The First Large Application of UHPC in the Czech Republic

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Abstract:

The unique cable stayed footbridge with bridge deck made of ultra-high performance concrete (UHPC) was opened in 2014. The footbridge is unique because of the first large application of UHPC for load carrying structure in the Czech Republic as well as being the largest main span (156 m, 170,6 yd) of cable stayed bridge in the Czech Republic. This paper deals with UHPC development, verification of construction details and with footbridge construction.

Keywords:

UHPC, cable stayed footbridge, strength, durability, shrinkage

1. Introduction

The footbridge is located in the city of Celakovice north east of Prague (Czech Republic), crossing the Labe River. The bridge has three spans; a main span crossing the river which is 156 m (170,6 yd) long; each of the two side spans is 43 m (47 yd) long. Two A shape pylons located on the river banks are 37 m (40,5 yd) high and made of steel. The bridge deck is assembled from precast segments made of UHPC. The width of the footbridge is 3 m (9,8 ft.) and it is designed for pedestrians and cyclists. It also allows for crossing of a light utility vehicle up to a weight of 3.5 t (7716 lb).

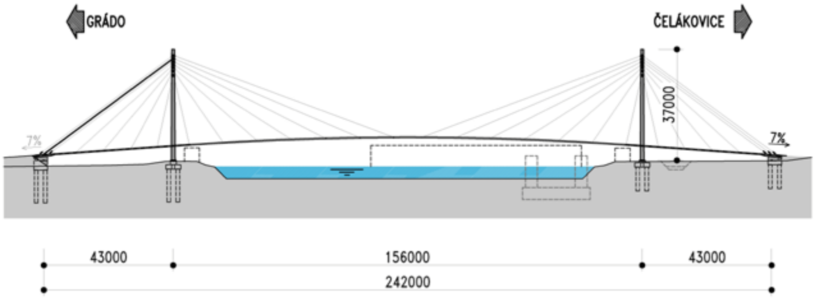


Figure 1 – Longitudinal footbridge cross section

The bridge deck has two longitudinal beams which are prestressed and where the stays are anchored. The beams are connected by a slab with a thickness of 60 mm (2,362 in), where no reinforcement is used (with exception of fibers in the UHPC). The slab is stiffened at regular intervals of 1 m (3,281 ft.) by small ribs reinforced by two steel bars. The locked coil strands of a diameter 20 to 35 mm (0,787-1,378 in) form the stays.

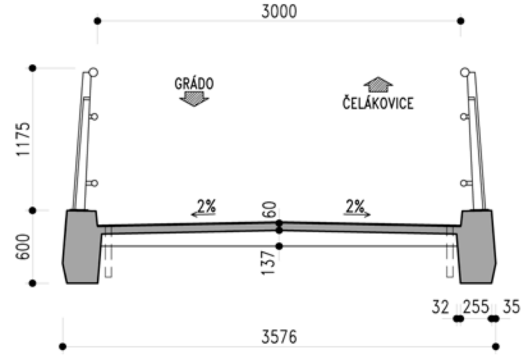


Figure 2 – Cross section of the footbridge

2. UHPC composition design

UHPC development started in 2011. At the beginning, there was no construction site with a demand for UHPC, so it was necessary to establish the final parameters of UHPC to be reached. Because of planned production at the concrete plant and cost efficiency, the decision not to use premix materials was made.

The UHPC was designed from local materials, therefore at the beginning appropriate materials had to be found and tested. Out of materials used for regular concrete production just cement and superplasticizer were chosen. Aggregate, powder, silica fume and fibers were used from different sources.

The planned material parameters were:

- Compressive cylinder strength ≥ 150 MPa (21756 psi)
- High tensile strength in bending
- Fine graded mixture, maximum grain size 8mm (0,315 in)
- High durability against chlorides and freeze
- Good workability
- Ready for transport with truck mixer

2.1 Laboratory development of UHPC

Different materials and their compatibility were tested in a laboratory. Initially materials were tested on mortars, where compressive and tensile strengths were measured on 160x40x40mm (6,3x1,575x1,575 in) prisms. The prisms were heat treated for faster results. Consistency and air content was measured in fresh material. The mortar with best results was mixed with coarse-grained aggregate and fibers. All demanded parameters were measured on this concrete. Cylinder compressive strength was 164 MPa (23786 psi), cube (100 mm, 3,937in) compressive strength was 168 MPa (24366 psi) and compressive strength on small prisms was 182 MPa (26397 psi).

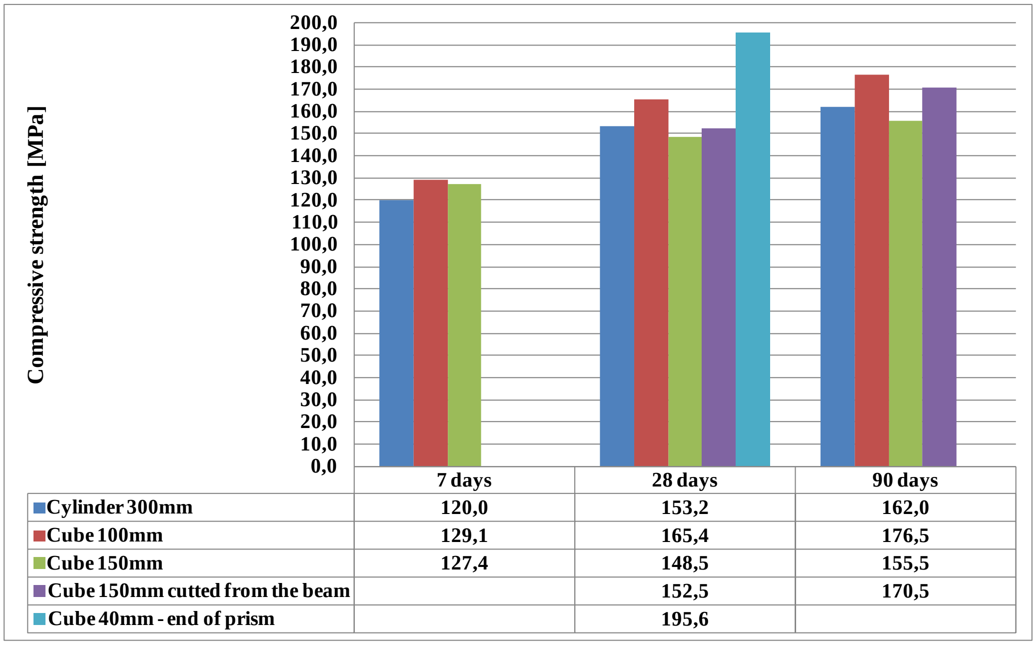
2.2 Transfer of UHPC production from lab to concrete plant

Since parameters of final UHPC composition from the laboratory were very promising, one concrete plant was prepared for regular production of UHPC. It was found very soon, that the composition prepared in the laboratory was not suitable for production in real mixing plants. The main reason was that the temperature of the mixed material was increasing very fast during mixing and when several batches were mixed in a row, the third one had a temperature above 30°C (86°F). Because of this high temperature, material set and lost its consistency very fast. Therefore the first and last batch had different parameters. The reason for this behavior was the cement CEM I 52,5 R, which had a very high reactivity.

Therefore, changes in UHPC composition were necessary. At the same time, new demands on material came from the footbridge project in Celakovice. New demands on material were:

- Minimal concrete strength class C110/130
- Tensile strength in bending (700mm(27,56 in) beam, 3 point test) ≥ 15 MPa
- Self compacting consistency
- Transport with a truck mixer to a distance of 26 km (16,1 mil)
- Fast hardening for early segment demoulding

An additional 30 concrete compositions were mixed at the concrete plant. Different types of cement with lower reactivity were used and mixing technology was optimized. Cement CEM III/B 32,5 N LH/SR was also tested with very good results from a strength point of view. Unfortunately a very slow strength development was observed, which was a problem for segment production. Finally Portland cement CEM I 42,5 R was found as an optimal for segments production.



	7 days	28 days	90 days
🟦 Cylinder 300mm	120,0	153,2	162,0
🟥 Cube 100mm	129,1	165,4	176,5
🟩 Cube 150mm	127,4	148,5	155,5
🟪 Cube 150mm cutted from the beam		152,5	170,5
🟦 Cube 40mm - end of prism		195,6	

Figure 3 – Comparison of compressive strength of final composition made on concrete plant
1 MPa = 145,038 psi
100 mm = 3,937 in

Compressive strength of the final concrete made at the concrete plant is illustrated in figure 3. The figure shows a comparison of compressive strengths in different concrete ages and in dependence on the testing specimens. The highest value was measured on 40 mm (1,575 in, parts of prisms remaining after bending tests) cubes and the lowest value was measured on cubes 150 mm (5,906 in). 100 mm (3,937 in) cubes were chosen for quality testing during UHPC production. The tensile strength in the 3 point bending test, measured on the 700 mm (27,56 in) long beams was 20,5 MPa (2973 psi) and in the 4 point bending test on the same beam the tensile strength was 18,1 MPa (2625 psi). Modulus of elasticity on the 300 mm (11,811 in) high cylinder was 48,5GPa (7034328 psi).

2.3 Experience with UHPC production and transport

The UHPC was supplied from the Prague Troja concrete plant of TBG METROSTAV. This concrete plant has a horizontal double shaft mixer for a concrete volume of $3m^3$ (3,924 cu). For UHPC maximum volume of one batch was reduced to $1m^3$. One batch was mixed 12 minutes which was necessary for good quality UHPC. For one footbridge segment, $4m^3$ (5,232 cu yd) of concrete were produced. This amount of concrete had to be transported by two truck mixers, because of the mould filling technology. The transport distance was 26 km (approximately 40 minutes). Each delivery was checked before unloading. The viscosity T500, measured by Abrams cone, was the most important factor. Time T500 means the time interval, when material flows across a 500 mm (19,685 in) circle, after Abrams cone is lifted. The optimum T500 was 8 – 12 seconds. When the time was shorter, the material would have not been stable and fibers could have segregated. If the time was longer, a problem with segment mould filling (blocking by the reinforcement) could have appeared.

Quality control tests confirmed that all demands were fulfilled. The average cube compressive strength in 28 days exceeded 150 MPa. In 90 days every sample exhibited cube compressive strength above 150MPa (21756 psi) and average compressive strength was higher than 160 MPa (23206 psi). The resistance against freeze thaw attack was perfect, with no erosion of the concrete surface even when the amount of freeze-thaw cycles were four time higher, then codes prescript. Water penetration under pressure was 0 mm on every tested sample.

3. Segment production and testing

11,3 m (37,073 ft) long segments were cast in two stages using a steel mould. The UHPC was produced about 26 km away from the casting yard and transported in truck mixers. The completed segments were transported to the site partially by trucks and partially by pontoons.

The side spans of the footbridge were assembled and prestressed on the fixed scaffolding. The main span was assembled using a gantry by cantilever method symmetrically, starting from the pylons. The segments were lifted directly from the pontoons and connected by prestressing bars to the existing part of the footbridge. The stays were simultaneously installed. At the midspan, the short segment was fixed and the two closing joins were cast using ordinary high strength concrete. The static and dynamic loading test verified the assumptions of the structural analysis. The mould filling by UHPC is shown in figure 4.

Figure 4 – Segment mould filling by UHPC flowing from truck mixers

Concrete flew simultaneously from both truck mixers. Concrete filled the whole mould without vibration in less than one hour. The total time from the start of mixing to the end of filling the mould was shorter than 3 hours. In this time, concrete had to have the same consistency (before the start of setting). On the other hand, the segment needed to be demoulded after 6 – 8 hours from the start of casting, so that the time schedule of construction could be kept. It was necessary to cast the new segment every second day. This was the reason heat treatment had to be used. Heat treatment started after the mould was filled and finished when the concrete reached the demoulding strength. The second reason for heat treatment was it reduced fast shrinkage at the start of setting. The influence of heat treatment on early age shrinkage and on strength development is shown in the figure 5. With heat treatment 50 MPa (7252 psi) strength was reached in 7 hours after casting.

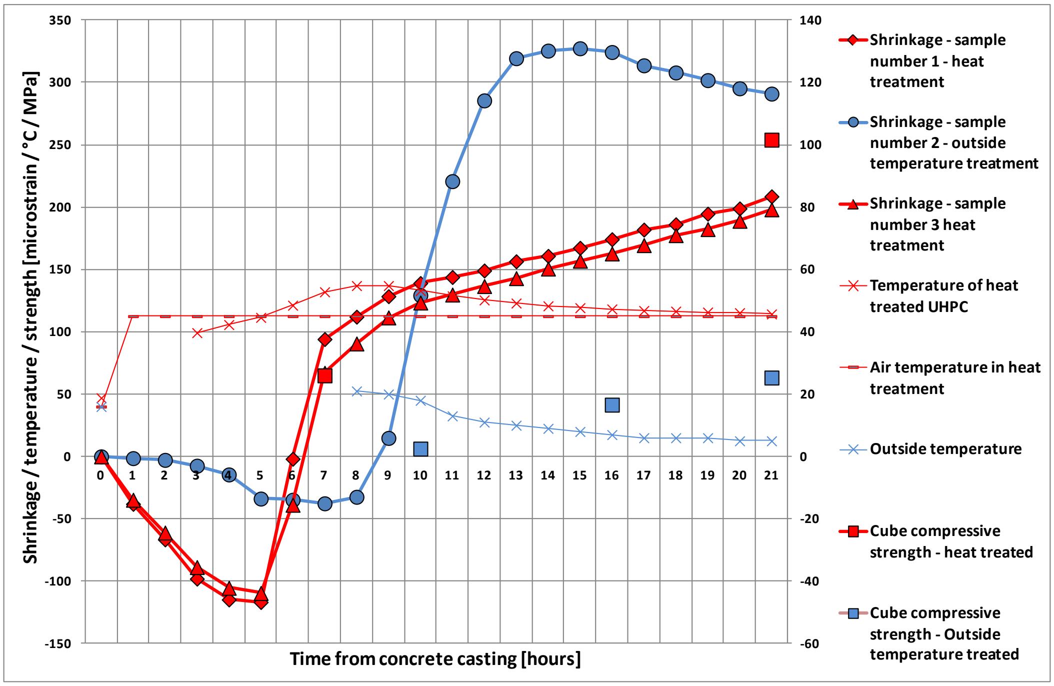


Figure 5 – early age behavior
1000 microstrain = 1mm / m
0°C = 32°F, 60°C = 140°F, 1 MPa = 145,038 psi

Additional experiments were focused on verification of the basic elements of the footbridge. The small dimensions of the edge beams of the bridge deck did not allow for the application of standard anchor plates of prestressing bars. Smaller anchor plates had to be used. The resistance of UHPC elements loaded by prestressing force applied on a smaller anchor plate was investigated experimentally using the ETAG 13 recommendations. It was observed that the smaller anchor plate is completely sufficient, even if the reinforcement was significantly reduced, since the fibre reinforcement of UHPC is able to carry the stress under the anchors. The two alternatives were tested. i) No bar reinforcement was used under the anchors and ii) small longitudinal bars and stirrups were in the specimens, since such reinforcement was used in the edge beams of the bridge deck. Cracks did not appear in the specimens until the load reached the level 1.4 – 1.7 of the characteristic prestressing force F_{pk}. The tests were conducted when the concrete was 5 days old.

The slab is not reinforced by any reinforcement with the exception of fibres. The load carrying capacity of the deck element in transversal direction was tested. Initially two point loads were applied (representing the axial load of a light vehicle). The maximum axial load is about 25 kN (5620 lbf). When the load of 80 kN (17985 lbf) was achieved and no cracks appeared, the test was modified and only one point load located in the middle of the slab between the transversal ribs was increased up to 110 kN (24729 lbf). The slab failed in bending of the transversal ribs. The slab itself remained without any damage (with the exception of small cracks) despite the point load being located between the ribs.

4. Assembly of the footbridge

After construction of the foundations, the steel pylons were transported to the site in three parts, which were welded onsite. Then the complete pylon was lifted by two cranes and anchored to the concrete foundation. At the ends of the footbridge the abutments were cast.

The bridge deck was assembled from the segments, which were initially connected by prestressed bars located in edge beams. The side spans were assembled on the light fixed scaffolding delivered by PERI. The first segment was assembled under the pylon and the others were laid on the scaffolding, then connected to the previous segment and prestressed by prestressing bars. The remaining part at the abutment was cast in situ using ordinary concrete.

The main span was assembled by cantilever method. The first segment, adjacent to that under the pylon, was laid on the riverbank and lifted by a launching gantry. The following segments were transported by pontoons and also lifted by the launching gantry (Figure 6). The launching gantry was specifically designed for the footbridge. There were two identical products which were used for assembly of the main span symmetrically from both sides of the river. The launching gantry had two main longitudinal steel beams, which were anchored to the top of the already completed footbridge, forming a cantilever approximately 12 m (39,37 ft) long. The new segment was lifted from the pontoon (or from the riverbank in the case of the first segment) using four bars operated by hydraulic jacks. The new segment was lifted about 0.5 m (1,64 ft) from the last segment. Then the prestressing bars (32 and 36 mm (1,26 and 1,417 in) in diameter) were connected. Then the new segment was moved longitudinally to the previous segment. The joint was filled with epoxy glue and it was closed by moving the frame and by prestressing of the bars.

The cantilever of the launching gantry had an auxiliary couple of stays suspended on the top of the pylon, which carried the substantial weight of the lifted segment. The reaction at the pylon was transferred to the abutment by back auxiliary stays. After prestressing of the new segment, the permanent stays were installed. Then it was possible to release the auxiliary stay on the launching gantry and to move the gantry into the next position.

After assembly of 7 segments on each side of the river, the middle short segment was lifted and two closing joints were cast in situ. For this operation only one launching gantry was used. It provided a stiff connection between the two cantilevers. The formwork for the two closing joints was suspended on the launching gantry. When the closing joints were cast and the concrete hardened, the longitudinal tendons (2 x 15 strands of 15.7 mm (0,618 in) in diameter) could be prestressed and grouted.

Figure 6: Assembly of the segments over the river using a launching gantry

During assembly of the segments, their positions and the forces in the stays were carefully monitored and adjusted if necessary. After completion of the superstructure, the sprayed waterproofing, which is also used as a pavement, was installed together with a light steel railing. During the static and dynamic loading test the deflections and natural frequencies were measured and a good agreement with the assumptions of the structural analysis was found. The bridge was completed in spring 2014 (Figure 7).

5. Conclusions

The project proved that the development of UHPC from local constituents was successful. A lot of experience was collected, but many problems remain for future solution. Many decisions were based on experimental verification. Recently various recommendations for design were published which will be later modified into design codes. Contemporary design recommendations, which have to be taken into account, should be updated. Higher concrete strength and its resistance against environmental effects also require modification of the prescribed concrete cover, detailing rules, etc. Without such changes the structures made of UHPC would suffer in competition with other structures.

During construction of the footbridge, it appeared that the design is rather conservative. It was a correct approach at the time of the design and planning, if the footbridge was designed now, additional savings could be found. However, the existing footbridge is lighter and more durable than that which would have been built without the application of UHPC according to the previous proposals.

The footbridge in Celakovice is the first bridge in the Czech Republic which has a superstructure made of UHPC. At the moment, it is also a cable-stayed bridge with the largest span in the country. The footbridge won 1st place, in the category ‘Infrastructure’, at the ACI

Excellence in Concrete Construction Awards. The main construction participants are listed in Table 1.

Figure 7: The completed footbridge

Table 1: Main construction participants

Client	The town of Celakovice
Bridge Designer	Pontex Consulting Engineers, Ltd.
Design Supervision	Stráský, Hustý and Partners, Ltd.
Main Contractor	Metrostav, a.s
Major Subcontractors	TBG Metrostav, VSL Systemy CZ, PERI, Freyssinet CS, OK-BE
Construction time	01/2013 – 04/2014

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