DEVELOPMENT OF UHPC FROM MATERIALS AVAILABLE IN CZECH REPUBLIC

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Summary

The paper presents experiences with development of so called UHPC (Ultra High Performance Concrete) prepared from raw materials available in the Czech Republic. This promising new cementitious material performs very remarkable mechanical properties as a high ductility, compression and possibilities to prepare very thin bearing structures. The material savings and possibilities to prepare sustainable structures are obvious. Some laboratory test results of UHPC material developed at laboratories of Klokner Institute, CTU in Prague are presented in this paper. Information about practical applications of bridge lost shuttering slabs is presented, too. These slabs were made for reconstruction of a bridge. Different aspects mainly from the technological point of view associated with implementation of the slabs will be described in this paper.

Keywords: UHPC, prefabrication, durability, shuttering, fibres

1 Introduction

The Ultra High Performance Concrete (UHPC) is a relative new cementitious composite material which is used for reducing of structure weight and eliminated, partly or entirely, conventional steel reinforcement bars and reinforcing cage. UHPC is defined as concretes attaining compressive strengths exceeding 150 MPa and tensile strength in bending 15 MPa. UHPC is densely-packed cementitious fine grained material reinforced by steel fibres. UHPC concretes exhibits increased mechanical properties and superior durability to NSC (Normal Strength Concrete – $f_{ck,\,cube,\,150\,mm}$ < 60 MPa) and HSC (High Strength Concrete – $f_{ck,\,cube,\,150\,mm}$ up to 105 MPa). A dynamic development and investigation of UHPC can be mainly found in France (Ductal [11]), Germany [12], the Netherlands, the United States, Canada, Japan (Sakata-Mirai Footbridge), Korea (Sunyudo Footbgidge, Seoul, Korea) and Australia (Shepherds Creek Road Bridge: NSW, Australia).

Probably the best world known type of UHPC is commercial material Ductal® developed at the end of 90's by companies Lafarge and Bouygues in France. UHPC was firstly used in the Sherbrook footbridge in Canada, which was erected in 1997 over the Magog River. The span of the bridge is 60 m while the thickness of the bridge slab is only 30 mm. There was not used conventional steel reinforcement. The upper and bottom flanges are made from UHPC with compressive strength approx. of 200 MPa.

Another significant example of the use of UHPC precast elements was production of 6 900 pretensioned ribbed panels for the Haneda airport situated in the Tokyo bay. The cost reduction in the required steel jacket fabrication for the supporting structure yields an overall construction cost savings for project, a direct function of the weight savings achieved through the use of UHPC slabs is 44 % then weight of pre-stressed concrete slab.

Currently the situation as to the use of UHPC in Czech republic is on the level of laboratory research works and first small applications.

2 UHPC mixture design

The company Skanska a.s., branch Prefa in co-operation with Klokner institute started development of UHPC type material that would be used mainly for the manufacture of precast elements in 2009. The main idea was to prepare high strength densely-packed cementitious fine grained material reinforced by randomly distributed steel fibres (i.e. UHPC material type) from raw materials ordinarily available in Czech Republic. The crucial requirement of potential applicant of UHPC material was acceptable an optimal combination of:

Technical parameters x material cost x production possibilities (1)

Many of different mixtures were prepared and tested in laboratory and at concrete plant afterwards. Different types of sand, micro fillers, fibres, superplasticiser etc. were combined. The small beam specimens 40 x 40 x 160 mm were used to optimize mixtures at laboratory. Tested specimens were treated in water until mechanical testing according to EN 196-1 at 28 day. Different mechanical properties were gained depend on mix design. Some examples of mixtures and results of laboratory testing of mechanical properties are presented in the **Tab. 1.**

Tab. 1 *Examples of mix proportions and results o mechanical strength*

Type of material	**unit**	**Mix 1**	**Mix 2**	**Mix 3**	**Mix 4**	**Mix 5**	**Mix 6**
CEM II/A-S 42,5 R + slag + microsilika	kg/m^3	831	870	926	840	880	980
Ground quartz filler	kg/m^3	0	0	255	110	50	50
Steel microfiber 13/0,2 mm	kg/m^3	100	120	100	120	120	120
Sand 0/4 – type I	kg/m^3	1216					
Sand 0/2 – type II	kg/m^3			871			
Sand 0/2 – type III	kg/m^3						
Sand 0/2 – type IV	kg/m^3		1235		1160	1177	1094
Super plasticizer	kg/m^3	40	40	40	30	30	30
Water	kg/m^3	165	160	165	160	160	160
Test results after 28 days of curing in water – EN 196-1							
Bulk density	kg/m^3	2380	2450	2400	2430	2450	2470
Compression strength	MPa	143,5	153	152,5	163,5	173,5	189
Bending strength	MPa	28,9	31	31,9	31,2	31,2	34

Aftecr discussions and cost x technology analysis finally mixture Mix 2 was chosen to produce the bridge slabs of lost shuttering in the frame of the project “Reconstruction of the Bridge in Benatky nad Jizerou, the Czech Republic”. Apart from the financial benefit of applied solution, the project has also a positive environmental impact as a due to use of the bridge lost shuttering slabs it was not necessary to erect any scaffolding or auxiliary supporting material under the bridge deck. Further in this paper, some observations and facts of the reconstruction will be presented in detail.

3 Bridge lost shuttering slabs

3.1 Design of slab

Designers proposed a shape of the lost shuttering slabs made from UHPC type of material, for the “Reconstruction of the Bridge in Benatky nad Jizerou, the Czech Republic” that was build up in 2012. The shape was designed following an aesthetical requirement for a plane bottom surface of the slab. Moreover, both the thickness of concrete cover and the composite deck slab had to be kept. Ground dimension of the slab was 1 x 1,6 m. Plate of the slab (20 mm) was stiffened by reinforcing ribs 60 mm around circumference and two cross ribs 40 mm height in the middle of the plate. Designer of slab required strength class min. C 110/130, material reinforced with dispersed steel fibers and min. 10 MPa bending strength tested on beams 150 x 150 x 700 mm according to EN 14651 standard. Final material decision was that bridge slabs of lost shuttering will be manufactured of UHPC like material composed as Mix. 2 (see table 2).

Design calculation was done according to fib Model Code 2010, final draft 09/2011 [11]. The proposed shape was verified on various numerical models and principal stresses were calculated in concrete (UHPC) steel fiber-reinforced. The dead-load, a weight of fresh concrete and the live-load were taken into account in the design of the proposed shape.

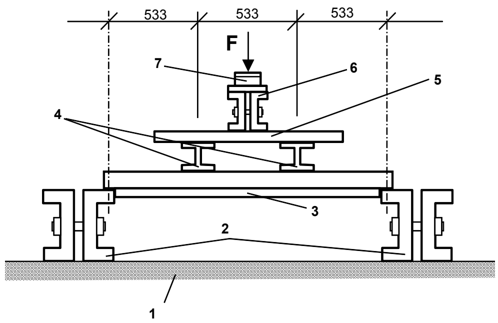
The numerical calculations of slabs, and a linear behavior of the material was presumed, by means of the software LUSAS. The elastic behavior of the slab can be considered approximately up to the value of F = 14 kN of the total force in the cylinder of the loading device, which means that the force of 7 kN is acting in each third of the lost shuttering slab span.

Tab. 2 *Comparison of the results of measurements and the theoretical (numerical) model*

	Load force F [kN]	Deflection at mid-span [mm]
Numerical model	13	3.8
Test sample 347/12	13	4.1

3.2 Type bending test of slab

First prototype bridge slabs of lost shuttering made from UHPC like material were manufactured for the project “Reconstruction of the Bridge in Benatky nad Jizerou, the Czech Republic” in Skanska a.s. branch Prefa. These slabs were transported to the laboratory of Klokner Institute, CTU in Prague and tested on a loading device to find out their tension strength in four-point bending. The set up can be seen in **Fig. 1**.



Legend:
1. floor
2. support beams (2x U-sections)
3. the tested UHPC bridge slab
4. load distributing HEB sections
5. load distribution (2x welded U-sections)
6. load distribution (2x bolted U-sections)
7. load distributing cradle hinge with pad/washer of steel plate

F – direction of the load (axis of the loading cylinder)

Fig. 1 *Arrangement of the test of the load-bearing capacity in four-point bending on the tested bridge lost shuttering slabs made of UHPC (reinforced only with steel fibres)*

With respect to the subsequent evaluation of the results, a continual loading method was chosen, which means that the load was increased continually until the limit value of the load-bearing capacity and disruption of tested slabs (origin and cracks distribution) were achieved. Tests were controlled by the speed of movement of the loading cylinder that was 0.01 mm/s. However, this speed rate in the descending section, i.e. once the maximum force was reached, was gradually increased up to 0.02–0.03 mm/s. Slabs were exposed to the loading for approximately 30 min. in total. Test results are presented on **Fig 2, 3.**

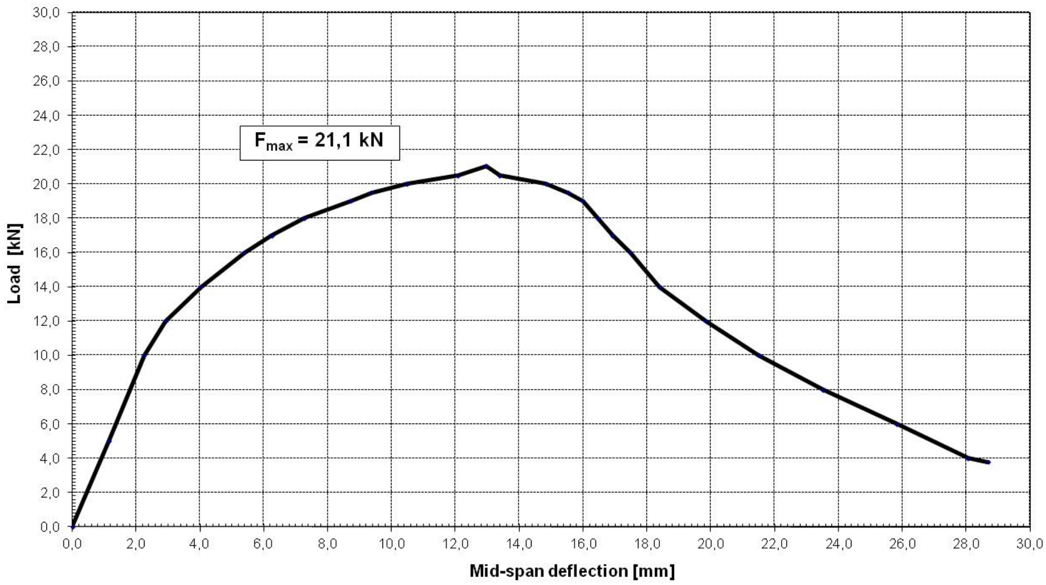


Fig. 2 *A typical result of the loading test of the slab. It shows dependence of the deflection of the mid-slab point on loading*

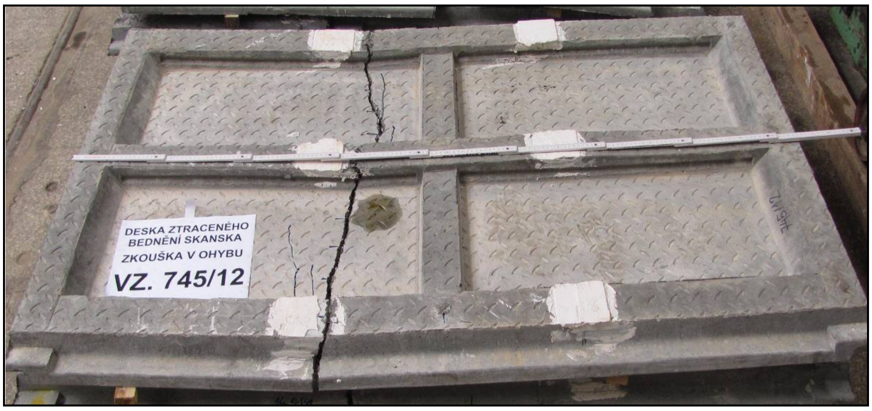


Fig. 3 *Typical destruction of slab.*

4 Manufacturing of bridge slabs and construction site application

As is described above, final decision of manufacturer was that bridge slabs of lost shuttering will be manufactured of UHPC like material composed as Mix. 2 (see table 1). Fresh UHPC was being produced at a concrete mixing plant with the maximum quantity of the forced-action mixer of 1.5 m^3. The mixing device was equipped with an automatic control system. Then the produced of fresh UHPC was transported from the mixing plant to the manufacture building on a special carriage and by means of a batcher was cast into formworks. The process of batching, mixing and the whole manufacture of the bridge slabs was describe in relevant technological specifications. Casting of the fresh UHPC into steel formworks, thoroughly cleaned and coated with a separation agent, was carried out continuously without any compaction. The mixture of UHPC slowly filled up the forms by itself and then the surface was leveled with a leveling lath. Then an agent preventing evaporation of water was spread on the surface. At the same time the surface was smoothen with a steel smoother every 5 minutes until formation of air bubbles on the surface stopped. The manufacture procedure is shown in **Fig. 4**.

Fig. 4 *Manufacture of the bridge slabs in the Prefa premises*

Fig. 5 *Installation of slabs on steel beams as lost shuttering*

5 Production material tests

Within the manufacture process material tests were being carried out as well. At the beginning, before the serial production started, a qualifying test was performed to prove designer requirements. Test samples for the test to detect the compression strength and determination of a bending strength and residual strength at specified deformation were tested on beams 150 x 150 x 700 mm. The mixing was provided in a standard mixing device in the Prefa premises. Processing of the UHPC like material into formworks was carried out by its casting in one layer without its compacting and the surface of samples was smoothened with a steel smoother. Samples were dipped into water according to EN 12390-2 where they kept until the tests started. A summary of the typical (average figures) results of the qualifying test when the production was started can be seen in the following table (**Tab. 3**). Qualifying tests control confirmed requirement of designer i.e. C110/130 and production tests followed up.

Tab. 3 *Qualifying test of UHPC like material designer requirement C110/130 XF4 was confirmed*

Description of test	Standard No.	Measured value
Settlement consistency – pouring within time of 25 min.	ČSN EN 12350-8	810 mm
Bulk density of fresh concrete	ČSN EN 12350-6	2450 kg/m^3
Compression strength of cylinders 150/300 after 28 days	ČSN EN 12390-3	125.0 MPa
Elastic modulus after 28 days	ČSN ISO 6784	45.0 GPa
Tensile strength in bending after 28 days – beam 150 x 150 x 700 mm with a notch	ČSN EN 14651+A1	13.9 MPa
Tensile strength in bending after 28 days at σ_1 for CMOD 1.0 mm	ČSN EN 14651+A1	9.5 MPa
Tensile strength in bending after 28 days at σ_4 for CMOD 4.0 mm	ČSN EN 14651+A1	4.9 MPa
Thickness/depth of pressure water infiltration	ČSN EN 12390-8	0.5 mm
Frost and defrosting salt attack test – spalling material from surface of test specimens, 125 cycles, method C	ČSN 72 1326	18.0 g/mm^2

6 Conclusion

This particular example shows that the requirements put on material UHPC can be fulfilled even if standard components of mixture ordinarily available in the Czech Republic are used. After discussions and cost x technology analysis finally mixture Mix 2 was chosen to produce the bridge slabs of lost shuttering in the frame of the project “Reconstruction of the Bridge in Benatky nad Jizerou, the Czech Republic” that was finalised during 2012. The compressive strength > 150 MPa on cubes or cylinders was not reached in fact, so the material was not pure UHPC. The economic technical aspect were taken into account and specified material C 110/130 fulfilled both of them best way. Another benefit was a practical proof that it is possible to fabricate a very thin-walled structural element without presence of any cavities and/or air pores. The results of the accompanying tests confirmed the latest knowledge and information presented in the literature. The utilization of the UHPC material can be extremely useful mainly in implementation of various future highways projects. This example had also a considerable ecological effect. Owing to the use of the bridge slabs of permanent formwork the fixed scaffolding could be entirely omitted. The scaffolding would have been erected under the bridge deck of the reconstructed bridge and due to this replacement a lot of timber material and other auxiliary material could be saved.

The main benefit, however, of the use of UHPC, apart from a positive impact on both the environment as such and working environment as well, is increase of operation properties and the lifetime of structures, mainly in the conditions of the environment with highly corrosive characteristics.

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