11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20–25, 2014, Barcelona, Spain

CRACK FORMATION AND DEVELOPMENT IN REINFORCED-CONCRETE EMBEDDED-DISCONTINUITY BEAM FINITE ELEMENTS

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Key words: *Embedded discontinuity, Layered beam finite element, Bond-slip relationship.*

In this abstract we present our recent work on crack formation and development including implementation in a reinforced-concrete beam element [1]. Crack initiation and growth are described using the laws of damage mechanics [2] in conjunction with the fracture mechanics concepts of Hillerborg et al. [3] leading to a novel embedded-discontinuity layered beam finite element in which the tensile stresses in concrete at a pre-defined point reaching the tensile strength will trigger a crack to open.

The number of layers in the element is arbitrary and they are assembled in a beam with a rigid inter-layer connection [4] - there is neither slip nor uplift between the layers, but the layers may rotate independently, thus allowing for cross-sectional warping and formation of an arbitrary crack profile upon cracking. Another layer of zero thickness, representing the reinforcement bar with its own material parameters and a constitutive law, is embedded within one of the concrete layers and may slip with respect to this layer. A transversal crack is embedded into the element, with the assumption that it propagates across the whole depth of the layer in which the tensile strength has been reached. Any layer which has cracked in this way will thus involve a discontinuity in the cross-sectional rotation equal to the crack-profile angle in the layer, as well as a discontinuity in the position of its reference axis.

Upon cracking, the reinforcement slips with respect to the surrounding concrete, which determines the amount of tangential stress (bond) transferred from the reinforcement to the concrete as a result of the actual shape of the bond-slip diagram (see e.g. [5]). The bond-slip relationship is implemented in the present model in a kinematically consistent manner. Further degrees of freedom are defined at the nodes to account for slippage between the reinforcement and the surrounding concrete.

The resulting multi-layer beam element is derived using one rotation per layer at each of the nodes, slip of the reinforcement bar and the two displacement components at each of the nodes, and, in addition, the crack profile angle for each layer as the internal degrees of freedom.

The proposed approach is capable of determining both the position of an opening crack as well as its width and depth. This puts it in stark contrast to the widely used techniques (see e.g. [6, 7]) whereby the tension-stiffening effect is modelled on the basis of experimentally obtained force-elongation relationships for a uniaxially loaded reinforced-concrete specimen. From these results, a mean strain of the specimen may be easily deduced and used to define the constitutive relationship needed for the numerical analyses, including those which may be performed using some of the commercial finite-element codes in which used-defined constitutive models may be integrated. Within this technique, however, the actual crack positions and other properties remain unknown.

On the other hand, the present beam finite-element technique should still be considered only as a reasonable simplification of various large-scale continuum-based approaches and is developed from the motivation to present an efficient numerical alternative to these approaches, which is particularly suitable for frameworks and is still capable of predicting where the cracks should occur, as well as what their widths and depths are.

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