Design and Build of Paks Danube Bridge, Hungary

Balanced cantilever camber control of Paks-Kalocsa extradosed Danube bridge superstructure

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Abstract The role of general and lead designer of the recently inaugurated Paks-Kalocsa Danube Bridge in Hungary was undertaken by CÉH Zrt. The total length of the bridge is 946 m, of which the length of the extradosed river bridge is 440 m. Span arrangement of the extradosed river bridge is 119+200+119 m and the deck width is 20.86 m. The parabolically haunched stiffening girder is a composite dual cell box section comprised of corrugated steel webs and post tensioned in-situ rc. concrete bottom and top slabs. The extradosed river bridge superstructure was erected by the balanced cantilever method.

In the presentation, superstructure camber control is presented on the below structural members:

- bespoke designed cable anchorage steel link members at rc. pylon heads
- general stiffening girder sections
- stiffening girder section with cast-in extradosed cable anchorage members

Regarding the pylon structure, the camber control of pylon formwork will be presented for each casting phase, the installation and adjustment of bespoke designed link members, as well as the spatial angle settings of cable anchorage plates.

The comparison of proprietary saddle elements with the bespoke designed link member will be presented as well.

In the presentation the vertical and horizontal camber setting routine will be explored for the general stiffening girder section.

For the deck section with extradosed anchorage members, the site measurement and setting routine of the centreline of cable anchorage tubes along with optional adjustment of anchorage support plates will be presented.

The presentation will explore the correction adjustment of the steel protective tubes that are cast-in the top deck plate with a shim plate rings to ensure the installation of the extradosed cables in later construction phases.

In the presentation we discuss the designer's data provision, geodetic measurement, site adjustment sequence and we provide the statement of quantities for the measurement points.

1 Introduction

The new Danube bridge at Paks, Hungary which was inaugurated recently overspans the Danube with a total structural length of 946.0 m (figure 1).
The river bridge superstructure is a 440.0 m long extradosed bridge with three spans haunched parabolically above the riverbed piers. The cross section is made of a two-cell composite structure (figure 2), and the spans are 119.0+200.0+119.0 m long. Regarding the extradosed bridge section, CÉH Inc. (H) took part as the lead designer in the project.
Two floodplain bridges adjoin to the river bridge. The floodplain bridge in the right bank (Paks side) is a 287.0 m long three span structure, while the floodplain bridge in the left bank (Kalocsa side) is a 221.0 m long three span structure. The structural system of both floodplain bridges is the same, both bridges are orthotropic deck, constant height, inclined web, single cell box, continuous steel girder bridges. The spans of the right bank bridge are 73+73+73 m, the spans of the left bank bridge are 95+95+95 meters. The extradosed bridge section was modelled in 3D (TEKLA Structures) preparing not only the detailed design, but also the workshop drawings, as well. Full scale structural and stage construction analysis was carried out by CÉH with the combined application of RM Bridge, AXIS VM and Sofistik FEM software packages.

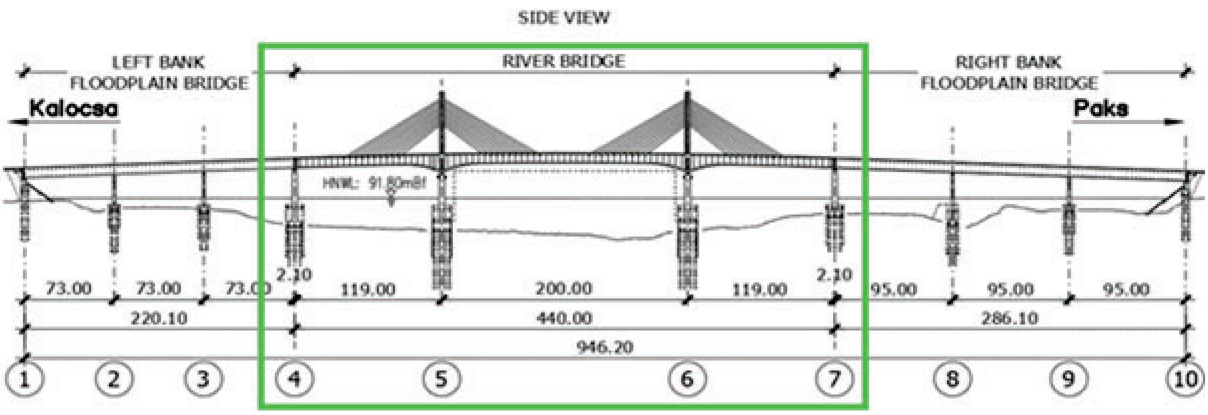


Figure 1: Elevation of the three adjoining bridges – © CÉH

The bridge accommodates 2x1 vehicle lanes and on both outer sides bidirectional bicycle lanes.

Figure 2: Rendered cross-section of the river bridge, main structural components of stiffening girder – © CÉH

The superstructure of the river bridge was constructed following the balanced cantilever method including the erection of the steel structure (corrugated steel webs and cross girders) and the casting of the bottom and top deck slabs, finally installing the internal post-tensioning members. The construction of the stiffening girder using the balanced cantilever method was carried out simultaneously at four places. Initially the steel segments had been lifted and adjusted in the main span and then followed by the side span (figures 3 & 4).

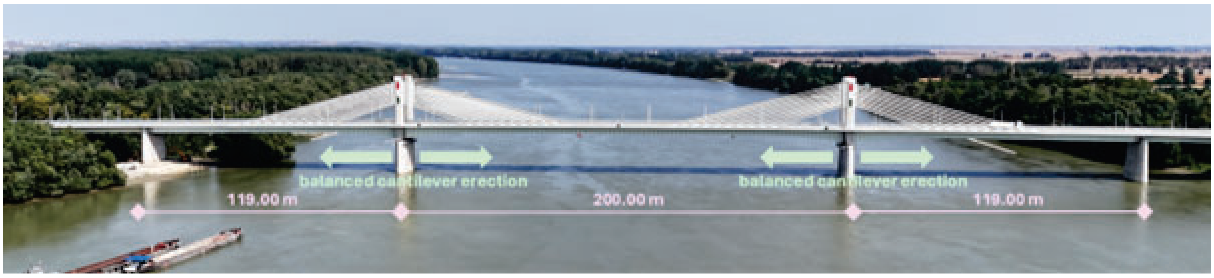


Figure 3: Idealised phases of the balanced cantilever construction – © CÉH

The camber control of the following structural elements will be presented in this paper:

- The reinforced concrete pylon and steel link units embedded in the pylon
- The typical steel segment of the stiffening girder
- The steel segment of the stiffening girder at the anchorage of the extradosed cable including the protection pipe

2 Camber control tasks during the construction of the pylons

The construction of the pylons on the upstream and downstream sides began by placing the connecting reinforcement into the cross girders at the river piers. Since the pylons, the cross girder

Figure 4: Balanced cantilever and form traveller – © CÉH

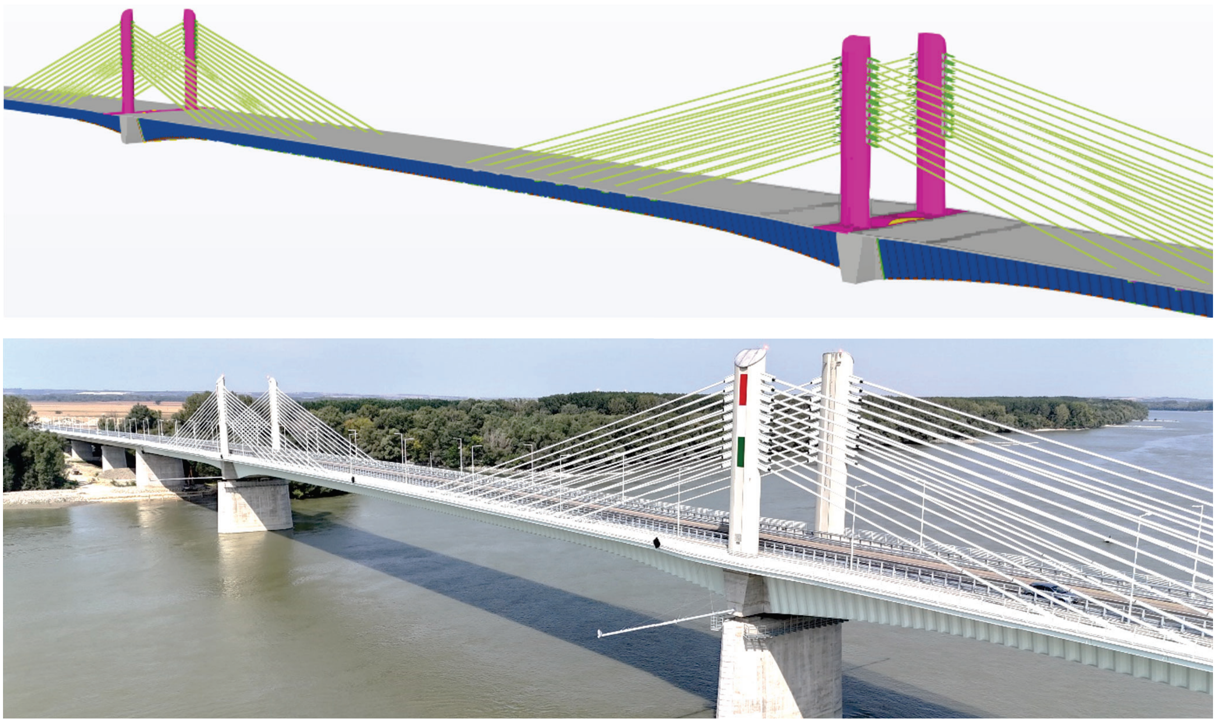
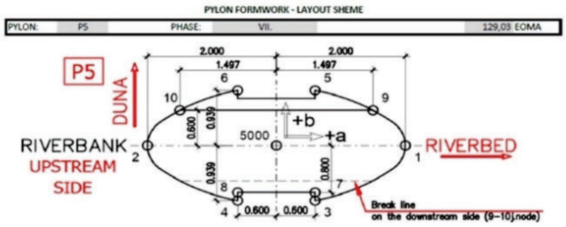


Figure 5: Cantilever form traveller (top), full-scale TEKLA 3D model (middle), as-built bridge (bottom) – © CÉH

at the river pier and the stiffening girder composes one monolithic structure, these moved together with the stiffening girder during construction. Therefore, these structural elements had to be built taking pre-camber also into account. The applied correction at the 22.0 m high pylon top was 115.0 mm longitudinally towards the riverbank and 44.0 mm transversally towards the edge of the bridge. One of the pylon's was built in seven construction phases applying 3.0 m high casting segments. After completing the reinforcement works of the casting segments, the setting-out data for the specific points of the elliptical cross section were provided by CÉH to adjust the formwork. This included the bidirectional correction values for the relevant construction segment. For the topmost construction segment, additional setting out data points were required due to the skewed cut of the pylon head (figure 6).



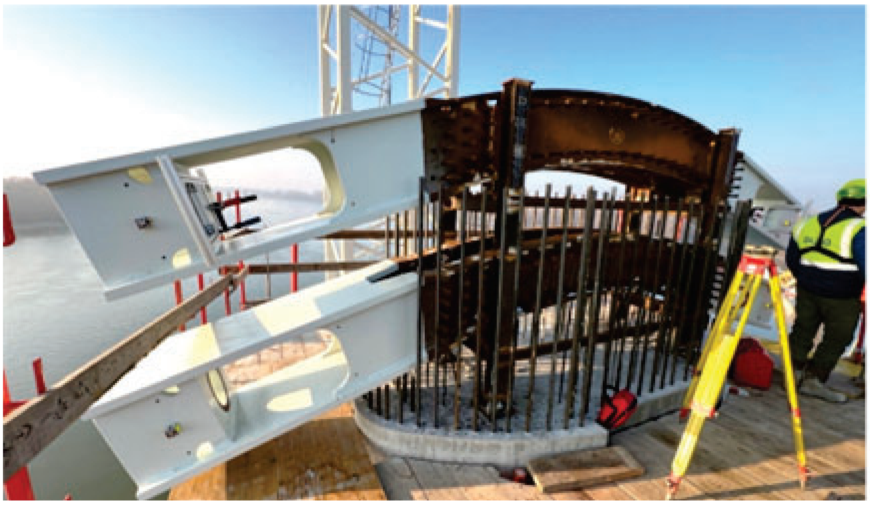
basepoint	Y	X	applied overlifting at level 129,03	Δa = -115 mm
5000	638 473,095	132 464,965		Δb = -44 mm

VII. CONSTRUCTION PHASE OF P5 PYLON ON UPSTREAM SIDE

planned points				measured points				discrepancies (mm)		
point name	a	b	M	point name	a	b	M	da	db	dM
1	1,888	-0,042	128,365	1	1,884	-0,048	130,06	-4	6	1695
2	-2,112	-0,042	128,349	2	-2,120	-0,046	130,10	8	4	1751
3	0,492	-0,979	127,305	3	0,478	0,985	129,10	-14	6	1795
4	-0,708	-0,979	127,301	4	-0,714	-0,986	129,10	6	7	1799
5	0,485	0,895	129,032	5	0,494	0,891	129,09	9	-4	58
6	-0,715	0,895	129,028	6	-0,715	0,896	129,09	0	1	62
7	0,491	-0,840	127,461	7	-	-	129,10	-	-	-
8	-0,709	-0,840	127,457	8	-	-	129,10	-	-	-
9	1,382	0,556	129,036	9	1,386	0,552	129,10	4	-4	64
10	-1,612	0,556	129,024	10	-1,618	0,549	129,09	6	-7	66
				Date of measurement :	21.04.2023					

Figure 6: Setting-out data for the pylon's topmost segment – © CÉH

From the fourth casting segment onwards, prior to the reinforcement works, three pieces of steel link units per casting segment had to be adjusted. The link units are supported by auxiliary steel structures made of steel angles which were being built simultaneously with the link units. The adjustment was carried out with assistance of geodetic measurement points fixed to the ends of the link units both on the main span side and side span side. For each link unit a schedule of setting out data was provided (figure 7).



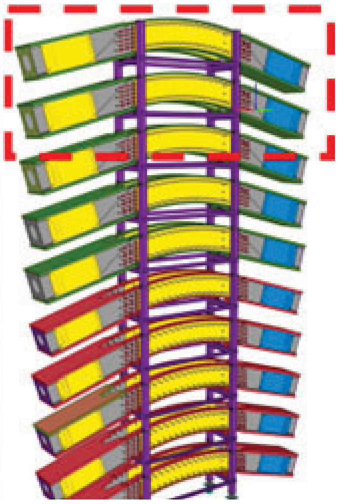


Figure 7: Fine setting of the top cable anchorage link unit (left), detailed TEKLA model of the link unit (right) – © CÉH

After the completion of the pylon structures, CÉH carried out the spatial angle checking of the link unit's anchorage plates. In the table below we compiled the comparison of the proprietary saddles offered by the stay cable manufacturers with the bespoke design link unit. The following aspects were compared:

- Bridge design.
- Definition of the friction coefficient.
- Inspection and maintenance of the cables.

Table 1: Results of the chemical analyses

Proprietary saddle	Bespoke design link unit
PRODUCT OF A SPECIALIST STAY CABLE COMPANY	BESPOKE DESIGN STEEL STRUCTURE IN COMPLIANCE WITH THE DESIGN CODES
BESPOKE DESIGN STEEL STRUCTURE IN COMPLIANCE WITH THE DESIGN CODES	CABLES COMPRISING OF DIFFERENT NUMBER OF STRANDS CAN BE APPLIED ON THE SIDE TOWARDS THE RIVERBED AND THE RIVERBANK. ECONOMIC SOLUTION WICH FOLLOWS EFFECTIVELY THE FLOW OF FORCES (FOR EXAMPLE: 55 STRANDS CABLE IN THE RIVERBANK SIDE AND 37 STRANDS CABLE IN THE RIVERBED SIDE)
THE DIFFERENT STRAND LENGTHS DUE TO THE CURVED ALIGNMENT MAKE THE STATIC CALCULATION MORE DIFFICULT	THE EFFECTIVE CABLE LENGTH BETWEEN THE ANCHORAGE POINTS CAN BE EXPLICITLY DETERMINED
THE CURRENT DESIGN RECOMMENDATIONS (FOR EXAMPLE CEB-FIB BULLETIN 89) PRESCRIBE THE LABORATORY TEST OF A TEST UNIT ACCORDING TO THE DESIGNED SOLUTION	THERE'S NO UNCERTAINITY REGARDING THE FRICTION, THE TOTAL CABLE FORCE CAN BE CONVEYED RELIABLY ON BOTH SIDES OF THE PYLON
THE INSPECTION OF THE STRAND SECTIONS WITHIN THE SADDLE IS NOT POSSIBLE	THE ANCHORAGE CAN BE INSPECTED APPLYING THE CONVENTIONAL METHOD
THE REPLACEMENT *OF THE* STRANDS SHALL BE CARRIED OUT ON BOTH SIDES OF THE PYLON	THE REPLACEMENT OF THE STRANDS IS POSSIBLE ONLY ON EITHER SIDE OF THE PYLON

3 Camber control tasks during the during the construction of the stiffening girder

3.1 Typical segments of the stiffening girder

The construction of the stiffening girder was performed by the balanced cantilever method which was launched from the P01-PM00-M01 launching segment (at each pylon supports). First the side span steel segment was lifted and adjusted, followed by the lifting and adjustment of the main span segment, all while maintaining balance. The geodetic measurement points were set out on the upper and lower flanges at the cantilever ends of the steel segments. To adjust a steel segment the schedule of pre-camber values of the current position was provided. In addition, we provided the relative height difference between the measurement points on the upper flange of the central webs of the current and preceding segments.

The geodetic survey and the adjustment were conducted preferably early in the morning in order to eliminate the daytime thermal effects. If the adjustment wasn't done in the morning due to construction management reasons than the additional data of the relative height differences were used to adjust the steel segment. Besides the vertical adjustment of the central web the lateral adjustment of the measurement points of the outer webs was also crucial. The outer webs at the

Figure 8: Transversal adjustment of the outer webs – © CÉH

ends of the cantilevers shifted easily in the transversal direction, requiring the bottom flanges at the cantilever ends to be held in position by an auxiliary structure welded to the formwork's steel frame prior to the reinforcement and concrete pouring works (figure 8). For the first six segments the changes in web height and bottom slab width due to the haunched stiffening girder geometry required special attention while adjusting the outer webs transversally according to the design.

3.2 Stiffening girder sections with cast-in extradosed cable anchorages

From the 7th to the 16th segments the cross girders of the steel segments include the extradosed cable anchorage nodes beneath the walkway cantilever, also called the "hammerhead". The hammerhead which is 955 m long measured along the cable axis is closed by the 80 mm thick anchor plate at the bottom and the 25 mm thick collar at the top. Both for the anchor plate and the collar auxiliary structures were fixed to enable the geodetic measurements of the 5-5 points (figure 9).

Evaluating the design values of the schedules provided for the measurements and the measurement results of the hammerheads of the adjusted steel segments, the angular difference between the measured and the designed cable axis was obtained. Since the hammerhead's upper collar is connected to the protection pipe – whose length varies between 3200-4200 mm due to the spatial skewness of the cables – and this protection pipe became a fixed structural element of the superstructure after the casting the deck slab, the protection pipe had to be aligned to the measured axis. It was achieved by placing annular wedge-shaped plates between the upper collar of the hammerhead and the lower collar of the protection pipe (figure 10).

To maximise construction efficiency, a stockpile of wedge-shaped plates was required and quick data provision by the designer after the geodetic measurement of the hammerhead axis. The spatial adjustment of the protection pipe as per the design could be provided either by the option of rotating the wedge-shaped plates every 45 degrees or applying even two wedge-shaped plates

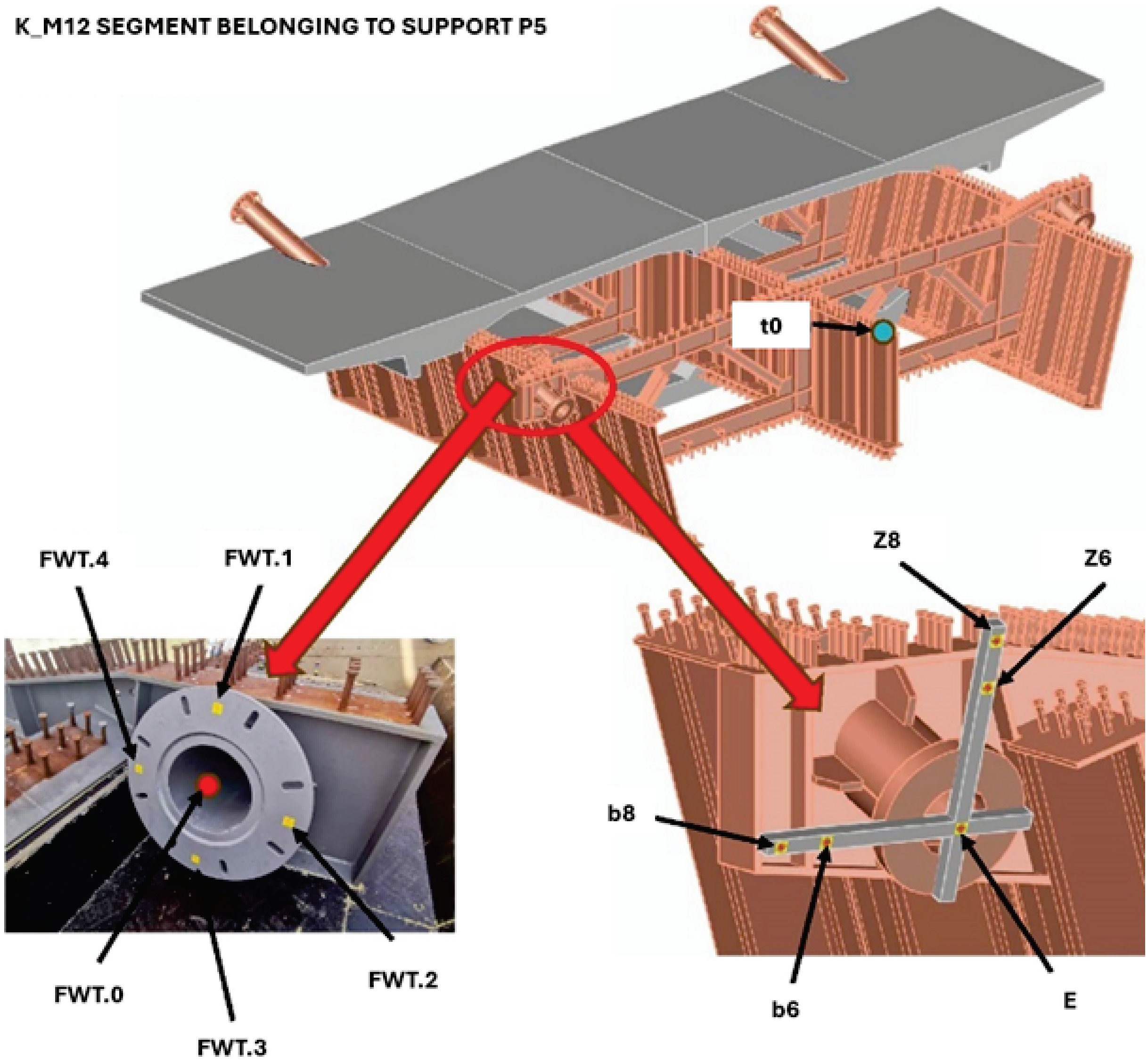


Figure 9: Measurement points of the „hammer head” – © CÉH

simultaneously. To carry out the geodetic measurement checks of the protection pipe’s adjustment, measurement points were installed onto its upper collar (figure 11).

4 Procedure of data provision during the construction of the superstructure

In the following section, we describe the procedure of the designer’s data provision – geodetic survey – adjustment by the contractor, and the statement of quantities for the measurement points. Data provision for the designed measurement points and evaluation of the measurements:

- Each steel segment’s pre-cambered position is different.
- The data for the adjustment were determined based on a series of AUTOCAD 3D figures.

Figure 10: The extradosed cable's protection pipe to be concreted into the anchorage block

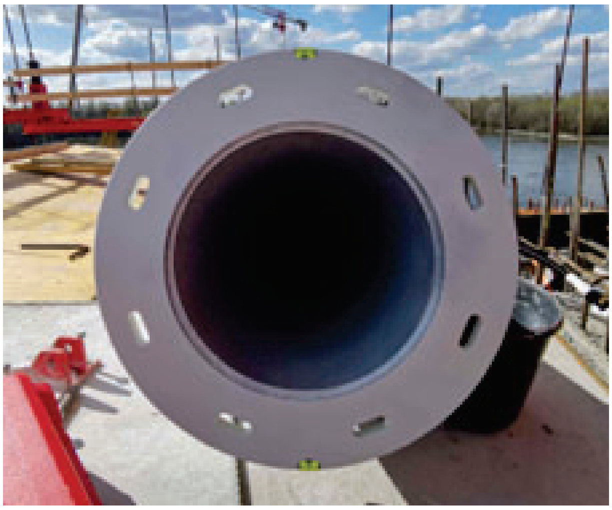


Figure 11: Upper collar of the protection pipe with the measurement points

- AUTOCAD 3D offers two options:
  - to provide identifiers for the points to be used for the adjustment
  - to copy the data set of the labelled spatial coordinates into an EXCEL file

The designer's data provision was maintained continuously throughout the balanced cantilever construction of the bridge.

For efficient construction, this required quick data provision from the designer:

- either the approval of the differences between the measured and designed data of the measurement points or the proposal regarding the correction of the adjustment
- to provide data for the adjustment of the protection pipe after the geodetic measurement of the “hammerhead” (even on the same day, within a few hours)

The adjustments of the protection pipes were carried out between March and October 2023, occasionally involving weekend shifts.

Measurement points of the pylon link units:

- Number of measurement points on one link unit: 2 x 13 = 26 pcs
- Total number of measurement points: 40 x 26 = 1040 pcs

Measurement points of the stiffening girder segments- number of measurement points excluded the closure segments:

- Adjustment of steel segment: 6 pcs
- Steel segment with extradosed cable anchorage
- „Hammer-head”: 2 x (5+5) = 20 pcs
- Cable protection pipe: 2 x 2 = 4 pcs
- Total number of measurement points: 82 x 6 + 40 x 24 = 1452 pcs

5 Summary

The new Danube bridge of Paks, Hungary is the 21th completed bridge in the Hungarian section of the Danube. The unique and complex extradosed structural arrangement with a main span of 200 m over the Danube required a complex and modern design approach, which CÉH as lead designer successfully completed. Completion of the bridge is a result of the successful collaboration between designer and main contractor (Duna Aszfalt Zrt.) and sub-contractor (Hídépítő Zrt), as well as other bridge designer firms (PONT-Terv Zrt.) involved in the project.

About the author and lead designer of the bridge:
Dr. Sándor Kisbán (1949)
Chartered structural engineer (Technical University of Budapest, 1973)

Lead bridge engineer at CÉH Inc. He started his carrier as bridge designer in 1975 at the company called UVATERV, where he took part in the planning of large span bridges (Northern bridge over the river Tisza in Szeged, Tiszapalkonya road bridge, Yugoslavia – Novi Sad cable stayed bridge). He gained his doctorate degree in the matter of cable stayed bridges in 1986 (Technical University of Budapest – Faculty of Steel Structures). He has been working as bridge designer at CÉH Inc. since 2002, where he has designed and controlled the design of several national river and motorway bridges (M0, M31 and M6 motorway bridges and viaducts, Megyeri-bridge). He is the designer of the Kalocsa-Paks new Danube bridge which was named after Pál Tomori. As the acknowledgment of his professional activity, he was awarded with the Gábor Dénes prize (2008), Széchenyi prize (2009), Menyhárd István prize (2023), Bridge engineer of the Year (2024). Member of the FIB Hungarian Division.