APPLICATION OF UHPC JOINTS OF CONCRETE ELEMENTS

VÍTEK Jan L. [1], ČÍTEK David [2], JURSÍK Pavel [3], KOLÍSKO Jiří [4], COUFAL Robert [5]

Abstract

Precast concrete elements are usually connected using joints filled with ordinary concrete. The joint must allow for a reliable transfer of tensile forces in steel reinforcement. If the joint is small the reinforcement must be connected by welding or by mechanical connectors. Welding of reinforcing steel is often not allowed and mechanical connectors may be expensive. If the joint is filled by ultra high performance concrete (UHPC), the tensile forces in steel reinforcement may be efficiently transferred. Extensive experimental research carried out at the CTU in Prague has proven that the anchorage length of the steel reinforcement and also that of prestressed steel in UHPC is significantly shorter than that in ordinary concrete. It allows for designing a very short overlaps of steel bars in UHPC. If the joint of precast elements is made of UHPC, it may be rather small and no welding or mechanical connection of steel is necessary. The joint may be produced easily and at reasonable costs. A series of experiments was designed and executed in order to evaluate the performance of joints subjected to shear and bending. The results of bond tests and the results of tests of joints will be presented in this paper.

Keywords: UHPC, bond of reinforcement, joints, composite beams

1. Introduction

Efficiency of composite bridges may be increased if the concrete slab is made of precast elements. The construction time can be shorter when modern technology and advanced materials are used. Favourable material properties of UHPC [1], especially high bond stress, allow for a very significant reduction of the anchorage length of reinforcement. The dimensions of joints of precast concrete elements may be optimized, i.e. significantly reduced. It leads to application of small amount of UHPC, which may result in a cheaper

[1]VÍTEK Jan L., Metrostav a.s, Koželužská 2246, 180 00 Prague 8, and CTU in Prague, Czech Republic, vitek@metrostav.cz

[2]ČÍTEK David, Klokner Institute, CTU Prague, Šolínova 7, 166 08 Prague 6, Czech Republic, david.citek@klok.cvut.cz

[3]JURSÍK Pavel, CTU Prague, Thákurova 7, 166 29 Prague 6, Czech Republic, pavel.jursik@fsv.cvut.cz

[4]KOLÍSKO Jiří, Klokner Institute, CTU Prague, Šolínova 7, 166 08 Prague 6, Czech Republic, jiri.kolisko@klok.cvut.cz

[5]COUFAL Robert, TBG Metrostav s.r.o., Rohanské nábřeží 68, 186 00 Prague 8, Czech Republic, robert.coufal@tbg-beton.cz

design e.g. at precast concrete composite bridges. Another reason of using UHPC as a material of joints is its capability to transfer local high stress concentrations. The number of shear connectors may be significantly reduced provided their structure is adapted to the anchorage in UHPC. It is possible to design shear connectors locally in groups instead of continuously distributed along the entire length of the top flange of a steel girder. The experience from already erected structures around the world shows that UHPC, used as a material of joints, may be a very good alternative, which results in excellent structural performance, increased durability of joints and makes acceleration of bridge construction possible.

2. Bond of reinforcement in UHPC

Extensive research program of bond between reinforcement and concrete and especially UHPC was carried out in Klokner Institute, CTU in Prague. Bond is one of the basic parameters for design of concrete structures, since it influences especially the anchorage length and then the design of the structure. Steel reinforcement in concrete requires designing the anchorage length for reliable transfer of the tensile force in steel bars into concrete. The shear stress between reinforcement and concrete and its distribution along the anchorage length of the reinforcement are the key parameters for the design of advanced structures made of UHPC with emphasis on their reliability and long-term durability. For evaluating the average shear stress on the boundary of the steel bar and concrete the RILEM RC6 recommendation was used. The steel bar with anchorage length 5 x diameters is embedded in the cube with dimensions 200 x 200 x 200 mm and then pulled out. In order to simplify the evaluation of experiments the assumption of uniformly distributed stress is accepted. The average shear stress is given by the ratio of tensile force in the reinforcement and contact area between steel bar and concrete. The experiments, which were carried out, had two parts. The results of the first part did not lead to failure of bond, in the second part the conditions were modified, in order to get the expected failure mode.

In the first part of the experiment, the three diameters of steel bars embedded in UHPC were tested (12, 16 and 20 mm). For comparison the same tests were carried out using the cubes made of ordinary concrete of the class C30/37. The failure of steel bars was observed at all specimens made of UHPC, while the failure of bond was observed at all specimens made of ordinary concrete. The average bond stress was significantly lower than that measured in the specimens made of UHPC [3].

The second series of tests was focused on the reduction of the anchoring length to 4 diameters, 3 diameters and 2 diameters of the steel bar. The balance between tensile strength of the bar and the bond capacity at the reduced anchoring length was searched. These tests showed that anchorage length of 4 diameters is sufficient (the failure of steel bar was similar to those with the anchorage length of 5 diameters). The failure in bond appeared when the anchorage length was reduced to 2 diameters of steel bar. The highest average shear stress was reached by specimens with the anchorage length of 3 diameters. At this value of anchorage length the largest ratio of tensile strength, which was close to the strength of steel and concrete reinforcement contact area, was observed. It can be concluded that the using of UHPC was significantly (about 2.5 times) increased the maximum average bond stress compared to normal concrete C30/37.

3. Initial experiments on UHPC joints

The results of bond tests led to the conclusion that the application of UHPC can significantly reduce the anchorage length and the overlaps of reinforcement compared with the ordinary concrete. On the basis of these tests the experimental model of UHPC joints of precast deck panels was designed [2]. The thickness of the bridge deck slab of 250 mm was assumed, since it corresponds to the realistic bridge design. The model was designed 0.6 m wide and 2.8 m long. The model represented the slab subjected to bending. Two parts representing precast slab 250 mm thick in the full scale were made of ordinary concrete. Based on the experience of the previous pullout tests, the joints were designed only 200 mm wide. The joint was located at the midspan of the slab subjected to bending. The performance of the joint made of UHPC was observed under increasing bending moment up to the collapse. Two alternatives of reinforcement (reinforcing loop and straight overlap of reinforcement) were tested. During the tests, the deflection of the slabs and the crack development dependence on the loading force were recorded. The tests represented the transversal bending of the bridge deck above the flange of the steel beam. Three elements were tested for each alternative of reinforcement. Totally 6 specimens (Fig. 1) were tested (three in individual alternatives of the reinforcement).

Fig. 1: Precast concrete deck with UHPC joint

Test specimens were initially loaded in 5 cycles up to about ½ of their load bearing capacity (75 kN – serviceability limit state level). During the test, cracks development was monitored, and the load values at the first crack level were recorded as well as the crack widths at the level of 50% of the total estimated load carrying capacity. Then the load was increased up to the failure of the slabs. The loading process was controlled by force when loading up to the serviceability level and by displacement (deflection growth), when loading until failure. Collapse of the model was achieved at the load level slightly higher than expected (in the range 160 kN to 170 kN, in dependence on the reinforcement type). Similar response was observed at all tests. The main failure crack was located either on the boundary between UHPC and ordinary concrete or in adjacent ordinary concrete. When the load reached a load level of 75 kN, cracks with maximum width of 0.3 mm were observed. No extension of the crack width was observed during cycling load. There was no failure of the specimen in bond of reinforcement in UHPC joint, which was considered as an important conclusion. Such result would be completely acceptable for a characteristic load combination in SLS. The specimens with simple overlap of reinforcement exhibited slightly higher load carrying capacity. The statistical scatter of load deflection curves was rather small, which has proven, that the structure performs regularly and the system is not extremely sensitive to any phenomena.

4. Composite beams

Excellent results of experiments of UHPC joints of precast deck elements led to design experimental model of UHPC connection between steel girder and precast concrete deck. This experiment intends to verify the performance of the joint closer to its reality. The joint is subjected to transversal bending, to longitudinal shear between concrete and steel and to longitudinal bending. The concrete over the steel beam resists in the supports areas of the continuous bridge to biaxial bending and to shear. In order to fit the performance of the model to the actual performance of the bridge slab, the cantilevers were chosen as appropriate models, which satisfy the requirements on tests and the dimensions of which will not be too large. Their dimensions are smaller than that of the real bridge. Composite beams are 3.8 m long, concrete deck is 150 mm thick and the steel girder is 400 mm deep. The shear studs are the most usual shear connectors. They are designed for application in ordinary concrete. Their dimensions are accommodated to the failure ratio between concrete and steel. I.e. the pull out force defining the concrete failure and the load carrying capacity of the welded joint of the stud to the steel beam are balanced. The usual studs are therefore rather long (corresponding to the concrete strength) and thin. Such dimensions are not suitable for their application in the UHPC. The suitable connectors should be shorter and their diameter should be larger than of those which are available on the market. Therefore it was decided to replace the shear studs by a perforated steel sheet working as a shear connection, which may be designed for the purpose of the experiment in a more suitable way. The loading is applied by two forces acting on the cantilever on the concrete slab outside of the axis of the steel beam. The load was distributed along the length of about 1 m, in order to induce a transversal bending moment in the concrete slab. The slip between concrete deck and steel girder, the deflection of the end of the cantilever and the edges of concrete deck under loading cylinders were measured. The scheme of specimens is shown in Fig. 2.

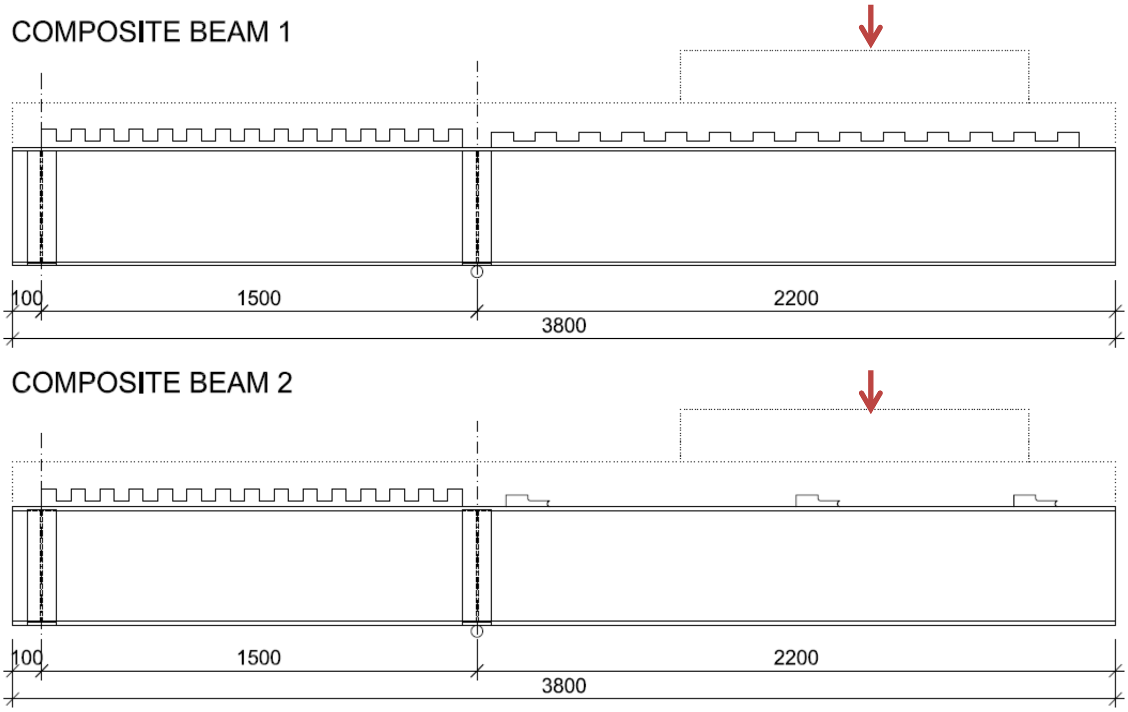

Fig. 2 Scheme of two types of composite beams – ordinary beam without joints and a beam with UHPC joints

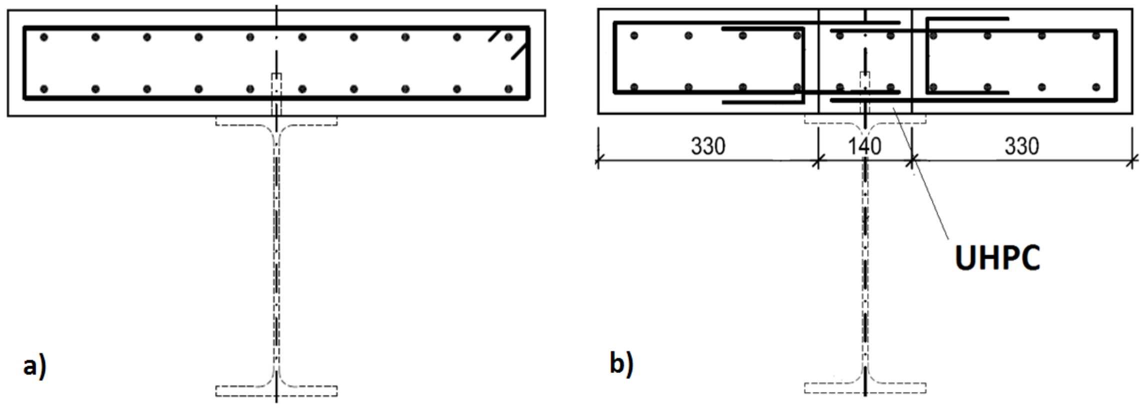

Fig. 3 Cross-section of the beams a) cast in situ slab, b) precast slab with the joint

Two types of composite beams are examined. The first (beam 1) was made of ordinary concrete without the joint. It represents usual cast in situ composite bridge deck. The second type of composite beam (beam 2) has a two parts of ordinary concrete slab with the joint filled by UHPC and represents precast concrete deck. The perforated steel sheet design was different for each type of connection. In ordinary concrete perforated sheet was welded along the entire length of cantilever and in the UHPC joint small parts of sheets were locally welded in a cantilever part. In the left part simulating fixed end of the beam, the perforated steel sheet is identical at individual beams, since the failure in shear should be avoided in this part.

At first the composite beams with cast in situ slab were tested. The results prove that welded perforated steel sheet is a sufficient connector. Almost no relative slip between the concrete slab and the steel beam was measured. The ultimate load of third specimen was about 932 kN. Extensive numerical analyses were done for verification of experimental results. The analysis is still continuing but some results are plotted in Fig. 4. Composite beams with UHPC joint are going to be tested after numerical analysis of first type of specimens is finished.

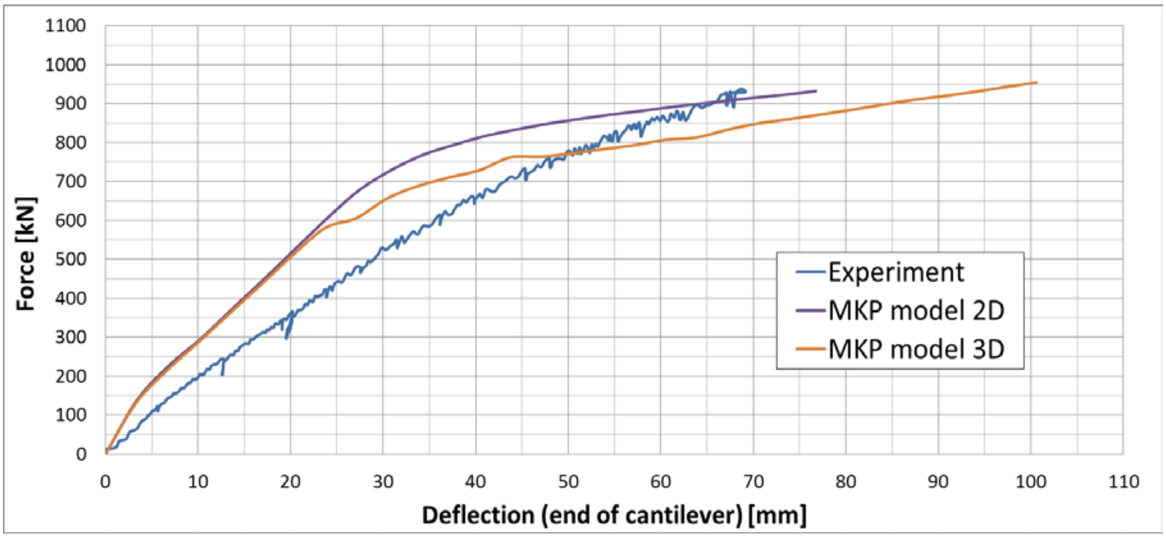

Fig. 4 Comparison of load deflection diagrams of experiment and numerical analysis

5. Conclusions

The first applications of UHPC can be found in the Czech Republic in both, building and transport structures. The first experiments which have been executed at the CTU in Prague show that also joints may be a field, where UHPC can find its application in load carrying structures. The high strength of UHPC in compression as well as in tension predetermines UHPC to be used in areas with high stress concentrations. The joints are exactly those locations where the stress may be high and where the interaction of stress in different directions takes place. The excellent bond between steel and UHPC makes it possible to reduce the size of joints, which is appreciated from the technological as well as from the economical point of views.

The experimental programs which are being executed follow two purposes:

1. A practical verification of an actual performance of a complex structural detail. Without an experiment it would be very encouraging to rely only on numerical analysis at such complex structural details.

2. From experimental results the necessary input data for numerical analyses will be received.

At the moment the reference specimens with the slab made of ordinary concrete were tested and satisfactory function of the shear connection using a perforated steel sheet has been found.

The experimental program will be continuing and when the performance under main loading cases will be checked, an experimental structure will be built.

Acknowledgement

The research was supported by Research centre CESTI, project No. TE 01020168. The tests were carried out in laboratory of Klokner Institute, Czech Technical University in Prague.

References

[1] VÍTEK, Jan L., COUFAL, Robert, ČÍTEK, David: *UHPC - Development and testing on structural elements*. Concrete and Concrete Structures 2013, Žilina, 2013, University of Žilina, str. 218-223, ISSN 1877-

[2] VÍTEK, Jan L., ČÍTEK, David, COUFAL, Robert: *UHPC joints of precast elements.* Fibre Concrete 2013 - Technology, Design, Application, Praha: České vysoké učení technické v Praze, Fakulta stavební, 2013, p. 407-414. ISSN 2336-338X. ISBN 978-80-01-05240-2.

[3] ČÍTEK, David, MANDLÍK, Tomáš, KOLÍSKO, Jiří, VÍTEK, Jan L: *Soudržnost betonářské a předpínací výztuže s UHPC*. BETONÁRSKÉ DNI 2014 a 5.post kongresové kolokvium SNK fib - Zborník prednášok.,Bratislava: Slovenská technická univerzita v Bratislave, 2014, s. 207-212. ISBN 978-80-8076-114-1.