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A simplified and fast computational finite element model for the nonlinear load-displacement behaviour of reinforced concrete structures

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Abstract: Numerical simulation of reinforced concrete structures requires the explicit representation of both the concrete and the reinforcement bars, where the two materials are modelled separately using appropriate constitutive laws including damage variables for concrete in compression and tension. Even if this way of modelling is convenient and satisfactory, it requires a huge computational effort especially in the case of large scale applications. The aim of this paper is to develop an alternative model dedicated for the simulation of large scale reinforced concrete structures with no need to represent explicitly the steel reinforcements. Based on the literature review, the authors developed a fictitious stress-strain relationship for reinforced concrete under tension. The model is based on the shape of the slip-adhesion curve between steel and concrete proposed by the European Committee for Concrete (C.E.B.) to estimate the crack opening widths. Relationships covering the cracked stage up to the yield point of the steel are proposed depending on the material properties of concrete and steel, on the reinforcement ratio, as well as on the crack widths. The developed model was successfully implemented in the ABAQUS commercial software. The effectiveness and computational efficiency are demonstrated through some examples under tensile and bending loadings.

Keywords: concrete, steel reinforcement, crack opening, bond-slip, FEM

1. Introduction

The design process of reinforced concrete (RC) structures is generally governed by the ultimate compressive crushing strength of concrete, while the tensile loading is assumed to be carried by steel reinforcements. Thus, cracking of concrete under tensile loading is expected to occur already in the service state and cannot be avoided in most structural engineering applications. On the other hand, taking into account the contribution of the tensile zone of the concrete, in the cracked stage, to the global stiffness of the entire reinforced concrete element is one way to describe more closely the real behavior of reinforced concrete structures and so to increase the robustness and capabilities of the computational methods.

Cracking of concrete under tensile loading is a complex phenomenon which leads to progressive reduction of the stiffness of the reinforced concrete structural element. The stiffness reduction is generally a combination between cracking of concrete under tension and the local loss of the bond (adhesion) between steel bar and concrete at a fully cracked section. It is, therefore, of primary importance to accurately model and predict the stiffness reduction during the cracked stage for a proper design of structural engineering applications.

Extensive experimental and numerical studies on both small-scale and full-scale RC beams and walls have been published in the literature. In these studies the finite element method is the widely used approach to predict the behaviour of the RC elements based on 3D continuum mechanics [1-8], among others. Usually, there are two main strategies: (1) both the concrete element and the steel