UHPC as a Lost Formwork for Bridge Structures

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Abstract: The use of UHPC in bridge structures provides many advantages but also some disadvantages. The main disadvantages are the high technological requirements and the high costs of this material. The main advantages are durability, tensile and compressive strength or ductility. Thus, the ideal application could be creating a precast shell of UHPC that surrounds normal strength concrete (NSC) to ensure durability of bridge structures such as beams or columns. This shell also makes formwork for filling concrete. The predicted behavior of the composite beam and column was verified experimentally.

Keywords: UHPC; Shell; Beam; Column; Shear stress

1 Introduction

The use of UHPC in bridge structures provides many advantages but also some disadvantages. The main disadvantages are the high technological requirements and the high costs of this material. UHPC is thus used mostly for prefabricated parts. The main advantages are durability, tensile and compressive strength or ductility. Thus, the ideal application could be creating a precast shell of UHPC that surrounds normal strength concrete (NSC) in structures to ensure its durability in bridge structures.

The research is focused on two basic types of structures - beams and columns. Samples consist of a lightweight UHPC shell which makes formwork and NSC infill. UHPC shell can be transferred by less load-bearing cranes compared to full-size precast segments. The shell may include conventional reinforcement, fibre reinforcement, and prestressing tendons and the shell itself may be prestressed. Shell beams may be temporarily supported, but it is not necessary. Other benefits besides the absence of conventional formwork are the high environmental resistance of the UHPC shell and the visual quality of UHPC.

Once the infill concrete has hardened, a composite element is created in which both the shell and the filling concrete bear the load. Many structural design options are available to make effective use of the UHPC qualities. An important part of the static calculation is a rheological model that deals with the redistribution of stress between these two materials of different qualities and ages.

The research also investigated the possibility of using secondary materials. Concrete with fluidized bed combustion-based ternary binder (FBC-TB), also called Sorfix binder, which is produced from power plant fly ash, was used as the filling material. The great advantage of this concept is precisely the fact that the filling material is not exposed directly to the environment, because it is protected by a durable shell. If the structure is properly insulated, then water and chemicals should not get to the infill.

The shear strength of the material interface, a composite beam and a composite column both made of UHPC shell and filling concrete were tested experimentally.

2 Methods

To ensure the transfer of shear forces between the shell and the filling concrete at the area of the material interface, two methods are proposed. The first option is creating texture on the shell contact surfaces by inserting a matrix into the formwork. The second option is using steel net as formwork. The choice of the option depends on the structure. In the case of the steel net, reinforcement can pass through this type of formwork. In the case of small elements tested, a texture of protrusions was made by button foil embedded in the formwork for the UHPC shell. Previously presented results showed sufficient shear strength at the interface [1]. The obtained data were used for the numerical model, which was made for beam and column elements.

Two mock-up experiments were arranged as part of this research. The first model represented a bridge beam, which consisted of a UHPC shell and an infill of NSC. The shell had a thickness of 40 mm. The beam was 6.8 m long and was additionally prestressed. The beam span was 6.0 m. The second element was a 2.0 m high column, which consisted of a 40 mm thick rectangular UHPC shell and an infill of NSC.

3 Results

3.1 Beam

To verify the load-bearing capacity and the failure mode, a U-shaped beam was designed. The cross-section and longitudinal section are shown in Fig. 1. Beam was supplemented with blocks at both ends for prestressing anchors and prestressing force distribution. On the inner part of the UHPC shell, a texture of protrusions was made. Two beams of identical dimensions were made. In one of them, half of the cement amount in the filling concrete was replaced with an environmentally friendly binder Sorfix. Loading and failure can be seen in Fig. 2.

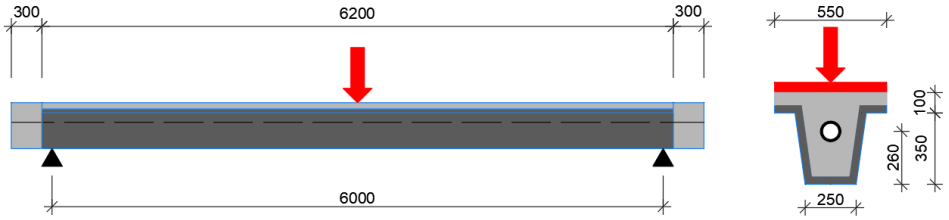

Fig. 1 Composite beam, dark-UHPC, light - normal strength concrete, in the middle is a duct for additional prestressing.

Fig. 2 Beam loading and the failure.

In the experiment, the shell itself was not prestressed. It was reinforced only with fibres and conventional steel reinforcement. The entire composite cross-section was then prestressed with an internal centric cable placed in the duct in filling concrete. The beam was designed to crush the concrete by compression and not to break the prestressing reinforcement during loading. The loading and failure of the beam are shown in Fig. 2. During loading, the first cracks were initiated in the bottom part. Subsequently, a compression failure occurred in the deck slab made of NSC. Then this crack extended and the UHPC shell later separated from the filling concrete.

The dependence of the applied force on the deformation is plotted in Fig. 3. Maximum possible shift of the hydraulic loading machine was approximately 300 mm. Once this deformation was reached, the beam had to be unloaded and an extender was placed. Then the loading continued until a deflection of approximately 500 mm.

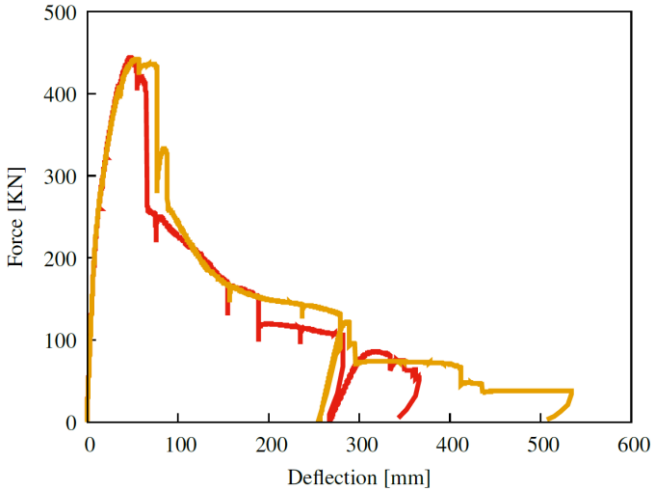

Fig. 3 Deflection of beams versus loading force.

The measured data were very close to the predictions of load-bearing capacity from the numerical analysis. This experiment provided very valuable data about the mode of failure. After reaching a deformation of 300 mm, the beam still provided a residual capacity of about 20% of the maximum load-bearing capacity. In a simplified view, this is about 40% of the design load-bearing capacity.

For large bridge beams, it would be recommended to add more connecting reinforcement to the top plate of the UHPC shell. This would prevent the delamination that can be seen in Fig. 2.

3.2 Column

The column test aimed to verify the whole manufacturing process and then the load-bearing capacity of the element. In this case, a steel net was used for the internal formwork of the shell. The shell was reinforced with longitudinal, transverse and fibre reinforcement. The column shell was concreted in the horizontal position, while the infill was concreted in the vertical position corresponding to the position in the structure. The cross-section and loading of the column are shown in Fig. 4.

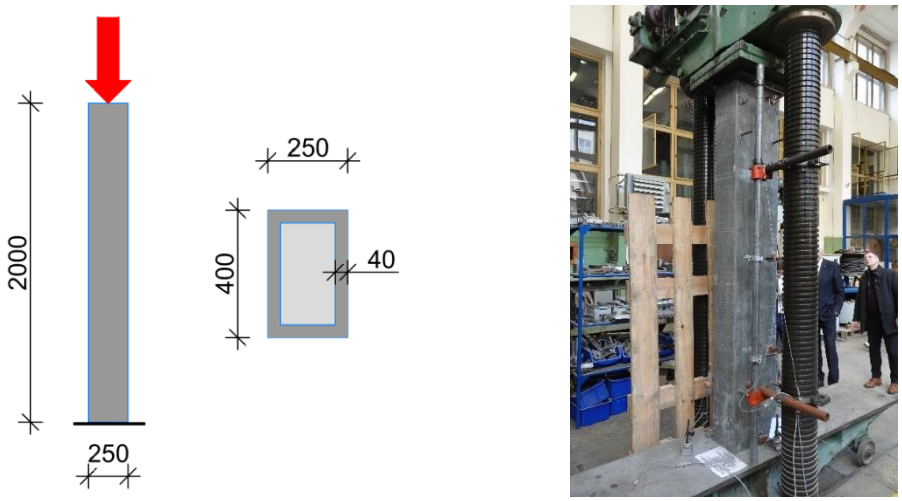

Fig. 4 Arrangement of the experiment.

The column achieved a load-bearing capacity of 4629 kN when shell failure occurred at its top, as shown in Fig. 5. The measured load-bearing capacity was lower than expected. The reason is that the loading method does not guarantee uniform load transfer to the shell and the filling concrete. More load is transferred to the shell due to the higher modulus of elasticity.

Fig. 5 Failure of the composite column.

The experiment has shown that it is necessary to pay attention mainly to the column head in real structures. This part can be connected to the superstructure by bridge bearing or directly or it can be connected to a transverse beam with bridge bearings. It seems more advantageous to create a full-size profile of UHPC in the head of the column or increase the amount of transverse reinforcement in this part of the UHPC shell.

Conclusions

UHPC has many favourable qualities that can be used for larger structures. One possibility is making composite structures combining UHPC shells with conventional concrete. The research proved the applicability of this solution to real bridge structures.

Destructive loading tests demonstrated the efficiency of this approach, the residual load-bearing capacity of elements and the mode of failure. The beam element achieved very good compliance with the predictions. It would be recommended to add more connecting reinforcement to the top plate of the UHPC shell to prevent delamination. The column element also showed a high load-bearing capacity, which could be further increased by more efficient transfer of normal force to the entire cross-section of the column and by more efficient design of transverse reinforcement at the upper part of the column.

When concreting elements made of UHPC, attention must be paid to the quality of the mixture and compliance with the technological rules. We consider it important to monitor the consistency of the mixture and its viscosity. In some cases, the mixture is difficult to work with or segregation of the dispersed reinforcement may occur.

Specimens with filling concrete, where half of the cement amount was replaced by a secondary material binder (fly ash), showed almost the same properties as the specimens with conventional concrete. Due to the properties of UHPC, this approach allows the design of a cement-free filling concrete. This can be the subject of further research.

Acknowledgements

The authors gratefully acknowledge financial support from the project CK02000047-Optimization of bridge construction and durability, using a new composite solution for UHPC and conventional concrete, mineralized admixtures and secondary materials, which was created with the support of the Technology Agency of the Czech Republic. This work was also supported by the Grant Agency of the Czech Technical University in Prague, grant No. SGS SGS23/053/OHK1/1T/11.

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