AN ASSESSMENT OF THE STEEL FIBRE DISTRIBUTION TO LOAD BEARING CAPACITY OF LOST SHUTTERING SLABS MADE FROM UHPFRC

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Abstract

The lost shuttering slabs investigated in this paper were made from relatively new UHPFRC cementitious composite materials reinforced by steel fibres. The slabs were used for reconstructing a narrowed steel-concrete bridge. The slabs were used as a permanent formwork. Sets of material tests were made while the mixture recipe was under development and then tests of the manufactured precast elements were carried out. The mixture recipe was optimized for the mechanical properties. But mixture recipe was also optimized for homogeneity of the steel fibre distribution in the cross section. The steel fibre distribution has a significant impact on the mechanical properties of lost shuttering slabs, especially on the load-bearing capacity at bending. This paper describes not only the mechanical tests on the slabs (tension strength in bending), but also methods for checking the homogeneity of the steel fibre distribution the cross section for hardened UHPFRC.

Résumé

Les panneaux de coffrage perdu, qui font l'objet de cet article, ont été coulés en BFUP renforcé de fibres métalliques. Ils ont été utilisés pour la reconstruction d'un pont mixte. Une série de contrôles a été faite lors de la mise au point de la formule, puis des essais des éléments préfabriqués ont été effectués. La formule et le procédé de coulage ont été optimisés en vue de l'obtention de propriétés mécaniques suffisantes et d'une distribution de fibres homogène. La distribution des fibres métalliques a un impact sensible sur les propriétés mécaniques des panneaux, et en particulier sur leur moment capable. Cet article décrit les essais de traction par flexion des panneaux, ainsi que la méthode de vérification de l'homogénéité de la distribution des fibres dans le BFUP durci.

1. INTRODUCTION

In the Czech Republic, UHPFRC is a relatively new cementitious composite material that is used for reducing of the weight of structures. It has been taking the place, partly or entirely, of conventional steel reinforcement bars and reinforcing cages. UHPFRC is defined as a cementitious composite material with compressive strengths exceeding 120 MPa and tensile strength in bending exceeding 15 MPa. It is a densely-packed cementitious material reinforced by steel fibres. UHPFRC has been developing dynamically, mainly in France (Ductal [13]), Germany [14], the Netherlands, the United States, Canada, Japan (Sakata-Mirai Footbridge [15]), Korea (Sunyudo Footbridge, Seoul, Korea [15]) and Australia (Shepherds Creek Road Bridge: NSW, Australia [15]).

Until now, only few structures have been built with HPC (High Performance Concrete - $f_{ck,\ cube,\ 150\ mm}$ = 105 MPa) in the Czech Republic. The first real application of UHPFRC elements was in the manufacture of precast elements for the lost shuttering slabs used in the project "Reconstruction of the Bridge in Benatky nad Jizerou, Czech Republic", at the beginning of 2012. The first trial test for the manufacture of UHPFRC bridge girders took place on the premises of Skanska a.s.

The mechanical properties of UHPFRC depend above all on the quality and the ratios of the mix composition components. However, when real structural elements are prepared, the mixing technology and the casting of UHPFRC in the frameworks also have a very important influence on the final results [1]. This impact is well known, and many publications and authors have described the effects of steel fibre homogeneity on fibre-reinforced cementitious composites. Publications such as Deutscher Ausschuss für Stahlbeton, Dauerhaftigkeit und Berechnung Ultra-Hochfester Beton (UHPC) and Model Code 2010 have established very important and comprehensive guidelines for UHPC. These publications describe the mechanical properties and design rules for testing elements made from UHPC, but they do not include precisely specified methods for determining and assessing the steel fibre distribution, which is necessary for developing this new material. Our paper describes methods for determining the steel fibre distribution for hardened UHPFRC for precast slabs, and its significant impact on load-bearing capacity.

2. CONTROLLING THE HOMOGENEITY OF STEEL FIBRES

The homogeneity of steel fibres is a crucial factor in determining the final mechanical properties of UHPFRC. Homogeneity of the steel fibre distribution is not dependent on the age of hardened UHPFRC, and can be determined both for fresh concrete and for hardened concrete. The homogeneity of the distribution is not easy to determine for fresh concrete. It can be observed visually, and the quantity of steel fibres can be determined as follows: the first is using a dosometer and the next is washing away the fine particles and then separating the steel fibres using by a magnet; the PVA fibres can be separated by manually collecting. These two methods are useful for determining the quantity of fibres for a known volume of concrete, but not for determining the distribution of the steel fibres throughout the volume of the concrete or in different layers of a structure.

The quantity, the orientation and the steel fibre distribution of hardened UHPFRC can be checked by an electromagnetic induction method, by an electromagnetic modified resistivity method, by X-ray analysis, by an optical microscopic method, or by 3D tomography. Experimental research aimed at establishing a non-destructive method is being carried out all round the world, but it is still at a problematic stage. The volume of steel fibres in a specific known volume of hardened concrete can be determined by drilling boreholes and crushing the extracted material. This destructive method is described e.g. in CSN EN 14488-7 [2], but it needs to be modified for use in determining the steel fibre distribution in structure elements.

3. RESEARCH WORK

3.1 Description and results of the load-bearing tests

The first application of UHPFRC in a structure in the Czech Republic was for the project to reconstruct the bridge in Benatky nad Jizerou, see Figure 1. The slabs, which had been manufactured by Skanska a.s., were transported to the Klokner Institute of the Czech Technical University in Prague and tested on a loading device. The test method and the loading process are shown in Figure 2.

Figure 1: Installation of the bridge slabs of permanent formwork made of UHPC on the reconstructed bridge in Benatky nad Jizerou

With a view to the subsequent evaluation of the results, a continual loading method was chosen. This means that the load was continually increased until the limit value of the load-bearing capacity was reached and the tested slabs were disrupted by cracks. The tests were controlled by the speed of movement of the loading cylinder, which was 0.01 mm/s. The speed was gradually increased up to 0.02 – 0.03 mm/s at the moment when maximum force was reached. The slabs were exposed to loading for a total of approximately 30 min.

More than 20 tests were carried out in the course of the trial. During the tests, the dependence of the deflection in the middle of slab span on the maximum loading value was mainly observed. The maximum loading value and deflection in the middle of slab span were the subject of a theoretical statics analysis.

Using LUSAS software, the results were compared with numerical assumptions for slabs, and linear behaviour of the material was presumed. The elastic behaviour of the slab can be considered approximately up to a total value of F = 14 kN of the load force in the cylinder of the loading device. A load-deflection diagram for the slab was produced as an outcome of each test (see Figure 3).

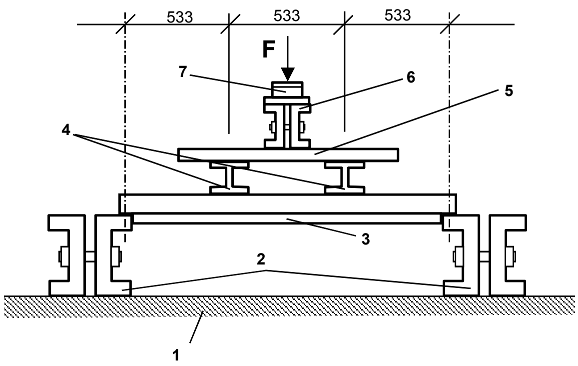

Figure 2: Arrangement of the load-bearing capacity test in four-point bending on lost shuttering slabs of the tested bridge. Slabs made of UHPC (reinforced only with steel fibres)

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 a steel plate pad/washer

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

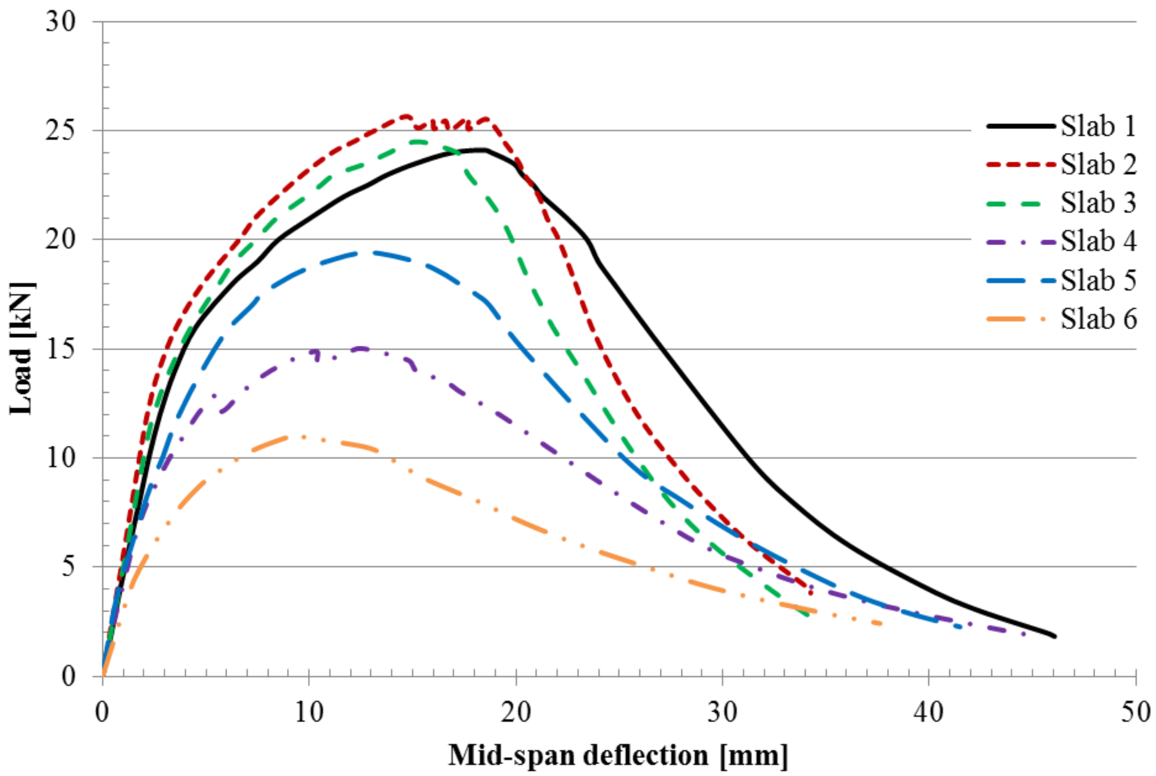

Figure 3: Results of the slab loading test, showing the dependence of the deflection on the mid-span point of the slab

3.2 Loading tests in-situ at Skanska a.s.

The slabs were tested in four-point bending in three loading steps. The slabs can safely carry the loads produced by people moving along a layer of fresh concrete laid on the surface of the slabs. The intensity of the testing load was chosen on the basis of the test results obtained at the Klokner Institute on the basis of the range of the elastic behaviour of the slabs. Load intensity of 13 kN was chosen for a deflection of 4.1 mm in mid-span of the slabs. The whole loading system consists of three concrete plates (1.5 x 0.8 x 1.6 m) and their total load weight of 1326 kg. The testing load was approximately 130 % of the operation load acting during construction of the composite slab of the bridge. The loading concrete plates were placed in the thirds of the slab span on wooden beams resting on longitudinal ribs of the slab. The deflection in the mid-span section was measured by means of mechanical or digital deflection gauges placed under the edge ribs (see Figure 4).

Figure 4: Static loading test of the permanent formwork UHPC bridge slabs on the Prefa premises

3.3 Steel fibre distribution at the cross section

Variances of the maximum load values within ± 10 kN were recorded during the bending tests. It was therefore decided to check the homogeneity of the steel fibres at a cross section. The distribution of steel fibres at a cross section was checked using an optical microscopy method [17].

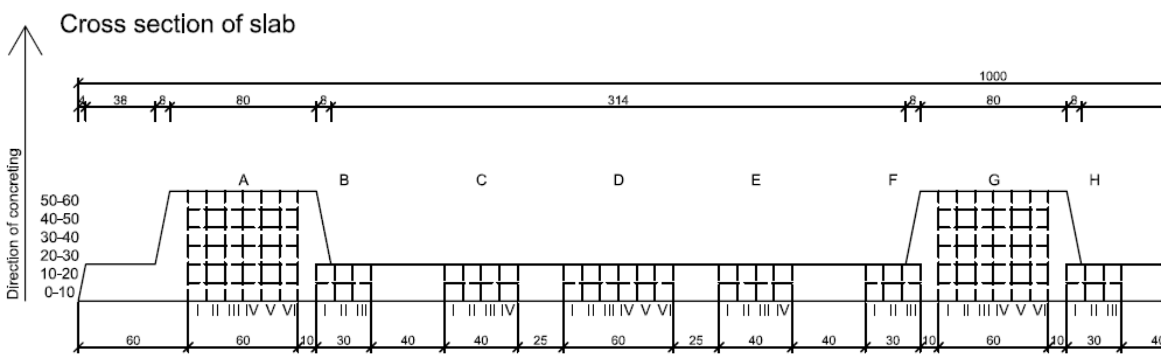

Figure 5: Cross section of the lost shuttering slab

The slabs were cut by a saw with a diamond disc near a macro-crack after the bending tests. The cut surface was divided into several areas, which were divided into sub-sectors 10 x 10 mm in size. The steel fibre distribution was checked at these subsectors A to M, see Figure 5. Figure 6 and Figure 7 show typical results for the distribution of steel fibres at a cross section.

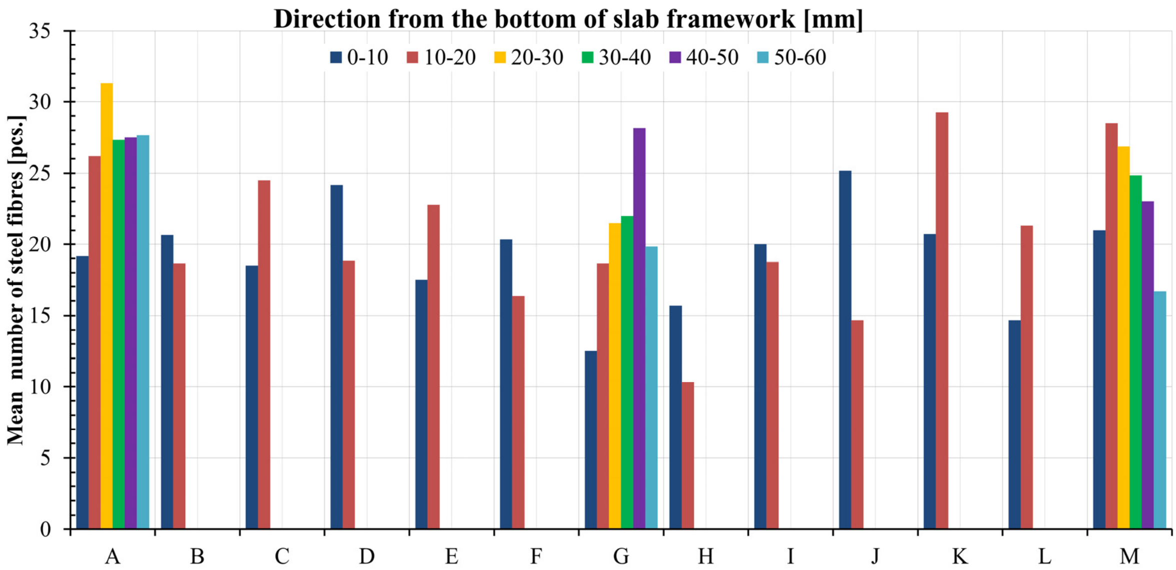

Figure 6: Steel fibre distribution – slab 2. Mean number of steel fibres on the vertical axis, controlled area on the horizontal axis.

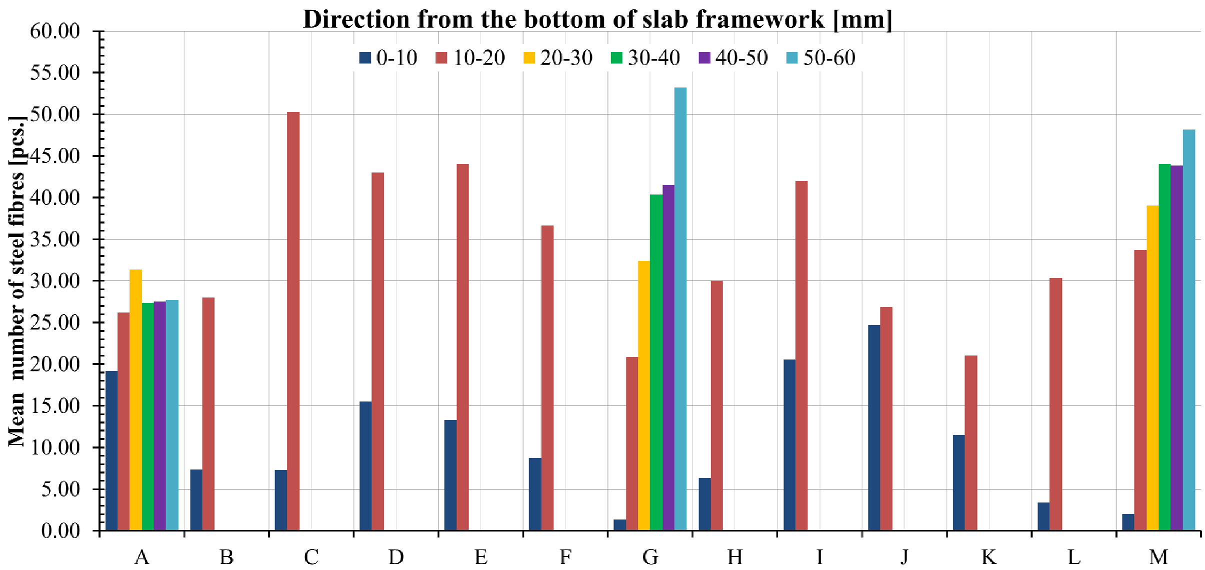

Figure 7: Steel fibre distribution – slab 4. Mean number of steel fibres on the vertical axis, controlled area on the horizontal axis.

Figure 6 shows relatively homogeneous steel fibre distribution for slab 2, and Figure 7 show segregation of the steel fibres in the supporting rib (area A, G and M) at the bottom of the framework. The first column in Figure 5 and Figure 6 represents 0 – 10 mm from the bottom; the second column represents 10 – 20 mm from the bottom; the third column represents 20 – 30 mm from the bottom (only for areas A,G,M); the fourth column represents 30 – 40 mm from the bottom (only for areas A,G,M); the fifth column represents 40 – 50 mm from the bottom (only for areas A,G,M), and the sixth column represents 50 – 60 mm from the bottom of the slabs (only for areas A,G,M). Areas A, G and M represent the supporting rib, while remaining areas represent a thin UHPFRC slab (thickness of the slab 20 mm).

4. CONCLUSIONS

UHPFRC is a relatively new material which is now being developed in the Czech Republic. This material is being developed in laboratories. The first real application of precast UHPFRC slabs in structure was in the project "Reconstruction of the bridge in Benatky nad Jizerou". Researchers and concrete companies are confronted with material and technological issues. One of these problems is the distribution of the steel fibre in the cross section, which determines the final mechanical properties of UHPFRC precast slabs, as shown in this paper. This effect cannot be eliminated totally, but it can be limited by the mixture recipe and by the technological process.

ACKNOWLEDGEMENTS

The research work presented in this paper has been supported by the Grant Agency of the Czech Republic, in the framework of grant No. P105/12/G059 "Cumulative time dependent processes in building materials and structures".

REFERENCES

[1] Vokáč M., at al. (2011). Experimental investigation of I-beam made from UHPC. In Fibre concrete 2011, ISBN 978-80-01-04836-8.
[2] ČSN EN 14488-7 (73 1304) Zkoušení stříkaného betonu – Část 7: Obsah vláken ve vláknobetonu 2006, EAN 8590963769578.
[3] Ferrara L., Faifer M., Toscani S., A magnetic method for non-destructive monitoring of fiber dispersion and orientation in steel fibre reinforced cementitious composites – part 1: method calibration. Materials and Structures (2012), doi: 10.1617/s11527-011-9793-y
[4] Bernasconi A., Rossin D., Armanni C. Analysis of the effect of mechanical recycling upon tensile strength of a short glass fibre reinforced polyamide 6,6. Engineering Fracture Mechanics 74 (2007), doi:10.1016/j.engfracmech.2006.10.002
[5] Lataste J.F., Behloul M., Breysse D. Characterisation of fibres distribution in steel fibre reinforced concrete with electrical resistivity measurements. NDT&E International 41 (2008), doi:10.1016/j.ndteint.2008.03.008
[6] Ferrara L., Meda A., Relationships between fibre distribution, workability and the mechanical properties of SFRC applied to precast roof elements. Materials and Structures (2006), DOI 10.1617/s11527-005-9017-4
[7] Fehling E., Schmidt M., Teichmann T., Bunje K., Entwicklung, Dauerhaftigkeit und Berechnung Ultra-Hochfester Beton (UHPC), Forschungsbericht an die DFG. Schriftenreihe Baustoffe und Massivbau, Universität Kassel, Heft 1 (2004)
[8] AFGC/SETRA: Bétons fibrés à ultra-hautes performances. Recommandations provisoires. Documents scientifiques et techniques. Association Française de Génie Civil, Setra, Bagneux Codex, janvier 2002

[9] JSCE-USC: Recommendations for Design and Construction of Ultra-High Strength Fiber-Reinforced Concrete Structures – Draft

[10] Model Code 2010, 1st complete draft, March 2010, 2 vol.

[11] Tichý, J.; Štěrba, A.; Trefil, V.; Žaloudek, I., (2009): "Ultravysokopevnostní beton v prefabrikaci", Hradec Králové, 16. Betonářské dny.

[12] Tichý, J.; J.; Kolísko, J., (2012): "Provozní zkoušky ultravysokohodnotného betonu v prefabrikaci", Pardubice, 10. konference Technologie betonu.

[13] Blais, P.Y.; Countere, M., (1999). "Precast Prestressed Pedestrian Bridge – World's First Reactive Powder Concrete Structure", Torino, PCI journal ISSN 0887-9672.

[14] UHPC's World – The world of UHPC: Ductal® opens the way. Ductal, 2012. WWW: < http://www.ductal-lafarge.com/wps/portal/ductal/1_2-UHPCs_World>.

[15] UHPC Brücken. Universität Kassel, 2012. WWW: < http://www.uni-kassel.de/hrz/db4/extern/wdbubc/index_uhpc_bruecken_en.php>.

[16] Ultra High Performance Concrete (UHPC). International Symposium on Ultra High Performance Concrete, Kassel, 2008. ISBN 978-89958-376-2. WWW: <http://www.google.cz/books?hl=cs&lr=&id=OMsdSJ-LUBQC&oi=fnd&pg=PA19&dq=uhpc+structure+france&ots=kf_Rrk57tL&sig=a8BLjxh-qoIjyyc9JKlIRktkBaA&redir_esc=y#v=onepage&q=uhpc%20structure%20france&f=false>.

[17] Rydval M. at al. (2012). UHPC recipe optimization with regard to matrix homogeneity and steel fibre distribution. In 19th Czech concrete day 2012. ISBN 978-80-87125-32-6