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NONLOCAL DAMAGE MODEL COMBINED WITH DISPLACEMENT DISCONTINUITY

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ABSTRACT

Failure of quasibrittle materials such as concrete is characterized by a gradual transition from diffuse microcracking to a localized damage process zone and finally to a macroscopic crack. Early stages of the failure process are satisfactorily described by inelastic stress-strain relations formulated within the framework of continuum damage mechanics, in the spirit of the smeared crack approach. Pathological mesh sensitivity can be eliminated by an appropriate regularization technique, e.g. by a nonlocal formulation of the damage evolution law. At late stages of the failure process, with fully developed macroscopic cracks, it is more appropriate to use fracture mechanics models dealing with displacement discontinuities, in the spirit of the discrete crack approach. Traditionally, the smeared and the discrete crack models have been used separately, often considered as competing approaches. It is tempting to develop computational techniques that combine these approaches in an optimal way, exploiting the advantages of each of them in the range in which it reflects the physical reality more closely than the other.

One of early studies on models with transition from the continuous description to a discontinuous one was presented by Jirásek and Zimmermann [1]. They combined an integral-type nonlocal damage model with a cohesive crack, which was implemented as an embedded displacement discontinuity passing across the finite elements. Comi, Mariani and Perego [2] used a similar material model but the discontinuity was captured by the extended finite element method. Sluys and coworkers replaced the integral-type formulation by other forms of regularization techniques, such as gradient-enhanced damage [3] or rate-dependent plasticity [4].

One of the most delicate components of a combined continuous-discontinuous model is the criterion for inserting a new discontinuity segment. This criterion is usually postulated ad hoc and has no direct physical meaning. If the discontinuity is considered as stress-free, it is usually inserted when the stress in the continuum model becomes negligible. But then the transition takes place at a very late stage of

material failure. Often it is desirable to consider the discontinuity as a cohesive crack and insert it at some intermediate stage of failure. The corresponding criterion can be based e.g. on a critical value of damage. For standard nonlocal damage models, the active part of the damage process zone (i.e. the part in which damage is growing) is shrinking during the loading process but keeps a nonzero width until complete failure. Therefore, inserting the discontinuity leads to an abrupt change of the strain rate distribution, and numerical problems may arise.

In this paper, a new nonlocal formulation of the isotropic damage model is proposed, with damage driven by a combination of local and nonlocal equivalent strain. Analysis of bifurcations from a uniform state reveals that a zero size of the process zone can be expected beyond a certain critical damage level. Numerical simulations confirm that the localized process zone attains zero thickness at damage substantially smaller than one. This new formulation allows a smooth transition to the cohesive crack, which is an improvement over previous techniques with ad hoc postulated discontinuity insertion criteria. Implementation of the discontinuous part of the model is handled via the extended finite element method.

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