Numerical Simulations of Advanced Problems in Concrete Mechanics

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Abstract. This overview paper covers three topical problems of computational concrete mechanics, stressing the importance of regularized fracture representation. First, an extension of the gradient-enhanced damage model is used to simulate the phenomenon of crack closing in a concrete beam. Then, a deterministic size effect is considered for a three-point bending test. Finally, the model is employed to analyze punching shear in a slab-column configuration. Some of the simulations are compared with experiments.

INTRODUCTION

Fracture is the dominating phenomenon in the structural response of concrete due to its specific mechanical properties, and usually mode-I fracture caused be tension dominates. It can be described as the formation of displacement discontinuities (discrete cracks) using interface representation (e.g. extended finite elements), or as a continuum model of stiffness degradation and decohesion. A host of such continuum models have been developed, including: smeared cracking (based on a constitutive description in terms of total stresses and strains), plasticity (based the plastic flow theory with Rankine 'inelasticity' criterion), and damage mechanics (usually, as here, in its isotropic format). In the continuum description a localization limiter is mandatory for obtaining results which do not depend on the discretization in a pathological manner, and for reproducing a deterministic size effect.

In this paper a gradient-enhanced damage model [1], possibly coupled with plasticity [2], is summarized. The description is limited to scalar damage which is a function of an averaged strain measure computed from a diffusion-like equation, discretized in addition to the momentum balance equation. The model is employed to simulate three non-trivial physical phenomena observed in concrete response. First, the gradient damage model equipped with a projection operator is used to simulate the phenomenon of crack closing in a concrete cantilever beam [3]. Second, the deterministic size effect is considered using a three-point bending test and the results are compared with experimental findings [4]. The model is then employed to analyze the punching shear in a slab-column configuration [5].
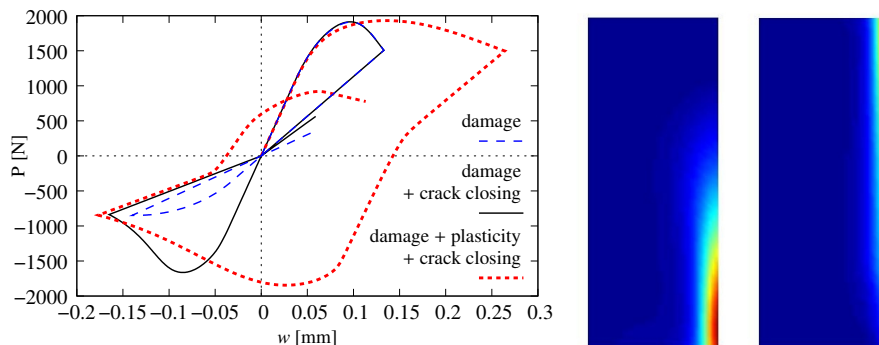

FIGURE 1. Load-displacement diagrams for extended gradient damage model. Contour plots of averaged strain in cantilever part near the process zone for maximum upward and downward displacement.
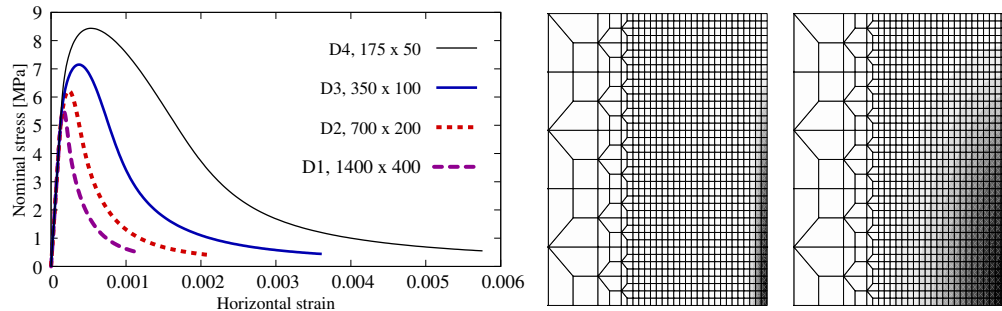
FIGURE 2. Size effect for concrete beam: nominal stress vs average horizontal strain diagrams for gradient damage, distribution of averaged stain measure at beam centre for specimens D_1 (left) and D_4 (right).

SIMULATION OF CRACK CLOSING

The employed gradient damage model, tuned to represent continuum fracture of concrete, can be coupled with the description of the behaviour of undamaged material skeleton by plastic flow theory. It provides proper results for a monotonic growth of deformation, which involves softening. However, when load reversals are to be included in the simulation, crack closing, i.e. the retrieval of elastic stiffness when cracking in tension is followed by unloading into compression, must be reproduced. This can be achieved using a so-called crack-closing projection operator. A concrete cantilever beam is solved. It is clamped at one end and loaded by an imposed vertical displacement at the other end. Fig. 1 presents the load-displacement diagrams for the gradient damage and damage-plasticity models extended with the crack-closing representation. Averaged strain distributions for two signs of loading are also shown.

SIMULATION OF DETERMINISTIC SIZE EFFECT

Unlike local constitutive models the regularized ones are able to reproduce the deterministic size effect. In this paper it is shown using the gradient damage model and the benchmark of a three-point beam bending (symmetric half is analyzed), where the damage zone represents a vertical crack at the symmetry plane, see Fig. 2. Four uniformly scaled beams D_1-D_4 are considered and the diagrams of nominal stress versus average horizontal strain presented in Fig. 2 clearly show the size effect in both the maximum stress and the softening response. The widths of the fracture zones are similar because they are determined by the internal length scale and the size of the mesh zone grows with the specimen. The results are confronted with experimental data from [6].

SIMULATION OF PUNCHING SHEAR

Finally, a slab-column configuration with concrete represented by gradient damage-plasticity and reinforcement modelled as steel bar elements is analyzed to simulate punching shear [5]. The Abaqus concrete damaged plasticity model with viscous regularization is also used to obtain reference solutions. Limitations of the models are discussed.

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