Robinson Bridge: The Newest Landmark of Budapest

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Abstract The Robinson Bridge is erected at the confluence of the Danube and its Soroksári-Ráckevei Danube-Branch in Budapest, Hungary. The new pedestrian and cycle bridge plays a vital role in creating access to the Danube waterfront between the city centre and Csepel Island. The bridge follows a curved path along the Danube with its pylon standing on a small island. The bridge was built within the framework of a new Stadium project, that hosted the Athletic World Championship 2023 in Budapest. Intended purpose of the bridge's design was to serve as a landmark: the slender cable-stayed design harmonizes with the architectural and environmental context of the stadium building. The 168 m long bridge with the 65 m tall pylon is the largest and highest bridge in Budapest and Hungary designed exclusively for pedestrians and cyclists. The superstructure is suspended with a two-plane cable system consisting of 53 FLC stay cables, while 3 backstay cables support the slender pylon in the transversal direction. The superstructure has no fix middle support, the 168 m long and 12,71 m width deck is suspended only by the FLC cables. The pylon and the bridge deck are both very slender, which was ensured by the combined use of structural steel and concrete. The stiffening girder and the pylon are made of steel tube cross-sections, which were later filled with concrete, thus forming a hybrid structure. The pylon and the parts of the superstructure - in which its advantages could be utilized - were designed and fabricated from high-strength and thermo-mechanically rolled S460 M/ML steel material, which required special attention during fabrication.

1 Introduction

The 'Robinson' Bridge is a newly built pedestrian bridge erected next to the new National Athletics Stadium in Budapest, Hungary. The 168 m span bridge follows a curved path along the Danube with its pylon standing on a small island. The slender cable-stayed design harmonizes with its architectural and environmental context. The 170 m long and almost 70 m tall bridge structure is the largest bridge in Budapest and Hungary, designed exclusively for pedestrians and cyclists. The Athletic Stadium project developed a new public space for sports and recreation by revitalizing an exceptional brownfield area of central Budapest. The pedestrian and cycle bridge plays a vital role in creating access to the Danube waterfront between the city centre and Csepel Island. [1]

Construction was implemented in line with the project schedule and on time. The commissioning process closed on December 20, 2022, when the opening of the bridge was officially authorized.

Figure 1: The Robinson Bridge is located at the confluence of the Danube and the Soroksári-Ráckevei Danube Branch (Source: Magyar Építők)

2 General arrangement

The bridge structure is a two-support, single-pylon, cable-stayed pedestrian bridge with a steel stiffening girder and an orthotropic deck. The bridge deck is suspended from the pylon by a two-plane cable system at a 6.00 m rhythm.

Table 1: Main attributes

Attribute	Amount
Span	168,00 m without intermediate support
Bridge length	168,90 m
Width of pedestrian path	7,00 m
Total width	12,71 m
Height of the pylon	65,00 m
Steel structure	1020 t S460 ML and S355 M
FLC cables	3500 m

The bridge is hung on a slender steel pylon located on an artificial island that divides the Danube-branch. The pylon's height is 65.00 m measured from the upper plane of the pile cap beam and its height above the roadway is 56.34 m. The pylon body has a circular cross-section with a maximum diameter of 2.00 m, which tapers conically upwards and downwards. Its axis is inclined from the vertical to the outside of the bridge at an angle of 9.0 degrees. The cable network nodes on the stiffening girder are distributed at 6.0 m intervals aligned with the crossbeams, and with a spacing of 1.5 m on the pylon. The cables are arranged symmetrically in a fan shape in the longitudinal direction. The bridge deck is supported by 53 small-diameter FLC suspension cables. The back anchorage stabilizing the pylon is located 25 m away, with three 100 mm-diameter cables used for anchoring. The bridge is balanced in its own weight; longitudinal forces can only arise from seismic and live loads.

The entire structure is arranged in a pure circular curve with a radius of 275 m (referring to the centreline of the roadway). Its total width is 12.71 m, and the width of the open walkway between the railings is 7.00 m. The bridge deck is supported by closed-section, welded box main girders on both sides, while an orthotropic steel roadway plate reinforced with longitudinal ribs at 40 cm intervals is situated in between. The 900 mm structural height curved lower chord crossbeams are radially placed and spaced apart at 6.0 m intervals. [2]

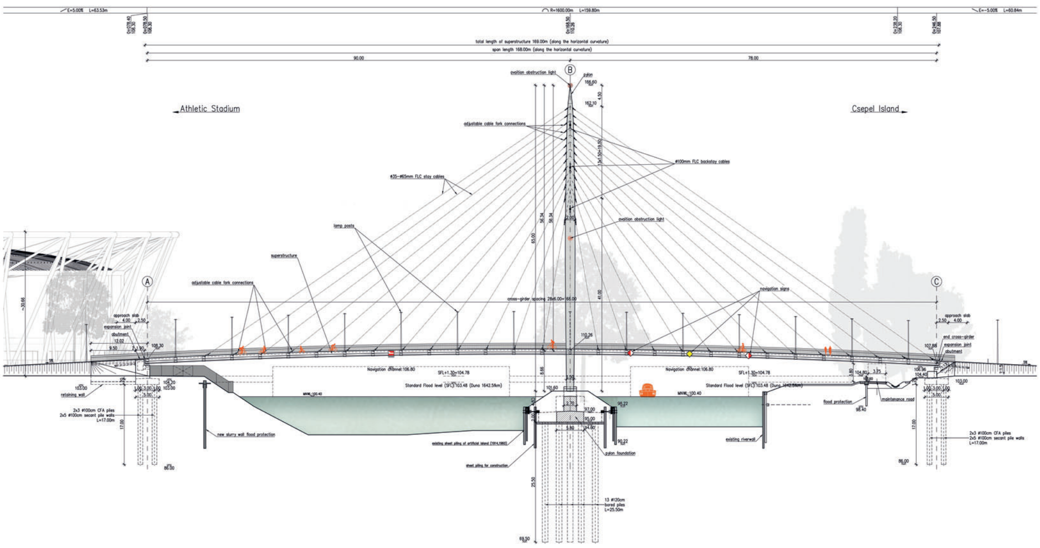

Figure 2: General arrangement (Source: Speciálterv)

To ensure adequate pedestrian clearance on the bridge's curved plan, the cables were cantilevered outside the main girders. In order to achieve this, steel edge beam tubes were installed with a diameter of Ø610 mm on either side of the roadway, connected to the roadway as a continuation of the crossbeams. The use of these tubes not only made the roadway transparent, but also enhanced the spatial experience and ensured a seamless connection between the bridge structure and the adjacent stadium details. The cross-section of the tubes is asymmetric, with the axis of the edge beam being situated 3.00 m away from the axis of the main girder on the inner side of the curve, and 1.50 m away on the outer side. Both the main and edge beams of the steel tubes were concreted. The cross-bracing of the roadway plate is one-sided, sloping towards the centre of the plan by 2.5%

and with a 5.0% counter-slope at the outermost 75 cm of the low point. The cables are connected to the edge beams through forked connections. The superstructure was constructed with a vertically curved length of 1600 m diameter, resulting in the roadway's highest point being situated 2.2 m above the bridge piers.

2.1 Pylon

The entire steel structure of the pylon is 69.80 m long and was assembled from 5 production units on a TS80 barge. The pylon structure is made of S460 ML structural steel plates, formed using a special rolling process. The determination of the node plates to be welded onto the single-curved conical surface was done using a 3D BIM model. In addition to determining the surface development shapes and the leading edges of the connecting elements, it was also necessary to determine templates and technology elements suitable for control measurements through close collaboration between the Contractor and the Designer.

The counter-diaphragms that connect to the internal stiffening rings lead the forces acting on the node plates into the pylon, minimizing the bending of the shell. The interior of the pylon was concreted, which is an efficient and economical way to increase the compressive strength of a steel tube. The internal stiffening rings of the pylon are capable of transmitting the compressive force of the pylon to the concrete as a cooperating grip, which is generated by the cable forces. The pylon has shear studs on the lower 4 m section that is clamped into the pile cap, on both the outer and inner surfaces, to release the pylon force and clamping torque.

2.2 Substructures

The bridge piers are solid monolithic reinforced concrete structures with pile foundations and parallel wing walls. The wing walls are designed to enclose the backfill, and are connected to the backfill closure cones. A pile wall is used to absorb the significant horizontal loads acting on the substructure, providing excellent horizontal support.
A unique bearing system is used to transfer the reaction force between the abutment and the superstructure: a total of 3 bearing support the superstructure at each abutment. Due to the plan curvature and inclined cables, significant lateral force is required to maintain the bridge deck in position ($\sim 4000kN$). As considerable tensile force is also required, the two effects were separated in the design: the outer bearing provide vertical (tensile) force absorption, while a purely compressed intermediate bearing was used to absorb the horizontal lateral force resulting from the curvature. These bearings were placed on a small shear cantilever connected to the crossbeam from below. The bridge is balanced in its own weight, with longitudinal force only generated by seismic and live loads.

The intermediate support constructed on the island is a pile foundation monolithic reinforced concrete structure. It supports and braces the steel pylon and also anchors the backstay cables that stabilize the pylon. Its geometry was designed to meet these functions. To absorb the significant

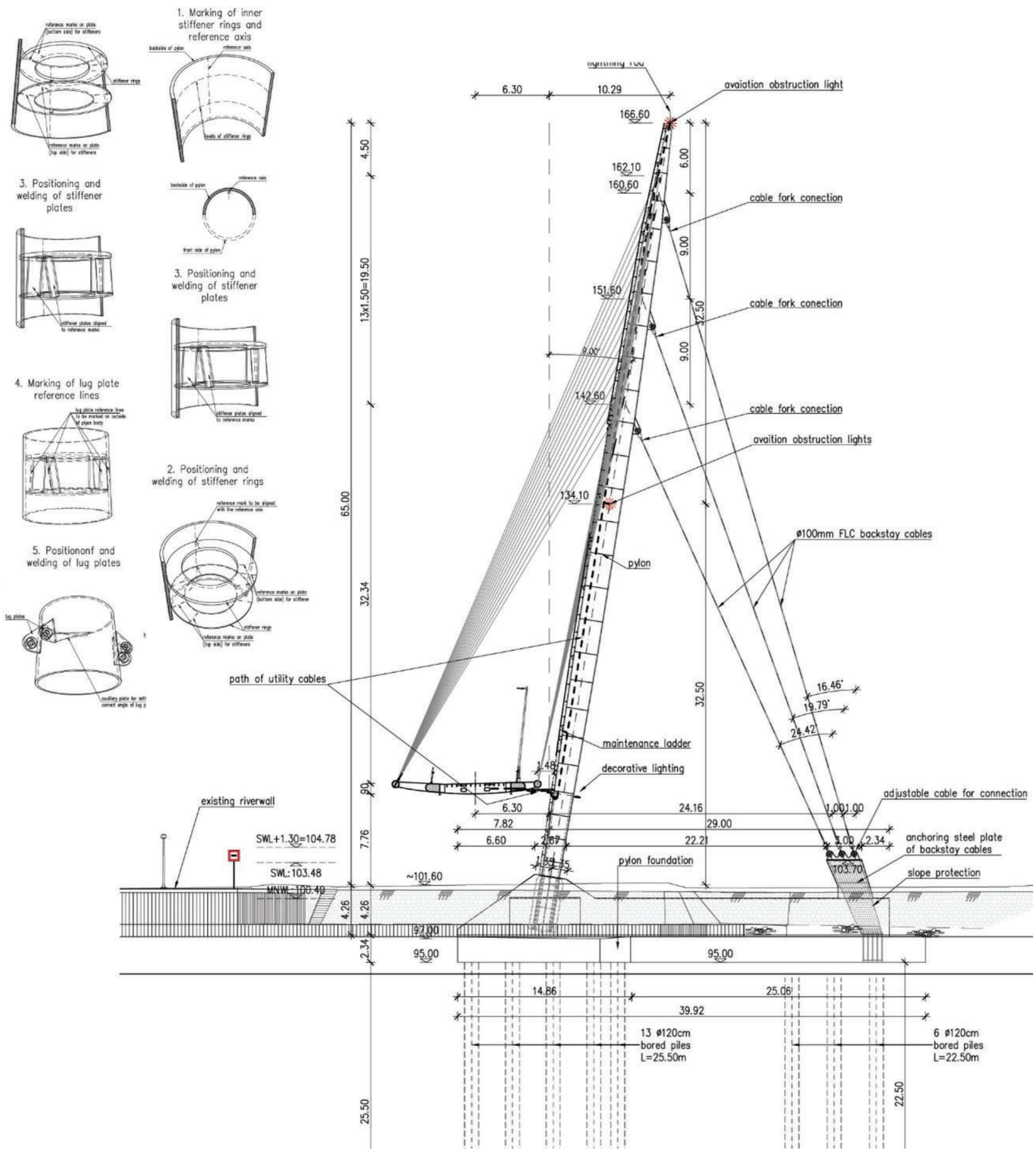

Figure 3: The equilibrium of the pylon is ensured by three backstay cables anchored to the support on the island. (Source: Speciálterv)

tensile forces of the 3 large-diameter cables that provide the pylon’s backstay, a steel section was cast into the pile cap.

The stiffening girder is supported by two closed cross-section main beams made of Ø711 mm diameter, 30 mm wall thick steel half-pipes, a 30 mm top flange, a 40 mm bottom flange, and an internal 30 mm vertical web forming a box girder. [3] An orthotropic steel deck is placed between the main beams, rigidly braced by longitudinal ribs at 40 cm intervals, with curved lower flanges and 90 cm high crossbeams placed every 6 m. The edge beams were made of Ø610 mm diameter steel tubular sections with 30 mm wall thickness, which had to be bent to follow the spatial curvature of the bridge deck. The crossbeams and the orthotropic steel deck were made of S355 M steel, while the welded closed box girders, edge pipes, and cantilevered crossbeams were made of S460 ML

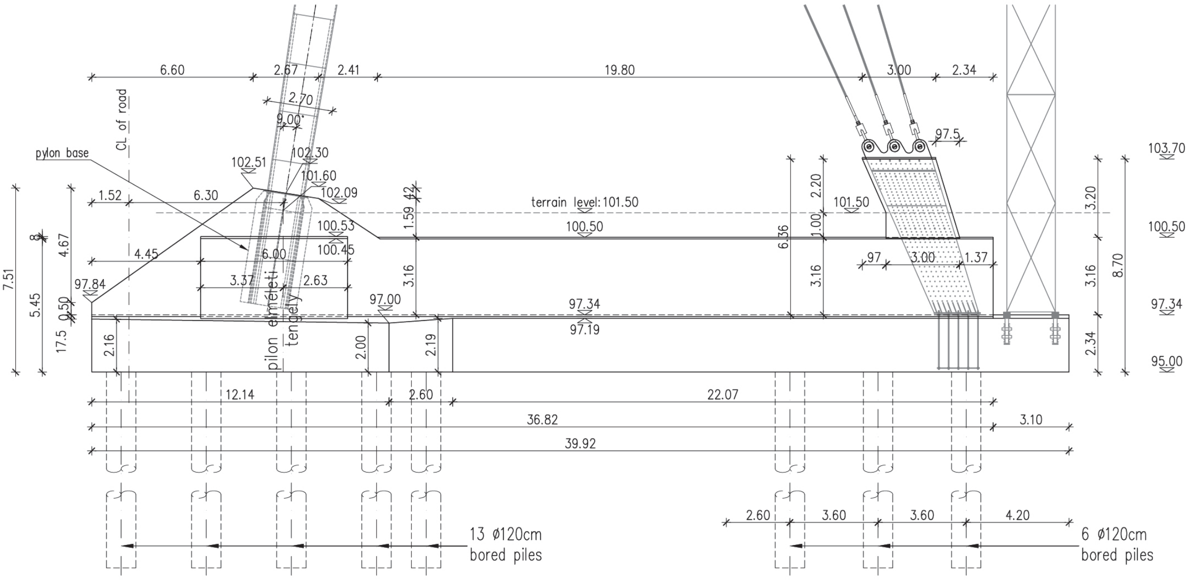

Figure 4: Side view of the pylon & backstay cable foundation (Source: Speciálterv)

steel. Both the main and edge beams of the steel tubes were concreted.

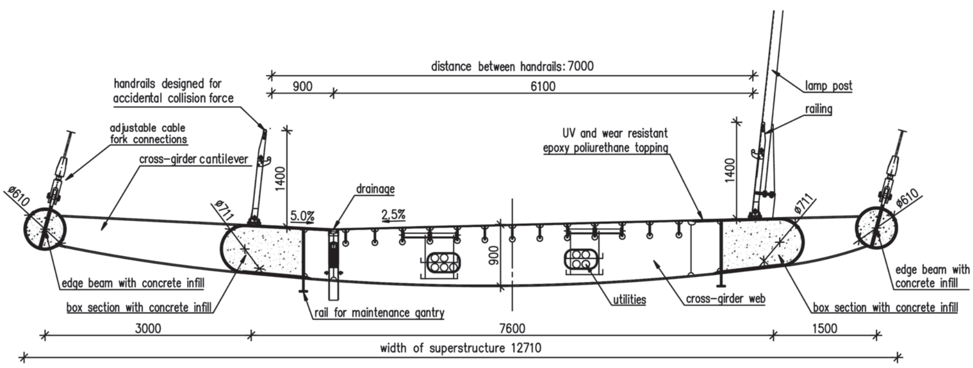

Figure 5: General cross-section of the superstructure (Source: Speciálterv)

2.3 Cables

The slender curved deck, which is nearly 170 m long, “floats” over the Danube branches without any lower support. The deck is suspended by 53 small cross-section cables attached to a pin-like pylon independent of the deck. Their diameters range from 35 to 65 mm, with 5 mm increments. The equilibrium of the outward-leaning slender pylon is ensured by three backstay cables anchored to a support located on the island. 100 mm nominal diameter cables were used for this, with fully enclosed steel wire ropes (“full-locked coil rope”) as hanger elements and forked cast heads.

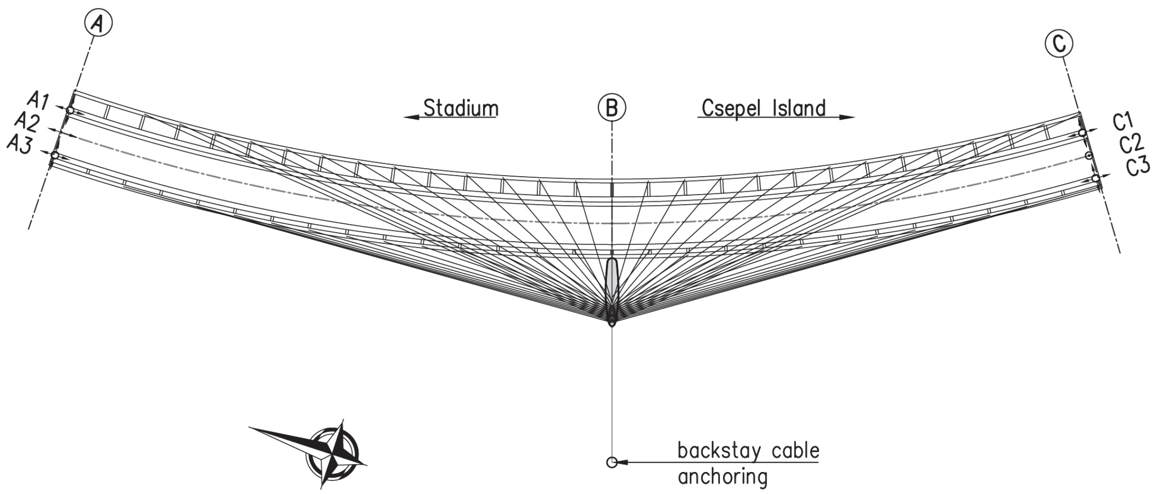

Figure 6: Cable arrangement (Source: Speciálterv)

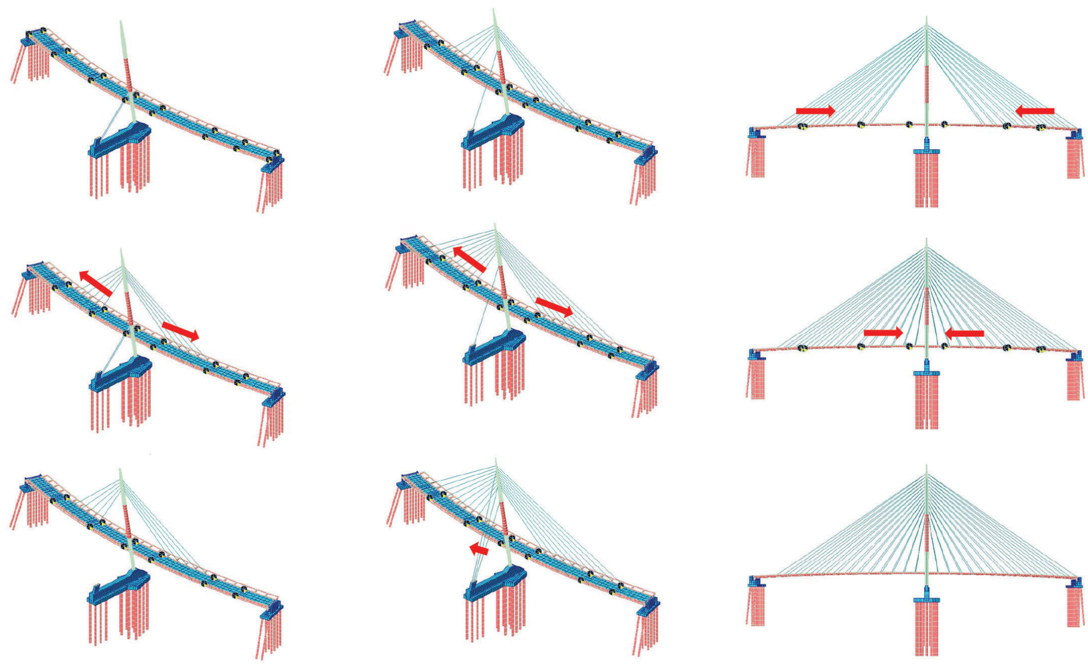

Figure 7: Designed cable suspension process (Source: Speciálterv)

2.4 Accessories

The bridge has vertical steel railings with bars. The handrails running at heights of 1.00 and 1.40 m are made of tubular sections. The railings are also designed to withstand impact forces to protect electric cars that may occasionally appear during events. The railings are not vertical but follow the inclination of the pylon on both sides of the bridge, emphasizing the spatial curvature of the bridge deck and the inclination of the pylon. The bridge deck is illuminated by 8 m high lampposts placed at 18 m intervals on the pylon side.

2.5 Construction technology

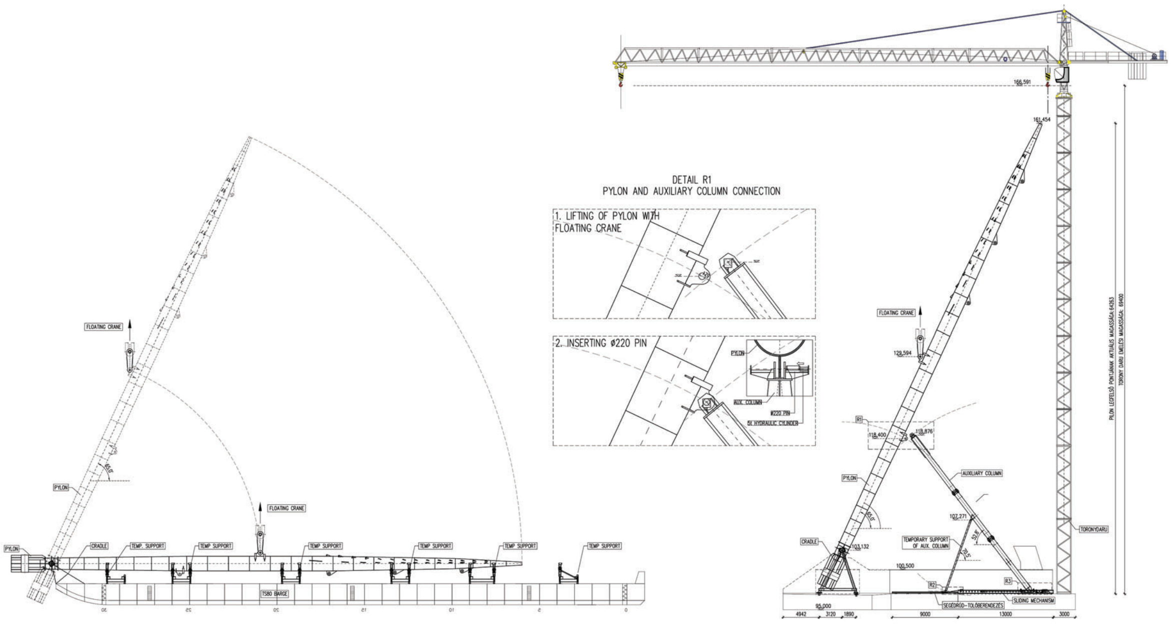

Figure 8: The pylon was transported to site on a barge, then lifted into position in one piece with precision (Source: Speciálterv)

The elements of the pylon were lifted onto a barge and fitted together in Csepel. The pylon was lifted in one piece by the Clark Ádám floating crane on January 7, 2022. The placement manoeuvre of the nearly 200 t steel element - which was 70 m long with the fittings - required the full lifting capacity of the Clark Ádám floating crane. The pylon was hung from the crane and rotated into its final position with the help of steel auxiliary structures. Several points of the operation were on the feasibility limit. Floating the loaded crane required a minimum water level of 200 cm in the Danube in Budapest, which the contractors waited for months. Lifting the pylon with a varying cross-section and weight distribution required several special auxiliary devices and inspection operations at the limit of the lifting capacity. During the placement, the tip of the pylon hanging from the crane had to approach the tower crane installed on the island within decimetres. The placement manoeuvre was carried out professionally, and the operation of placing the pylon in its final position, which was originally planned to take two days, was completed in just a few hours.

2.6 Launch of superstructure

The steel elements of the stiffening girder were transported from the manufacturing hall of Acélhidak Ltd. in Csepel to the assembly area on the Csepel side [4], where the newly arrived elements were aligned with the end of the bridge deck and then launched into their final position in stages. During the pushing process, temporary supports were placed every 24 meters to support the structure. Hídépítő Co., the contractor for the bridge structure also used a launching nose at the front of the assembly to reduce bending moments. After reaching the final position, the cables were tensioned in pairs over a total of 30 steps. The horizontally curved main girder underwent significant deformations during the tensioning process, which needed to be considered during the planning and execution of the construction technology. After each launching phase, we evaluated the geodetic measurement results and granted permission for the connection after providing the necessary corrections, followed by the next pushing phase. The "twisting" geometry in space deviated by several decimetres from the final state, as the assembly only reached it after the tensioning steps, so the temporary track determined during the pushing had to be followed with the target software. This control required close cooperation between the contractor, static engineer, and steel constructor.

Figure 9: The launch of the superstructure was closely monitored by the BIM engineering team (Source: Speciálterv)

2.7 Statical calculations

The static analysis of the bridge structure was performed using more FEM programs. We built a global model using AXIS VM and SOFISTIK AG software, while a team at BME (Budapest University of Technology and Economics) used ANSYS FEM to examine the time-varying loads on the static framework and to check the expected vibration modes. The static calculations were also repeated for the measured shape during the launch, allowing for the online monitoring of the structure's behaviour during the construction processes. By applying this method, we processed the on-site measurements in a BIM model and forwarded them to the static calculations, using the obtained results to inform the steel structure plans. This provided data for the expected geometric corrections during the next element's connection, thereby guiding the step-by-step geometric regulation of the bridge during the launching process

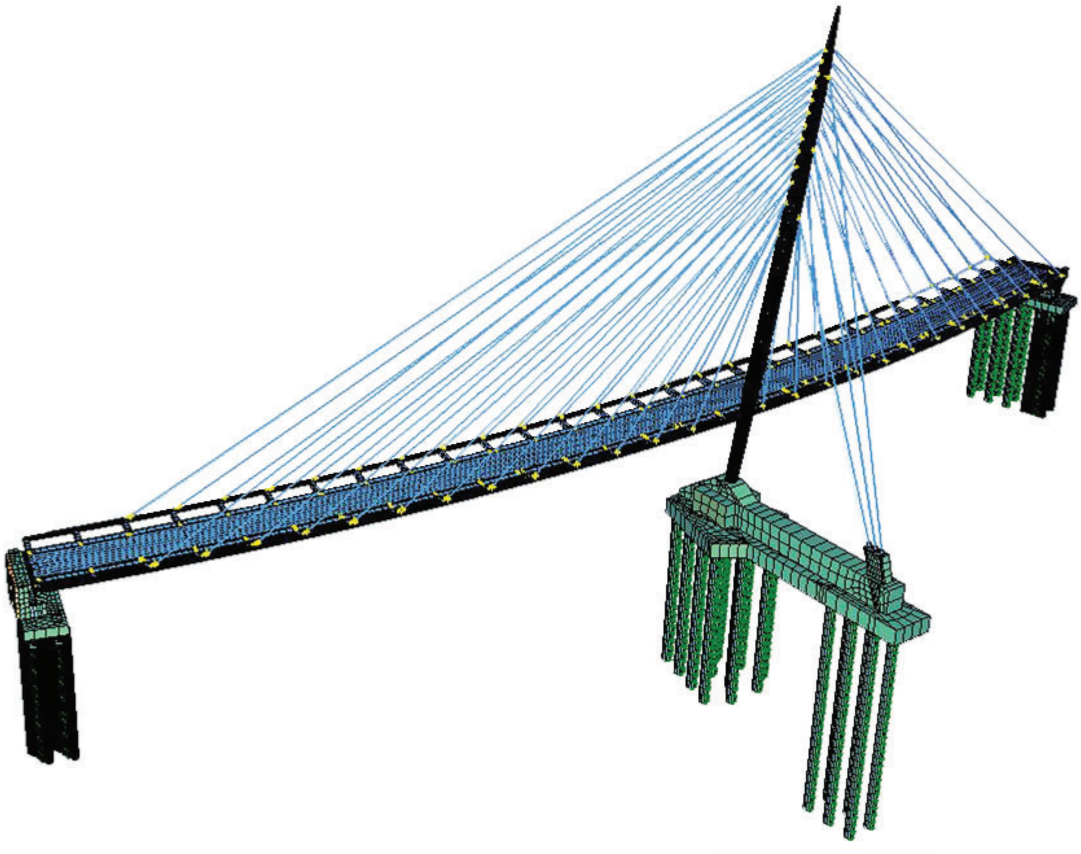

Figure 10: Model in Sofistik (Source: Speciálterv)

2.8 Damping devices

The dynamic effects generated by pedestrians crossing the cable-stayed bridge were analysed using dynamic calculations. Damping devices (TMDs) were installed to ensure the appropriate comfort level (vibration, acceleration) for pedestrians using the bridge. Based on the detuning options determined jointly with the Department of Structural Engineering at the Budapest University of Technology and Economics, five cross-sections were finally selected for vertical and one for horizontal damping.
Static and dynamic load tests were also carried out on the completed bridge structure, which proved that the high-span and large-area bridge structure also meets the maximum comfort requirements (a.vertical <0.5 m/s2, a.horizontal <0.15 m/s2).

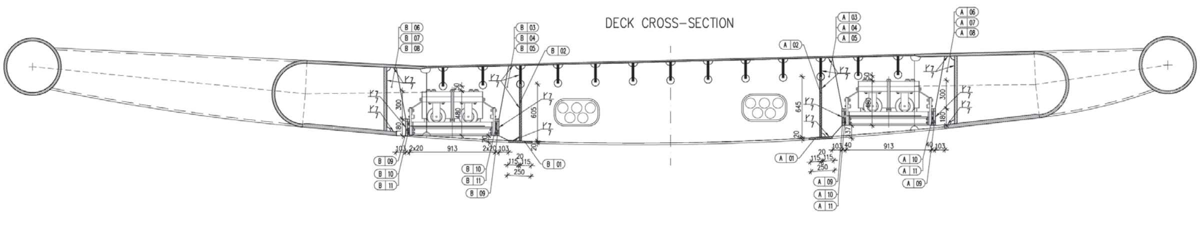

Figure 11: MTMD-H damper supports (Source: Speciálterv)

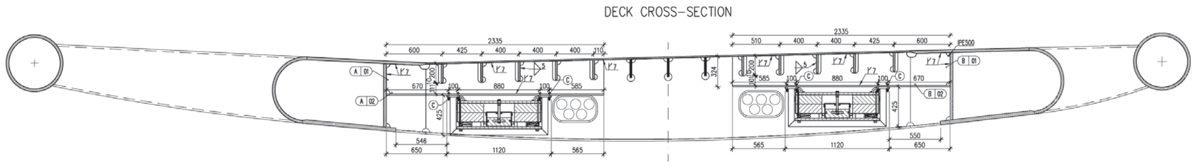

Figure 12: MTMD-V damper supports (Source: Speciálterv)

Figure 13: Side view of the bridge (Source: Magyar Építők)

3 Conclusion

The Robinson Bridge is an important addition to the city as it extends the cycle & pedestrian corridor from the city centre to Csepel Island. The bridge is barrier-free, designed to be accessible to people of all ages and abilities, making it a welcoming step towards creating a more inclusive city. Overall, the Robinson Bridge is an exciting new development for the city, providing a safe and convenient pedestrian and cycle route along the Danube while also contributing to the growth and development of the surrounding neighbourhoods. The 'Robinson' Bridge's design goes well beyond its functional role as it creates a highlight in its neighbourhood and provides numerous benefits to the surrounding districts as well as the city as a whole. By filling an important, but previously missing connection, it is a valuable addition to the city's infrastructure. The social and media reception of the 'Robinson' Bridge structure has been very favourable so far, some Budapest residents already see it as a landmark structure. Due to the extremely complex shape of the structure, planning, production, and construction could not have been realized without state-of-the-art software, procedures and BIM models that enable 21st century 3D and 4D planning. Designing and constructing cable-stayed structures is among the greatest challenges in the field of civil engineering. The construction of a slender, curved, asymmetric cable-stayed bridge involves dealing with significant deformations, which is a serious task for both designers and contractors to control. In the case of 'Robinson' Bridge, this difficulty was successfully overcome by close collaboration between the designers and contractors using a measurement-evaluation-control process aided by parametric design tools. The designed pylon and the bridge deck are both extremely slender, which was ensured by the combined and economical use of steel structure and concrete. The pylon and the parts of the superstructure in which its advantages could be utilized were designed and fabricated from high-strength and thermomechanically rolled S460 M/ML steel material, which is not yet common in bridge construction, and requires special attention during design and fabrication. To this end, a number of unique manufacturing and welding technologies were used.

Assembling the steel structure of the pylon on barge and lifting it together with a 200t floating crane was one of the most spectacular and complicated operations of the construction, which was able to be realized effortlessly and with almost incredible precision within just a few hours as a result of almost a year of careful preparation. [4]

4 References

[1] Pál, G.: Track and steel. Bridge design & engineering magazine Issue No.109 Fourth Quarter, 54-55 (2022).

[2] Pál, G.: Atlétikai stadion melletti gyalogoshíd tervezése. MAGÉSZ Acélszerkezetek XIX/3, 13-23 (2022).

[3] Pál, G.: A Robinson híd. Mérnök újság, XXIX/1-2, 26-17 (2022)

[4] Magyari, L., Bóka, A.: A Nemzeti Atlétikai Stadion osztószigeti gyalogoshíd pilonjának és pályaszerkezetének gyártása és szerelése, MAGÉSZ Acélszerkezetek XIX/3, 2-12 (2022).