Modeling Cracking in Quasi-Brittle Materials Using Isotropic Damage Mechanics

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Abstract

Several methods for modelling localized deformations in quasi-brittle materials such as cracking in concrete are available in the literature. One way to categorize these is to look at how the modelled cracks affect the displacement field [1]. Using this criterion, three categories can be distinguished, as seen in Figure 1. Category 1 implies a jump in the displacement field, and consequently a singularity in the strain field suggesting that cracking is localized to element boundaries. Category 2 implies a discontinuity in the displacement field and hence a jump in the strain field. With such methods cracking usually becomes localized in single rows of elements. In the third category, the displacement field remains continuous and cracking is typically distributed over several elements.

In this paper, models of category 2 are implemented in COMSOL Multiphysics® using an isotropic scalar damage constitutive law based on the work of [2]. Given that a constitutive law in solid mechanics relates stresses and strains, a law where deformations localize into single rows of elements becomes highly mesh dependent. To overcome this, the Crack band method [3] introduces the element size into the constitutive law where the global material behavior is given by a stress-crack opening law. However, on the local level of each Gauss point, a unique stress-strain relationship is defined from this global behavior.

The implementation in COMSOL is done using a combination of the built-in features of the Solid Mechanics interface and equation-based-modelling. The local damage mechanics law in its stress-strain format is included by defining a new nominal stress measure that replaces the default stress measure in the Linear Elastic material model. This new nominal stress depends on a damage parameter, which in effect reduces the relative amount of load carrying material. This parameter is in turn set up as an internal variable through a domain ODE and the Previous Solution solver attribute. To construct the unique stress-strain relationship of each Gauss point, a characteristic element length is calculated. This is here done by projecting the nodes of each element onto planes defined by the principal strain directions, thus taking the crack direction into account. A physics interface that includes these features has been created using the Physics Builder. It is lastly shown how to implement a model of category 3 in COMSOL, by only making minor modifications to the local model.

A number of verification examples are presented that compare results from COMSOL with experimental data from the literature; both for unreinforced and reinforced concrete, as

seen in Figure 2. More results can be found in [4].

The study shows how to implement a constitutive law to describe localized deformations in quasi-brittle materials in COMSOL that is set up in a way that ensures mesh objectivity of the solution. By analyzing a number of experimental results from the literature it is shown that such a model can effectively describe cracking in concrete.

Reference

[1] M. Jirásek, Modeling of localized inelastic deformation, Lecture notes, Czech Technical University, Prague, Czech Republic (2014)
[2] J. Oliver et al., Isotropic damage models and smeared crack analysis of concrete, In: Proceedings of the 2nd International conference on computer aided analysis and design of concrete structures, 945-957, Zell am See, Austria (1990)
[3] Z. P. Bažant and B. Oh, Crack band theory for fracture of concrete, Matériaux et Constructuin, Vol. 16, pp. 155-177 (1983)
[4] T. Gasch, Concrete as a multi-physical material with applications to hydro power facilities, Lic. thesis, KTH Royal Institute of Technology, Stockholm, Sweden (2016)

Figures used in the abstract

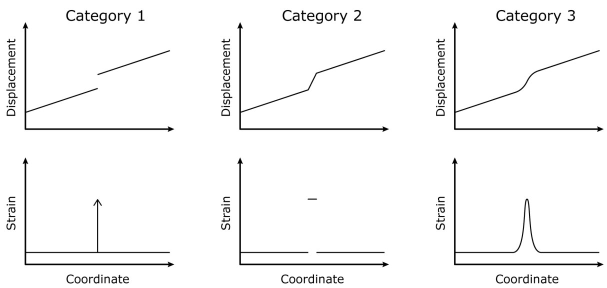

Figure 1: Schematic displacement and strain distribution for different categories of models to describe localized deformations.

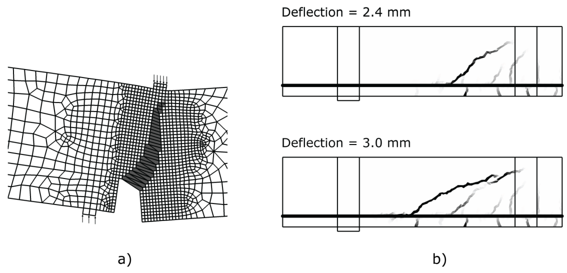

Figure 2: Cracking in an unreinforced concrete beam under 4-point loading (a) and a reinforced concrete beam (b) with the reinforcement outlined by thick lines.