"Lip-field" regularization of anisotropic damage

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Continuum Damage Mechanics aims to describe the continuous degradation of the mechanical properties of materials. Softening stress-strain responses, however, lead to strain and damage localization. From a mathematical viewpoint, this induces a loss of uniqueness in the solution of the rate equilibrium problem to be solved. From a numerical perspective, this translates into a pathological dependency of the structural response on the discretization of the spatial domain. Nonlocal enhancements and regularization techniques are used to make the response independent of the finite element mesh.

The recently proposed "Lip-field" approach [1, 2] belongs to the second class of techniques. According to this approach, the unknown displacement and damage fields are computed via the alternated minimization of an incremental potential over each time step. Contrary to what is done in phase-field models, in the "Lip-field" approach, only the so-called local potential is minimized, and a Lipschitz continuity constraint introduces damage regularization on the damage field. This ensures the boundedness of the damage gradient over the domain and naturally introduces an internal length parameter.

While this approach is attractive due to its sound mathematical framework, it seemed limited to isotropic damage formulations. However, damage-induced anisotropy should be considered when modeling certain materials (e.g., quasi-brittle materials such as concrete).

In the Continuum Damage Mechanics framework, this can be done by using a tensorial damage variable (see *e.g.*, [3]). The tensorial nature of these models makes it more challenging to use certain regularization techniques. In particular, the question of their suitability for variational-based regularizations is left open.

The present contribution proposes the first "Lip-field" formulation for anisotropic damage. A variational formulation of anisotropic damage is developed. To describe the induced anisotropic material behavior, we define a convex free-energy potential according to [3]. This model is numerically attractive due to the unboundedness of its tensorial damage variable (the so-called Ladeveze damage tensor). The model's definition of a potential guiding dissipation is a crucial aspect. This choice is directly related to the definition of a proper scalar variable on which the Lipschitz-continuity is imposed. In this formulation, we introduce a so-called "accumulated damage" variable. This allows rewriting the potential to be minimized with regards to this scalar variable while the anisotropic nature of damage growth is taken into account via the evolution law. Thus, the minimization can be naturally performed on this variable, and by enforcing its Lipschitz-continuity, one can effectively prevent localization while keeping the anisotropic properties of the model.

The proposed model is implemented in a finite element code to demonstrate its feasibility and advantages over a purely isotropic approach.

References

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