

# **Experience with ready mixed UHPC for strengthening of concrete structures**

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## **Abstract**

This paper focuses on experience from strengthening works, done with ready mixed UHPC delivered on building sites by truck mixers.

The first part is a summary of the results from the research project. This research project was focused on the quality of the existing concrete surface and the connection between the old concrete structure and the new strengthening layer made of UHPC.

The main part of the paper focuses on two projects in which UHPC was used for strengthening and where the results from the research project were used. For UHPC quality control on the second project the new guidelines TP ČBS 07 were used. These guidelines, made and published by the Czech Concrete Society, have been valid in the Czech Republic since 2022.

The first project is a small bridge reconstruction in Meziboří, where UHPC was used for strengthening of the bridge abutments. The ready mixed UHPC was transported from a concrete plant over a distance of nearly 110 km (68 mi), but especially for small project like this (11 m<sup>3</sup> (14 cu yd)) it is a very effective solution.

The second project is the strengthening of the bridge deck of Barrandov bridge in Prague. For this project about 400 m<sup>3</sup> (523 cu yd) of ready mixed UHPC was used, transported by truck mixers from a concrete plant over a distance of nearly 14 km (8 mi).

**Keywords:** ready-mixed UHPC, overlay, strengthening, bond, reconstruction

## **1 Introduction**

UHPC is a modern cementitious material with very high compressive and tensile strength. One of its biggest advantages is its extreme durability. On the other hand its price, which is also very high, means we have to think carefully about how to use this material.

The main areas of use of UHPC are new bridge superstructures, cladding elements, precast elements' joints and strengthening of old structures. This article focuses on strengthening, where we can save very large old structures with very low amounts of UHPC.

Reconstructions and strengthening of existing structures with UHPC represent a large area of interest [1]. UHPC is a material which exhibits an excellent bond to the existing concrete. It is a very good property which simplifies application of UHPC as a strengthening layer. If the quality of an existing concrete structure is reasonably good and its surface is treated well, shear connectors need not be required in a reasonable number of practical applications. If the shear connectors are not required, a significant cost saving and also acceleration of construction can be achieved.

The high strength of UHPC makes the strengthening efficient also in cases when only a thin layer of UHPC is applied. Application of a thin layer of additional UHPC means a small increase of dead load which makes the strengthening even more efficient. Even a thin layer not only strengthens the structure, but also protects the old structure against exposure to water and chlorides. Fibre content is very important. When fibre content is higher it can greatly reduce the crack width, which is crucial for protecting substrate structures against water and chlorides leakage. Therefore, it is recommended to use a minimum of 3% fibre content in UHPC for overlay structures.

This article focuses on the use of ready-mixed UHPC, transported to a building site by truck mixer, instead of using dry UHPC, mixed on the building site.

### **1.1 Technical guidelines of the Czech Concrete Society**

The guidelines for application of UHPC in building practice have been developed in many countries. The international guidelines are still not available, however, it is expected that some information will become a part of the new *fib* Model Code 2020. The Czech Concrete Society developed its own guidelines [2] to support the application of UHPC in the Czech Republic. The document is now published in Czech, but due to the interest of foreign experts there is an intention to translate it to English. The document is based on the recommendations and codes developed primarily in Germany, France, and Switzerland regarding the experience with earlier UHPC applications in the Czech Republic. The guidelines are divided into 3 basic parts;

1. Production of UHPC and quality control
2. Design of new structures
3. Execution of structures made of UHPC.

The rules are compatible with European codes. The fourth part dealing with strengthening of existing structures is supplemented as an annex, since it follows the general rules and supplementary specific rules dealing with the interaction of the existing structure and the part made of UHPC.

## **2 Bridge reconstruction in Meziboří**

### **2.1 Bridge description**

In 2021 a small bridge for local transport over Wild Stream was reconstructed. The bridge is located in the town of Meziboří in western Czech Republic. The span of the bridge is only 2 m (6.5 ft). During reconstruction the superstructure of the bridge was replaced and the substructure was strengthened by UHPC.

The main reason for this solution was to minimize demolition and excavation works in the surrounding urban area and decrease the amount of waste. The primary goal was to minimize environmental impact as well as to decrease duration and cost of the reconstruction. For strengthening of the substructure, a new method of ribbed vertical layer of UHPC was used. It was a very small bridge in this case, but this method could be used for any size of bridge.

The quality of the substructure concrete was very poor and its function in the reconstructed bridge is just as filling material and load is transmitted solely by the UHPC ribbed layer.

A surface layer of 75 mm (2.95 in) of old concrete was removed from the old substructure and vertical ribs were created. Ribs were 100 – 110 mm (3.94 – 4.33) wide and were cut approximately to the depth of 225 mm (8,86 in) into the old concrete, so as to be 300 mm (11.81 in) in total depth (75+225 mm). In the bottom and upper parts, ribs are widened. In the horizontal frame corner, where the wing wall is fixed to the abutment, thickness of the layer is increased to 150 mm (5,9 in). On the upper edge of the UHPC there is a 300 mm (11.8 in) wide horizontal reinforcing rib and in the rear part of wing walls is a transverse rod to connect their ends and to decrease loading. A strengthening layer is done with UHPC 130/140 (in accordance with current guidelines C130) with 2% of microfibers. This layer is also reinforced with steel reinforcement, but distribution bars are substituted by microfibers in UHPC. The UHPC layer is anchored to the old concrete by steel bars.

The new superstructure of the bridge is made with ordinary concrete and is not a subject of this paper.

### **2.2 UHPC application in Meziboří bridge**

For this project UHPC was designed with characteristic cylinder compressive strength C130 (130 MPa, 18855 psi). Volume of steel microfibers was 2% and minimal strength in tension  $f_{R1}$  in accordance with ČSN EN 14651 was specified to 15 MPa (2175 psi).

Consistency was self-compacting, with no need for vibration during casting. UHPC was mixed on a typical concrete plant of TBG Metrostav company and was transported by truck mixers. Distance from the concrete plant to the construction site was 110 km (68 mi). The workability had to be at least 6 hours due to of long transport and slow casting by concrete basket. In total 11 m<sup>3</sup> (14 cu yd) of UHPC was delivered for this project.

The test results are presented in table 1. UHPC with two types of microfibers were delivered. The first type was waved fibers in diameter 0.3 mm (0.0118 in) and the second narrow fibers in diameter 0.2 (0.0079 in). Comparisons of UHPCs with these two fibers are made in Table 1 and Graph 1.

**Table 1** Mechanical parameters of UHPC used

			Fibers in diameter 0,3 mm - 2 %	Fibers in diameter 0,2 mm - 2 %
Strength in compression	Cube 100 mm	[MPa]	148,6	149,0
Strength in compression	Cylinder 200 mm	[MPa]	143,8	146,7
Strength in tension during bending	Beam 700 mm	[MPa]	20,0	21,2
Modulus of elasticity	Cylinder 300 mm	[GPa]	44,2	44,6

100 mm = 3.937 in, 1 MPa = 145 psi

Graph 1 – Influence of fiber type on strength in tension UHPC during bending in accordance with ČSN EN 14651

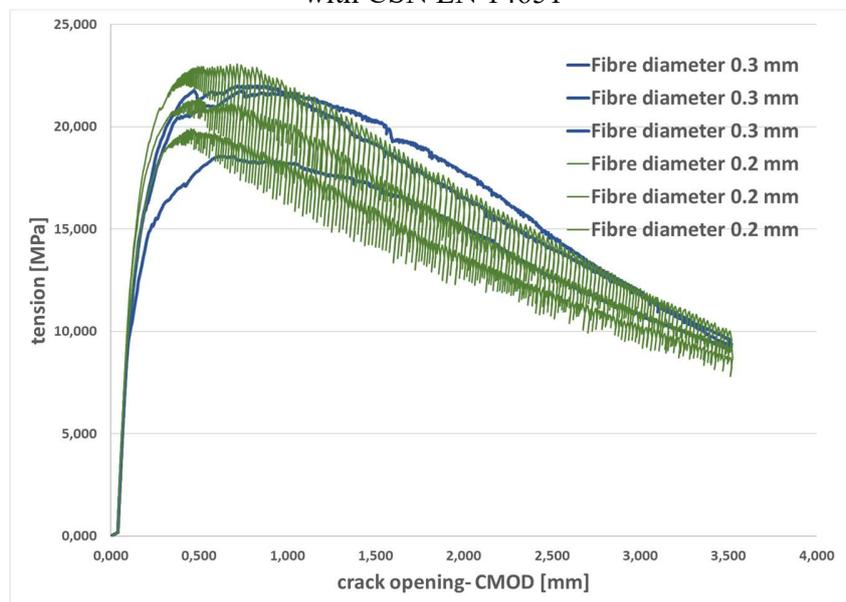


Fig. 1 UHPC casting

### 2.3 Results of Meziboří bridge strengthening

The use of UHPC for a slim vertical strengthening layer was successfully confirmed on the Meziboří bridge. Thanks to the chosen technology it was possible to significantly reduce the amount of demolition and excavation works in the surrounding urban area and decrease the amount of waste. The amount of material used was also decreased.

The possibility of transporting UHPC by truck mixers from a concrete plant over a very long distance was also proven. It is not necessary to mix UHPC on a construction site from dry mixes.

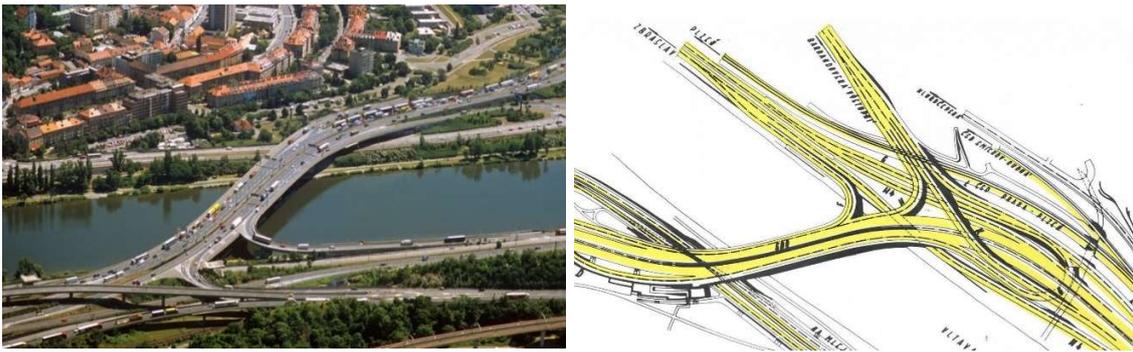
### 3 Strengthening of the bridge deck of Barrandov Bridge in Prague

In the year 2022 reconstruction of the most used bridge in The Czech Republic was commenced. More than 140 000 cars use Barrandov Bridge daily. The bridge was opened in 1983, when its southern part was finished, in 1988 the northern part was completed. The condition of the bridge decreased during 40 years of operation and because of the extreme traffic load some parts were even significantly damaged.

A decision was made to start design and survey works in 2018. The main contractor was chosen in 2022 and in the same year works commenced. The bridge reconstruction is very complex and is divided into 4 stages over 4 years. The first stage was completed in 2022. This paper focuses solely on the part of reconstruction works with UHPC overlay.

At the beginning of the first stage of the reconstruction it was discovered, that the original assumption about the thickness of road layers were not fulfilled. In many places there were significantly higher thickness of road layers than stated in the documentation (by up to 350 mm (13,8 in)). In accordance with valid codes, it is impossible to provide this thickness just in asphalt layers. It was also necessary to maintain profile grade, a suitable solution for a leveling layer had to be found.

Out of consideration of the time schedule of the building site, UHPC overlay was chosen for the purpose of strengthening and protecting the old superstructure surface.



Figs. 2, 3 General bridge overview, traffic solution

### 3.1 UHPC application

UHPC specified for overlays of bridge superstructures has to fulfil additional demands. Most important are:

- Changed thixotropy for casting with surface in slope

- High fibre content in order to decrease reduce the crack width

UHPC for Barrandov Bridge had to be applicable in slope up to 6%. UHPC composition for this purpose had to be developed.

Fibre content was set to 3% of concrete volume. Strength in tension during bending  $f_{RI}$  in accordance with ČSN EN 14651 was 20 MPa (2900 psi).

Strength in compression is not as important for this application therefore the basic cylinder strength class in compression C110 (15954 psi) was chosen. According to the technical guidelines ČBS 07 this strength is tested on brushed cylinders of height 200 mm (7.88 in) and diameter 100 mm (3.94 in). Additional tests were made on cubes 100mm (3.94 in), but these tests were made solely for strength development not for conformity tests.

Maximum grain size was 4 mm (0.157 in) because thickness of UHPC layers started from 25 mm (0.984 in) and due to the high content of fibers.

### 3.1.1 UHPC production and transport

UHPC was produced on a typical concrete plant in Prague Libeň. Maximum batch size was 1.25m<sup>3</sup> (1.6 cu yd) and mixing of one batch took 5 minutes. The capacity of concrete plant at that time was 15 m<sup>3</sup> (19.6 cu yd) of UHPC per hour, which was more than workers on the building site were able to apply. Usual daily delivery was 30-40 m<sup>3</sup> (39 – 52 cu yd) of UHPC.

Typical volume of UHPC transported to the building site by one truck mixer was 3.75m<sup>3</sup> (4.9 cu yd) and the maximum possible load of a truck mixer was 7.5 m<sup>3</sup> (9,8 cu yd) of UHPC. The distance of the building site from the concrete plant was 14 km (8 mi), which was approximately 20 minutes of transport. The workability time was 3 hours.

### 3.1.2 Test results

All specified parameters were fulfilled. Averages of all results from testing during production are in Table 2.

**Table 2** Average test results

Sample	Test	Age of UHPC	Test result	Unit
Cube 100 mm	Compressive strength	7 days	100	MPa
Cube 100 mm	Compressive strength	28 days	130	MPa
Cube 100 mm	Compressive strength	90 days	140	MPa
Cylinder 200 mm	Compressive strength	28 days	127	MPa
Beam 700 mm	Strength in tension $f_{RI}$	28 days	22	MPa

100 mm = 3.937 in, 1 MPa = 145 psi

### 3.1.3 UHPC overlay casting

UHPC overlay has two main functions on Barrandov Bridge. Firstly, to level the upper surface of superstructure and secondly to strengthen the upper deck of the box section of the bridge (mainly to increase load capacity in transverse direction). UHPC overlay was not intended as water insulation.

UHPC overlay on Barrandov Bridge was the first large application of UHPC overlay in the Czech Republic.

A very important part of this technology is preparation of the substrate surface. In this case there were two types of surfaces. On the side cantilevers, the original concrete surface was exposed following water insulation removal. The quality of the concrete surface was very variable in this part. Some parts of the surface were not possible to treat, even by high pressure water jet blasting and in other parts, water jet blasting made large disruptions of the surface (fig. 4). In the area of traffic lanes, the surface of the original concrete was milled. The surface after milling appeared to be good, but roughness was not sufficient. Aggregate of the old concrete was milled as well (fig. 5), which is not good for bond of a new UHPC layer.



**Fig. 4** Concrete surface above cantilever



**Fig. 5** Milled concrete surface

The thickness of the overlay was highly variable and ranged from 25 – 250 mm (1-10 in). Layers of the thickness of 25 – 40 mm (1 – 1.6 in) was without steel reinforcement and stress in tension was transmitted solely by microfibers in UHPC. Thicker layers were reinforced.

UHPC was cast in strips of width 3 to 4.5 m (9,8 – 15,8 ft). UHPC was cast directly from truck mixers (fig. 6). Immediately after leveling the surface, UHPC was cured by curing agent and by plastic sheets (fig. 7).



**Fig. 6** UHPC casting



**Fig. 7** UHPC curing

In parts, where it was not possible to prepare the concrete surface properly, additional shear connectors were used.

### **3.2 Results of Barrandov Bridge strengthening**

It emerged that the application of UHPC overlay was successful. The surface of the superstructure was strengthened, which contributed to increased durability against local load of the box section upper deck and cantilevers in transverse direction. New experiences were obtained for subsequent applications on bridge structures. The quality of the substrate concrete structure was crucial. The possibility of ready-mixed UHPC use and its application in slopes was verified. More than 400 m<sup>3</sup> (523 cu yd) of ready-mixed UHPC was delivered for this project. In accordance with experiences, use of shear connectors between UHPC and old concrete on the edges of concreted sections is recommended. In the case of Barrandov Bridge, UHPC overlay was not used as waterproofing, but it is recommended to use it as well for this purpose on subsequent applications. Details and sealing of bay joints have to be solved.

## **4 Summary**

It was shown that UHPC is a very convenient material for reconstruction and strengthening works. This paper outlined the main result from preparation research and two examples of successful UHPC application were given.

A new type of ribbed vertical UHPC layer was tested on the Meziboří bridge, in order to preserve the old substructure of the bridge and decrease the amount of waste material, demolition and excavation works. Transport distance of ready-mixed UHPC of 110 km (68 mi) and workability up to 6 hours was tested.

UHPC overlay was used on Barrandov Bridge in order to strengthen the box section upper deck and cantilevers in particular. It verified the use of ready-mixed UHPC on a very large bridge, where more than 400 m<sup>3</sup> (523 cu yd) of UHPC were cast.

It was shown, that delivery of UHPC to building sites by truck mixers from typical concrete plants is possible as well as being more comfortable and economic than dry mixes.

## **5 Acknowledgements (Optional)**

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## **6 References**

- [1] Brühwiler, E.: UHPFRC is ready to revolutionize existing and new structures. Proc. of the IABSE Symposium “Challenges for Existing and Oncoming Structures”, Prague, May 25-27, 2022, 67-79
- [2] Coufal, R., Kalný, M., Kolísko, J., Vítek, J. L.: Ultra-high Performance Concrete (UHPC), Technical guidelines no. 07, Czech Concrete Society, Prague, 2022 (in Czech)