and in controlled environment. Also, the eight longest bridges, with a total length of more than 3.3 km, are seismically isolated, which is one of the first uses of seismic isolation in Serbia. These bridge are the first bridges in Serbia which are in the same time seismically isolated and pretensioned. Seismic isolation provided large savings for the substructure reinforcement demand, while limiting the expansion segment length to about 200m.

1 Introduction

Morava Corridor Motorway Project is a 112 km dual-carriageway motorway currently under construction in Serbia, with a design speed of 130 km/h, from Pojate and the A1 (the North-South motorway in central Serbia) through Kruševac and up into Preljina in the north of Čačak. The project runs east/west in the West Morava River valley and is seen as a key enabler of the economic corridor to the industrial city of Kruševac and its ultimate international connections to Bosnia, Montenegro and Macedonia. It consists of 78 bridges, 26 overpasses, and 11 underpasses. With the length of the motorway and the number of structures currently under construction, this is one of the largest construction projects currently in Serbia. In this paper, experiences during design and construction of these bridges has been presented. The following types of bridges have been used on Morava Corridor: (1) U-shaped precast prestressed concrete beam bridges, (2) T-shaped and I-shaped precast prestressed concrete beam bridges, (3) integral frame RC bridges, and (4) RC culverts. Design approaches and construction aspects of the project have been reviewed. The motorway is located in seismically active region, with peak ground acceleration up to 0.2g. Precast construction was used for the majority of structures, which enable fast and efficient construction. Pre-tensioning of the concrete beams has been applied on almost all bridges, which is the type of the prestressing extremely rare in Serbia, where posttensioning is always used in bridge construction. By pretensioning, large number of beams were produced in timely manner and in controlled environment. Also, the eight longest bridges, with a total length of more than 3.3 km, are seismically isolated, which is one of the first uses of seismic isolation in Serbia. These bridge are the first bridges in Serbia which are in the same time seismically isolated and pretensioned. Seismic isolation provided large savings for the substructure reinforcement demand, while limiting the expansion segment length to about 200m [1], [2]. The contractor for the projects was Bechtel Enka Joint Venture, and the bridge designer was DB Inzenjering from Belgrade, Serbia.

2 Construction of bridges on Morava Corridor

Construction of the bridges on Morava Corridor is described in this chapter. By discussing the construction, types of bridges on the corridor will be introduced – their design follows in the next chapter.

2.1 Pile construction

Bored piles has been used as foundation for all bridges, except RC culverts. Equipment for pile rebar cage assembly that was used during construction of the corridor is shown in Figure 1. Before lowering the rebar cage into bored hole, a SPT test was done on the bottom of the hole to verify the soil condition. Quality control of the pile construction has been done in two ways: (1) “low-strain” dynamic testing, i.e. pile integrity test (PIT), and (2) “high-strain” dynamic testing, i.e. pile driving analyzer (PDA). With PIT (a nondestructive method), a “low-strain” dynamic testing of the pile integrity is done by measuring the response of the constructed pile by impact of the hand hammer (Figure 2). By measuring the acceleration of the compression wave, defects of the piles such as cracks, widening or narrowing of the pile cross section can be detected anywhere along the pile. PIT test has been done on each pile, on each bridge on the corridor. Also, PDA test, i.e. “high-strain” dynamic testing has been done to determine the geotechnical capacity of piles and to compare it with the computed values (Figure 2). It is possible with this test to determine entire pile capacity, as well as skin and pile base capacity, by controlled dropping of the 15-tonnes mass. Several piles were tested in one day with PDA test. There was, in general, several PDA tests on longer bridges, and one test on shorter bridges (for example, an overpass with several spans), and none on small bridges, if PDA test was already done in the vicinity of that bridge.

Figure 1: Equipment for pile rebar cage assembly

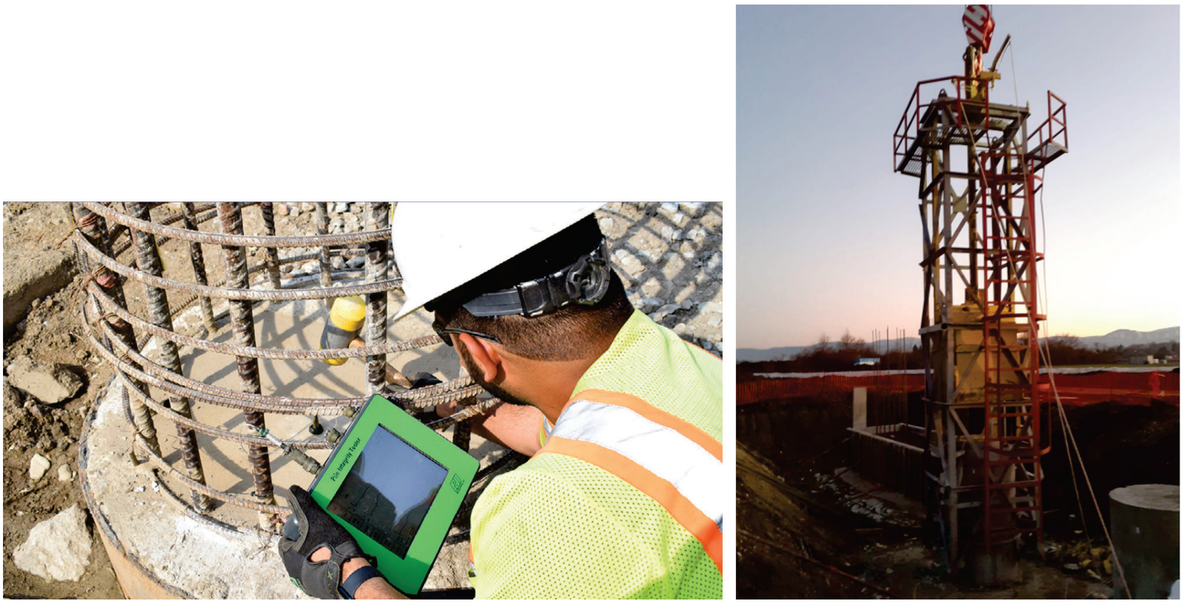

Figure 2: Pile integrity test (PIT) – Pile Dynamics, Inc. catalog [3] (left), and PDA test on Morava Corridor (right)

2.2 Precast construction – U beams

Eight longest bridges (with a total length of more than 3.3 km) on the corridor has characteristic cross section of three U-shaped precast girders, monolithically connected with cast-in-place RC slab. These bridges consist of a series of simply-supported spans, each up to 40 m in length. The simple spans are connected between each other by means of 25-cm-thick link slabs over the piers. The flexural stiffness of the link slab is several orders of magnitude smaller than the mid-span flexural stiffness. The characteristic cross section is shown in Figure 3. Casting of the U-shaped precast beam is shown in Figure 4. Erection of the U-beams has been performed with launcher shown in Figure 5. The launcher, carrying the U beam, is sliding over the top portion of the pier caps shown in Figure 10, until it comes above the final position of the U beam, and the beam is set down in position. Once all beams in one span are erected, RC slab is cast over the beams.

2.3 Precast construction – T beams and I beams

Second type of the bridges on Morava Corridor is integral continuous T-shaped precast concrete beam bridge, with its characteristic cross section shown in Figure 6 on the left. The erection of the T-shaped precast beam is shown in Figure 7. Once all beams in one span are erected, RC slab is cast over the beams. On Figure 6 on the right, precast plant and constructed beams laid out on the future corridor are shown. With this concept, efficient linear transport of the beams along the corridor is obtained. Also, semi-integral or integral continuous I-shaped precast pretensioned concrete beam bridges have been built.

2.4 Precast construction – RC culverts

For shortest spans, RC culverts were used, that were either cast-in-place or constructed using precast segments. Special attention was given for the durability and long term behavior of the waterproofing joints for the precast culverts (shown in Figure 8).

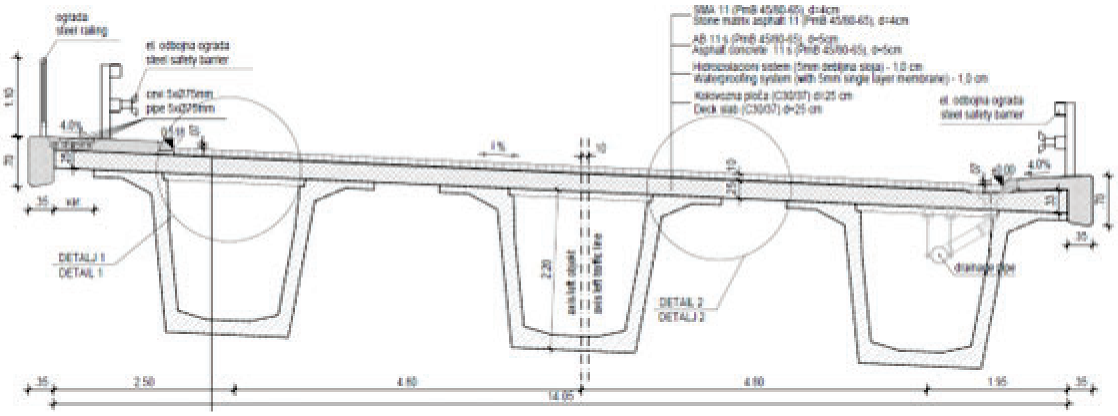

Figure 3: U-shaped beam bridge characteristic cross section

3 Design of bridges on Morava Corridor

During design of bridges on Morava Corridor, among other methods, seismic isolation and strut-and-tie has been used. Also, pretensioning of the beams has been done, which introduce slightly different analysis approach than posttensioning. These aspects have been discussed in the following chapters. Regarding the foundation design, bored piles have been used for all bridges. Their geotechnical capacity was checked – also a limit on settlement of 10mm has been set. As an output of settlement analysis, the vertical springs on the piles representing soil stiffness can be easily calculated. By using these springs, any imposed load effects due to differential settlements of adjacent piers is automatically captured in the analysis of the model.

Figure 4: Casting of the U-shape precast beam

Figure 5: Erection of U-shaped precast beams with the launcher [4]

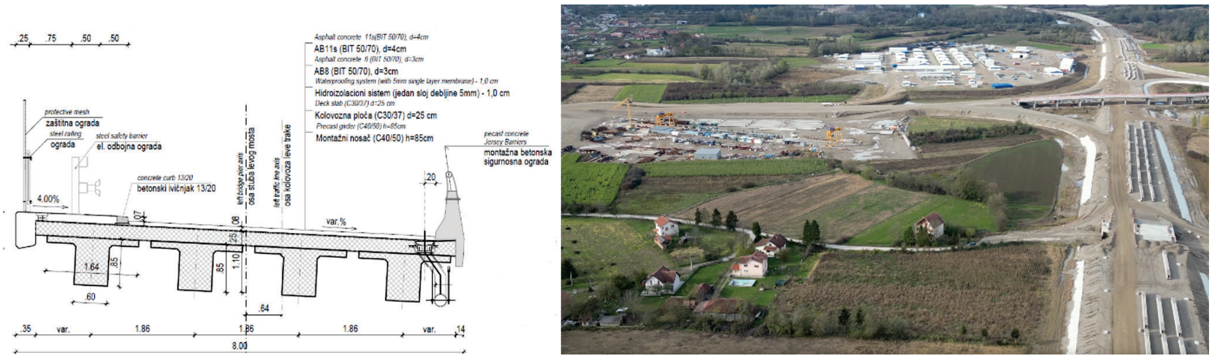

Figure 6: T-shaped beam bridge characteristic cross section (left) and precast concrete plant (right) [5]

Figure 7: Erection of T-shape precast beam [4]

Figure 8: RC box precast culvert

3.1 Seismic isolation

The concept of the seismic isolation involves softening the structure by providing an additional flexible element (elastomeric bearings) to support the relatively large percentage of the total structure mass. The effective stiffness of the structure is then the combined stiffness of the conventional structure (e.g. the bridge pier) and that of the flexible isolation device. Such a reduced stiffness increases the period, which in turns results in decreased acceleration (and therefore reduced seismic forces), but also increases displacements obtained from the response spectra. The effect of period shift and reduced seismic acceleration (and therefore forces) for a more flexible structure is illustrated in Figure 8. The concept of isolation is often used in bridge structures throughout the world, primarily for the following two reasons: (1) elastomeric bearings are routinely used in bridges for non-seismic purposes (supporting the superstructure, which is a large percentage of the total mass of the bridge), and (2) bridges are often classified as "important" structures, designed to remain functional even after major earthquakes. Apart from their inherent purpose as vertical supports, elastomeric bearings can effectively perform the period shift when used as an isolation device, but without increased energy dissipation. This gives way to reduced seismic acceleration, but with increased seismic displacement. Their hysteretic loop is narrow, providing around 5% damping, which is the value typically used as part of conventional design. Therefore, the usual response spectrum curve for 5% damping should be used in the case of elastomeric bearings. If the displacement were to become unacceptably large (which was not the case in this project), one solution would be the use of lead-rubber bearings instead of conventional elastomeric bearings. This would provide additional damping, reducing the entire displacement response spectrum, and therefore reducing the displacement due to increased damping. An analysis of lead-rubber bearings is presented in [7] and [8].

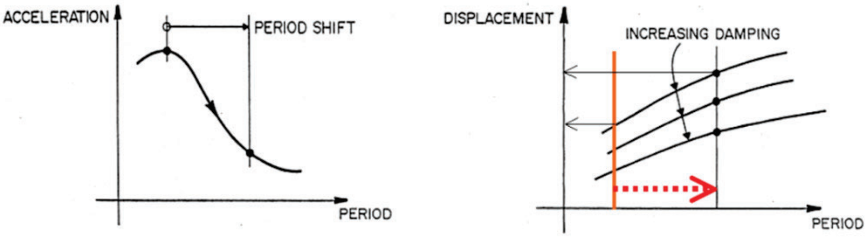

Figure 9: Response spectrum with the effect of period shift and increased damping [9]

Eight longest bridges (more than 3.3 km long in total) on the corridor, consisting of three U beam precast girders, is seismically isolated. This typical seismically isolated superstructure is a series of simply-supported spans, each up to 40 m in length, connected between each other by means of 25-cm-thick link slabs over the piers. Longitudinal view of link slab of the built bridge at km 8+519 is shown in Figure 10. The superstructure is supported on the substructure only by laminated elastomeric bearings, - superstructure is otherwise completely separated from the substructure. A polystyrene layer separates the link slab from the pier cap at the interface between the two components. Seismic blocks, however, are used as "the last line of defense" to prevent the unseating of the superstructure in the case of catastrophic earthquake or unforeseen structural behavior of the bridge. The necessary gap between the girders and seismic blocks were calculated as a maximum of 10 cm for both seismic and ULS combinations, which included both, temperature and shrinkage (see Figure 10 for the locations of seismic blocks). If the superstructure "floats" and the deflection relative to the substructure is greater than the calculated gap, the superstructure would collide with the substructure (seismic block). The resulting global behavior would be completely different – there would no longer be any seismic isolation. Expansion joints are designed for the seismic design situation to provide both free longitudinal and lateral movement, since the seismic isolation concept, or "floating superstructure," refers to free oscillation in any direction during an earthquake. Conventional laminated elastomeric bearings are used in this project and they play a dominant role in the seismic response of the structure. According to EN 1998-2, such bearings are referred to as "simple low-damping elastomeric bearings" and are used as seismic isolators. They must be in compliance with EN1337-3 (European norm for elastomeric bearings), but need not to be in compliance with EN15129 (European norm for anti-seismic devices). Elastomer bearings type B have been used – these are bearings without steel or any other type of plate attached to the top or bottom surfaces of the elastomer, according to EN1337-3. The minimum pressure requirements for this type of bearing were checked and found to be acceptable. According to EN1998-2 7.5.2.4(6), the creation of two independent models is necessary for seismic loads; one with lower bound design properties of the elastomer, and one with upper bound design properties. The reason behind the upper and lower bounds is the fact that the elastomer properties change over time due to aging and variations in temperature.

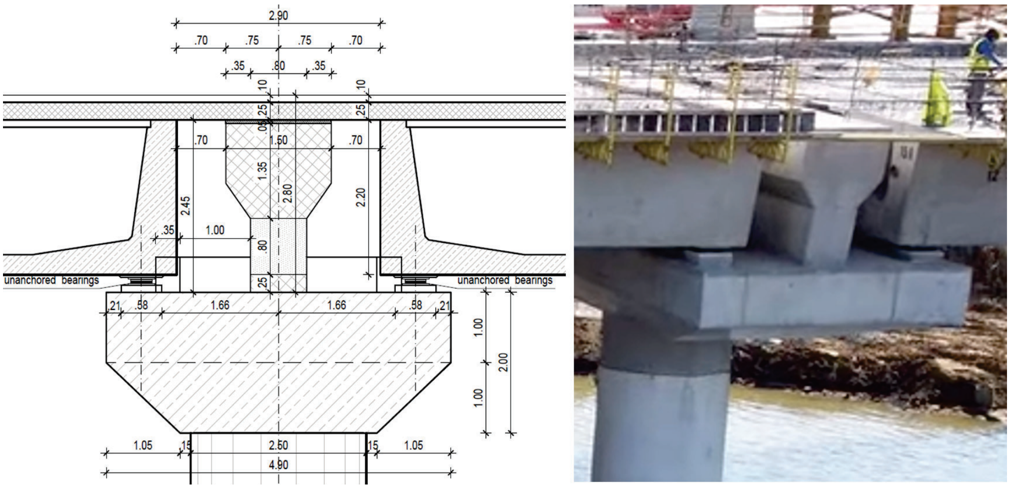

Figure 10: Link slab and supporting detail on the pier

The 3D finite element method (FEM) model (Figure 11) was generated to perform the analysis of the seismically isolated bridges. Elastomeric bearings are modeled with link elements having an appropriate shear stiffness. The first and second mode shapes (shown in Figure 11) clearly illustrate the concept of the "floating superstructure" – the superstructure displacement is much larger than that of the substructure. Most of the structural displacement is concentrated in the bearings. Since the finite element method, in general, is easily "used and abused" [10], simple hand calculations were performed to verify the full 3D model. The simple hand calculations consist of single-degree-of-freedom (SDOF) analyses representing a single column and tributary superstructure mass, also known as the fundamental mode method in EN 1998-2. The SDOF system is shown in Figure 12. Since the column height, in general, is different for each pier, an averaged column height in one expansion segment should be used for this SDOF system. Location of the point of fixity of the SDOF system is questionable, but in this case it is irrelevant, since the stiffness of the entire bridge system is dominated by the elastomeric bearing stiffness.

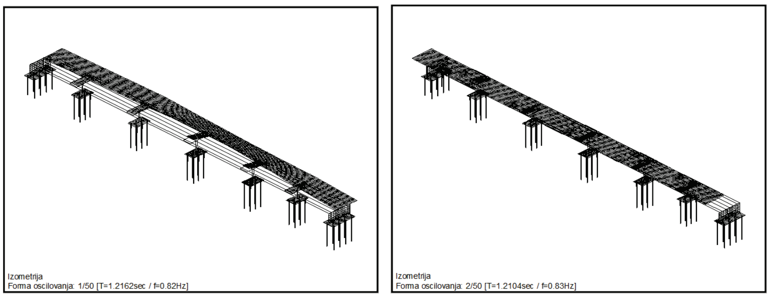

Figure 11: First and second mode shape

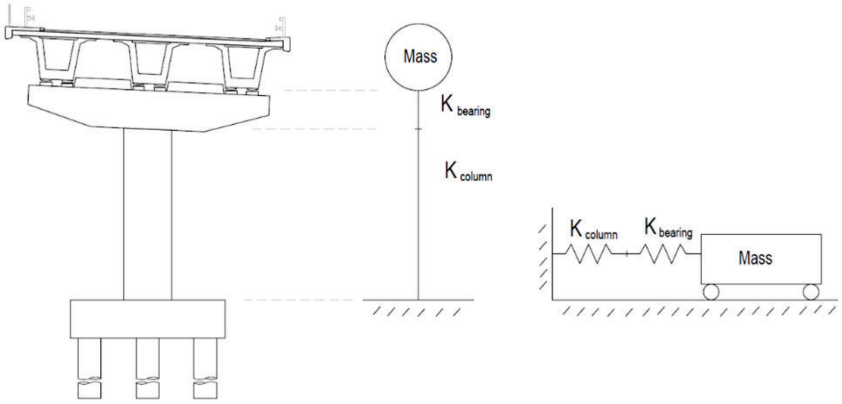

Figure 12: SDOF model of the bridge

3.2 Strut-and-tie modeling

Strut-and-tie method, in general, is a practical application of the static theorem of plasticity [11]. The consequence is that the solution of the STM model is safe as long as the forces are in equilibrium. The structure will eventually come to the assumed strut-and-tie model force equilibrium, but if it is not the appropriate model, a severe unacceptable cracking and redistribution of forces will occur first. Therefore, a standardized procedure for constructing the STM model for each application is needed, for its accurate and fast application in practice. The bridge pile caps on this project have been checked with the step-by-step methodology for creating the STM truss models presented in [12]. One such STM model is shown in Figure 13. By this method, fast creation of safe and accurate STM model of the pile cap with any number of piles and any pile arrangement is possible. Unique model is made, where numerous load combinations can be applied with alternating biaxial bending and compression force.

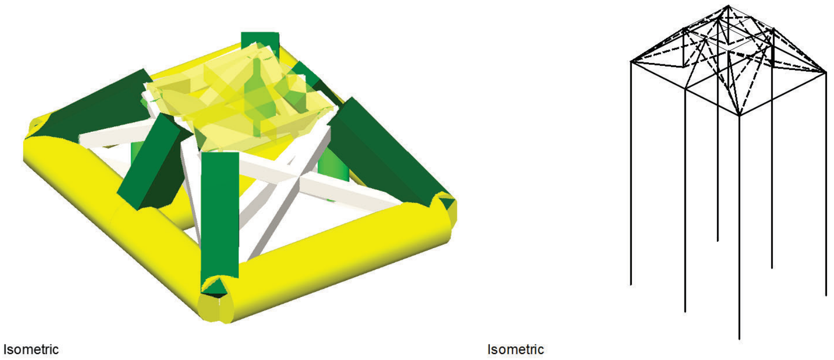

Figure 13: 3D render of the STM model of the pile cap (left figure does not include piles present in the model)

Pier caps on the bridges in this project were also checked with the strut-and-tie method. All stages during construction of the pier cap have been checked. For the final stage, the constructed strut-and-tie model is shown in Figure 14. It consists of two models: (1) the first model (shown in the left part of the figure) transfers the beam reaction to the top of the inverted T section, and (2) second, main model (shown in the right part of the figure) is possible once the precast beam reaction is transferred to the top of the inverted T section. This is similar to the model proposed in the literature for a different pier cap, but applicable also in this case[13], and in accordance with EN1992-1-1. The STM method is applicable method for analysis of the so called D-regions; however, even if the classical beam theory is applied in these case, it would require more reinforcement than the STM method. Also, the reinforcement would be on the more appropriate (accurate) locations with STM approach [14].

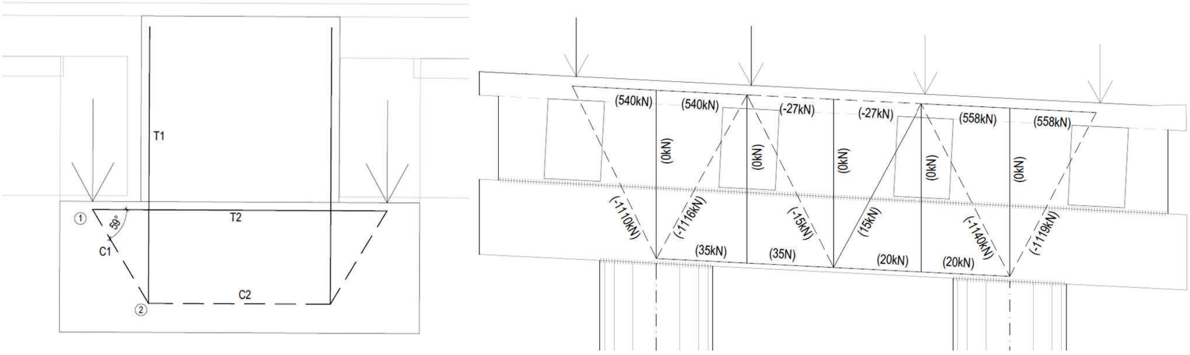

Figure 14: STM model of the pier cap in final stage – transverse direction (left) and longitudinal direction (right)

3.3 Pretensioning

On almost all bridges on Morava Corridor, pretensioning of concrete beams has been applied. Typical strand pattern is shown in Figure 15 (left). Control of beam stresses at the beam ends has been done with strand debonding at ends (circled strands in Figure 15 on the left), by placing the isolating material around the strand, as shown in Figure 15 (right). This is one of the differences when compared with the posttensioning – while in posttensioning there is a freedom in optimum tendon longitudinal geometry for concrete stress control, in pretensioning, strand layout is usually predetermined with the precast plant patterns, with straight or polygonal longitudinal layout. Another difference is gradual prestress force increase in the strand with pretensioning, starting from beam ends along the transfer length, while in posttensioning prestress force is applied in discrete points at the anchorages. Pretensioning is very often applied, for example, in the U.S.A, where labor is more expensive than material, so the main design philosophy is that the design should be such that the construction is fast and simple [15]. This is probably the main reason for popularity of the pretensioning in the U.S.A, since it is effectively done in precast plants – beams are set for installation after just a few days after casting. In this case, pretensioning become effective due to extremely large number of beams to be produced, allowing for the fast serial production.

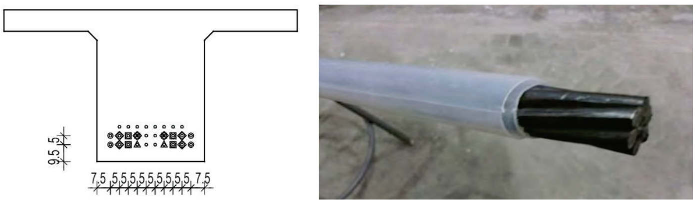

Figure 15: Typical pretensioning strand pattern (left) and pretensioned debonded strand[16]

4 Conclusion

During construction of the Morava Corridor, which is one of the largest infrastructure project in Serbia currently, several specific construction approaches proved to be efficient method. Precast construction was used for the majority of structures, which enable fast and efficient construction. Pretensioning of the concrete beams has been applied on almost all bridges, where large number of beams were produced in timely manner and in controlled environment. Also, the eight longest bridges, with a total length of more than 3.3 km, are seismically isolated, which is one of the first uses of seismic isolation in Serbia. Seismic isolation provided large savings for the substructure reinforcement demand, while limiting the expansion segment length to about 200m. The STM method is applicable method for analysis of D-regions; however, even if the classical beam theory is applied in these case, it would require more reinforcement than the STM method. Also, the reinforcement would be on the more appropriate (accurate) locations with STM approach.

5 References

[1] D. Bobera, P. Bakić, and G. Milutinovic, “Seismic isolation of bridges on Morava Corridor,” in Proceedings of the DGKS Conference 2022, Arandjelovac, Serbia, 28–30 September 2022,

[2] D. Bobera, P. Bakić, I. Gavrilovic-Bukvic, G. Milutinovic, I. Tadic, and D. Spasojevic, “SPECIFIČNOSTI PROJEKTOVANJA MOSTOVA NA MORAVSKOM KORIDORU,” in the Proceedings of SGP 2024, Borkovac, Serbia.

[3] “https://pdiwebsitestorage.blob.core.windows.net/websitedocstorage/2024/02/PDI-Family-Brochure-1.pdf.”

[4] “https://www.youtube.com/watch?v=tA4bf0vaB9w.”

[5] “https://www.youtube.com/watch?v=jI_FL8fpnlQ&ab_channel=Vlad089.”

[6] “https://www.youtube.com/watch?v=FtFGD8tpCWU&t=573s.”

[7] D. Šumarac, F. Đorđević, D. Matić, and G. V. Milutinović, “PRAJZAHOV MODEL HISTEREZISNE PETLJE ELASTOMERNOG LEŽIŠTA SA OLOVNOM ŠIPKOM,” Zb. Rad. Građev. Fak., vol. 37, pp. 263–274, 2021, doi: 10.14415/konferencijaGFS2021.25.

[8] R. Salatic, R. Mandic, and N. Tosic, "EFFECT OF BASE ISOLATION ON SEISMIC RESPONSE OF MULTI-STORY BUILDINGS – A CASE STUDY," in the Proceedings of GNP conference, 2014, pp. 17–21.

[9] M. C. Constantinou, I. Kalpakidis, A. Filiatrault, and R. A. E. Lay, "LRFD-Based Analysis and Design Procedures for Bridge Bearings and Seismic Isolators," 2011.

[10] R. M. Barker and J. A. Puckett, Design of Highway Bridges. 2013. doi: 10.1002/9781118411124.

[11] Rade Hajdin, Primena teorije plasticnosti u proracunu armiranih i prethodno napregnutih betonskih konstrukcija (in Serbian). Naucna Knjiga, 1991.

[12] G. Milutinović, N. Pecić, R. Hajdin, S. Mašović, and D. Bobera, "A PRACTICAL METHOD FOR STRUT-AND-TIE MODELLING OF THE BRIDGE PILE CAP," in the Procedings of INDIS conference. NOVEMBER, 2023.

[13] C. Williams, D. Deschenes, and O. Bayrak, "Strut-and-Tie Model Design Examples for Bridges: Final Report," FHWA / Texas DOT, 2012.

[14] G. Milutinovic and D. Bobera, "COMPARATIVE ANALYSES OF BRIDGE PIER CAP USING STRUT-AND-TIE AND BEAM MODEL," in the Proceedings of MASE conference 2023, Skopje, Macedonia.

[15] G. Milutinovic, R. Hajdin, and D. Bobera, "Differences in bridge engineering between USA and Serbia," in Proceedings of the DGKS Conference 2022, Arandjelovac, Serbia, 28–30 September 2022,

[16] C. French, "Debonded Strands in Prestressed Concrete Bridge Girders," Minnesota DOT Research Report.