Reinforced UHPFRC Tension Chords

Marion RAUCH
Civil Engineer
Institute of Concrete Structures, Hamburg University of Technology, Germany
m.rauch@tu-harburg.de

Marion Rauch (1975) received her civil engineering degree from the University of Karlsruhe, Germany and the University of Wisconsin at Madison, USA; since 2005 she is a research associate at the Hamburg University of Technology.

Viktor SIGRIST
Professor
Institute of Concrete Structures, Hamburg University of Technology, Germany
sigrist@tu-harburg.de

Viktor Sigrist (1960) received his diploma and doctoral degree from the ETH Zürich, worked as a structural engineer for several years and has been a professor for concrete structures since 2002.

Summary

Ultra high performance fiber reinforced concrete (UHPFRC) has a compressive strength in the range of 200 MPa as well as improved durability properties compared to normal strength concrete. By the addition of short steel fibers the behavior of UHPFRC in compression and tension is affected in a beneficial way. However, for structural applications conventional reinforcement is still required to obtain ductile failures. Although the mechanical properties of UHPFRC have been widely studied, UHPFRC is quite unexplored in practical applications. Therefore, the deformation behavior of UHPFRC tension chords reinforced with conventional as well as high-strength steel has been experimentally examined. In this paper an analytical model is presented which enables the calculation of the cracking and deformation behavior of reinforced UHPFRC elements in tension.

Keywords: Ultra high performance fiber reinforced concrete, tension chords, high-strength reinforcing steel, bond behavior.

1. Introduction

Ultra high performance concrete (UHPC) is characterized by high compressive (≈ 200 MPa) and tensile strengths (≈ 8 MPa). Due to the quite brittle behavior of UHPC short steel fibers are added which improve the material's ductility in compression and in tension. The tensile strength is increased as well; values of up to 10 MPa are reached and during the cracking phase a strain-hardening behavior is achieved. However, to obtain ductile failures conventional steel reinforcement is still required. Additionally, UHPFRC exhibits improved durability properties. Because of the high density of the UHPC matrix the ability to protect the reinforcement from corrosion is remarkable. For these reasons UHPFRC opens a field of new applications for structural concrete and enables the construction of particularly filigree and aesthetically appealing structures.

The mechanical properties of UHPFRC are widely studied. In practical applications ultra high performance fiber reinforced concrete is still quite unexplored. Therefore, the behavior of UHPFRC tension chords reinforced with conventional as well as high-strength steel has been examined in an experimental study with the focus on the cracking and deformation behavior. Subsequently, an analytical model was developed to enable the calculation of the cracking and deformation behavior of UHPFRC elements in tension.

2. Analytical Model and Test Results

To gain a better understanding of UHPFRC in structural applications, an experimental study was carried out at the structures-laboratory of TUHH (Hamburg University of Technology). The

https://doi.org/10.2749/222137908796292894

investigations comprised UHPFRC elements reinforced with different types of reinforcing steel; conventional as well as high-strength reinforcement was used. The focus of the experiments was on bond, cracking and deformation behavior of UHPFRC in tension. Based on the test results an analytical model was developed to determine crack widths and deformations of reinforced UHPFRC tension chords up to failure.

In Fig. 1 test results are compared to the results from the analytical model. The nominal steel stresses $\sigma_{s,nom} = F/A_s$ (where F denotes the applied force) are plotted versus average strains. Prior to cracking all specimens exhibit an almost linear elastic behavior. Due to micro cracking the stiffness of UHPFRC is reduced which causes distinct kinks in the stress-strain-curves. Because of shrinkage the applied stresses in the concrete at the formation of micro cracks are lower than the tensile strength of the concrete matrix $f_{ct,m}$. The concrete tensile strength referring to macro cracking f_{ct} is reduced as well. In the cracking stage the stress-strain-curves run almost parallel to those of the reinforcement. As can be seen, the appearance of macro cracks has only a minor influence on the stiffness of the tension chords.

The tests and the analytical model demonstrate that tension chords with the chosen reinforcement ratio and hot-rolled reinforcing steel reach maximum load at the onset of yielding (Fig 1a). Due to the yield plateau the applied load slightly drops and one macro crack controls the following deformation behavior. As soon as the fibers are fully pulled out, the specimens fail by rupture of the reinforcing steel. For the specimens with the strands a smooth transition to the yield phase can be observed and predicted (Fig 1b). In this case, maximum load corresponds to the rupture of the prestressing steel.

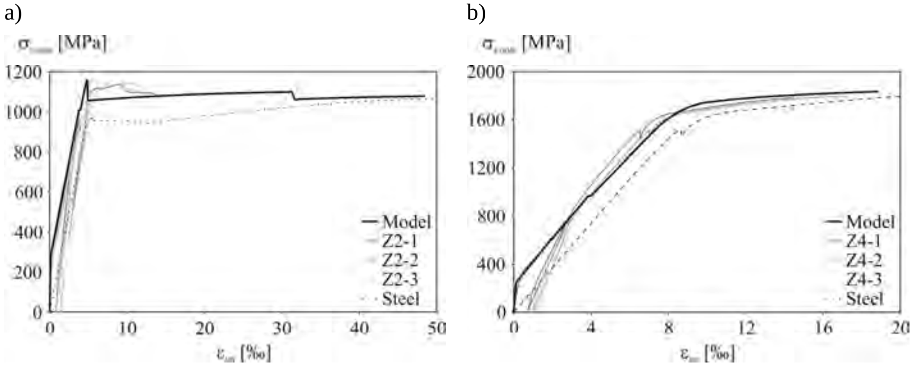

Fig. 1: Stress-strain-diagrams of reinforced UHPFRC tension chords: a) Specimen Z2, b) Z4

3. Summary and Conclusion

In this contribution, an analytical model is described that enables the calculation of the cracking and deformation behavior of reinforced UHPFRC elements in tension. The model is based on an experimental study of reinforced UHPFRC tension chords carried out at Hamburg University of Technology. The results demonstrate that the results of the analytical model are well in accordance with the experimental findings.

From this investigation, it can be concluded that there is a relative rigid bond between concrete and reinforcing steel in all load stages; bond stresses are reduced in the yielding stage but are still relevant. Tension stiffening and the stress-strain-characteristic of the steel have a significant influence on the deformation behavior. Furthermore, it can be deduced that the use of ribbed high-strength reinforcement is reasonable in combination with UHPFRC; because of the higher tensile strength moderate reinforcement ratios can be chosen. This avoids detailing problems especially for filigree structural elements. The overall aim of this research is to develop reliable procedures for the conception and design of structural members made of UHPFRC.