WHAT A SPATIAL GRAPHICS - THE M44 TISZA BRIDGE

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Dedicated to Prof. György L. Balázs
for his 65th birthday

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In this paper the design and the construction of a unique bridge are presented, and the history of the basic idea is described as well. The bridge spanning over the second largest river is innovative in many ways in Hungary, such as the first bridge with non-prestressed reinforced concrete pylons (allowing tension), the first cable-stayed bridge applying cable saddles, the first cable bridge with composite stiffening girder, etc. These facts and the immaturity of the preliminary designs repeatedly raised problems to which unique answers had to be found in the detailed design phase.

To bring them into their exact final position, the erection control of the pylon and the composite stiffening girder had to be designed and carried out, which required extremely precise calculation and construction. The building of the half ellipse pylon, which also proved to be a serious challenge to the contractors is also discussed.

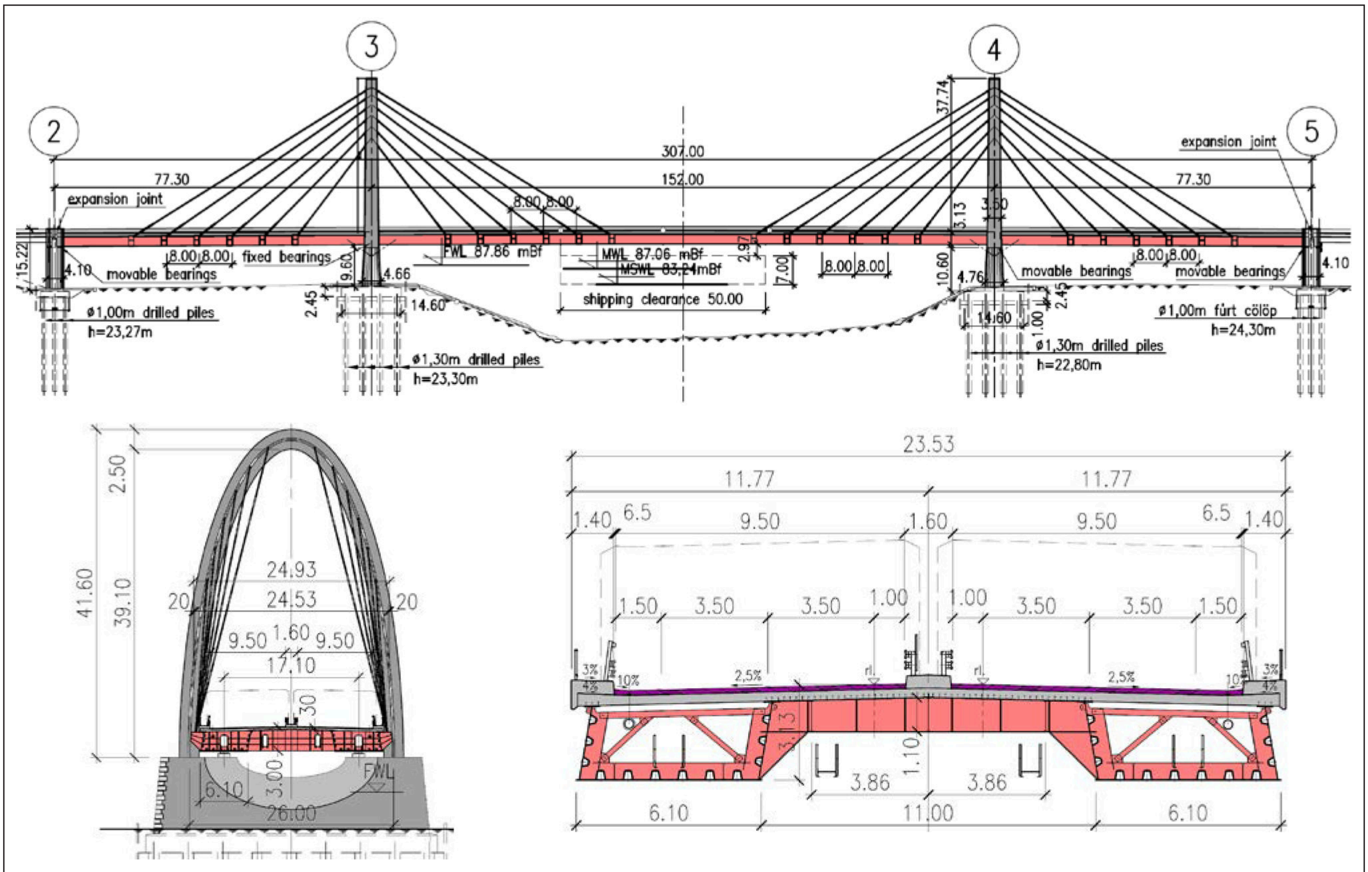
Keywords: arched pylon, concrete pylon, cable-stay, composite stiffening girder

1. INTRODUCTION

The history of the bridge started in 2005 with an invitation-only design competition announced by the Town of Esztergom for a study titled “New Danube Bridge between Esztergom and Štúrovo.» The idea occurred that the bridge was so wide (two lanes of traffic, sidewalks, and a bike lane on both sides) that only a smaller bridge could cross it. An arch would be suitable for this, and the roadway would just need to be ‹attached› to it. Using 3D software, a rudimentary model was built, and the result was remarkable. To everyone›s surprise, this version was finally awarded, and the Uvaterv Bridge Department placed second.

The competition itself was exemplary, offering a rare opportunity for bridge designers to a brainstorm without constraints or obligations. Until that time and since then, no such opportunity has arisen. After the award ceremony, the group of designers gathered spontaneously in a local

Fig. 1: Main properties of the bridge



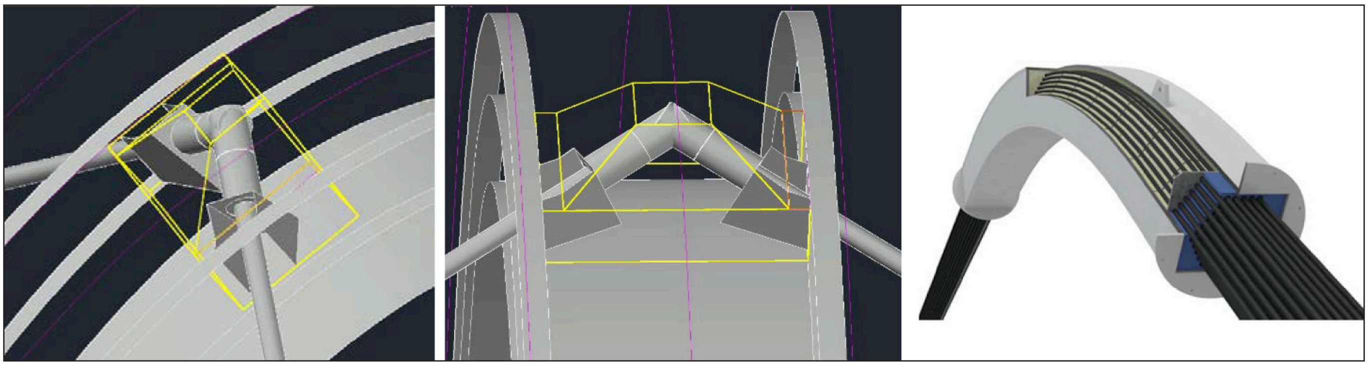


Fig. 2: Earlier and final version for the pylon-cable joint

restaurant, where they praised each other›s work while also criticizing it. It was there that the opinion was first expressed that the shape was interesting, but in such a scale, it was impossible to implement.

2. PRELIMINARY DESIGN PHASE

Fortunately, encouraged by the success, the Bridge Department did not let the project sink into oblivion. As much as possible, it was continuously included in multiple study plans as a potential design option. Finally, in 2015, a study plan was created for the Tisza Bridge, as a part of the M44 expressway, with several variations. The cable-stayed bridge with an arched pylon and composite stiffening girder proved to be economically competitive and enjoyed the support of the client.

In 2016, the designs for approval could be prepared for this favourite idea. During the planning process, the specific proportions and dimensions, including the pylon height-span ratio, the quantity of cables, and their connection points (both at the pylon and the superstructure) were roughly estimated for the first, and essentially for the last time. The height and elliptical shape of the pylon were also determined. The cross-section of the stiffening girder was designed by considering and coordinating as many aspects as possible (*Fig. 1*).

The steel section of the stiffening girder was a beam grillage consisting of two box-girder longitudinal beams and the cross beams between them, which would later be covered with reinforced concrete. The final width of the box-girder was intended to be optimized in later stages of the design, reducing it as much as possible within the limits of the calculations. A composite stiffening girder was chosen because, unlike the original Esztergom Bridge, the span to be bridged was at the lower end of the economic range for cable-stayed bridges, and the heavier reinforced concrete deck could increase the weight and stiffness of the structure. I presented this design phase at the CCC2017 international conference, where the "impossible" opinion was heard for the second time (Teiter, 2017).

3. CONSTRUCTION DESIGN PHASE

Designing continued in 2018 when Duna Aszfalt Co. Ltd. won the tender for both the construction and the right to have a 3rd party to design the bridge for construction. The basis of the public procurement procedure was the approval design for the bridge, which meant that the tender design phase was skipped. As a result, the existing plans, although not mandatory in terms of details according to professional requirements, were legally "frozen" due to the tender process. There was no longer any possibility to change the drawn - at that time still approximate - dimensions, cable layouts, and main details of the approved version, so the narrowing of the above-mentioned steel box couldn't be carried out.

According to the tender specifications, the contractor had 38 months to complete the project, during which time they had to have us prepare construction and fabrication designs from the approval designs. Typically, only this design phase would take 1.5-2 years in such cases.

When selecting the appropriate one from the initial study designs - which were essentially visual designs - and had us design the final approval version, our primary task was to pour the form into drawings and (according to the requirements) ensure the adequacy and feasibility of the main dimensions. The initial approximate designs that became mandatory were therefore not well thought out in many aspects (Teiter and Bedics, 2022)..

According to more experienced colleagues, the above-mentioned "impossible" level has become even more difficult. The main challenges were as follows:

- driven by the aesthetics, the usual backstay cable of cable-stayed bridges was not used, which made it difficult to stabilize the pylons;
- the cable anchoring cantilevers of the stiffening girder were located outside the cross-section, causing problems in taking up the horizontal components of the cable forces (it is not without reason that pedestrians usually walk outside the cable line);
- the introduction of the forces of these cantilevers into the steel-reinforced concrete composite stiffening girder had to be done by the steel structure only, which meant that the steel structure had to transfer unusual additional forces to the concrete deck slab;
- the aesthetic solution of the pylon-cable joint could only be achieved by anchoring the cables in the pylon or passing the cables through the pylon by a cable saddle (*Fig. 2*). The former was not possible due to space constraints, so the saddle had to be chosen, but then there could be no significant difference in the forces in the cables at the two sides, so complicated construction phases had to be incorporated in order to keep the proportions under control;
- by determining not only the amount of steel but also the camber of the steel structure due to the necessity of production at the beginning of the design, this already meant a constraint and a given for the further design period. As the different construction phases approached in time, they became more precise, additional demands and changes arose from the contractor, which also affected the cambering. Since we had already specified it earlier, production continued, we could "play" only with the remaining free parameters - primarily the magnitude and

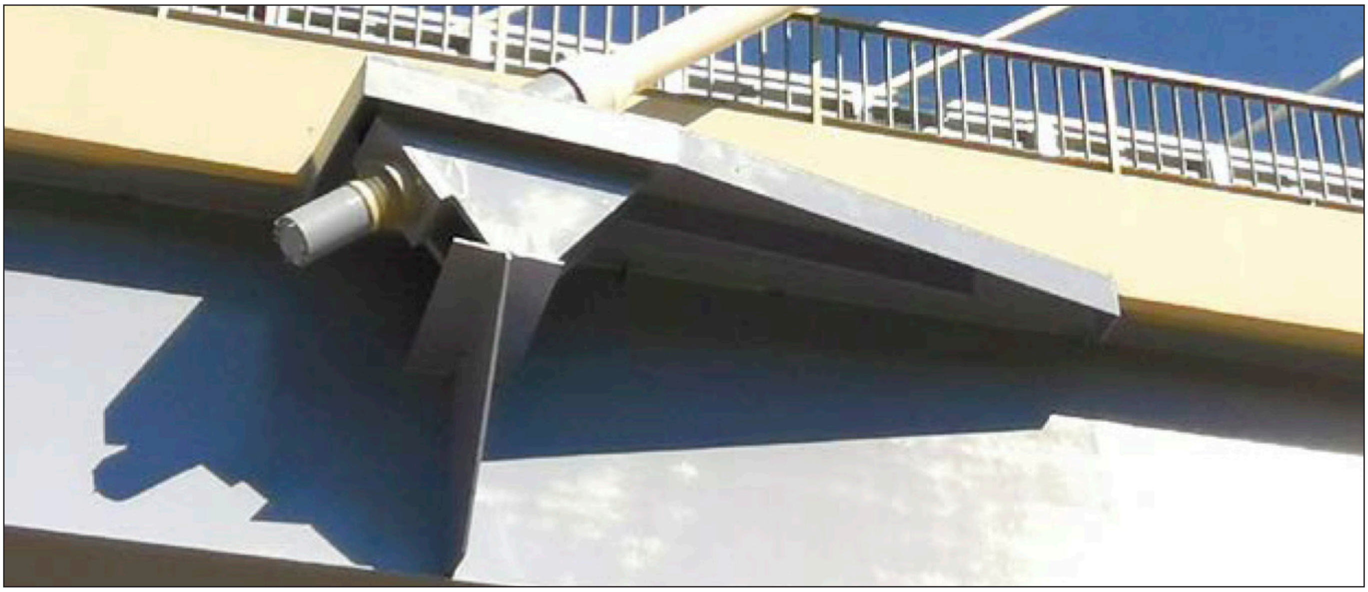


Fig. 3: *Cable anchoring cantilever of the stiffening girder*

sequence of the stressing forces - to keep the cambered shape of the steel structure still appropriate.

- however, the variation with the stressing forces was restricted by keeping the displacements of the pylons within limits (see later in the construction technology) and by the ratio of the cable forces on both sides due to application of saddles in the pylon;
- the final cable stress was intended to be helped by the weight of the reinforced concrete deck slab, so the first stressing happened against only the relatively lighter steel structural part. In order to do this, at the specified stages of construction, we had to use such anchoring elements at the temporary lifting points next to the vertical bearings situated at the pylons that could be removed later;
- Sűsimilarly, for the reasons mentioned above, it was problematic that the inclined cables in the transverse direction applied a pulling effect on the outer upper flange of the steel main girder that was not stiffened. Thus, a stiffening system had to be found that prevented the upper flange from horizontal curving while only minimally increasing the amount of steel.

During the design period, we continuously sorted out the above and always focused on the most important ones and looked for the solution. Of these, the unique design of the cable connection cantilever of the stiffening girder is unique in our opinion. It is unusual, simple, yet rigid, and the result of our thorough research (*Fig. 3*).

Despite the constraints of the construction design phase, the engineering consulting firm, Speciálterv Ltd., which carried out the independent structural analysis of the bridge, examined various parabolic pylon shapes, most of which would have been structurally more favourable. However, for aesthetic reasons, we decided to insist on the half-ellipse form. Subsequently, Király's Scientific Student Research Project at the Department of Bridges and Structures at BME dealt with the shape of the pylon, revealing numerous advantages of curved pylons over shapes such as Λ, Π, etc (Király, 2021).

4. CONSTRUCTION

The pylon was made of solid reinforced concrete and was built by the subcontractor (A-HÍD Co. Ltd.) using a climbing formwork, which was re-adjusted for each concrete placement phase. The ellipse started from two independent "legs", then at 3/4 of the total height, the legs were temporarily braced together to finish the peak (*Fig. 4*).

The placement of the saddles required exceptional precision in both during calculation and construction phases. When specifying their coordinates, it was necessary to take into account all the later displacements of the pylon legs until the finished state, and we had to ensure that their exit direction would point towards the cantilevers of the stiffening girder in the final state.

In order to protect the surrounding areas and to enable the parallel work necessary due to time constraints, the subcontractors (Hódút Kft., Steel-Millennium Kft.)

Fig. 4: *Pylon under construction*

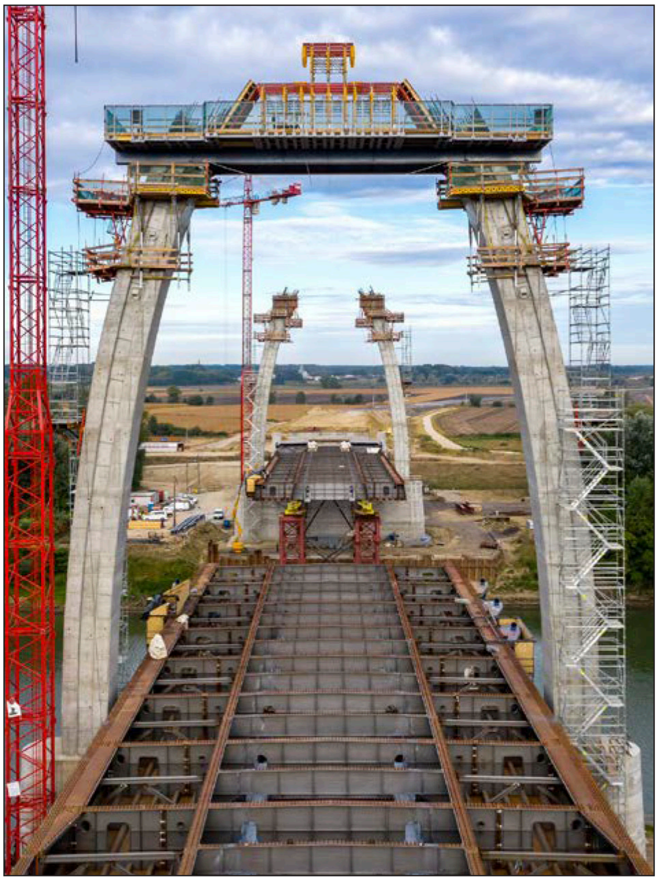


Fig. 5: *Parallel construction from four places*

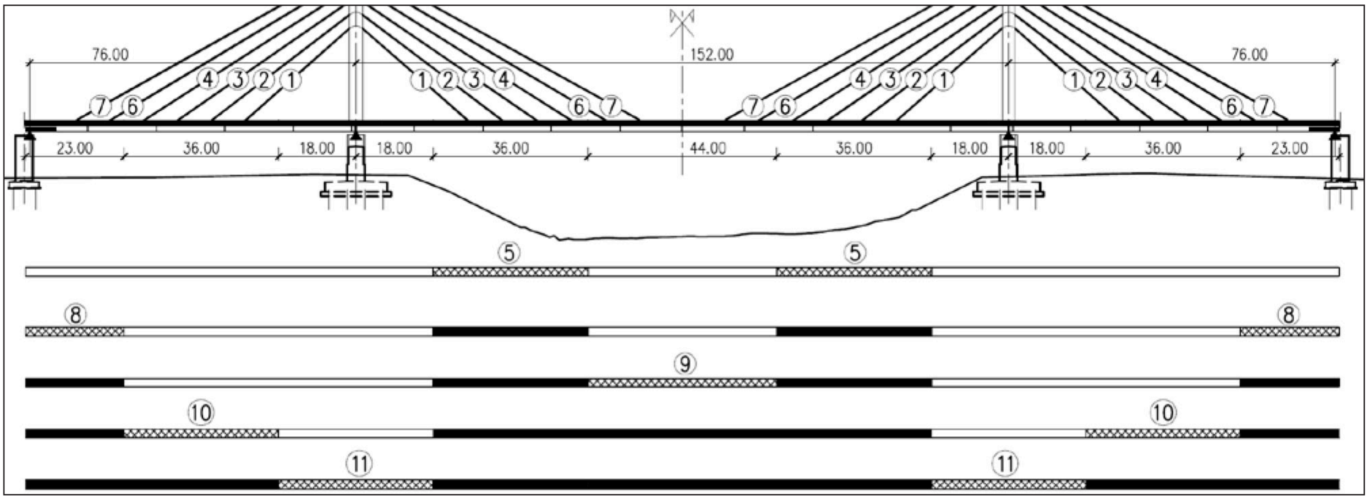


Fig. 6: *Construction stages: order of prestressing and concreting*

constructed the steel part of the bridge's stiffener girder at the same time by incremental launching from behind the pylons (*Fig. 5*). To help the launching, temporary supports were used in the first quarters of the bed width. When the steel structure met at mid-span, the connections were completed, and the final steel segment was built between the assembly-launching platform and the abutment in the outer spans.

Also, due to the need for parallel construction, it was required that the construction of the reinforced concrete pylon and the installation of the steel structure should not interfere with each other so that construction could proceed at four locations simultaneously, at the two pylons and from the launching platforms of the two sides.

After these, the cables were tensioned and the deck was concreted, both in multiple stages and partly overlapping each other for static reasons (*Fig. 6*). The effect of concreting of a composite superstructure in several stages was already well known (Teiter, 2008).

5. COMPLETED BRIDGE

The completed bridge shows a different image from every point due to the twisting cable surface in space. Travelers on the river see a cable-stayed bridge, while those driving on the road see two arches whose cables embrace vehicles and lure them to pass under the pylon (*Fig. 7*). Eleonóra Balogh, a Hungarian award-winning glass artist and restorer, expressed it in a professional way: *"What a 'space graphics'... When the function and the structure draw the form in an authentic way, building from itself! ... The well-considered, self-building structure cannot make a formal mistake... such as nature..."*.

6. CONCLUSIONS

In addition to its form (*Fig. 8*), the third cable-stayed river bridge in Hungary's bridge-building history displays many professional innovations. The concrete structure of the pylon is unique in our country. For the first time in Hungary, a larger bridge pylon was constructed with reinforced concrete without any tensioning elements. At the joining of the pylon and cables, a simple and clean appearance was maintained by implementing cable saddles, which otherwise caused many technical difficulties, and which was also unprecedented in the case of a Hungarian cable-stayed bridge.

The biggest professional challenge was the completion of the stiffening girder supporting the roadway. In Hungary, there has never been a cable bridge (be it an arch or a pylon structure) where such a stiffening girder was composite

Fig. 7: View of the pylons from the bridge

Fig. 8: The bridge from the air after its opening

(combining reinforced concrete slab and steel main girder). In addition to the construction difficulties, this structure - due to the concrete part - has time-dependent stiffness, and thus its deflection also constantly changes. Accordingly, the shape (vertical position) of the stiffening girder must be designed by taking into account the timing of the main construction phases, and its characteristics during its service life. Although this type of structure is cheaper, due to its complexity, riskiness, and a previous bad domestic example, most engineers are cautious about designing larger composite structures. This bridge is an example of how such a bridge can be built well. The bridge's stiffening girder and thus the vertical alignment of the road passing over it were realized with an accuracy of 1 cm.

7. ACKNOWLEDGMENT

Only a brief overview of the project could be provided here, which is obviously result of a teamwork. Information about the participants and many other details can be found on the *m44tiszahid.hu* website (articles, pictures, videos, reports, publications, etc., Teiter, 2021).

8. REFERENCES

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