Abstract

The present research represents a theoretical and experimental contribution to the understanding of the structural behaviour of elements made of ultra-high performance fibre-reinforced concrete (UHPFRC).

UHPFRC is investigated as an advanced cementitious material offering particular potential in innovative bridge design. The optimised material composition results in high compressive strength and non-negligible tensile strength and ductility, provided by multi-microcracking. This allows significant tensile forces to be sustained by elements in bending even without the use of ordinary reinforcement. Thanks also to the material's resistance to environmental degradation, very thin structural elements can be constructed.

This research focuses primarily on the bending behaviour and design of thin UHPFRC beams and slabs. Punching-shear is also investigated as a possible failure mode of thin UHPFRC slabs. One of the main differences between other concretes and UHPFRC is that the latter requires mechanical models capable of taking tensile behaviour into account for rational structural application. Analytical and numerical models are developed in this study to simulate the non-linear bending response of UHPFRC beams and slabs. This permits the assessment of element behaviour at service states and prediction of failure loads. Theoretical research on both bending and punching-shear failure is supported by experimental research on beams and slabs made of BSI® UHPFRC with *2.5 %* volume of *20-mm* long steel fibres.

The analytical model for beams in bending takes both material multi-microcracking and macrocrack propagation with tensile softening into consideration. Multi-microcracking is modelled as a pseudo-plastic tensile behaviour, while the macrocrack is simulated based on the assumptions of the fictitious crack model. The results are in good agreement with experimental data and simulations obtained from a developed finite element model. Using theoretical results and experimental data it is demonstrated that pre-peak behaviour and bending strength are mainly governed by multi-microcracking. The propagation of the macrocrack provides only a minor additional contribution to bending strength, but, in the case of thin beams, plays an important role in providing ductility in bending. Theoretical results demonstrate that, due to the presence of pronounced pseudo-plastic deformations, size effect on bending strength is much less significant for UHPFRC than for other quasi-brittle materials, which corresponds to experimental observations. It is however shown that, even if the pseudo-plastic phase is less pronounced, thin elements develop behaviour similar to that of elements with high pseudo-plastic tensile deformations, owing to the low stress decrease in tensile softening. Nonetheless, in the absence of pseudo-plastic tensile deformations, the behaviour of thick elements approaches that of typical quasi-brittle materials, with a more pronounced size effect.

In the case of thin statically indeterminate beams and slabs, it is shown that a high level of tensile ductility can allow sufficient internal force redistribution to occur, leading to a significant increase in load-bearing capacity. Moreover, high rotations can be sustained after cracking while almost constant bending strength is maintained, resulting in a plastic-like behaviour. It is demonstrated that the theory of plasticity can thus be applied: a formulation is proposed to predict the resistant plastic moment, enabling easy estimation of the bending failure load for thin elements. The analysis results show good agreement with test results for slabs of different thicknesses. However, due to the remarkable size effect on ductility in bending, the rotation capacity of UHPFRC elements thicker than approximately *100 mm* is limited, and the theory of plasticity does not apply.

Experimental and theoretical research on the punching-shear failure of thin UHPFRC slabs demonstrates the influence of structural parameters on achieved shear resistance. A proposal is made for considering fibre contribution in shear resistance as a structure-dependent parameter, relating the critical shear crack opening to slab rotation. This approach results in more accurate predictions for thin elements with larger deformations as compared to current code predictions that overestimate resistances for such elements.

With a view to the structural application of UHPFRC in bridge design, the concept of ribbed deck slab is studied. Based on the theoretical and experimental results it is demonstrated that thin UHPFRC slabs (*40-60 mm*) without ordinary reinforcement can be effectively used in this concept: sufficient bending and punching-shear resistances to locally applied traffic loads can be ensured. With prestressed ribs, UHPFRC ribbed slabs attain high load-bearing capacity, while structural dead weight is significantly decreased. This concept could open up new vistas in the design of new structures and offers effective possibilities for the structural repair or widening of existing bridges.

Keywords: ultra-high performance fibre-reinforced concrete (UHPFRC), beam, slab, thin elements, structure, bridge, ribbed deck, bending, punching, design, plastic analysis, cracking, tensile hardening, tensile softening, bending strength, ductility, size effect