e-mosty

ISSUE 01/2020 March

D4R7 The Danube Crossing

OVERVIEW DESIGN FOUNDATIONS CONSTRUCTION MSS BEARINGS EXPANSION JOINTS

e-mosty

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Photo Front Cover: View of the Danube Bridge Construction. Photo Back Cover: Movable Scaffolding System.
Photo Credit: D4R7 Construction s.r.o.

International, interactive magazine about bridges e-mosty ("e-bridges").

It is published on www.e-mosty.cz. Open Access.

Released quarterly:

20 March, 20 June, 20 September and 20 December

Peer-reviewed.

Number: 01/2020, March

Year: VI.

Chief Editor: Magdaléna Sobotková

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Editorial Board

The Publisher: PROF-ENG, s. r. o.
Velká Hraštice 112, 262 03
Czech Republic

VAT Id. Number: CZ02577933

E-MOSTY ISSN 2336-8179

Dear Readers

This special issue is dedicated to the __PPP Project of D4R7__ in the Slovak Republic with a focus on the __Danube Crossing__. There are 116 bridges in total on the project, with the overall plan surface equal to 200,000 m^2*. Approximately half of this area comprises the 3km long crossing of the Danube River.*

In the first article, Patrick Wagner of Porr Bau provides __General Overview__ of the Project and information of __construction__ of the Danube Crossing – the Main Bridge, its Approaches and the Kayak Bridge.

In the next article, __design__ of the Danube Crossing, __design principles__ and the __solution__ adopted are described.

__Deep foundation works on water and land__ mainly included the foundation works for two Danube piers, two piers in the area of a kayak channel and another 33 piers on land at the West and East approach bridges; temporary works (sheet piles and jet grouting sealings) and permanent piling works. They are described in the subsequent article.

In order to simplify the construction, the central box girder and the lateral wings were built in different stages by different equipment. The viaducts central box girder was built as a full span continuous beam using movable scaffolding systems, while the main bridge central box girder was built by the balanced cantilever technique using form travellers. The cross section of both viaduct decks is very similar. They were designed to be built by similar __movable scaffolding systems__. The description of two movable scaffolding systems (MSS) designated as __M1-70-S__ is provided in the next technical article.

The fifth article was prepared by Mageba and looks at __Bearings and Expansion Joints__ for D4R7 Project.

The last article of this special issue was prepared by Maurer and provides information on __Spherical Bearings__ for D4R7 Bridges.

*On behalf of the organizers **we invite you to Expo & Multi Conference infra BIM** which will be held **on 13 – 15 October 2020 in Arena Gliwice in Poland.** More information is on page 58.*

*I would like to thank all authors and the companies involved for their cooperation, to **Ken Wheeler for reviewing this issue, to Peter Paulik for his valuable comments, and Guillermo Muñoz-Cobo Cique (Arup) for his final check.***

I would also like to thank our partners for their continuous support.

*I am happy to announce that e-mosty magazine has **a new partner: Aas-Jakobsen**. Aas-Jakobsen is a leading building and construction consultancy, specializing in civil engineering and employing highly qualified experts in a range of disciplines. We look forward to our cooperation.*

*Our **partnership offer** is on page 6. If you are interested in cooperating with us as our partner, please contact us. General information on partnership with our magazines can be found on e-mosty or e-maritime.*

Magdaléna Sobotková

Chief Editor

e-mosty

The magazine e-mosty ("e-bridges") is an international, interactive, peer-reviewed magazine about bridges.

It is published on www.e-mosty.cz and can be read free of charge (open access) with possibility to subscribe.

It is published quarterly: 20 March, 20 June, 20 September and 20 December. The magazines stay **available on-line** on our website as pdf.

The magazine brings original articles about bridges and bridge engineers from around the world. Its electronic form enables publishing of high-quality photos, videos, drawings, links etc.

We aim to include **all important and technical information** and show the grace and beauty of the structures.

We are happy to provide media support for important bridge conferences, educational activities, charitable projects, books etc.

Our Editorial Board comprises bridge engineers and experts from the UK, US and Australia.

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30 March, 30 June and 30 November.

September Issue is shared with the magazine e-mosty ("e-bridges"):
"Bridges, Vessels and Maritime Equipment"
which is published on 20 September on www.e-mosty.cz.

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The magazines stay **available on-line** on our website as pdf.

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The magazine e-mosty was established in April 2015 and its first issue was released on 20 June 2015 as a bilingual English – Czech magazine aimed mainly for Czech and Slovak bridge engineers.

Very quickly it reached an international readership.

In 2016 we extended the already existing Czech and Slovak Editorial Board by two bridge experts from the UK, and since then four more colleagues – from the USA, Australia and The Netherlands – have joined us.

Since December 2016 the magazine has been published solely in English.

Each issue now has thousands of readers worldwide.

Many of our readers share the magazine in their companies and among their colleagues so the final number of readers is much higher.

Most importantly the readership covers our target segment – managers in construction companies, bridge designers and engineers, universities and other bridge related experts.

The magazine e-maritime was established in 2018 and its first issue was released on 30 March 2019.

The magazine is published in English. It is going to cover a vast range of topics related to vessels, maritime equipment, ports, docks, piers and jetties - their design, construction, operation and maintenance, and various maritime and construction related projects.

The Editorial Board already has two members – from the UK and the Netherlands.

Both magazines are with Open Access with possibility to subscribe (free of charge).

In January 2019 we established their own pages on LinkedIn with constantly increasing number of their followers. Number of subscribers of both magazines is also increasing.

We also know that the readers usually go back to older issues of both magazines.

PPP PROJECT D4R7 IN BRATISLAVA
AN OVERVIEW AND CONSTRUCTION

Patrick Wagner, PORR Bau GmbH

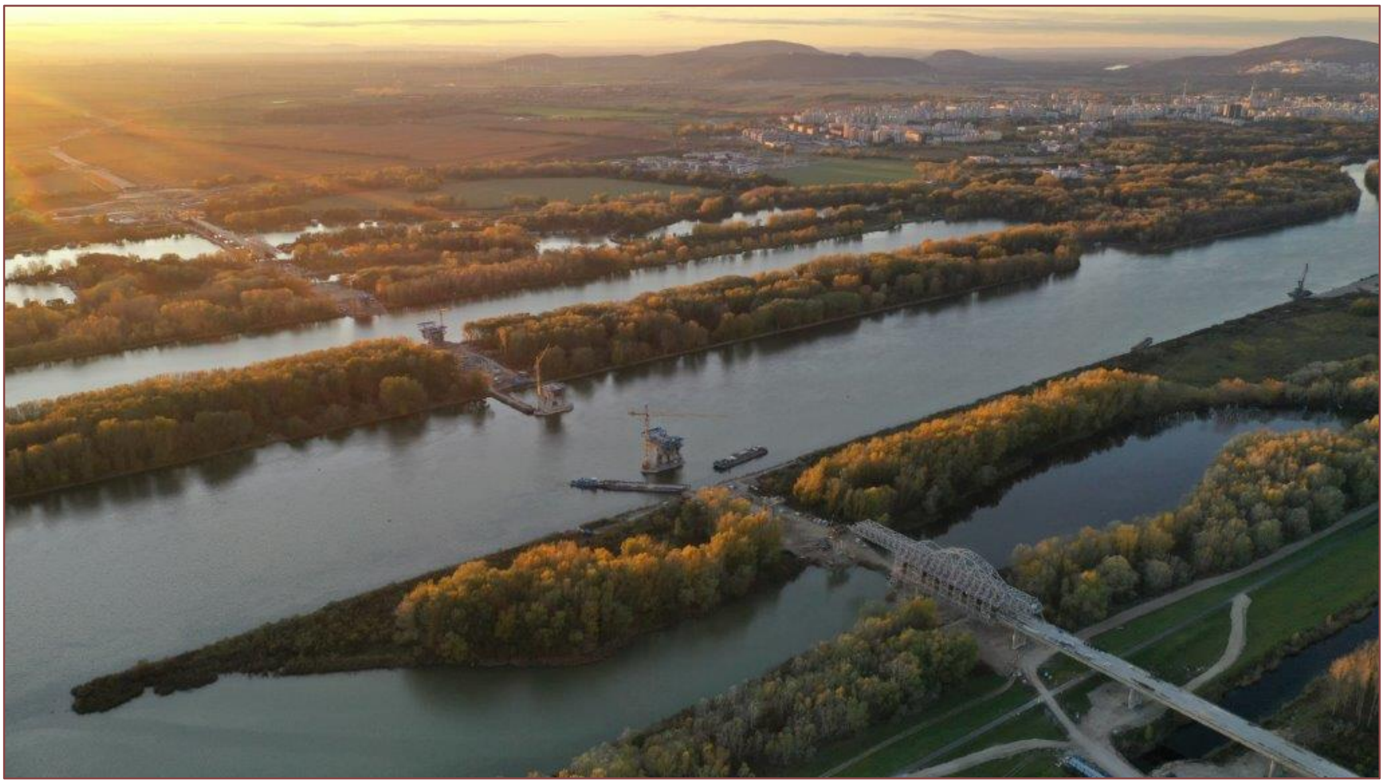

Figure 1: Aerial View of the construction site

INTRODUCTION

The D4R7-Bratislava Bypass is a public private partnership (PPP) project for the design, construction, financing and operation of almost 60km of highway and expressway.

The employer is the Ministry of Transport of the Slovak Republic, and the Concessionaire, Zero Bypass limited (ZBL) is a joint venture (JV) of Cintra, Macquarie and PORR AG.

The design and construction works have been subcontracted to a Construction Joint Venture (CJV) composed of Spanish Ferrovial Agroman (daughter company of Cintra) and Austrian PORR Bau GmbH.

The CJV is established and based in Bratislava and the works are performed as an integrated JV.

GENERAL INFORMATION

The project includes 27km of highway (D4) and approximately 32km of expressway (R7), and has an estimated construction period including the design phase of 53 months.

The required land and the building permits for the works have been provided by the client.

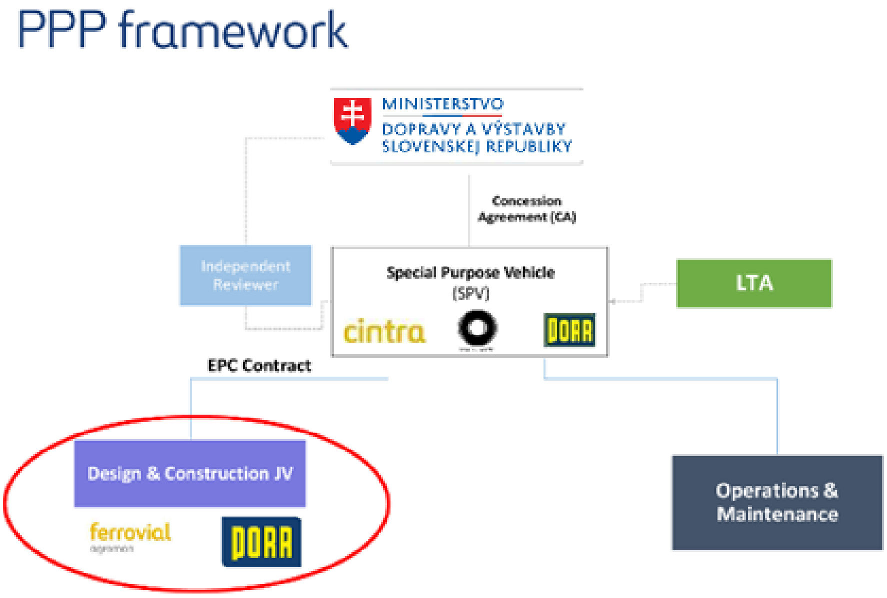

Figure 2: Project Organization

The entire scope of works is not only the construction of almost 60km main alignment, but also requires construction of 14 intersections, more than 100 bridges, and the huge Danube Bridge which has a total bridge surface of more than 100,000m^2, as well as all required safety measures, concrete crash barrier, steel guards, the entire dewatering system, noise barriers, and Intelligent Traffic Systems.

During the design phase of the main alignment the designer optimized the gradient in order to reduce the amount of imported material needed as the alignment is mainly constructed on embankments throughout the entire project.

Even with those design optimizations there was approximately 9 million m^3 of imported embankment fill.

Another challenge in the project was that more than 450 utilities were affected.

Many of these were existing utilities where relocation was required, and the rest were new utilities.

Although cooperation with the utility owners was quite good, the process was nevertheless lengthy.

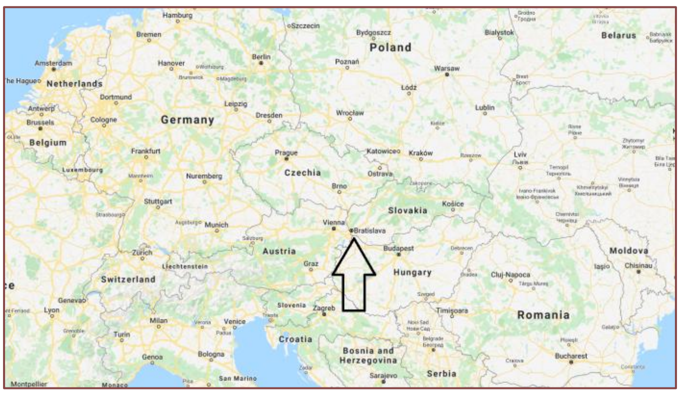

Figure 3: Location of the project

Source: Google Maps

Figure 4: Project Overview

The new highway passes partially through the Natura 2000 area, where it was required to perform so-called compensatory measures which had to be completed prior opening the section 1.

Those measures included mainly grassing of land plots and planting of trees on a total area of more than 145 hectares and an approximately 6km long channel with attenuation structures which regulate the water level.

At the peak of the construction works, more than 1,600 people were engaged in the project.

The main structure within the Project is the Danube Bridge with a total length of approximately 3,000m and a width of 35m.

It will be described in detail below.

- Main figures:
    - 100,000m² bridge surface
    - 18,000m piles 1200/1800mm diameter
    - 110,000m³ concrete
    - 22,000 tonnes reinforcement
    - 3,700 tonnes prestressing steel

DANUBE BRIDGE – APPROACH BRIDGES

The crossing has a total length of approximately 3,000m and consists of two approach bridges and two main bridges integrated into a seamless single crossing of the Danube River.

The cross section of the bridge (shown in Figure 6) is a single hollow concrete box girder with a width of approximately 9m and cantilevered decks providing an overall width of 35m.

The deck cantilevers are supported every 5m with precast concrete struts.

The approach bridges are constructed with a movable scaffolding system (MSS).

The regular span on the east side is 70m and the east approach has 18 spans giving a total length of 1,250m.

The west approach has 12 spans of typical length 67.5m and a total length of 750m. The cross section is constructed in two stages.

The first stage is the construction of the central spine with a width of 14.4m constructed with a MSS.

The standard cycle for the regular span on the east and on the west side is 16 calendar days, mainly without night shifts. To achieve this cycle a large amount of reinforcement pre-fabrication is required.

The reinforcement for the webs and bottom slabs is pre-fabricated in moulds at the site yard.

Only the reinforcement for tensioning blisters and the top slab is installed in-situ.

Even the empty ducts for post tensioning are already temporarily fixed in the webs, but not in their final position. This is adjusted after the reinforcement is installed.

Approximately 1,000m³ of concrete is needed for the casting of one regular span. Bottom slab, webs and top slab are poured in a continuous process which lasts approximately 24 hours.

After the concrete has reached its required compressive strength, the structure is post tensioned. In the longitudinal direction tendons with 31 strands each are generally used.

The segment above the pier, the “zero segment”, is constructed in advance of construction of the central spine with the MSS.

This method has two advantages. Firstly, the most complicated element within one span is done in advance and is therefore not critical in regards of time.

Secondly, the MSS is supported on top of the zero segment and thus not required to be supported off the pile cap which reduces the risk of idle time due to a flood of the Danube.

Figure 5: Construction of the Zero Segment

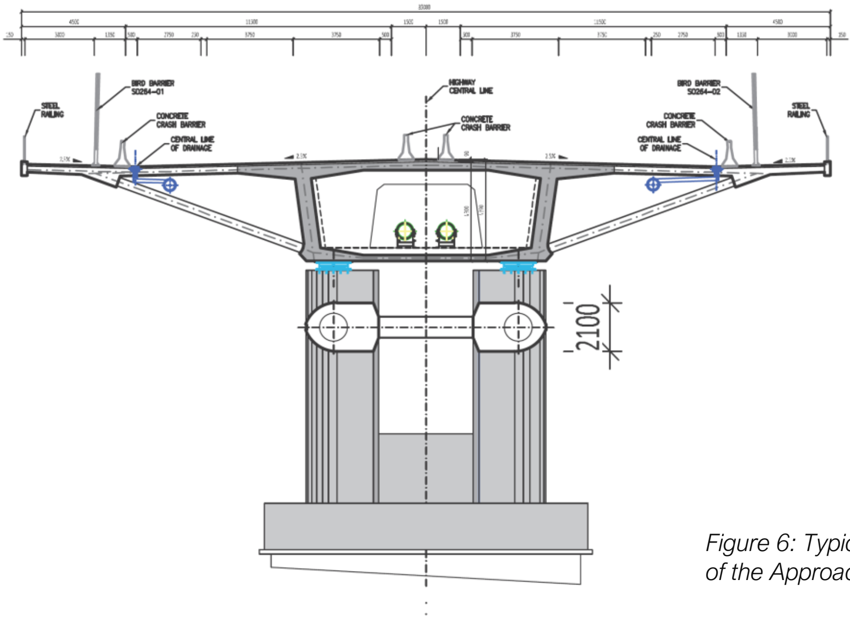

Figure 6: Typical Cross section of the Approach Bridge

After the central spine construction with the MSS, a second form traveler is used to construct the cantilevered deck wings, adding approximately 10m of width to either side of the spine.

Figure 7: Form traveler for deck wings

During this second stage the pre-fabricated concrete struts are installed.

After the wings are poured and the concrete has reached the required strength, the post tensioning tendons, which are placed every 80cm, are stressed.

These wings are being constructed in 20m lengths with an average cycle time of 5 days.

DANUBE BRIDGE – SPECIAL FOUNDATION

Details of the special foundations for the Danube Bridge main piers are described in a separate accompanying article.

DANUBE BRIDGE – MAIN BRIDGES

Aside from the approach structures, the main crossing is further split into two independent bridges. Both bridges are constructed using the balanced cantilever method.

The Kayak Bridge has a main span of 210m and the Danube Bridge has a main span of 170m long. The total length of the Main Bridge is 900m.

The cross section for both bridges is in principle the same as for the approach bridges, which

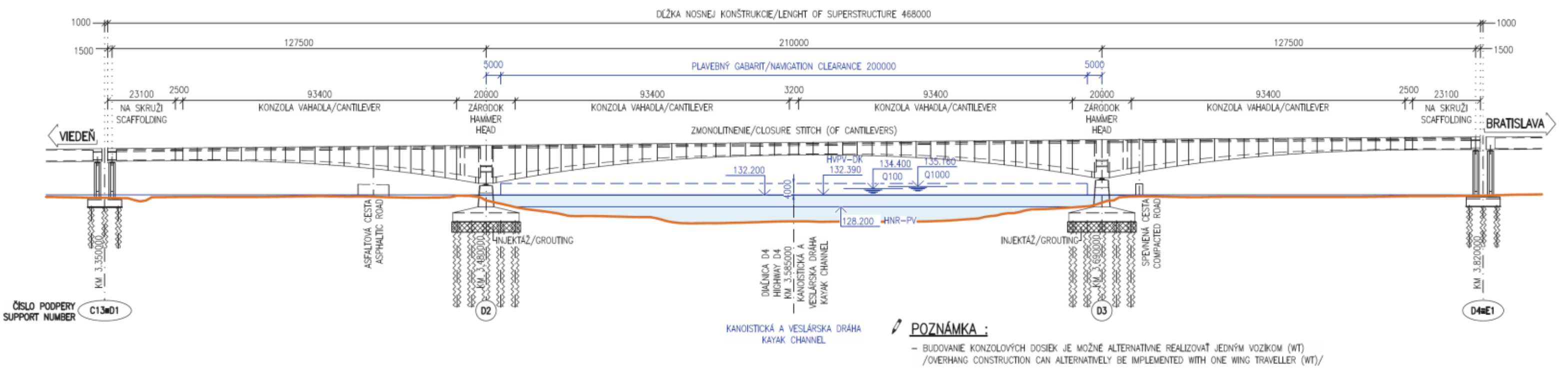

Figure 8: Longitudinal section of Kayak Bridge

← *Figure 9: Inner Formwork of MSS*

↗ *Figure 10: Concreting of the superstructure in Kayak Channel*

means a single hollow concrete box girder with cantilevered wings giving a total width of 35m.

However, in the case of the main crossing, the depth of the central spine is variable and much deeper at the pier locations.

The piers at the Kayak Bridge are situated at the channel banks and founded on 30 piles each with a diameter of 1,800mm.

The superstructure hammerhead has a length of approximately 20m.

The balanced cantilever has 20 segments on both sides of the pier with lengths between 3.8 and 5.0 meters.

The Danube Bridge has two piers situated in the river with 26 piles at each foundation.

The superstructure hammerhead is also approximately 20m long and the balanced cantilever system has 16 segments excluding the closure segment.

The segment length is also between 3.8 and 5.0 meters.

Four pairs of form travelers are used at the same time for the construction of the balanced cantilever superstructures.

All travelers are designed for a fresh concrete weight of 450 tonnes and they are expected to achieve a regular cycle of 7 days after an initial learning curve.

The concrete used is a C50/60 mix, which is delivered from two different batching plants procured for the Project, one for the east side and one for the west side.

The Project Works are progressing well. Many of the separate activities within the Project such as provision/relocation of utilities and provision of local amenities (the Transfer Elements) have already been handed over to the relevant Authorities.

The first substantial section of the Project to be handed over to the client is a 28km stretch of the R7 expressway, which will be opened to traffic in spring 2020.

The completion of the construction works is estimated for summer 2021.

Video 1: Construction Progress in December 2019

Click on the image to play the video

More information about the project

https://www.d4r7.com/en

DESIGN OF THE DANUBE CROSSING

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INTRODUCTION

The technical preparation of the project execution started in June 2016, when consortium ZBL (Zero Bypass Bratislava) concluded the contract on design and construction of D4 Highway and R7 Expressway (so called EPC Contract) with company D4R7 Construction s.r.o. (D4R7), a subsidiary of FERROVIAL AGROMAN, S.A. and Porr Bau GmbH).

The core of the Design Team for the development of the proposal is formed by DOPRAVOPROJEKT Bratislava (main consultant), TORROJA INGENIERÍA, S.L. Madrid, BGG Consult Vienna, CEMOS Bratislava and SHP Brno.

The public procurement of the concession allowed for changes from tender documentation to optimize the technical solutions and obtain the most efficient tender bid. In previous years, both parent companies of the contractor's consortium participated in similar or larger traffic infrastructure projects in different countries where alternatives to the technical solution were applied.

Assessment of the proposed alternatives to the technical solution were considered under the optimization of the "4 E" principles: Efficient (functionally and structurally), Economic (both during the construction and the operation), aEsthetic (large part of the project is in highly urbanized surroundings), Environmental (considerable part of the project alignment crosses natural country site with the highest conservancy class and European significance – NATURA 2000) solutions.

The technical proposal, which forms part of the Concession Agreement, resulted in extensive changes to the project – changes in the vertical alignment and width configuration of the highway and expressway themselves, including interchanges; structural changes of bridges, adjustment of the drainage system, etc. as well as the adjustment of related objects, especially the relocations of existing roads and utilities.

BRIDGES AND STRUCTURES

There are 116 bridges in total on the project, with the overall plan surface equal to 200,000m^2. Approx. half of this area comprises the 3km long crossing of the Danube.

Other structures comprise abutment walls, most of which are formed by concrete revetment – facades of reinforced earth structures with the visible (face) side exceeding 55,000m^2.

Further, 1,092 pcs of large-diameter piles, with overall length 12,300m, are used in bridge foundations.

Significant attention was paid to the design of bridges where precast elements could be efficiently used.

The character of the site suited the use of prefabrication in the construction process which was used as much as possible.

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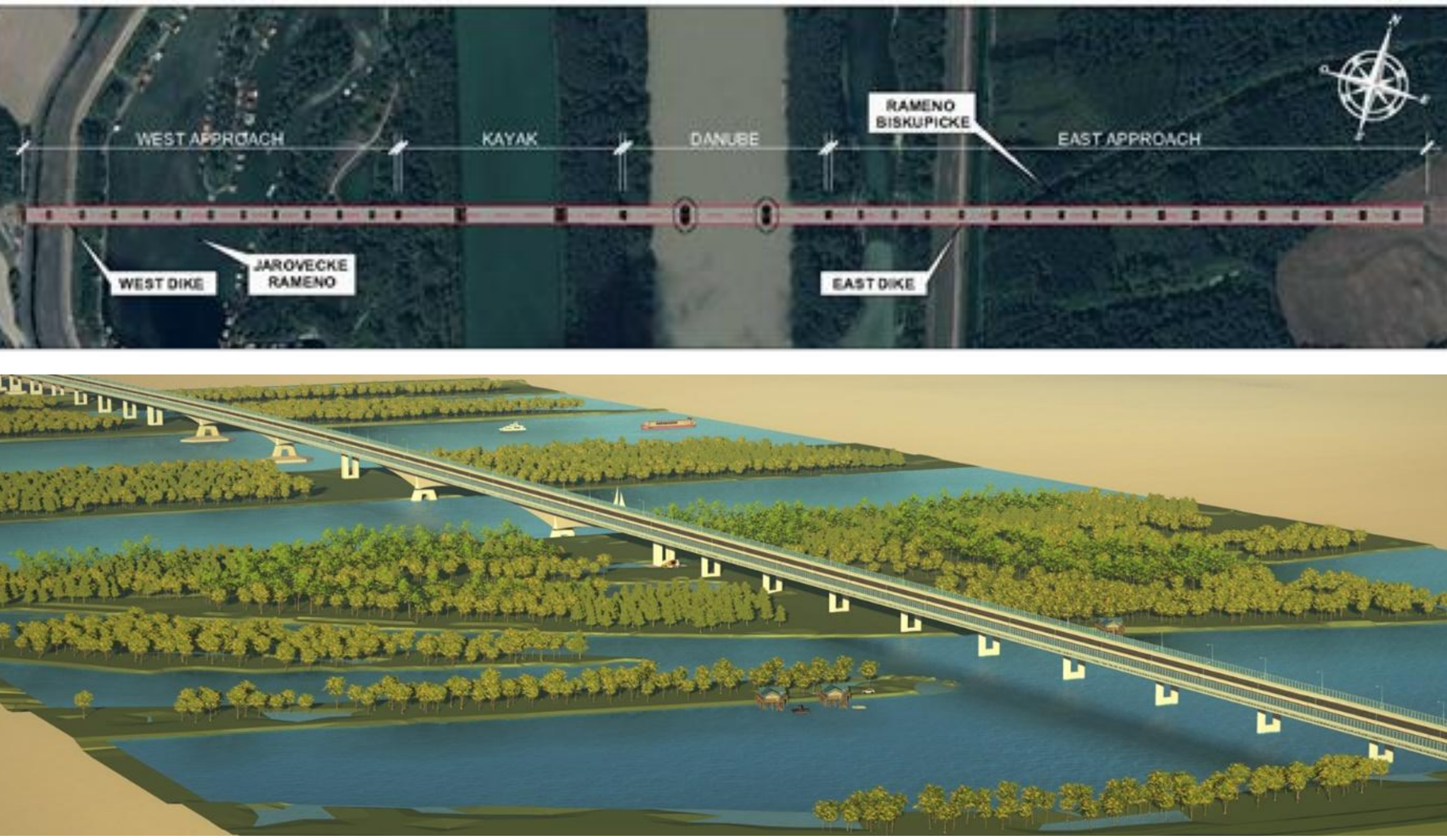


Figure 1: Danube Crossing. Plan View and 3D model

The static and structural optimization resulted in the design of a series of new precast beams of different lengths, heights and I-shaped cross section.

Two types of beams (A and B) were designed in terms of the width of their upper and bottom flange, ranging from 800mm to 1,900mm depending on the height of the beam cross section.

When installed at a spacing of 2.0m, these beams are suitable for road bridges with maximum span of 19m to 39m.

More than 1,000 precast, pretensioned prestressed beams are used to construct 66 bridges - the total length of beams is 32,075m.

DANUBE CROSSING

The Danube Crossing comprises 3km of continuous elevated highway on structure over the rowing - kayak channel, Danube river bed, its floodplain and adjacent areas (Figure 1).

It consists of four statically independent structures:

West Approach includes the approaches spans, crossing of the dike and associated seepage canal on the west shore and the Jarovecké Rameno which is connected to the main watercourse downstream and usually has no river current except in flooding events.

Nowadays it is an area for residential floating houses and recreational water activities.

According to the tender technical requirements, this crossing shall have no more than 5 piers inside the Jarovecké Rameno (at typical water level) and any pier of the bridge shall have a minimum horizontal clearance to the dike and seepage canal (this applies also to East Dike).

This condition implies a minimum span length of 55-60m.

Kayak bridge crosses a completely isolated canal (not connected to main river watercourse nor to the Jarovecké Rameno at typical water level), surrounded by riverside vegetation of rectangular shape 2,000m long and 200m wide.

The channel is used for rowing and kayaking activities and potentially in the future could include sport facilities.

According to the tender technical requirements, the bridge shall avoid any pier in this Kayak Canal and provide a vertical clearance of 4m.

It is the most restrictive requirement for the span arrangement, requiring a clear span of 200m.

Danube Bridge crosses the Danube main watercourse which is approximately 300m wide and 6m deep in this section in normal circumstances.

According to the technical requirements, the bridge shall comply with the navigation clearances of 150m wide and 10m high in highest water level scenario for navigation (132.4m a.s.l.).

East Approach leads from the east bank of the Danube to the east dike and comprises 325m of deep vegetation and frequently flooded area.

After the dike, for a short distance (225m) there is the seepage canal and the last stretch of Biskupické Rameno which is heavily skewed to the bridge alignment.

According to the tender technical requirements, this former canal shall be restored as a part of the environmental compensatory measures and no pier columns shall be located within it.

This latter requirement, and the restrictions resulting from adjacent dike and seepage canal, are the governing constraints in East Approach for pier locations.

In fact, the skewed crossing requires a span of 70m.

The next 650m, outside of the floodplain area, is a protected forestall area under the Natura 2000 declaration.

The tender technical requirements require the bridge length to be extended with enough vertical clearance for wildlife crossing, leaving an additional safety margin to the protected area.

BRIDGE CROSS SECTION

According to the tender technical requirements, the functional cross section comprises the following:

- 2 + 2 traffic lanes with widened shoulders allowing 3 + 3 lanes in an emergency scenario.
- Two lateral 1.5m corridors between safety barriers and bird barriers.
- Two lateral user paths 3.0m wide for pedestrians (one side) and cyclists (other side).

This configuration requires a minimum cross section width of 34.5m, which forms the most relevant design parameter for the structural assessment.

In the first section of the West Approach, the cross section is even slightly wider due to a merging lane onto the bridge (right side).

PROJECT SPECIFIC TECHNICAL REQUIREMENTS

All the structures have been designed in accordance with Slovak Technical Standards (STN, ON) and Regulations, specially the European Standard Eurocodes and their Slovak National Annexes.

Specific project requirement has been:

- All bridges have been designed for the design life category 5 – informative design service life of 100 years, in accordance with STN EN 1990.
- Construction loads for balanced cantilever construction method (STN EN 1991-1-6).
- Vessel collision: 20,000kN longitudinal impact for a Class VII ship, in accordance with CEMT classification system (STN EN 1991-1-7).
- Seismic acceleration load: A design seismic acceleration of $0.63 m/s^2$ has been considered (STN EN 1991-8 parts 1 and 2).
- Selfweight special consideration in constructive balanced situations (STN EN1990).
- Pressure of the flowing water on piers in the flow (STN EN 1991-1-6).

Danube Crossing bridges have been designed with longitudinal and transversal prestressing.

Two decisions have resulted in durability improvement and economy:

- A specific analysis of the nonlinear transverse distribution of longitudinal stresses in the typical section of the deck has been performed, due to the 35m width of the deck.

  This study has permitted to significantly reduce the required longitudinal prestressing quantity.

  As a result, it has been possible to design all the longitudinal prestressing within the concrete cross section, not being necessary to specify external prestressing, as in other similar bridges.

- Considering the transverse behavior of the bridge, it has been necessary to specify the transverse prestressing with bonded tendons using flat plastic ducts.

  Protection level PL2 ducts have been designed, following the prescriptions of Fib bulletin 33 (Durability of post-tensioning tendons) and Fib Model Code 2010.

DANUBE CROSSING DESIGN PRINCIPLES

In order to develop a satisfactory and competitive cost-effective proposal that is fully in line with the project requirements, the following guiding principles were followed:

a) Harmonized Solutions in each of four bridges of the 3 km Crossing.

b) Geometrical adjustments. Crossing length in the West Approach was adjusted to the left side of the seepage canal, avoiding unnecessary extra length in structure.

   In addition, adjustment of the road elevation of the Crossing was undertaken to comply with the required vertical clearances which also provides environmental benefits (visual and bird impact).

c) Construction strategy. Due to the time constraint for construction phase in the project, it was foreseen to construct each bridge of the Danube Crossing with separate construction equipment, in an independent and simultaneous execution, in such a way that the finishing of one bridge would not put at risk the finalization of any other one.

d) Span arrangement. Mainly to optimize construction productivity in the Approach Bridges, all spans were harmonized to the same length.

   The review of the constraints and after some preliminary structural assessments, it was proposed to construct the East Approach as a 1,250m jointless bridge with 16 identical straight spans 70m long (length governed by skewed Biskupické rameno).

   The same exercise in the West Approach led to a continuous bridge with 10 identical straight spans 67.5m long.

   Due to edge constraints, side spans of Approach Bridges are not exactly within the optimal ratio for a typical span.

   This inconvenience (i.e. additional PT tendons in these side spans) is by far compensated by the benefits of the harmonization of typical spans.

   For the main bridges (Kayak and Danube), the required minimum main span lengths were fixed to 170m and 200m.

   The review of constraints (distance between spans and connections with approaches), led to two options:

   - Option 1: 2 bridges / 3 spans each (130m+210m+130m) (130m+170m+130m).
   - Option 2: 1 bridge with 3 main spans + 2 side spans (120m+3x220m+120m).

   The first option prioritized the “minimum span length“ criteria (assumed as the most cost efficient solution for bridge decks) while the second one prioritized the “harmonization“ criteria.

   A comparison was made (including bearings, piers and foundations in river, unbalanced deck sections to be built on ground, etc...) and after some discussions, Option 1 was adopted.

e) Structural form of bridges. The first approach to the structural form of bridges was to use, in all of them feasible (later confirmed), the post-tensioned concrete box girder as the optimal outcome from cost and durability point of view:

- For the main bridges (Kayak and Danube) The minimum required span length (200m in Kayak and 170m in Danube) are compatible with the bridge type of "cast in situ" concrete box girder built using the balanced cantilevered method from the main piers.

  Hence it was not necessary to use a cable-stayed bridge type that would have resulted in a less competitive solution (for such span lengths).

  Also, a girder bridge form appears to be more suitable in the flat vegetated natural countryside.

- For Approaches the required span length (approx. 70m) is well suited with a PT box girder that could in principle be constructed with one of the following construction methods: precast segmental construction; incremental launching; movable scaffolding system (MSS).

  The first two methods were discarded as they are not optimal for this arrangement: precast segments would have to be erected in cantilever (70m is too much for span-by-span erection) and would be slower than other options.

  It also would have logistics issues with precast yard location (shore) and segment transportation.

  Regarding incremental launching, it is a significant length (especially in East Approach) to be launched only from one side (abutment) and uphill.

  The MSS method was selected because the currently available equipment in the market allows such span length (70m) and the bridge configuration justified this ancillary investment with many repeated identical spans in a straight alignment. Local references of similar bridges were also a key decision factor [4].

f) Structural form of cross section. Two options were studied:

- Two decks (two parallel and separated box girder bridges).
- One deck (one single bridge 35m wide single cross section).

The first option (two decks) has a typical cross section width of 17.5m for each bridge to be built in one phase.

As disadvantages, it requires twice the number of equipment (and construction teams, etc...) and potential clashes in the median for the second deck equipment.

The second option (one deck) requires a sequential construction; first to be built is the core section of the box girder by means of a MSS (approaches) or traveler (main spans) and afterwards, a wing traveler completes the second stage of transverse cantilevers (overhangs).

The overhangs are supported on the core box girder by means of diagonal struts that are more effective than structural transverse ribs (for this overhang size) or a big multi-cell box.

This option (one evolutive deck) was selected because, as the structure is concentrated in one single element instead of two, it is the most effective for construction (less equipment and working cycles) and design (structural optimization of decks, piers and foundations).

This transverse cross section arrangement (core box girder with struts), with origins in some bridges built in Germany some decades ago, is becoming a trend in similar recent projects around the world, with also some Slovak examples.

Finally, for aesthetical purposes and once assessed its feasibility without relevant penalization in effectiveness, the geometry of the cross section and associated details (as struts spacing and shape) has been harmonized between approaches and main bridges.

g) Type of prestressing. Internal PT (bonded) was preferred instead external (unbonded).

The reasons are: more eccentricity is possible in the cross section than external (inside the box); external PT requires to be executed after the concrete girder construction (delays); ducts and infill less expensive and less concerns about durability.

It has, as disadvantage, a more difficult definition inside the concrete due to geometrical reasons.

In the Approaches, it has been preferred overlapping of PT tendons instead of couplers; 50% of PT tendons are overlapped in each blister, one at each side of the pier to prevent risk of local overstressing in blister.

Couplers require more time for installation before concreting the segment. It also has severe consequences for remediation in case of failure (partial demolition of concrete slab).

h) Spherical Bearings. Spherical Bearings (Maurer) have been selected instead of the typical Pot Bearings for the higher working stress that allows higher capacity for the same size.

It was almost mandatory at the main piers of Kayak and Danube Bridge due to the huge vertical loads (ULS 210MN, diam. 2.5m).

On the other hand, they have longer service live; for such bearing size and loads, bearing replacement operation is a very important aspect of design.

All Piers at Danube Crossing (including main piers of Kayak and Danube Bridge) have been designed to allow the bearing replacement operation.

i) Earthquake. Recent updates in the Slovak Code have led to require earthquake structural assessment in almost the entire country (previously most of the country was below the low seismicity threshold), and in addition, local response spectrum is more demanding than general EU curves.

It has two impacts in design: higher requirements for Kayak and Danube main piers (due to the associated mobilized mass), and in East Approach Bridge, 1,250m long, it required four reinforced central fixed piers and a more refined methodology for its earthquake assessment.

j) Substructure.

Main bridges (Kayak and Danube). The deck-pier connection was designed as articulated in service life (fixation during cantilever construction is achieved by means of an adjacent temporary pier for unbalanced forces).

This releases moments to the foundation due to unbalanced forces in construction (cantilever or overhangs stage) while preventing uplift risks compared to double walled pier scenario.

The piers have a hydrodynamic shape to minimize the water drag in flood events.

The hydrodynamic shaped pile-cap of the Danube main piers are located at water river level and piles are extended to the riverbed.

This configuration gives a robust response to a ship impact event, as well as facilitates the construction of the substructure in the river.

Approaches (West and East). Piers in Approaches comprise two independent slender pier shafts with no connection at top. This elegant arrangement meets hydrodynamics requirements while is a cost-effective solution for construction. The deck construction is achieved by building a Zero Segment in advance of the MSS arrival, which is temporarily fixed to the pier columns.

DANUBE CROSSING. DESCRIPTION OF THE SOLUTION ADOPTED.

The Danube Crossing consists of four bridges supporting a 4-lane motorway and pedestrian and cyclist footways across the Danube and adjacent waterway area, with a typical bridge width of 35 m.

The Crossing also carries water pipes and other utilities.

Along the entire Crossing, a bird barrier is provided on both sides.

The cross-section geometry of all bridges meets the required space requirements and the shape of bridges corresponds to each other.

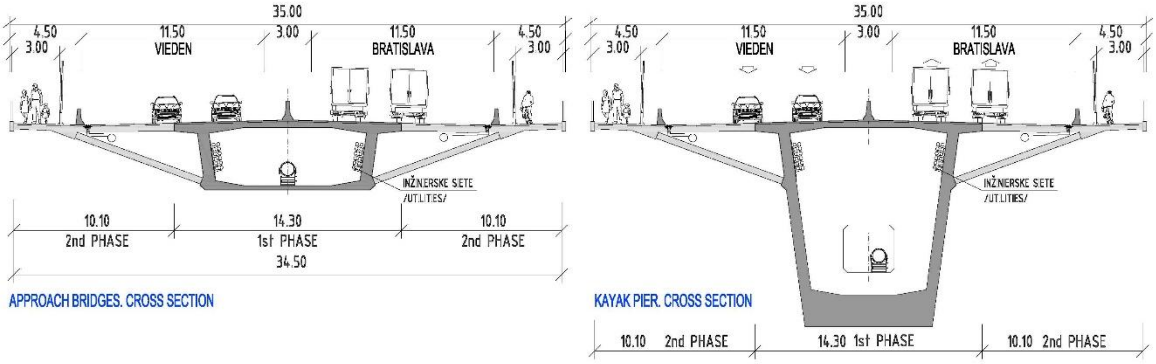


Figure 2: Cross section

The bridge superstructure is a single pre-stressed concrete box girder with lateral long overhangs supported by precast reinforced concrete struts (Figure 2).

The bridge over Jarovecke rameno (West Approach Bridge)

This bridge carries the D4 motorway over the west seepage channel, dike and the Jarovecké rameno.

The bridge superstructure comprises a continuous single concrete box girder, 4.3m constant deep, with 12 spans (53.0+10x67.5+52.5 m) and total length of 786.9m.

The superstructure is pre-stressed both in the longitudinal (two phases) and transversal direction.

Each longitudinal PT phase comprises 8 number of 31-strand cables.

In the first phase, the core of the superstructure (box with short overhangs) is built by the MSS technology.

At this stage of the construction, the first part of the longitudinal tendons will be pre-stressed in each individual span.

The construction of the superstructure core was designed by the span-console system and is divided into 13 stages.

In the second phase, the overhangs are built. The precast struts are spaced, the concreting of the overhangs executed using a wing traveler to complete the full width. This phase comprises pre-stressing of top slab transverse tendons and the second phase of longitudinal tendons, which prevents tension stresses in the overhangs.

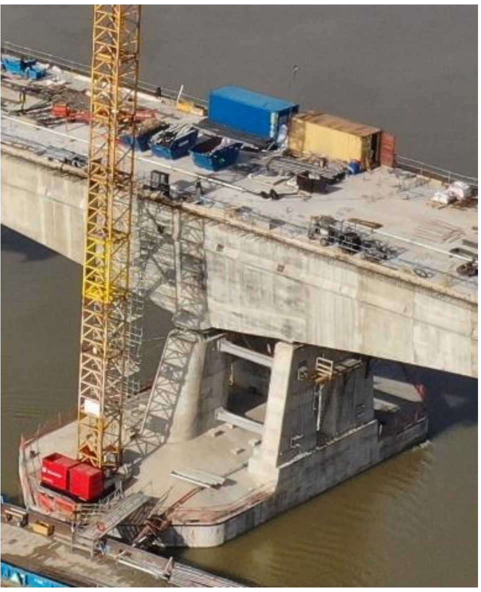
The substructure of the bridge consists of one abutment, eleven intermediate piers and one joint pier with the next bridge structure – the Kayak bridge.

The deck is fixed longitudinally only to the 3 central piers, while is transversally fixed at all supports.

Piers are designed as a pair of hydraulically-shaped column shafts interconnected by a wall at their base.

The top elevation of this wall is the same for all bridges. The substructure is founded on 1.20m diameter piles.

Figure 3: Construction aerial view (February 2020)



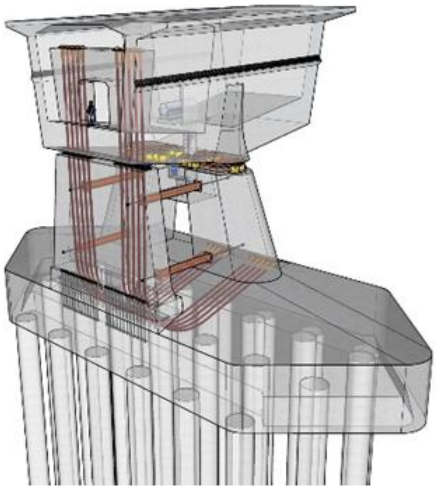


Figure 4: Temporary support assuring the stability of the balanced cantilever during construction (left Photo Danube bridge, middle scheme Danube bridge, right scheme Kayak bridge)

The bridge over Kayak channel (Kayak Bridge)

This bridge carries the D4 motorway over the Kayak Channel.

The bridge superstructure comprises a continuous single concrete box girder with 3 spans (130+210+130m) and a total length of 468.0m.

The section depth varies from 4.3m (lateral spans and middle of main span) to 13.0m at the main piers.

The bridge construction methodology is balanced cantilevered construction from the main piers.

The continuous core box girder (1st stage) is constructed from two starting segments (hammerheads) by individual segments symmetrically erected in relation to the pier axis.

Stability of the balanced cantilever is provided by a temporary support in the external spans (Figure 4).

After casting each segment, the section is prestressed by top slab longitudinal cables (cantilever tendons). The unbalanced deck segments at the end spans are constructed on temporary scaffolding. End segments and both balanced cantilevers are connected by in–situ segments.

After completing the construction of box girder core section, the post–tensioning bonded longitudinal tendons in the bottom slab are prestressed (continuity tendons).

Afterwards, precast struts are fitted on both sides of the box girder and the transverse cantilevers of the deck slab are concreted (2nd stage).

After top deck slab concreting and curing, the top slab is prestressed by means of prestressing tendons in the transverse direction.

In the last stage, the complete section is longitudinally post–tensioned by tendons within the top and the bottom slabs of the box section core (3rd phase of longitudinal prestressing).

The substructure comprises two lateral supports shared with adjacent bridges (West Approach and Danube bridges) and two intermediate main piers.

Main piers are designed as a pair of inclined pier shafts embedded in the foundation block. The top of the pier shafts is transversely connected with a crossbeam 2.50m deep, creating a frame. Spherical bearings are placed on top of the pier shafts.

The substructure is founded on 1.80m diameter piles.

The deck is fixed longitudinally only to one of the principal piers, while transversally is fixed to all supports.

The bridge over Danube watercourse (Danube Bridge)

This bridge carries the D4 motorway over the Danube River.

The bridge superstructure comprises a continuous single concrete box girder with 3 spans (130m+170m+130m) and a total length of 430m.

The section depth varies from 4.3m (lateral spans and middle of main span) to 10m at main central piers.

The bridge construction methodology is balanced cantilevered construction from the main piers.

The continuous core box girder (1st stage) is constructed from two starting segments (hammerheads) by individual segments symmetrically erected in relation to the pier axis. Stability of the balanced cantilever is provided by a temporary support in the external spans.

After casting each segment, the section is prestressed by top slab longitudinal cables (cantilever tendons).

The unbalanced deck segments at the end spans are constructed on temporary scaffolding. End segments and both balanced cantilevers are connected by in–situ segments.

After completing the construction of the box girder core section, the post–tensioning bonded longitudinal tendons at the bottom slab are prestressed (continuity tendons).

Then, the same procedure follows to terminate the superstructure as it is described above, for the Kayak bridge.

The substructure comprises two lateral supports shared with adjacent bridges (Kayak and East Approach bridges) and two intermediate main piers.

Main piers are designed as a pair of inclined pier shafts embedded in the foundation block.

The top of the pier shafts are transversely connected with a crossbeam 2.50m deep, creating a frame.

Spherical bearings are placed on top of the pier shafts. The substructure is founded on 26 piles of 1.80m diameter.

The deck is fixed longitudinally only to one of the principal piers, while transversally fixed at all of the supports.

The bridge over Biskupicke rameno (East Approach Bridge)

This bridge carries the D4 motorway over the Danube east dike, seepage channel and the Biskupické rameno.

The bridge is a continuous single concrete box girder, 4.3m constant depth, with 18 spans (67.5m+16x70m+65m) and total length of 1251.5m.

The superstructure is pre-stressed both in the longitudinal (two phases) and transverse direction. Each longitudinal PT phase comprises 8 number of 31-strand cables.

In the first phase, the core of the superstructure (box girder with short overhangs) is built by the MSS technology.

At this construction stage, the first phase of the longitudinal tendons is pre-stressed in each individual span.

The construction of the superstructure core was designed by the span-console system and is divided into 18 stages.

In the second phase, the overhangs are built. The precast struts are spaced; the concreting of the overhangs is executed using a wing traveler to complete the full width.

This phase comprises pre-stressing of top slab transverse tendons and the second phase of longitudinal tendons, which prevents tension stresses in the overhangs.

The bridge substructure consists of one shared pier with the adjacent Danube Bridge, 17 intermediate piers and one abutment.

The deck is fixed longitudinally only to the 4 central piers, while is transversally fixed at all supports.

Piers are the same as in West Approach Bridge: a pair of hydraulically-shaped shafts interconnected by a wall.

The top elevation of this wall is the same for all bridges. They are founded on 15 piles with 1.20m diameter.

CONCLUSIONS

PPP D4R7 is a complex and demanding project. With regard to the „open tender“, from which the changes of almost all building objects have resulted, a special situation occurred, whereby project activities at different stages of design documentation – documents for assessment of changes within the process EIA (change of proposed activity), processing of documentation for the need of change of existing building permits (DCCC), detailed design and production-technical documentation (DD, PTD) - were ongoing at the same time together with construction.

Technical solutions and their details have been analyzed in detail by numerous groups of experts.

Many engineers led by the design department of D4R7 Construction and design team of the company DOPRAVOPROJEKT cooperated when designing solutions which have not been used so far in Slovakia.

Top experts from Slovak universities and research institutes (also from abroad) were invited to review such designs.

In addition, the parent companies of the members of contractor joint venture engaged their expert capacities, which independently or together with the Slovak experts confirmed the design and effectiveness of the submitted solutions.

Particularly, the 3-km long Danube Crossing, an exceptional construction project.

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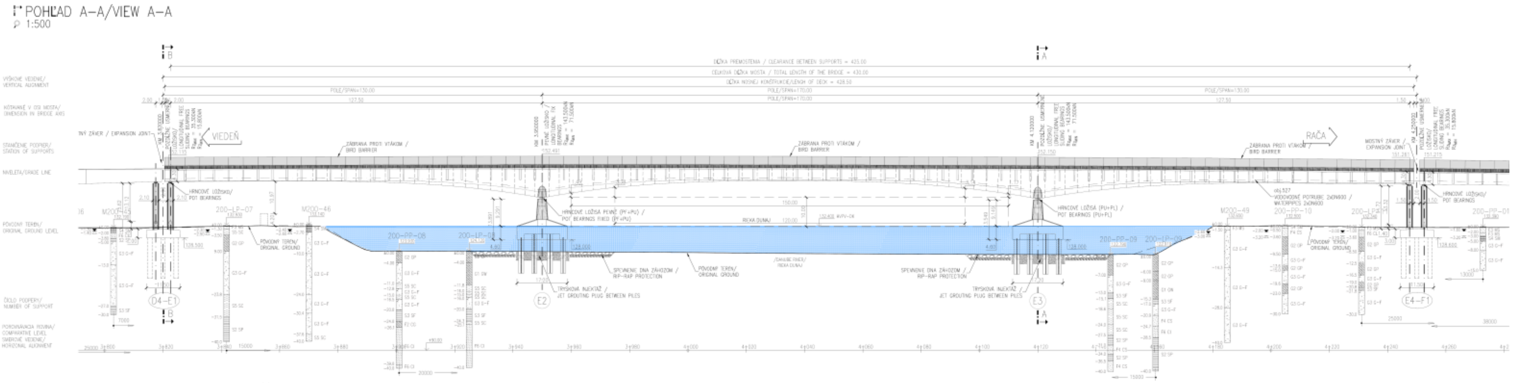
THE DANUBE BRIDGE DRAWINGS – GENERAL ARRANGEMENT



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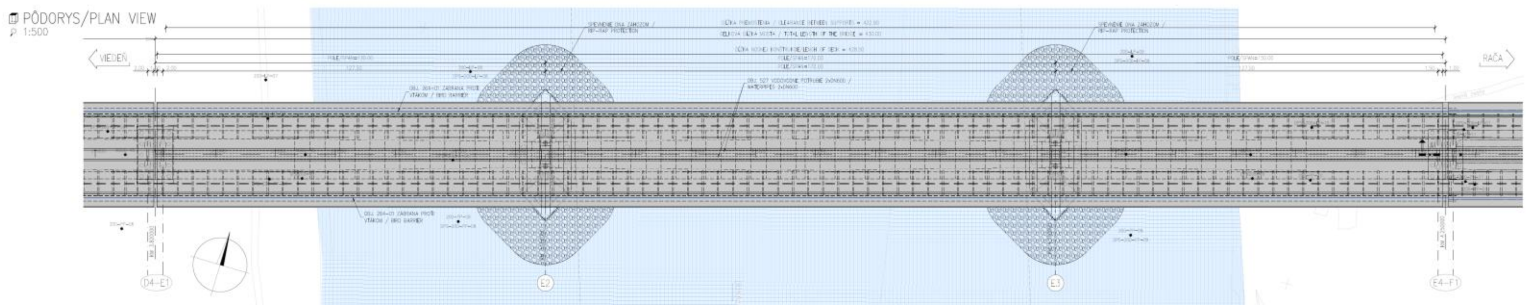

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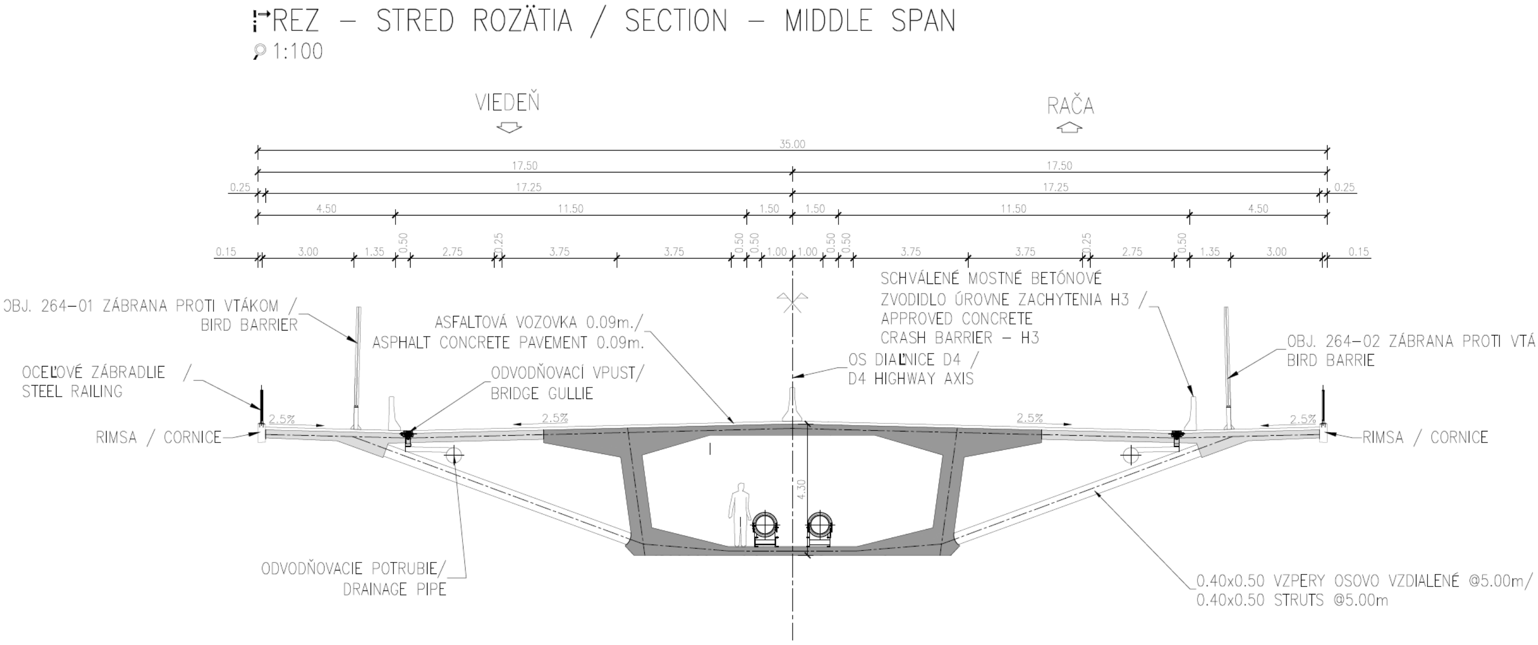

REZ – PILIER / SECTION – PIER

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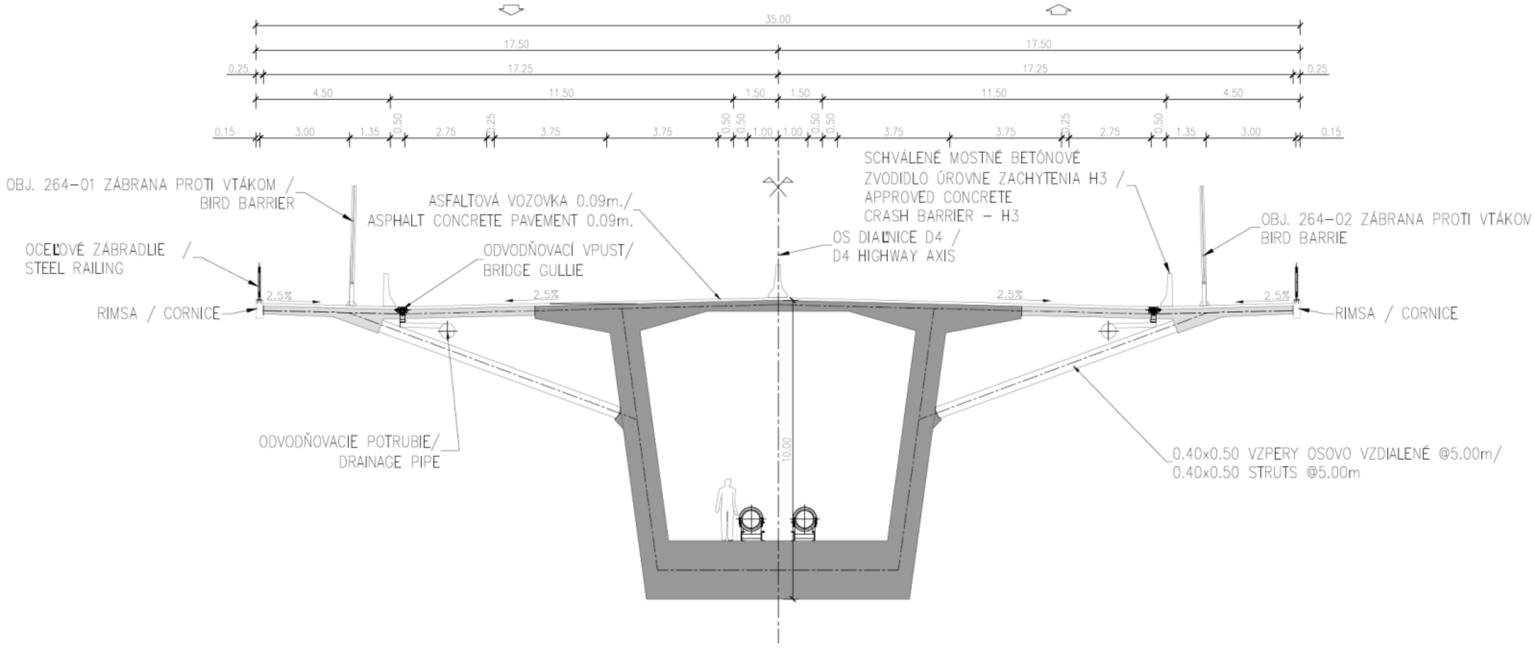

REZ A–A/SECTION A–A

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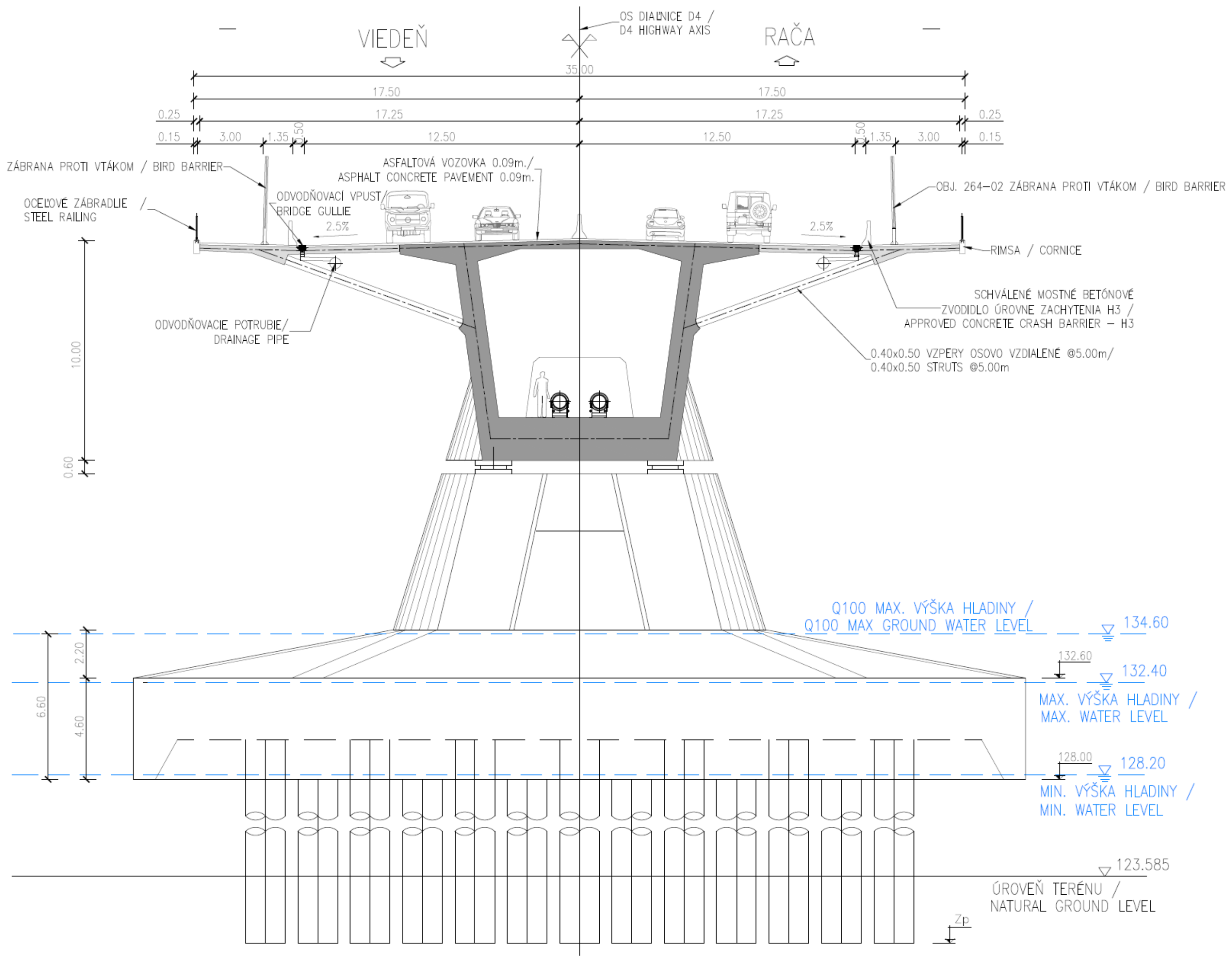

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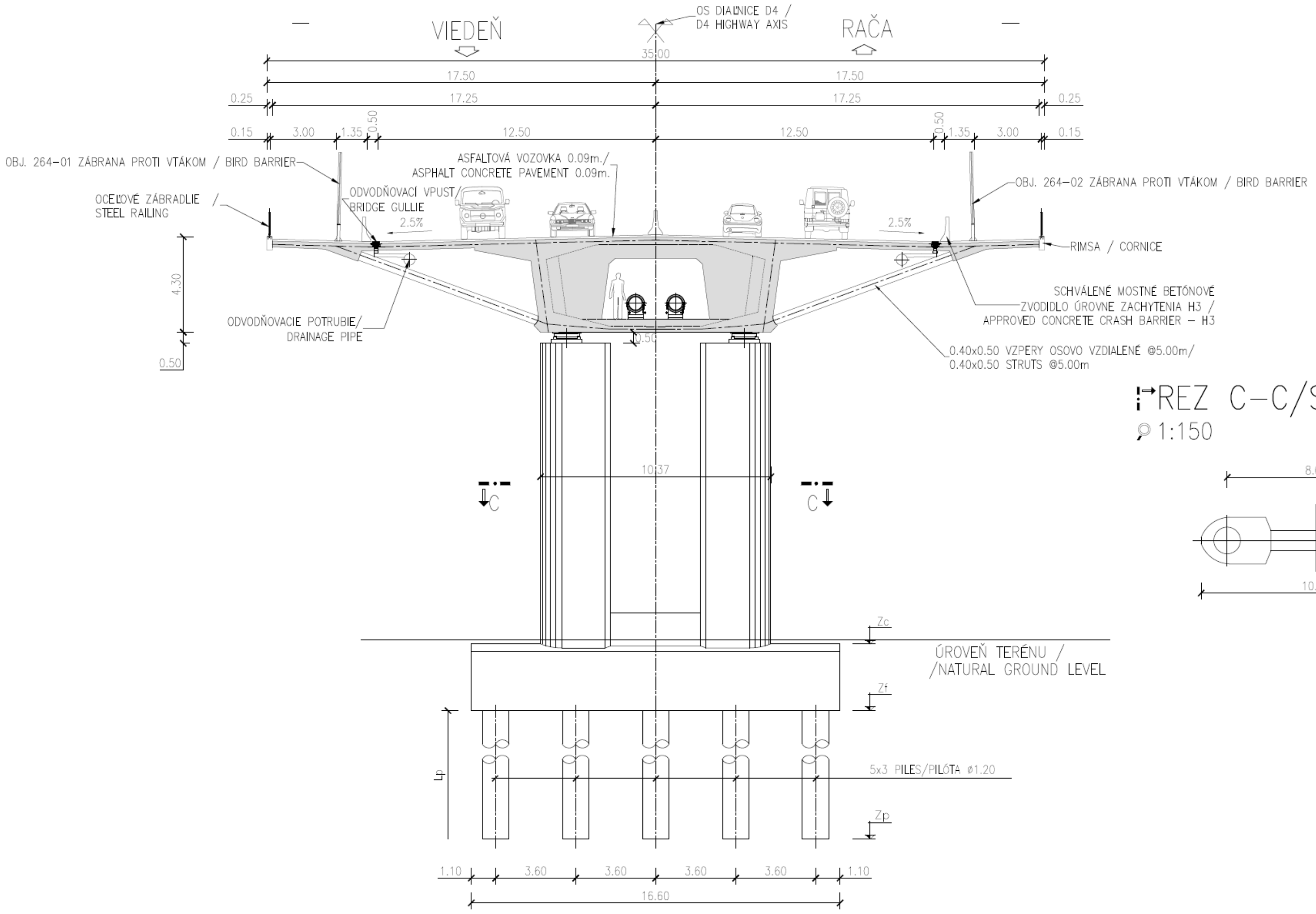

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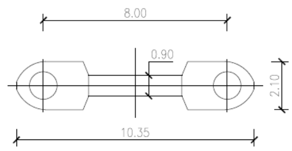


LEGENDA/LEGEND

	JEMNOZRNNÉ SEDIMENTY (FLUVIÁLNE A FLUVIÁLNO–EOLICKÉ), LOKÁLNE TENKÁ VRSTVA PIESKU / FLUVIAL SEDIMENTS (FINE–GRAINED), LOCAL LAYERS OF SAND
	FLUVIÁLNE PIESČITÉ SEDIMENTY / FLUVIAL SAND
	FLUVIÁLNE ŠTRKOVITÉ SEDIMENTY, LOKÁLNE TENKÁ VRSTVA PIESKU / FLUVIAL GRAVEL, LOCAL LAYERS OF SAND
	USTÁLENÁ HLADINA PODYEMNEJ VODZ / STABILISED GROUNDWATER – LEVEL
BH–5–201–01	VRT/ BORE HOLE
DPH–5–201–.	DYNAMICKÁ PENETRAČNÁ SONDA / DYNAMIC PROBING HEAVY
TP–5–201–.	KOPANÁ SONDA / TRIAL PIT
– – – – – – – –	TRVALÝ ZÁBER/PERMANENT OCCUPATION
– – – – – – – –	DOČASNÝ ZÁBER DO 1 ROKA /TEMPORARY OCCUPATION FOR LESS THAN 1 YEAR
– – – – – – – –	DOČASNÝ ZÁBER NAD 1 ROKA (DZ) /TEMPORARY OCCUPATION FOR MORE THAN 1 YEAR

OZNAČENIE POUŽITÝCH MATERIÁLOV/MATERIAL LIST

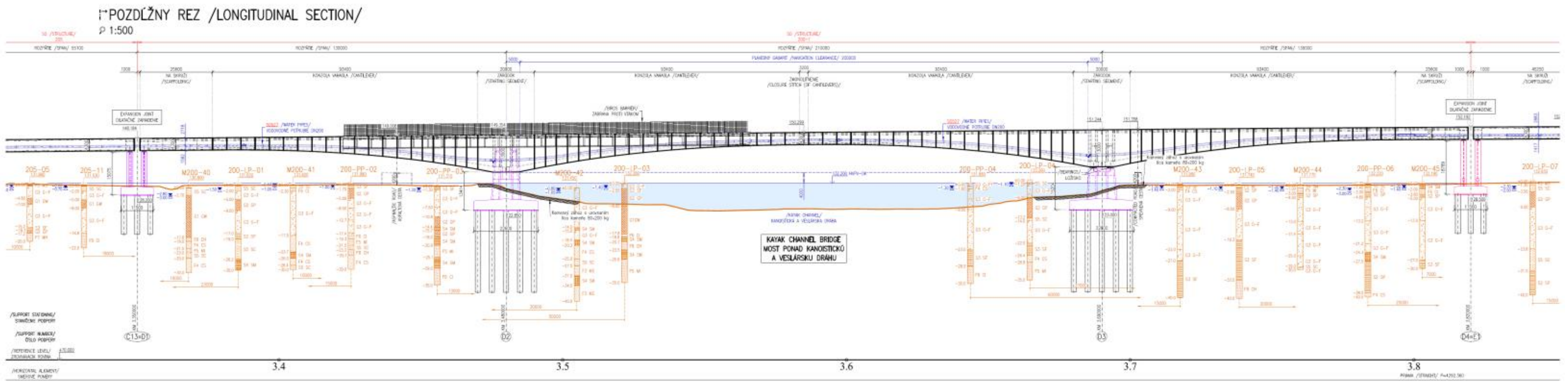
TYP KONŠTRUKCIE/ TYPE OF CONSTRUCTION	PEVNOSTNÁ TRIEDA BETÓNU / STRENGTH CLASSES OF CONCRETE
PODKLADNÝ BETÓN /LEVELLING CONCREATE /	STN EN 206 C12/15 – X0 (SK)
PILÓTY /PILES /	STN EN 206 C30/37 – XC2,XM3 (SK)
ZÁKLAD PILÓT /PILE CAPS /	STN EN 206 C30/37 – XC2,XF2,XM3 (SK)
ÚLOŽNÉ PRAHY A DRIEKY /PIER CAPS AND PIER COLUMNS /	STN EN 206 C30/37 – XC3,XD1,XF2(3) (SK)
LOŽISKOVÉ BLOKY /BEARING BLOCKS /	STN EN 206 C35/45 – XC4,XD3,XF4 (SK)
KOMOROVÝ NOSNÍK A KONZOLY /DECK BOX GIRDER AND OVERHANGS /	STN EN 206 C50/60 – XC4,XD1,XF2 (SK)
PREFABRIKOVANÉ PODPERA /PRECAST STRUT /	STN EN 206 C45/55 – XC4,XD1,XF2 (SK)
RIMSY /CORNICE /	STN EN 206 C35/45 – XC4,XD3,XF4 (SK)

POZNÁMKA: PRE HODNOTY MODULOV PRUŽNOSTI JEDNOTLIVÝCH PEVNOSTNÝCH TRIED BETÓNOV JE NUTNÉ SPLNIŤ USTANOVENIA V ZMYSLE STN EN 1992–1–1 (ČL. 3.1.3, TAB. 3.1)/
IT IS NECESSARY TO FULFILL FOLLOWING PROVISIONS OF 1992–1–1 (ARTICLE 3.1.3, TABLE 3.1) FOR VALUES OF ELASTICITY MODULUS OF PARTICULAR CONCRETE STRENGTH CLASSES/

PRE PRÍSTUPOVÉ SCHODISKÁ , ŽLABY A INÉ DETAILY PLATIA MATERIÁLY PODĽA VL4/
FOR APPROACH STAIRS, CHANNELS AND OTHER DETAILS ARE VALID MATERIALS ACCORDING VL4)/

BETONÁRSKA VÝSTUŽ /REINFORCING STEEL /STN EN 1992–1–1 – B 550B, fyk=550MPa, TRIEDA ŤAŽNOSTI "B"

THE KAYAK BRIDGE DRAWINGS – GENERAL ARRANGEMENT



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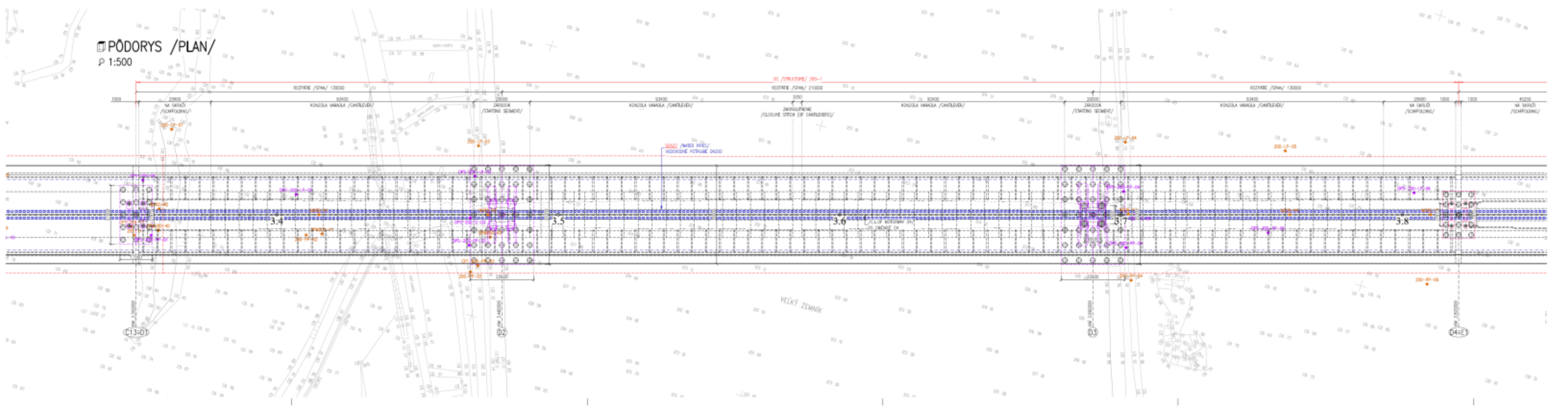

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PRIEČNY REZ A–A /CROSS SECTION/

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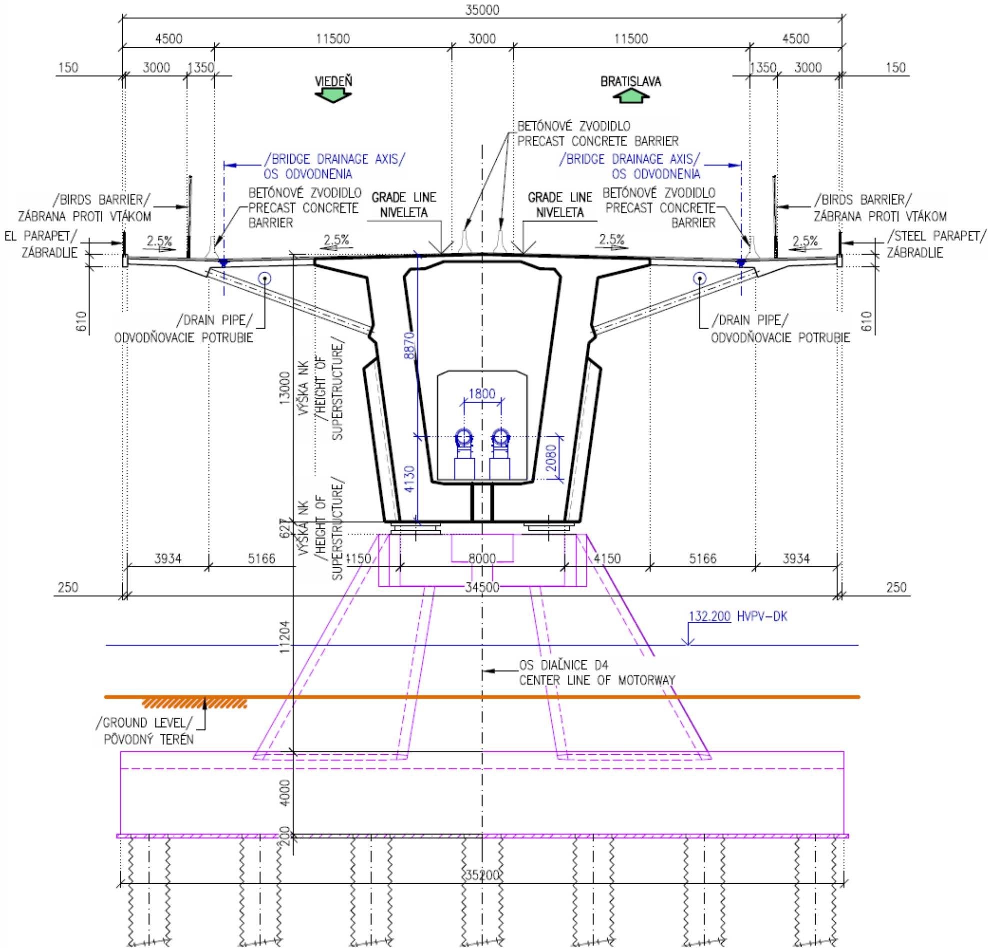
S0200–1 – REZ NAD PILIEROM D2 /SECTION ON THE PIER D2/



PRIEČNY REZ B–B /CROSS SECTION/

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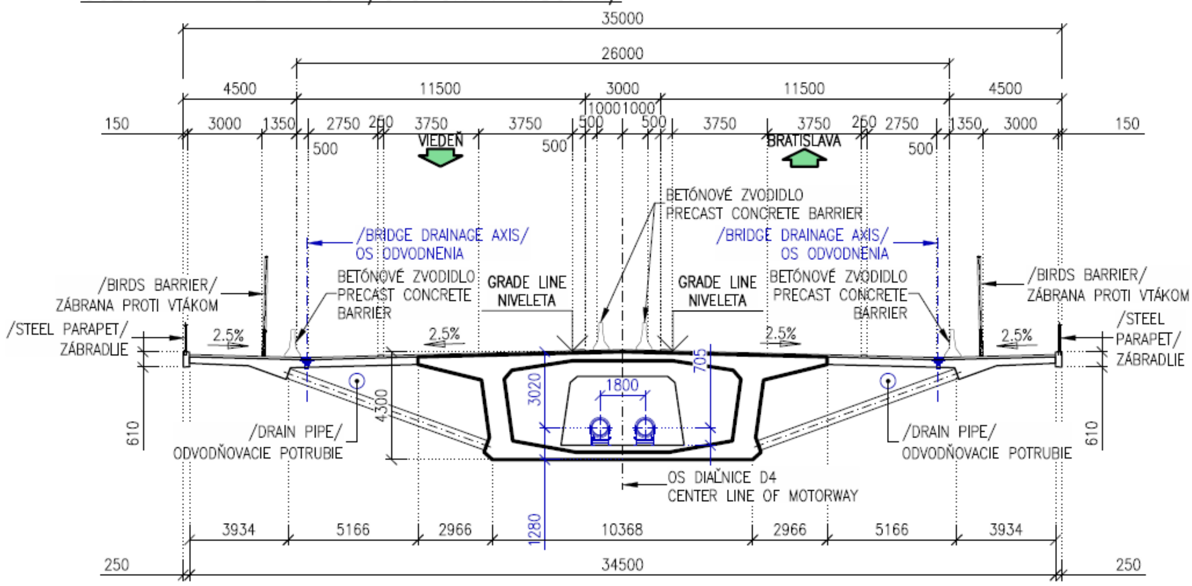
S0200–1 – REZ V POLI /SECTION AT MIDSPAN/



PRIEČNY REZ A–A /CROSS SECTION/

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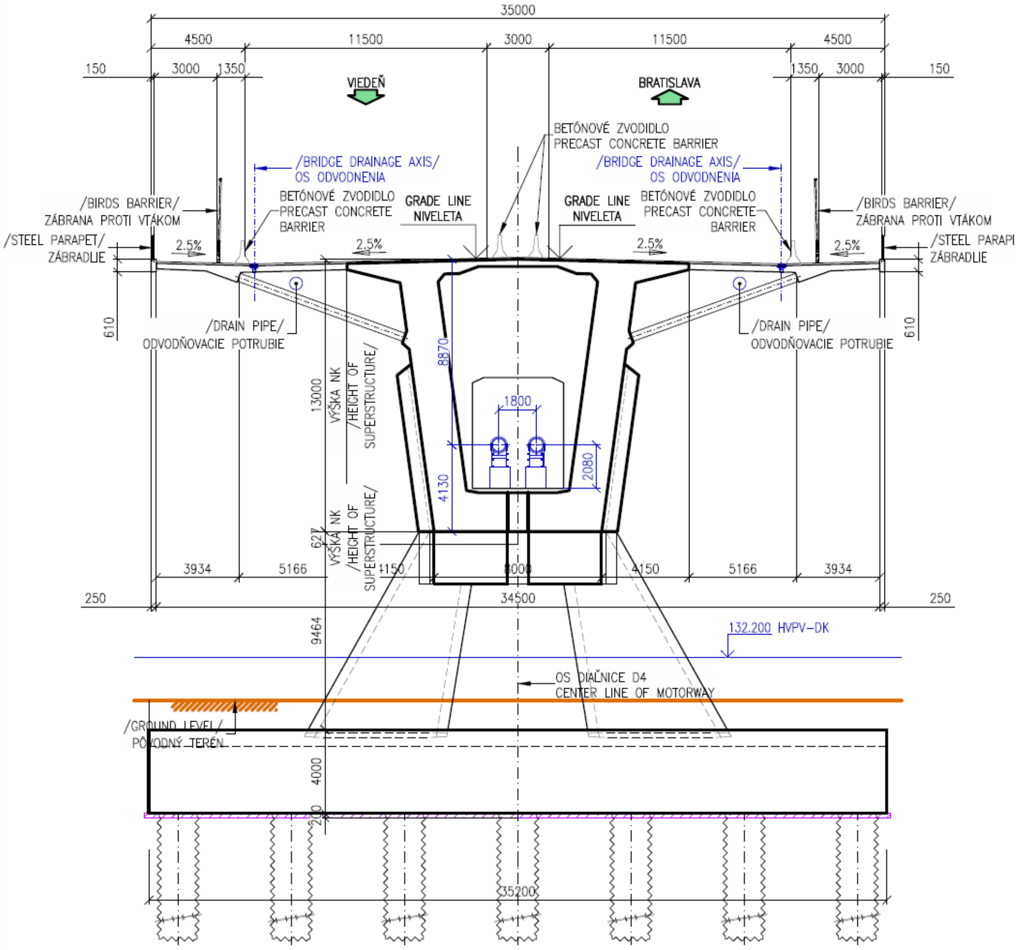

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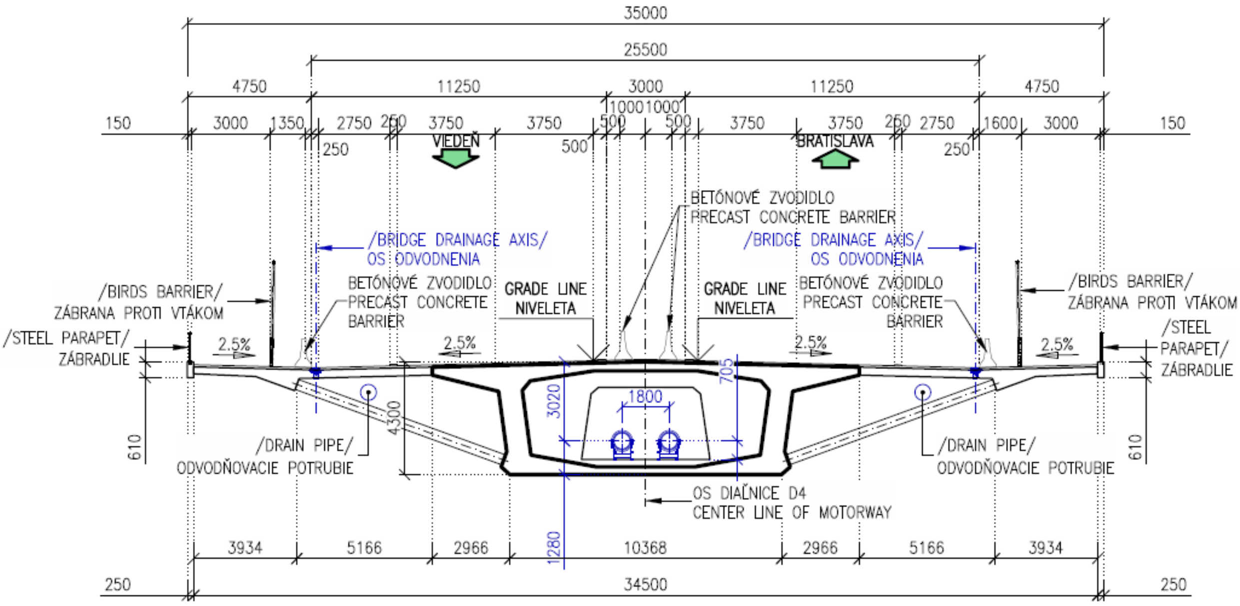
S0200–1 – REZ V POLI /SECTION AT MIDSPAN/



D4R7 PROJECT

CHALLENGING DEEP FOUNDATION WORKS ON WATER AND LAND

Dipl.-Ing. Dr. techn. Klaus MEINHARD
Dipl.-Ing. (FH) Johannes BURGER
Dipl.-Ing. Miklos BAKA
PORR Bau GmbH, Department of Deep Foundation Engineering Vienna

BRIEF SUMMARY

D4R7 Project - Bratislava Bypass - is a PPP project that involves the design, construction, financing and operation of 27km of D4 highway near Bratislava as well as 32km of R7 expressway.

Due to the conditions of the Project, extensive deep foundation works were necessary for the construction of the piers onshore and offshore.

The joint venture of Ferrovial Agroman and PORR assigned the construction of the foundation works at the area of Danube crossing to the company PORR Bau GmbH.

These works mainly included the foundation works for two Danube piers, two piers in the area of a kayak channel and another 33 piers on land at the West and East approach bridges; temporary works (sheet piles and jet grouting sealings) and permanent piling works.

PORR Bau was responsible for designing and building of the temporary works like sheet pile walls and jet grouting sealing.

PORR Bau was also responsible for the deep foundation works (bored piles) which are designed from the clients´ subcontractor.

The main construction period for the foundation works lasted from April 2018 to spring 2019.

1. GENERAL

1.1. PROJECT OVERVIEW

As is shown in Figure 1, the D4R7 project is divided into several construction sections, which are designated as follows:

- D4 Jarovce – Ivanka Sever
- D4 Ivanka Sever – Rača
- R7 Bratislava Prievoz – Ketelec
- R7 Ketelec – Dunajská Lužná
- R7 Dunajská Lužná - Holice

A crucial part of the foundation works (see the Figures 1 and 2) is the part of D4 Jarovce – Ivanka Sever which is located westwards.

It is connected onto the existing D2 highway in the highway interchange Jarovce and the kayak channel, which crosses the Danube River and the protected area Natura 2000 located eastwards.

The construction of the highway bridges required foundation pits and deep foundations for a total of 37 bridge piers.

Especially remarkable are the measures for the Kayak and Danube bridge piers.

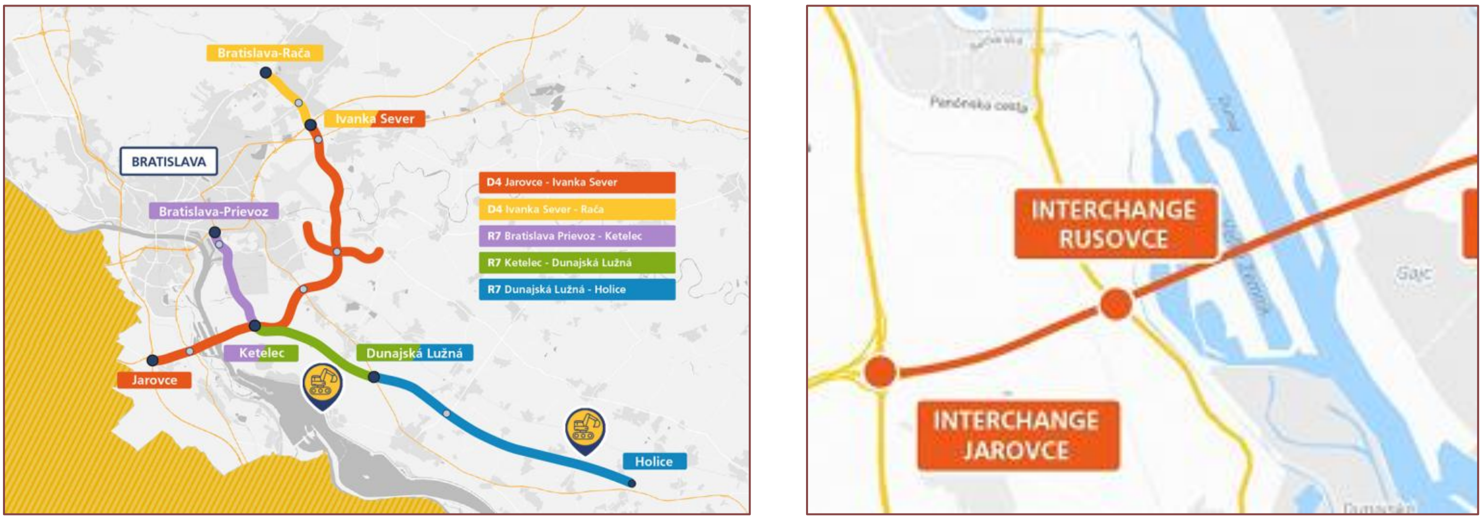


Figure 1: Project overview: D4R7 sections of the construction project (on the left);
Construction area of the foundation works for the Danube crossing (on the right) (www.d4r7.com)

1.2. GEOLOGICAL CONDITIONS

The section of the construction project "D4 - West" included the crossing of the Danube River and its side arms, which was the main challenge of this section.

It has a subgrade of classic Danube sediments (Quaternary) and a layer sequence of sands and silts (Neogene) from a depth of 15 to 30 meters.

However, in contrast to the soil properties prevailing along the Danube in Austria, in the Neogene here, there are no so-called classical "stagnation conditions" (clays / silts).

The exploratory boreholes, which formed the basis for the design of the construction pits and the deep foundation, were undertaken at all pier locations.

Just in the area of the Danube crossing, the exploratory boreholes were undertaken after the completion of the auxiliary islands, in order to confirm the subgrade conditions before starting with the actual piling works.

The layer sequence, especially with regard to the properties of the gravel and sand, was an essential input for the construction of the large drilled piles supported with a bentonite suspension.

Figure 2: View from the West to the East: West approach bridge - Kayak Channel – East approach bridge
Viewer.hangar.com

2. DESIGN

The design tasks of PORR Bau GmbH concerned the design of the temporary supporting system of the construction pits.

These were used to construct the pile foundations under the bridge pier in a dry environment.

The depth of the pile structures was determined by the bridge designer. They are founded, with only a few exceptions, below the terrain or groundwater level, with different thickness of earth cover.

The construction pits designed for this building case consisted of steel sheet pile walls, with inner supported steel bracings, as required.

The pit constructions of the approach bridges, 13 locations westwards and 16 locations to the eastwards from the Danube, had a very similar layout (approx. 12 -14m x 20m).

The excavation depths varied between 4 and 8 metres from the upper edge of the terrain.

The piers adjacent to the two large bridge spans (over the kayak channel and the Danube River), were substantially different from the construction pits of the approach bridges.

The construction pits for the kayak channel piers are larger (25 x 30m and 9m deep), located directly on the river bank of the kayak channel, but able to be constructed onshore.

The bridge piers of the Danube crossing are located entirely in the river bed, approx. 60 to 70 meters away from the river bank, with their diamond-shaped geometry (length approx. 45m, width approx. 20m), chosen to minimise water flow effects.

Construction of the Danube river pier pits is summarised as follows.

The “career” of these construction pits starts firstly not as construction pits, but as the outer shell of a cofferdam-like structure.

These form a working platform for the equipment in order to construct pile foundations in open water.

For this purpose, temporary island structures (cofferdams) were designed, reusable as construction pits in a second step.

Over the past 15 years, PORR has constructed several bridge piers using a construction pit in the Danube, including the management of design and construction.

This proven know-how in connection with many new ideas was able to be transformed into an optimal solution for this construction site.

Basically, a sheet pile construction was proposed, which is able to fulfil the function of an outer shell of the cofferdam resisting the pressure applied from the inside (the pressure of earth and water), and also able to resist the pressure applied from the outside (the pressure of water) in a second construction step.

The structure must be designed for different Danube water levels in both construction phases (pressure from inside and outside), depending on the relevant load position.

The drilling level is approximately 10.5 meters above the river bed and the level of the top of the pile structures is approximately 4.5 meters above the riverbed.

The external water pressure in the first case (cofferdam) was considered assuming the Danube water level was at the upper edge of the sheet piling.

Figures 3 and 4 show the corresponding cross sections related to the construction stages of the cofferdam island, the construction pit and the final state of a Danube pier.

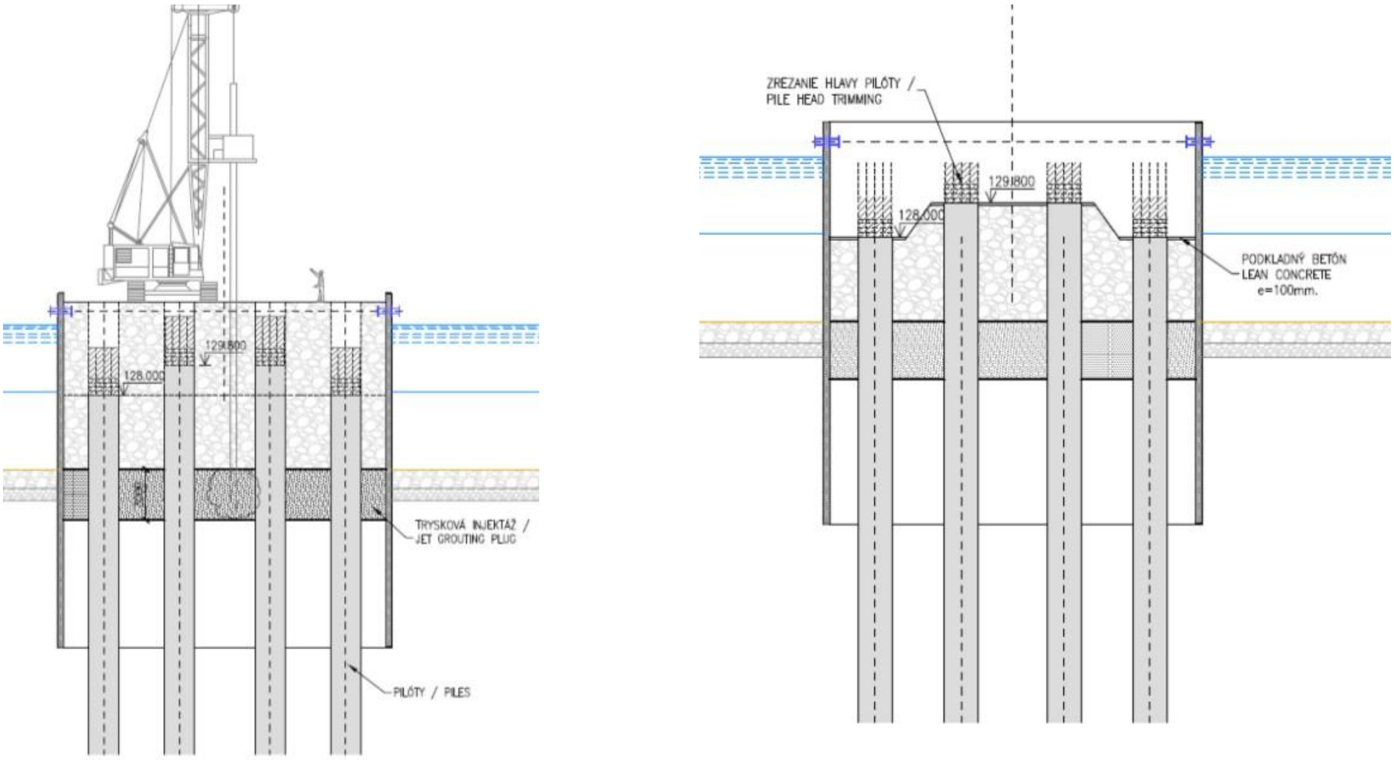


Figure 3: Cross section of the "cofferdam island" (on the left) with tension bars in the bracing level and the construction pit (on the right) with pressure in the bracing level - Excavation of foundation (extract from D4R7 tender documentation)

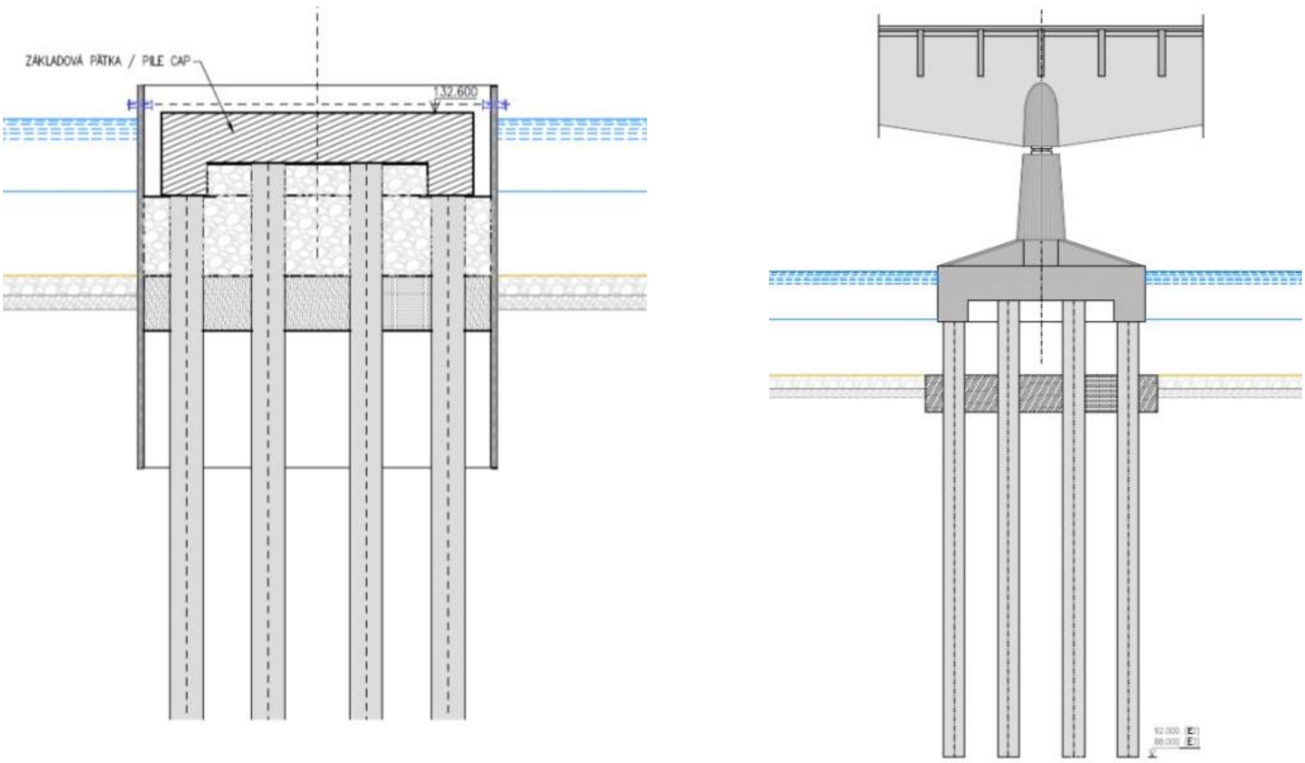


Figure 4: Cross section of the "construction pit" concreting of foundations (on the left); completed pier (on the right) (extract from D4R7 tender documentation)

Particular attention during the design of the cofferdam island and construction of the pit structure was given to the following:

- The geometry of the pile distribution in order to avoid conflict with the drilled piles → arrangement of the internal components (steel bracing), thin design to ensure sufficient distance between the individual bored piles.
- The reusability of the individual steel bracing components → use of common profiles, reasonable division, geometry.
- Assembly as quick as possible → reduced working hours on site, many prefabrications.
- Smallest possible installation dimensions / weight → material costs, transportation costs.
- Determination of a construction method with the lowest possible time investment of work above the free water level → safety reasons.

A steel frame was constructed for the sheet pile enclosure, consisting of double U-profiles, which resist the tension and compression of the sheet pile walls as a bracing horizon, but also used as a template for the sheet piling works.

This frame was made up out of four main parts (two triangular parts for "tip" and "tail" construction and two straight connecting pieces), which could be pre-assembled from prefabricated smaller parts on the landside using screw fittings.

The four main pre-assembled parts were lifted from the ship on an auxiliary structure of pre-driven steel beams with consoles.

After lifting into the correct position (determined by surveyors), these main parts were connected to each other using screw fittings.

The sheet piling was installed from the ship using the bracing as template. Subsequently, the sheet piles (each double pile) were tightly connected to the frame - by using short GEWI threadbars.

With this solution an outer bracing was not necessary to be installed.

The connections of the two long sides in the "case of tensile load" were also designed and executed with GEWI threadbars.

After completely installing these parts, the cofferdam could be filled with soil material and the drilling island could be completed. In this load case water and earth pressure is acting outwards and the pressure of the deep Danube water is acting inwards.

After construction of the drilled piles and the jet grouting sealing plug, the construction pit was excavated. In this case of loading, braces are necessary in the bracing horizon, since the external water pressure is increased with increasing excavation depth.

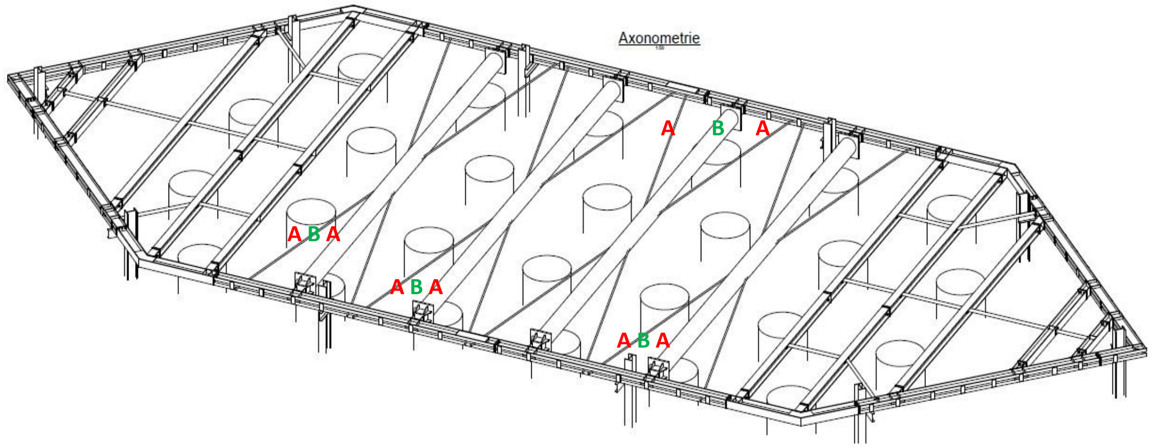
Therefore the GEWI threadbars A were changed against pipe bracings at a predefined excavation level, to resist the compressive loading (see Figure 5) by using the existing outer bracing steel profiles.

Furthermore, it was designed to install a water-level gauge into the construction pit during the drilling works, which was a very simple but quite effective inspection and control tool. Therefore the load on the excavation pit could be controlled by regulation of the inner water level.

This procedure allowed relief of the bracing construction if necessary, and simplify the modification of the bracing from tensile usage to compression usage.

It was also necessary to increase significantly the factor of safety for the whole construction (a load-free case is also achievable under certain circumstances).

This tool also helped during the quality assurance of the tightness of the construction pit. The overall tightness of the sheet piling / jet grouted structure could be easily inspected with a pumping test and monitoring.



A) Use only in the case of tensile load, GEWI threadbar connection - construction of an island for drilled piles and jet grouting

B) Use only in case of compressive load, pipe braces - construction pit for the execution of pile structures and piers

Figure 5: Bracing frames including pile distribution (pile diameter 1,800mm)

After completion of the pier, the construction of the pit structure can be dismantled. According to the schedule, this takes place after the flooding of the excavated part in order to relieve the loading of the system.

Similar to the assembly, the large parts may be lifted in one piece and dismantled onshore.

A large part of the steel beams/bracing, GEWI threadbars as well as the sheet pile walls can be reused elsewhere with little or no extra effort.

3. CONSTRUCTION OF DEEP FOUNDATIONS

Six large pile drilling machines, three jet grouting units, one sheet piling rig and carrier ships, barge and pontoons for equipment were used for the construction period from May 2018 to January 2019. The main quantities are summarised as follows:

- 13,000 meters of cased bored piles DN 1180
- 4,500 meters of bored pile with supporting fluid DN 1800
- 15,000m^3 of jet grouting sealing plugs
- 17,000m^2 of sheet pile walls
- 460 tonnes of bracing material

3.1. TEST PILES

In order to optimize or prove the load capacity of the foundation structure, large scale pile load tests using Osterberg type cells were carried out on three test piles with a diameter of 1,180mm before starting the actual works.

The maximum applied load was chosen to be 25MN.

For this purpose, a two-storey expansion of the Osterberg cells was required.

Due to the limited accessibility to the selected test pile locations, a cable excavator was chosen for construction.

Different to the planed piles with a diameter of 1,800mm, the test piles were made with a diameter of 1,180mm.

The length of the piles was chosen to be between 21 to 35 metres.

Figure 6 shows the Osterberg cells built into the reinforcement cage.

The test results confirmed the values of the load bearing capacity used for the design of the deep foundation.

Figures 6a and 6b: Reinforcement cage of the testing piles with installed Osterberg cells

3.2. PIER LOCATION - DANUBE

The Danube bridge piers were constructed via pontoons in the riverbed by using up to 17 meters long PU32 sheet pile walls.

These temporary construction pits, with approximately 50 tons of steel bracing construction, provided a template for sheet pile walls as well as bracing, and were sealed at their bottom in the Danube gravel with a jet grouting plug.

This gravel filled cofferdam was used as a drilling platform for the bored piles. The foundation consists of 26 drilled bored piles per pier, each with a diameter of 1,800mm and a depth of up to 46 meters.

Based on these dimensions and the determined geology it was decided to case the piles down to the depth of the dense gravel, which was founded at a depth of approx. 28 meters, and then to use a supporting fluid to the final depth.

The production of a fully cased pile was considered to be too risky due to the depth, diameter, refilled cofferdam with loose gravel, and possible loss of a drilling casing.

The extra costs for the construction site equipment, higher time demand and equipment costs were accepted. In order to ensure a continuous construction progress (necessary concrete more than 100m^3 for one bored pile), the works on bored piles and jet grouting were carried out during day and night shifts.

The following Figures 7 and 8 show an extract from the design drawings of the E3 Danube pier as well as the photos of the construction.

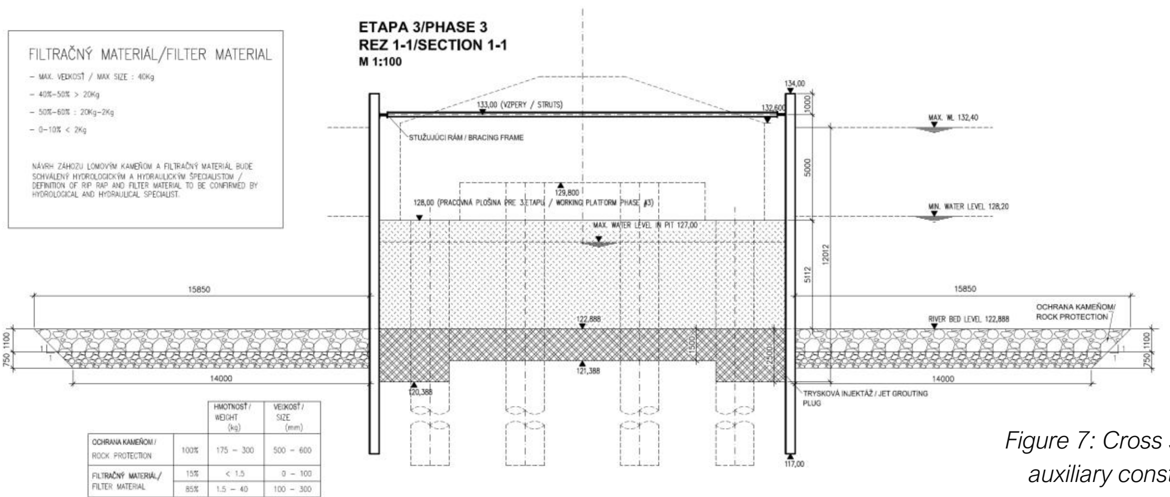


Figure 7: Cross section of the auxiliary construction pit, bracing frames, drilled piles and jet grouting plug for the Danube pier E3

Figures 8a and 8b: Construction of the sheet pile island for the Danube pier E3

3.3. PIER LOCATION - KAYAK CHANNEL

On the shores of the rowing and kayaking channel, two piers were built partly on an artificial embankment.

PU28 profiles with a length of 15 meters were driven into the ground for the sheet pile wall construction pits with dimensions of 20 x 30 meters.

Bracing, dead man anchors, jet grouting plugs and bored piles with a diameter of 1,800mm and a length of 38 meters completed the deep foundation works there.

On these piers, 30 bored piles were also constructed with bentonite support, for a depth of 19 meters.

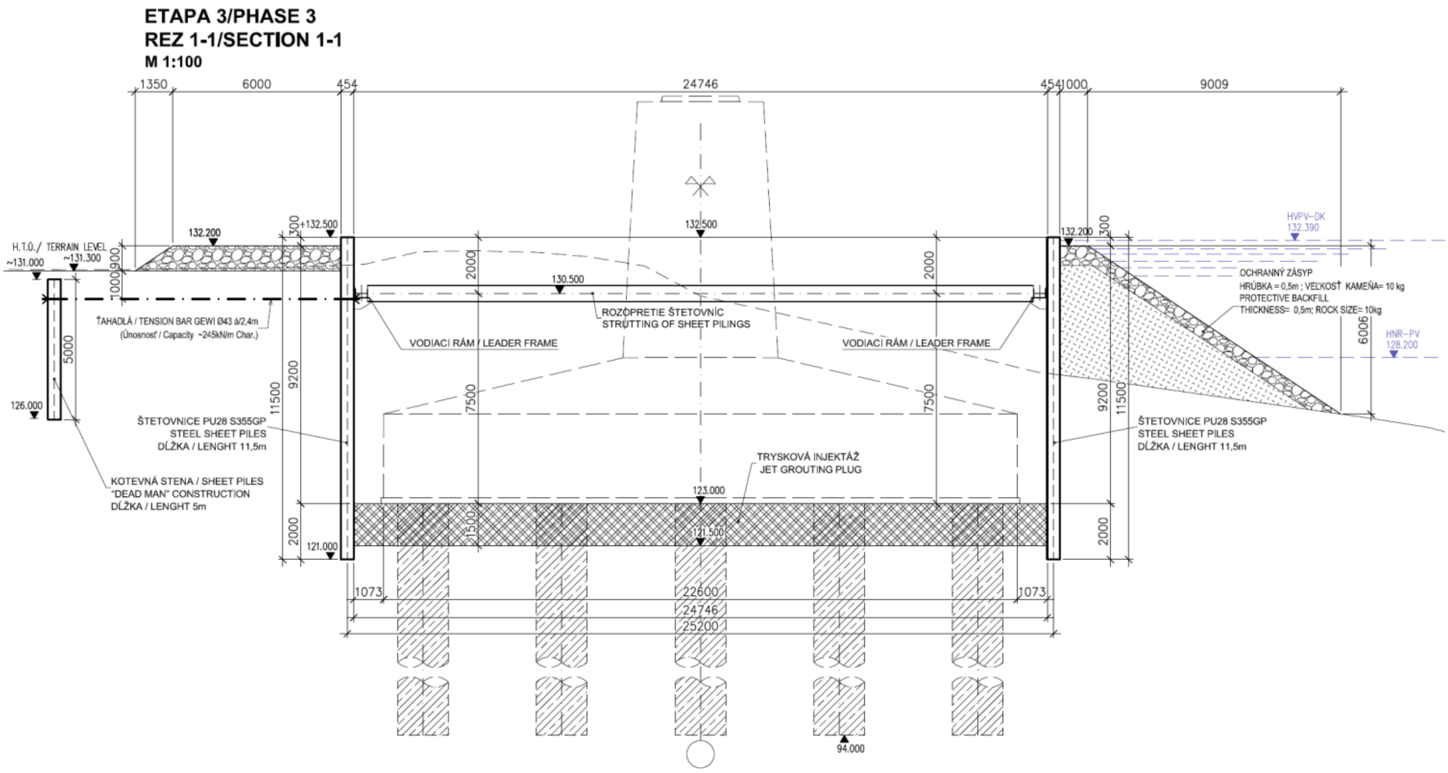


Figure 9: Cross section of the auxiliary construction pit, bracing frames, drilled piles and jet grouting plug for Kayak pier D2

Figures 10a and 10b: Construction of drilled piles - Kayak pier D2

In comparison to the Danube piers, the excavation extends to just below the upper edge of the jet grouting plug, which lies at a depth of approximately 9 meters. In general, the client decided to test the 1,800mm bored piles by using Cross Hole Sonic Testing.

For this testing method individual pipes had to be installed in advance into the reinforcement cage along the pile circumference.

The pile integrity test using a hammer penetration method was omitted due to the diameter and depth of the drilled pile of 38 meters.

Figures 9 and 10 show an extract from the design drawings of the D2 Kayak pier as well as the photos of the construction.

3.4. PIERS OF EAST AND WEST APPROACH BRIDGES

For the piers of approach bridges, another 33 construction pits with dimensions of approximately 12 x 20 meters were constructed, the main difference here is a smaller diameter of bored piles of 1,180mm than used for the Danube and Kayak piers.

The 15 bored piles per pier could be produced as fully cased piles due to the smaller pile diameter and the soil conditions there, with pile lengths from 20 up to 38 meters.

Due to the geological conditions, bracing and jet grouting plugs were necessary for the construction of the pier foundations.

Figure 11: West Approach

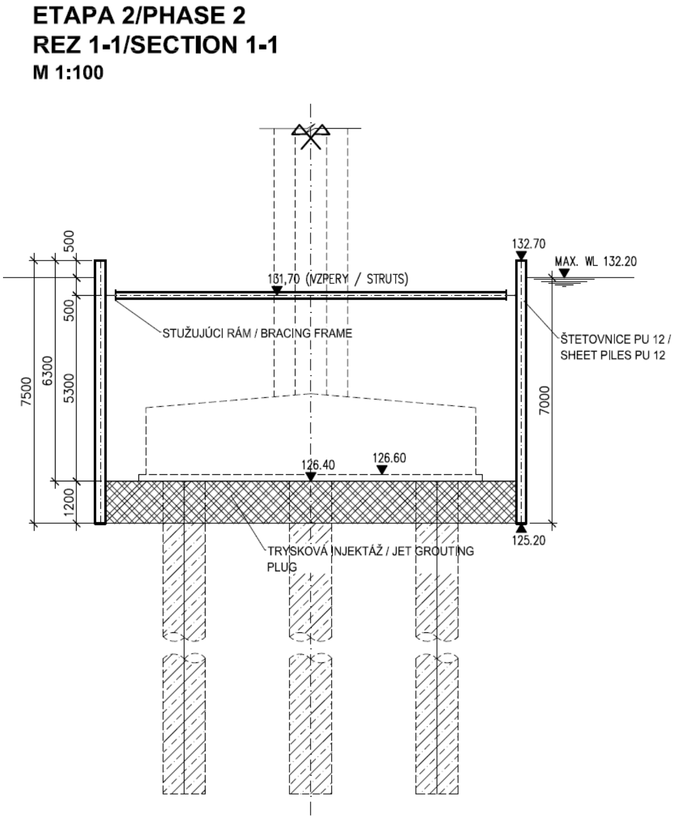


Figure 12: Cross section of the construction pit including the deep foundation on C4 pier of an approach bridge

Figure 13: Excavation of C4 pier after the construction of drilled piles DN120, sheet pile wall and jet grouting plug

Figure 11 shows aerial view of the West Approach Bridge, Figure 12 shows an extract from the design drawings of Pier C4 of the approach bridges, and Figure 13 shows the construction.

CONCLUSION

As stated in the main part of the article, the conditions on the construction site presented a particular challenge for the design and construction of the deep foundation works, especially of the auxiliary construction pits in the Danube riverbed and on the shoreline of the Kayak channel.

Another challenge in theory and in practice was the construction method of the up to 46 meter deep 1,800mm piles in the nature conservation area and on the temporary Danube islands.

The complex construction procedure, which was subject to optimisation attempts, with up to 6 pile drilling machines (working during day and night shifts), 3 jet grouting devices, sheet piling works and the production of the necessary bracing in connection with the tight construction schedule of the client and its subcontractors for the execution of foundations, and the subsequent construction of the bridge did not always make it possible to work on the over three kilometre long construction site without amendments and changes of previous plans on papers.

The construction process had to be constantly adapted to the actual circumstances.

M1-70-S MOVABLE SCAFFOLDING SYSTEM (MSS)

FOR THE D4R7 DANUBE BRIDGE

Pedro Pacheco (BERD), André Resende (BERD), Hugo Coelho (BERD),
Filipe Magalhães (CONSTRUCT – Faculty of Engineering, University of Porto)

Figure 1: Construction of West approach Viaduct to the Danube Bridge (Photo Credit D4R7)

THE DANUBE BRIDGE

The Danube Bridge (Bratislava Bypass), currently under construction, is a highway bridge, with a total length of 2,934.5m, part of it spanning over the Danube River, 10km from Bratislava city centre.

In structural terms, it comprises the 900m long central main bridge and two access viaducts – 784m long West viaduct (span arrangement of 53m + 10x67.5m + 53m) and 1,250.5m long East viaduct (span arrangement of 62.5m + 16x70m + 65m).

In order to simplify the construction, the bridge superstructure was built in two different stages: the central box girder and the lateral wings were built in different stages by different equipment.

Figure 2: West viaduct construction: M1-70-S Movable Scaffolding System at the 9th span and wing traveller at the 1st span (Photo Credit D4R7)

The viaducts central box girder was built as a full span continuous beam using movable scaffolding systems, while the main bridge central box girder was built by the balanced cantilever technique using form travellers.

In both cases (main bridge and viaducts), the lateral wings were built in a second stage by auxiliary equipment designated as wing travellers.

The cross section of both viaduct decks is very similar.

They were designed to be built by similar movable scaffolding systems.

The construction method valued the following criteria: fast construction cycle, minimizing interference with the ground (only longitudinal access near the piers alignment was provided), minimizing the need for external auxiliary machinery, timely planning and organization of tasks and last, but not least, maximizing safety.

M1-70-S MOVABLE SCAFFOLDING SYSTEM (MSS)

The movable scaffolding systems (MSS) applied in the construction of the approach viaducts are designated as M1-70-S (Figure 3) since they are a version of the larger span overhead MSS family from BERD named as M1, already successfully used in construction of 4 prestressed concrete viaducts with 90m long spans.

In this specific application, the M1-70-S span range is limited to 70m.

In generic terms, the M1-70-S comprises the following components:

1) Main Girder;
2) Transversal Structures;
3) Supporting Frames;
4) Formwork;
5) Platforms, and
6) Equipment (hydraulic and electrical components).

Figure 3: BERD'S MSS M1-70-S, West viaduct construction (Photo Credit D4R7)

The Main Girder is the key structural component, capable of spanning the distance between the supports loaded by its self-weight and by the weight of the deck under construction.

Structurally, the Main Girder is a variable depth steel trussed box section with an arched upper chord in the central part and suspension ties for the front cantilever.

The Transversal Structures support the Formwork and include the necessary kinematic mechanisms for Formwork adjustment and for bottom part rotation needed to pass through the front pier section during longitudinal movement between adjacent spans (Figure 4).

There are 3 types of Supporting Frames depending on the specific position/function:

1) Pier Frame is placed on the zero-segment fixed to the pier cap and is used during the entire construction cycle;
2) Concreting Frame is fixed to the Main Girder and is the rear support during the MSS fixed phase (usually called Concreting);
3) Launching Frame is assembled on the span, being used only during the Launching.

The Platforms provide the access and safe working conditions on all working areas.

Finally, the Equipment is distributed along the MSS to accomplish the several kinematic functions of the MSS, namely the load transportation (with chain winches), the longitudinal launching (with hydraulic winches), the Main Girder vertical movement and opening/closing of Transversal Structures (with hydraulic cylinders).

The electrical energy is supplied by a diesel generator placed on the Main Girder rear area for better access to the refill tasks.

In Figure 4, the M1-70-S transversal section is presented in two different configurations: configuration for concrete pouring with transversal structures closed (left side) and configuration for MSS launching with transversal structures open (right side).

This figure highlights one of the advantages of using M1-70-S in this particular application – it allows construction of decks very close to the ground, therefore minimizing interference and excavation volumes.

This feature was essential while the MSS was operating over the dike in the West side of the Danube Bridge.

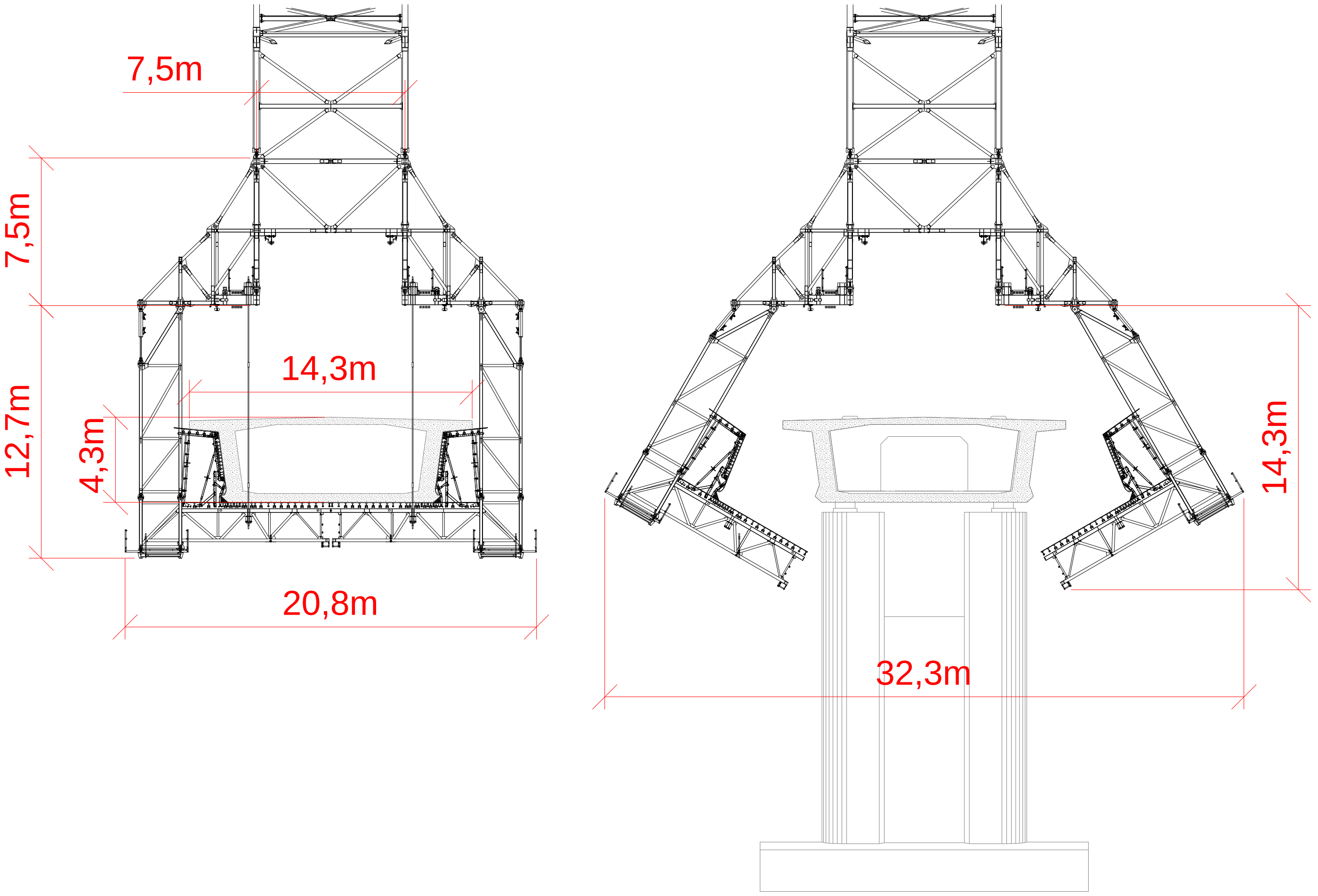


Figure 4: Transversal section of M1-70-S: Concrete Pouring (left) and Launching Configuration (right)

MONITORING PROVIDED BY OPS (ORGANIC PRESTRESSING SYSTEM)

In both MSS used for construction of the viaducts, the main girders are strengthened by an active prestressing system – OPS - patented by BERD, featuring a continuous mid-span deflection monitoring and compensation system.

For the Main Girder deflection measurement, a system based on the “communicating vessels principle” with pressure transducers at the supports and at mid-span is used.

The deflection at mid-span causes pressure variation on the mid-span transducers from the reference defined by the alignment of transducers at the supports.

When the mid-span deflection of the MSS reaches a predetermined threshold, the OPS algorithm transmits to the OPS hydraulic cylinders instructions to compensate the deflection.

To avoid uncontrolled loss of force on the OPS hydraulic cylinders, lock nuts are used to ensure a mechanical retention of force if the hydraulic circuit bursts.

For appropriate operation, the OPS measures continuously several variables, including the mid-span deflection, pressure and stroke of hydraulic cylinders, lock nut position and temperature of the

Figure 5:- Transversal section of M1-70-S

cabinets and of the oil in the deflection measurement circuit and the hydraulic cylinders circuit.

These variables are recorded on files that allow the analysis of any anomalies and malfunctions.

Furthermore, the OPS ensures additional safety during concreting by real time MSS monitorization, emitting warnings and alarms if an anomaly is detected.

The OPS layout is presented in Figure 6, which shows the different components of the system, namely:

1) Active anchorage (hydraulic actuator);
2) Hydraulic unit;
3) Prestressing tendons;
4) Main board including the rear pressure transducers;
5) Mid-span pressure transducers;
6) Front support pressure transducers;
7) Passive anchorage.

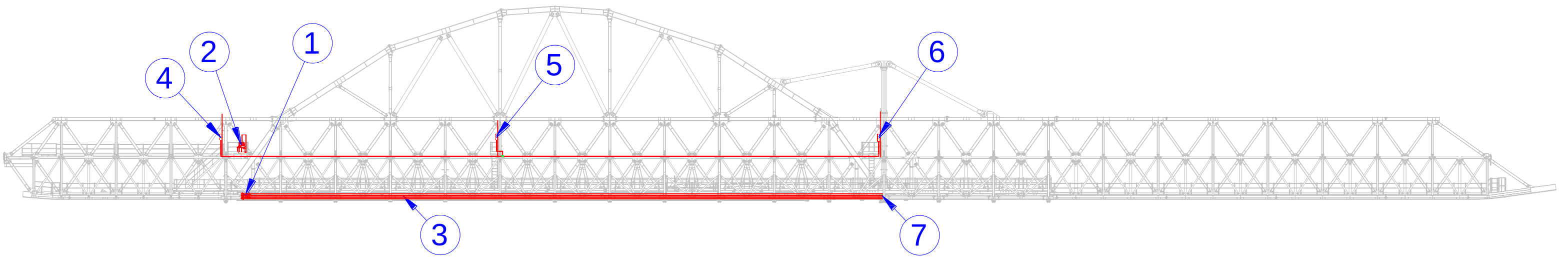


Figure 6: OPS layout

COMPLEMENTARY MONITORING SYSTEM

While the OPS provided continuous and real time monitoring for both MSS, a complementary monitoring system was installed exclusively for the West side MSS, covering the 12 spans to be built.

This complementary system gathered and analysed data with the intention of further development of the OPS into a Smart OPS.

The complementary monitoring includes three subsystems, comprising sets of anemometers, strain gages and accelerometers.

Together, these subsystems allow the characterization of loadings.

Wind is the most important variable load.

The permanent loads are obtained by the sum of the weight of the individual elements.

The static structural response is determined by measurement of strains on representative elements and the dynamic response (vibration) is measured by accelerometers.

The monitoring of wind characteristics provides validation of design assumptions and the correlation between the structural response and the excitation, to better define the interaction between the air flow and a flexible structure.

The time series are processed by algorithms that allow the real time identification of the dynamic modal parameters that define the dynamic response of the structure.

Since the natural frequencies are a function of the structure stiffness, any damage, incorrect assembly or structural deterioration that imply a reduction of the stiffness is identified by a reduction of the natural frequency.

The precise measurement of the natural frequency variation with time enables the detection of small structural changes.

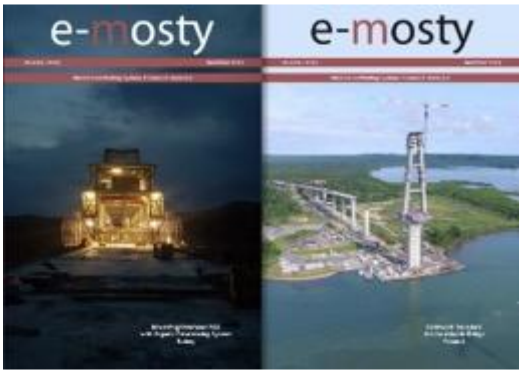
However, since natural frequencies are also affected by the temperature, wind speed and operation conditions, these effects have to be mitigated with statistical models.

The measurement of strains at fast sampling rate is also a tool used for structural monitoring, namely for the stress state and fatigue assessment.

This last component of the monitoring system is very important in the determination of the residual life of the structure.

Figure 7: MSS M1-70-S in the last span construction

This article is a result of the project SMART_OPS (Proj. nº 33511), supported by Norte Portugal Regional Operational Program (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, through the European Regional Development Fund (ERDF).



More information about MSS with OPS can be found in e-mosty – click on the image to open the magazine as pdf

M1-70-S @ D4R7 BRATISLAVA BYPASS
MORE INFOS HERE

PHOTO CREDITS: D4R7

BEARINGS AND EXPANSION JOINTS FOR D4R7 PROJECT

Peter Haluška, CSO mageba Slovakia s.r.o.

Figure 1: Crossing on section Ketelec – Dunajská lužná with SO220 where mageba delivered 20 pot bearings

Mageba was very interested to take part in this extraordinary project from its beginning.

It was successful during initial tender stages and subsequently became one of the contractors for this construction.

In 2018 first contracts were concluded with the D4R7 construction consortium.

Afterwards, we have cooperated with the Client and together we have brought a bespoke solution for the bridges which are part of the D4R7 Project.

Up to now, mageba has supplied:

- 120 pcs of pot bearings for vertical forces of max. 17,800kN and horizontal forces of max. 3,400kN.
- 328 pcs of elastomeric bearings in compliance with EN 1337, with max. size up to 350 x 450 x 105mm.
- 24,750 pcs of elastomers 30 x 30 x 20mm.
- Expansion joints for movements of ±40mm (RS80) 4 pcs, in total length of 29.6m.
- Special expansion joints for cumulative movements in axis x, y of ±100mm RS = 2 pcs, in total length of 140.7m.

Apart from supplying bearings and expansion joints of smaller sizes, mageba is very proud to supply the expansion joints for the "D4R7 The Danube Bridge".

This bridge is the sixth bridge crossing the Danube which will form part of the Bratislava Bypass by the D4 highway.

It is the Danube group of bridges comprising four separate bridges in succession with a total length of about 3,000m.

Mageba is contracted to fabricate, supply and install five expansion joints with a total length of about 170m and weight of 150.5 tons.

For this challenging task the following modular expansion joints will be used:

- TENSA®MODULAR LR5-LS to LR14-LS for dilatation movements from ±250mm to ±700mm, with life span min 30 years.

Figures 2 and 3 below provide details of the LR14-LS modular expansion joint.

Mageba TENSA-MODULAR modular expansion joints can accommodate movements in the bridge deck.

The total movement of the bridge deck is provided by a number of individual elastomeric seals supported by horizontal surface beams.

The individual gaps are regulated by an elastic control system.

The drainage of the joint is via the drainage system of the bridge deck.

TENSA-MODULAR expansion joints are used when the movements of a bridge exceed the capacity of a single gap joint.

Due to the requirement for noise reduction, the expansion joints will be delivered with sinus plates which can reduce the noise from traffic by up to 80%.

The supply and installation of the expansion joints is planned for 2020 and 2021.

After installation of LR14-LS joint, this expansion joint will become the joint with the biggest dilation movements in the Slovak Republic.

We believe that mageba group with mageba Slovakia s. r. o. (Ltd.) will prove to its partners in this construction that its products are traditionally of high quality as well as price competitive, costs effective and they bring to Slovak structures world's best practice.

We are happy that by supplying expansion joints and bearings to this remarkable project we will contribute to the future long-lasting and smooth usage of this Bratislava Bypass.

Reference: www.mageba-group.com

mageba group Leaflet

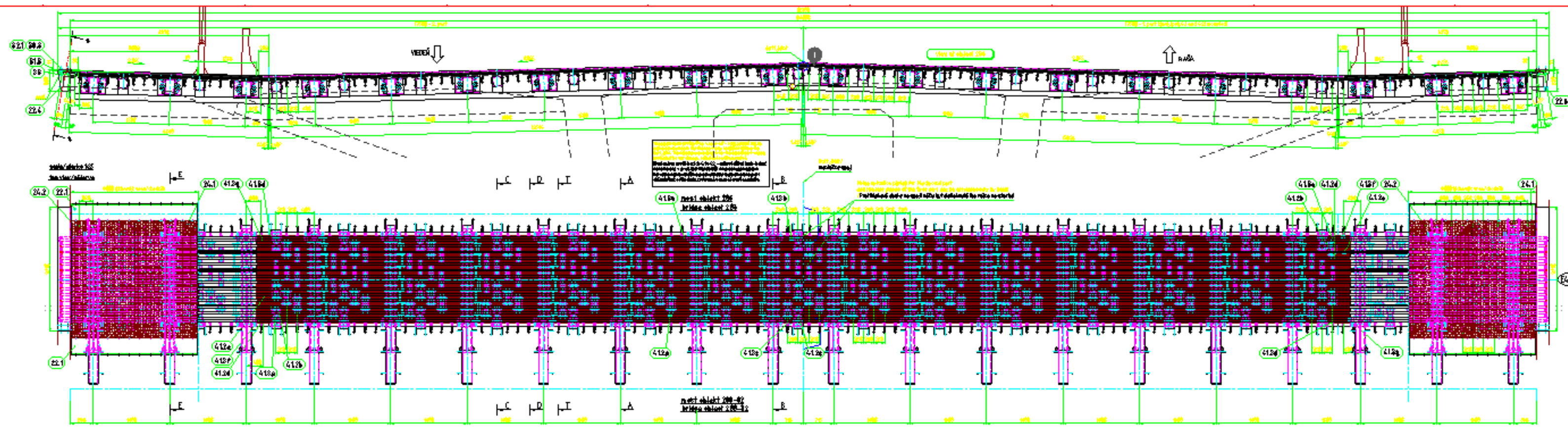


Figure 2: Plan view and a side view of the expansion joint LR 14-LS

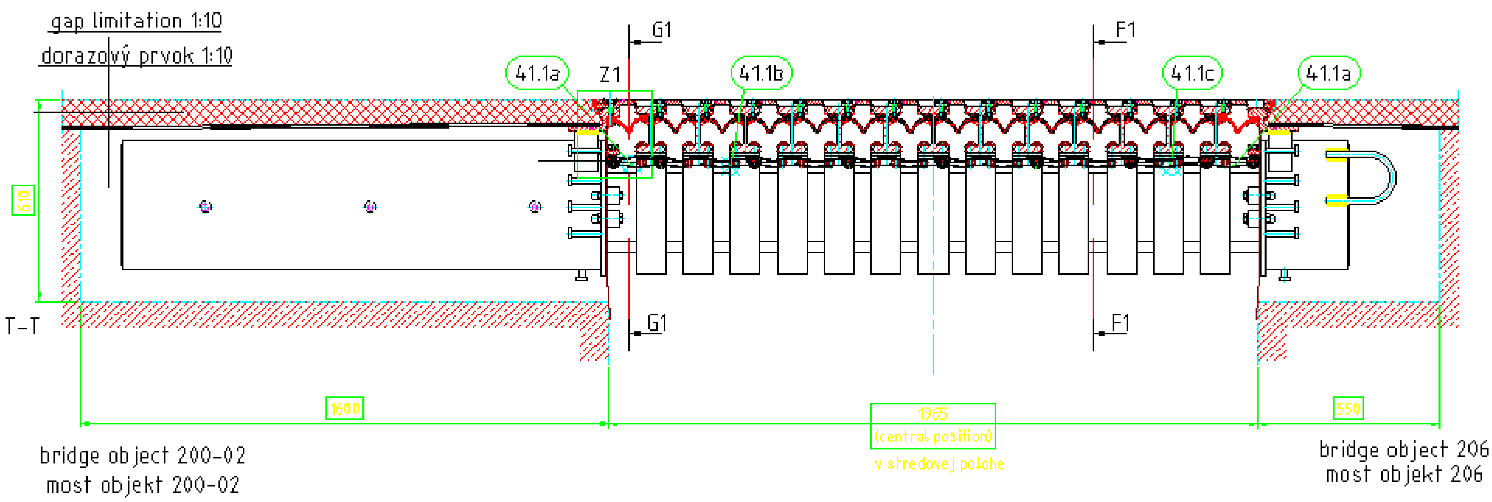


Figure 3: Section of the expansion joint LR 14-LS

SPHERICAL BEARINGS FOR D4R7 BRIDGES

Luca Paroli, Maurer

The challenge of this project was to design bearings for high vertical and horizontal loads while allowing them to fit on top of the piers with limited space, demanding the use of high performance sliding materials like MSM® (MAURER Sliding Material), capable of withstanding high pressures and guaranteeing durability over the years.

MSM® is designed for a nominal life of 50 years, 50km accumulated travel and pressures twice as high as other sliding materials.

MSM® is also suitable for earthquake motion and a wide range of application temperatures (-50° to 80°C).

MAURER provided 80 spherical bearings for the Danube and Kayak Bridge and their approaches, equipped with top and bottom concrete anchor plates.

Spherical bearings allow the transmission of vertical and horizontal forces and allow high rotations at low friction.

The vertical loads range from approximately 21MN to as much as 210MN, the horizontal loads of the guided bearings reach almost 40MN, contributing to make these devices absolutely special.

The introduction of new earthquake regulations in Slovakia was the reason for the high horizontal loads arising from a relatively low ground acceleration multiplied by the high mass of the concrete bridges.

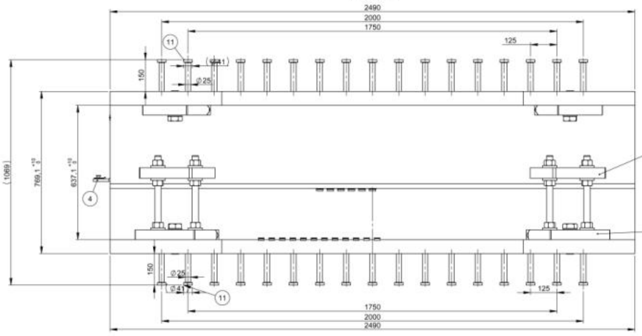
Some of the bearings were supplied with temporary fixity blocks to allow them to be used as a fixed point during construction.

These blocks are removed after the construction is over.

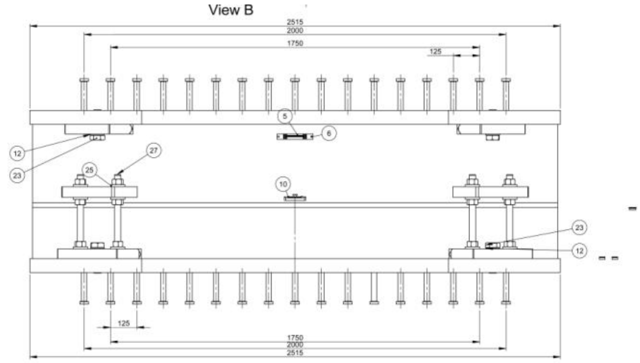
The biggest bearings weigh as much as 30 tons and have a footprint of 2.8 by 2.8m.

Table of forces and displacments			
(Lagerlasten und Verschiebungen)			
	ULS	SLS	Seismic
	---	---	---
max V [kN]	210000	155000	183400
min V [kN]	74000	89000	51000
H_x [kN]	±10200	±7400	±38800
H_y [kN]	±6900	±4600	±32900
w_x [mm]	±0	±0	±0
w_y [mm]	±0	±0	±0
φ_x [rad]	±0,01	±0,01	±0,01
φ_y [rad]	±0	±0	±0

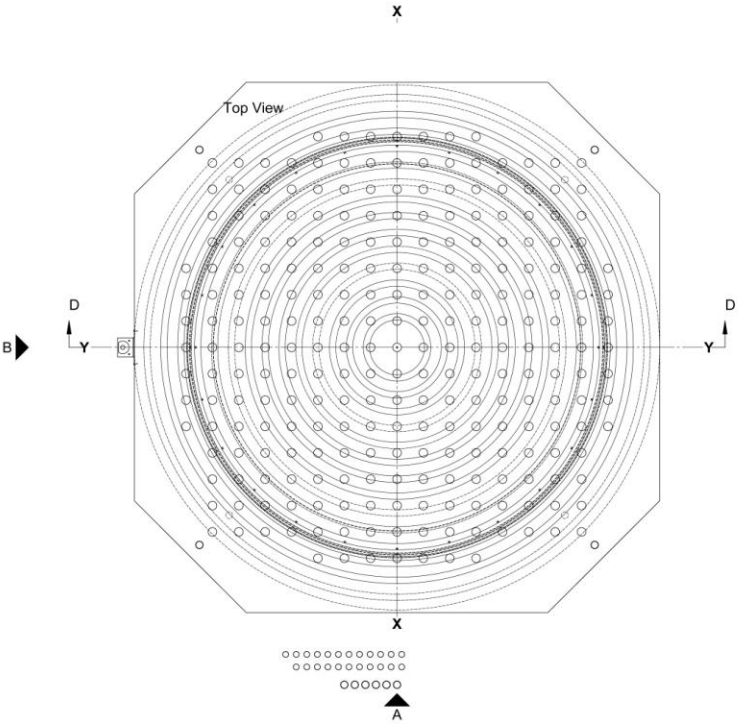
View A



View B



Top View



Isometrie (1 : 10)

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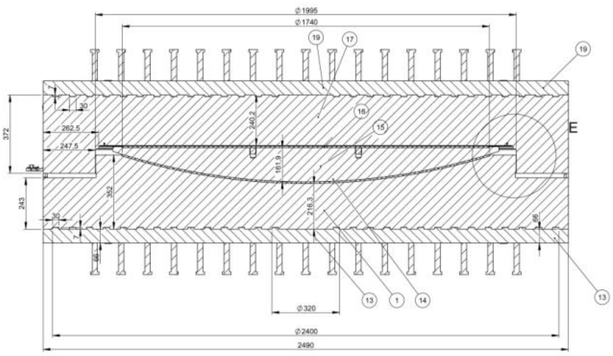

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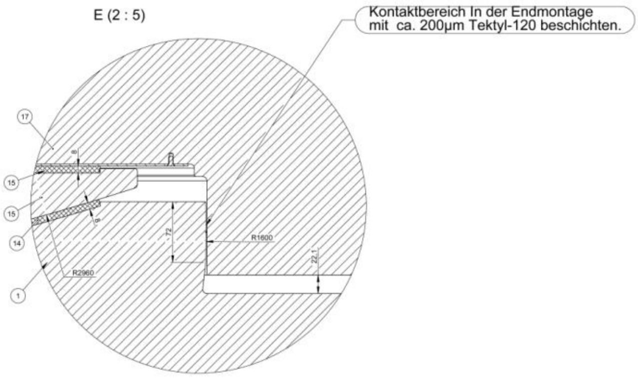
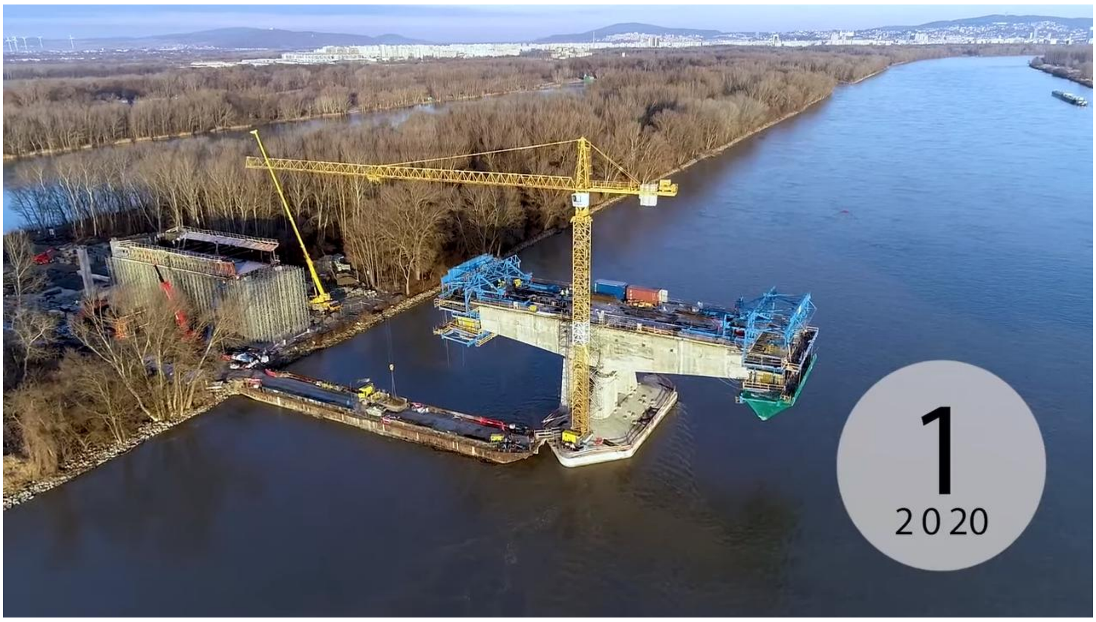


Photo Gallery

Photo Credit: D4R7 Construction s.r.o., Porr Bau and e-mosty



Video: Construction progress, January 2020

Click on the image to play the video

Editorial Plan

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If you and your company have been involved in related projects and are interested in cooperation and preparation of an article for our magazines, please contact us. We welcome cooperation with you and will be happy to publish your articles.

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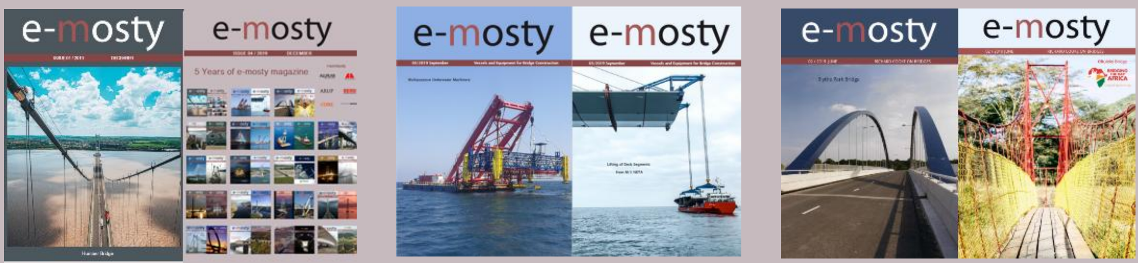

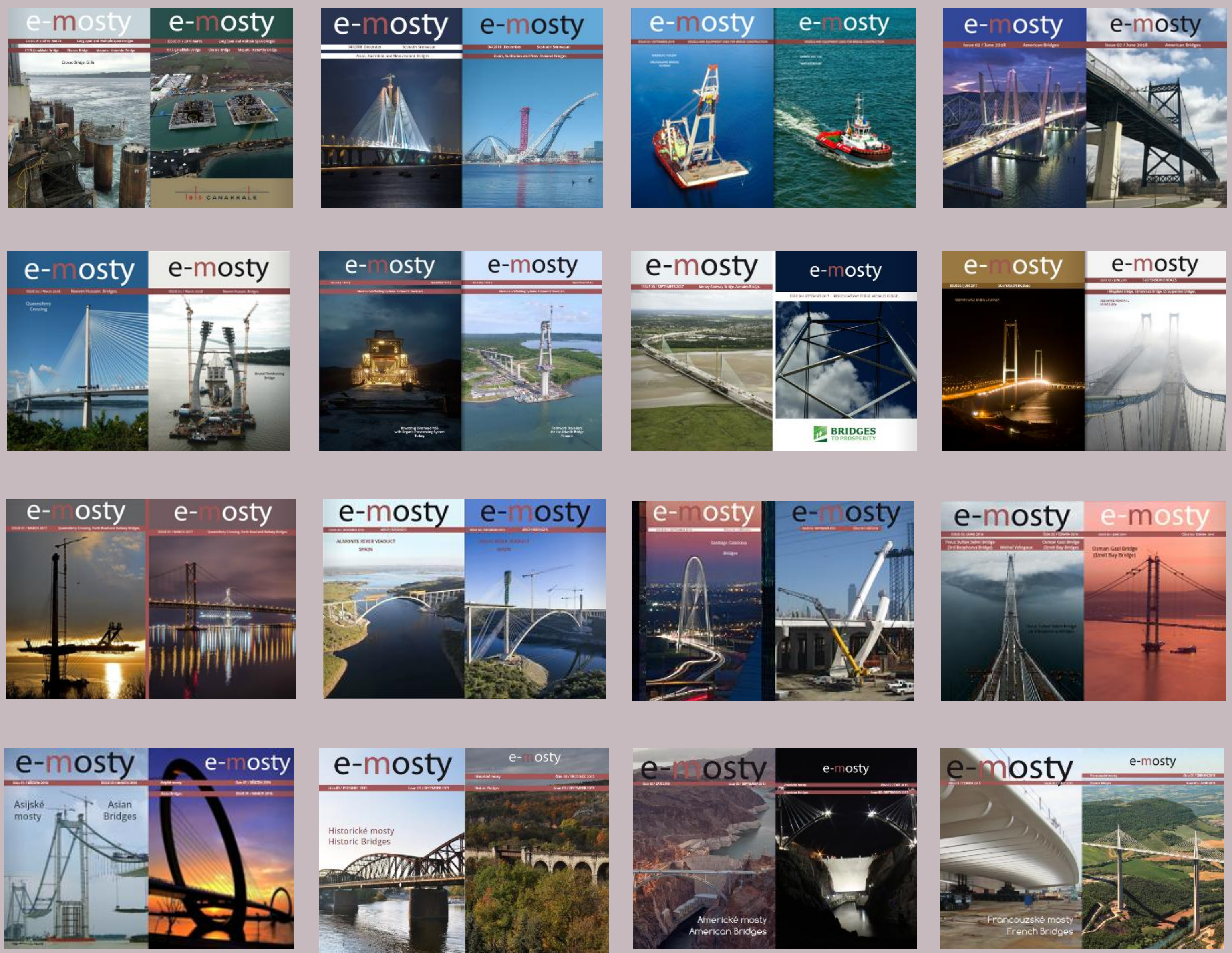

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ISSUE 01/2020 March

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