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Modelling of reinforced concrete by means of homogenization approach including steel-concrete interactions

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ABSTRACT

The main focus of this paper lies on the modelling of reinforced concrete considering the main steel-concrete interactions such as bond slip and dowel action. Reinforced concrete is modelled as a composite material using an appropriate homogenization approach to describe the macroscopic mechanical response including all relevant interactions. In the present study, reinforced concrete is formulated in the framework of the Mori-Tanaka homogenization scheme assuming a three-phase composite material formed by a continuous matrix (concrete) and two different sets of straight rebars (reinforcement).

For the concrete matrix material, a multi-surface fracture energy based damage-plasticity theory is adopted in order to characterize the non-linear behaviour of concrete beyond the elastic range (Meschke et al. 1998). Cracking of concrete due to tension is accounted for by means of Rankine criterion, employing three failure surfaces perpendicular to the axes of principal (matrix) stresses $\boldsymbol{\sigma}_m$. The ductile behaviour of concrete subjected to compressive loading is described by a hardening/softening Drucker-Prager plasticity model. For the steel reinforcement, the admissible stress field within the rebar $\boldsymbol{\sigma}_s$ is described by a classical J_2-plasticity model (Simo and Hughes 1998). The non-linear regime beyond the yield stress is governed by an isotropic linear hardening law based on the von Mises yield condition.

Interfacial debonding mechanisms are taken into account by adopting a two-phase serial system consisting of the steel bar and of the bond surface (Linero et al. 2006). The redistributed stresses due to crack formation at the steel-concrete interface are governed by slip strains $\boldsymbol{\varepsilon}^i$ leading to re-formulation of the constitutive steel law. The related bond-slip vs. bond-stress relationship is derived from classical pull-out tests. The residual shear stiffness in cracked reinforced concrete (dowel action) is modelled by treating each steel bar as a beam embedded in the surrounding concrete ('beam on elastic foundation'-theory) (He and Kwan 2001). From the analytical solution given for this problem, the calculated shear stiffness is considered in the constitutive law of the steel reinforcement. The angle between cracks and the reinforcement entering the formulation is determined at initiation of cracks. Since matrix cracking is considered within the smeared crack concept, the compatibility with the adopted dowel action model is ensured.

In the proposed model the Mori-Tanaka homogenization scheme is adopted in order to derive the macroscopic constitutive law for the composite behaviour (Mori and Tanaka 1973). Reinforced concrete is regarded as a three-phase composite material represented by the concrete matrix and two different sets

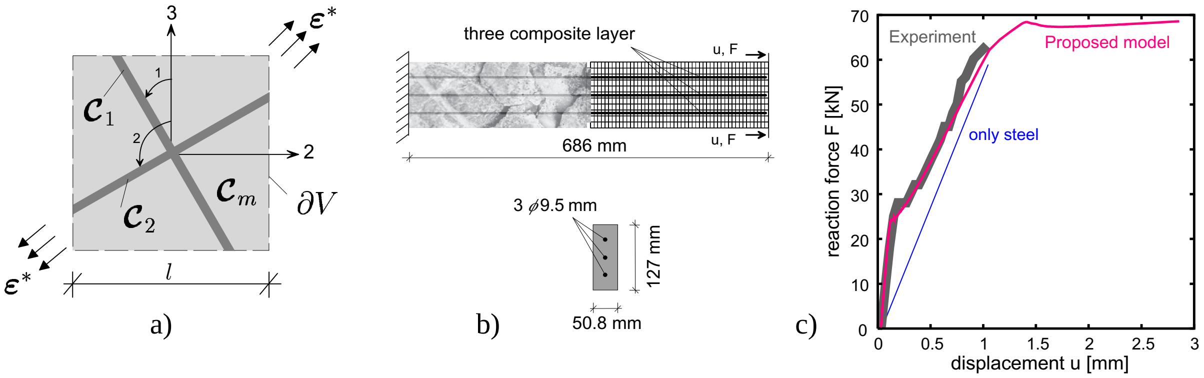

Figure 1: a) representative volume element (RVE), b) uniaxial panel test (Ouyang et al. 1997), c) load-displacement curves

of reinforcement layers. Applying homogeneous strain boundary conditions ε^* to the representative volume element (Figure 1a)) the fourth-order concentration tensors $\mathcal{A}_i$ linking the macroscopic strains ε^* with the strains of each constituent can be derived analytically.

The proposed model is implemented in the finite element code MSC.Marc. As a first benchmark test, an uniaxially loaded panel experiment where the ultimate load carrying capacity is determined by debonding failure (Figure 1 b,c) is re-analysed (Ouyang et al. 1997). Furthermore, the applicability of the proposed model is demonstrated by numerical analyses of reinforced concrete slabs (Collins et al. 1985).

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