UHPC IN CZECHIA – RESEARCH AND APPLICATIONS

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

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Ultra-high-performance concrete (UHPC) is in this paper always considered as a cement composite material made of local constituents and reinforced with high strength steel fibres. Extensive research was carried out in order to understand its behaviour under different loading conditions. Successful tests enabled its application in various structures. Footbridges are structures where UHPC can be successfully applied. The next step of research works was focused on rehabilitation of existing concrete structures. Promising research results led to rehabilitation of a large bridge in Prague using UHPC. The Technical specifications prepared by the Czech Concrete Society will be soon approved by the Ministry of Transport. Then the new applications for Highway and Railway administrations are expected.

Keywords: Bridge, concrete, durability, experiment, research, structural performance, UHPC (Ultra-High-Performance Concrete)

1. INTRODUCTION

UHPC (ultra-high-performance concrete) is an excellent material which was developed in 90^{th} of the last century. Its extraordinary properties like high compression and tensile strengths and resistance to environmental impact are now well known and provide field for its application in new structures as well as in rehabilitation of existing structures. In this paper, the term UHPC is used exclusively for material which is made of concrete matrix and high strength fibres (although some authors call this material UHPFRC – Ultra-High-Performance Fibre Reinforced Concrete).

The development of UHPC in Czechia started about 2010. At that time, precasting plant of the company Skanska started to produce small slabs applicable as a lost formwork for bridge decks. At the ready-mixed concrete producer TBG Metrostav, s.r.o., the extensive research was begun with the aim to produce UHPC from local materials applicable not only for precast elements but also for cast in situ structures. First the composition of the mortar was developed, further experiments were focused on concrete composition. Beside classical material tests (like compression strength, flexural strength, elastic modulus), additional properties were investigated. Early shrinkage development (autogenous shrinkage in particular) is very important for production of elements and their demoulding. The mould often prevents free deformation of elements. The restrained deformation in early stages can be a reason for initial cracking of structural elements. Attention was paid also to the bond between UHPC and mild and prestressed reinforcement. Further research was focused performance of structural details like joints and composite steel concrete elements (Vitek, Citek, 2016), (Vitek, Citek, 2017).

During the time the research results appeared as promising and possible applications were found. The paper will illustrate some experiments in the laboratory, and on sites, and finally, some applications in structures are described. Initially the compression strength of 150 MPa and higher was considered as a minimum for UHPC. During last years, it was concluded that the compression strength is not the most important parameter. The tensile strength, ductility and preferably the durability was considered as more important in dependence on the applications. Now a suitable material with the compression strength 110 MPa and higher can be considered as UHPC, if its properties satisfy specific conditions. In Czechia, the Technical specifications of UHPC were developed in the Czech Concrete Society. They will be soon approved by the Ministry of Transport, which will provide a possibility for application of UHPC in structures of the transport infrastructure.

2. EXAMPLES OF LABORATORY AND SITE EXPERIMENTS

2.1 Bond of reinforcing steel and UHPC

Bond of reinforcing steel and UHPC is very important. It was expected that the bond could be rather good. However, a verification and quantification were necessary. The bond was tested using a simple pull-out test. The mean bond stress τ_m was calculated from the loading force very simply using Eq.1

$$\tau_m = \frac{P_m}{a\,o} \tag{1}$$

where P_m is the pulling force, a is the anchorage length and o is the perimeter of the reinforcing bar. In the first series of tests, different diameters of reinforcing bars were used, while the anchorage length remained constant (5 diameters of the bars). The bars were embedded in UHPC and in ordinary concrete of the class C30/37. The tests of specimens made of ordinary concrete finished by failure of bond, while the tests of specimens made of UHPC finished by failure of steel. The bond of steel and UHPC was higher than the strength of the bars (*Fig. 1*). The second series used only one diameter

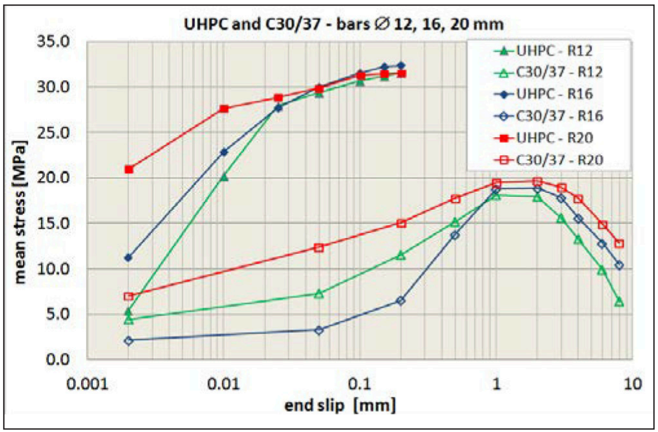

Fig. 1: Pull-out tests. Mean bond stress – comparison of specimens made of UHPC and C30/37

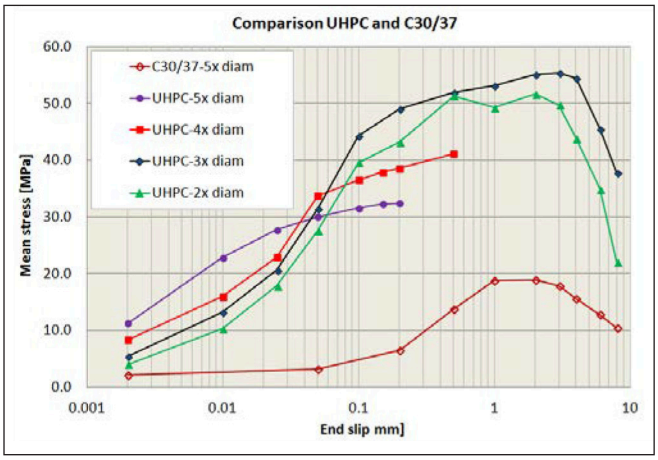

Fig. 2: Pull out tests. Mean bond stress – comparison of different anchorage lengths

of the steel bar and the anchorage lengths varied from 2 to 5 diameters of the bar. The results are plotted in *Fig. 2*. The anchorage lengths 5 and 4 diameters were sufficient and the failure was in steel bar. The anchorage lengths 2 and 3 diameters resulted in failure of bond. The extensive experimental study on bond resulted in recommendation that the minimum anchorage length in UHPC is 10 diameters and for dynamically loaded elements it should be increased to 15 diameters.

2.2 Joints of precast elements

UHPC is an expensive material. It should be used for those parts of structures, where its properties are really needed. The joints of precast elements can be one of the areas of its application. Precast elements are usually members exhibiting very good quality. On site they are connected into the final structure. The joints used to be the weakest points of a precast structure. Application of UHPC can be a possibility of improvements of the joints. First, the quality of UHPC is superior, it is a suitable material for joints, second, a small anchorage length of reinforcing bars makes it possible to reduce the dimensions of joints in comparison with a classical solution where the joints are filled with ordinary concrete.

The slabs with joints were tested. The two joint reinforcements were tested in slabs of the span of 2.5 m. Type R (*Fig. 3*) had a simple overlap of the bars in the joint. The anchorage length of bars was 170 mm, overlap length 140 mm (=10 profile of the bar). Type S *(Fig. 3)* had bent bars in the joint. The bents from each side were overlapped. The slabs were subjected to 3-point bending test. The results were compared with those measured on reference slabs without

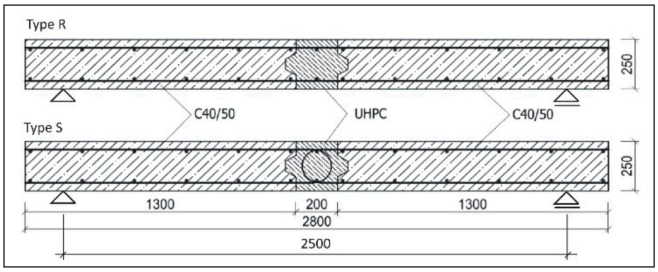

Fig. 3: Longitudinal sections of the slabs with joints

any joint. The results were almost identical, no difference in load carrying capacity was observed. All slabs cracked; no cracks were observed in the joint. The cracks were either on the contact of UHPC and ordinary concrete or in ordinary concrete. The slabs with the type R reinforcement had slightly higher load carrying capacity than those with reinforcement of the type S. It was possible to conclude that the joint made with UHPC has no effect on load carrying capacity of the slab. The long-term tests even with shorter overlap lengths confirmed the same results. However, overlap length of 12 profiles for elements with static loading and 18 profiles for elements with dynamic loading were recommended as a conservative measure.

2.3 Joints of precast elements in steel-concrete composite slab

Steel-concrete composite slabs are often used in bridges as well as in buildings. It is convenient to use precast slabs and which can be connected using UHPC over the steel beams. The most unfavourable situation can be close to the support, where the joint is subjected to tension in the longitudinal and also in the transversal directions. The models were produced in the laboratory and tested. The 2 models were produced – without the joint and with the joint. In the longitudinal section the cantilever was loaded with 2 point loads acting on the edges of the slab. The length of the cantilever was 2.2 m. The standard rolled steel IPE beam of the depth 400 mm was connected to the slab 800 mm wide and 150 mm thick. The cross-sections of the reference beam and of the beam with the UHPC joint are plotted in *Fig. 4*.

The arrangement of the test is illustrated in *Fig. 5*. The results showed that the behaviour of the beams with the UHPC joint were slightly stiffer than that of reference beams at larger load levels. The failure load was rather similar. The tests proved that the joint has no effect on reduction of the load carrying capacity or stiffness and it can be used in bridges and buildings as a reasonable method for connecting precast elements.

2.3 Tests on structural elements

Many tests were executed on elements which were parts of actual structures (Vitek, Coufal 2013). The deck of the

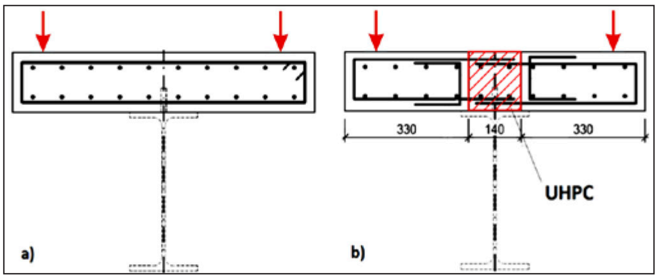

Fig. 4: Cross-section of the reference beam (a) and of the beam with the joint (b)

Fig. 5: Steel concrete composite beam with the UHPC joint of the precast slab – scheme of the test

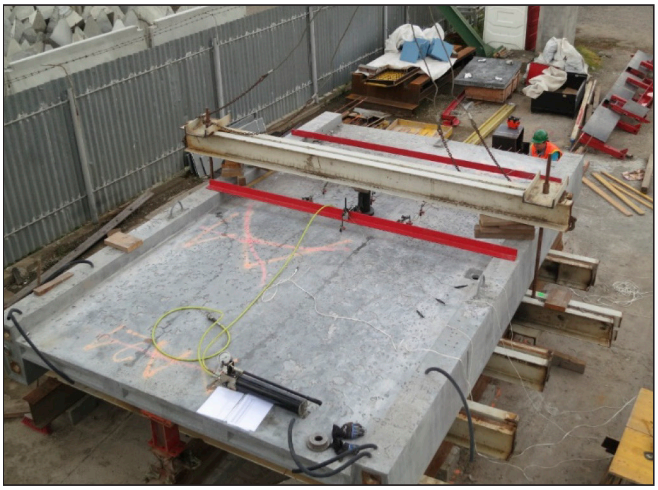

Fig. 8: Punching test of the slab of the segment – test arrangement

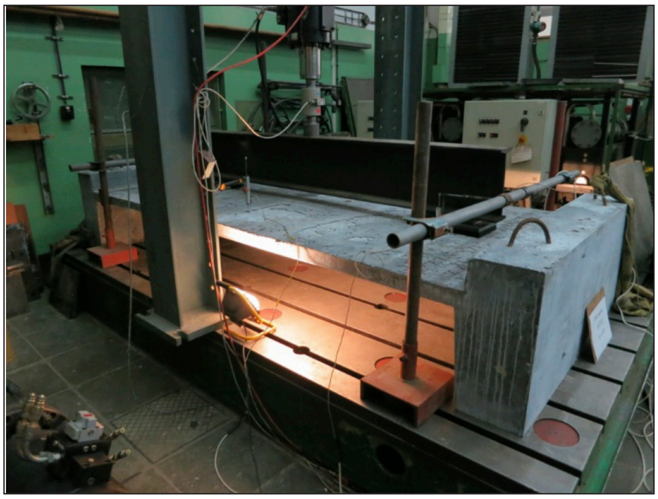

Fig. 6: Model of the footbridge segment loaded by 2 point loads representing an axle load of the light vehicle

Fig. 9: Punching test of the slab of the segment – failure cone

footbridge had a slab only 60 mm thick without any bar reinforcement, only with fibres. The safety verification involved also testing of the slab in transversal bending and in punching. The cross-section of the footbridge had two edge beams *(see Fig. 12)* connected with a 60 mm thick slab and transversal ribs. The ribs were reinforced with 2 bars 16 mm in diameter and they were 160 mm deep at the ends.

The footbridge was designed primarily for pedestrians and cyclist. The vehicle of the rescue system also were able to drive along the footbridge. It represented the highest local load acting on the bridge deck. The weight of this small vehicle was 3.5 t. The back axle was loaded by 25 kN. A model of the footbridge segment in the scale 1:1 was cast. Its length was only 1.5 m, while the width of the model was 3.5 m. The model was initially loaded by 2 point loads, each of 12.5 kN, which represented the axle load (*Fig. 6*).

When the total load reached about 80 kN and no cracks appeared, the loading scheme was changed to 1 point load in the middle of the width of the segment. The model failed in transversal direction (the transversal ribs failed in bending) at the loading level of 110 kN (*Fig. 7*), which is more than 3 times the total weight of the vehicle. The slab of the segment remained without significant damage, with exception of few cracks.

The load carrying capacity of the slab in punching was tested on the entire footbridge segment (3.5 m wide and 5.6 m long). The segment was loaded by a single point load in different positions The point load was acting on the circular area of 200 mm in diameter. The test arrangement is illustrated in *Fig. 8*. The load was slowly increased and the

Fig. 7: Failure of the model in transversal bending

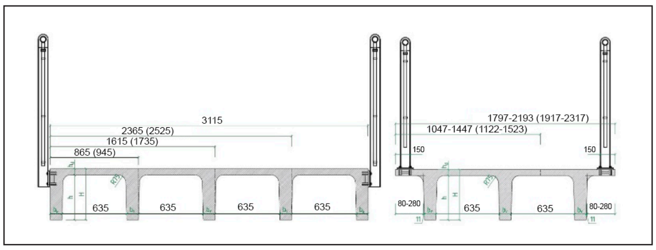

Fig. 10: Cross-sections of small footbridges made of UHPC

Fig. 11: Loading test of a pretensioned beam

failure load in punching was in the range of 320 to 370 kN, in dependence on its position, which is about 10 times the weight of the vehicle. The flat failure cone is shown in *Fig. 9*.

The load carrying capacity of the slab in punching is very large. However, in spite of this result, it was not recommended for future structures to reduce the thickness of load carrying slabs without bar reinforcement. The load carrying capacity significantly drops down if the thickness is reduced. Additionally, it is strongly dependent on the distribution and orientation of fibres. If the thickness is reduced, a thorough testing is recommended.

Light footbridges with small spans can be made of UHPC. The entire footbridge can be cast as one element in a precasting plant. A pretensioning technology is suitable, UHPC provides excellent protection of prestressed strands and no ducts and grouting are necessary. The weight of footbridges is small, the transport and the assembly with the crane are rather easy. Typical cross-sections of footbridges applicable for the span length up to 12 m are shown in *Fig. 10*.

Before the production of the footbridges started, the model was tested. *Fig. 11* shows a very large deflection of a pretensioned beam. The crack width remained moderate, because of fibres in UHPC and because of the bonded pretensioned reinforcement.

3. STRUCTURES MADE OF UHPC

UHPC was used preferably for smaller precast elements and for footbridges. A number of footbridges were already built, some representatives will be mentioned in this chapter.

3.1 Footbridge in Celakovice

Footbridge is Celakovice crossing the Labe River is located about 30 km east of Prague (Vitek, Kalny 2015). It was the first large footbridge with the deck made of UHPC in Czechia, completed in 2014. The footbridge for pedestrians, cyclists is a three-span cable stayed bridge. The main span is 156 m long, the side spans have the length of 43 m. The bridge deck is made of precast segments made of UHPC and the 2 pylons (37 m high) are made of steel. The free width of the footbridge between railings is 3.0 m.

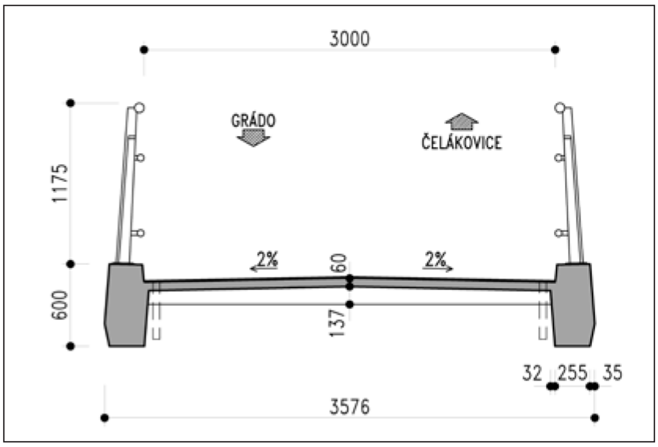

Fig. 12: Cross-section of the footbridge in Celakovice

Fig. 13: Filling of the mould by UHPC from 2 truckmixers

The cross-section of the bridge deck is plotted in *Fig. 12*. The two edge beams are 0.6 m deep and 0.3 m wide. The slab is only 60 mm thick, and it is reinforced only by fibres. There is no bar reinforcement in the slab. The slab is stiffened by transversal ribs 160 mm deep located in spacing of 1.0 m. The ribs are reinforced by 2 bars 16 mm in diameter. The edge longitudinal beams are reinforced by small longitudinal bars and stirrups. Two prestressing bars and one prestressing cable composed of 15 strands 15.7 mm in diameter are located in each of the edge beams. The bars were prestressed during construction of the bridge deck and the cables were prestressed after its completion.

The bridge deck is assembled from precast segments. This structure was the first large application of UHPC in Czechia, therefore, because of the lack of experience, a great attention was paid to casting segments. Many tests were carried out to develop a suitable technology of casting to keep the fibres uniformly distributed in segments. Because of the inclined and uneven top surface of the segment, the top cover of the formwork had to be used. Each segment of the bridge deck was 11.3 m long. In order to make the casting feasible and reliable, only a half of the segment was cast in one step (5.65 m). The steel mould was smaller and reinforcing bars were used to bridge the working joint between the two halves of the segment. The mould was filled by UHPC from two truck mixers by simple flowing of UHPC into the mould (*Fig. 13*).

After filling the mould, the mould was heated to accelerate hardening of UHPC. After about 9 hours after pouring of UHPC, the segment could be demoulded.

The segments were produced in a precasting plant close to the river, where only the space for production of segments was rented. Then most of the segments were transported by pontoons to the site. The UHPC was not produced in that precasting plant, it was transported from Prague (about 25 km). The production also verified, that the transport of UHPC in truck mixers is possible. Now the progress in concrete technology allows for the transport of distances more than 100 km long. The segments were match-cast. During the assembly of the deck, the joints were glued by

Fig. 14: Assembly of the segments in the main span

Fig. 15: Completed footbridge in Celakovice (2014)

epoxy resin and prestressed with 2 prestressing bars in each edge beam. The assembly is illustrated in *Fig. 14.*

A special gantry for assembly of the segments was developed. Because of lifting the segments from pontoons, the gantry was located above the bridge deck.

After assembly of all segments the two cables were prestressed and all ducts were grouted. All prestressed units are bonded and protected by grouting using a cement grout. Additional protection against water is a sprayed waterproofing which is continuous along the entire length of the footbridge. A completed footbridge can be seen in *Fig. 15*.

3.2 Footbridge in Luzec

A similar cable stayed footbridge was built some years later in Luzec crossing the Vltava River north of Prague (Tej, Vrablik 2022a). The footbridge is slightly smaller. The footbridge has two spans and only 1 pylon. The main span crossing the

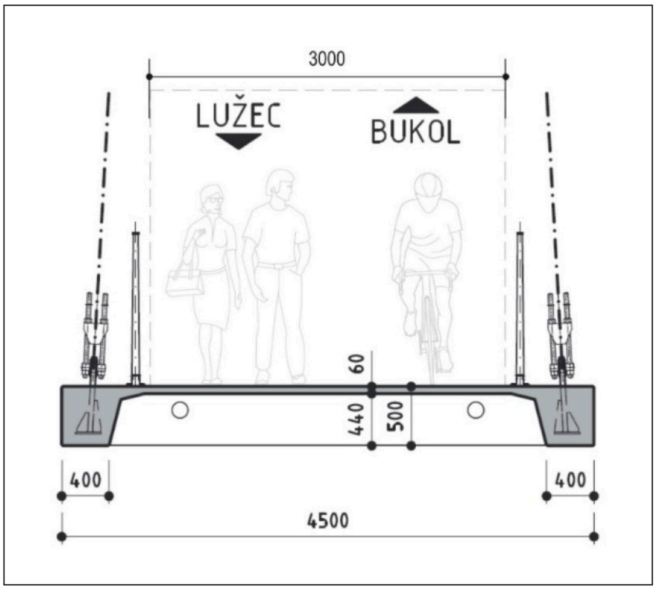

Fig. 16: Cross-section of the footbridge in Luzec

Fig. 17: Assembly of segments of the footbridge in Luzec

river is 99 m long, and the side span is 32 m long. The pylon is almost 40 m high. The bridge deck is made of segments produced of UHPC and the pylon is made of steel.

The contractor simplified the production of segments significantly. The cross-section of segments is plotted in Fig. 16. The top surface is flat which made it possible to use a simple mould without a top cover. The transversal slope is achieved by slight inclination of the entire segment. The joints of segments were not match-cast but cast in situ. So called wet joints were used. The joints of the thickness of about 25 mm were filled with a special high strength mortar. The surface is not protected by additional layer, it is directly exposed to the traffic.

The segments 4 m long were assembled by a large crane. The crane put the segments on the gantry which was located under the bridge deck (*Fig. 17*). The two segments were assembled, the joints were filled and after hardening of the joints, the two bars were prestressed. After completion of the deck, two external cables composed of 19 strands 15.7 mm in diameter were prestressed. The cables are protected against corrosion using the HDPE duct grouted by cement mortar. The cables are not hidden inside the deck, regular inspections are possible. A completed footbridge is shown in *Fig. 18*.

Fig. 18: Completed footbridge in Luzec (2020)

3.3 Comparison of the two cable stayed footbridges

Both footbridges are cable stayed and both have a bridge deck made of UHPC and pylons made of steel. The difference is mainly in joints and in prestressing. The match cast segments of the footbridge in Celakovice are connected using dry joints glued with epoxy resin. The joints of the footbridge in Luzec are wet joints. Prestressing of the Celakovice footbridge is bonded inside the cross-section. Prestressing of the footbridge in Luzec is external outside the cross-section. The protection of prestressing steel against corrosion is in both cases satisfactory and complying with the requirements on the long-term durability. The footbridges show that both alternatives of joints and prestressing are applicable. The construction of the Luzec footbridge was slightly simpler. The Luzec footbridge was completed in 2020 and it was possible to observe, that the experience from earlier built UHPC structures was used.

3.4 Footbridge in Pribor

Footbridge in Pribor (northern Moravia) is a simply supported beam made of UHPC (Tej, Vrablik, 2022b). It is a post-tensioned structure assembled of 5 segments of the length 7.2 m. The span of the beam is 35 m and the width is only 2.5 m. The cross-section is a rectangular box girder with 3 webs (*Fig. 19*). The depth of the cross-section is very low – only 0.8 m.

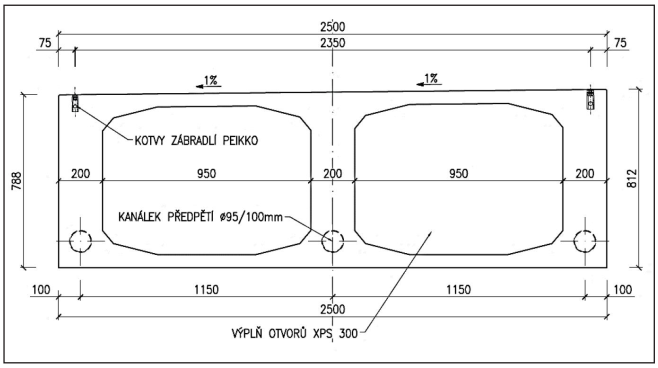

Fig. 19: Cross-section of the footbridge in Pribor

The longitudinal prestressing is composed of 3 cables 17 ∅15.7 mm. In order to guarantee the long-term durability, the monostrands were used, which are additionally grouted in ducts. In the joints, special connectors of ducts are used, which improve their tightness.

The segments were cast in a steel mould. Although the segments were not match-cast, the dry joints glued by epoxy resin were used. The segments were assembled on the fixed scaffolding, the joints were glued and the footbridge was prestressed.

The surface is directly exposed to traffic and no protection of the top surface used. A completed footbridge is shown in *Fig. 20*.

Fig. 20: Completed footbridge in Pribor (2019)

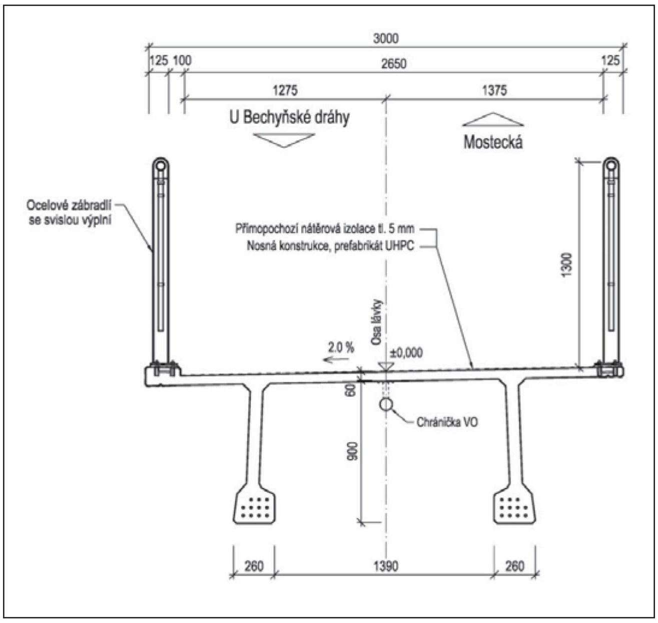

Fig. 21: Cross-section of the footbridge in Tabor

Fig. 22: Completed footbridge in Tabor (2018)

3.5 Footbridge in Tabor

Tabor is a regional city about 90 km south of Prague. The footbridge is a simply supported beam made of UHPC (Komanec, Kalny, 2022). The span of the 3 m wide footbridge is 27 m long. The beam is pre-tensioned. It was cast in a precasting plant in one step without any working joints. The cross-section is plotted in *Fig. 21*.

The cross-section of the double T shape is prestressed by 11 strands (profile 15.7 mm) in each web. The thickness of the top slab is only 60 mm and the depth of the cross-section is 960 mm.

The footbridge was transported to the site and assembled using two cranes within 2 hours. No temporary structures were used for assembly. The top surface is protected by sprayed waterproofing which also provides anti-sliding surface. A completed footbridge is illustrated in *Fig. 22*.

3.6 Comparison of the two simply supported footbridges

The footbridge in Pribor and the footbridge in Tabor have similar spans (35 and 27 m). The Tabor footbridge is shorter but wider. Their areas are not too different (Pribor 90 m^2 and Tabor 82.5 m^2). When looking at the cross-sections (*Figs. 19 and 21*), a significant difference can be seen. The footbridge in Pribor has the very thick cross-section (3 webs, each 200 mm thick – *Fig. 19*), while the cross-section of the footbridge in Tabor is rather thin-walled (*Fig. 21*). A material consumption shows even more different figures. Consumption of UHPC and of prestressing steel: Pribor 0.39 m^3/m^2 and 24 kg/m^2, Tabor 0.14 m^3/m^2 and 8,65 kg/m^2. The durability of the footbridge in Pribor required application of monostrands grouted in ducts with special sealing elements in joints. This is rather expensive solution which still has a risk of incorrect function. The pretensioning, which is used at the footbridge in Tabor is a cheapest possible solution without any difficulties and easy to execute. The UHPC provides very good protection of strands because of fibres and practically total elimination of cracks.

A construction process also exhibits significant differences. While the footbridge in Pribor required a fixed scaffolding, assembly of segments with adjustments, gluing of joints and finally post-tensioning and grouting, the assembly of the footbridge in Tabor was easy, made in two hours using standard cranes.

It is necessary to learn from such experience. It is important to decide already in the initial stage of the design on the structural system and on the materials taking the construction process into consideration. The section of the Pribor footbridge could have been designed from any concrete, no UHPC was necessary. Only by this change a significant savings could have been achieved. The footbridge in Pribor could have been made also as a pretensioned lightweight structures without joints. The span of 35 m would allow for the assembly of one beam. On the other hand, the footbridge in Tabor is a nice example of a structure, where the design, material choice and construction are in mutual balance resulting in efficient and also sustainable structure.

Fig. 24: Typical segment of the footbridge in Prague (2023)

Fig. 25: A completed footbridge in Prague (2023)

3.7 Footbridge in Hradec Kralove

Hradec Kralove is a city about 100 km east of Prague. The footbridge is crossing the Labe River close to the city centre. An original design of the suspension footbridge combines steel structure with a concrete deck. The deck is made of segments made of UHPC. The footbridge has 2 spans 69 and 33 m long. They are supported by 2 suspension ropes which support the bridge deck by means of slender steel frames (*Fig. 23*).

Although the structural system is rather complex and the construction of the footbridge was not easy, this example shows a suitable application of UHPC. A thin bridge deck is light and it is directly exposed to traffic. The quality of UHPC can guarantee a long-term durability of the bridge deck.

Fig. 23: Completed footbridge in Hradec Kralove (2022)

3.5 Footbridge in Prague

This year (2023), a new footbridge made of UHPC was opened in Prague. It connects two parts of the city and the island Stvanice in the Vltava River. It is a rather long continuous parapet girder made of white UHPC. The longest spans are 55 m long. A white colour was required by the architect. In the Czech conditions, there is only one white cement available. Rapid hardening and high heat of hydration of the cement are the properties, which made the execution difficult. The footbridge is made of large U – shape segments (*Fig. 24*). They are typically 5 m wide and 5.5 – 6.0 m long. The depth of the parapets is 1.85 m.

Segments were produced in the precasting plant in the opposite position. After demoulding, they were turned to the definitive position and transported to the site. On the site, the segments were put on the fixed scaffolding, the joints were glued and the bonded prestressing cables were prestressed. Some joints were wider (cast on the site) which allowed for adjustments of the footbridge geometry.

A completed footbridge is shown in *Fig. 25*. The footbridge was rather expensive. Many questions could be posed, e.g., if the design is so excellent that it is worth to invest high costs, or whether it was really necessary to use UHPC for this design. If the bridge was made of a good quality ordinary concrete, would it be so different? etc.

4. UHPC IN RECONSTRUTIONS

4.1 Experience from research

UHPC is a material with excellent properties, which makes it suitable also for applications in repair and in rehabilitation of existing structures. Extensive research was carried out in Czechia (Vitek, Bohacek, 2022). Usually, added thin layer of UHPC cast on top of the existing structural element can significantly improve its load carrying capacity or even its stiffness. The amount of added material is low, additional weight represents only a small increase of loading of existing structure and it makes the strengthening efficient.

The old concrete elements were tested in different loading situations. Experimental works showed that the interaction of added layers of UHPC with existing concrete belongs to crucial factors influencing the behaviour of the rehabilitated structure. If concrete of the existing structure is good, in most cases no connectors between existing concrete and UHPC are necessary. The bond between UHPC and concrete could be sufficient for reliable connection of individual materials. However, if the quality of existing concrete is not very good, it is highly recommended to think about the application of UHPC, if it is really the optimal way of repair, or at least to apply the connectors. In loading situations with prevailing shear loading, like punching of slabs, it is recommended to use shear connectors also if existing concrete is of a good quality.

The different approach for strengthening must be selected in buildings and in bridges. In buildings, often the floors are strengthened. The floors are usually horizontal and they are not exposed to environmental impacts. The self-compacting UHPC can be used for additional layer. In usual floors, some parts of the additional layer are subjected to compression and some to tension (assuming continuous slabs). The reinforcement of the UHPC in areas subjected to tension improves the ductility and increases the load carrying capacity. In areas close to columns, where punching is expected, the shear connectors should be installed.

In bridges, the surfaces of bridge decks are usually in slope. Special composition of UHPC is then required, so that the additional layer could be cast and flowing away was avoided. In bridges the added layer of UHPC can work also as a waterproofing. Then it is necessary to avoid cracking. High fibre content is therefore necessary. The working joints have to be executed as watertight. Additional layer of UHPC can help to increase significantly the load carrying capacity as well as the durability of the existing structure. The service life of the UHPC layer is much higher than that of any classical waterproofing layer.

4.2 Strengthening of the bridge

The Barrandov bridge in Prague is a heavily loaded bridge. Daily, more than 140 thousands vehicles drive along the bridge. The bridge has two independent superstructures completed in 1983 and in 1988. Each superstructure carries 4 lanes of traffic. Now after almost 40 years, a corrosion of prestressing cables was observed, waterproofing required repair and general maintenance of the bridge is necessary.

The bridge is about 350 m long, it has 6 spans, the length of the main span is 72 m (*Fig. 26*). The cross-section of individual bridges is composed of 3 boxes. Original prestressing is located in webs of the cross-section. The main parts of the rehabilitation cover installation of additional unbonded cables, which increase the prestressing force in the entire bridge and complete replacement of layers on the top of the bridge deck. The rehabilitation is planned to 4 seasons. Because of the heavy traffic, only 2 lanes from 8 can be temporarily closed. The works started in 2022 and continued in 2023 on the south bridge, where the works are now completed. In the next 2 years the works will continue on the northern bridge. In 2022 it was decided that UHPC could be a good alternative for strengthening of the south bridge (Vitek, Bohacek, 2023). However, there was no earlier experience with this technology. The client agreed to use the UHPC as a strengthening layer but he did not accept the risk of leakage if the UHPC was used also as a waterproofing. It was a correct decision, since no tests for waterproofing were executed in Czechia before. Now the tests are prepared and if they are successful, the UHPC could be used also as waterproofing on the northern bridge in 2024 and 2025.

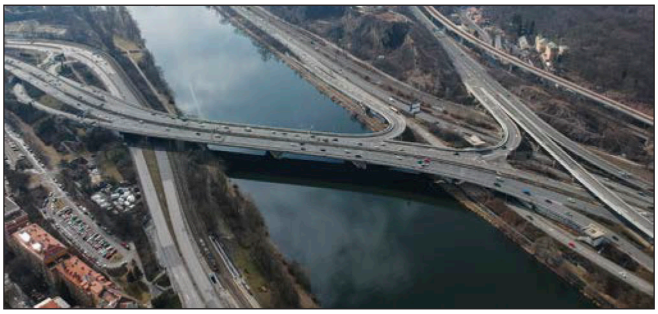

Fig. 26: View on the Barrandov bridge in Prague before reconstruction

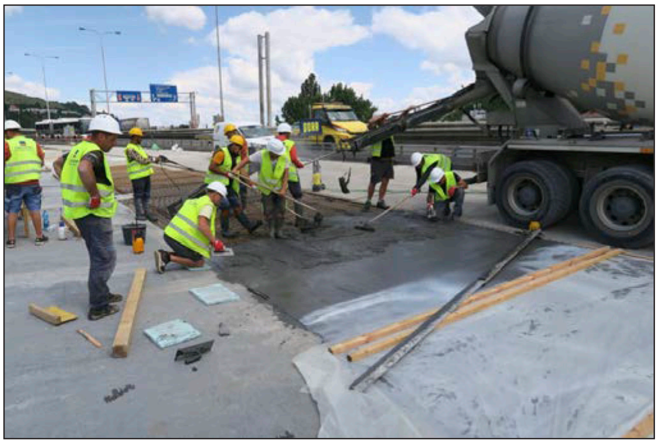

Fig. 27: Pouring of UHPC on the bridge deck and immediate curing

The UHPC for the strengthening of the bridge deck was developed on the basis of the results of the research project. The mix has a maximum aggregate size 4 mm and fibre contents of 3% of high strength fibres. The flexural strength measured on beams with the notch exceeds 20 MPa. The UHPC was transported by truck mixers to the site. During the day, the amount of 30 – 40 m^3 was delivered.

The quality of surface of the bridge deck was rather variable. The tear off tests exhibited a large scatter. The surface was treated by water jet blasting using a pressure from 2000 to 2500 bars. In some parts a combination of milling and water jet blasting was used.

The reinforcement of the additional UHPC layer was used if its thickness exceeded 40 mm. All the works were executed in summer time, when the traffic is lower due to the holiday season. High temperatures resulted in rapid drying of concrete. In the first stage of repair, the edges of the cast segments of UHPC delaminated due to drying shrinkage. In the second stage, the anchors were used at the edges (along the working joints, which resulted in avoiding the delamination.

The UHPC was poured from the truck mixer and distributed manually (*Fig. 27*). The use of finisher will require additional research and more experience.

Immediately after finishing, the surface was protected against drying by using a spray against evaporation of water and it was covered by a PE foil.

The experience for the first stage of repair in 2022 led to some improvements realized in the second stage (2023). The technology of strengthening with UHPC was successful and now preparation works are made for the 3rd stage which will be started in summer 2024.

5. CONCLUSIONS

Almost 15 years of development of UHPC in Czechia brought some promising results. Successful new footbridges were built and the works on reconstructions show a slow progress too. Czech Concrete Society produced guidelines for production, design and execution of structures made of UHPC with an annex describing principles of application of UHPC in reconstructions. The guidelines became a basis for Technical specifications of Ministry of transport on using of UHPC. It is expected that this document will open the door for application of UHPC also in large structures of the transport infrastructure.

On the other hand, UHPC is still a new material and the knowledge on its behaviour is limited. New research results are very welcome. The structures where application of UHPC is expected must be designed by experienced engineers so that the favourable properties of expensive UHPC could be used. A single wrong application of UHPC which would result in some difficulties can be a reason for stopping or slowing down of future applications for years.

UHPC is a specific material. It is expensive and it is also demanding in terms of the ecological reasons. High amount of cement means also high CO_2 emissions and apparently a material which is not very suitable for sustainable structures. However, sustainability must be evaluated on the entire structure and not only on the material which is applied. Some examples illustrated here show that the consumption of UHPC can be very small and although the cement consumption is high in the material, the cement consumption in the structure can be reasonably small and consequently such structure can be more sustainable than that made of ordinary concrete (especially if durability is considered).

UHPC is considered as an advanced material. Many unexperienced designers try to apply it under any circumstances. Incorrect use of UHPC results in structures which are expensive and finally need not be durable. The durability of the structure is given by the element with the lowest durability. In case of a bridge, the details which are sources of cracking, working joints which leak, corrosion of steel etc., can be sources of difficulties and of reduction of the durability or even the load carrying capacity, although UHPC is used.

Design of structures (or rehabilitation works) requires experienced designer who is able to evaluate all influencing factors which are in favour or against application of UHPC and who decides on optimal choice of the material. The structural design and the design of construction process are mutually interrelated with material. Only the right way of application of UHPC, where its properties are actually used can lead to future successful structures.

6. ACKNOWLEDGMENTS

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