Design and production of a segmental prestressed UHPFRC bridge in Příbor

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Abstract:

This paper deals with the design, production and assembly of a segmental prestressed footbridge made of UHPC (Ultra High Performance Concrete) which is sometimes referred to also as UHPFRC (Ultra High Performance Fibre Reinforced Concrete) and installed in the Town of Příbor. The UHPFRC or UHPC material gradually finds its way to interesting and unique structural applications in conditions of the Czech Republic. The paper presents the design, production and assembly of a segmental footbridge, the first of its kind in the territory of the Czech Republic, designed as a simple beam with a span of 35 m and a total length of 36 m, which is formed of the bracing of 5 two-chamber segments with a width of 2.5 m and a height of approx. 0.8m. The structural material selected was UHPFRC of the C110/130 class with dispersed steel reinforcement which was developed in the Klokner Institute (KI) and optimised and operationally tested at KŠ PREFA s.r.o., according to the design drawn up by architects and the Novák & Partner company in cooperation with the KI staff.

Keywords: UHPC, UHPFRC, segmental structure, footbridge, prestress

1. Introduction

UHPFRC or UHPC is a new prospective ultra-high performance cement-based material; see articles [1], [2], [3], [4]. Its mechanical properties (compression strength 120-180 MPa, tensile strength and bending strength approx. 20-40 MPa) and processability make it possible to design newly various structures with specific parameters and shapes. At the same time, a principal characteristic for practical use is its very high durability several times exceeding ordinary concrete. Methodologies for larger dissemination of possibilities of designing and applications of UHPC and UHPFRC in the Czech Republic have been drawn up under the Klokner Institute's leadership. This relatively modern cement composite was used, in this particular case, for construction of a footbridge designed as a simple beam with a span of 35 metres and total length of 36 metres, of UHPFRC C 110/130 with dispersed steel reinforcement. Visualisation of the appearance is clear from Fig. 1 and 2. The footbridge is installed with the help of four steel roller bearings with a diameter of 200 mm on a reinforced-concrete substructure. The surface of the structure is directly ascendable (without any additional water-proofing systems and cover surfaces) with drainage by using a direct gradient of 1.0%. The bridge is fitted with handrails with a height of 1.1 metres, formed of optically subtle circular columns with a diameter of 22 mm. These columns are longitudinally connected by means of a solid varnished acacia grab bar. The space inside the grab bar includes integrated lighting of the footbridge, including necessary accessories.

Figure 1. Introductory visualisation of the architectonic design consisting in simple concepts of the bridge as precision noble stone laid over the water

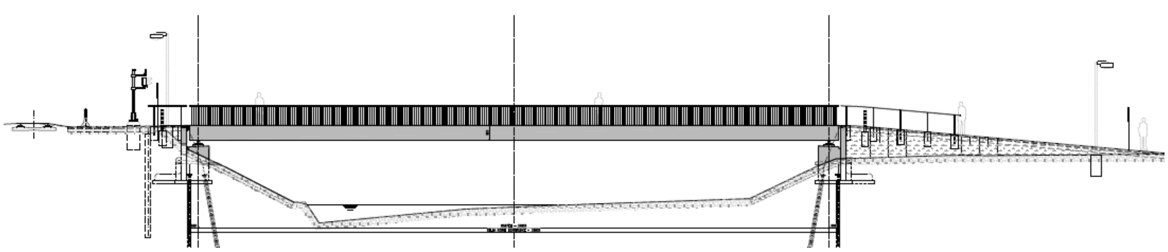

Figure 2. Structural design of the footbridge

The bearing structure with a height of 800 mm is divided, in the longitudinal direction, into five segments with a length of 7.2 metres and a cross section according to Fig. 3. The slenderness ratio of the structure is therefore 1:44. The total width of the cross section is 2.5 metres. The footbridge volume is lightened with twenty spacious polystyrene blocks, which limit the UHPFRC material consumption and lighten the footbridge in general. That is why it is in fact a hidden grillage structure of the beam formed of a system of interacting longitudinal and transversal ribs.

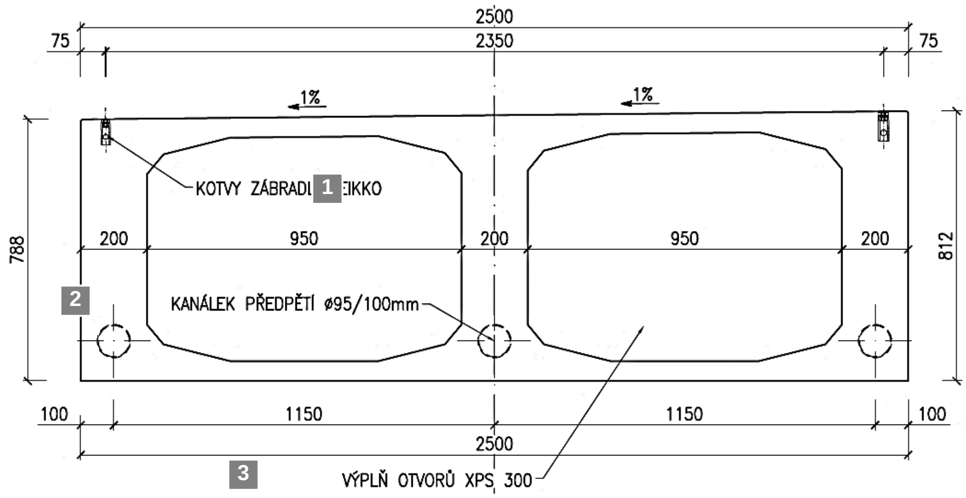

Figure 3. Arrangement of the chamber cross-section of the footbridge

(Legend: 1) Peikko handrail anchors; 2) Pre-stress channel; 3) Filling of the holes)

The footbridge segments are longitudinally coupled with the use of prestressing cables conducted in longitudinal ribs of the internal grillage. Prestress is designed, quite untraditionally for segment structures, through raised cables of a parabolic trajectory. This design has a favourable influence on the values of normal stress along the structure length, on the arising of transversal raising forces etc., nevertheless its consequence is a different position of the passage of cables through transversal joints between the segments. Therefore it was principal for the design (with regard to the segment technology of the construction) to reliably protect the system of longitudinal prestress against the damage by corrosion. A unique multiple system of protection of prestressing cables is designed for the footbridge, consisting in the following facts:

- Sealing of joints with epoxy putty
- Coupling of cable channels in the joints by using special Liaseal (Freyssinet) couplings
- Injection of cable channels
- Use of the Monostrand (Freyssinet) type cables supplied in protective sleeves

This protection will ensure a trouble-free load bearing capacity and usability of the footbridge for the term of the design lifetime of 100 years. An impulse for assurance of maximum measures preventing possible corrosion of the prestressing cables from occurring was especially the collapse of the Troja footbridge at the end of 2017.

The substructure of the bridge is designed through standard reinforced-concrete supports with perpendicular wings. The construction is founded on micropiles.

The handrail of the bridge consists of stainless steel columns installed in threaded cases embedded in concrete in the upper footbridge surface. This way it is possible to achieve absence of footing plates of the handrail. The wooden grab bar is fitted with spot lights, including their power supply which is conducted into the grab bar through hollow handrail columns at the beginning of the bridge. The handrail grab bar is formed of solid acacia wood with final surface treatment based on yacht varnish coating. The drainage of the bridge is resolved through direct outflow of water from the surface thanks to a unidirectional gradient of 1.0% (see fig. 3)

2. Footbridge production

Production of individual segments was carried out by KŠ PREFA s.r.o., Štětí concrete mixing plant. Test segments of a half length were made there in advance for verification of design presumptions. This was followed, in one-week intervals, by production of five segments of the bearing structure, which were transported to the construction site after 14 days from the pouring of concrete for the last segment. The total weight of the bearing structure is approximately 88.5 tonnes, the weight of the edge segments being approx. 19.5 tonnes, while the weight of the central segments is 16.5 tonnes.

2.1. Formwork and elements embedded in concrete

With regard to the directly ascendable surface of the footbridge it was necessary to carry out concrete pouring in an inverted position so that the finally visible surfaces can be in a contact with the formwork. The formwork of each segment can be basically divided into two parts - formwork of the bottom and sides, which was formed of the Phenox concrete plywood; and formwork of the fronts and segments with the help of steel sheets.

The side and lower formwork consists of simple large-format Phenox plates, where edges are formed of round corner bars with a radius of 10mm. The front steel sheet is a principally more complex element, which includes (in itself) shear locks in the shape of a flat truncated pyramid and tube-shape centring extensions for the key centring of mutually follow-up cable channels of longitudinal prestress. Each joint between segments is designed as a normal of the course of the prestressing cable axis, which means that every joint between segments must be created by means of a special front formwork metal sheet. Thanks to the symmetry of the structure it was possible to minimise the total number of front formwork metal sheets to 3 pieces.Shear dents are created in the front metal sheet by a milled steel plate inserted into the metal sheet area. Its main task is to create dents for the transfer of shear forces between joints, nevertheless thanks to precision of the casting of segments it serves also for the correct guiding of segments during their mutual gluing. Although from the external view the segments look very simple, elegant and clean in terms of their shapes, it was necessary to embed a large quantity of assembly, protective and handling elements into their inner parts. These are especially:

- Handrail stainless steel thread cases in a total number exceeding 500 items
- Handling stainless steel thread cases for both production and final areas - approx. 80 items
- Protective conduits of prestressing channels, injection tubes
- Liaseal cable couplings for protection of the prestress passing through joints
- Plates installed under the bearings
- Jigs serving for rotation of segments from production to assembly positions
- Through-passes for power supply inlets to the integrated lighting system
- Thread rods and cases for the coupling and gluing of segments
- Through-passes for injection of cable channels
- Polystyrene blocks outlining the shape of the cavities

Figure 4. View of the counterweight with the anchoring of lightening polystyrenes and other embedded elements, such as bearings and handling cases.

2.2. UHPFRC material

The UHPFRC mixture used was developed in the Klokner Institute and optimised in cooperation with KŠ PREFA s.r.o.. Segments were produced with the use of the C110/130 class UHPFRC, XF4 with dispersed steel reinforcement in the form of steel wires. The final mixture consists of cement, fine aggregate with maximum size of 2 mm, cinder, micro-silica and steel micro-fibres with a length of 10 mm. The voluminous share of fibres was 1.5%. The volume of water and super-plasticizer was optimised with regard to processability. No additional pigment was used during production of individual segments. The mixture was developed as self-compactable and self-levelling. With regard to the very good consistence of the mixture it was not necessary to carry out any additional compacting and all the parts of the mould were filled without any problems. Basic mechanical properties were tested in the laboratories of the Klokner Institute. The parameters of the mixture are as follows:

- The density achieved values of 2,420 - 2,480 kg/m^3.
- Compression strength of concrete measured on cylinders (150/300 mm) within the range of 137.6–145.9 MPa.
- The modulus of elasticity oscillated within the range of 47.5 – 49.6 GPa.

2.3. Production

Production was carried out continually, in a continuous series. The previous concreted segment with the installed front metal sheet thus formed the wall of the formwork of the subsequent segment. Individual concrete pouring operations were carried out in record-breaking volumes (if compared to other projects in the Czech Republic) oscillating between 6.5m^3 for central and 7.7m^3 for edge segments. Temperature development during the hydration process in the edge end crossbeam of the first and last segments was verified on testing segments. This is a concrete monoblock with dimensions of 1.0x2.5x0.8 metres. Concrete pouring for the bearing structure segments took place in summer months early in the morning in order to eliminate the effect of high temperatures on water evaporation from the mixture and generally on hydration heat development. Protective wax-based film was applied with double spraying on the free surface of the structure after dismantling of each segment.With regard to hydration heat development during the hardening of the mixture it was necessary to guarantee as even and as slow cooling of concreted prefabricated materials as possible. Only this way it is possible to eliminate occurrence of cracks from difference shrinkage between elements of different thicknesses. The cooling of the entire element always lasted for several days, and for this reason the segments made were covered with polystyrene plates for this time.

3. Footbridge assembly

The footbridge assembly was carried out in a segmental way during one working day. A heavy centring piece of the Pižmo type consisting of a couple of simple beams with an assembly support in the river bedding in the middle of the span was assembled in advance on the construction site. The centring piece floor was formed altogether of four solid steel beams which minimised the bending deflection from the load of the own weight of the prefabricated elements. The upper surface of the centring piece was further fitted with subsidence wedges, which enabled both the raising of the structure for elimination of the centring piece bending deflection and at the same time the raising and subsequent decentring of the bearing structure after its prestressing.

The segments were transported by five lorries (in total) to the construction site. Loading was carried out with the use of portal cranes in KŠ PREFA Štětí. A heavy-duty crane with a load bearing capacity of 550 tonnes was assembled on the construction site in advance for the purpose of assembly of prefabricated materials.

Figure 5. Assembly of the S2 segment (the fourth one in the installation order)

It was necessary to mutually connect individual segments after assembly by the sealing of the joints. The gluing of segments was made with epoxy putty with an extended time of processability for approx. 30 minutes. The coupling procedure was as follows:

- Levelling of the height position of the prefabricated material to be connected
- Lifting of the prefabricated material to be connected, by approximately 1.0 m
- Putty application onto the front of the prefabricated material, LIASEAL coupling installation
- Displacement of the prefabricated material
- Synchronous coupling of segments until the pushing out of the putty
- Surface finishing of the joint and team movement to another segment

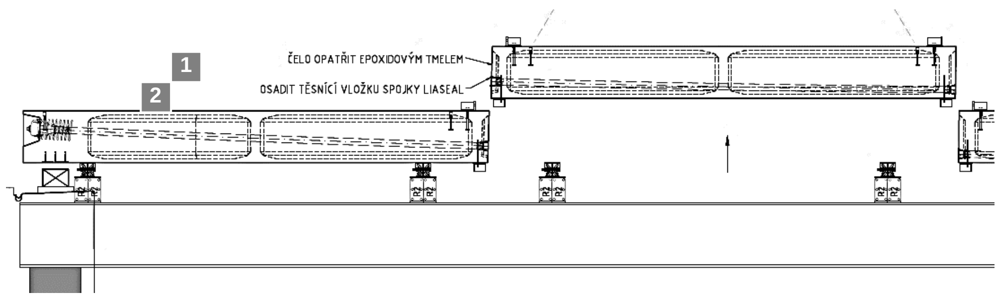

Figure 6. Coupling procedure chart

(Legend: 1) Provide the front with epoxy putty; 2) Install the sealing insert of the Liaseal coupling)

For the sealing of the joint it is necessary, during the gluing of segments, to monitor gradual pressing out of the epoxy putty along the cross section circumference. In the figure it is possible to see the treatment of the fronts of each segment. The aim of this treatment is to minimise the area of the surface glued. The epoxy putty used for the gluing of prefabricated elements features a high viscosity and in case of larger areas it tends to create resistance to the coupling force.

3.3. Prestressing and decentring of the structure

Freyssinet was the selected supplier of reinforcement. The prestressing reinforcement of the footbridge is formed of three cables conducted inside the bridge in a parabolic arch, the camber being 400 millimetres. Every cable consists of 17 ropes without bond, of the mono-strand type (Ø15.7mm – St 1640/1860) with a protective plastic layer preventing contacts of ropes with any corrosion medium from occurring. The cables were tensioned unilaterally by using the anchoring tension of 1440 MPa, approximately one week after the gluing of segments. The channels were injected with cement mortar on the following day after the prestressing of the cables. The injection tube was installed in the lowest lace of the parable of the prestress with the mouthing into the lower bridge surface. The prestressing anchors "19C15" are left freely in end pockets.

4. Conclusion

At the moment of submission of the article the bridge has been fully completed and handed over for use yet and its condition is clear from the following fig. 12.

Figure 7. Footbridge in Příbor before completion

The assembly of the handrail with integrated lighting and installation of bridge closures were completed on the footbridge. Finishing works are underway on the substructure, together with execution of the remaining backfills, ramps and pathways. Verification of the state with both statical and dynamical load tests is to be carried out simultaneously. Its existing results confirm the design presumptions. The implementation of the footbridge confirms the UHPFRC capabilities of creating unique aesthetically interesting structures. All members of the implementation team, i.e. staff members of the Klokner Institute of the Czech Technical University in Prague, KŠ PREFA s.r.o. and Novák & Partner s.r.o., are satisfied with the bridge which was opened to use in November 2018.

5. Implementation team

Architectonic design: Petr Tej, Marek Blank
Construction design: Jan Mourek, Petr Tej, Jan Marek, Lukáš Vráblík
Structural stress and dynamical designs: Lukáš Vráblík
Material design: Jiří Kolísko, David Čítek
Bearing tructure production: KŠ Prefa, Prefa Štětí

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