# Reconstruction of the Southern Connecting Railway Bridge in Budapest

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**Abstract** The Southern connecting railway bridge is Hungary's most important and busiest railway link on the river Danube, in the centre of Budapest. The condition of the existing old superstructure required its reconstruction. The reconstruction had to be carried out in such a way as to maintain double-track rail traffic while the bridges were being rebuilt. The reconstruction involved building a new superstructure, transferring traffic to the new bridge and demolishing an old bridge. The operation was repeated once again and then the third bridge was built. To accommodate the superstructures, we had to reconfigure and raise the existing pillars. The steel structures were fabricated in our own plant and prefabricated in a local port in 80-metre long and 500-tonnes pieces. The bridge elements were floated to the site, where they were lifted by two floating cranes onto a self-developed heavy lifting system. It consisted of 4 to 4 lifting towers mounted on 2 barges of 52 m length, on which the floating units were positioned perpendicular to the longitudinal axis of the barges. The floating units were lifted onto the scaffolds and were moved to the lower lifting level by 2 pushers to the lifting position, where they were lifted to the height of the pushing plane by the lifting platform. Subsequently, the bridge was pushed into position according to the site-plan. The pushing operations were complicated by the fact that the adjacent bridges were within the distance of half a metre. After closing the bridge steel structure, the railway track was placed, a test load was applied and the railway traffic started. The demolition of the two old bridges and the construction of the three new railway bridges took a total of 36 months to plan and build.

## 1 Introduction

### 1.1 The project actors

The reconstruction of the bridge was carried out by Duna Aszfalt Zrt. on the order of NIF National Infrastructure Development Ltd. being the predecessor of the Ministry for construction and Transportation. The general designers of the project were FŐMTERV Zrt. and Kontúr Csoport Kft., while the specialist designers of the bridges were Msc Kft., FŐMTERV Zrt. and Speciálterv Kft. The new superstructures were manufactured by WKS Duna Polska sp. z o.o. as part of the Duna Group, and the shop corrosion protection was carried out in the painting plant on the premises of Közgép Építő- és Fémszerkezetgyártó Zrt. The on-site water organisation, floating and lifting of the bridge elements was carried out by HSP Hídépítő Speciál Kft. The technical inspection and control tasks were performed by ECO-TEC Kft. The operator of the bridges is MÁV Magyar Államvasutak Zrt.

### 1.2 Basic data of the bridge

The Southern connecting railway bridge connects Buda with Pest, links Western Hungary with Eastern Hungary and connects Western Europe with Eastern Europe. These bridge structures offer the potential for a quantum leap in suburban transport, as well as being the only major crossing point of the international Mediterranean corridor, the Rhine-Danube corridor and the Eastern/Eastern-Mediterranean corridor, and the future Budapest-Belgrade railway line. The origins of the bridge go back a century and a half. The first structure of the bridge was built more than 150 years ago. Interestingly, the iron structure was made of French and Belgian wrought iron in the Cail et Cie factory in Paris and transported to the site from there. The first superstructure had to be dismantled after 36 years, and the one that replaced it was demolished during the Second World War. The superstructures were then reconstructed and replaced by two temporary bridges of different structures, and then, in 1948 the 5th superstructure of the Southern connecting railway bridge, which is to be demolished as part of the project, was built and served rail traffic for over 70 years. Each element of the bridge is a mosaic of history. The ravages of war did not avoid it thus it has been rebuilt and reconstructed several times.
The existing pier bridges (to be demolished as part of the project) are 393 m long, four-span, continuous truss-girder girders with symmetrical trusses with traight-lined spans above the abutments. The flood-plain bridge on the Pest side has two 47,4 m long girder bridges supported by pendulum columns, and the flood-plain bridge on the Buda side has one 32 m long girder bridge supported by pendulum columns. The bridges were made of of 36/24 12 mild steel, mild iron, bar iron, wide iron and structural steel in accordance with the MOSZ No. 122 standard that came into force in 1933.

On the new bridges, the main girder is a bottom (orthotropic) deck, with 6 holes, top edge truss with parallel belt, continuous truss girder, without columns symmetrical truss. The main support spans are 49.26 metres, four times 98.52 metres and 49.26 metres, with a grid height of 8 metres, a spacing of 8.21 metres between nodes and a crossing angle of 90°. The spacing between the main supports is 5.20 metres. The inclined bars (except for the end bar) are welded I-sections with a maximum enclosure size of 610 x 500 mm. The upper belts and the final truss are “hat” sections with a maximum enclosure size of 720 x 680 mm. The free ends of the spine plates of the hat sections are braced by 100-millimetre-wide horizontal plates. The top belt bars are stiffened by a K-grid top edge grid. The bridge has a sturdy gate at each end. The lower belt is formed by an orthotropic plate which runs through the entire cross-section and thus includes, among other things, the longitudinal members, the longitudinal ribs and the bar section in the main span line. The two main beams are connected by a grid of cross and longitudinal beams tied into the nodes, the upper belt of which is the orthotropic plate. The cross beams are connected to the nodes of the lower belt, and are thus 8.21 m apart. The distance between the longitudinal uprights of the

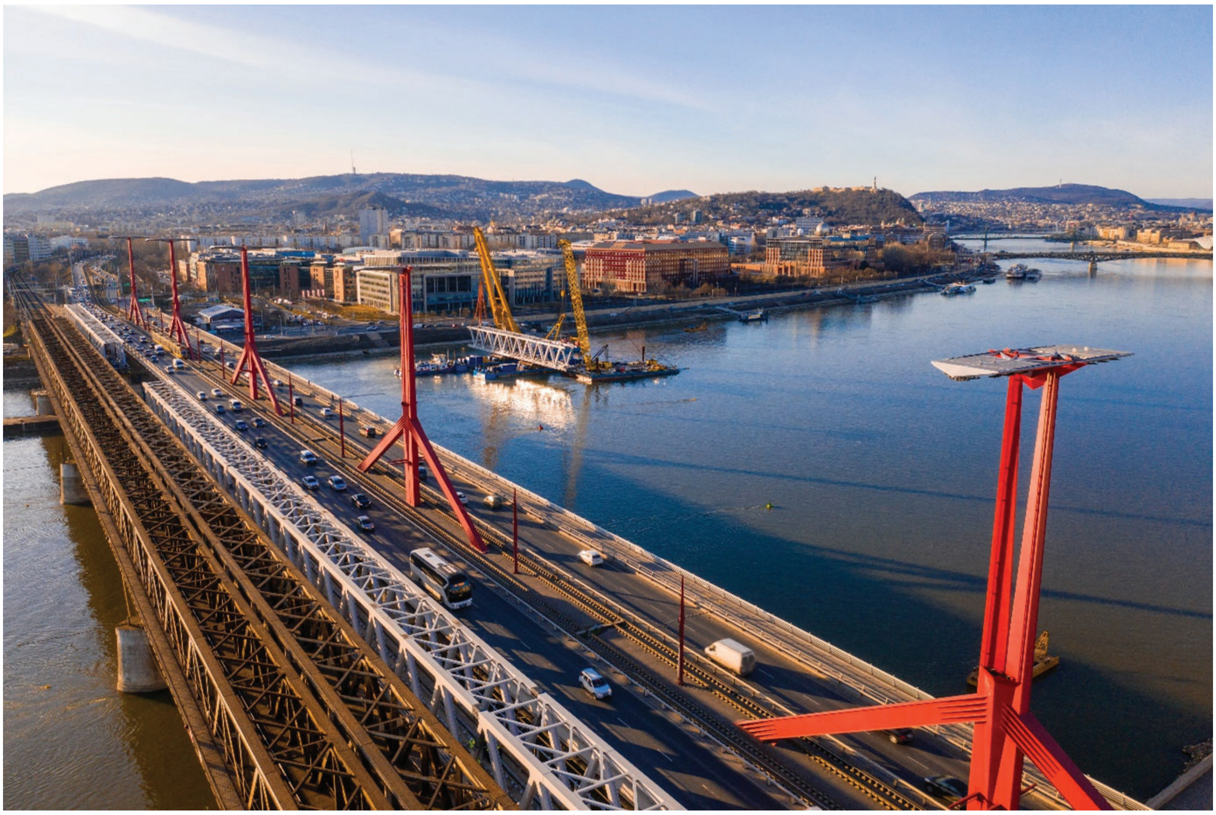

**Figure 1:** Two older structures and a newly constructed one adjacent to each other

same height is 1.52 m. The spine plates of the brackets are of the same height, ~950 mm, and their lower belts are 500-30 mm. The thickness of the spines is generally 16 millimetres, except for the cross members above the intermediate supports and the longitudinal members connected to them, where the thickness varies between 20 and 30 millimetres. The thickness of the orthotropic slab is 16 millimetres, and the thickness of the 240-millimetre-high flat steel longitudinal ribs, designed every 500 millimetres, is 20 millimetres. For this reason, the height of the longitudinal ribs projecting above the track slab is 310 mm. In the end bridge openings, the height of the end longitudinal ribs is 260 mm. The ribs protrude through the transom spine. The structural height is 1226 mm. The deck is horizontal longitudinally and slopes transversely outwards from the bridge axis by ~2%. The superstructure is fabricated with a production overlift to allow for 40% of the total dead load and 40% of the payload "LM71". The minimum dimensions of the free space provided on the bridge (at the gates) are 4520 x 7050 mm above the rail crown. The structural steels for the railway load (according to ISO EN 10025-2:2005) are S 355 J2+N and S 355 K2+N. Other structures are S 235 JR and S 235 JR.

Due to the structural movements over the bridge deck, the structural beam of the Pest bridge deck had to be dismantled and rebuilt with a new abutment, which has a shoulder design to accommodate the ribbed levelling plate. In the abutment, a covered passage opening, open from above, was created for the cables and wires installed in the north side walkway of the superstructure I. The Buda bridge deck under tracks II and III was demolished and a new pile-wall bridge deck was built 15.44 m further back, with a width sufficient to accommodate 3 superstructures, which is connected to the reinforced concrete pile-wall structure previously built under track I by means of a connecting reinforcement. The reason for this is that, in addition to the road lanes, pedestrian lanes and cycle lanes of the Buda-side coastal opening, the abutment and the coastal pier also accommodate the track pairs of the Buda Phased Tramway Phase II. The piles under the Buda abutment are 1.5 m in diameter. The structural beam of the connecting pile section has been dismantled and a new knee wall installed. The new pile-supported bridge deck also received a structural beam of the same cross-section. The shoulder design of the knee wall of the structural beams is suitable to receive the ribbed levelling plate. In the kneewall, a covered passage for cables and wires in the north side walkway of superstructure I has been provided.

**Figure 2:** preparation of the abutment construction

The pile-connecting beam of the pile-connecting beam parallel to the railway adjacent to the Rákóczi Bridge is in the shape of a “Z”, with a height of 4.2 m between the pile-connecting beam between the pile towards the bridge opening and the upper plane of the pile in the backfill. Due to the longitudinal stresses, a triangular reinforced concrete wedging is used here. To accommodate the steel piling beams, the anchorage nests of the piling beams had to be designed. All existing and remaining concrete surfaces were renovated. The visible concrete surfaces were protected against salt corrosion. Due to the construction schedule of the three superstructures, the new structural beam sections of the intermediate supports were completed in several phases. The construction joints were formed with inter-working connections, so that in the final state the structural beams of the abutments will function as one structure per abutment. In the first phase, superstructure I and its substructures were completed. The structural beam elevations of the substructure under the

intermediate abutments were completed during the construction of the adjacent Rákóczi Bridge, but needed to be renovated. The geometry of the existing structural beams was not suitable to accommodate the significant dilatation movement over the Pest abutment, and therefore required their partial dismantling and reconstruction. In the case of superstructure II and III, the piers had to be raised at the level of the wedging, because the lower belt of the new steel superstructure, unlike the previous structure, was 'flush' with the bridge along its entire length.
The 60E2 R400HT track system is supported directly on the orthotropic plate above the longitudinal supports. The superstructure has a continuous flexible bed, achieved by placing a flexible rubber sheet between the steel rail troughs fixed to the track bed and the rail and filling the entire trough with a flexible casting material with excellent noise protection and capable of supporting the rail load. The track troughs were bolted to the bridge deck, using around 16,000 bolts per bridge. The guide rail was a welded section in the shape of a flat "T", the higher edge of which could not be more than 30 mm above the level of the rail crown, and the spacing between the guide rails had to be 180-200 mm to allow the bicycle to ride on the steel rails in the event of a derailment.
This direct rail reinforcement system is sufficiently flexible and has favourable noise and vibration parameters, and is suitable for speeds of v=160 km/h.

## 2 Manufacturing and construction

### 2.1 Manufacture of steel structures

The steel structures of the new bridges were mainly made in the Duna Group's production plant. The steel structure of the bridge weighed nearly 10 000 tonnes. With such a large quantity of material, it is very important from an economic point of view to extract the material during the dismantling process. As the manufacturer's projects progressed, and in accordance with the process of continuous development, testing and design based on the principles of series production, the quantity of material required was not ordered using standard steel plate slab sizes on the market, but using individual, project-specific sizes. This solution improved their material yield by 5-6%, which meant hundreds of tonnes less waste for the project. The supply of materials, and with it the production, was based on the needs of the works on site, in the same order in which the floating units of the bridge were lifted over the river Danube. The elements of floating unit 1 were delivered first, proceeding from the Pest side. This was followed by the track elements, main girders and wind grates of floating units 2 and 3. When they reached the middle of the bridge, they turned to the Buda side, where the previous elements were followed by the elements of floating unit 6. Then came the 5th and ater that the 4th so-called "closing unit". A floating unit is made up of 8 track elements, 8 main beams and an average of 42 bars and 61 wind grids. This means that 144 track elements, or 768 bars, for example, had to be produced for the three bridges as a whole. The assemblies were assembled with well-templated auxiliary equipment for production, on flat benches that are leveled and continuously maintained and controlled. Various buffers, spacers, clamping devices and special bench designs were used to position the plate products. These are designed to ensure that a given plate can only be placed in one specific position during assembly, thus reducing the possibility of error. Often, the template system makes it possible to detect and

eliminate possible errors during the first steps of the assembly process.
The first step in the manufacturing process is to check and mark the raw material and its receipts or certificates delivered to the plant in accordance with the relevant specifications. The materials to be used were then reprocessed by means of granulation and then cut to size using flame or plasma cutting machines. During the production of the track plates, the longitudinal ribs and the longitudinal spine plates were fixed to the track plate with a comb template and then welded by a 135 consumable-arc arc welding process using an active shielded arc welding gas. Then the lower belt and the longitudinal stiffening spars were assembled using an assembly template, also welded using the 135-method procedure. The cross brackets were placed on the track plate, secured with stitching, and the assembled unit was then turned over and the outer longitudinal tie plate was folded over the track plate, which was placed upside down on the flat bench, and secured with stitching. Welds were made to the cross-member spines, longitudinal spines, outer stiffener and track plate using 135 gauge and then to the remaining track element seams using 135 gauge and 136-gauge flux cored wire electrode arc welding with active shielded arc welding. In order to minimise the heat-induced deformation by the welds, the welds were made simultaneously with two welders from the centre outwards. Since cracks may occur as a result of solidification of the weld pool (e.g. in the end crater) at the start and at the end of the weld arc, the arc was started on the infeed plate and finished on the outfeed plate. In the case of sectional welds, and in the case of arc ignition and arc termination on the structure, the start and finish of the welds were always back-ground. In order to facilitate the on-site fitting of the track elements, 150 mm of the seams (neck seams) were left out and welded during the on-site installation. The main support is inverted U-shaped with inverted bracing plates. Their fabrication started with cutting to size, similar to the fabrication of the track plates, then the belt plates and back plates were laid flat on a flat bench and the transverse butt welds were welded in position by rotation using a 121 covered arc welding wire electrode process. The upper belt of the main beam was placed on the flat bench upside down, then, the ribs were positioned. Welded the main girder upper belts and ribs, the longitudinal stiffening ribs, the main girder back plates, the main girder stiffening ribs, and finally the edge truss stubs in position by rotating in position and using welding procedures 135 and 136 according to the weld. The truss rods were placed in an assembly template, secured with stitching and then welded in position by continuous rotation welding procedure 135. The fabrication of the gates and edge gratings was similar to the fabrication of the bars.
The floating units were largely connected by strap plates, with holes drilled in the plant only in the base elements. The holes were drilled with a drilling template on the ready-made components that had passed geometric inspection, the templates being made from the hole patterns of the strap plates. In the case of the strap-plate connection, particular attention had to be paid to the flatness of the plates and the tolerance of the hole positions.
The welds were tested using destructive and non-destructive tests. In the non-destructive tests, compliance was checked by visual inspection, ultrasonic, radiographic and magnetic testing. Destructive tests were performed for all the most typical types of structural connections.

## 2.2 Corrosion protection

The bridge is a freestanding structure exposed to the corrosive and damaging effects of the environment; therefore, the bridge has an atmospheric corrosivity category C5 and the service life of the bridge coating systems is very long (VH), i.e. an expected service life of over 25 years according to the relevant standard MSZ EN ISO 12944-2:2018. An interesting feature of the bridge's corrosion protection was that it was probably the first bridge project in Hungary to be built to the new 2018 edition of the Corrosion Protection of Steel Structures with Paint Coating Systems standard. The bridge coating system can be divided into two parts. The anti-corrosion paint coating systems on the steel surfaces of the bridge were to be applied with a zinc powder primer with a minimum of 3 layers (MNOC) at an average thickness of $320\mu m$ and on the field splice seams at an average total nominal dry coating thickness (NDFT) of $360\mu m$. On the other hand, the reinforced coating system was applied on the Rákóczi Bridge side of the bridge structure I to provide even greater protection against the salt spray from the Rákóczi Bridge traffic. An average total nominal dry coating thickness of $400\mu m$ was required at these locations on the structure. For the priming of the above coating systems and for the full thickness of the coating, the specification for the evaluation of the coating thickness required by the above standard (ISO 19840) had to be taken into account, highlighting the correction factor of $25\mu m$ dry coating thickness corresponding to the roughness depth Ry5 as required in the above-quoted standard. The requirement for steel substrates to be coated with the paint coating system is a steel surface with a surface cleanliness Sa 2 ½ according to ISO 8501-1:2008 and a medium (G) (min. $50\mu m$) Ry5 roughness depth according to ISO 8503-1:2012. The colour of the bridge structure is mainly RAL 7047 full grey, and partly the colour of the accessible surface of the deck is RAL 7016 anthracite.

## 2.3 Pre-assembly of steel structures

The steel structures were pre-assembled at a local port near the bridge, where a harbour is operating on the bank, suitable for receiving and loading barges. The control machine of the harbour is a mobile derrick crane with a load capacity of 250 t, with a track perpendicular to the edge of the bank, which can lift up to two groups of "TS" barges side by side in the harbour. In the pre-assembly area, the incoming structural elements were assembled and welded on a bench under the track of a buckram. They were then rotated to the upright position using a rotating bench, the two halves of the bridge were assembled, adjusted and then welded together. The edge trusses were installed, the adjacent mounting units were cut to shape and the strap-plate connections for the on-site float unit joints were drilled out. The pre-fitting units were then drawn into the paint tent on a rail track, where they repaired the weld zones and prepared the overlay corrosion protection coating. The pre-assembly units were pulled out of the painting tent into the track of the harbour crane. The pre-mounting units with corrosion protection were fitted with the plant walkway and brackets, the steel rail track was lifted onto and temporarily fixed, and the harbour crane was then lifted onto the 80 m long TS 80 transport crane in the harbour, where they were welded together to form the floating units. Each barge had four pre-mounting units. The length of the floatation units was greater than the length of the barge deck, so the bridge at the end of the barge was overhanging. The bridge axis was nearly the same as the barge axis, slightly offset due to the weight of the walkway. Stepped trestles were placed under the pre-mounting units to provide support. One barge required 16 trestles. The pre-mounting units were adjusted to the pre-mounted shape according to the measuring instructions. The measurement required a great deal of attention and experience, as the barges were constantly moving on the water, the barge was constantly twisting slightly on its axis due to the waves, the shape of the barge was constantly being swung by the load of the new elements, the bridge element was constantly moving due to temperature changes and the bridge shape was also affected by welding shrinkage, which was finally completed on site.

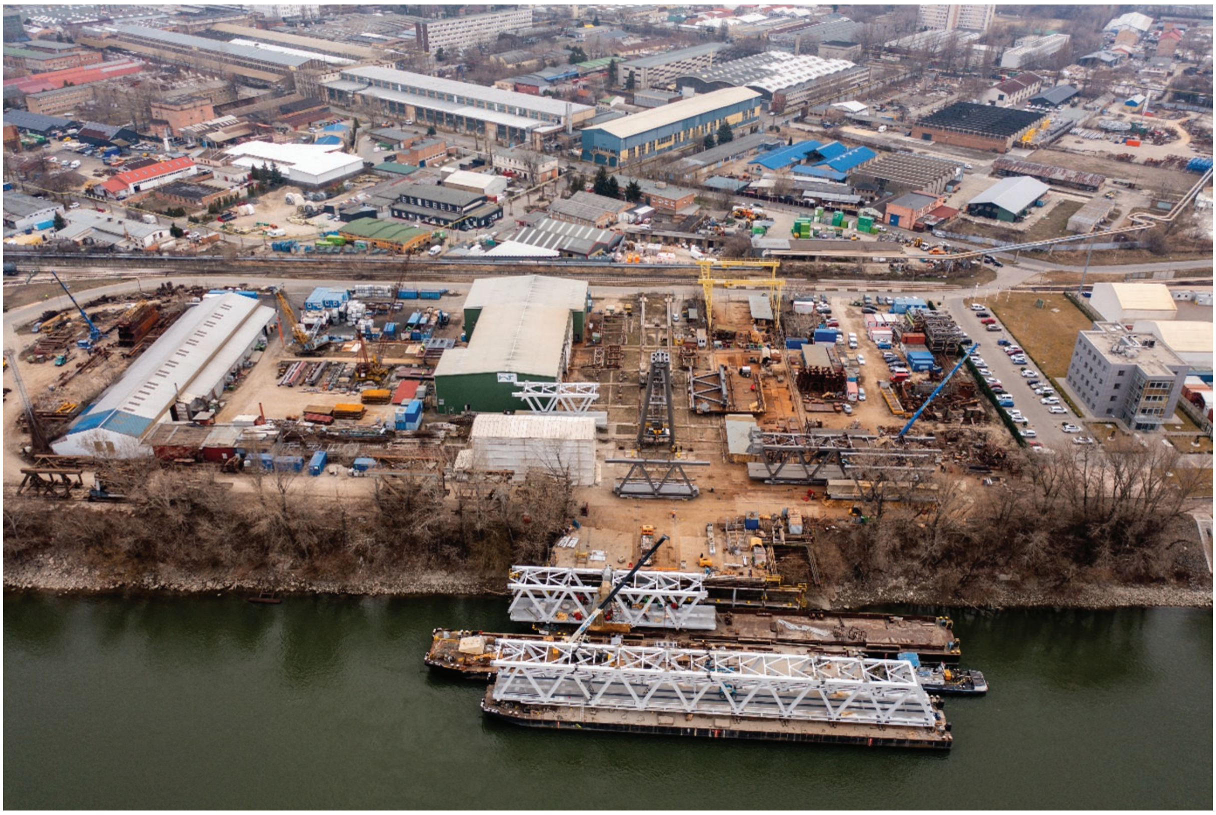

**Figure 3:** Pre-assembly a demolition area

## 2.4 On-site assembly

The 80.385 - 90.305-metre-long floating units assembled on the transport barge were lifted by the 200-tonne capacity "Clark Adam" floating crane and the 300-tonne capacity "HEBO LIFT 8" (formerly known as Atlas) floating crane onto a cassette system heavy lift rack system. The scaffolding system consisted of 4 to 4 lifting towers, converted from TS 40 transport barges, mounted on 2 parallel transport barges of 52 m length, on which the floating units were positioned perpendicular to the longitudinal axis of the barges. The floatation units were lifted onto the racks and moved to the lower lifting level by 2 pushers to the lifting position, where they were raised to the height of the pushing plane by the lifting platform. The bridge was then pushed into position in a site-planned manner. The pushing and lifting operations were made very difficult by the fact that the bridge was not built as an open field project, sometimes with adjacent bridges within half a metre of each other. The moving operations were carried out by highly experienced sailors and installation specialists. The installation started by lifting and extending the Pest side, then the Buda side, and was completed by lifting the end span. The manipulation operations required the construction of the 4 yoke systems.

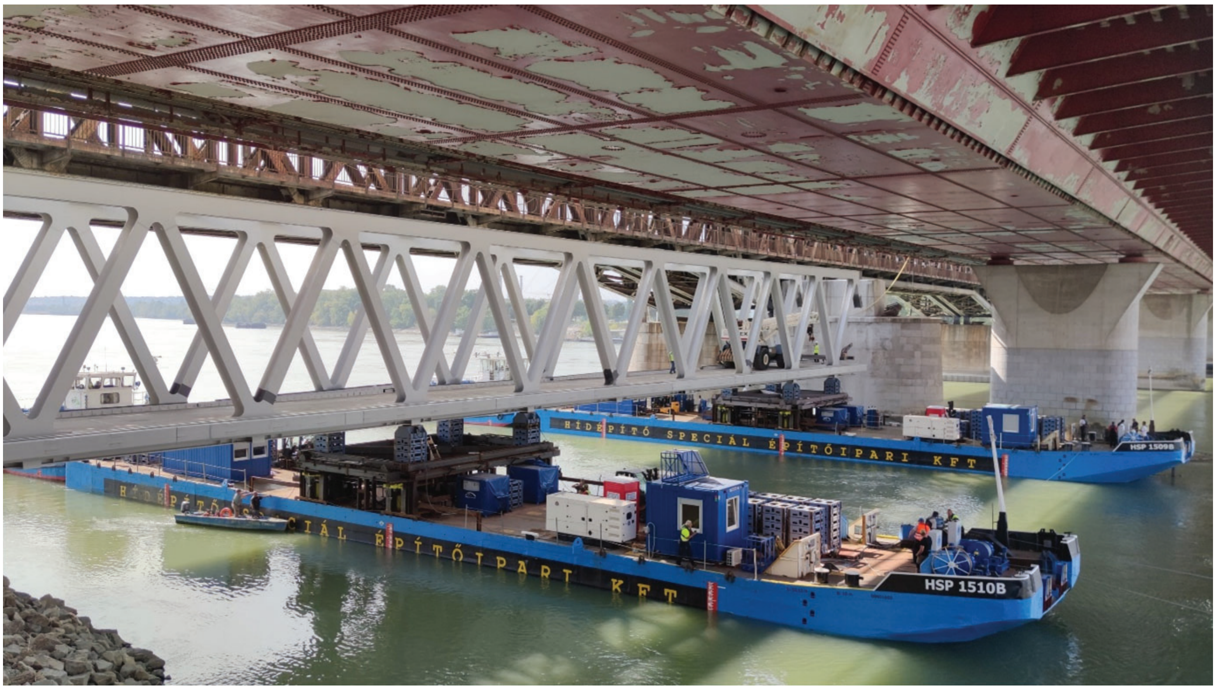


**Figure 4:** Heavy lifting equipment designed and built for this project

On the Pest side, the yoke systems were placed in the area between Laczkovich Street and the HÉV track and on the side of the pillar above the Danube, on the Buda side on the side of the pillar above the Danube and on the southbound side of Dombóvári Street. After the floating units were assembled, the bridge cranes were installed, the bridge was lowered, the steel rail track was set, the inspection trolleys were installed, the missing pavement and barrier elements were fitted, and the on-site corrosion protection and countermeasures were completed. Subsequently, the utility and railroad construction tasks were completed. Following the construction of the first bridge, traffic on Bridge II was shifted to the new Bridge I. It was then possible to start the demolition of the Sign II bridge. As the steel structure of the north track is made by wedging above the piers, the demolition is carried out by means of lifting platforms in the form of large elements of approximately 77-90 m in the abutments and 16 m above the piers by means of "HEBO LIFT 8". The demolition of the river bridges on the Pest and Buda sides of Bridge I (first) had to be carried out at the same time as the demolition of the embankment bridge. First, the reinforced concrete walkways, railings, rails and sleepers of the embankment bridges had to be demolished. Demolition of the river bridges was carried out by crane on the opposite side to the fixed spur, on the outflow side of the bridge. Following the demolition of the existing bridge II, the new bridge II was built using the same construction techniques as bridge I. On the outfall side of the existing riverbed and floodplain bridge III, the adjacent bridge structure no longer prevented the bridge from being lifted, so this bridge was demolished with the help of a lifting platform, floating cranes and a mobile crane.

**Figure 5:** Lifting the bridge elements into place was like threading the needle

## 3 Conclusions

The construction of the bridge was made very difficult by the fact that the project was located in one of the busiest parts of Budapest, with double-track rail traffic, Danube shipping traffic, Dombóvári út traffic, HÉV traffic, Rákóczi Bridge Road and tram traffic, and pedestrian traffic on the Buda side having to be maintained at all times. These closures could only be requested in individual cases, months in advance or, in the case of some organisations, a year in advance. The reconstruction of the bridge was a very interesting task requiring great care. The bridge was built by 30 site managers, 15 designers, 10 contractors, 20 technical inspectors, 25 boatmen, 195 people for the steel structures, 35 for corrosion protection, 65 for pre-assembly in Csepel, 70 for on-site assembly and substructure construction and 25 for demolition. In total, nearly 500 people worked to successfully complete the project.

## 4 References

The photos were taken by Mihály Nagy, photographer of the Magyarépítők.

**Figure 6:** The three new bridges

**Figure 7:** Despite being a railway bridge, it blends well into the cityscape