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Stress-based nonlocal damage model

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ABSTRACT

Progressive microcracking in brittle or quasi-brittle materials, as described by damage models, presents a softening behavior that in turn requires the use of regularization methods in order to maintain objective results. Such regularization methods, which describe interactions between points, provide some general properties (including objectivity and the non-alteration of a uniform field) as well as drawbacks (damage initiation, free boundary).

A modification of the nonlocal integral regularization method that takes the stress state into account is proposed in this contribution. The orientation and intensity of nonlocal interactions are modified in accordance with the stress state. The fundamental framework of the original nonlocal method has been retained, making it possible to maintain the method's advantages. The modification is introduced through the weight function, which in this modified version depends not only on the distance between two points (as for the original model) but also on the stress state at the remote point.

The efficiency of this novel approach is illustrated using several examples. The proposed modification improves the numerical solution of problems observed in numerical simulations involving regularization techniques. Damage initiation and propagation in mode I as well as shear band formation are analyzed herein.

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1. Introduction

In quasi-brittle materials, nonlocality originates in the interactions between microcracks (Bažant, 1991) and leads to stress magnification in some of the areas surrounding a microcrack, thus allowing for the creation or growth of new microcracks. Nonlocal damage models aim to describe the behavior of quasi-brittle materials in microcracked areas that have not yet degenerated into a large open crack. In addition to restoring objectivity in numerical modeling for strain softening behavior, these models offer physical reliability to the results by explicitly introducing the nonlocal nature of microcracking.

Gradient-enhanced media (Peerlings et al., 1996) or the nonlocal integral method (Pijaudier-Cabot and Bažant, 1987), used as localization limiters, avoids the ill-posedness of governing equations of equilibrium and thus avoids mesh dependency. Both of these methods introduce an internal length into the constitutive law that may be related to the characteristic size of the material (i.e. aggregate size). In addition to this added length however, the nonlocal approach also explicitly introduces the shape of the interaction domain through the weight function shape. Peerlings et al. (2001) demonstrated that these two methods are strictly equivalent when Green's function is used as the weight function in the integral approach. Even though the shape of the weight function only plays a minor role in a 1D setting, we will still focus on the second approach since it provides greater flexibility and facilitates the introduction of non-isotropic nonlocalities by directly expressing the interactions between points within the weight function.

Nonlocal regularization methods are intended to determine global behavior of the structure as well as macrocracking according to a diffuse approach using the damage field. However, several drawbacks arise when using the original nonlocal model, namely:

(a) Damage initiation in the crack tip problem.
Eringen et al. (1977) exposed the crack tip problem in nonlocal elasticity. They indicated that the point subjected to maximum stress is not located at the crack tip. Simone et al. (2004) demonstrated that this problem leads to erroneous damage initiation due to an inaccurate prediction of the maximum nonlocal equivalent strain in the presence of a predefined notch. Jirasek et al. (2004) concluded that different strategies could be adopted in order to model the notch either explicitly by geometry or by filling it with a completely damaged material. Moreover, they were able to better fit the size effect on fracture energy in the case of a notch modeled as a layer of completely damaged material.

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