Finite element modeling of shear connectors in steel – UHPFRC-composite members

Peter Harsanyi, Sandra Ofner and Norbert Randl

Carinthia University of Applied Sciences
Villacher Str. 1, 9800Spittal an der Drau, Austria
E-mail: p.harsanyi@cuas.at

Abstract

In a research cooperationbetween GrazUniversity of Technology, Carinthia University of Applied Sciences and the industrial partners voestalpine special wire GmbH and Kirchdorfer Fertigteilholding GmbH, the load bearing behaviorof composite beams made of high strength steel (S460) and ultra-high performance fibre reinforced concrete (UHPFRC) is investigated. The project is funded by the Austrian Research Promotion Agency (FFG).

Keywords: UHPFRC, push-out tests, interface, composite dowels

1. Introduction

The high compression strength of around 180 N/mm² and the ductile behavior of ultra-high performance fibre reinforced concrete (UHPFRC) are commonly known. To activate the full potential of UHPFRC in composite structures, it is useful to combine it with high strength steel and thus create slender structures with very high load bearing capacities. In order to transfer the loads between the steel girder and the concrete deck slab in such composite structures, puzzle and other composite dowels have already been used for both normal and high strength concretes [5]. In combination with UHPFRC only a few studies have been conducted so far, therefore further investigations are required.

2. Experimental program

The experimental program consists of two different types of newly designed push-out and push-off specimens, made of high strength steel S460 and UHPFRC plates (Figure 1). The design of the composite dowels is partly based on the recommendations of the German general Technical Approval Z-26.4-56 [4], which applies for connection of steel and normal strength concrete. The used composite dowels have a puzzle and clothoid like shape. The main parameters to be investigated in theexperimental campaign are the geometry of the steel dowels, the transverse reinforcement degree and the fibre content in the concrete slab and the variation of thickness of the concrete overlay. The major principal strains and the crack pattern of the specimens are derived using a digital image correlation system (DIC).

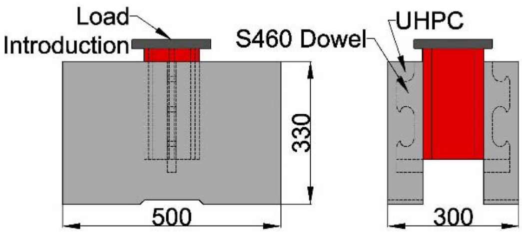

Figure 1: Push-out test (type 2)

3. Numerical analyses

The numerical 3D- simulation was performed with the common nonlinear finite element (FE-) program ATENA. This program was especially designed for the analyses of concrete and reinforced concrete structures. Topics like stress behavior in the structure till the peak force is reached and also after peak behavior can be analyzed as well as dynamic loading. A summary of the most important features like biaxial strength failure criterion according to [7], triaxial fracture-plastic model according to [8], [9], smeared crack formulation and crack band model approach according to [2] is given in [10]. For calibration of the used material UHPFRC in ATENA, three-point bending tests were performed according to [1] to reproduce the tensile behavior, as well as compressive tests to determine theafter-peak plastic strain and the plastic displacement w_d after reaching the maximum compressive strength.

3.1. Material models

The calibrated material was incorporated as a user defined material in ATENA, in which the relations of the different parameters like tensile strength with elongation and compressive strength with contraction can be implemented as diagrams. The added reinforcement was modelled by a bilinear stress- strain law with hardening. The composite dowel was modelled with a bilinear law according to Von Mises failure hypothesis. The yield and tensile strengths values of the bars and the dowels were taken into account according to manufacturer's certificates from uniaxial tension tests as well as the maximum strain at fracture and modulus of elasticity. To model the interface between steel and UHPFRC, parameters such as normal and tangential stiffnessand cohesion of the interface were calculated like recommended in [3], depending basically on the tensile strength of the weaker material next to the interface and the element size nearby the interface. In the present case the crack model was defined as fixed which causes a reduction of the shear modulus after cracking [6].

3.2. Modelling in ATENA

Because of the symmetric setup of the performed push-out tests, only one quarter of the structure was modelled in ATENA. The symmetrical plane in the middle was modelled with a fixture normal to the plane to simulate the effect of the other half of the model, as seen in Figure 2. The model was also fixed in the

vertical direction on the bottom steel plate and in the second horizontal direction. The added reinforcement bars were modelled with perfect bond boundary conditions as 1D elements, which means that they only have stiffness in one direction. The load was introduced as a surface displacement (1 mm per load step).
To perform the non-linear analyses, Newton-Raphson was applied with an update of the stiffness matrix after every single iteration step. For the iterative convergence procedure for equilibrium, at each load step a limit of 80 iterations was set and convergence criteria settings were chosen as recommended [3].

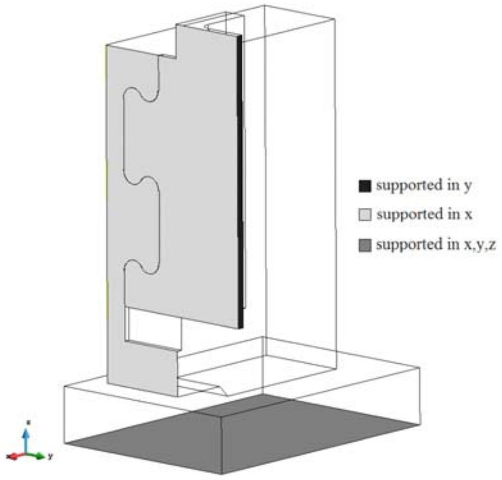

Figure 2: Supports in ATENA model

The whole system is modeled with tetrahedron elements in quadratic element order, which means that they only have integration points on each edge of the finite element. The height of the tested UHPFRC was devided into 6 elements. A refinement close to the dowel was set to investigate the local interaction between UHPFRC and steel, see Figure 3. The interfaces were modelled as volume contacts.

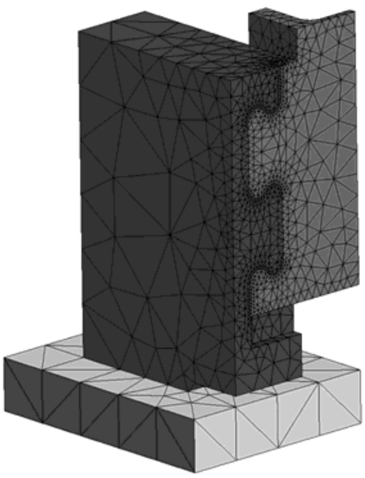

Figure 3: Model in ATENA

4. Simulation

The different test setups were simulated and compared with the experimental results. Hereby the focus lied on the crack pattern, the stresses in concrete and steel and the deformation, as seen in Figure 4. The possible four different failure modes concrete failure, steel failure, shear off and splitting of the concrete were evaluated.

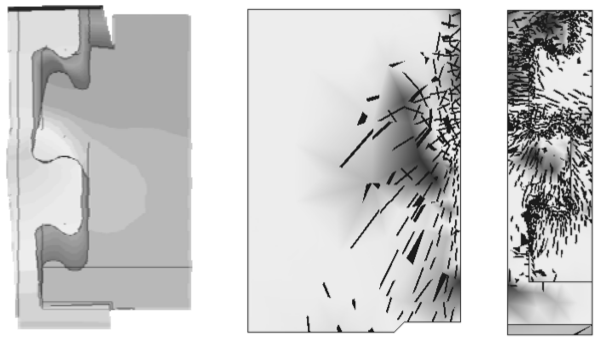

Figure 4: Deformation (left) and crack pattern (right)

5. Conclusion

The variation of the thickness of the concrete layer shows that there is an influence in the spread of the cracks. The added transverse reinforcement in the concrete slab leads to an increase of the ultimate load bearing capacity. The varying thicknesses and shapes of the dowels show different effects like partial area pressures and that the stiffness of the system is influenced significantly.

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