e-mosty

ISSUE 01/2026 MARCH

DVORECKÝ BRIDGE, PRAGUE, CZECH REPUBLIC

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INTERNATIONAL ONLINE PEER-REVIEWED MAGAZINE
ABOUT BRIDGES

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

Released quarterly:

20 March, 20 June, 20 September and 20 December

Number: 01/2026, March **Year:** XII.

Chief Editor: Magdaléna Sobotková, MSc.
Contact: magda@e-mosty.cz

Editorial Board

The Publisher: BRIDGES ONLINE, s. r. o. (Ltd.)
Velká Hraštice 112, 262 03 Czech Republic
VAT Id. Number: CZ02577933

E-MOSTY ISSN 2336-8179

Dear Readers

The first part of this edition is dedicated to the **Dvorecký Bridge in Prague***, Czech Republic. Three articles provide information about the competition, the architectural solution, and the design and construction of the Bridge.*

This part also features a comprehensive construction gallery, showcasing the bridge's progress from the start of construction to its current state, as well as videos and drawings.

In his article, **Aquilino Raimundo** *of* **STRUKTURAS,** *proposes an integrated interpretation of the Movable Scaffolding System from three complementary perspectives: its historical framework and conceptual evolution; its interpretation as a mobile industrial unit and the systematic application of work study methodologies as instruments for optimising production cycles.*

In 2022, following technical reviews and supplier audits, **Fatzer** *was commissioned to undertake the detailed design, testing, manufacture and supply of the new hangers for the Menai Suspension Bridge. You can find more information in the last article of this edition.*

I want to thank our Editorial Board, especially **Richard Cooke,** *for their assistance with this edition and review of the articles.*

We also thank **our partners** *for their continuous support.*

On behalf of the organisers, we would like to invite you to the following conferences:

- ***13th International Conference on Bridge Maintenance, Safety and Management IABMAS****, which will be held from* ***7th to 9th July 2026 in Orlando, Florida, USA****. More information about the conference is on pages 9 and 10 and at https://iabmas2026.org.*
- ***2026 World Bridge Engineering Conference****, with an emphasis on Innovative Bridge Technologies and Accelerated Bridge Construction, which will take place on* ***1st and 2nd December 2026 in Miami, Florida, USA****. More information is on page 11.*
- ***SISMICA S&G 2026*** *International Conference on Structural & Geotechnical Engineering, which will be held* **online** *from* ***18th to 20th June 2026.*** *The Conference will be bilingual (English / Spanish). More information at www.sismica-institute.com, https://sismica-institute.com/sismica-sge-2026-pre-registration/ and on page 12.*

The next e-mosty will be published on 20th June, and it will focus on Australian and New Zealand Bridges.

The next e-BrIM will be released on 20th May, in both **English** *and* **Spanish***.*

We welcome your articles for both the e-BrIM and e-mosty magazines. You can contact me at magda@e-mosty.cz.

Magdaléna Sobotková

Chief Editor

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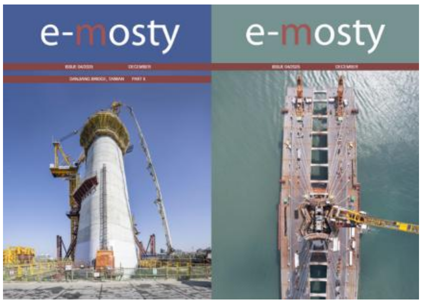

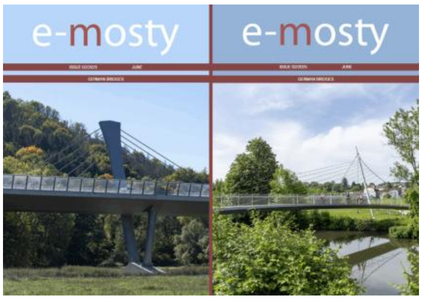

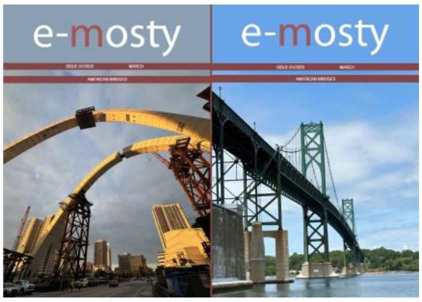

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It is published at www.e-mosty.cz and can be read
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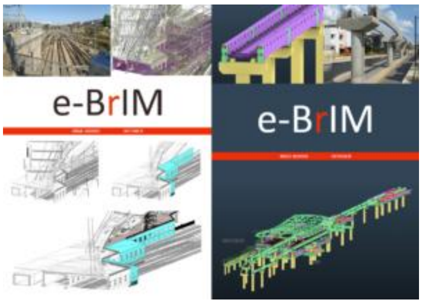

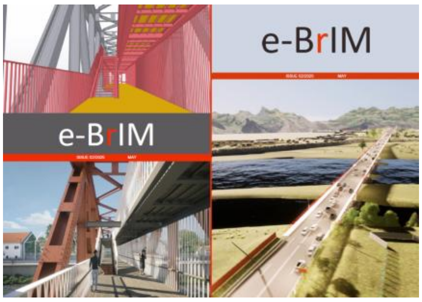

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The implications and applications of artificial intelligence, digital twins and robotics in the management of existing bridge stocks are also among the relevant objectives. IABMAS 2026 aims to act as a forum for academics, practitioners, owners and operators to discuss recent advances and identify future research directions. Together, we will share knowledge, inspire progress, and strengthen connections within our vibrant international community. We look forward to welcoming you in Orlando in July 2026.

Learn more at iabmas2026.org

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July 7-9, 2026

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Hae-Bum Andrew Yun

Chairs of IABMAS 2026 Conference, Orlando, Florida

KEY DATES

The conference dates will be July 7-9, 2026. The welcome reception will be on July 6, 2026, and the technical tours will be on July 10, 2026. For other key dates please visit our website.

GENERAL INFORMATION - VENUE, ACCOMODATION, CITY

The conference venue will be Rosen Plaza Hotel. The newly renovated hotel and its settings will enable easy access to sessions, comfortable and spontaneous networking and meeting opportunities, as well as relaxing spots for the attendees and accompanying persons. Located on International Drive, the hotel is walking distance to many attractions, restaurants, 5 minutes from Sea World, 15 minutes from Universal CityWalk and Walt Disney World. While you immerse yourself in the technical sessions, don't miss the opportunity to explore the wonders of Florida. Orlando, renowned for its world-class attractions and offers endless entertainment for all ages. Additionally, you can discover the unique natural beauty of Florida's diverse ecosystems with visits to the Everglades, pristine beaches, and the picturesque springs.

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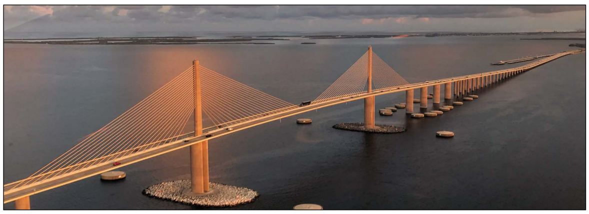

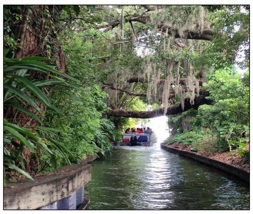

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DVORECKÝ BRIDGE, PRAGUE, CZECH REPUBLIC ARCHITECTURAL COMPETITION AND DESIGN

Radek Šíma, Atelier 6 ✉

Figure 1: Render of the bridge

INTRODUCTION

In October 2017, the City of Prague announced an open two-stage architectural and structural design competition for a new bridge over the Vltava River in the Zlíchov (West bank) – Podolí (East bank) area.

A year later, the designated jury selected the winning design, and the first steps were taken to prepare for the construction of this important structure. According to the competition specifications, the bridge is to be used primarily for public transport.

COMPETITION PARAMETERS

The aim of the competition was to find the most suitable solution for a new bridge over the Vltava River, which will create an important tangential connection – linking the banks of the Vltava between the Zlíchov and Podolí embankments and connecting Smíchov and Pankrác, Figure 2.

The aim of its construction is to improve transport links between the city on both banks of the Vltava River in the southern part of the capital city of Prague.

Another significant benefit is the connection of cycle paths that run along both banks (A1, A2), i.e., as a replacement for the problematic connection via the Barrandov Bridge (A12).

The Dvorecký Bridge in Prague is a prominent architectural feature in the Vltava River valley south of Vyšehrad. The competition conditions defined the plan and height of the bridge, requiring a solution designed for tram and bus lines of public transport and the integrated rescue system, while also ensuring the movement of pedestrians and cyclists, Figures 3 - 5. The use of the bridge for individual car transport was not included in the assignment.

A full-fledged three-arm intersection is being built on both banks. On the west (Smíchov) side, it respects the height and layout of the track connections to the "Reconstruction of the Nádražní tram line" project, while on the east (Podolí) side, it is based on the existing track positions. The design includes a new combined bus and tram stop on the west side of the bridge.

It is clear from the specifications that this is a significantly asymmetrical bridge, both in its layout relative to the Vltava River and in its height. The total elevation is around 10 m, with the highest point approximately above the left bank of the river. These two "slopes," in terms of both layout and height, which were given in the competition specifications, later proved to be essential when searching for the actual design of the bridge.

The actual design of the bridge was not part of the competition conditions; only the maximum permissible number of piers in the riverbed was defined – two. The minimum width and height of the navigation space in general were defined, as well as the navigation corridor of the existing boat hotel anchored on the Podolí side of the river.

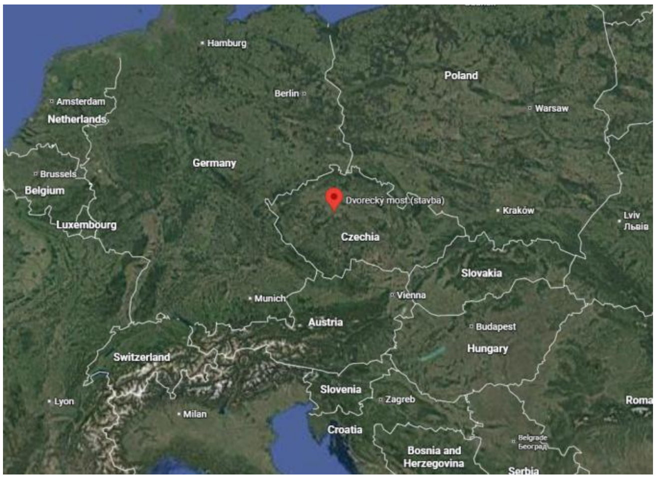

Figure 2: Location of the bridge. Click on the map
Source: Google Maps

DESIGN TEAM	
Lead Architect:	Radek Šíma
Lead Bridge Designer:	Petr Souček
Architect:	Štěpán Braťka
Bridge Designer:	Martin Blatský
Lead Project Engineer:	Jiří Pech
Artistic Design:	Krištof Kintera
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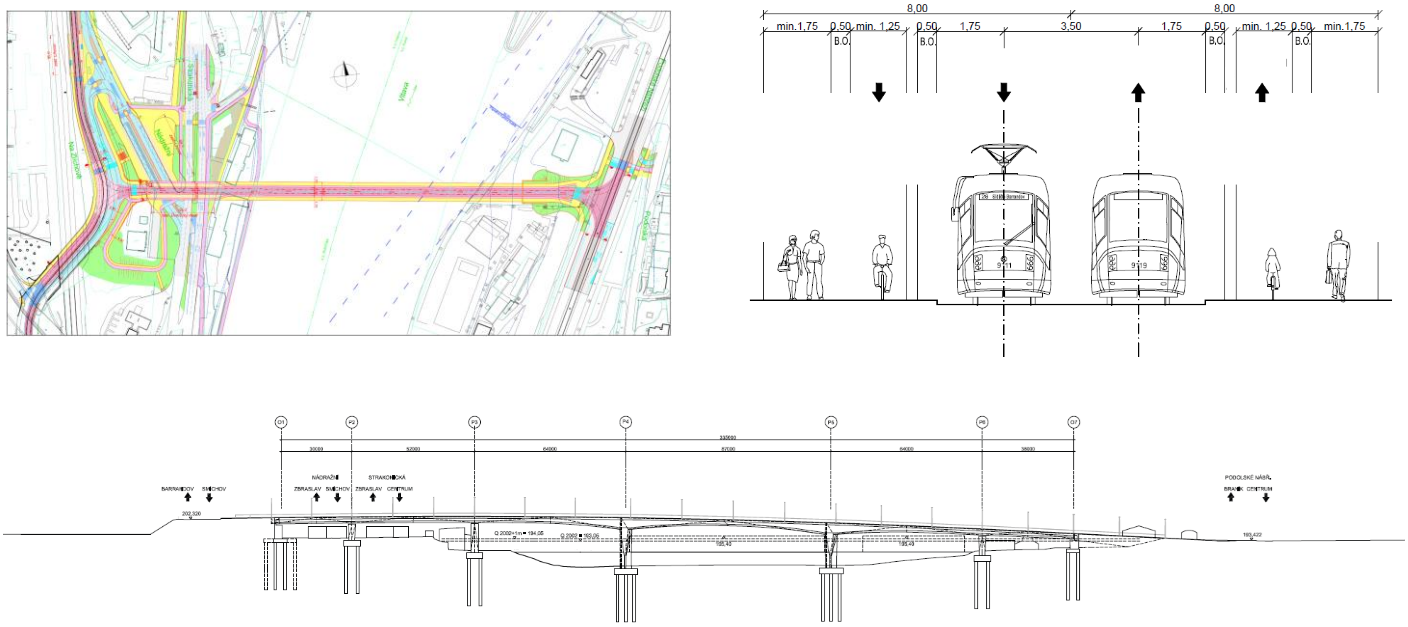


Figures 3 - 5: Competition parameters. Click on the image to open it in a higher resolution

It was required that all bridge elements requiring increased maintenance and servicing (e.g., bearings) be located above the Q2002+1m level, in our case, above the 194.200 level.

SEARCHING FOR SHAPE

At the outset, it was crucial to establish cooperation between the team of authors – bridge engineers and architects. Communication took place from the initial considerations in defining the intention and starting points for the solution, throughout the work on the competition design, to the processing of the final outputs. The energy, mutual respect, and relationships that developed during the project were the most important prerequisites for success in the competition.

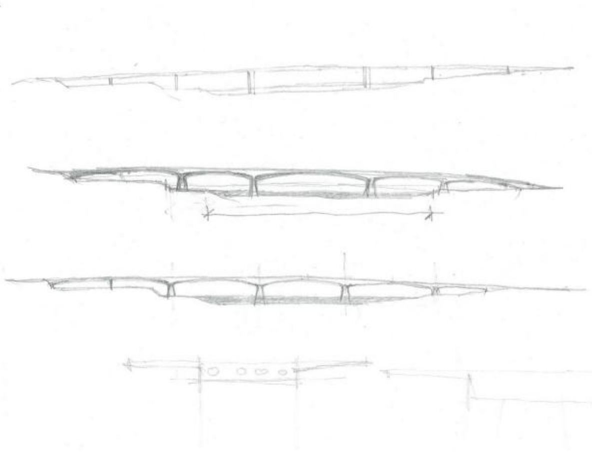
Our search for a design solution was inspired by the reflections of art historians who defined the character of Prague as a place with a very specific atmosphere, such as V. V. Štech and the Norwegian theorist of architecture, sociology, and history Christian Norberg-Schulz.

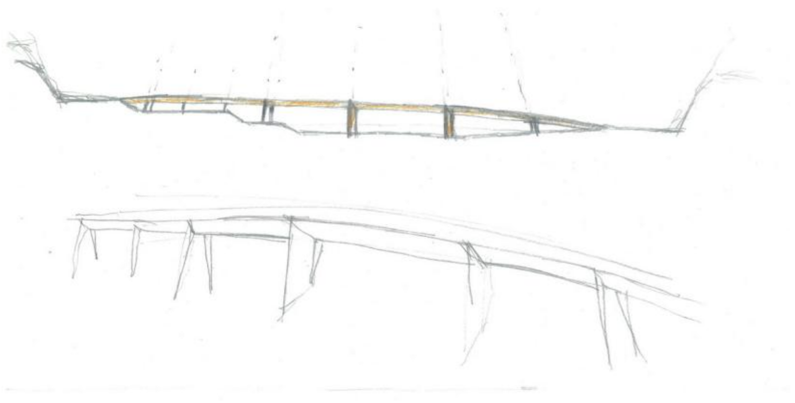
"And so we unwittingly ask ourselves what actually makes Prague so beautiful. I would say that it is primarily the landscape. Indeed, one could even speak of geographical predestination. ***It is a landscape shaped by the Vltava River****. ... The Vltava creates a basic plain against the hills and valleys that make up the rest of Prague. These hills mean plasticity, movement of the terrain. This is the first sign that determines the character of Prague.* ***It is a plastic city.*** *A city that has no parallel in Europe."*

V. V. Štech: Walks through Prague, Chapter Character of Prague, 1972

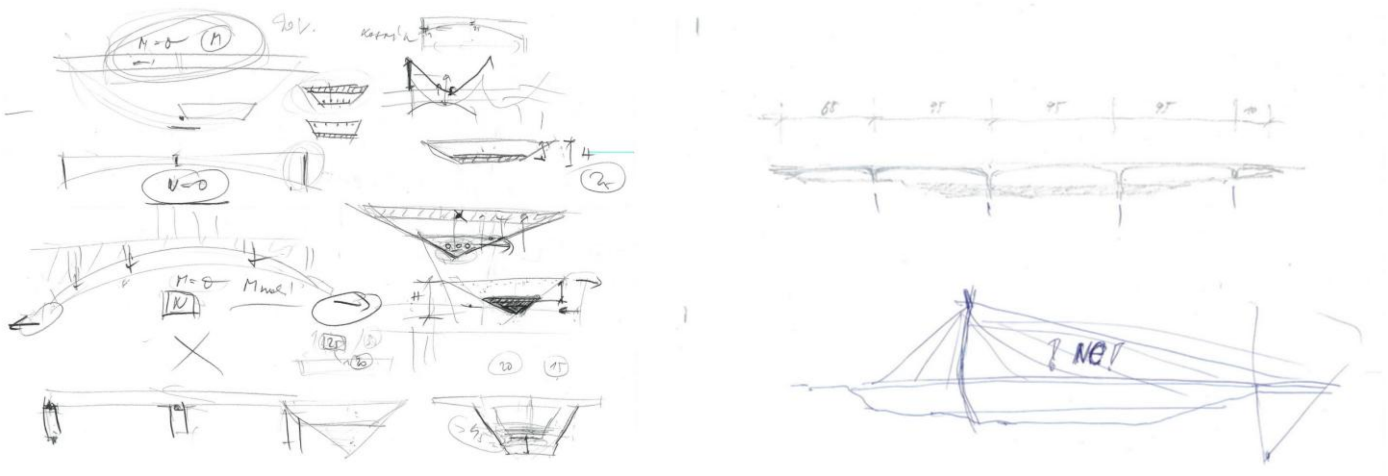
Few places evoke such enchantment as Prague. Other cities may be more spectacular, more charming, or more "beautiful." However, Prague will captivate you and hold you with a power unlike any other place. ... ***The enchantment of Prague stems primarily from an urgent sense of mystery.*** *Here, you get the impression that it is possible to penetrate ever deeper into the inner workings of things. Streets, doorways, courtyards, and staircases lead you into an endless "interior." ... Walking through old Prague, one has the feeling of being "at the bottom" of spaces that are mysterious and threatening, but at the same time warm and protective."*

"Prague as a whole is characterised by the contrast between earth and sky. *The steep hill on which Prague Castle stands contrasts with the horizontally spread cluster of the Old Town, and the Castle itself concentrates the local character in its long horizontal lines, above which St. Vitus Cathedral rises to the sky. This last juxtaposition is the culminating view of the "famous view of Prague": the view across the Vltava River, flowing horizontally, to the vertically rising Lesser Town. The two main parts of Prague, the Old Town below on the plateau at the bend of the river and the Lesser Town and the hill with the Castle on the other side, are connected by Charles Bridge.* ***In Prague, the bridge truly "brings together the land as a landscape around the river",*** *but at the same time it also brings together what man has contributed to this place as an urban landscape of unique quality. ... From the bridge, one perceives the whole as an environment in the deepest sense of the word;* ***the bridge forms the true centre of this world, which brings together so many meanings****.*





Figures 6 and 7: First sketches of the Bridge



Figures 8 and 9: Evolution of the Bridge

*“**The size of Prague as a place also stems from its imagery.** We do not get lost in its mysteries; the mysterious interior spaces are always part of a broader, meaningful structure that connects them like the mysteriously **glowing facets of a gemstone**. Prague truly transforms like a gemstone with the changing weather, times of day, and seasons. The light is usually filtered by clouds, the towers are "foggy," and the sky is covered. And yet this does not mean a loss of presence. **In Prague, what is hidden seems even more real than what can be immediately perceived.**"*

*"The architecture of Prague is cosmopolitan, yet never loses its local flavour. **Romanesque, Gothic, Renaissance, Art Nouveau, and even "Cubist" buildings coexist as if they were variations on the same theme**. ... The catalyst that made this process possible was the genius loci itself, which lies in a special sense of the earth and sky. In Prague, classical architecture becomes romantic, and romantic architecture absorbs classical character. Both become cosmic, not as an abstract order, but as a spiritual endeavour. **Prague is definitely one of the great meeting places where a multitude of meanings converge.**"*

Christian Norberg-Schul: Genius Loci, Chapter IV, Prague, 1st Image, 1979

It was clear that fundamental attention needed to be paid to the overall horizontal effect of the bridge, which would complement the Vyšehrad walls, the Podolí waterworks, and, in a way, on the other side, upstream, the Barrandov Bridge. We soon abandoned all options with dominant elements above the bridge deck (pylons, upper arches) in our considerations.

When searching for a design solution, we had in mind the personality of František Mencl (1879–1960) – a building advisor, city engineer, and bridge designer for our capital city. He was well aware of how important it was for the historic city centre that the bridge fit well into the surrounding buildings and the cityscape, so that its appearance would not disrupt the valuable panorama but rather emphasise and complement it.

At the same time, in his opinion, new bridges should respect the appearance of older ones, Figure 10. In the context of the history and landscape of the Vltava valley in Prague, he preferred arched bridges, which would create a unified whole in terms of construction but a diverse one in terms of artistic design.

The iconic view from the Hanavský Pavilion in Letná, looking both upstream and downstream, became fundamental to us.

Figure 10: Prague bridges

All Prague bridges, although built in various periods from Gothic to Functionalism, form a single whole. Although each one is from a different historical period, and this is reflected in their construction, architectural and technical design, they have three elements in common: they have no supporting structure above the bridge deck, they are all arched, and the piers in the river span the entire width of the bridge deck.

The fact that the piers span the entire width of the bridge deck means that, when viewed from the front, Prague's bridges are relatively slender, but when viewed from the embankment, we perceive the full width and mass of their piers (a double reading of a single object, depending on the observer's position).

These three principles, together with the conditions of the competition brief, became our starting points in the search for form.

The piers across the entire width of the bridge deck, together with the sloping ground plan of the bridge in relation to the current, required, for hydrodynamic reasons, a rotation in relation to the bridge deck; the piers on the banks (especially on the Smíchov side) had to be placed in relatively cramped conditions at the base (between existing roads or structures); and had to be significantly wider under the bridge deck (bearing placement) and therefore of an expanding shape.

Gradual refinement began to reveal the "cubist" shape of the bridge; cubism, as a phenomenon of Czech architecture, whose fundamental source lies on the other side of Vyšehrad, see Figures 11 and 12.

COMPETITION DESIGN

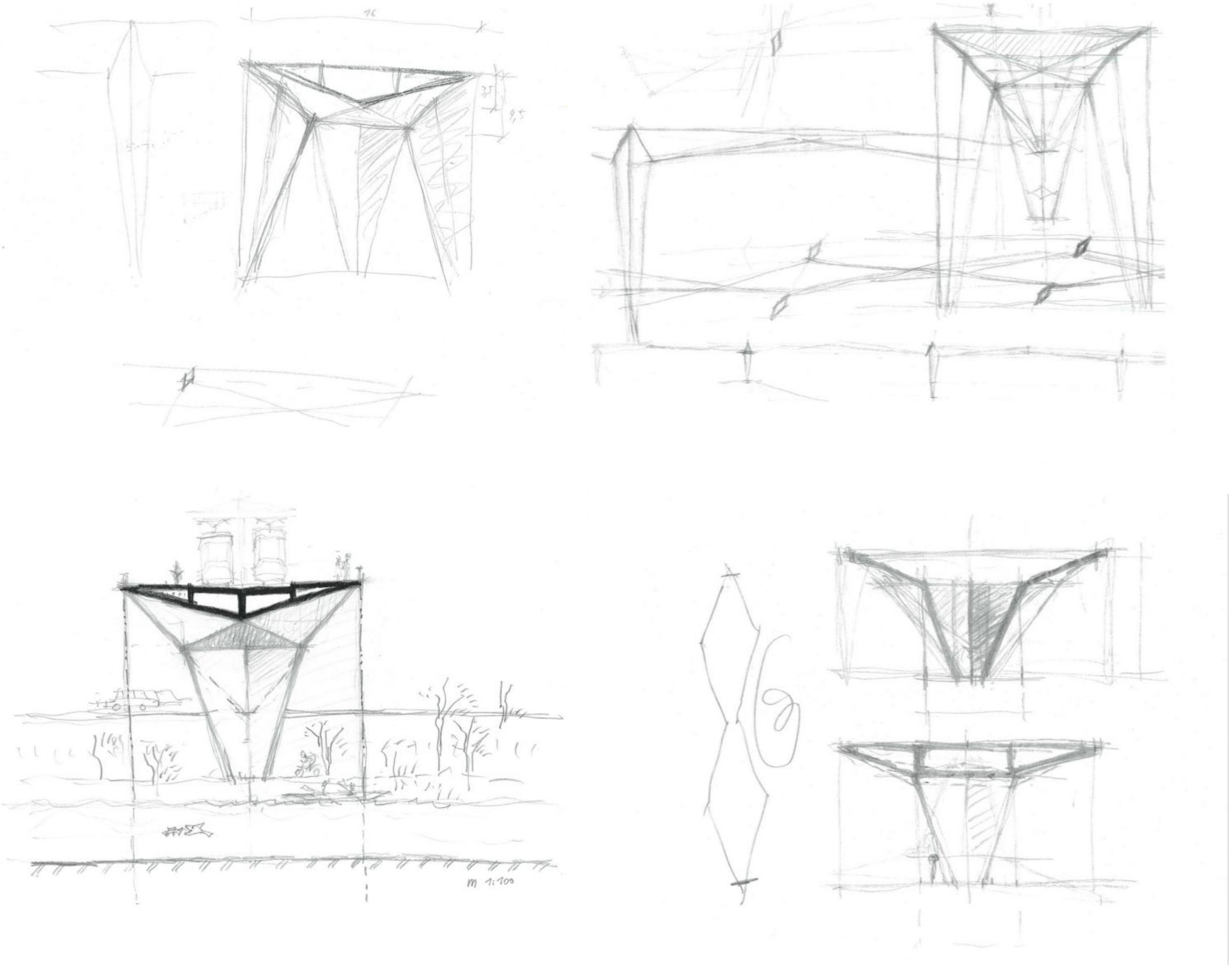
A total of 45 teams participated in the two-round competition, including foreign teams, among which were names such as Santiago Calatrava and Wilkinson Eyre.

The competition was anonymous, with a seven-member jury, three of whom were dependent (the mayor of the city and the mayors of the affected city districts, Prague 4 and Prague 5), while the independent part of the jury was represented by two bridge experts – structural engineers, an urban planner, and an architect.

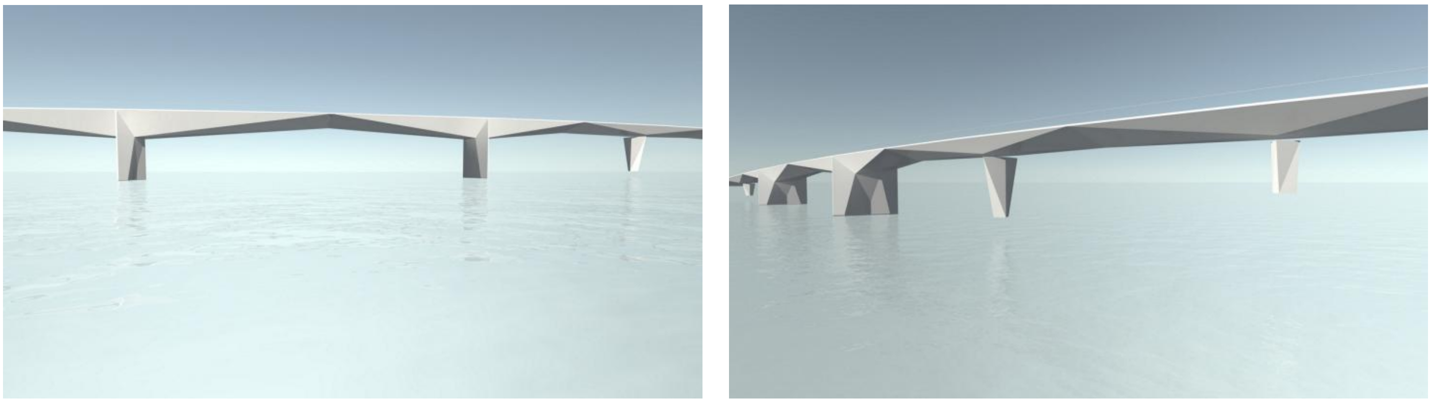
The winning design was submitted by a team of architects and engineers from Tubes and Atelier 6.

The selected design responds to the given conditions of the site and the assignment (asymmetrical in height, sloping towards the Vltava River, the underside of the bridge deck exposed to view), refers to the tradition of Prague's arch bridges, without a structure above the bridge deck (especially in distant views above the Vltava River), and to the existence of nearby Cubist buildings (cubism as a Czech and Prague phenomenon).

Figures 11 and 12: Cubist architecture near the Bridge



Figures 13 - 16: The Bridge takes its shape



Figures 17 and 18: First renders showing the shape of the Bridge

Figure 19: The shape of the whole Bridge

We are shaping the bridge like a sculpture – a white gateway to the city (piers in the water across the width of the bridge deck, integrated with the supporting structure).

The river piers fulfil the function of the "water gauge" – so-called "Bearded Man" of Charles Bridge. The shape corresponds to the norm, and extreme water levels will be visually noticeable. Emphasis was placed on designing the bridgehead in a manner common in the city's built-up area.

It is a six-span beam bridge with a prestressed reinforced concrete box-girder cross-section, with a superstructure length of 337.8 m (30 + 51.5 + 62.5 + 87 + 62.5 + 42.5 m). The main span of the bridge crosses an 80 m wide navigation channel.

The structure consists of a three-box cross-section with two main load-bearing inner walls of variable height. The outer sloping walls define the structure's shape; they are inclined. The cross-section, which changes from trapezoidal above the piers to triangular in the middle of the span, defines the shape of the bridge.

The tram track space on the bridge is designed to be directly accessible, and the public lighting columns are integrated to support the traction line.

WORK DESIGN, PROJECT FOR COMBINED LAND USE AND BUILDING PERMITS

In subsequent design stages, we focused on refining the shapes of the piers, bridge supports, and bridge surface from an architectural perspective—white concrete with exposed formwork texture from unplaned boards, and the design and shaping of combined public lighting/tram poles or railings, Figures 20 and 21.

The railing made of flat posts is a spatial mirror image of the bridge deck, while the handrail itself is designed from artificial stone and backlit with LED strips.

The main emphasis at this stage was on designing the approaches on both sides of the river so that the bridge, in addition to meeting the requirements of strength and functionality, would also be a natural part of the public space.

A public transport interchange on the west bank, called Lihovar, includes a new tram/bus stop directly on the bridge. Several access routes are planned from the bridge to the bus stop under the bridge, including a prominent staircase on both sides of the bridge and a separate footbridge on the south side, which will provide a direct, barrier-

Figure 20: White concrete of the Bridge

Figure 21: Combined Lighting/Tram Poles and railings

Figures 22 and 23: Footbridge and the staircase

free connection for pedestrians and cyclists between the bridge and Nádražní Street, Figures 22 and 23.

It is a light, transparent, significantly curved structure with 16 spans and a length of 126.6 m. Its superstructure consists of a bridge deck of steel profiles and crossbars, with a walkable surface of gratings; the supports are also made of steel.

On the north side of the bridge, a multifunctional Public Transport Information Centre building is integrated into the slope, Figures 24 and 25.

The building's functional content includes a café. It also includes toilets not only for visitors to the building, but also for the public. In front of the building, the public space is extended to create a covered outdoor garden with seating.

The modifications around the bridge include landscaping designed to look as natural as possible. The landscaping design is the work of landscape architect Zdeněk Sendler and includes a staircase along Nádražní Street, which connects to the Information Centre building.

ARTWORKS

The Dvorecký Bridge will become an important new transport artery of the metropolis. In addition to its significant role in the city's infrastructure, it also plays an equally important cultural role.

On both sides of the bridge, unique urban environments are being created that connect it to its surroundings and add unexpected value.

The aim of the sculptural and environmental intervention in the Dvorecký Bridge project is not to create a sculptural decoration for the bridge, but primarily to solve urban planning problems generated by the very existence of the bridge (an area on the Podolí bank 40 m long and 16.5 m wide, with the bridge deck itself) and on the existing character of the place (the inner periphery on the south side of the abutment on the Smíchov bank with all the negative social phenomena resulting from this).

The artistic design creates an environment whose attractiveness lays the groundwork for the long-term social use of these locations and

Figures 24 and 25: Multifunctional building

Figures 26 and 27: Light against darkness – collection of street lamps, visualisation

complements it with a new socio-urban environment in its approach areas in Podolí and Zlíchov.

On the left bank, there is an installation called "Light Against Darkness", a unique collection of street lamps from 81 countries around the world. In 2021, synergistic cooperation began with partner cities of the capital city of Prague, Czech Centres, representative offices and embassies, and last but not least, friends and acquaintances around the world.

The garden of lighting fixtures and columns is being created according to a design by artist Kryštof Kintera, with the lighting intensity continuously adjusted and controlled by external conditions.

A smaller portion of these lights will be used for the footbridge itself, Figures 26 and 27.

In the Podolí area, the bridge's final section crosses gently rising terrain to the cycle path along the embankment.

The space under the bridge, which can often be problematic for use, has recreational potential due to its proximity to the spa complex.

In collaboration with Kryštof Kintera, an artificial urban landscape has been designed for this area – an arena shaped in accordance with the bridge structure above it, intended to create a suitable environment for organised events and performances and for everyday outdoor activities, Figures 28 and 29.

The installation of works of art (sculptures, lighting fixtures) is also planned, and the construction includes preparations (installation) for a possible refreshment facility. The space is also intended for sports use (skateboarding, bouldering).

Figures 28 and 29: Artistic installation under the bridge

Figures 30 and 31: The area under the bridge, with a specific urban landscape and lighting

The bridge abutment, therefore, also includes arena facilities, such as toilets and storage space. The arena space under the bridge will be accessible from the embankment via walkways along the connecting wings of the abutment and the coastal path from the Racek boat hotel.

The arena space will be lit, among other things, by an artistically atypical bent column from the bridge, Figures 30 and 31.

RELATED PROJECTS – LIHOVAR

The design is based on an effort to cultivate the space, which, together with the Dvorecký Bridge, becomes the gateway to Smíchov and, in fact, the entire inner city of Prague when arriving in the centre from the south.

Although this space has significant limitations due to the busy roads around its perimeter, especially Strakonická Street, it can be cultivated to the point that it serves as the city's entrance hall.

Its importance will increase in the future, as construction of an entirely new city district in the unused area near the Praha-Smíchov railway station progresses.

It should allow people and cyclists to pass through without any problems and enable the pleasant use of the space in a traditional urban way. Its main ambition is to increase the amount of greenery.

The solution is very simple and clear in principle, consisting essentially of just three elements: stone paving of Prague granite mosaic around the perimeter, a gravel area in the middle, and a regular grid of plane trees.

This is complemented by traditional urban furniture – benches, drinking fountains, trash cans, bike racks, tree grates, and lighting.

Figures 32 and 33: Development of areas on the west riverbank and related areas

RELATED PROJECTS – SCOUT BASE

The water sports scout group's premises are being built to replace the existing premises, which will be demolished in connection with the construction of a bridge.

It is located on the right bank of the Vltava River in Podolí, bordered by the Racek boat hotel parking lot to the north, the foot of the Dvorecký Bridge to the south, and a busy embankment road to the east, along which runs a popular and heavily used walking and cycling path.

Despite its busyness, the area has a pleasant recreational character, largely due to the presence of the Vltava River (Podolí swimming complex, Žluté lázně).

The atmosphere is complemented by a number of buildings whose uses are linked to the river's potential, such as rowing clubs and river spas.

Unfortunately, the vast majority of these buildings have disappeared (Podolí lido), while some are undergoing gradual redevelopment or expansion, which often obscures their original poetic character.

The most significant preserved building from this group of structures is the "Czech Yacht Club," a wooden, four-storey building on a peninsula near the port in Podolí, below the Vyšehrad rock.

Its form, a black volume with white window frames, also inspired the design of the proposed boating base.

The proposed complex consists of three separate buildings. These are the scouts´ clubhouse, a boathouse, and a workshop.

These three structures are located along the edges of the flat part of the plot and are oriented toward significant elements of the surrounding area—the river, bridge, and road—so as to leave as much space as possible for the inner courtyard, which is used for children's outdoor activities.

The buildings are connected by a solid wooden fence, which ensures the greatest possible privacy for the courtyard despite its proximity to sources of noise.

All buildings are wooden, clad with boards charred using the historical Japanese construction technique "Shou Sugi Ban Yakisugi."

This method protects the wood from decay, mould, and wood-destroying fungi, while significantly increasing its fire resistance.

Based on the principles of the circular economy, the material consists of recycled planks from bridge formwork, which were stored throughout the construction period.

Figures 34 and 35: Newly built complex

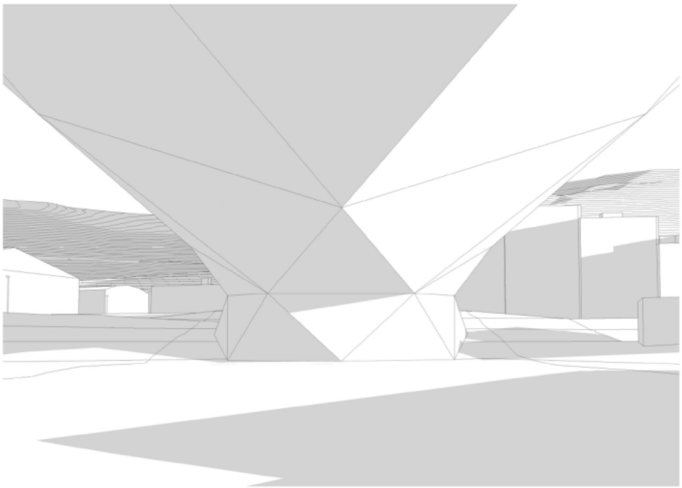


Figure 36: Abutment on the eastern embankment (Podolí)

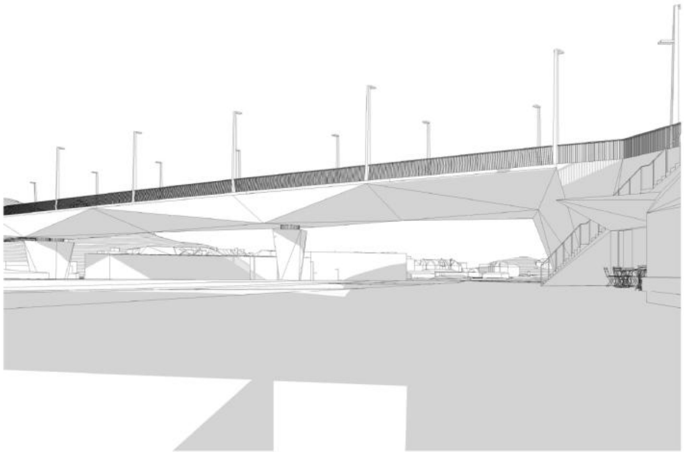


Figure 37: Bus stop on the western embankment

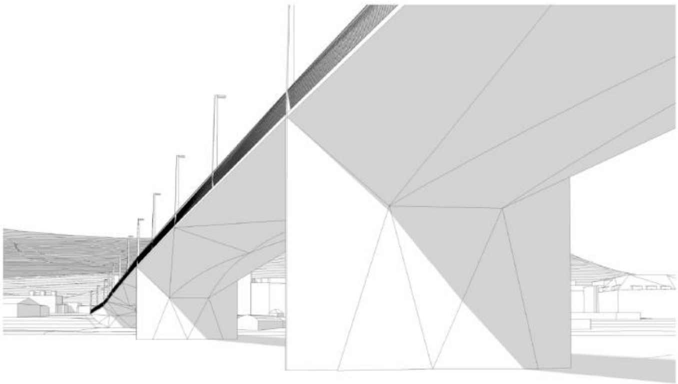


Figure 38: A view towards Podolí side

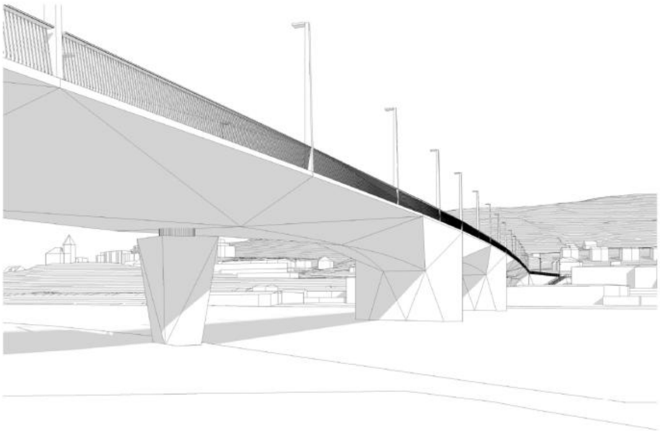


Figure 39: A view towards Smíchov side

Sketches, drawings and models by Atelier 6, Tubes and Krystof Kintera

DESIGN AND CONSTRUCTION OF THE DVORECKÝ BRIDGE, PRAGUE, CZECH REPUBLIC

Petr Souček, Martin Blatský, Pontex
Miroslav Seidl, Pragoprojekt

Robert Brož, Petr Koukolík, Maroš Híreš, Metrostav TBR
Radim Cihlář, Strabag
Roman Škoch, Firesta – Fišer

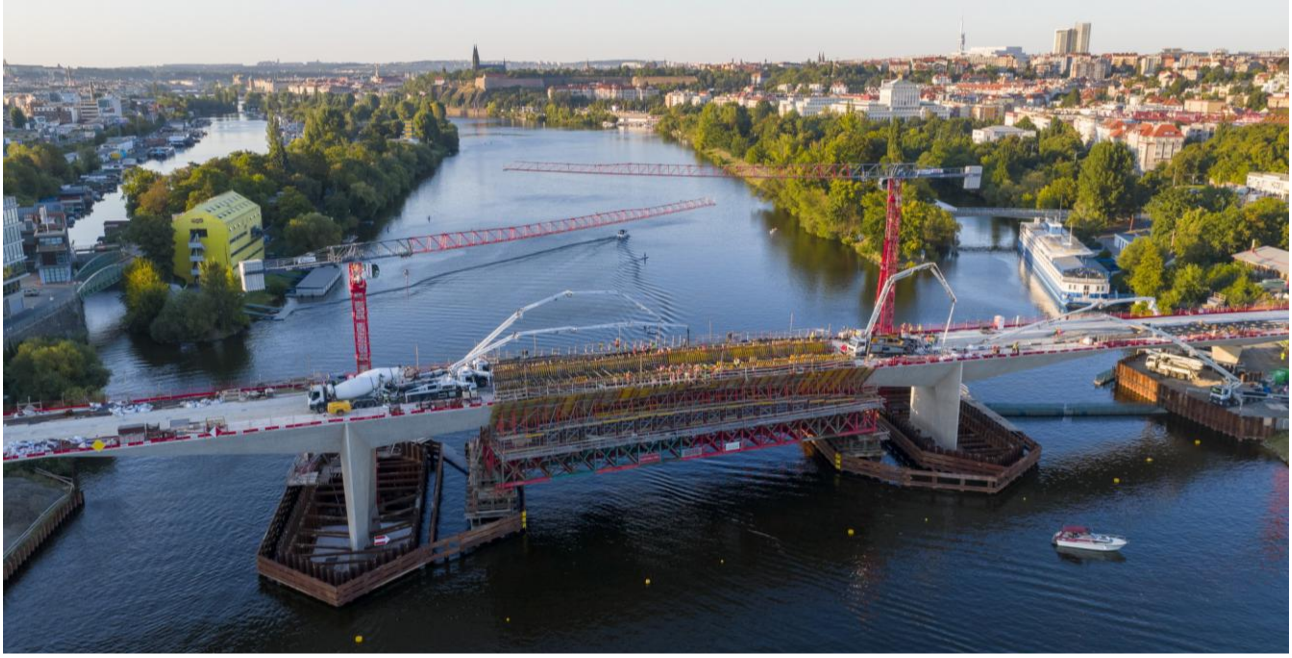


Figure 1: Dvorecký Bridge under construction – casting of the main span

INTRODUCTION

Upon its imminent completion, Dvorecký Bridge will be Prague's 19th bridge across the Vltava River. The location and use of the bridge were selected by the Prague City Council and incorporated into the city's zoning plan.

The designated use of the bridge for trams and buses, excluding individual car traffic, is a debatable topic. However, the reason for this restriction is not the bridge itself, but the insufficient traffic capacity of the connecting intersections and roads on both sides of the bridge.

The design of the bridge was the result of an architectural competition. Atelier 6 and Tubes, where the authors (architects and civil engineers) of the winning competition design worked, subsequently prepared the necessary stages of project documentation in 2019-2021, obtained the necessary construction permits and prepared the tender documentation.

Subsequently, the team around the authors and co-authors of the design at the design offices Pragoprojekt and Pontex spent more than three years developing detailed documentation for the contractor, which was selected in a public tender in 2022 and is a consortium comprising Metrostav TBR, Strabag and Firesta-Fišer. Construction began in the autumn of 2022 and is currently just a few weeks away from completion and commissioning.

This article focuses on the main bridge structure of the project, the bridge over the Vltava River.

OVERALL DESIGN OF THE BRIDGE

The bridge is designed as a continuous 337.8m long box girder structure made of prestressed concrete with six spans, each 30 + 51.5 + 62.5 + 87 + 62.5 + 42.5 m. The bridge's distinctive shape corresponds precisely to the winning design's architectural expression.

All visible surfaces of both the substructure and the superstructure of the bridge consistently use the motif of triangles. Their interplay in space creates a structural peculiarity – a purely triangular cross-section in the middle of all bridge spans.

All visible parts of the structure are designed in white concrete. The width of the superstructure is a relatively modest 16.5 m, due to the relatively narrow roadway (only 7.0 m) intended only for trams and city buses. The 4.5 m wide sidewalks on both sides allow pedestrians and cyclists to move around comfortably.

Due to the connection of the route to the bridgeheads, the axis of the bridge runs diagonally across the river, with the width of the river on this alignment exceeding 180 m. There are two main wall piers in the river, which respect the direction of the river current and are therefore skewed to the bridge axis. These piers are frame-connected to the superstructure.

The main span is 87 m, allowing navigation on the river with a single navigation profile of 80 m perpendicular width. In the adjacent span on the Podolí bank, the bridge structure exceeds the 40 m wide navigation profile for handling the Racek boat hotel.

On the left (west) bank, the first two spans of the structure cross Nádražní and Strakonická Streets, and behind the abutment, the route smoothly connects to Na Zlíchově Street with the existing tram line.

The main span of the bridge safely crosses the 7m high navigation profile of the river, and towards the right (east) bank, the bridge level descends to connect smoothly with the tram line on Podolské nábřeží.

Despite the significant drop in level on the right bank, the superstructure is located above the prescribed standard reserve above the Q2002 level (the flood level in Prague in 2002, corresponding to approximately a thousand-year flood).

GEOLOGICAL CONDITIONS

The structure is located in the river valley floodplain, with the existing banks covered by thick, often highly heterogeneous fill that was historically dumped here to protect against high water levels in the Vltava River.

The Quaternary cover consists mainly of low-bearing sandy-clayey alluvium and relatively high-bearing waterlogged terrace gravel. The rock massif is composed of shales with tuff layers.

The shales are irregularly weathered at the surface, and the massif is folded with variable layer inclination.

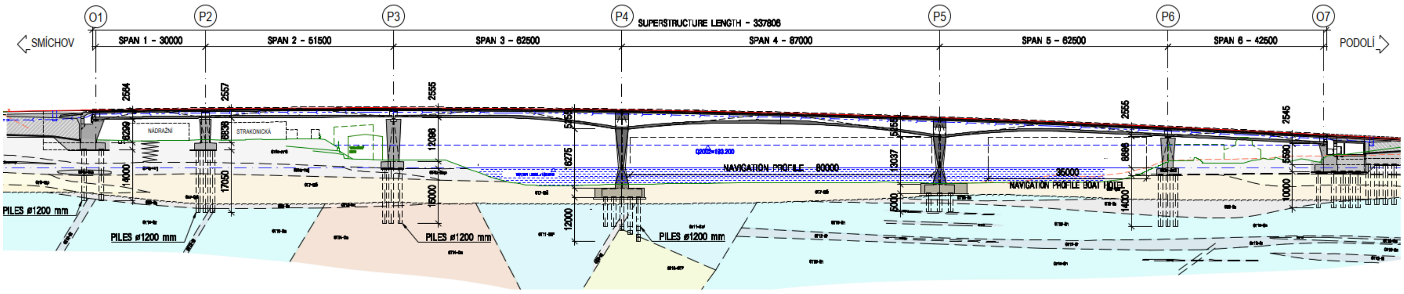


Figure 2: Longitudinal section

Click on the image to open it in a higher resolution

A key factor complicating the foundation is the existence of a geological fault (a significant fault zone) in the river area of pier P4. The survey found very complex geological conditions here, with rapid changes in the quality of the rock massif under the riverbed.

Strongly tectonically disturbed shales and quartzites were found here, and a lamprophyre vein was also documented on the edge. Significant tectonic disruption in the shales is manifested by local degradation of rock with low to extremely low strength, frequent smoothing and crushing, and abundant clay filling of numerous cracks.

Often, in such significantly disrupted rock, disconnected blocks of significantly stronger rock (slate, quartzite, or even lamprophyre) of various sizes "float freely". In quartzite locations, tectonics manifests as significant disruption, and the rock shows fragmentary decay, with clay filling the cracks also being common.

BRIDGE FOUNDATION

From the outset, the piers and both abutments were designed to be founded on 1200 mm piles, usually with the bases embedded in class R4–R3 (R2) bedrock.

The exception was pier P4, located in a fault zone, where the possibility of implementing deep foundation elements was the subject of numerous consultations with geotechnical engineers and foundation experts during the design preparation phase.

Some recommendations suggested abandoning the pile foundation and replacing it with a shallow foundation, along with extensive subsoil grouting, while others suggested a foundation on small-profile piles up to 300 mm in diameter.

Others, on the contrary, suggested using piles with the largest possible diameter so that any boulders encountered could be removed or solid layers broken up.

In the tender documentation, the designer for pier P4 ultimately opted to use a larger number of 900 mm-diameter piles. Due to the significantly poorer quality of the rock (class R5/R6), the piles were designed to be 20 m long, whereas for the sister pier P5 outside the fault zone, short piles 5 m long were planned, embedded/supported in healthy subsoil class R3-R2.

During construction, the following difficulties arose with the bridge foundation:

During the construction of the P2 piles, a massive concrete mixture leak occurred outside the boreholes when the casings were pulled out of two piles.

After partial hardening, the piles were drilled out the following day and rebuilt. It turned out that in the area of Strakonická Street, there are various historical objects in the subsoil, in layers of massive fillings, albeit demolished and buried, with unfilled spaces where fresh concrete from the completed piles spilt.

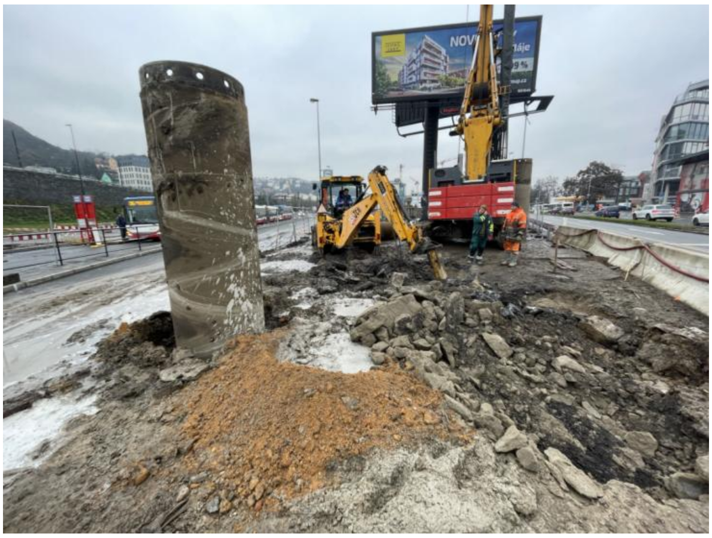


Figure 3: Piles of pier P2

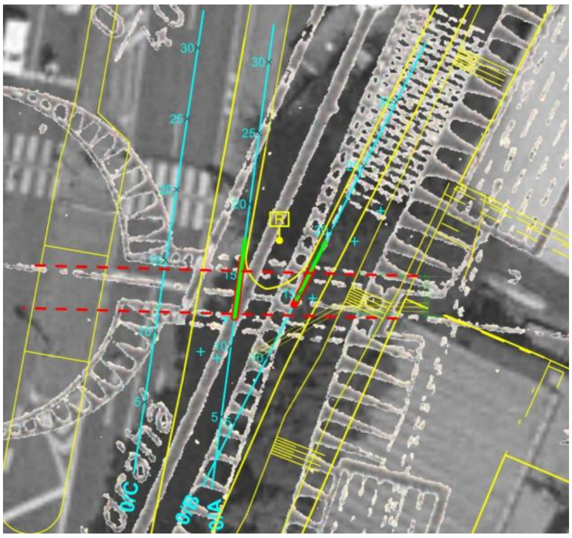


Figure 4: GPR survey at the rowing club

According to a historical map of Smíchov obtained later, there was a sawmill in this area for processing timber floated down the Vltava River on rafts, to which a vaulted bridge led from the river as a so-called "timber lift". This historic arched bridge, now located under Strakonická Street, was also discovered during construction, and its presence posed an obstacle to the subsequent installation of falsework for the superstructure in the second span. The falsework was then installed on a slab supported by additional piles outside the historic arch.

After experiencing problems with the execution of the P2 pier piles, an additional georadar survey of the subsoil was carried out at the O1 abutment to identify possible cavities and heterogeneity of the fill. Based on this survey, sacrificial piles made of plain concrete were installed at selected locations to verify that there would be no significant leakage of fresh concrete during the installation of the system piles, as had happened with the neighbouring P2 pier. However, the sacrificial piles did not encounter any significant heterogeneity, and so the system piles of support O1 were subsequently drilled without any serious problems.

The most demanding part of the bridge construction was the execution of piles P4 and P5, along with their construction pits. The drilled piles for both piers in the riverbed were constructed from a floating pontoon, on which a drilling rig was placed, and drilling was carried out through the water column to the riverbed.

Pier P5 is based on a total of 23 drilled piles 1200 mm in diameter, with a total length of 5.0 m. The foundation joint of pier P5 is at a depth of approx. 3.5 m below the level of the bottom of the Vltava riverbed, so the boreholes were approx. 8.5 m long.

Although hard rock up to class R2 was encountered about 6 m below the riverbed, the required minimum pile length of 5.0 m was ultimately achieved with considerable effort. The pontoon with the drilling rig then moved to the location of pier P4 to construct 20m-long piles.

Although this was a fault zone, the actual construction of the piles almost replicated the scenario at pier P5, where hard rock, difficult to drill, was encountered relatively early on.

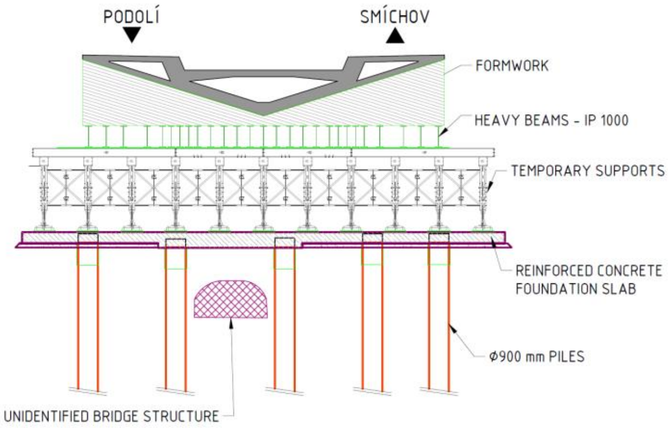


Figure 5: Falsework above old buried vaulted bridge

After several attempts at various locations on the foundation with similar results, work on the piles for pier P4 was suspended, and it was decided to prepare a more detailed supplementary geological survey.

As part of this, five additional core drillings were carried out in the ground plan of the P4 pier foundation, along with other supplementary tests and measurements (logging measurements and seismic tomography between drillings).

The results of the work refined the interpretation of the geological composition of the subsoil and the characteristics of the geotechnical types encountered, and provided information on the distribution of tectonic disturbance areas in the form of a 3D subsoil model.

Figure 6: Pile drilling at pier P5

The basic characteristics of the disturbed massif were specified as class R4 rock. Based on the additional survey, the technical solution for the foundation was recalculated and modified. Pier P4 is ultimately founded on a total of 48 piles Ø 1200 mm, with a total length of 8.0–12.0 m, where the variable length of the piles is designed with regard to the detected inclination of the layers of firmer positions from the 3D model of the subsoil. With the help of a special drill head, the piles were successfully executed in accordance with the modified design.

At the same time, grouting of the bases of all piles of pier P4 was designed and subsequently carried out in order to eliminate possible settling at the bases caused by possible loosening of the rock on the contact surface of the pile base due to the drilling technology and difficult cleaning of the bases in rocks of varying quality, small thickness and significant inclination of the layers. This limited the possible differential settlement of the foundations of piers P4 and P5, which would have been unfavourable for the frame structure.

The piles for all bridge supports are made of C30/37-XA2 concrete. Based on analyses of groundwater aggressiveness, the concrete mix for the O1 abutment and P2 pier piles was designed for sulphate resistance from 600 to 3000 mg/l, and for the other supports (i.e. piers P3 to P6 and support O7) for sulphate resistance from 200 to 600 mg/l. The piles were constructed in shored boreholes protected by steel casings, and integrity tests were performed on all piles.

COFFERDAMS IN THE RIVERBED

Even before work began on the P4 and P5 water piers, several sheet pile driving tests were carried out to verify the feasibility of constructing sealed sheet pile cofferdams for the foundations and shafts of piers P4 and P5.

The test results showed that the originally planned design of sealed double-shell cofferdams, constructed using conventional or vibratory pile driving, with subsequent sealing of the space between the two shells with a clay-cement mixture, appeared infeasible.

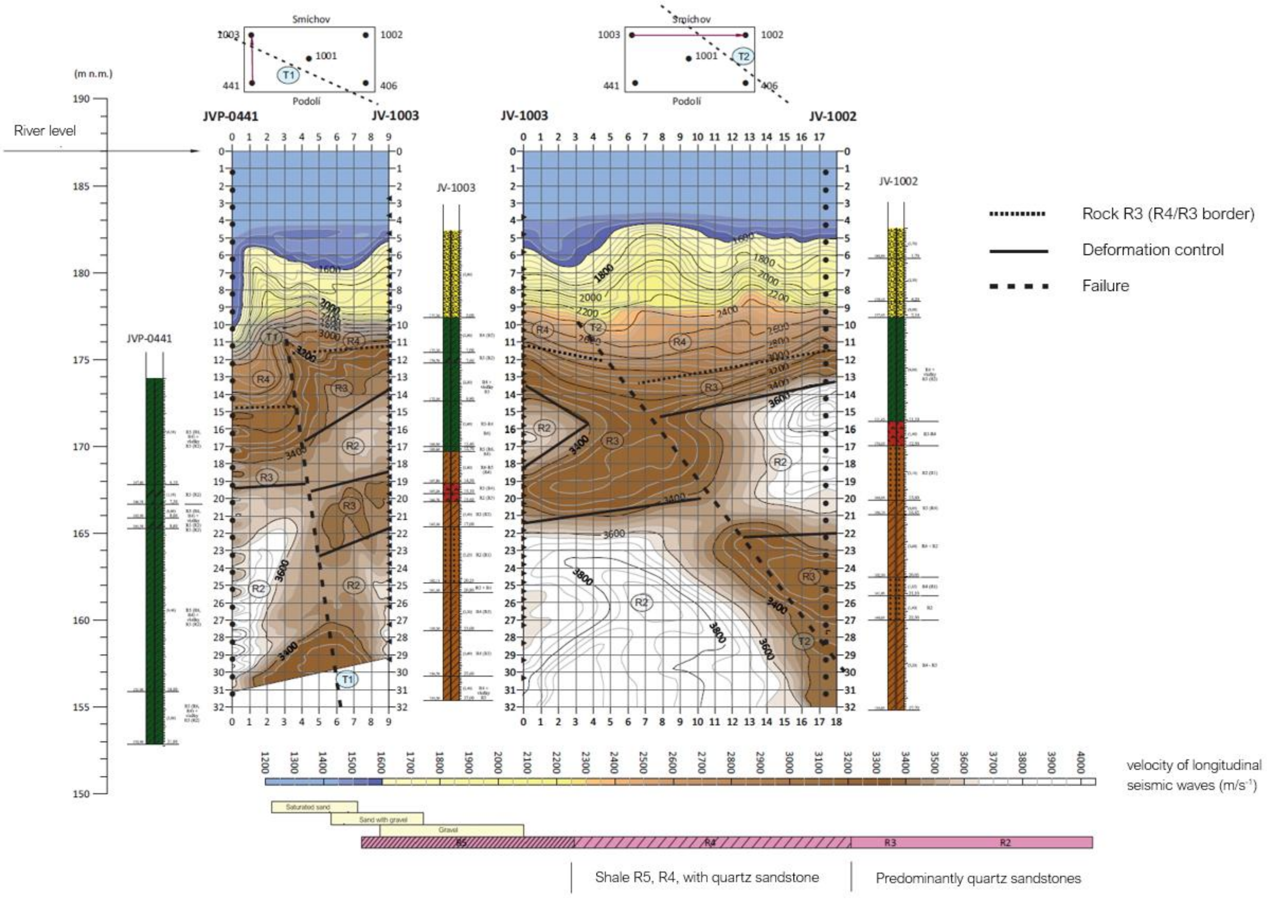


Figure 7: Seismic tomography of the subsoil of pier P4

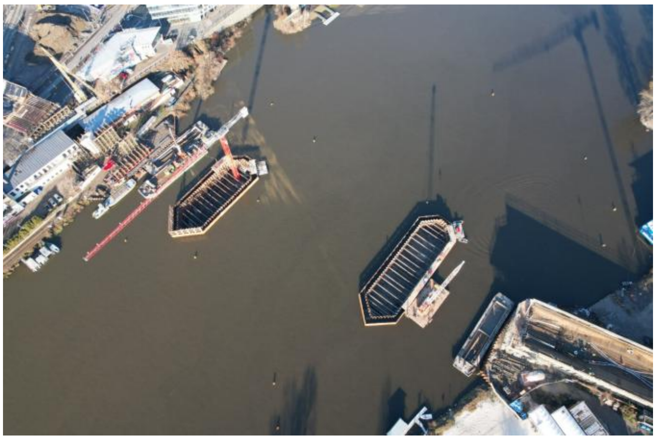


Figure 8: Cofferdams of piers P4 and P5

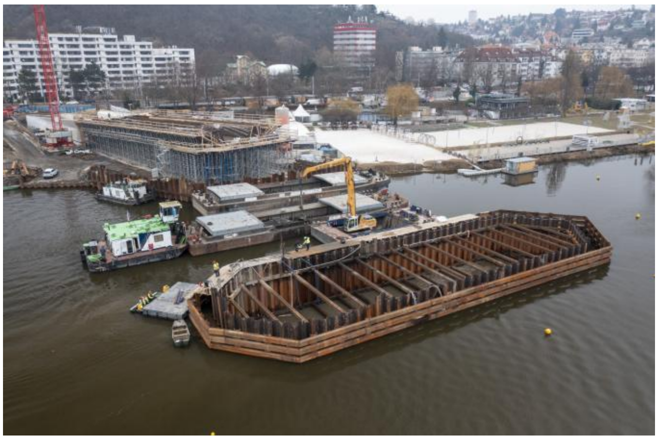


Figure 9: Sealed cofferdam of pier P5

During the tests, it was not possible to drive the sheet piles down to the weathered edge of the rock subsoil, which was intended to prevent water from flowing under the feet and thus ensure the functionality of the cofferdam.

Based on this finding, the technical solution for sealed sheet pile cofferdams was changed to single-shell cofferdams, with sheet piles driven into pre-drilled holes 1200 mm in diameter, and the holes subsequently filled with a clay-cement mixture up to the riverbed level.

The pre-drilled holes were made to a depth of approximately 6.5 m from the bottom level, so the sheet piles were embedded at least 1.5 m into the rock bedrock under the gravel terrace.

The cofferdams were then gradually secured statically during water drainage using massive steel spacer frames on two levels, and reinforced with concrete at the bottom.

The outer shell of the cofferdams is protected against impact from vessels by a fender system installed on an independent set of sheet piles. During construction, the cofferdams proved to be sufficiently watertight, and residual inflows into the pit were easily pumped out.

Only once during construction did the water level in the Vltava River rise to a height that required flooding the cofferdams for safety; after the water level dropped, they were drained again.

SUBSTRUCTURE

All elements of the substructure are monolithic reinforced concrete. The shapes of the substructure of the abutments and piers follow the architectural design of the entire bridge; all visible surfaces are composed of triangles with accentuated sharp edges.

The abutments of the bridge follow the shape of the superstructure, as do the adjoining wings in the form of retaining walls. Safety doors are installed in the abutment walls, or rather in the side surface of the wing, allowing access to the superstructure box.

The O1 abutment on the Smíchov side is significantly sloped in its ground plan, following the course of Nádražní Street under the bridge. The O1 abutment consists of a massive shaft with a bearing sill and screen walls smoothly connecting to the shaft.

The front face of the abutment shaft is significantly inclined forward and further divided into triangular sections. Along both wings, there are separate structural elements, such as access staircases to the bridge.

The O7 abutment on the Podolí bank is perpendicular to the bridge axis. The main part of the abutment consists of a massive shaft with a bearing sill, and screen walls smoothly connecting to the shaft, and wing beginnings. The front face of the abutment shaft is composed of triangular surfaces at various angles. The abutment also includes an internal divided space behind the

Figure 10: Formwork of abutment O1

Figure 11: Formwork of abutment O7

closing wall, which will serve partly as a publicly accessible facility with toilets and partly as non-public spaces used for the operation of the arena under the last bridge span.

The abutment's bearing sill has two height levels: the higher one at the level of the bearing pads that support the superstructure, and the lower one, allowing access from the facilities to the inner chamber of the abutment.

The adjacent wings are then formed by separate monolithic reinforced concrete angle walls.

Piers P2, P3 and P6, located on both banks, have a similar structural design, consisting of a single slender shaft. In the horizontal section, the shafts have a trapezoidal shape, variable in height in both directions, and, transversely, they widen with height, allowing bearings to be placed on them at the top.

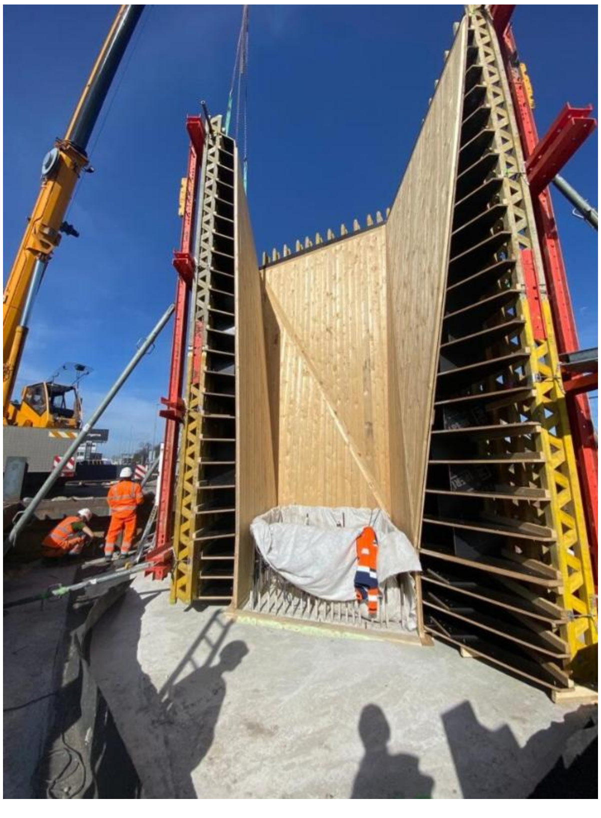


Figure 12: Formwork of pier P2

Figure 13: Formwork of pier P3

The surfaces are again formed by triangular planes. In addition, the individual edges of the P2 pier shaft rotate in one direction, creating the impression of a helix, so that the pier is not symmetrical to any of the axes in a horizontal section.

Piers P4 and P5, located in the bed of the Vltava River, have a different shape and character than the piers located on the banks. They are oriented parallel to the river flow and thus are skewed to the bridge axis. They are frame-connected to the superstructure and significantly influence the bridge's architectural expression.

The piers rest on a massive foundation slab laid under the riverbed. This is a wall shaft across the entire width of the bridge's superstructure. The wall surfaces are faceted, again forming triangles.

Overall, the walls of these piers are very slender in the longitudinal direction of the bridge, tapering to a point at the upstream and downstream edges, thus achieving a hydraulically favourable shape.

The central triangular surface of the wall has its apex at the normal water level of the Vltava River at an elevation of 187.00 m above sea level and will thus naturally indicate the water level in the river.

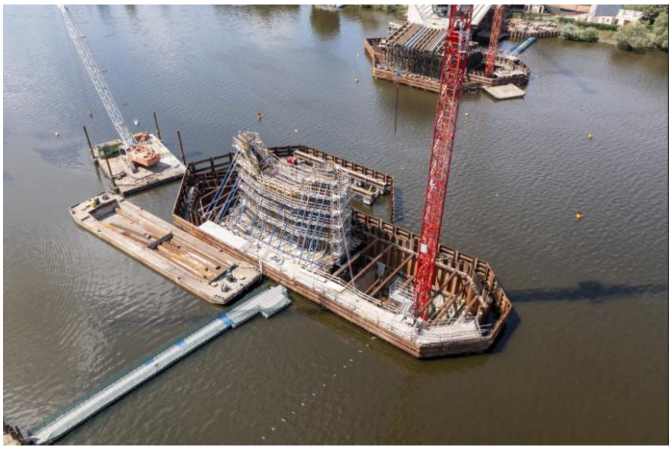


Figure 15: Formwork of pier P5

Figure 14: Shaping of abutment O7

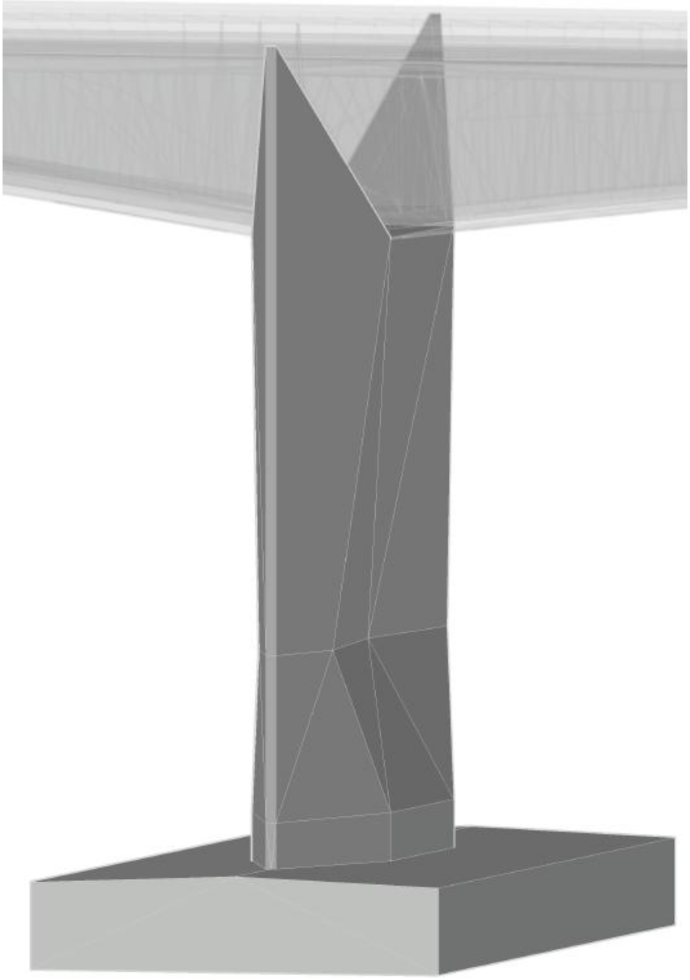


Figure 16: 3D model of pier P4

Figure 17: Pier P4

Figure 18: Spherical bearing P2P

Spherical bearings for supporting the superstructure are located on both abutments and all bank piers (P2, P3, P6).

On the highest of these piers (P3), there is a niche in the upper surface of the pier (and above it an opening in the crossbeam of the superstructure). This modification allows access to the pier bearings for inspection and maintenance.

The complexity of the project and the subsequent construction of the substructure, caused by the atypical shaping and variability of the cross-sections, was further compounded by the architect's requirement to minimise, or even eliminate, construction joints and holes for fixing the formwork in exposed, visible areas.

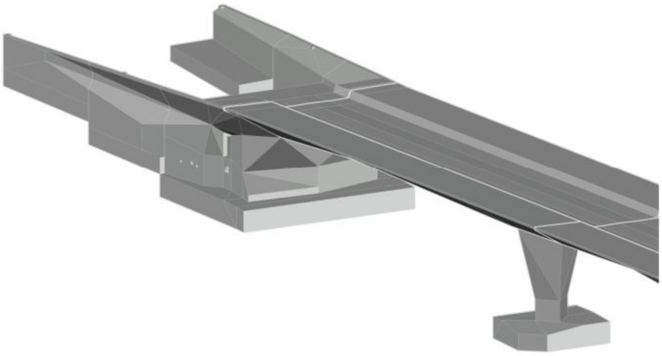


Figure 19: Models of abutment O7 and pier P6

This leads to the casting of larger units in a single stage and more demanding formwork assemblies with higher support requirements.

All substructure, abutment and pier structures were modelled in 3D, and the models were also used to produce reinforcement drawings.

Due to the considerable variability of the substructure cross-sections, the reinforcement composition, including the shapes of the individual rebars, was complex and therefore technically and time-consuming for both the designer and the manufacturer, as well as during installation.

Figure 20: Complex reinforcement of pier P4

SUPERSTRUCTURE

The structure consists of a three-box cross-section with two main load-bearing internal walls of variable height. The outer sloping walls define the structure's outer shape and serve as struts for the pavement cantilevers. These struts are inclined and kinked, and their linear shift of the kink point defines the change in the shape of the cross-section along the length of the bridge span, with the cross-section changing smoothly from trapezoidal above the piers to purely triangular in the middle of the span.

The outer surface is thus again composed of triangles, the length of which is always half the length of the span. Concrete pavement slabs are integrated into the superstructure and fully utilise the available structural height.

The top slab of the central box is forcibly (and structurally unsuitably) placed in a lowered position in order to create space for the construction of an independent fixed concrete tram track.

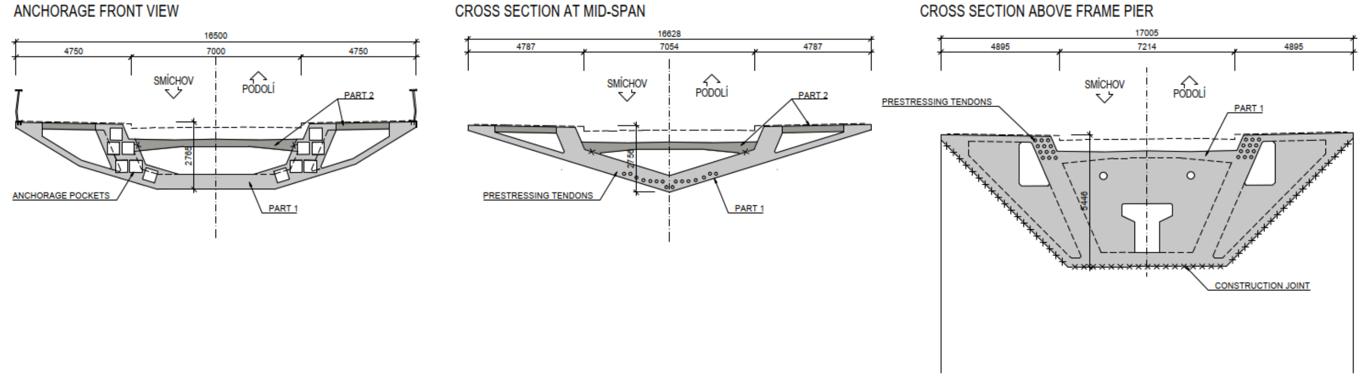
The depth of the superstructure in the outer spans (outside the river profile) is a constant 2.7 m; in the spans above the river, it changes smoothly with parabolic haunches from 3.1 m in the main span (or 2.7 m in the adjacent spans) to 5.4 m above the main piers.

The complexity of the superstructure is further increased by its varying skew layout in plan above the individual supports, where the cross-section arrangement changes smoothly from a very skew support above support O1 to a perpendicular arrangement above piers P2 and P3, then again to be rotated above the frame piers P4 and P5 in the Vltava riverbed, so that the cross-section returns to perpendicular above pier P6 and support O7.

Figure 21: Completed bridge view

Due to continuous changes in the superstructure's skew layout and depth, and to different prestressing alignments along the length of the bridge, almost every cross-section of the superstructure is unique.

The C45/55 concrete structure is longitudinally prestressed by 27 Y1860 S7-15.7 bonded prestressing units. The prestressing tendons are connected at the joints between individual spans or anchored in blisters within the box. The geometry of the tendon routing is extremely complicated, especially in the ground plan, as the tendons must follow the geometry of the main walls, which, with their kinks, shape the outer surface of the superstructure, transitioning to a triangular shape in the spans.



ANCHORAGE FRONT VIEW

CROSS SECTION AT MID-SPAN

CROSS SECTION ABOVE FRAME PIER

Figure 22: Typical cross section

Typical lifting tendons, which must be placed in the box wall above the support at the upper fibres and inside the span at the lower fibres of the cross-section, thus fundamentally change their transverse position from the usual "outer" position at the wall-upper slab joint to a position at the very centre of the cross-section at the apex of the triangle in the centre of the span.

The ground plan curvature of the prestressing tendons is thus greater and their routing is more complicated than the curvature and alignment of the tendons in the vertical plane.

Overall, the trajectory of each tendon consists of general curves, which makes it all the more difficult to check compliance with certain required parameters of the prestressing system, e.g., the minimum radius of curvature of the tendon in space.

Above the piers P2, P3 and P6, transverse prestressing of the diaphragms is also designed using 7-strand lifting tendons, which compensate for the increased stress in the diaphragms from the indirect setting of the structure on the bearings.

Based on a corrosion survey, the bridge was designated for protective measures of grade 4 against stray-current effects. Taking into account the tram line running directly on the bridge, the proximity of the railway line and the metro line on the Zlíchov bank, a number of measures were designed for the bridge to limit the impact of stray currents on the bridge structure, including the use of a fully electrically insulated prestressing system (PL3).

During the elaboration of the detailed design documentation for the superstructure, it became apparent that a large amount of mild reinforcement would be required, up to approximately 300 kg/m³.

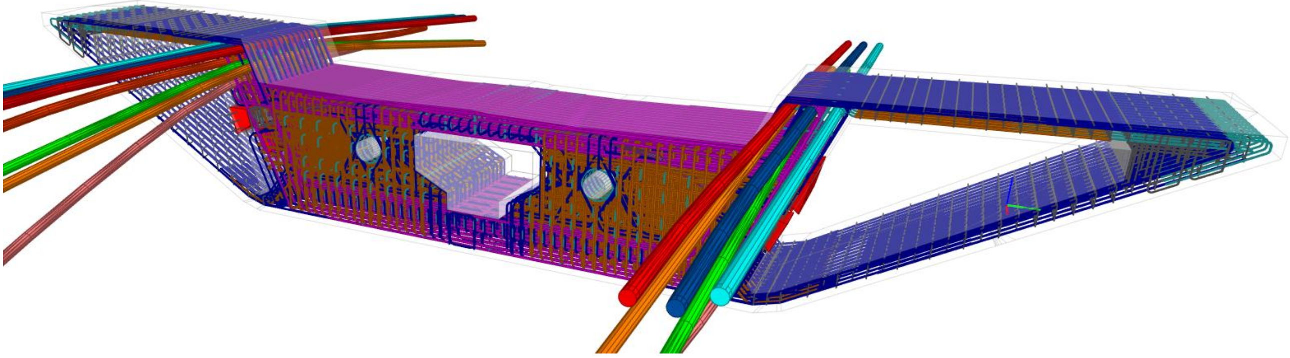


Figure 23: Detailed 3D reinforcement of the diaphragms above P2

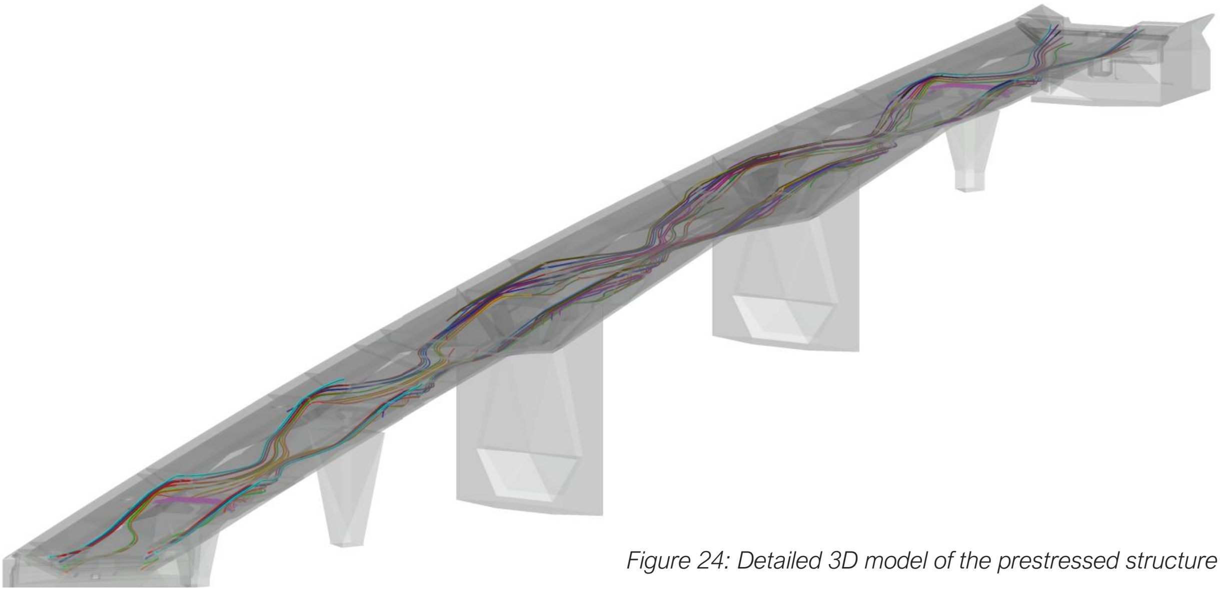


Figure 24: Detailed 3D model of the prestressed structure

The reasons for this high consumption include, in particular, the reduced torsional stiffness of the triangular cross-section in the middle sections of the bridge spans, the greater need to transfer radial forces from the curved tendon routing, and the greater number of cross-sectional changes in both the transverse and longitudinal directions, which the individual rebars must follow in shape.

Given the need for strong structural reinforcement, the complex prestressing and its electrical insulation, and the concreteability of the cross-section, it was necessary to design the layout of prestressing tendons and rebars for each section with unusual detail and precision.

The number of sections thoroughly designed and the number of different rebar items are many times greater than the standard; all cross-sections on the superstructure were designed at 150 mm spacing. Due to potential collisions between prestressing tendons and rebars, the cross-section shape within the box was further refined locally.

For example, reinforcing cross ribs were added in the centre of the main spans to accommodate a sufficient amount of rebars to absorb radial forces from prestressing, etc. The primary tool for this work was a complete, detailed 3D model of the entire superstructure, including all prestressing details.

The 3D model also served as a basis for the design of formwork and supporting structures, and for setting out structures on the construction site. For certain structural elements, the reinforcement was designed directly in 3D.

The bridge's architecturally distinctive appearance distinguishes it from conventional box girder bridges of similar dimensions and significantly impacts both the scope and labour intensity of the design work and the labour intensity of the construction itself.

Nevertheless, the consumption of basic materials for the superstructure was kept at normal levels (concrete: 1.0 m³/m², prestressing reinforcement: 36 kg/m²).

Figure 25: Prestressing and mild reinforcement of the middle main span

Considering the demanding requirements of the assignment, in particular the load from tram traffic on the bridge, the prescribed tram track construction with an independent fixed track on the bridge, and the relative slenderness of the superstructure given the limited space between the prescribed elevation and the obstacles to be crossed, the design can be considered economical overall in terms of the consumption of concrete for the superstructure and prestressing.

On the other hand, the above-described increase in the consumption of mild reinforcement compared to conventional box structures is significant, but not significant in terms of the total construction costs.

CONSTRUCTION OF THE SUPERSTRUCTURE

Due to the structure's complex geometry and the spatial conditions and limitations on both abutments, the tender documentation already envisaged a gradual construction on fixed falsework.

The construction was divided into six stages, with work expected to proceed in individual spans (each with a short overhang into the next span) from both abutments towards the river, with the central section of the main span across the river being the last to be constructed.

Above the river, it was envisaged that the formwork would be placed on several intermediate trestles, placed on steel structures embedded in the riverbed.

During implementation, various modifications to this procedure were considered, including starting construction of the superstructure with the section over Strakonická Street to gain time to address problems at the Zlíchov abutment. A complete redesign of the construction method for the central part of the bridge (3 spans over the river) using balanced cantilevering was also considered, but it did not produce the expected effect either.

Figure 26: Construction of stage 4

Figure 27: Temporary support structure of stage 4

Therefore, the construction procedure was not changed systematically in the end.

The fixed falsework on both abutments was partly made up of spatial falsework (partly in Span 1 – PERI UP Rosset Flex and then completely on the Podolí bank – DOKA Staxo 100) and partly heavy falsework (steel beams on trestles in Span 2 and part of Span 3.

The falsework above the river was solved in an interesting way. The dimensions and positions of the cofferdams were adjusted to accommodate the placement of the falsework support towers within the cofferdams next to the piers.

Similarly, the shoring on both riverbanks was prepared for the placement of the falsework towers.

The falsework in Spans 3 and 5 above the river was then made of massive steel truss girders, which had previously been used to construct temporary railway bridges. These structures were transported in parts to the assembly yard about 5 km away, where they were assembled into pairs, each to the required lengths of 39 m and 54 m, respectively, and gradually moved onto Helios pontoon vessels and transported down the river to the site.

Here, they were lifted directly from the pontoons into the desired position on the support towers using hydraulic jacks. In total, these structures weighed almost 900 tonnes.

The main parts of Spans 3 and 5 were then constructed on these structures.

Figure 28: Temporary supports – erection

Figure 29: Temporary supports - transport

The outer parts of the central span at the piers in the river were constructed at the same time on short girders resting on only two intermediate trestles set up in the main riverbed between piers P4 and P5.

After the concreting, the supports from the Podolí side were moved on pontoons to the main span to execute the final stage, which connected both parts of the bridge into a single unit.

The complexity of the actual construction of the superstructure of the Dvorecký Bridge lay mainly in projecting the shape of the bridge into the formwork design, which had to correspond not only to the given geometry, but also to the architect's requirements to minimise the number of visible construction joints and holes for fixing the formwork.

The formwork was supplied by PERI (VARIO system) and DOKA (Top50), and the repeatability of the formwork elements used was minimal, also due to time constraints. The system formwork had to be combined with wooden beams.

The main challenge was placing the concrete and prestressing into the formwork of a complex shape.

Due to the large amount of mild reinforcement (a total of 1,770 tonnes), it was necessary to work with increased precision so that the smooth routing of the prestressing tendons was not disrupted even locally and so that the contact between the reinforcement and the tendon ducts, which could impair the electrical insulation properties of the prestressing system, was minimised (and provided with special inserts).

Given the curvature of the tendon ducts as they approached their minimum radii, this task proved quite challenging.

Measurements of electrical resistance in the tendons immediately after installation, after casting, and after prestressing demonstrated the ducts' sensitivity to damage from strand movement and pressure in the curve during tensioning.

During construction, the type of ducts was therefore changed, and the use of inserts at the contact points between the ducts and the rebars was further intensified.

The system of measures protecting the structure and its prestressing from damage by stray currents was therefore additionally reinforced beyond the original specifications.

Due to the shape of the structure, the concreting of each stage was divided into two parts. In the first part, the so-called outer envelope was cast, i.e. the bottom slab of the box, including the inner walls of variable heights.

In the second part, the upper slab for the tram track and the outer pavement slabs were cast.

Figure 30: Superstructure formwork of stage 5 (PERI)

Figure 31: Superstructure formwork of stage 3 (DOKA)

The largest volumes of concreting were in stages 4 and 5, each containing almost 1,300 m^3 of concrete.

WHITE ARCHITECTURAL CONCRETE

The outer surface of all visible structures is composed of triangular areas defined by edges that appear to be placed almost randomly in space. These lines are emphasised by parallel strips in the formwork, which clearly separate the individual areas, even when the angle between adjacent planes is small.

In detail, therefore, the usual chamfering of sharp concrete edges was not used. The architect approved the orientation of the boards for all surfaces. For example, the lower surface of the bridge deck has boards perpendicular to the bridge axis, and this orientation is only apparent when viewed directly up from below.

Due to the spatially inclined surfaces, the orientation of the boards always appears different, depending on the observer's current position.

Similarly, this phenomenon can also be seen on the substructure - most of the piers have boards that are "vertical" when viewed along the axis of the bridge, but from the side, the same boards appear inclined.

The prescribed use of white concrete also significantly complicated the concreting work.

Figure 32: Cross section of stage 5

The desired colour was achieved using white cement. This was custom-made and imported from Slovakia. Due to the increased amount of cement in the mixture, the rate of heat release during hydration was higher than in conventional concrete mixtures.

In view of the robustness of some structural elements, the effect of cooling the concrete, during setting on the development and magnitude of hydration heat and thus on possible structural changes within the microstructure of the concrete was tested.

Figure 33: Construction of the central part of the main span

According to the verification samples, the cooling effect was positive, with the temperature inside the concrete element reduced by more than 10 °C. This also reduced the overall temperature gradient across the cross-section during the setting phase, eliminating any impact on the concrete microstructure and the possible formation of cracks on the visible surfaces.

Taking into account the development of hydration heat in fresh concrete, the concrete supplier decided to pre-stock cement so that older cement at lower temperatures could be used in the fresh mixture. Fresh cement from production can reach high temperatures, and gradual cooling to ambient temperature takes weeks to months.

COOLING OF THE CONCRETE MIXTURE

For the reasons mentioned above, it was decided to cool the fresh concrete mixture for the concreting of more massive parts of the structure. Cooling the individual components of concrete, especially aggregates, is particularly difficult in the summer months, so it was decided to cool the freshly laid concrete using a cooling system that circulates a cooling medium (water) within the freshly cast-in element.

The aim of cooling was to reduce the maximum temperatures in the concrete structure so that the prescribed limit values were not exceeded and, at the same time, to direct the cooling effect to the area of the highest temperatures, thus reducing the temperature gradients in the structure.

To verify the cooling system's functionality in high-hydrating concrete, an experiment was conducted on a 2x2x2 m test concrete sample. This tested the temperature control of the cooling medium and the flow through the cooling system. The experiment was then compared with a numerical analysis, which demonstrated the effectiveness of the cooling system.

Figure 35: Cooling of concrete mixture (abutment O1)

Figure 34: Pier P6

BRIDGE ACCESSORIES AND EQUIPMENT

The roadway with tram tracks on the bridge is designed to be covered with mastic asphalt so that it can also be used by road traffic. The independent tram track structure (fixed track with W-tram fastening system) is embedded in the bridge and rests on a lowered upper deck slab, which is separated from it by asphalt insulation bands (NAIP) and anti-vibration rubber mats.

Given the length of the bridge, the transition of the tram track from the bridge to both approaches is achieved using track expansion devices. The bridge expansion joints are of the finger type. The bridge insulation is full-surface; the insulation from the trough beneath the roadway extends continuously to the pavement cantilevers.

The surface of the pavements will be covered with a coloured layer from ACO (asphalt concrete), and the kerbs are made of stone.

Water is drained from the road surface and pavements on the bridge by means of longitudinal and transverse slopes into bridge gullies located on both sides of the road. In the area of zero longitudinal slope, the gullies are replaced by a continuous trench drainage along the kerb.

Water from the bridge is then drained through longitudinal drainpipes in the bridge box via end walls into the sewer system on both approaches.

On both outer edges of the bridge, there is a column-free railing, which is locally interrupted in designated places by steel poles of the tramway traction line. These also serve to mount public lighting fixtures.

The railing structure itself, with a solid white artificial stone handrail at a height of 1.30 m above the pavement surface, and the shapes of the traction line poles with a square cross-section tapering conically along the height of the pole, are designed according to the architect's requirements and connect to the triangular surfaces of the superstructure.

The white handrail itself is illuminated from below by an inserted continuous lighting strip with spot LED elements, which illuminate the adjacent pavement surface and serve for ceremonial lighting of the bridge and supplement the public lighting fixtures on the traction line poles.

The bridge is equipped with monitoring devices and systems that allow the following to be monitored:

- the temperature and deflection behaviour of the structure;
- penetration of aggressive substances into the concrete;
- relative deformation of the structure;
- tension in the prestressing tendons (directly – dynamometers and indirectly – EM sensors);
- electrical insulation properties of the prestressing system;
- corrosion potential of prestressing and mild reinforcement.

Some of these measurements are connected to a data logger and transmission unit via an IoT system and are essentially available online.

Figure 36: Railing and atypical column no. 133

SAMPLING PROCESSES

Given the bridge's overall effect on architectural and structural design, considerable attention was paid to the design of details. For this purpose, sampling of both the main structural elements and certain products was prescribed.

Under the supervision of the chief architect of the construction, a series of samples of the colour of the white concrete and the final surface of the formwork were taken before the concreting began.

Sampling was carried out repeatedly, combining different types of formwork (planed and unplaned elements), different types of edge highlighting and plank placement, methods of fastening planks, types of formwork release agents, specific concrete mixtures, etc. Various types of anti-graffiti coatings were also tested. Their effectiveness was tested so that in the event of vandalism, the bridge could be restored to its original condition as soon as possible without changing the colour of the concrete surface.

Figure 37: Sampling of asphalt mixtures

Figure 38: Sampling of concrete and formwork surface

We have already mentioned the requirement to minimise the number of construction joints and holes for formwork tie rods. Even where the placement of formwork tie rods was permitted, the design of their placement was coordinated with the structure's architect. Samples were taken of the railing components, the asphalt mixture of the pavement surface, etc.

CONCLUSION

The highly atypical shaping of the bridge, both the substructure and the superstructure, based on a design that emerged from an architectural and structural competition, posed an extraordinary challenge for designers and builders from the outset. In addition to the shape of the bridge itself, it was necessary to address strict requirements for the quality of the white concrete facing surfaces and numerous details.

Among the most demanding elements of the project and construction were the design and implementation of prestressing, given the geometry, the maintenance of the prescribed electrical insulation properties of the system, and the mild reinforcement of the superstructure. We should also mention the foundation of water piers under the riverbed in difficult geological fault conditions.

Figure 39: Sampling of anti-graffiti coatings

All this had a significant impact on the technical and time demands of the design work and construction activities.

All this within the built-up area of the metropolis, where it is necessary to carry out construction in the immediate vicinity of buildings, busy roads and railways, a frequented river navigation route, and a large number of various utility lines. Only a limited construction site is available, and access to it is also limited.

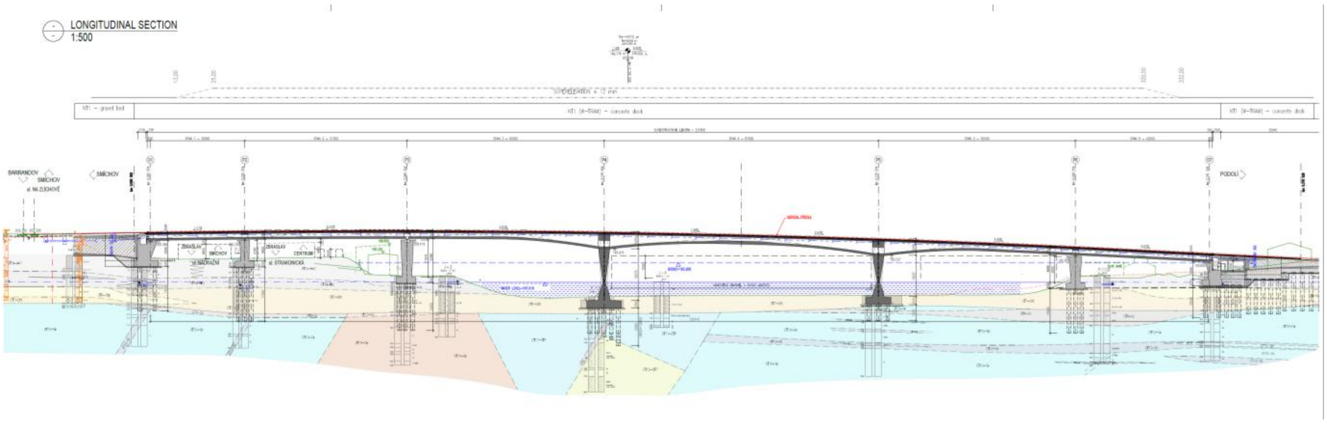
At the same time, it was necessary to coordinate the work, at least in terms of traffic restrictions and closures, with other construction projects in the city, such as the reconstruction of the nearby Barrandov Bridge and the ongoing construction of the Lihovar residential complex. In order to carry out such a construction project under these conditions, it was necessary to use inventive solutions – for example, the flooding of the falsework structures for the construction of the main spans above the river using pontoons.

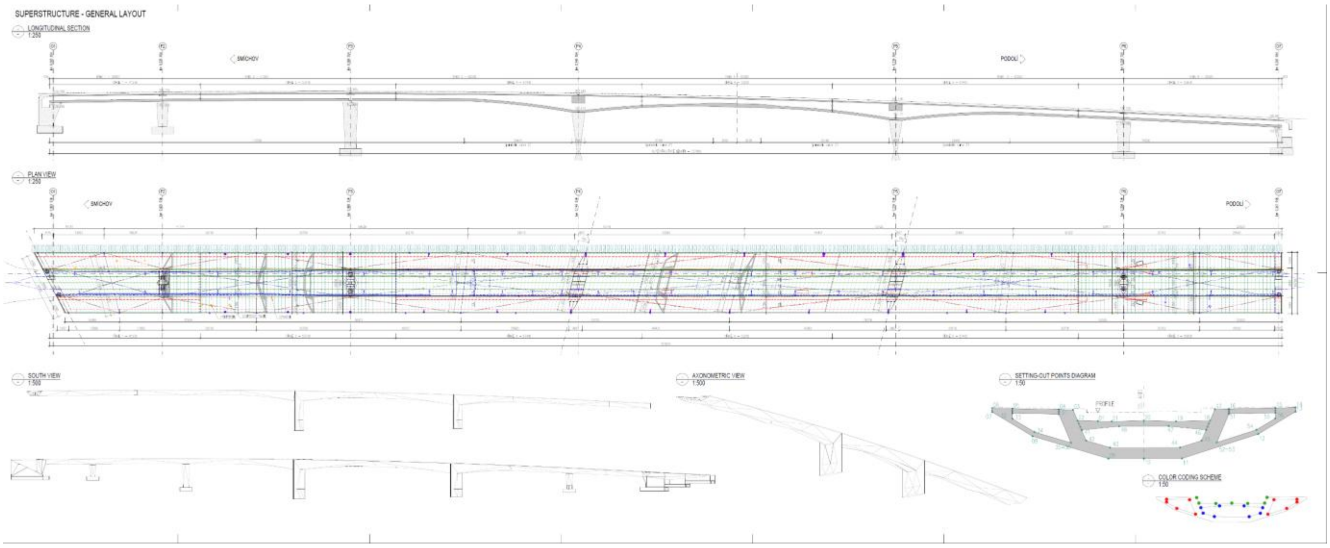
The construction of the Dvorecký Bridge is nearing completion, with the grand opening and commissioning expected in April this year.

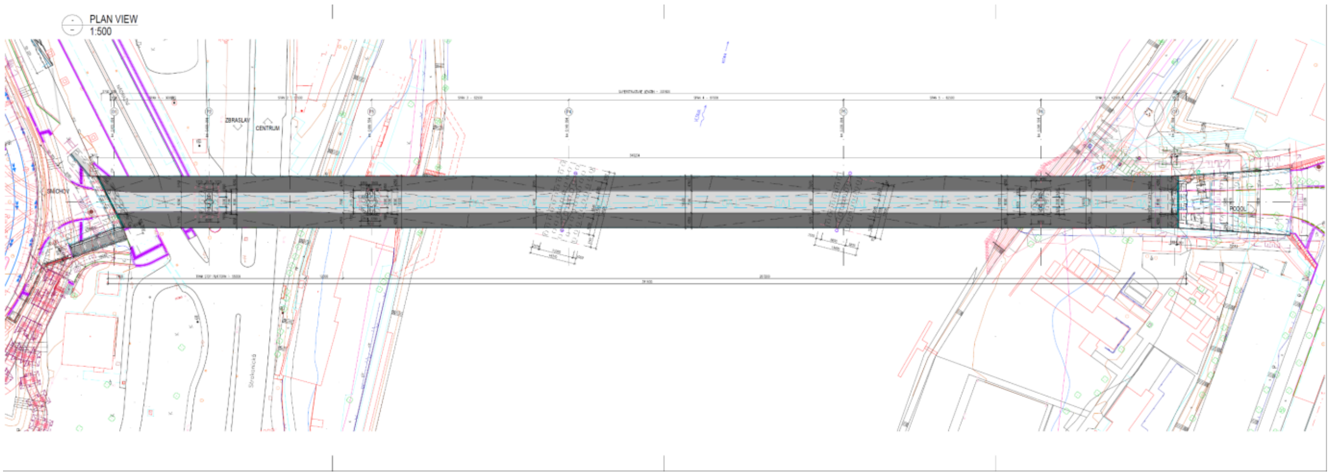
The Dvorecký Bridge will thus become a new addition to Prague's collection of mostly exceptional bridges over the Vltava River. Due to its distinctive shape and location on the edge of the city centre and within sight of historical monuments, it will probably become unmissable. The designers and builders hope it will be well received by both the general public and experts and that it will be a worthy addition.

DRAWINGS

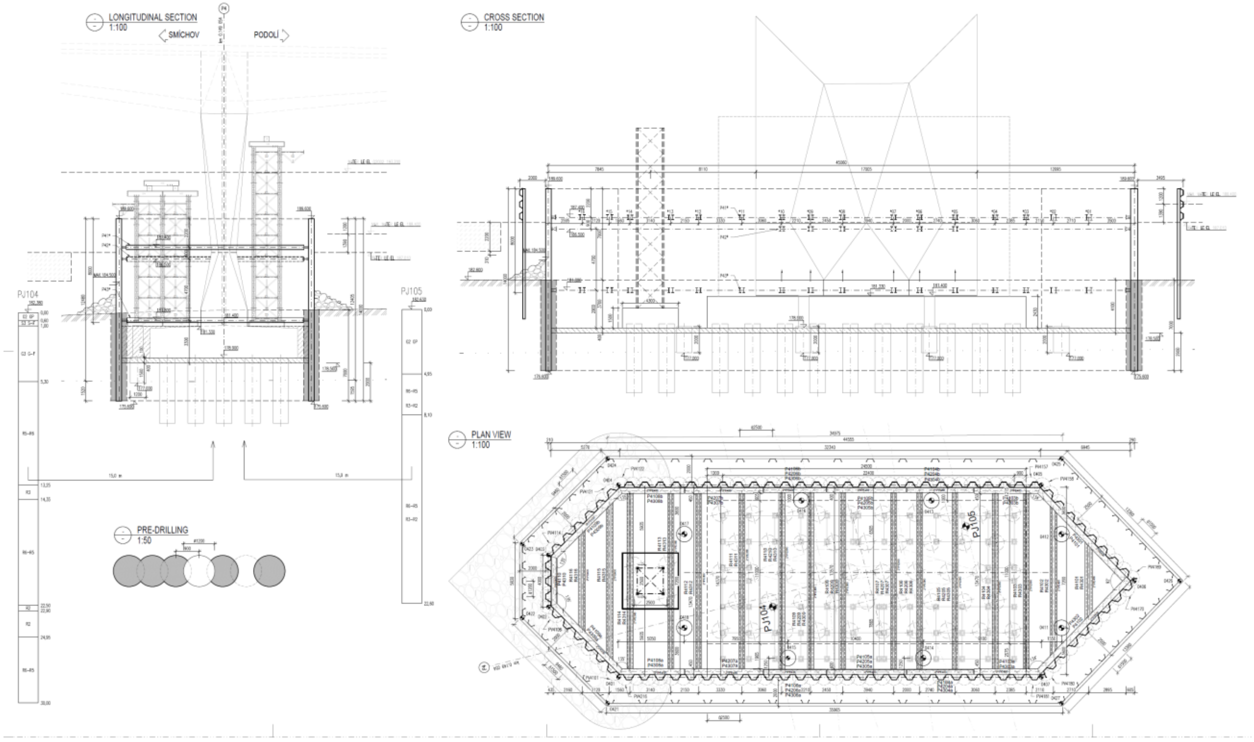
Click on a drawing to open it in a higher resolution



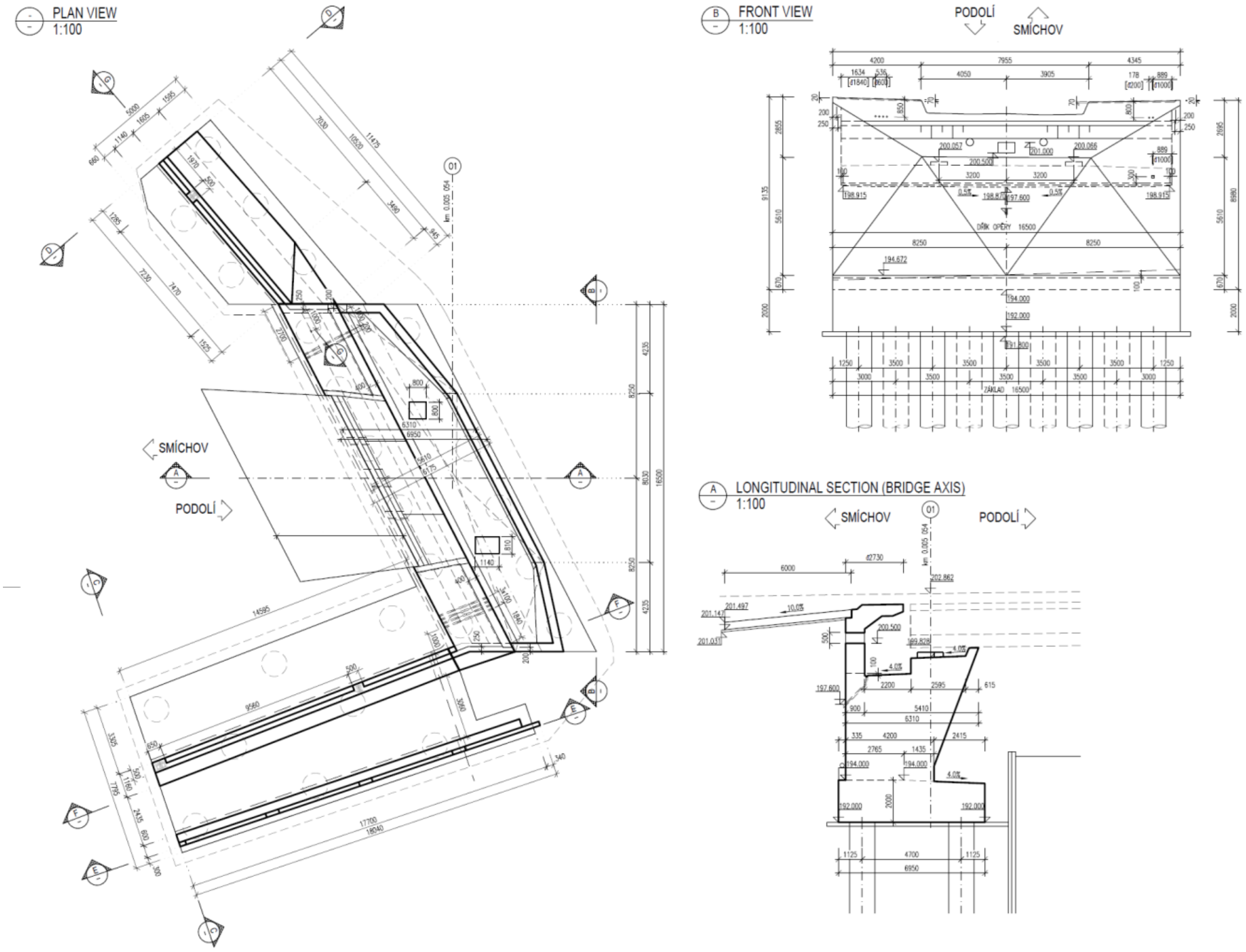


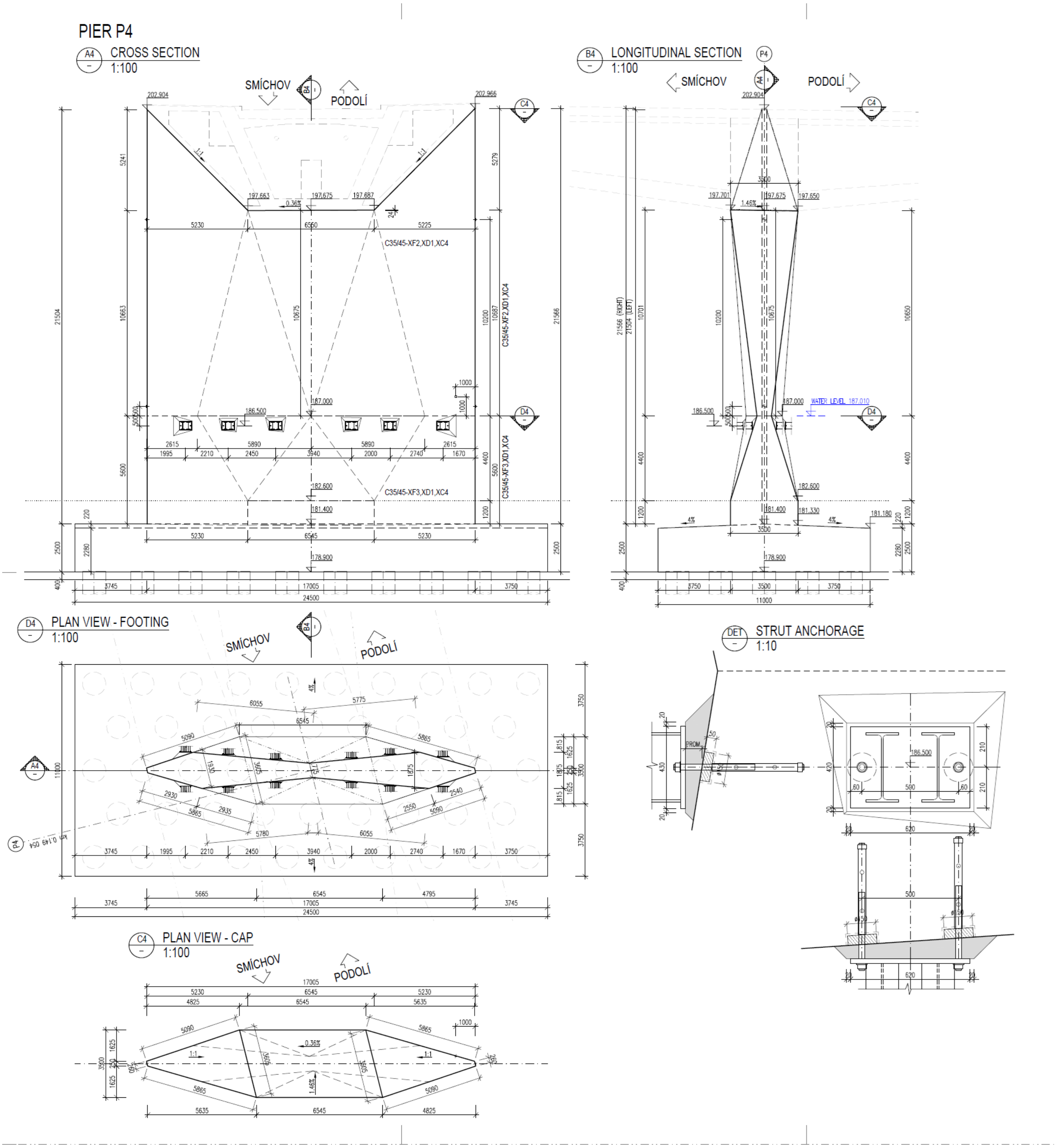


COFFERDAM P4



ABUTMENT O1

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5225
C35/45-XF2,XD1,XC4
C35/45-XF3,XD1,XC4
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187.000
182.600
181.400
178.900
21504
21566
10663
10675
10687
10200
5241
5279
5600
4400
1200
2500
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17005
24500
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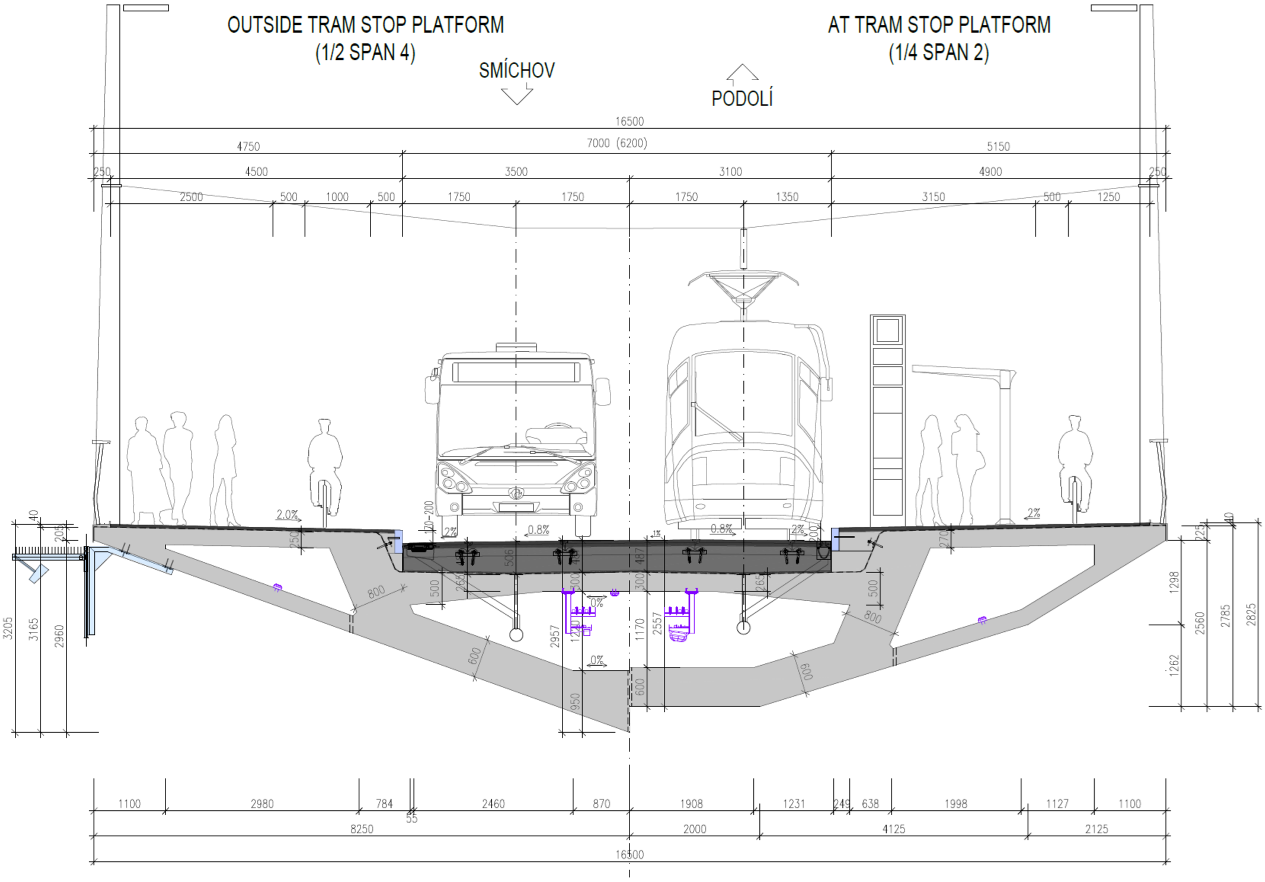
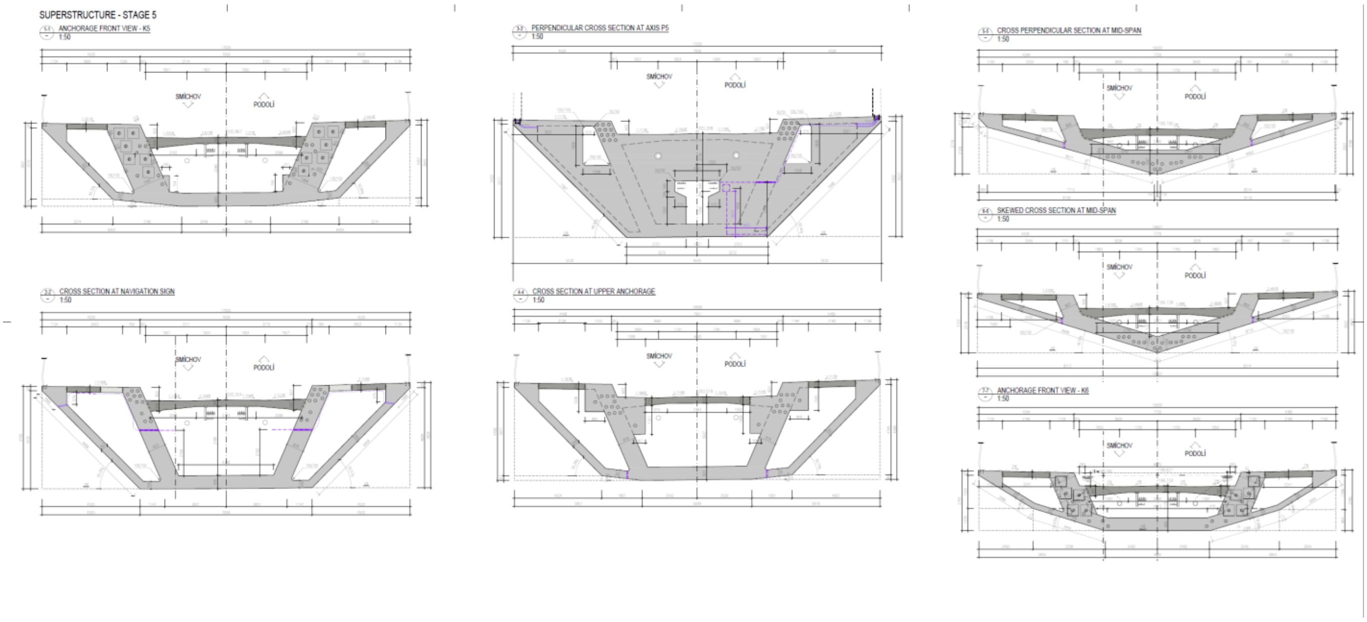
CROSS SECTION





Drawings by Pontex and Pragoprojekt

TEMPORARY STRUCTURES FOR THE CONSTRUCTION OF DVORECKÝ BRIDGE IN PRAGUE, CZECH REPUBLIC

Vít Němčic, Metrostav TBR ✉
Jakub Veselý, Metrostav TBR ✉
Vladan Michalík, LODĚ HELIOS ✉
Jan Blažek, V – CON ✉
Jiří Žák, Firesta ✉

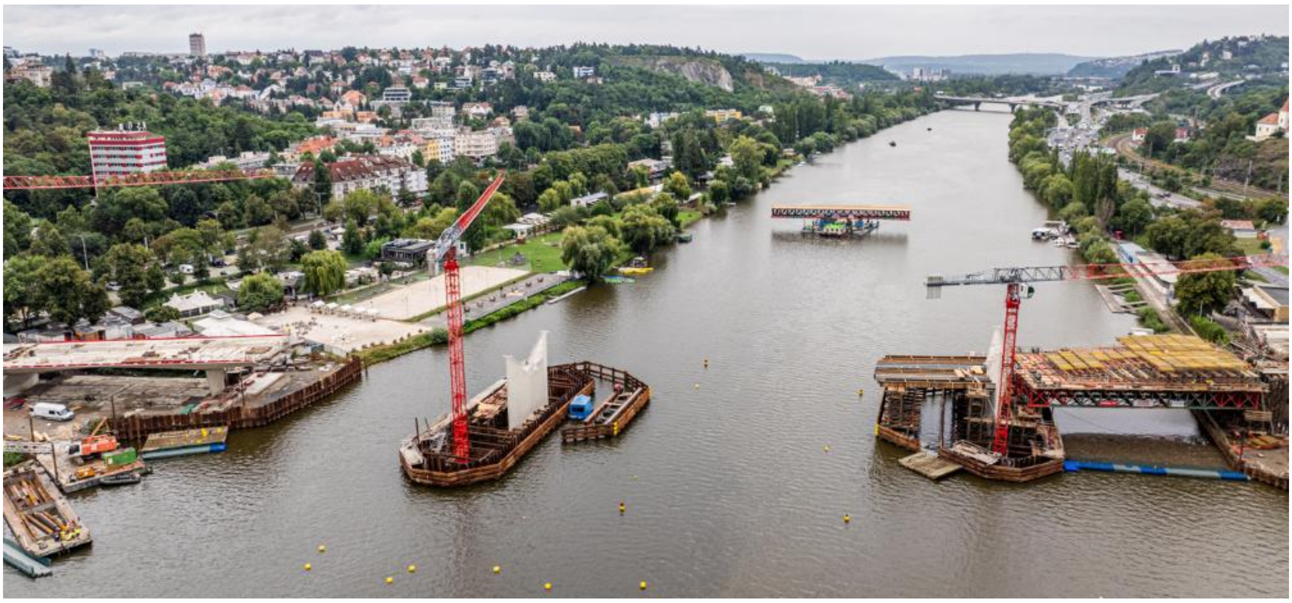


Figure 1: Dvorecký Bridge under construction

INTRODUCTION

The construction technology of the superstructure posed several technical and organisational challenges. The bridge structure is in a complex environment comprising major road infrastructure, the Vltava River, and the adjacent floodplain area, which required the design of an appropriate combination of several supporting systems.

As part of the project preparation for the Dvorecký Bridge in Prague, several technological variants for constructing the main spans were therefore assessed.

The evaluation focused primarily on technical feasibility, the extent of works carried out in water, potential interventions into the superstructure, construction risks, and compliance with the flood protection plan.

For the construction of the first and sixth spans, a spatial truss system was selected from several alternatives. For the superstructure of Span 2 and part of Span 3, a beam falsework system was designed, consisting of temporary bridge trestles and steel I-girders.

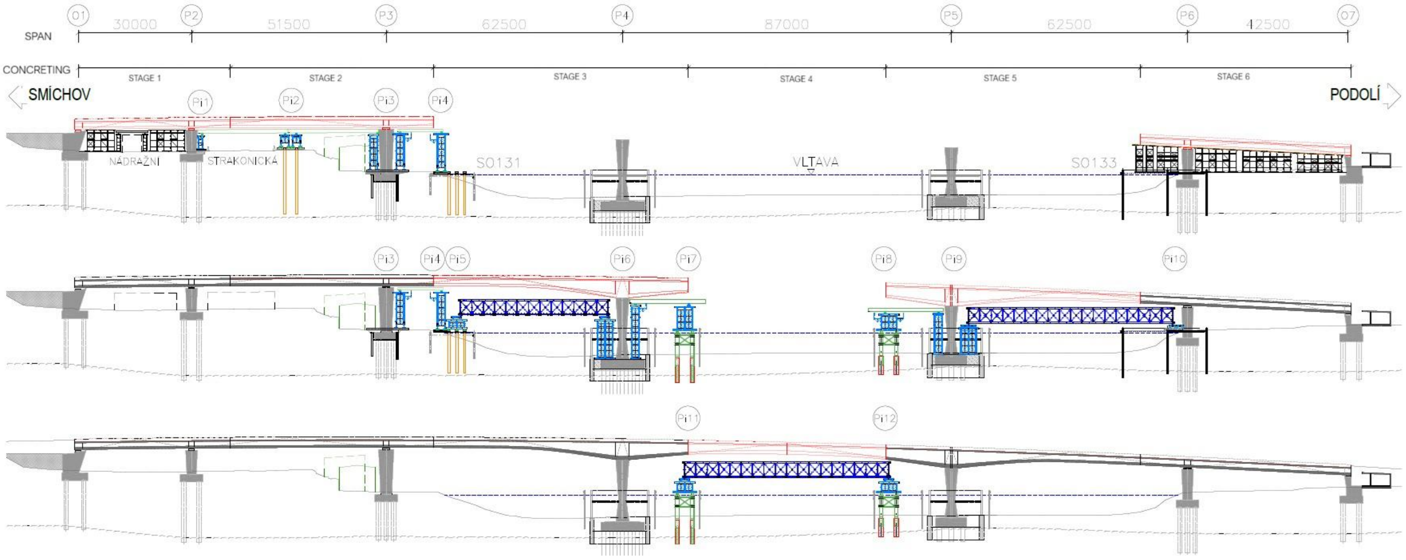


Figure 2: Construction procedure scheme

The most complex part of the project was constructing the superstructure in the Vltava River channel.

Several alternatives were considered at this location. An overhead launching gantry was deemed unsuitable, primarily due to the required interventions into the permanent structure, the complex formwork, and the construction of massive temporary supports in the water.

Additional disadvantages included increased material consumption and the need for a special gantry that is not commonly available.

An underslung launching gantry could not be used because the piers located within the river channel have a width corresponding to the full width of the superstructure, which significantly complicates the launching trajectory.

Its implementation would have required extensive foundations for temporary structures in the water, a high number of handling operations, and a substantial increase in material volume.

Another option considered was balanced cantilever construction, Figure 3, which was assessed as technically feasible but exceptionally demanding to execute.

Several risks were identified, particularly those related to the construction of starter segments, prestressing operations, and overall construction organisation. This variant would have led to a significant increase in construction joints, atypical details, and costs, as well as an overall increase in construction time.

Ultimately, the construction of the superstructure within the river channel using an underslung launching gantry made of the innovative standardised temporary bridge system, Figure 9, supported on temporary structures, was selected as the most suitable solution.

Figure 3: Construction of the superstructure of Spans 3, 4 and 5 using balanced cantilever construction

Special floating pontoons were used to move the gantry within the river channel, enabling its transport from the fabrication yard in Velká Chuchle to the construction site. Subsequently, the pontoons also provided transportation within the site itself.

The selected technology fully respected the architectural requirements of the bridge, minimised interventions into the river channel, and reduced the extent of work in the water.

II. FOUNDATIONS OF TEMPORARY STRUCTURES

The spatial truss structure in the first and last spans was founded on a panel platform foundation.

Between piers P2 and P3, three auxiliary temporary trestles (Pi1–Pi3) were designed, Figure 2. The trestle Pi1, located adjacent to pier P2, was founded on a panel platform and, together with trestle Pi2, supported the steel girders spanning Strakonická Street.

The trestle Pi2 was founded on 10 bored piles, each with a diameter of 900 mm and a length of 17 m, Figure 4. Deep foundations were designed retrospectively due to the discovery of an unknown bridge structure and unfavourable geological conditions.

The construction was further complicated by clashes between the piles and underground utility networks, as well as by the severely restricted working space between the I/4 road (Strakonická) and the Rowing Club buildings on the adjacent slope.

The width of the construction site was approximately equal to the width of the drilling rig. As the temporary structure extended into the sidewalk area, it was necessary to construct a temporary pedestrian and cyclist footbridge prior to the commencement of works, Figure 8.

Adjacent to pier P3, the trestle Pi3 was constructed and founded on a reinforced concrete slab. Compared to the original design, the foundation method was modified from a panel platform to a reinforced concrete slab due to unsuitable geological conditions.

For the temporary bridge support structure, a temporary trestle Pi5 was prepared on the riverbank, Figure 11, onto which the launching gantry was installed.

The trestle was deep-founded on 15 bored piles with a diameter of 600 mm and a length of 10.5 m. Reinforced concrete pile caps with a steel grillage were constructed atop the piles to support the structure.

Trestle Pi6 was located in a sheet-pile cofferdam and had a combined foundation system: partially shallow-founded between the permanent foundation of pier P4 and the cofferdam wall, and partially supported by the pier's permanent deep foundation.

A significant part of the preparation involved coordinating the spatial arrangement of the temporary support structure with the bracing system of the sheet pile cofferdam.

Figure 4: Foundation of temporary trestle Pi2

Figure 5: Combination of cofferdam bracing and temporary structures

The cofferdam struts passed through the stiffening members of the structure (Figure 5), necessitating precise coordination of their vertical positions to avoid potential clashes.

At the same time, the deck of the trestle served as a working platform for the formwork of the second concreting stage of pier P4.

For the construction of Span 6, two temporary supports were installed in the river channel, each located 16 m from the respective bridge pier. Due to unfavourable geological conditions, the foundation solution was modified compared to the tender documentation. The originally designed driven steel sections were replaced with bored reinforced concrete piles, connected with heavy-walled steel tubes TR 920 × 20 mm.

Each support consisted of two rows of 10 piles. The steel tubes extended above the water level of the Vltava River and were spaced at 4 m longitudinally and 4.6 m transversely. The tube lengths were 9 m at pier P4 (Pi7, Pi11) and 10 m at pier P5 (Pi8, Pi12) (Figure 2).

The connection between the pile and the steel tube was achieved by welding the longitudinal reinforcement of the reinforcement cage to the inner wall of the tube, Figures 6 and 7.

The prefabricated assembly was installed into a pre-drilled borehole, after which the pile was concreted to the required level, Figure 6. Upon completion of piling works, the structure was stiffened using a system of steel collars and sections.

The collars were composed of two parts, assembled with bolted connections and subsequently interconnected by a pair of U260 sections.

Spatial stiffness was ensured by diagonal bracing made of U300 sections. After assembly, the tubes were cut to a uniform elevation and fitted with steel caps measuring 1.3 × 1.3 m with triangular stiffeners, Figure 6.

Due to the elevation of the bracing system relative to the river level, part of the installation had to be carried out with the assistance of divers. Given the proximity to the navigation channel, protective steel barriers made of Larsen sheet piles were installed around the temporary supports.

Figure 6: Foundations of trestles in the Vltava River

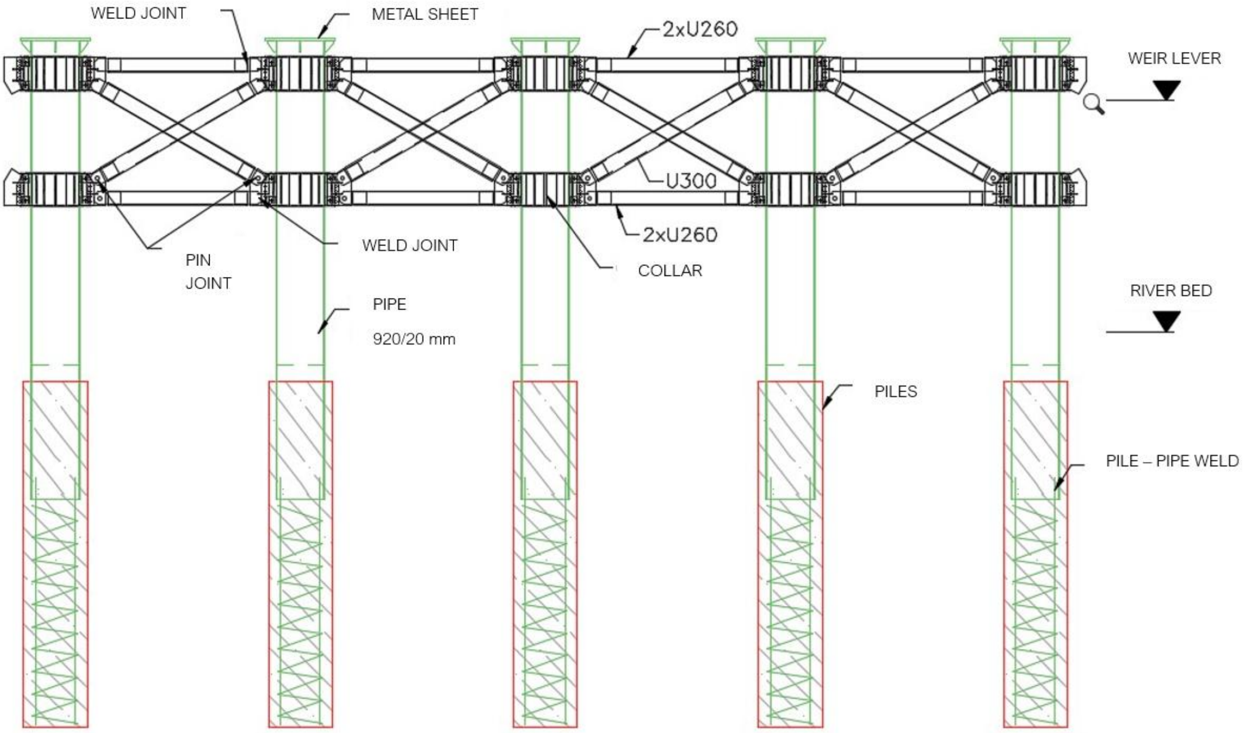


Figure 7: Foundation scheme of temporary trestles in the Vltava River

The temporary trestle Pi9, located within the sheet pile cofferdam of pier P5, was structurally designed in a manner similar to Pi6, combining a shallow foundation with additional concrete infill and support from the pier's permanent deep foundation.

Trestle Pi10, situated at pier P6 on the Podolí riverbank, was shallow-founded on a reinforced concrete slab.

As in the case of Pi3, the foundation method was modified from the original panel-platform design to a reinforced concrete slab due to unsuitable geological conditions.

III. CONSTRUCTION TECHNOLOGIES USED FOR BRIDGE STRUCTURE

Among the principal challenges in the execution of the spatial falsework in Span 1 and the beam falsework between piers P2 and P3 was their placement in a confined, technically complex area.

The structures were situated between heavily trafficked roads, Nádražní and Strakonická Streets, and the Rowing Club buildings located on sloped terrain, which significantly influenced both the foundation design and the construction procedure, Figure 8.

Spatial constraints were considerable. For example, the bottom flanges of the girders were positioned very close to the roof of an adjacent building.

This condition imposed increased demands on assembly precision, deformation control, and the stability of the temporary structures under severely restricted access conditions.

A further significant factor was the high traffic load on Nádražní and Strakonická Streets, which complicated the design and implementation of traffic management measures.

As a result, assembly works were carried out predominantly during night-time hours and required detailed scheduling and coordination.

In the area of pier P3, the limited space between the club buildings further restricted access for machinery and significantly affected the overall organisation of the construction works, Figure 8.

A key stage of the bridge construction was crossing the watercourse, i.e., the construction of structures in the river environment, which represented the principal technical and organisational challenge of the entire project. Construction within the riverbed imposed increased demands on the design of

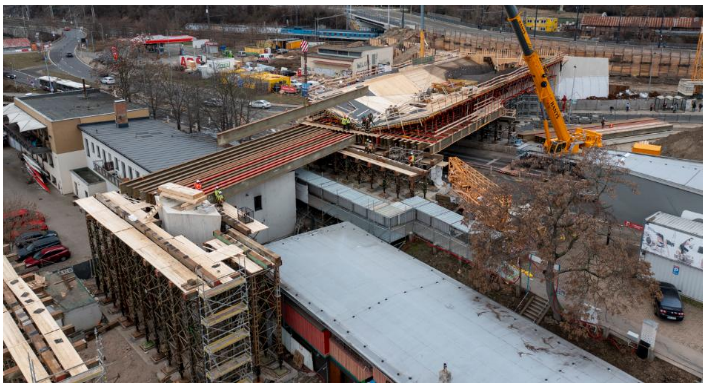


Figure 8: Assembly of the beam falsework

Figure 9: Temporary support structures in Velká Chuchle

temporary structures, their stability, the assembly procedure, and the coordination of individual technological operations with respect to hydrological conditions and limited working space.

The assembly of the temporary structures proceeded in parallel with the construction of the permanent superstructure. It commenced in January 2024, while transport of the structures from the assembly yard to the site took place in July and August, Figure 9.

In total, 900 tons of material were assembled using more than 30,000 bolts. During assembly, it was necessary to fabricate atypical components that enable non-standard connections and adapt the structure, originally designed for a railway bridge. The geometry of all newly designed structural elements was verified directly on site due to system imperfections.

The assembly of the temporary support structures was carried out at a pre-assembly yard in Velká Chuchle, where transverse and longitudinal launching tracks were installed to enable the movement and loading of the structures onto a pontoon assembly on the water.

Four separate structures were produced in total: two structures for the Span 3, each weighing 150 t and measuring 39 m in length, and two structures for Spans 4 and 5, each weighing 300 t and measuring 54 m in length. The 54 m-long temporary support structure was designed to allow repeated use in Span 5 (Stage 5) and subsequently in Span 4 (Stage 6), Figure 2.

The transverse movement of the structure was carried out using cable winches.

Once the transverse shift had been completed and the structure was positioned as required, longitudinal launching was initiated, Figure 9. This operation was performed using a pair of hollow hydraulic jacks. The longitudinal launch was carried out onto prepared hydraulic supports on the pontoon assembly, which was stabilised during launch by hydraulic legs bearing against the riverbed.

After completion of the longitudinal movement, the hydraulic legs were released, and tugboats were used to move the structure into the bridge opening. Final positioning within the span was performed using cable winches, followed by lowering onto the bearings with hydraulic supports.

Initially, the structure was transported from Velká Chuchle to Spans 3 and 5. After the superstructure in Span 3 was concreted, the temporary support structure was transported back to Velká Chuchle for dismantling.

The structure used in Span 5 was subsequently relocated to Span 4 and positioned as required. The transport from the assembly yard along the Vltava River covered approximately 5 km and required careful coordination with the Braník and Barrandov Bridges to avoid collisions.

Each river transport operation required a temporary closure of the navigation channel. The assembly and dismantling of other temporary structures on the water were carried out from pontoons and likewise required complex coordination of all activities.

At the construction site, the temporary structure was supported on trestles and bearings. Installation

Figure 10: Installation of the temporary structure onto bearings

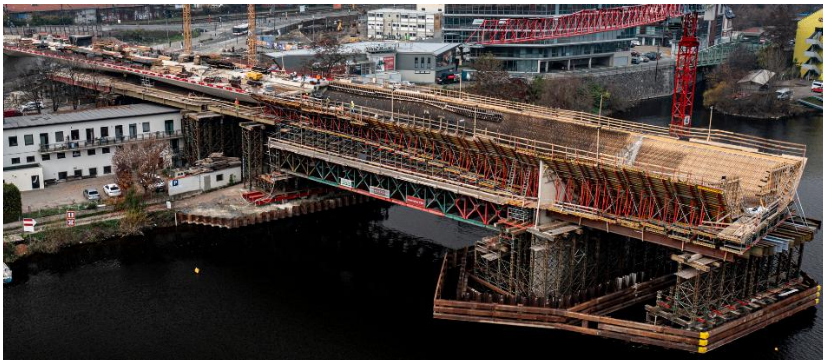


Figure 11: Concreting Stage 4 – temporary structures

onto the bearings directly from the pontoon required very precise coordination, as the structure had to be accurately positioned into the bolt holes of the bearings, Figure 10.

All operations had to be thoroughly prepared in advance to ensure a smooth and complication-free process, with each step demanding precise timing and organisational coordination among the assembly teams.

After installation on the bearings, the entire structural system of the gantry acted, until the superstructure was concreted, as a simply supported span with a fixed support on one side and a sliding support on the other.

Upon completion of the concreting works, the fixed bearing was released, and the system began to operate in a "floating" configuration.

The bearing design thus allowed the static scheme of the temporary structure to be modified during construction while maintaining the safety and reliability of the structural system throughout all stages of execution.

Verification of the design assumptions also included monitoring the deformations of the temporary support structure and comparing them with calculated values. For example, in the final, sixth concreting stage, the measured deformation was 128 mm, whereas the calculated value was 132 mm.

Similarly, in the fourth stage, the calculated deflection of the falsework was 83 mm, while the actual measured deformation of the temporary support structure at mid-span reached 80 mm.

The measured values showed very good agreement with the theoretical predictions, confirming the correctness of the structural model and the selected static scheme during the individual construction stages.

During staged concreting of the superstructure (Figure 2), progressive deformations of the falsework occur due to loading from the self-weight of the structure, formwork, reinforcement, and fresh concrete.

These deformations are manifested primarily as settlement of the structure in the construction joint between individual concreting stages.

If not compensated, this would result in a vertical misalignment at the connection between the already concreted portion of the structure and the newly cast segment.

A specific feature of this structure was that architectural requirements did not permit any interventions into the superstructure, particularly the creation of openings or other cross-sectional modifications.

Consequently, the adjustment of the joint between successive concrete stages had to be carried out exclusively by hydraulic means from below the structure, without interfering with its load-bearing components. The solution was based on controlled lifting (re-levelling) of the falsework along its support axis using hydraulic jacks, Figure 12.

The lifting operation enabled the formwork to be pressed against the face of the previously concreted cantilever segment, ensuring smooth continuity between the new concreting stage and the previously concreted cantilever segment without forming a vertical "step" at the construction joint. The magnitude of the required corrections is illustrated, for example, by concreting Stage 5, during which the temporary support structure was lifted by up to 70 mm at trestle Pi10.

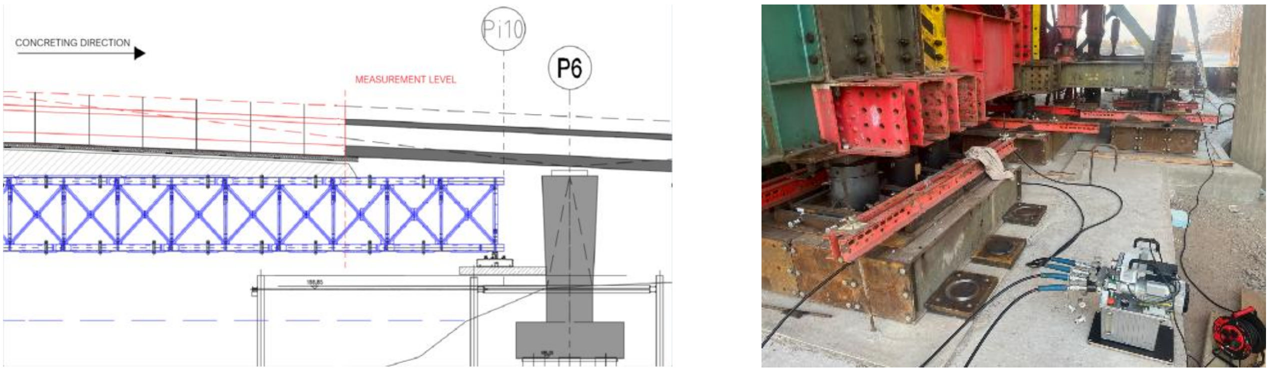


Figure 12: Lifting the temporary structure

The procedure consisted of two main phases:

1. Before concreting: After reinforcement of the new stage had been completed, the settlement of the structure due to additional loading was evaluated geodetically. Based on the measured values, the falsework was hydraulically lifted to the corresponding deformation magnitude, so that the formwork was pressed back against the construction joint in the designed position.
2. During concreting: Throughout the placement of fresh concrete, the position of the structure was continuously monitored. The developing deflections were compensated by gradually regulating the hydraulic jack pressures, thereby maintaining the structure's geometric continuity.

The hydraulic jacks, positioned along the support axis of the falsework, enabled uniform redistribution of reactions and precise lifting control with millimetre accuracy.

The system was interconnected into controlled hydraulic circuits, allowing individual adjustment of each lifting point and ensuring uniform elevation of the entire structure.

A key component was the continuous geodetic monitoring of reference points in the construction joint area. Based on these measurements, the lift magnitude was adjusted to achieve the required geometry and minimise differences between successive concrete stages.

The designed principle of controlled re-levelling thus ensured the elimination of vertical offsets at the construction joint while fully respecting the architectural and structural constraints.

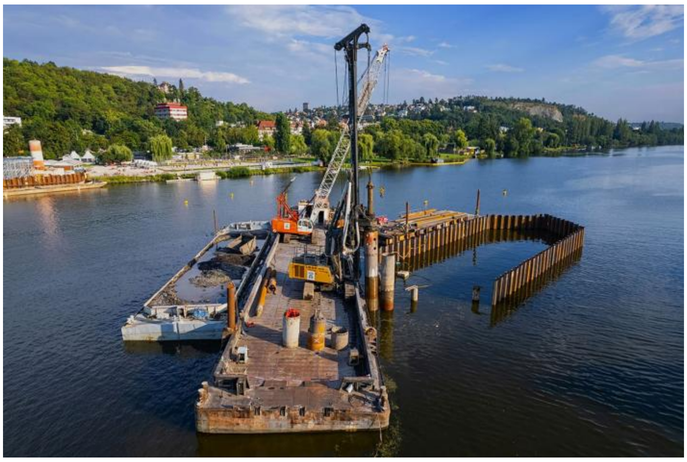
IV. CONCLUSION

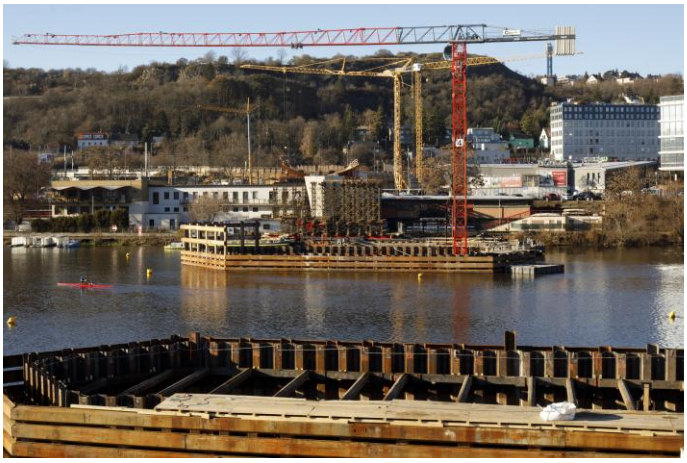
The construction of the superstructure of the Dvorecký Bridge in Prague represented an exceptionally demanding technical and organisational process, significantly influenced by complex spatial conditions, unfavourable geological conditions, and the execution of works within the Vltava River channel.

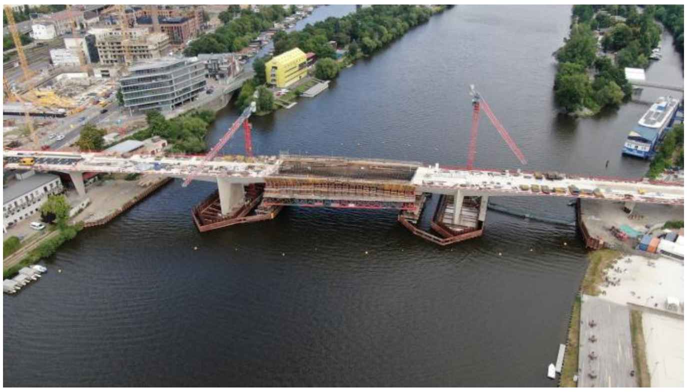
During both the project preparation phase and the actual construction, several technological variants were assessed. The most suitable solution proved to be a combination of spatial and beam falsework systems supplemented by an underslung launching gantry supported on temporary structures. The selected technology enabled the minimisation of interventions in the river environment, the respect of the bridge's architectural requirements, and the simultaneous assurance of a safe and efficient construction process. A key role was played by the precise coordination of individual stages, the detailed preparation of assembly operations, the use of pontoon transport, and the ability to respond flexibly to changing geological conditions and spatial constraints of the construction site.

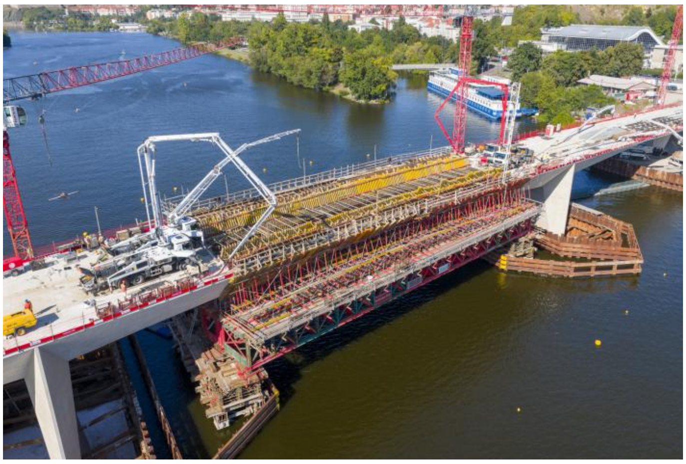
Verification of the design assumptions through deformation measurements confirmed the correctness of the structural model and the chosen structural solution. The implementation of a controlled hydraulic re-levelling system enabled compensation of falsework deflections during staged concreting and ensured the required geometric accuracy without any intervention into the superstructure. Overall, the bridge construction demonstrated a high level of technical preparation, engineering coordination, and the ability to apply innovative solutions under the demanding conditions of an urban and riverine environment.

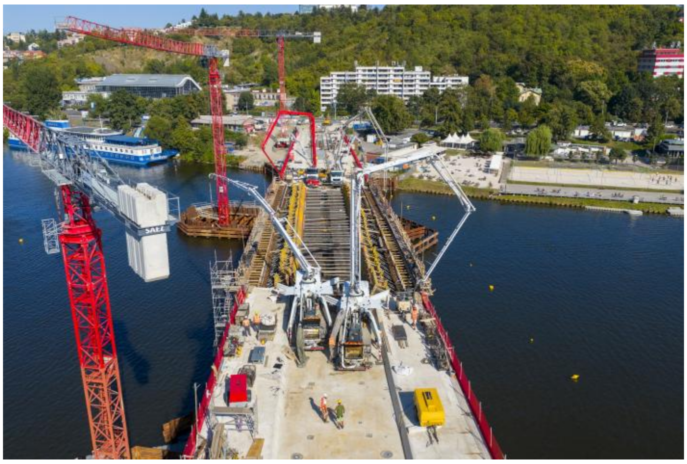
CONSTRUCTION GALLERY

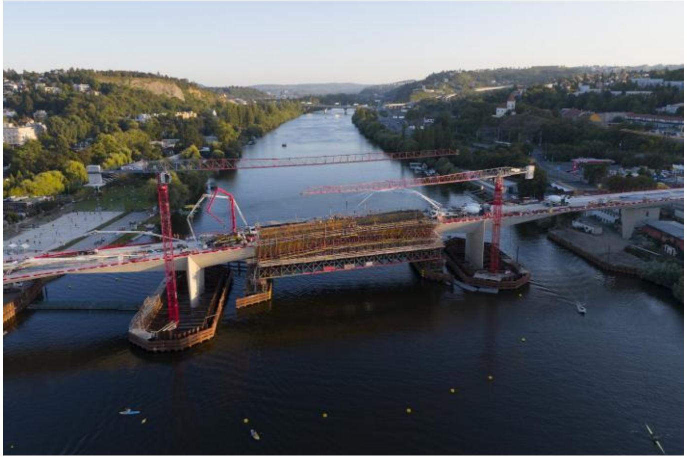


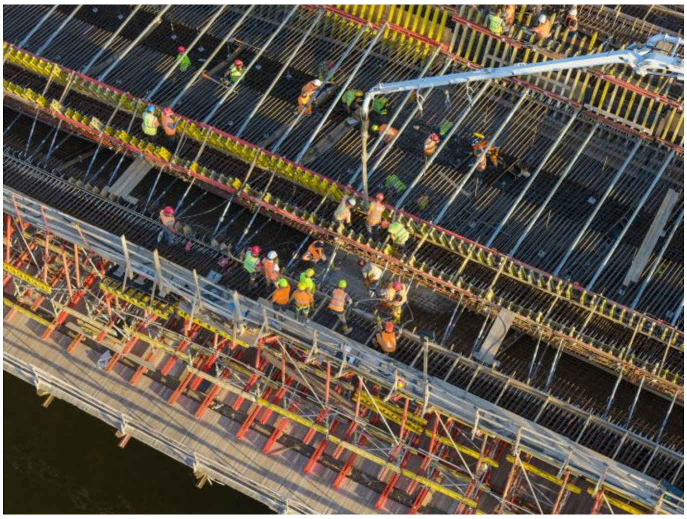




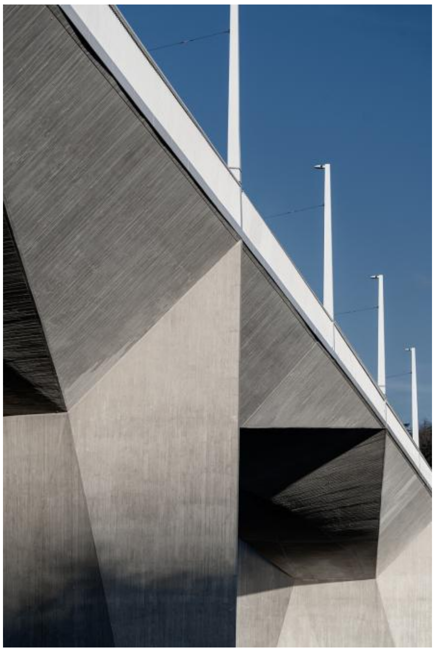








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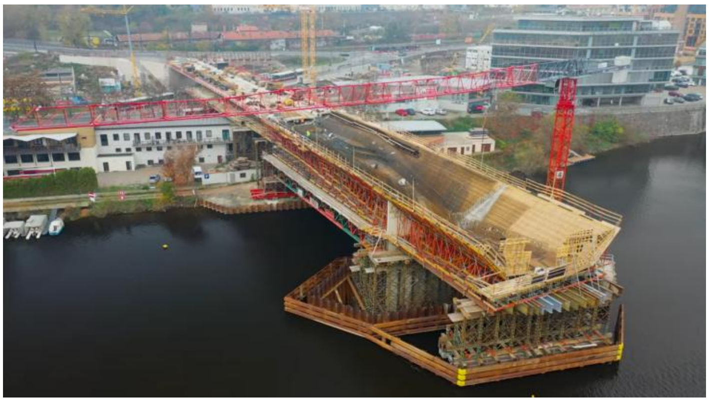
CONSTRUCTION VIDEOS



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INDUSTRIALISATION OF IN-SITU CAST CONCRETE BRIDGE DECK CONSTRUCTION

THE MOVABLE SCAFFOLDING SYSTEM AS A MOBILE INDUSTRIAL UNIT

Aquilino Raimundo, Civil Engineer
Chief Methods Engineer, STRUKTURAS

INTRODUCTION

The use of Movable Scaffolding Systems (MSS) represents one of the most advanced forms of industrialisation in the construction of prestressed reinforced concrete bridge decks.

More than a formwork system, the Movable Scaffolding System constitutes a mobile production unit that enables the application of classical industrial engineering principles to heavy construction, namely production planning, work study, and the corresponding optimisation of operational flows.

This article proposes an integrated interpretation of the Movable Scaffolding System from three complementary perspectives: the historical framework and conceptual evolution of this type of equipment; its interpretation as a mobile industrial unit — a true “factory in motion”; and the systematic application of work study methodologies as instruments for optimising production cycles executed with reduced crews.

It is argued that the full industrialisation of construction using the MSS begins in the structural design of the deck and piers — prioritising geometric and constructive simplicity and repetition — and culminates in a site organisation closely aligned with classical industrial models, oriented toward productivity, predictability, and operational efficiency.

HISTORICAL FRAMEWORK

The invention and development of the MSS is closely linked to the evolution of prestressed reinforced concrete bridge and viaduct construction, particularly for decks with significant longitudinal development integrating multiple spans typically ranging from 30 m to 50 m. The consolidation of this concept resulted from technical advances concentrated in the late 1950s and early 1960s, with prominence in Germany.

Until the end of the 1950s, the scaffolding systems used in concrete deck construction predominantly consisted of ground-supported structures, which had to be dismantled and reassembled span by span.

From a historical and technical perspective, the name most consistently associated with the birth of the Movable Scaffolding System is the German engineer Hans Wittfoht (1924–2011).

The Krahnenbergbrücke, Figure 1, built between 1961 and 1964, is widely recognised as the first fully developed application of a system exclusively supported on the piers and launched to the next span as a single unit.

In the construction of this bridge, the scaffolding ceased to be merely temporary falsework and became a self-supporting structure equipped with its own launching devices, forming a repetitive system and a true production unit.

Figure 1: Krahnenbergbrücke, road bridge over the Rhine River in Andernach, Rhineland-Palatinate, Germany

Figure 2: General view of an Underslung Movable Scaffolding System equipped with a tower crane

The concept of the MSS was thus developed within German engineering and was subsequently disseminated internationally.

THE MOVABLE SCAFFOLDING SYSTEM AS A FACTORY IN MOTION

The emergence of the MSS introduced a clear break from the traditional logic of prestressed concrete bridge construction that prevailed until the late 1950s, by transforming the construction site into an industrial-type production environment.

Unlike conventional methods, in which resources are dispersed across the site, and operations vary significantly from span to span, the MSS concentrates, within a single mobile unit, all the resources required for the systematic execution of the deck.

The result is a true factory in motion, advancing along the bridge axis in parallel with the deck construction.

This concept is based on the creation of an autonomous production unit equipped with a main structure, supports, formwork, working platforms and access ladders, lifting systems, particularly in overhead Movable Scaffolding System typologies, geometric control devices, auxiliary infrastructure (power supply, compressed air, safety systems), and launching systems.

Each concreting cycle is therefore carried out in a nearly constant physical environment, regardless of the span location, pier height, or underlying ground conditions.

As in an industrial production line, the final product — the deck span — results from the rigorous repetition of a predefined sequence of operations.

The analogy with a factory becomes particularly evident when analysing the production cycle of the Movable Scaffolding System.

Each launch corresponds to a “production batch”, subject to detailed planning, with clearly defined durations, resources, and operational sequences.

The stability of the layout and the repetition of processes make it possible to reduce variability, minimise errors, and introduce incremental improvements over time, in a logic closely aligned with continuous improvement as applied in the manufacturing industry.

Figure 3: MSS launching subsystem

Another fundamental aspect of this industrial approach lies in the control of the production environment.

Although operating within a construction context, the MSS provides significantly more predictable conditions than traditional methods: stable platforms, defined access routes, repeated working positions, and clear interfaces between teams.

This predictability facilitates not only production planning but also quality and safety control, since procedures can be standardised and systematically verified in each cycle.

From an organisational standpoint, the MSS imposes a structure comparable to that of a factory unit. Teams are specialised by task, material flows are planned, operation times are monitored, and deviations are analysed.

The management of the MSS thus ceases to be merely a matter of site coordination and instead incorporates concepts typical of industrial management, such as functional layout, operation balancing, and optimisation of internal flows.

Finally, by moving along the deck while maintaining its essential configuration, the Movable Scaffolding System decouples the production process from the external constraints of the construction site.

The ground no longer serves as the support for production; it is the equipment itself that carries the “factory” with it.

This characteristic constitutes one of the system’s greatest advantages, allowing advanced industrial principles to be applied in a sector traditionally marked by the singularity of each project.

The MSS thus embodies a rare synthesis of mobility and industrialisation, positioning itself as one of the most mature expressions of construction rationalisation in contemporary bridge engineering.

STRUCTURAL DESIGN OF BRIDGES AND VIADUCTS AND THE INDUSTRIALISATION OF THE CONSTRUCTION PROCESS

The industrialisation of in-situ cast concrete deck construction using Movable Scaffolding Systems begins at the structural design stage of bridges and viaducts.

Figure 4: Overhead Movable Scaffolding System and detail of the transport of the pre-assembled reinforcement cage, Lima River, Portugal

The efficiency of the production cycle depends not only on the performance of the equipment but also, to a large extent, on the geometric and constructive choices made in the design phase.

Design solutions that favour geometric simplicity, structural repetition, and dimensional stability of spans are decisive for maximising the performance of systems based on stabilised production cycles, such as the MSS. However, these premises are not always properly considered, and in many cases, the impact of certain design decisions on overall cost, including labour, auxiliary equipment, and additional operations required for deck construction, is underestimated.

Among the factors most frequently identified in contemporary bridge designs that hinder the optimisation of construction cycles and require additional adjustment and regulation operations when using the MSS, the following stand out:

- Vertical or near-vertical inclination of the deck webs over their full height or part of it, preventing the simple lowering of the external formwork and requiring prior panel opening operations, with consequent significant readjustments of the MSS.
- Absence of openings in internal diaphragms of box girder decks with dimensions adequate to allow the passage of closed internal formwork mounted on mechanised transport trolleys.
- Definition of transverse superelevation only at the top slab level, while maintaining the underside of the deck horizontal, leading to variation in web height and thereby preventing the use of constant-height formwork and precluding single-stage concreting in box girder decks.
- Design of piers without consideration of the actions transmitted by the MSS during the launching phase, potentially requiring supplementary propping or bracing systems.
- Reinforcement detailing that hinders preassembly, thereby compromising the rationalisation of the critical task within the production cycle, namely the assembly of the reinforcement for each span.
- Prestressing solutions incompatible with reinforcement preassembly or with the sequential organisation of the production cycle.
- The existence of multiple spans with different lengths requires readjustment of the camber settings of the MSS each time it is moved to a span of a different length, thereby introducing additional operations into the production cycle and increasing process variability.
- Adoption of spans adjacent to expansion joints or abutments with lengths exceeding 80% of the maximum span, requiring the MSS to be designed for this most unfavourable condition, with a direct impact on its self-weight and on the required formwork length.

These examples demonstrate that the optimisation of the construction process cannot be dissociated from the structural design of the bridge or viaduct.

Figure 5: Opening in the diaphragm to allow the passage of the internal formwork

Figure 6: Pre-assembled reinforcement of the U segment

The mechanisation of internal formwork transport in box girder decks constitutes a paradigmatic example of the industrialisation effort, showing how the compatibility between structural design and construction methods enables the reduction of ancillary operations, stabilisation of the production cycle, and enhanced overall process efficiency.

Effective industrialisation of construction using Movable Scaffolding Systems therefore requires an integrated approach, in which design and construction methods are understood as inseparable components of a single technical system.

Whenever the structural design of the bridge or viaduct is conceived with awareness of the industrial logic of the MSS, the production cycle stabilises rapidly, allowing the teams' learning curve to generate cumulative productivity gains.

Industrialisation is not merely a consequence of the MSS; it is also a design decision made at the bridge or viaduct conception stage.

THE PRODUCTION CYCLE AS A UNIT OF ANALYSIS

Although the structural design of the MSS, as a temporary steel structure, is decisive in ensuring its structural safety under the various load scenarios considered (from initial assembly to final dismantling, including concreting and launching phases) and therefore demands the highest level of technical attention, there is often an excessive focus on optimizing the structural efficiency of the equipment to the detriment of its overall functionality as a production unit. It may compromise essential principles associated with the industrialisation of the construction process.

The design of Movable Scaffolding System solutions should therefore be carried out by multidisciplinary teams, integrating structural design in accordance with applicable codes and criteria, user safety, ergonomics, and, crucially, optimisation of the production cycle by minimising the number of operations required to construct a span.

A thorough understanding of the construction cycle for each span and the tasks inherent to the system's operation is an essential condition for developing truly optimised solutions that minimise the total cost of span construction.

Figure 7: Mechanised transport of the internal formwork in a box girder deck

This cost results not only from the investment in the MSS itself, but also from the auxiliary support equipment involved and the labour required throughout the cycle. The sum of these factors determines the final cost and, consequently, the perceived effectiveness and competitiveness of the adopted solution.

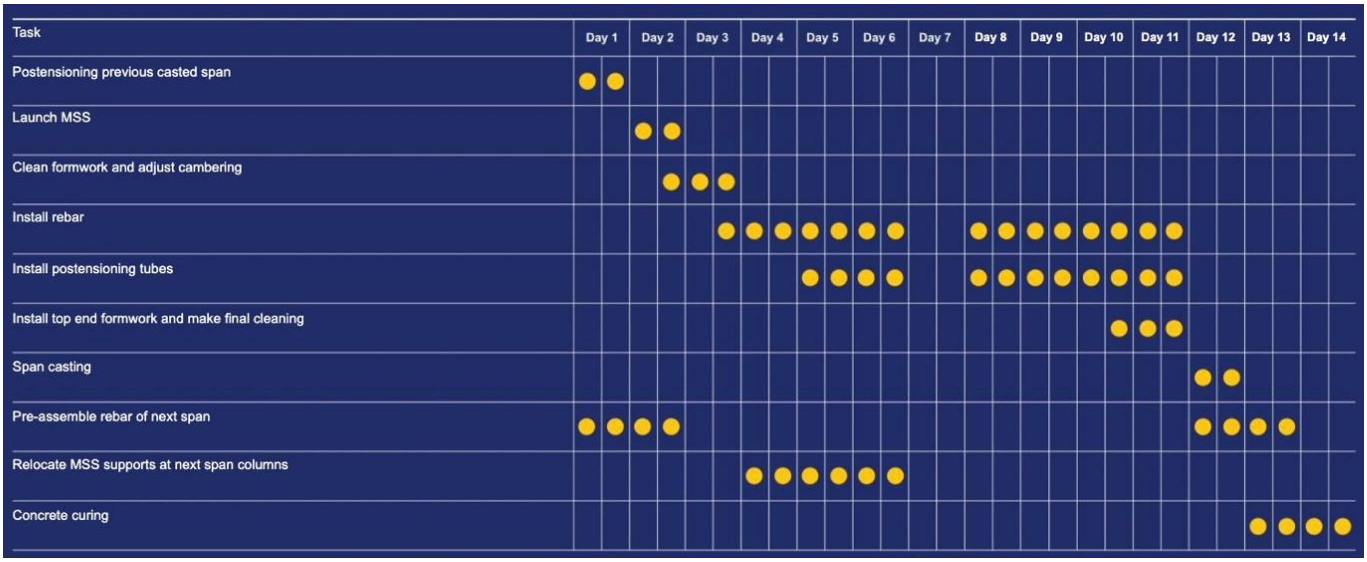
It is observed, however, that many systems currently available on the market do not yet fully embody the principles of industrialisation, presenting functionally sub-optimised solutions that require ancillary tasks and excessive reliance on auxiliary equipment — aspects that a more integrated design approach, oriented toward the production cycle, could eliminate or at least significantly reduce.

Practice demonstrates that the first solution conceived by the engineer is rarely the most efficient; optimisation emerges through critical analysis of the process and the progressive elimination of redundant operations.

Applied to Movable Scaffolding Systems, this principle means that the equipment must be designed to minimise tasks that do not add direct value to span construction.

The key to success lies in organising the cycle according to the principles of work theory: eliminating unnecessary movements, avoiding recurring and potentially avoidable adjustments, and stabilising procedures.

The shorter the distance each Movable Scaffolding System operator must travel to complete the production cycle, and the fewer ancillary interventions required beyond the essential system



Task	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14
Postensioning previous casted span	●●													
Launch MSS		●●												
Clean formwork and adjust cambering		●	●●											
Install rebar			●	●●	●●	●●		●●	●●	●●	●●			
Install postensioning tubes					●●	●●		●●	●●	●●	●●			
Install top end formwork and make final cleaning										●	●●			
Span casting												●●		
Pre-assemble rebar of next span	●●	●●										●●	●●	
Relocate MSS supports at next span columns				●●	●●	●●								
Concrete curing													●●	●●

Figure 8: Typical cycle of a Movable Scaffolding System

adjustments, the greater the industrial maturity of the equipment and its alignment with the true concept of industrialisation.

Practice shows that even in bridges and viaducts with identical structural design, the number of man-hours required, reliance on auxiliary equipment, and production cycle duration may vary substantially across different MSS solutions.

MSS, demonstrating that the efficiency of the process depends strongly on the quality of its functional design. It should be noted that the average duration of a span construction cycle under normal conditions is between 1 and 2 weeks.

Figure 8 shows the typical duration of a construction cycle for a box-girder deck. For spans between 45 m and 55 m, the team of operators responsible for launching and adjusting the MSS, including formwork operations, may consist of approximately 12 experienced workers.

For concrete decks with TT cross-sections and spans on the order of 25 m to 35 m, geometric simplification generally reduces the cycle duration to approximately one week, with the required team comprising 9 to 10 experienced operators.

Naturally, when discussing cycle durations, it is necessary to consider the type of concrete used in span construction, the waiting time after concreting before prestressing can be applied and the MSS can be stripped, and the prestressing method.

The functional specialisation of the teams involved in span construction is a key element. In an industrial environment, repetition fosters learning and efficiency.

In the MSS, the consistent allocation of tasks to specific teams (rebar workers, formwork carpenters, prestressing operators, concreting crews) helps reduce errors, improve execution quality, and stabilise operation times. This specialisation, however, must be accompanied by effective coordination to ensure continuity of the production process and to avoid discontinuities between phases.

Quality control also assumes an industrial dimension. The repetition of cycles allows for the definition of standardised procedures, checklists, and systematic inspection points. Each span becomes a product with clearly defined geometric and structural requirements, whose compliance can be objectively verified. This framework enhances traceability and the early detection of deviations, reducing rework and increasing the overall reliability of the solution.

WORK STUDY APPLIED TO MOVABLE SCAFFOLDING SYSTEMS

In a Movable Scaffolding System, the production cycle must include only the operations strictly necessary to execute the span, eliminating all activities that do not add direct value to the construction process.

The organisation of the cycle requires a clear distinction between productive and non-productive work, suppressing waiting times, unnecessary movements, interference between teams, and avoidable recurring adjustments.

This rationalisation, based on the classical principles of work theory, is an essential condition for the MSS to function as a truly industrial system.

The systematic repetition of the production cycle makes the MSS particularly well suited to the application of methodologies developed in industrial engineering. In a context where operations are repeated in a virtually identical manner over dozens of spans, it becomes possible to observe, measure, compare, and optimise methods with a degree of rigour rarely achievable in traditional construction.

Work study is founded on two complementary pillars: method study and time study. In the case of the MSS, both find a particularly favourable framework, since the physical layout, operational sequence, and general execution conditions remain stable throughout the repetitive cycle.

The industrialisation of deck construction using MSS requires that the production cycle be analysed and organised in accordance with the classical principles of Work Study.

This discipline, developed within the field of industrial engineering, aims to reduce work to that which is strictly necessary to achieve the intended result.

In the context of span construction, the work involved in adjusting and operating the MSS can be broken down into three fundamental categories:

- **Fundamental work:** indispensable for the adjustment and operation of the MSS for span execution (its lowering, opening the formwork, launching to the next span, cambering adjustment, etc.).
- **Supplementary work:** resulting from deficiencies in method, organisation, or design (for example, dismantling parts of the MSS to allow other tasks to be carried out, such as the transport of preassembled reinforcement, etc.).
- **Unproductive time:** associated with waiting periods, unnecessary movements, crew interferences, or unplanned interruptions.

Industrialisation consists precisely in the progressive reduction of supplementary work and unproductive time, preserving only fundamental work in its simplest and most rational form.

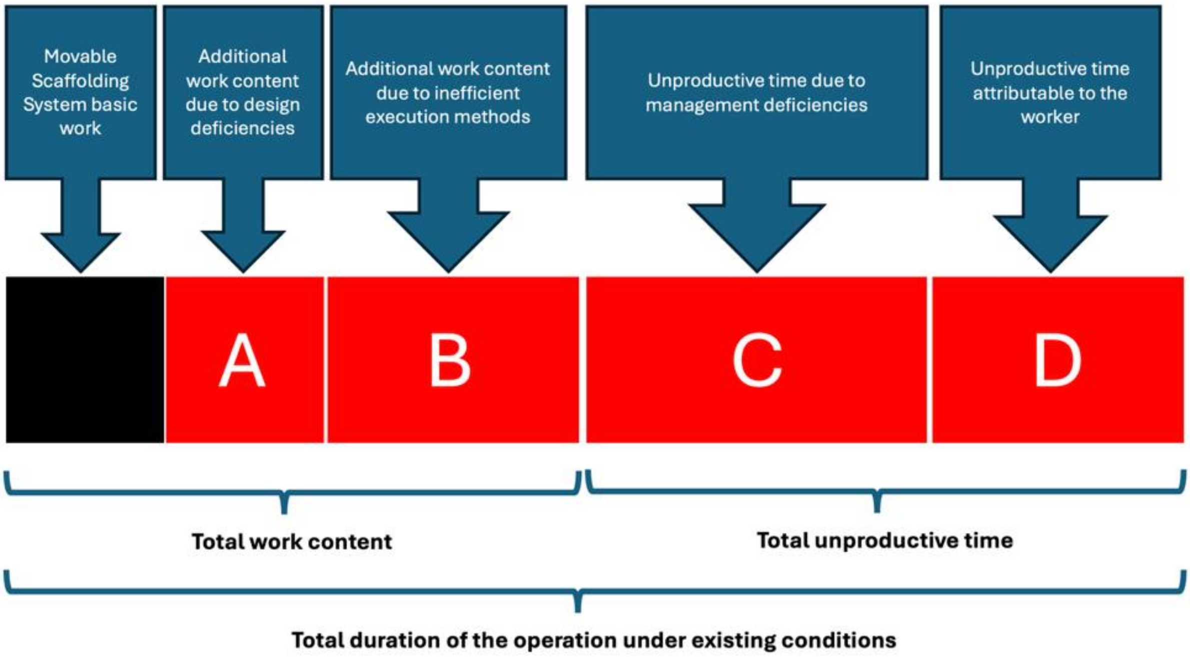


Figure 9: Breakdown of the total duration of an operation

Method Study

The methodological study aims to critically analyse how the adjustment and operation tasks of the Movable Scaffolding System are carried out. In each production cycle (preparation, lowering of the system, opening and closing of formwork, cambering adjustment, longitudinal launching, among other phases), different equipment subsystems are involved.

Each of these phases can be broken down into elementary, observable, and repetitive operations that can be analysed and simplified.

It is precisely in this decomposition that the essence of MSS design lies: a functionally under-refined solution inevitably introduces supplementary work and unproductive time that could have been avoided at the design stage.

This decomposition allows the following questions to be raised:

- Are the adjustment and operation subsystems of the Movable Scaffolding System the most appropriate?
- Is the sequence of operations the most logical?
- Are there tasks that could be eliminated?
- Are there recurring manipulations or adjustments resulting from insufficiently refined design solutions?
- Does the layout of working platforms and access ladders facilitate or hinder the work?
- Is the number of levels that operators must access to adjust and operate the Movable Scaffolding System reduced to the minimum necessary?

The systematic application of these questions simplifies the operation and adjustment cycle of the MSS. However, it is important to emphasise that many of the operations carried out on site do not arise from unavoidable functional requirements, but rather from design choices related to the equipment's own subsystems.

Whenever the MSS requires intermediate dismantling, recurring adjustments, complex reconfigurations, or auxiliary interventions to enable subsequent tasks, it generates additional work.

This work does not add value to the span; it results from a design that has not been sufficiently optimised.

At this point, the technical responsibility of the MSS supplier becomes evident. Industrialisation depends not only on site organisation, but also on the functional quality of the system as designed.

A well-engineered system should minimise handling operations, simplify interfaces, and reduce the number of operations required to adjust the equipment for each new span.

Time Study

Time study complements the method study by quantifying the actual duration of operations. The systematic repetition of adjustment and operational cycles in the MSS creates particularly favourable conditions for reliable time measurement and for the establishment of stable performance benchmarks.

Time analysis makes it possible to clearly distinguish between:

- **Productive time** (associated with fundamental work);
- **Supplementary time** (resulting from avoidable operations);
- **Unproductive time** (waiting, unnecessary movements, interferences).

By making these time components visible and measurable, an objective basis for continuous process improvement is established.

In systems characterised by repetitive use, such as the MSS, small inefficiencies accumulate over dozens of cycles and therefore significantly impact the overall cost of the project.

Every unnecessary movement, every avoidable adjustment, and every operational interference adds up to accumulated man-hours.

Responsibility in the Design of the MSS

A set of subsystems must be adjusted at each cycle to adapt the equipment for the next span. The way these subsystems are designed directly influences the amount of supplementary work generated.

The more complex the interfaces and the greater the number of interventions required to reconfigure the system, the greater the operational effort associated with the cycle. Systematic analysis of methods and times demonstrates that a substantial portion of supplementary work can be eliminated during the equipment design phase.

Structural and functional simplification of sub-systems reduces interventions, stabilises procedures, and decreases man-hours per span.

The application of work study principles to the MSS, therefore, leads to a clear conclusion: the system's industrial maturity is measured by its capacity to reduce work to its fundamental form.

Responsibility for the industrialisation of deck construction does not lie solely with site organisation; it begins with the structural design of the bridge or viaduct and continues with the functional design of the MSS itself.

A supplier who designs solutions that require unnecessary operations effectively introduces additional work into the production system. Conversely, a functionally refined system enables the cycle to be executed with the fewest interventions, movements, and adjustments.

Industrialisation is not merely a management methodology; it is a direct consequence of the technical quality of the equipment design, enhanced by a well-conceived structural design of the concrete bridge or viaduct.

INTEGRATED SAFETY WITHIN THE SYSTEM

The consolidation of the MSS as a mature solution for the industrialisation of deck construction has required the development of a rigorous certification and technical compliance framework, particularly within the scope of the Machinery Directive.

By concentrating structural, operational, and safety functions within a single large-scale piece of equipment, the MSS ceases to be merely a formwork system and assumes the status of specialised construction equipment, subject to technical requirements comparable to those applicable to industrial machinery or complex temporary structures.

Its certification must encompass structural design verification, assessment of transient phases (assembly, concreting, launching, and dismantling), and the clear definition of operational limits.

The regulatory framework results from the combination of standards applicable to steel structures, work equipment, temporary structures, and collective protection systems, requiring an integrated approach from the design stage onward.

Technical responsibility is shared among the designer, the manufacturer, and the user. Comprehensive documentation is indispensable, including design criteria, calculation reports, assembly and operation drawings, dismantling procedures, reaction forces transmitted to the bridge or viaduct structure, operation manuals, checklists, manufacturing quality control documentation, risk assessments, parts lists with references and weights, and related technical records. MSS compliance depends not only on correct structural design but also on strict adherence to the defined operating conditions.

Prior to commissioning, the system must undergo appropriate tests and verifications. During operation, periodic inspections ensure continuous control of structural and functional performance. The very repetition of production cycles constitutes an ongoing opportunity to monitor and validate the equipment’s behaviour.

The standardisation of procedures (work methods, operational sequences, and acceptance criteria) reinforces the industrial logic of the MSS, reducing ad hoc decisions and promoting consistency, traceability, and operational discipline.

Certification should therefore not be regarded merely as a regulatory obligation, but as a structural component of risk management and system efficiency. It ensures that the industrialisation of deck construction using an MSS rests on sound technical foundations and is compatible with contemporary safety and quality requirements.

Far from being peripheral, certification and standardisation are integral components of the MSS concept, which is a factory in motion.

They guarantee that the industrialisation of prestressed concrete deck construction is supported by robust technical principles aligned with the demands of modern civil engineering in terms of safety, quality, and professional responsibility.

CONCLUSIONS

The Movable Scaffolding System represents one of the most advanced expressions of industrialisation in the construction of prestressed reinforced concrete bridges and viaducts.

Its true effectiveness, however, does not result solely from its structural capacity, but from its conception as an integrated production system.

The industrialisation of construction using an MSS is based on three fundamental pillars: a structural bridge design oriented toward geometric simplicity and repetitiveness; rigorous organisation of the production cycle as the primary unit of analysis; and the systematic application of work study methodologies aimed at eliminating supplementary work and unproductive time.

When these elements are properly aligned, the MSS transforms the inherent variability of construction into a predictable, controlled, and progressively optimised process.

The repetition of cycles enables the stabilisation of methods, the reduction of crew size without compromising productivity, the enhancement of operational safety, and the strengthening of quality control.

The industrial maturity of a Movable Scaffolding System is not measured solely by its structural design, but by its ability to simplify work, reduce ancillary interventions, and minimise unnecessary movements.

The true refinement of the system lies in the continuous optimisation of its subsystems and in the coherent integration between structural design, construction method, and work organisation.

In this sense, the MSS should not be understood merely as auxiliary construction equipment, but as a mobile industrial unit — a factory in motion — that carries its production environment with it, dissociating it from site constraints and bringing heavy construction closer to the organisational models of the manufacturing industry.

The industrialisation of cast-in-place deck construction is therefore not an automatic consequence of using an MSS; it is the result of a deliberate decision regarding design, organisation, and technical management.

It is in this alignment that the system's true transformative potential resides.

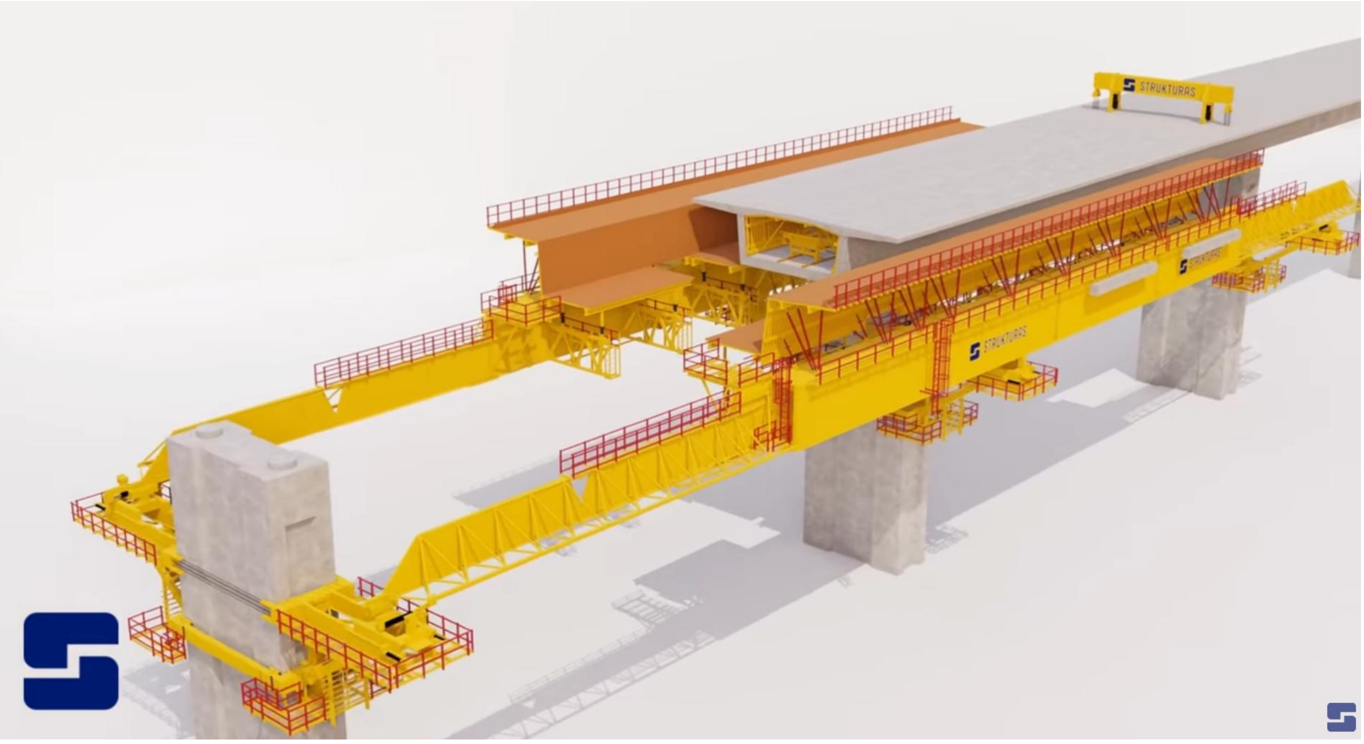
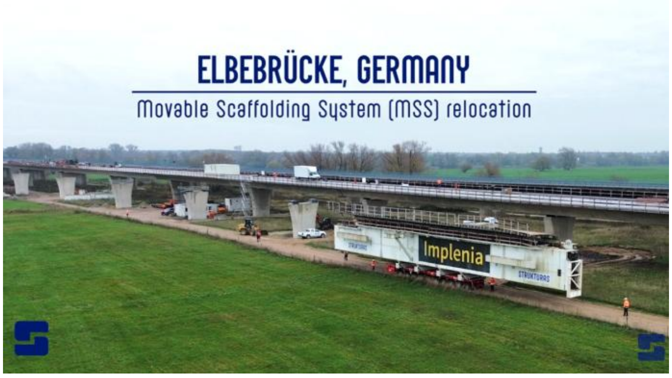


Figure 10: General view of the underslung Movable Scaffolding System during launching

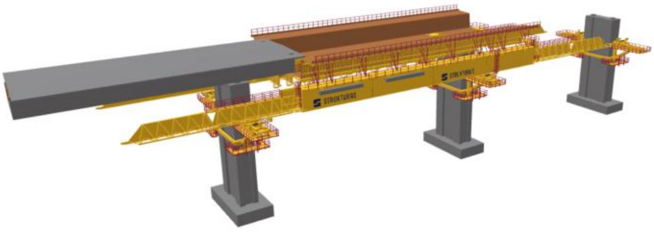
UNDERSLUNG MSS VIDEOS

Underslung MSS Box Cross Section typical cycle

Rail Baltica Neris Bridge Construction Animation – Underslung MSS



Elbebrücke MSS relocation using underslung MSS with tower crane



Underslung MSS VR/AR model

Click on the image to play the video

OVERHEAD MSS VIDEOS

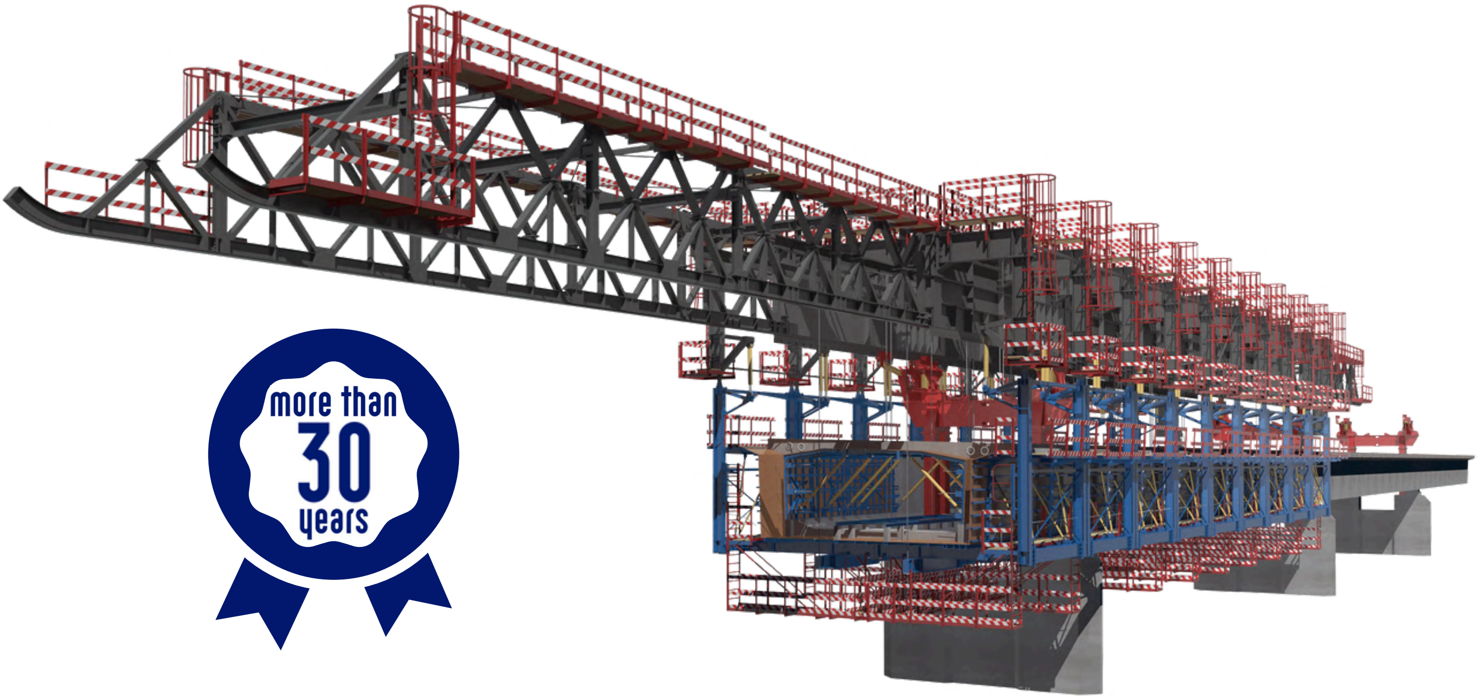
Overhead MSS typical cycle

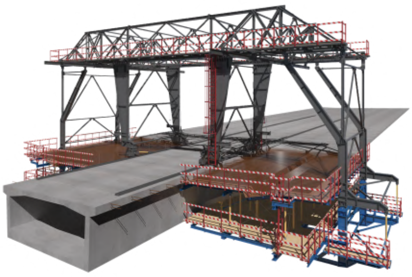
Overhead MSS in Slovakia

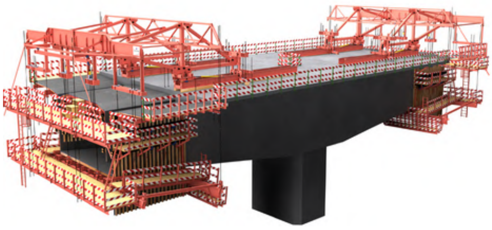
Overhead MSS VR/AR model

MSS internal formwork kinematics

Click on the image to play the video







ROPES CARRYING THE WEIGHT OF HISTORY: AESTHETICS MEETS QUALITY

Kai-J. Thiem, Engineer, Head of Technical Department Structural Ropes
Fatzer AG, Switzerland

Figure 1: The Menai Suspension Bridge was the first to span the Menai Strait, connecting Anglesey to mainland Wales

INTRODUCTION

Fatzer, the Swiss-based manufacturer of structural steel ropes, relies on years of experience and proven engineering expertise to realise even the most demanding projects. Iconic Menai Suspension Bridge, celebrating its 200th anniversary this year, is now part of their portfolio.

This is how history lives on. For 200 years, the Menai Suspension Bridge has connected the Isle of Anglesey with mainland Wales. At the time of its opening in 1826, the bridge, designed by Thomas Telford, with a span of 176 m, was the longest suspension bridge in the world. Even today, the Grade I listed Menai Suspension Bridge stands as a testament to the legacy of British engineering, and it is set to continue doing so for many years to come.

NEW DESIGN CLOSELY RESEMBLING THE ORIGINAL

The world's second-oldest suspension bridge, still in use for vehicle traffic, has, since 2022, been undergoing a comprehensive refurbishment program under the direction of Spencer Bridge Engineering.

For its efforts, the engineering specialist was honoured with the Bridges Award for New Life at the 2025 Bridges Awards. The scope of the works also included replacing 168 hanger ropes, which was carried out with the utmost care for the historic structure.

In 2022, following technical reviews and supplier audits, Fatzer was commissioned to undertake the

Figure 2: After carefully installing 42 wires into the stranding machine over two days, it took only half a day to manufacture the Menai rope

Figure 3: The sockets were cast in India

detailed design, testing, manufacture and supply of the new hangers. The delivery included hangers with a diameter of 34 mm and a minimum breaking load of 1,120 kN, ranging from 1.5 to 12 m in length, totalling 1,300 m of rope, and 346 end connections.

From the very beginning, the client, consultants and contractor maintained close communication to do justice to this cultural asset.

Preserving the heritage bridge poses a challenge, as it not only spans the banks but also bridges the gap between preserving historical integrity and meeting modern safety standards.

To satisfy the aesthetic requirements under the Grade I listing of the structure, the design of the existing sockets was adapted, ensuring they also complied with current construction regulations and were geometrically compatible with the existing steel structure.

INTENSIVE TESTING AT THE SWISS ROPE SPECIALIST

Because the latest design requirements prevented a one-to-one replica of the original socket, Fatzer had to initiate an intensive development phase and a comprehensive testing program to find a new solution.

Figure 4: After an intensive design phase, the design of the existing sockets was adapted

Figure 5: As preparation for the socketing process, the sockets were heated to about 350°C

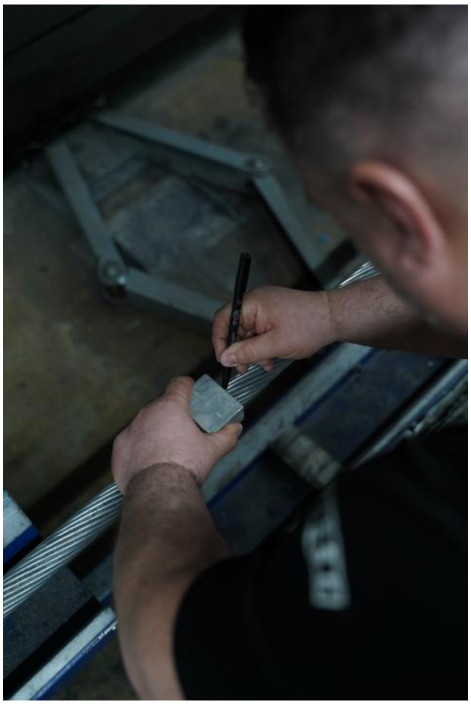
Figures 6 and 7: The sockets have a conical inside, which, for the rope end, opens into a brush to sit in. A special zinc alloy was molten at about 450°C and poured into the inside to form a cone with the wires.

After evaluating various geometric options, Fatzer collaborated with a specialised supplier to produce several prototypes. These underwent rigorous evaluation both at in-house laboratory and at independent Material testing institutes in Switzerland.

The protocol included loading ten sockets to 150% of the rope's bearing capacity, mechanical destruction testing of 20 sockets, and ultrasonic and magnetic powder inspections of all sockets for defects.

Finally, 10% were randomly selected for X-ray to validate the results. The tests carried out on the open spiral strand ropes were no less rigorous than those on the sockets.

Standard practice at Fatzer dictates that before cable assemblies leave the factory, their breaking strength must be tested and verified. This means that for every production run of a particular cable, a test piece is subjected to a break test in-house or at a material testing laboratory.



Figures 8 and 9: Every rope was pre-stressed with the aim of bedding in.

The markings were made under load using a digital robot.

The required break load is the decisive factor in choosing a lab, with Fatzer's technical department able to test cable assemblies under loads of up to 3,000 kN.

During the tensile test of the ropes, the representative cable assembly reached a breaking load of 1,220kN, which was 10% in excess of the required capacity. The results of the fatigue test were equally positive - after 2,000,000 load cycles, the hanger showed no signs of fatigue.

With a 190-year track record of cable production, Fatzer's know-how and experience are second to none. This expertise, however, extends beyond the production of cables and ancillary components used in iconic tensile structures.

Project-specific consulting covering detailed design, quality management, material testing, and installation support, along with advanced monitoring solutions, rounds out the types of solutions the structural ropes team delivers to clients day in and day out on a global basis.

HIGH DEMANDS ON ACCURACY

Hanger production is a highly controlled process; however, tolerances in the fabrication process mean the final length of a hanger may vary from the specified one.

The requirements for a maximum deviation of 3 mm per rope were strict, and these were successfully achieved by applying load already during manufacturing: the free rope length was marked under load and the sockets were pre-loaded up to 40 tons during manufacturing. This eliminates any settlements on site. The length of the hangers was checked after each manufacturing step, and corrections were implemented in subsequent steps if deviations were identified.

With the delivery of the prefabricated ropes in summer 2024, an extraordinary project was completed, which can now be viewed in a video documenting Fatzer's work at the local Menai Heritage Museum.

Figure 10: Complete hangers were tested for ultimate load in a static break test

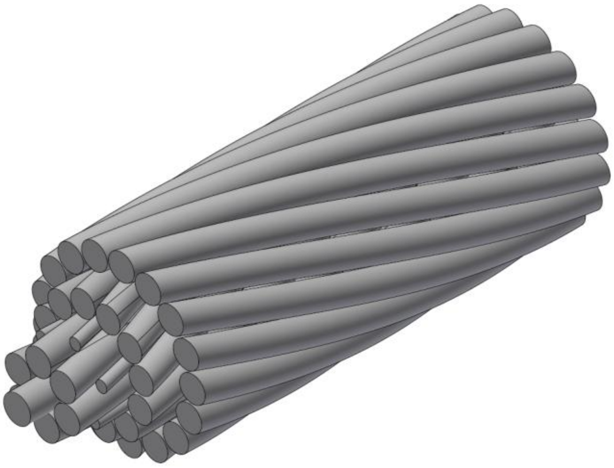


Figure 11: 3D view of the rope. The wires have different tensile grades depending on their diameter.

Figure 12: Visualisation of the final socket, modelled after the original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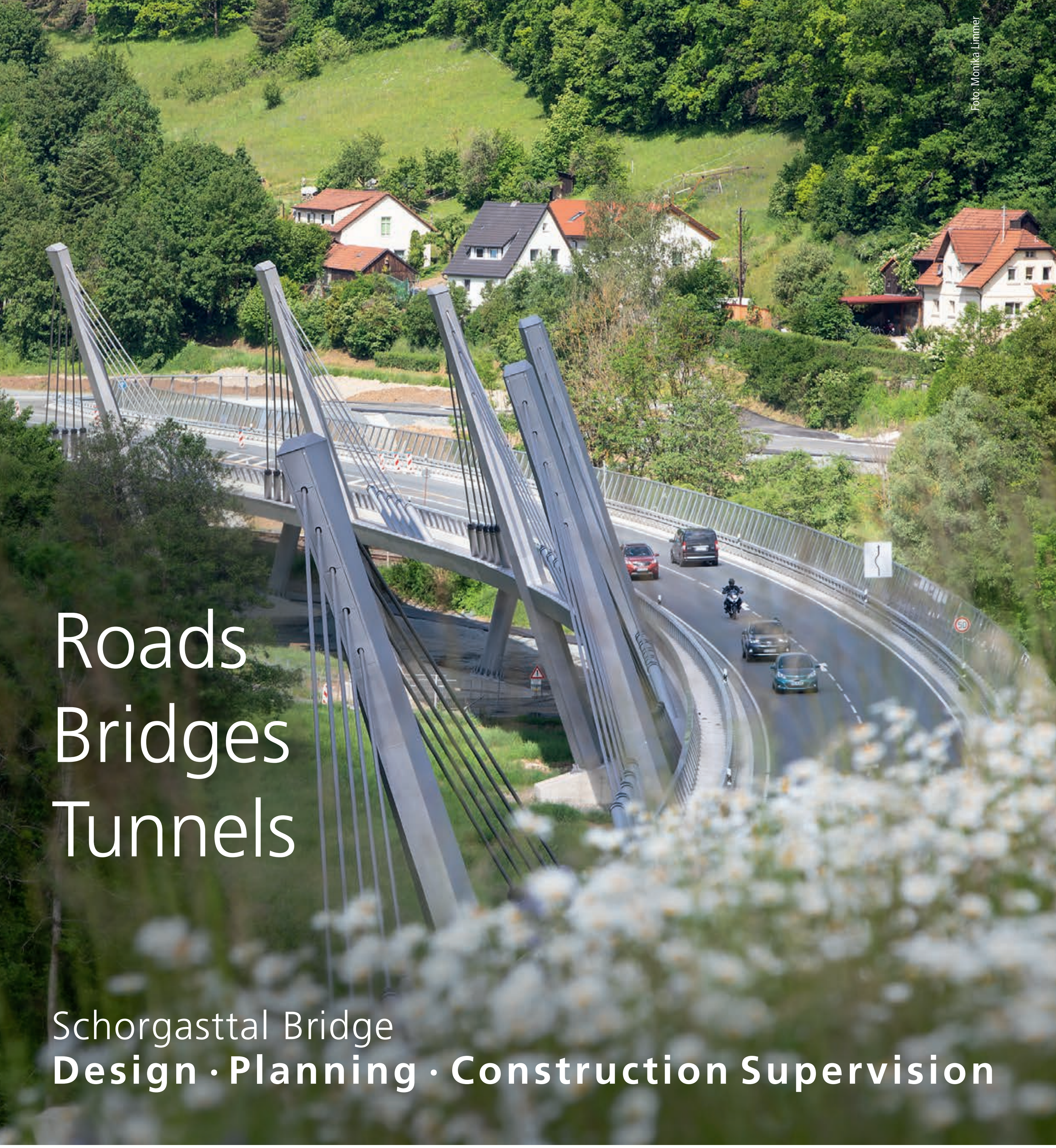

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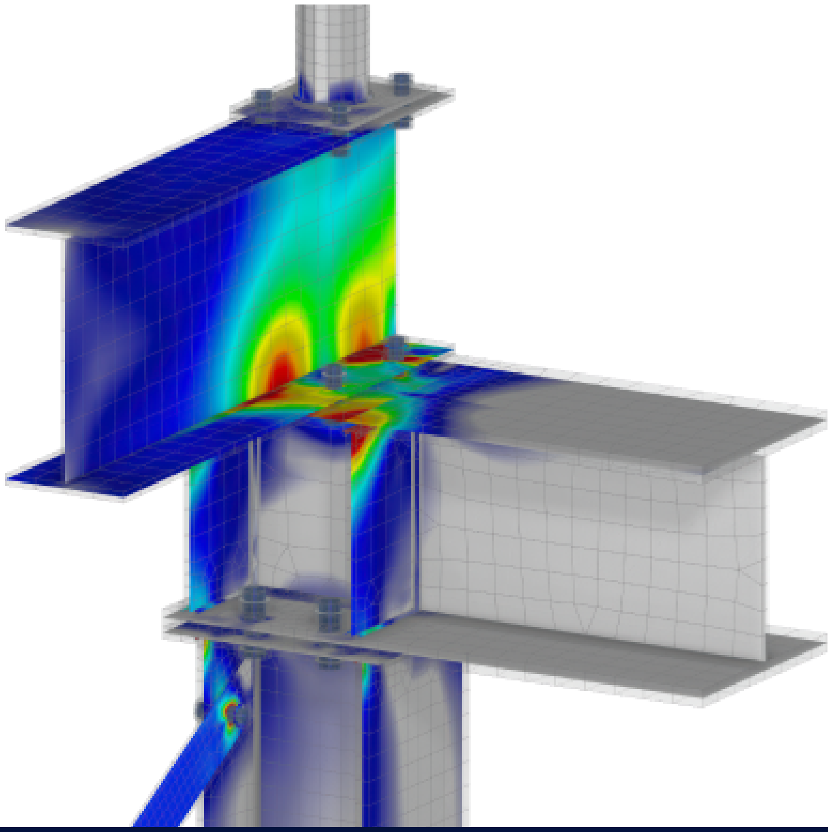

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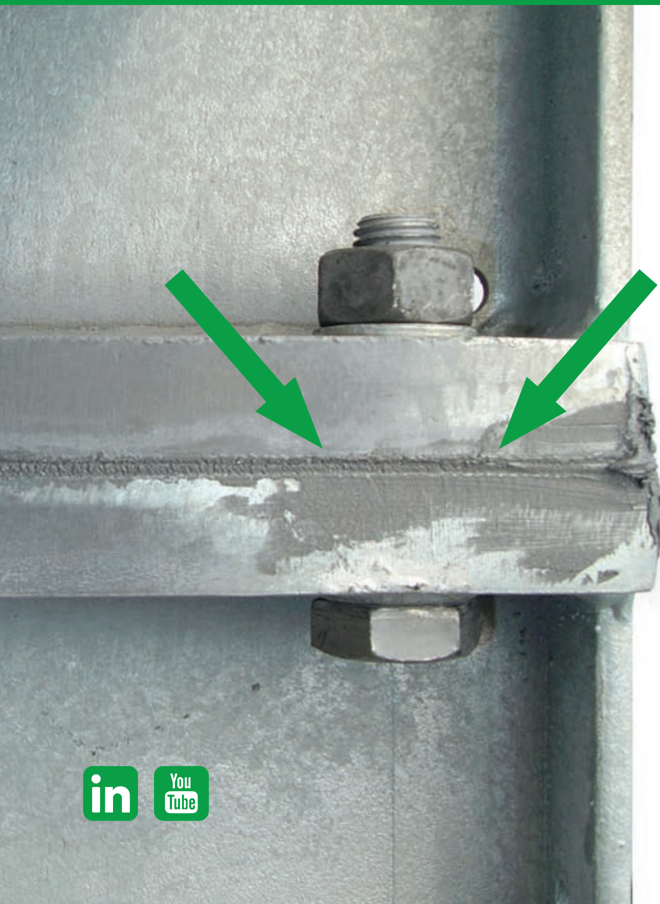
References:

- Bahia de Cadiz, Spain
- Hochmoselübergang, Germany
- Osman Gazi Bridge, Izmit, Turkey
- Mainbrücke Randersacker, Germany
- Millau Viaduct, France
- Rheinbrücke Schierstein, Germany
- Rion Antirion, Greece
- Russky Island Bridge, Vladivostok, Russia
- Tsing Ma, China



DIAMANT
MM1018
Putty - Component A
#1436A
MM1018
Putty - Component B
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GERMAN GENERAL BUILDING
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APPROVAL

Helgeland Bridge, Norway

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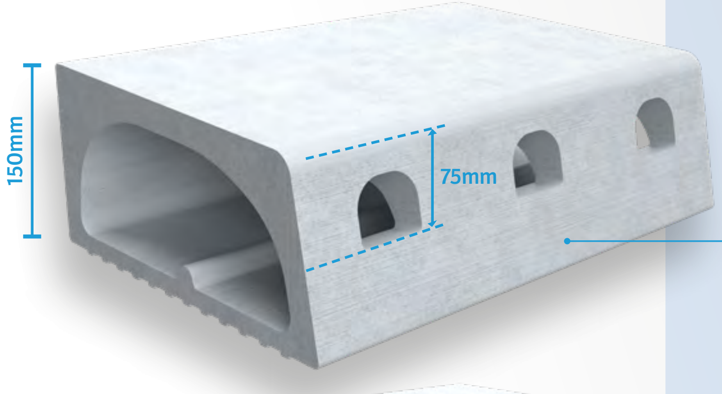

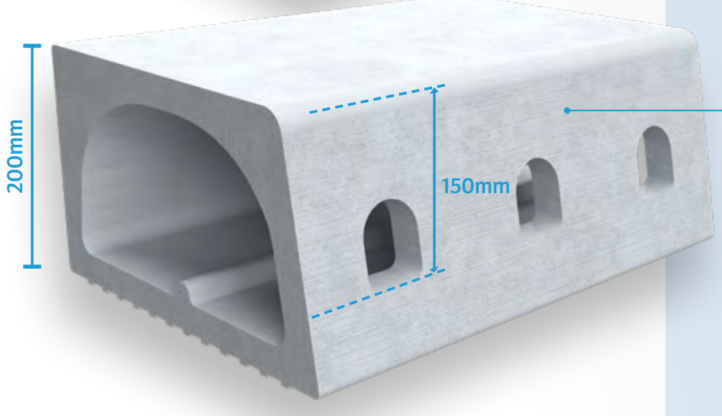

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