UHPC panels utilized as permanent formwork of in-situ cast reinforced concrete deck bridges

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Abstract. UHPC has a number of unique properties, which stands over conventional concrete. The demand for these high performance properties predetermines some elements as typical representatives for the use of UHPC. For this reason, the range of use of UHPC elements is very wide. This article deals with the numerical design and assessment of the three variants of UHPC slabs forming permanent formwork of reinforced concrete bridge deck of the footbridge. Utilisation of outstanding properties of UHPC in this special case would enable unique and easier way of construction of this bridge.

1. Introduction
The footbridge in Týnec nad Sázavou allows multilevel transfer of pedestrian routes, respectively cyclists across the river Sazava and Jawa factory yard. The walkway leading from the railway station Týnec nad Sázavou along the concrete mix plant Eurobeton CZ, Ltd. is directly connected to this footbridge at one side and on the other side, the bridge is ended with a staircase, which begins at the walkway leading along the road III / 1068 from Týnec nad Sázavou to Kostelec. The barrier is the Sázava river of approximately 58 m width and a Jawa factory yard. The footbridge has a 3.0 m total free width.

The footbridge has four spans. In the outer spans, the supporting structure is a truss system without vertical struts with an upper deck with height of 1.75 m and a composite slab at the level of the top flange on which will be mounted the railing on the outer sides. In central fields (above the river) forms the supporting structure of the bridge also a truss system without vertical struts. This two-storey construction has a height of 3.2 m. Such solution enables the movement of pedestrians on upper level and then at the bottom are conducted all utilities. The height of the main beam is designed so that the upper edge of the upper flange also served as a handrail (Fig. 1).

The lightweight construction is made of rolled tubes and profiles. These longitudinal bearing trusses are after mounting at place connected by steel rolled I profiles, on which are placed the permanent formwork panels of UHPC for concreting of the coupling deck slabs. This article discusses the numerical design and assessment of the three variants of UHPC slabs forming permanent formwork of reinforced concrete bridge deck, which could be used for other bridge structures of similar type and arrangement.

The distance of flange of the steel beams was 2000 mm. The thickness of concrete slab was designed 150mm. For these reasons it was not possible to use conventional permanent formwork of Cetris boards, because even at the largest 40 mm thickness is the bearing capacity not sufficient. Moreover, there would be a significant weakening of reinforced concrete slabs or the Cetris board would have to be hanged beneath the flanges of the beams. Another option was to use concrete filigree. Elements should however have large thickness - min. 80 mm in the longitudinal direction and...
could not be counted into the thickness of the structure. The remaining option was to use complicated conventional formwork.

For these reasons it was examined the possibility to use a thin-walled ribbed slab of permanent formwork made of UHPC; while the slab thickness is only 20 mm. Its shape was designed based on the requirement of flat lower surface of slab with regard to aesthetics of the design, maintaining cover of the reinforcement of coupling slab and the thickness of coupling bridge deck slab. By the proper design of the shape is possible to include the ribs of the slab of permanent formwork in the stiffness of coupling slab and the supporting structure as a whole in both directions, so the slab height above the surface of the flanges of steel beams is calculated as a whole.

Permanent formwork made of UHPC uses a large tensile flexural strength, which is about 15 MPa, the tension zone is the whole width of the board. The stressed areas represent upper fibers of ribs where it is utilized the high strength of the material in a pressure which exceeds 150 MPa. UHPC provides a high degree of protection of the reinforcement, which is placed on the ribs of the slab, and secures 60 mm cover. Because of the span of the slab is the deflection from the load of several mm insignificant.

Slabs of UHPC will better withstand condensed humidity and deicing agents from passage of vehicles than the conventional concrete monolithic slab. The elements are not too complicated in terms of production. The board is due to its weight ~ 140 kg easily transportable and mountable. Placing on the flange of the beam was ensured by flexible band.
2. Numerical analysis
Numerical analysis of UHPC panels was conducted in a non-linear 3D software Atena Engineering. Desk slab was modeled by slab macroelement, reinforcing ribs and the linear support were modeled using standard macroelements. Plan dimensions of slab macroelement were according to the panel variants 1850/775 mm and 1850/1550 mm with 20 mm thickness. The ribs along the perimeter of the slab have 40 mm thickness and according to variations of the panel 96, 54 and 48 mm wide. The inner lateral side of peripheral front ribs of the slab was beveled in addition, so that the width of the ribs were 75 to 115 mm. The ribs in the surface of the panel, perpendicular to the span of the panel were 20 mm high and wide according to variations of the panel 50 and 88 mm.

For all macroelements was generated by ATENA program the material model based on UHPC cube strength of 130 MPa. The model was loaded by its self weight and surface load of 1 kN / m² at each step. Support of the model was implemented via standard macro elements of flexible material 3D Elastic from the catalog of Atena program. The model was through these macroelements supported as a simple beam - that is simply supported with the removal of all three shift options on one side and two shift options on the other side. Slab was meshed by quadratic model bricks of size 0.2 m and ribs of the model were meshed by linear finite elements with the size of 0.04 m. The model was loaded by its self weight in five steps with a coefficient of 0.2 and then in the subsequent steps of 1 kN / m² to failure.

![Numerical models of UHPC panels with finite element mesh](image)
Figure 4. Deflection and cracks of UHPC panel – I. variant – max. value of deflection 4,2 mm, max. crack width 0,1 mm

Figure 5. Deflection and cracks of UHPC panel – II. variant – max. value of deflection 3,68 mm, max. crack width 0,084 mm

Figure 6. Deflection and cracks of UHPC panel – III. variant – max. value of deflection 4,4 mm, max. crack width 0,125 mm
3. Conclusion
For the bridge in Týnec nad Sázavou, lost formwork from UHPC boards was proposed in several variants. Variants of formwork boards with perimeter frames, which are shaped to touch the steel structure of the bridge, have been considered.

Panels of I and II. variants fail at typical load 10 respectively 8 kN / m² (+ dead weight). The deflections and width of cracks of these variants of panels just prior to failure are shown in Figures 4 and 5. Further, an assessment was made on the ultimate (resistance) and the serviceability limit state (deflection and crack width) of panel III. variant. This panel is best suited to be used because of its smaller self weight. The aim of the numerical analysis was to determine the deformation and width of cracks that occur during loading of UHPC panel by layer of fresh concrete of 150 mm thickness. The panel will securely transmit its self weight of + 9 kN / m² characteristic load. When analyzing the first limit state, the panel failed to design loads of self load + 7kn / m² design load. Since the load of fresh concrete layer causes a characteristic load of 0.15 * 26 = 3.9 kN / m² and a design load 0.15 * 26 * 1.35 = 5.265 kN / m² it can be stated that the panel when analyzing both limit states complied.

Designing a lost formwork for the bridge in Týnec nad Sázavou is advantageous in terms of saving the construction height of the bridge board. Lost formwork will be statically coupled to the monolithic bonded board due to the peripheral and central ribs of the panel structure. The resulting panel shape is also manually manipulable by optimizing its weight.

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