Design of the Danube Bridge at Mohács

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Abstract The next Danube-bridge of Hungary has recently received the green light for its construction, to be located in south-central Hungary, near the historical town of Mohács. The town and its surrounding region have long awaited the construction of a permanent bridge to establish a lasting connection between the two sides of the Danube. The 756-meter-long bridge structure comprises three spans, supported by only two intermediate piers. These piers are strategically located: one in the floodplain forest and the other in the shallow waters of the Danube's left bank according to the environmental and water management restrictions. This arrangement divided the structure into three sections, consisting of a series of 230-meter, 250-meter, and 270-meter tied arch superstructures with orthotropic decks are made from S355 and S460 steel. The arches are constructed with a network suspension system, which allows an efficient and cost-effective structure. The width of the bridge is 22,82 m, consist of 3,30 m bicycle road and 2x2 traffic lanes. The structural height of the superstructure is 2,73 m. The arches made by 1,60 m width and various high box girders connected by network layout steel pipes cross girders. The stiffening girders of the tied arch bridges are 1,64 m wide and 1,80 m high box girders, connected with open cross sections a various height "I" cross beams. The cross beams support the orthotropic deck in every 4 m. The network arrangement suspension cables are arranged into different planes. Monitoring system installed on the bridge will enable real-time control during operation.

Keywords : Large Span Danube Bridge, network arch

1 Context

Mohács and its surrounding region have long awaited the construction of a permanent bridge to establish a lasting connection between the two sides of the Danube, as the town currently relies on a ferry as the sole means of crossing the Danube River. The project aims to enhance regional connectivity, stimulate local economies, and provide a reliable transportation link that withstands the test of time and nature. Over the past decades, numerous studies have been conducted. In 2019, the development of a comprehensive plan commenced. Preliminary studies, environmental and economical investigations, site selection, and structural analyses were followed by the permitting process, detailed design, and construction plans for the new Danube bridge crossing.

The vehicular, cycle and pedestrian crossing is part of a large scale infrastructural project. The works will connect the M6 highway with Route 51 and comprise 30km of new roads, junctions and 13 additional structures, including another bridge in Mohács (163m in length) and a 234m-long bridge over the Ferenc Canal. Designed roads will partially have 2x2 lanes and partially 2x1 in the first phase with the possibility for 2x2 lanes on the entire section in later phases. The Danube bridge cross-section will carry 2x2 traffic lanes.

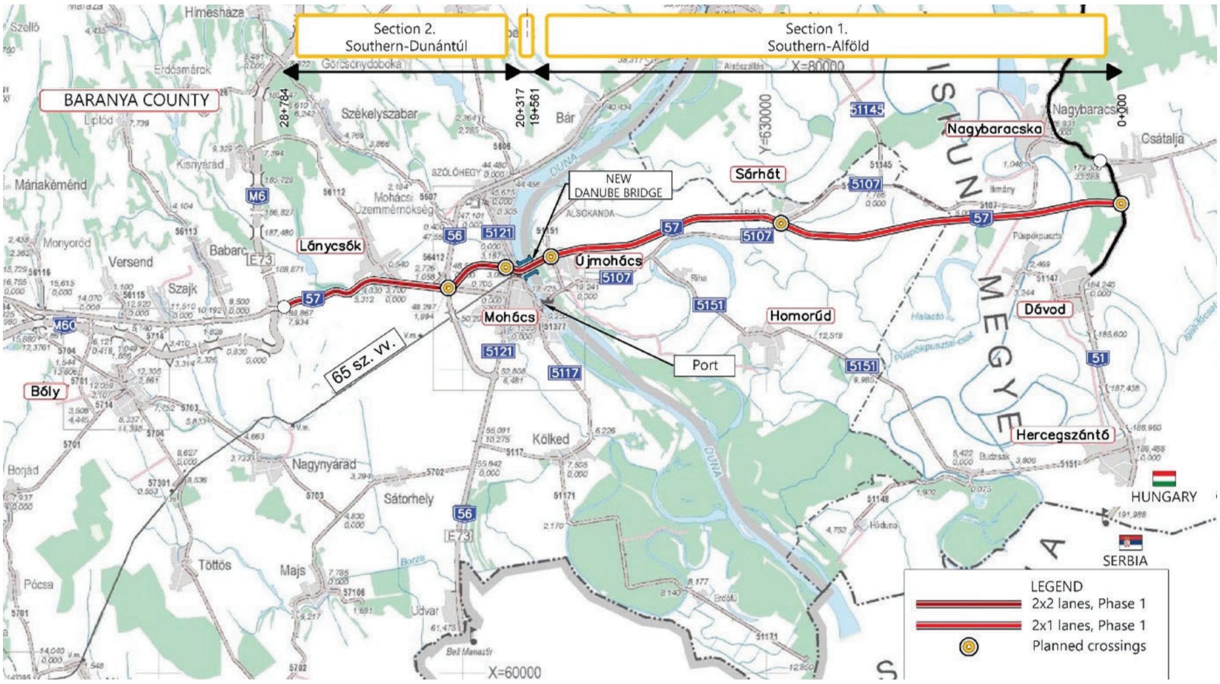

Figure 1: Sections of the designed Main Road No. 57.

1.1 Water management aspects

The location of crossing is at section 1448+238 river km of the Danube River. The Danube bed has an asymmetrical form at under the bridge – the main floodway is located along the Mohács bank with a width of 350 m, with another 350 m wide floodplain on the opposite side - the Újmohács bank. The floodplain is under strict environmental protection except for the road on parcel no. 0297 that leads through the protection zone nearly parallel to the river. This nature conservation constraint had a significant impact on the location of the bridge's supports. There is a high bank on the Mohács side without any a flood protection dam, while the area of the flood protection dam on the Újmohács side falls out of the environmental protection zone. The main span crosses an international waterway classified as VI/C, the second-to-last category for water courses of international importance.

Figure 2: The bridge structure is series of three network arches

1.2 Navigational Considerations

At river kilometre 1448+238 of the Danube River, according to Decree 17/2002 of the Ministry of Transport and Water Management (KöVIM), a VI/C waterway clearance profile must be ensured. The height requirement is +9.50 meter freeboard above the Higher Shipping Water Level, and the width requirement is 200 meters instead of the standard 180 meters, as requested by the Government Office of the Capital City Budapest, Transport Department, Navigation Licensing and Inspection Division. For all the proposed bridge variants, the above-mentioned navigational clearance profile must be ensured on the Mohács side in the main channel opening.

1.3 Environmental aspects

The design site of the new Danube bridge is located within the 'Béda-Karapancsa' Natura 2000 site protected under the Birds Directive, as well as the Ramsar and UNESCO Biosphere Reserve (WNBR). During the design of the structure, it was a priority that the supports do not affect zones under strict protection. The location of the floodplain supports was designated to best preserve the wildlife around the bridge. Environmental considerations have been taken into account during the design of the road as well as the construction of the bridge.

2 Structural variations

In the initial phases feasibility studies examined various bridge structures, including single and double pylon cable-stayed bridges, girder bridges and arch bridges with different span arrangements [1]. Ultimately, a bridge comprising three consecutive arches was selected. The structural efficiency, aesthetic appeal, and landscape integration of the arch bridge were determining factors in the decision. The jury voted a version with 3 big span steel arch bridges made with orthotropic deck and network cable system.

Figure 3: The visualisation of the upcoming bridge

3 Permit and detailed design

3.1 Bridge Specifications

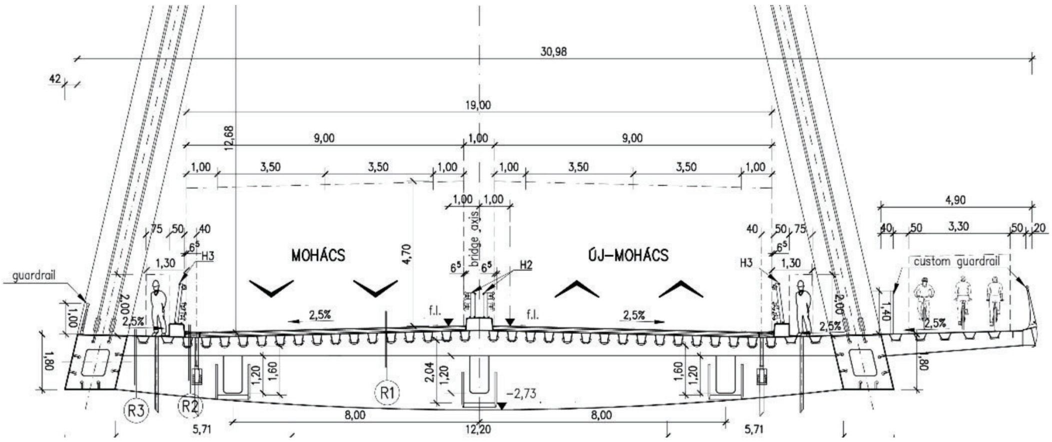

Figure 4: General cross-section of the new bridge

The structure is set to feature three consecutive network arches with varying span distances, as a series of dual support girders. The tied arch bridges made with an orthotropic steel deck, box girder arches and main girder with network cable arrangement. On the southern side of the bridge, a 3.30-meter-wide EuroVelo bicycle path is provided. The stiffening girders are 1.80 meters high, making them non-accessible inside. However, the airtight closed cross-section design prevents

moisture and oxygen from entering the structure, thus eliminating two of the conditions necessary for corrosion. The crossbeams are designed with an arch shape to fit the stiffening girders, and three maintenance walkways run underneath the deck, eliminating the need for an inspection bridge.
The spans of the three arch structures are 270 meters, 250 meters, and 230 meters, respectively.
Total length of the bridge: 755,70 m.
The permit design made with and expandable solution: first stage 2x1 lanes which can be widened to 2x2 in the future. After the permit phase the Ministry change the concept to a 2x2 lanes cross section, the detailed design made according to this requirement.

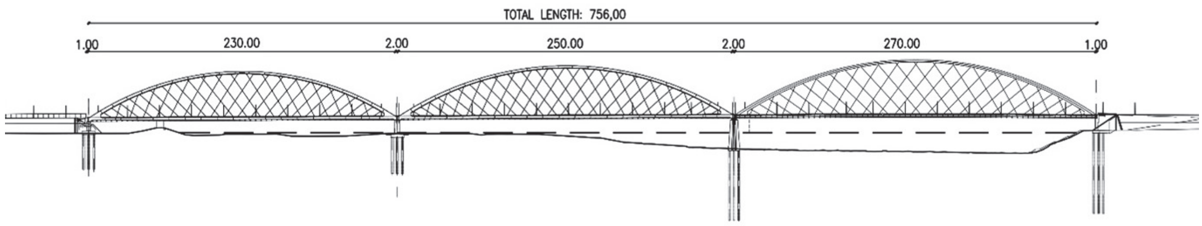

Figure 5: The three spans of the bridge – the asymmetrical riverbed and the flooding forest under the bridge

The river pier is located on the inner side of the river bend, thus positioned in a hydraulically favourable location, allowing for a properly designated 200 m wide navigation channel.

3.2 Cable Arrangement

The structure is a steel tied arch bridge, suspended by a network arrangement of suspension cables. In recent decades, arch bridges with network suspension systems have become widely adopted in international practice. Their significant advantages include:

- **Efficient load distribution:** The inclined suspensions within the plane of the arch effectively distribute concentrated live loads along the length of the bridge. This reduces the magnitude of moments in the arches and stiffening girders, allowing for the use of smaller cross-sections.
- **Aesthetic appeal:** The slender structural elements are visually pleasing.
- **Reduced Structural Mass:** The decreased structural mass is beneficial for the substructures and temporary construction structures.
- **Lower maintenance Costs:** The reduced surface area needing painting significantly lowers the cost of corrosion protection and maintenance.
- **Versatility:** While these advantages are particularly pronounced for smaller spans where the live load ratio to dead load is high, they also have favourable effects on larger spans.

The arches are inclined towards each other with a tilt angle of 13°. The cross-section of the arch is 1.6 meters high and 1.6 meters wide at the centre, increasing uniformly in height closer to the deck, reaching 3.0 meters at the lowest part. The two arches are connected by an X-bracing system composed of tubular sections with dimensions of 610-16 and 610-36 mm.

Literature recommendations provide detailed guidance on optimizing cable arrangements. The five basic cable arrangement variants based on design principles are:

1. Variant 1: The inclination angle of the cables is constant.
2. Variant 2: The inclination angle of the cables follows the formula $\alpha(i) = \alpha(i-1) + \Delta\alpha$.
3. Variant 3: The inclination angle of the cables follows the formula $\alpha(i) = \alpha(i-1) - \Delta\alpha$.
4. Variant 4: The steepness of the first and last cables is determined, and the intermediate cables are drawn from the resulting intersection point.
5. Variant 5: The cable deviates from the tangent drawn to the arch at a constant angle. (In this case, the connections at the stiffening girder are not evenly spaced).

These variants provide different methods for arranging suspension cables to optimize structural performance and aesthetic appeal. Among the various design options—depending on the span and the number of cables—there can be a 20-30% difference in the stresses generated in the arch!

3.3 Steel superstructure

The steel structure is assembled from manufacturing and assembly units. The orthotropic deck plate is considered classic type, with its uniqueness stemming from the significant cross-beams, which feature a continuously varying height design that adapts to the internal forces. The box-shaped stiffening girder and arch are constructed in an airtight design from the inside. The upper cross-bracing network resembles a network system akin to that of a suspension system, imparting a distinctive "historicizing" character to the bridge structure, which is being built near a historical city.

3.4 Remote Monitoring System

Since neither the stiffening girders nor the arches are designed to be accessible inside, the internal conditions within these structures are monitored using a remote monitoring system designed by the Department of Bridges and Structures at the Budapest University of Technology and Economics (BME), in consultation with the Client and the Operator. The system measures the following effects:

- Air Temperature
- Structural Temperature

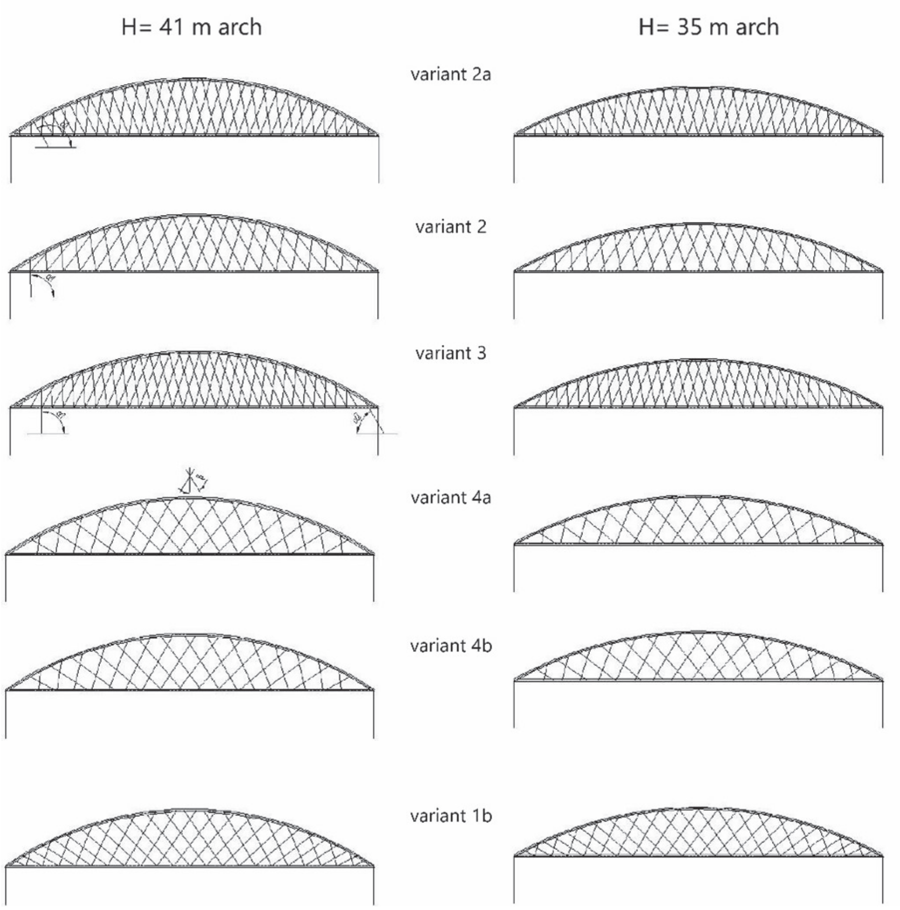

Figure 6: Cable arrangement versions

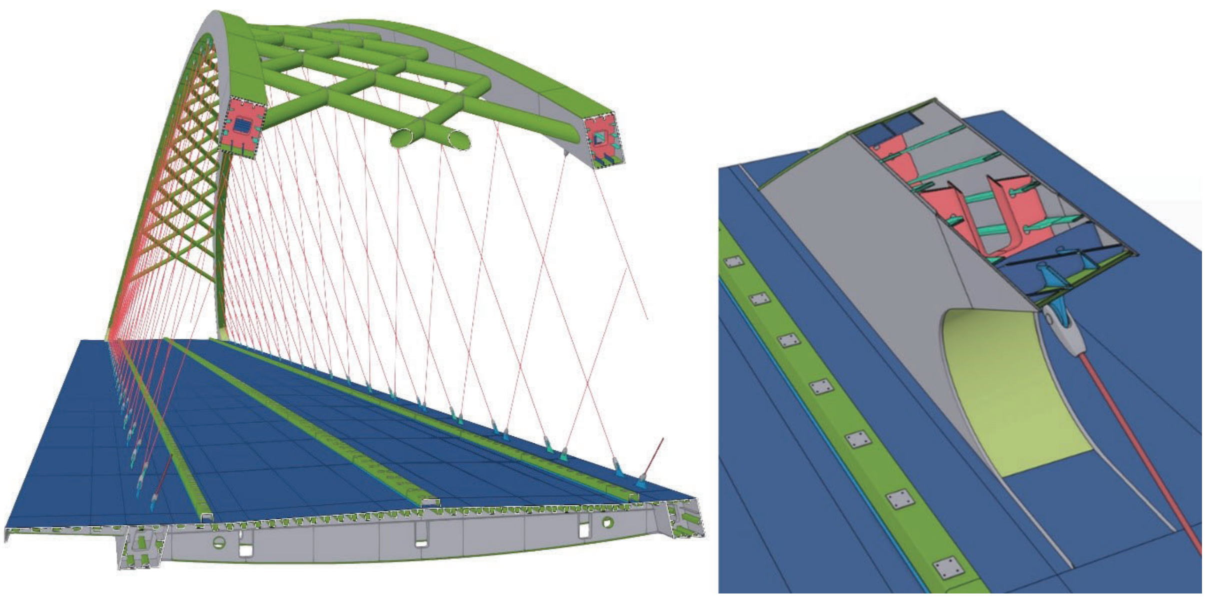

Figure 7: 3D Tekla model

- Internal Temperature and Humidity of Closed Cross-Sections

- Wind Speed and Direction
- Vehicle Axle Load

The system also measures the following structural responses:

- Bearing Reaction Force
- Bearing Displacement
- Acceleration
- Mechanical Stress (Strain) in Cable Connection Welds

Both the arches and the stiffening girders are divided into 7 air compartments (in line with the construction technology), allowing for more precise monitoring of local phenomena.

3.5 Substructures

The river pier was designed to be built using precast formwork elements. The pier is relatively narrow (8.68 m at the bottom), supported by 37 No. D120 cm pile, with the length of 52 m. In order to reduce the weight of pier – and the pile reactions –, the middle of the support has a space between the columns, with a steel walkway bridging this part.
In the design of the river piers, it was assumed that they could be constructed using shell elements. The relatively narrow pier (only 8.68 m wide at the base) is supported by 37 piles, each Ø120 cm in diameter and 52 m long. To reduce the self-weight of the pier—and consequently the amount of concrete required—the central part is designed to be hollow, which is bridged by a steel-structured maintenance walkway.

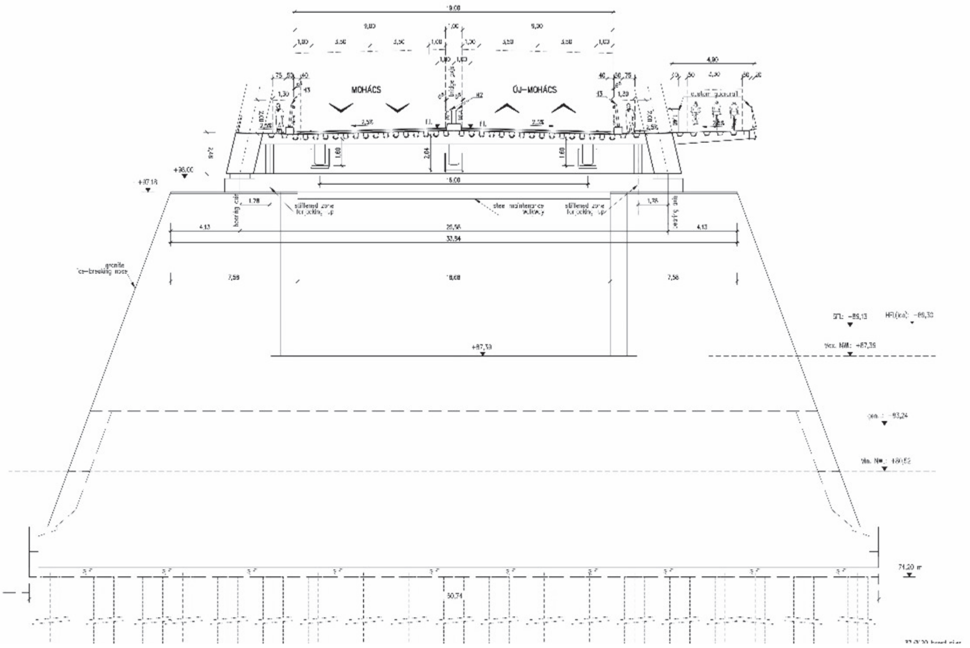

Figure 8: Floodway pier

The abutment on the right bank is very close to the river, thus it is relatively high. (The front wall is 8.53 m high above ground level). The right bank abutments are positioned close to the bank edge, making them significantly high (the façade is 8.53 m above the ground level).

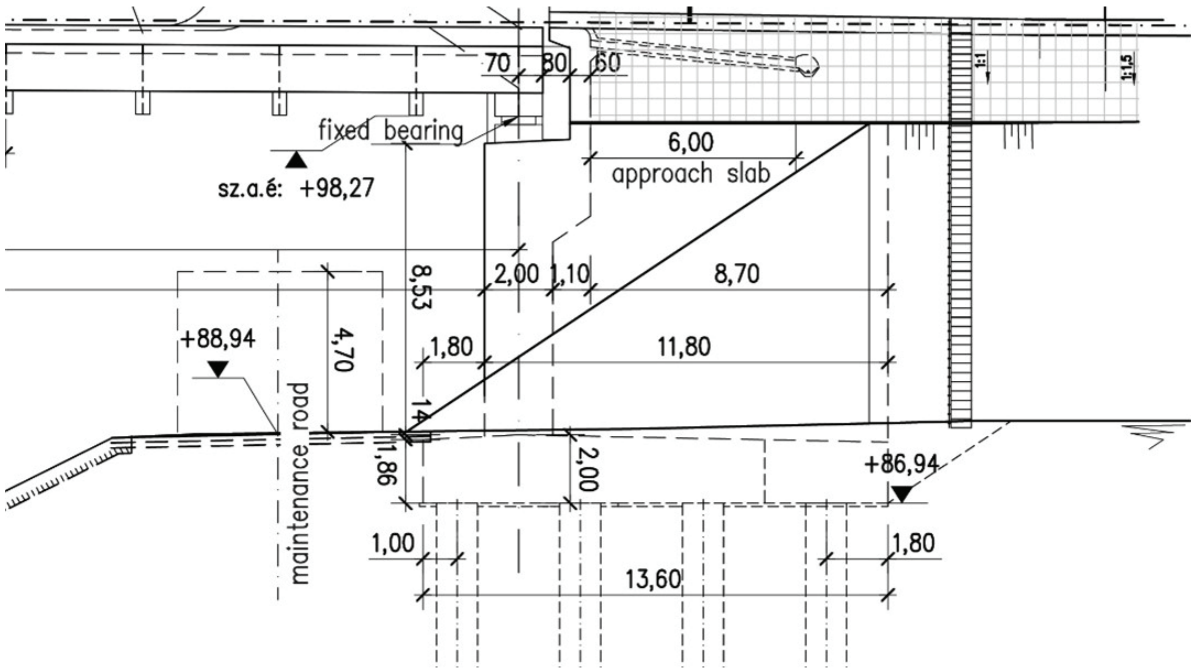

Figure 9: Abutment at the right bank

3.6 Construction technology

During the preparation of the permit and detailed design, several possible construction methods were examined. The final and applicable technology will be selected by the winning contractor. The individual structural elements will be transferred, assembled and positioned for launch at the two sides of the river. Two arches will be launched from the left side and one from the right side of the river. The assembly areas differ significantly on the right and on left banks. Considering this, two separate technological methods are being developed.

4 Summary

The structural efficiency, aesthetic appeal, and landscape integration of arch bridges were significant factors during the design of the bridge. The choice of network arches was made based on economic and construction considerations, as network arches are known for their efficient load distribution, which can lead to material savings and lower construction costs. The design employs the latest engineering principles and materials to ensure the bridge's durability.
Currently, construction preparations are ongoing. Assembly of the bridge is expected to take place in 2026 to coincide with the 500th anniversary of the battle of Mohács.

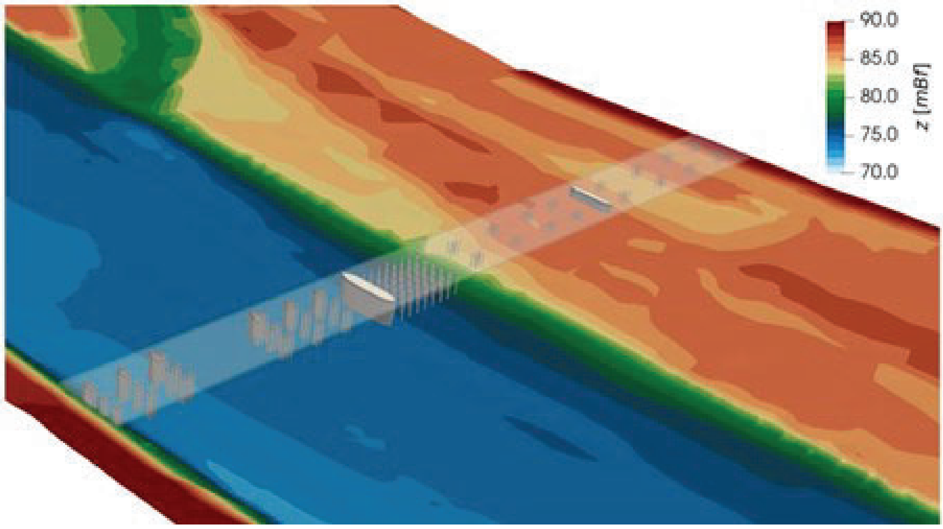

Figure 10: Hydraulic flow model was used to examine the effects of the temporary structures during the construction

5 Design team

Client: Ministry of Construction and Transport of Hungary
Contractor: Duna Aszfalt Co.
Lead designer of the project (between road no. 57.and highway no. M6 incl. the intersection of roads no. 56-57.): SPECIÁLTERV Ltd.
Lead designer of the Danube-bridge: FŐMTERV Co.
Designer of floodway bridge and pier (270 m span): FŐMTERV Co.
Designer of floodplain bridges and piers (250 and 230 m spans): RING Railway Engineering Ltd. & SPECIÁLTERV Ltd.
Danube hydrological studies: BME Department of Hydraulic and Water Resources Engineering
Remote monitoring designs: BME Department of Structural Engineering
Independent statical calculations: Uvaterv Co.

6 References

[1] Pál, G., Zádori, Gy., Horváth, A., Süle F., A.: A mohács-I Duna-híd tervezése, Hidász Napok 2023 előadásainak gyűjteménye, Issue No. 39, 271-298 (2023).