DESIGN, INSTALLATION AND LONG TERM MONITORING OF UHPC FOOTBRIDGE OVER OPATOVICKY CHANNEL

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Abstract

New prestressed footbridge made from ultra - high performance concrete (UHPC) was installed in Čeperka village across Opatovicky channel. A precast UHPC girder was casted in the premises of Skanska company. As a part of a footbridge design, UHPC handrail panels were also made from coloured UHPC. Skanska and Pontex company with cooperation with Klokner institute developed matrix of UHPC used for footbridge construction. Material properties were verified during whole developing and producing process. During the girder casting a set of strain gauges were installed in order to obtain strains and deflections of the girder during storage, erection and operation of the footbridge's girder. Actual contribution describes design, production and installation of footbridge. Main part of this paper is focused on results of long term monitoring of UHPC girder and also on visual monitoring of handrail. These measurements are very important in terms of long-term behaviour of the structure and also to gather experience about this favourable material.

Résumé

La nouvelle passerelle précontrainte faite en béton à ultra hautes performances (BFUP) a été installée dans le village de Čeperka au-dessus du canal d'Opatovicky. La poutre en BFUP a été coulée dans les installations de l'entreprise Skanska. Faisant partie de la conception de la passerelle, les garde-corps en BFUP ont également été fabriquées à partir de BFUP coloré. Les sociétés Skanka et Pontex, en coopération avec l'institut Klokner, ont développé le BFUP utilisé pour la construction du pont. Les propriétés du matériau ont été vérifiées pendant tout le processus de développement et de production. Pendant le coulage des poutres, un ensemble de jauges de déformation ont été installées afin d'obtenir les valeurs de déformation de la poutre pendant le stockage, le montage et l'exploitation de la poutre de la passerelle. L'article décrit la conception, la production et l'installation de la passerelle. La plus grande partie se concentre sur les résultats de l'instrumentation de la poutre sur le long terme ainsi que sur le contrôle visuel des garde-corps. Ces mesures sont très importantes en termes de comportement à long terme de la structure, ainsi que pour acquérir de l'expérience sur ce matériau prometteur.

1. INTRODUCTION

UHPC as a material is heavily promoted and researched all over the globe and it was used for a numerous significant applications, mainly in North America, Japan, Australia and Western Europe. The first applications have taken place also in the Czech Republic for a reconstruction of a bridge over the highway R10 at the Benatky nad Jizerou and unique cable stayed footbridge over the river Elbe in Celakovice. Most commonly it is used in bridge structures, mostly in bridges for cyclists and pedestrians. However, they are also known applications in the construction of buildings such as prefabricated wall panels in Aubervilliers in France or thin-walled facade panels in Malmö [1-5].

In the terms of footbridge design, the long-term monitoring is also important. Laboratory tests show very good results of the UHPC material in the long-term horizon, both in strength and especially durability. The test and monitoring performed on real structures helps to gain an experiences and knowledge about the behaviour of the material and the structure exposed to ordinary conditions. Methods of the monitoring and evaluation of the achieved results are long term monitoring of deflection, strain and development of cracks.

2. DESIGN AND PRODUCTION OF UHPC FOOTBRIDGE

In 2014 the opportunity came to make and build an experimental construction of the bridge girder made from UHPC. It was the modernization of the railway Hradec Kralove - Pardubice - Chrudim. Construction - section applies to raildoubling Steblová - Opatovice nad Labem, object SO 04-38-09 - footbridge across the Opatovicky canal.

2.1 Design of UHPC girder

The original design considered a single monolithic frame construction with consoles with a span of 15.3 m of concrete class C35/45-XC4, XF3. The construction of the footbridge was designed as a prestressed girder (2 pieces of 12 - ø15,7 mm strands cables at the lower part of girder and 2). Total volume of used concrete was about 14.0 m^3.

Pontex Company designed a significantly thinner and more efficient girder shape of a double prestressed "T" cross section, and made of UHPC Class C 110/130 XF4 (Figure 1). UHPC volume is about 2/3 less (about 4 m^3). Favorable properties of UHPC allowed to implement a thin-walled construction with 14 prestressed cables ø15,7 mm. The thickness of the webs is 50 mm and the ribs 80 mm. To maintain structural rigidity, the deck is reinforced by ribs (height 50 mm) at a distance of 1 m between the legs of tee with diminishing height toward the edge of the webs. Dosage of the steel fibers was 1.5 % and maximum used aggregate was 2 mm. Handrail is attached using the embedded bushes at the edge of the deck. Due to the manufacturing reasons precast bridge is designed with one-sided inclination. In the precast plant the bridge was casted with the deck in horizontal position and then rotated to the final position. Precast girder is complete monolithic. Additional constructions (wings) were made of concrete C35/45-XF4 (total volume of 1 m^3).The structure and its parameters considerably exceed the parameters of the original design, concrete has also high durability against freeze/thaw cycles and it is completely non-absorbent. The element is considered to be mounted in one piece. The total weight is lower than 13 t, which is a very favorable value.

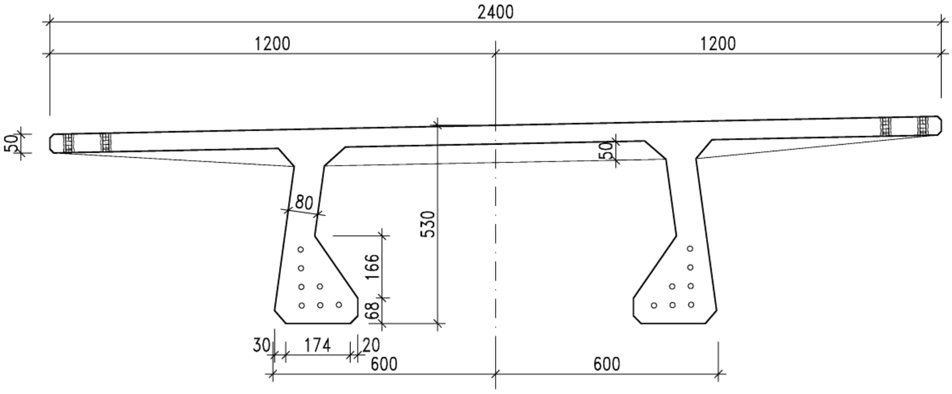

Figure 1: Cross section of prestressed footbridge beam from UHPC

2.2 Production of precast prestressed UHPC girder

Concrete mixture class C110/130 XF4 with scattered steel reinforcement according to the Model Code 2010, the fib, Final Draft 09/2011was designed for the construction of precast prestressed UHPC girder. Fresh UHPC with scattered steel reinforcement was produced at the precast plant Steti with a maximum mixer capacity of 1.5 m^3, equipped with an automatic control system. After the previous preparation of the mold a fresh UHPC was transported from the concrete plant to the production hall with a special truck and then cast into a steel mold, combined with plywood. The procedure weighing, dosing, mixing and producing the entire girder was accurately described in the technical regulations prescribed by KI. Completely cleaned mold from dirt and remain of bearing agent was filled by UHPC without any additional compaction of fresh concrete. UHPC slowly spilling itself, the surface was aligned. It was then sprayed against water evaporation and smoothing until the surface was without air bubbles creating. The production sequence is illustrated in Figures 2 and 3.

Figure 2: Pouring of the fresh UHPC

Figure 3: Curing of the prestressed UHPC girder

2.3 Production of handrail panel from coloured UHPC

Instead of the originally designed steel handrails, Pontex company designed steel balusters, which will be filled with handrail panels made of UHPC. Shade of handrails panels DB 602 has been prescribed in the project documentation. It had to be followed not only by steel balusters, but also by handrail panels. At first preliminary tests of casting and curing of handrail panels were executed. Because the individual components of UHPC have to be weighed in laboratory with an accuracy of grams, mixer M250 had to be used. The procedure dosing, mixing and producing the entire facade panels has been exactly described in the technical regulations. To the completely cleaned a reinforcing net was inserted. Reinforcement was anchored to the longitudinal angles. First, a series of tiles with different doses of inorganic pigments and tiles was made. Final decision has to be used for real handrail panel onsite (Figures 4 and 5).

Figure 4: Detail view on handrail panel made from coloured UHPC

Figure 5: Final view to installed footbridge with handrails

2.4 Results of material tests of UHPC

In parallel with the production of prestressed girder a number of additional tests on various specimens were carried out in Klokner Institute of Czech Technical University in Prague. The results of these tests are always determined from the average of three specimens. Modulus of elasticity was about 41/43 GPa (measured on cylinders/beams), compressive strength about 125 MPa (measured on cubes 150 and 100 mm) and flexural strength about 27 MPa (measured on beams 40 x 40 x160 mm). Creep and shrinkage are also laboratory measured. These values will be compared with long term monitoring of strain (deformation) of the girder.

Before casting, resistive strain gauges were installed into girder for measuring deformations in short intervals during prestressing girder and then at longer intervals for determination of deformation due to the development of volume changes and the effect of the creep and shrinkage. Currently ongoing continuous measurement is installed and results will be presented at part 3.

2.5 Installation of footbridge

The mounting girder footbridge was in October 2015. Footbridge was transported on truck from Steti to Ceperka. Figure 4 shows the finished footbridge UHPC including additional casted cross beams and wings at the village Ceperka, across Opatovicky canal. Steel balusters and handrail panels were installed after installation of the girder.

Figure 6: Installation of the prestressed UHPC girder

3. LONG TERM STRAIN MONITORING

3.1 Long-term monitoring with use of strain gauges

During the production of the girder integrated temperature sensor and a resistive strain gauges (type TES/5.5/T – Gage Techniques) were installed in the girder. Strain, respectively deformation and temperature development has been monitored during production, storage, installation and during operation. Also long-term behaviour of the beam is now measured and evaluated. Measurement was initiated immediately after the casting, when the reading interval set after 1 minute. After a few weeks interval was reset to 1 hour. Values of deformation and temperature are read continuously during operation of the footbridge.

3.2 Description of the strain gauges and their location in the girder

Figure 7: Bottom and upper strain gauges in girder

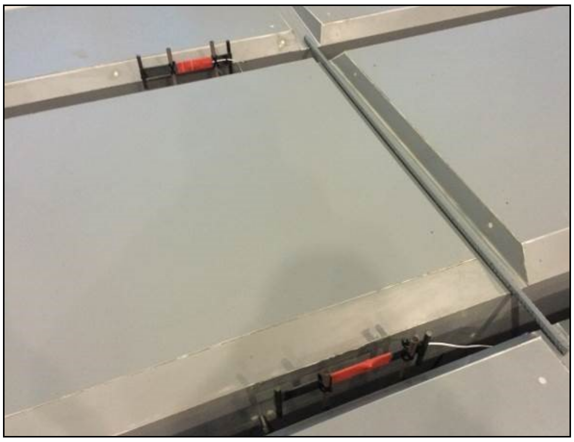

Figure 8: Two upper strain gauges in the bridge deck

Development of the strain of concrete at the time is measured by four resistance strain gauges. Two pairs of strain gauges together with temperature sensors were placed in the deck and two pairs in the lower part of the leg of tee between the prestressing strands so that in each leg of tee, respectively, in cross section above were placed in each one or two sensors. Location and fixation of the strain gauges in a girder and deck are presented in Figure 7 and Figure 8.

3.3 Results

Deformation was measured in the middle of the 15.3 m long girder. Reading and downloading of the measured values was performed at intervals of 2-3 months depending on the frequency of each measurement. The results of deformation at different time intervals are shown in these graphs in Figures 9 and 10. The trend of deformation development in time is better shown in the graph in Figure 10. The empty part of the graph represents a problem with measurement device. After this problem was fixed, measurement is still working.

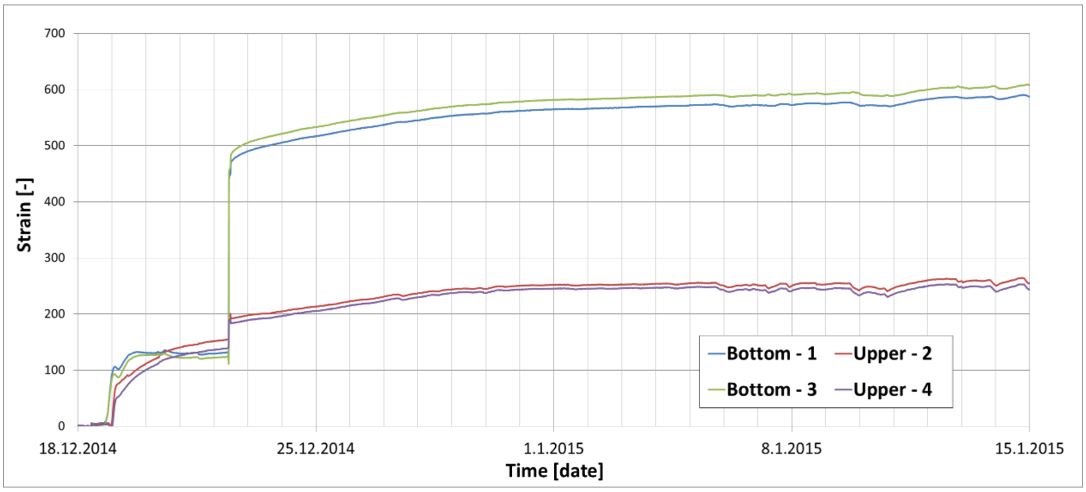

Figure 9: Strain development at first 3 months

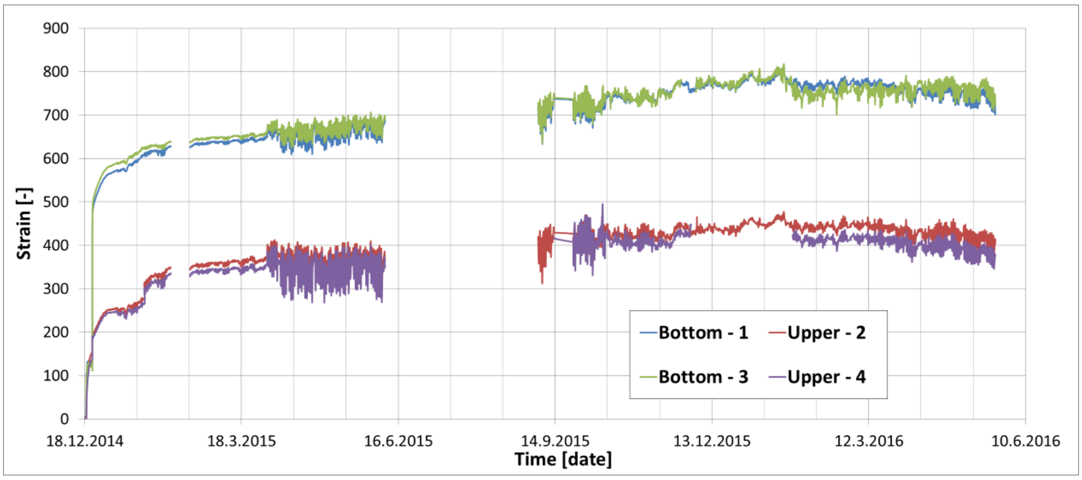

Figure 10: Strain development after 18 month

The most significant increase in deformation was observed during prestressing of the beam on the third day after casting. The graph shows the increase in deformation especially at the bottom of the legs of tee, where a majority of the tendon are located. After transporting the beam from the hall to the exposed area the graph shows the influence of temperature on deformations - scattering of measured values dependent on the daily cycle. After installing the footbridge to the final position and due to the development of concrete material scatter of the values is smaller. Measurements showed an evident stabilization of deformation in time and no unintended behaviour of the structure. Over the last year there was an average measurement of deformation growth of 50 microstrain. This value corresponds to a minimum - 0.76 mm for entire length of the bridge. Culminating point when it reverses the direction of deformation (decrease) is due to the principle of creep - the beam was stressed at the beginning of the most compressive preload force. Compared to the ordinary concrete, which has a creep coefficient about 1,1 (28 days, t_0 = 3 day) and 2,2 (170 days, t_0 = 3 day) a UHPFRC has lower creep coefficient – about 0,8 (28 days, t_0 = 3 day) and 1,4 (170 days, t_0 = 3 day). After some time, final disposal and loss of preload changes the stress distribution over the beam cross section and its creep. The results of these measurements are important in the longer term, such as where sudden drops or deformation downward trend may indicate a potential construction problem.

4. LONG TERM POSITION AND HEIGHT MEASUREMENT

The survey was performed in order to determine the subsidence of the footbridge from the creep and shrinkage and also to obtain information about the girder stability. A Trimble S6 total station and Groma 8 computing software were used to carry out these measurements. The heights were set in the Baltic height system.

Local network points were stabilized by surveying nails put in to the girder's concrete and by dents drilled in the top of each screw joining the handrail columns in the girder. The position/placement of the points was chosen according to the following scheme: 4 on each end and 4 in the middle of the span, according to Figures 11 and 12.

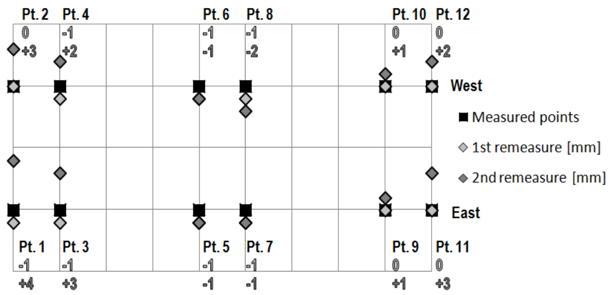

Figure 11: Results from the height measurement of the girder

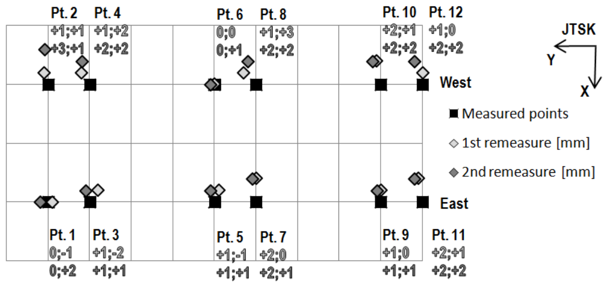

Figure 12: Results from the position measurement of the girder

The measured deformations are not significant and do not have any serious impact on the function of the structure. Yet, all the measuring will continue in order to validate the presented conclusion. Obtained results in long term horizon will be put into a context with long term monitoring of the strain development.

5. VISUAL CONTROL OF HANDRAIL PANELS

The UHPC handrail panels were fitted into a steel frame on both upper and lower edge. By the sides, they were fixed by screws to the steel columns. Since the longitudinal thermal expansion of the steel and concrete differs, some micro cracks were expected to occur in the area of handrail panels. This fact is caused because of thickness of the panels and local stress in anchorage, which was designed with was designed to allow movement but with different toughness compared to UHPC panel.

5.1 Description of the visual monitoring

The visual monitoring of the panels was proposed so as to describe if and where the cracks occur. Micro cracks have arisen soon after the installation of the panels. The first monitoring was done on 8th June 2016 and it should have recorded the "zero condition", which shall be compared with further measurements. A form was created for each panel and the width, length and position of every crack has been recorded. The panels were indicated with a letter representing the side of a footbridge (W – west, E – east) and a number, representing the order from the railway station. All cracks which were visible during the daylight were inspected.

5.2 Records gained from the "zero condition" control

The panels were divided by the number of cracks into four groups – green (no cracks or 1 crack), yellow (2 to 5 cracks), orange (6 - 10 cracks) and red (> 10 cracks). From the total 18 panels were 9 in the green and 5 in the yellow group. Two panels were in the orange group and the two remaining panels were amongst the red group, thus having more than 10 cracks (18 and 21 cracks), as can be seen on Figure 13.

W 1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9
E1	E2	E3	E4	E5	E6	E7	E8	E9

Figure 13: Number of cracks in panels (green 0-1; yellow 2-5; orange 6-10; red >10)

The most harmed panels were E2 and W7. The E2 panel showed 21 cracks with the crack area of 37.34 mm^2, while the W7 panel displayed 18 cracks with the area 46.25 mm^2. The total crack area of all panels was 189.09 mm^2, from which about 53 % were on the east-sided panels and 47 % on the west-sided panels. The area of a crack was established as a product of crack's length and its maximal width. The widest crack was 0.2 mm wide and this value has occurred three times. The most common crack was 0-0.05 mm wide. Most often (37 %) the crack has occurred nearby the middle opening in the panel. As it is evident from Figure 14, the location of the panel has no visible influence on the total crack number or area. On the other hand, cracks occur mainly in the surrounding of the middle opening. The first and the last panels on each side showed no crack. It this doubtful, if this fact is caused by the location of the panels, or by the fact that these panels were shorten to about 65 %. Air temperature was about 21 °C during measurement.

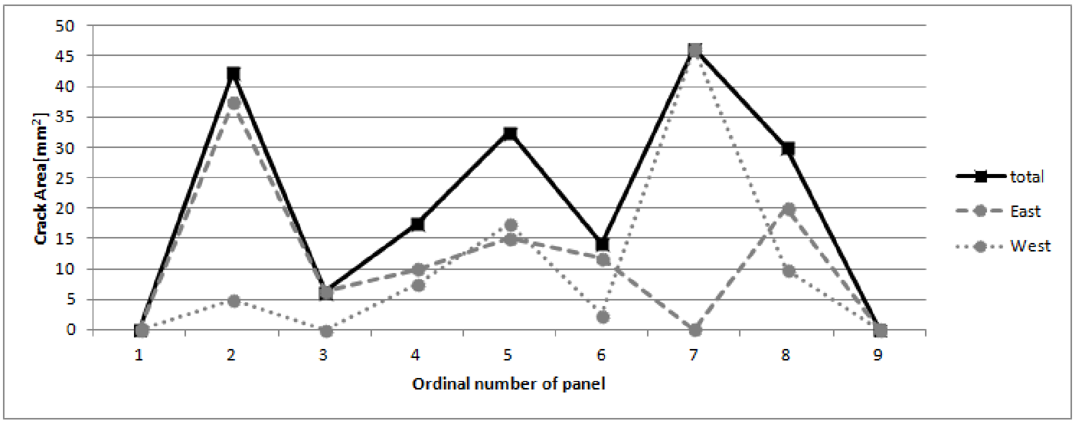

Figure 14: Crack area according to the panel position

5.3 Changes of cracks after following controls

One another control was made. The crack area has risen up by some 2.5% to a total of 193.95 mm^2. The number of cracks has increased to 95 from original 75 cracks. Thinner cracks has occurred mainly, hence the total area did not rise significantly. Cracks distribution among the panels can be seen on Figure 15. The control has been performed on 21st September 2016. Air temperature was about 15 °C.

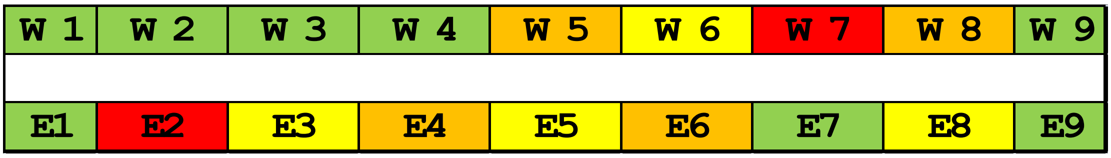

Figure 15: Number of cracks in panels after second control (green 0-1; yellow 2-5; orange 6-10; red >10)

6. CONCLUSION

The UHPC is very promising material. High compressive strength, high tensile strength and excellent durability allow to design modern and optimized construction. Extensive research made in Klokner Institut, Skanska and Pontex company in field of material mixture optimization, verification of material properties and application in real construction led to design modern footbridge across Opatovicky Channel, wich is one of the first bridge construction made from UHPC in the Czech Republic. Whole project shows and highlights possible and real application of modern material focusing on long term durability.

Long-term monitoring of the footbridge across the Opatovicky channel helps to expand knowledge about the behaviour of UHPC in the longer time period and also about the creep and shrinkage characteristics of the girder with comparison to laboratory tested specimens. The results of these measurements are important in the longer term, such as where sudden drops or deformation downward trend may indicate a potential problem on which it is possible to respond. Visual crack development control has a positive impact to optimization of new construction details designed for new constructions. All gained data confirmed good function of the footbridge and motivates to keep the measuring to continue.

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REFERENCES

[1] J. Tichý, J. Kolísko, M. Kalný, P. Huňka, First practical implementation of UHPC in Czech Republic, 8th CCC congress (2012), Plitvice Lakes, Croatia.
[2] P. Y. Blais, M. Coutere, Precast Prestressed Pedestrian Bridge – World´s First Reactive Powder Concrete Structure, PCI journal (1999), Torino, Italy.
[3] J. Tichý, J. Kolísko, M. Kalný, J. Komanec, Destructive Tests of Prestressed UHPC Beams, 10th CCC congress (2014), Liberec, Czech Republic.
[4] M. Kalný et al., Cable-Stayed Footbridge with UHPC Segmental Deck, Key Engineering Materials vol. 629-630 (2014), Pfafikon, Switzerland.
[5] J. Tichý, D. Čítek, J. Kolísko, J. Komanec, B. Slánský, M. Hubka, S. Řeháček, UHPC Footbridge over the Opatovicky canal, Solid State Phenomena vol. 249 (2016), Pfafikon, Switzerland.