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Optimization-based design of structural concrete using hybrid reinforcements

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Optimization-based design of structural concrete using hybrid reinforcements

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For my loved ones.

Abstract

Optimization methods are applied to a variety of problems in engineering disciplines. In structural engineering, however, most constructions have a unique character, and optimization hence remains only sparingly used. In addition to other approaches, topology optimization carries excellent potential for the application to structural engineering problems. By providing information on where to place or remove material within a prescribed design domain, topology optimization can assist engineers at different levels of the design process. The more practice-oriented works in this field either focus on generating qualitative design suggestions, which still require manual post-processing, or resort to simplified calculation models, which inadequately describe the behavior of reinforced concrete.

The main objective of this thesis is to make topology optimization more readily available for practical application in structural engineering and to fully integrate it into the design process in order to provide reliable, qualitatively and quantitatively ready-to-use reinforced concrete (*RC*) concepts. To achieve this goal, this thesis is divided into two main parts.

The first part focuses on the development of a topology optimization approach tailored to *RC* design. This approach is based on combined truss–continuum topology optimization (*TCTO*), which couples continuum- and truss elements in a single analysis model. Trusses are associated with steel, whereas continua represent the concrete matrix by employing a bilinear material model and hence offer an appropriate representation of *RC*. A new *Optimality Criteria*-based solution strategy is deduced to improve the usability of *TCTO*. By employing this new solution strategy, a numerical study is able to identify the application limits of the most relevant input parameters, which serve as the basis of practical recommendations for generating accurate optimization results that follow engineering theory. Building upon these results, *TCTO* is further advanced to facilitate the consideration of steel fiber- and hybrid steel fiber–rebar reinforcements as well as robust multi-load optimization by including exclusive load case combinations.

The second part of the thesis is devoted to the practical application and experimental validation of the newly devised quantitative optimization methodology at the example of segmental lining longitudinal joints. The experimental analyses comprise four individual series, which focus on the enhancement of the joint by employing various reinforcement- and material concepts: low-deformation, welded rebar cages; steel fibers with and without modification of their orientation; hybrid steel fiber–rebar configurations;

and hybrid material schemes that combine standard materials and localized, high-performance steel fiber-reinforced concrete additions in sensitive areas. The results provide several insights into both the load-bearing behavior of concrete elements under partial area strip loading as well as segmental lining longitudinal joints, which are transferred into practical design recommendations.

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