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DEVELOPMENT OF NOVEL ENERGY LIMITER-BASED DAMAGE MODELS FOR BRITTLE, QUASI-BRITTLE AND DUCTILE FRACTURE

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In Chapter 1, the introduction of the dissertation is given. Then, the rest of the thesis is structured as follows:

It is described in Chapter 2 novel computational localized mass-field (MF) damage approaches at finite deformations using standard finite element method (FEM) for brittle failure. As the main objective, it first revisits the formulation of the original MF by Faye et al., 2019. It is emphasized that the original theory does not differentiate fracture behavior in compression and tension, thus resulting in physically unrealistic damage patterns. To overcome such limitations, new constitutive laws for mass source and mass flux by means of the energy decomposition technique are introduced. Furthermore, the developed MF is also extended to crack propagation in anisotropic composite media. The anisotropic MF is shown to be an effective tool for investigating directional failure in the unidirectional fiber-reinforced structure.

In Chapter 3, the local energy limiter-based damage theories for brittle and quasi-brittle cracking simulations are given. In this setting, new forms of the strain energy density (SED) function by means of the energy limiter integrated with the damage threshold, serving as the foundation of the local damage approaches, are proposed. The evolution of crack here is driven by the damage variables which are newly defined from the energy limiter idea. This makes the current theory completely different from existing damage models available in the literature. To reduce the mesh spurious solutions, the crack band idea is employed. While to avoid nonphysical cracks under compression, the spectral decomposition for the strain tensor is adopted to split SED.

In the next part, Chapter 4, a new implicit gradient damage model for brittle fracture analysis based on the energy limiter concept is addressed. The objective here is to combine the physics-based energy limiter formulation with the nonlocal/gradient-enhanced theory to build a more effective and physical numerical tool for damage analysis. As shown in Chapter 3, the local damage theories could offer good solutions, and the mesh-dependent issue on the force-displacement curve is adequately reduced by the crack band technique. However, the mesh bias or pathological mesh sensitivity on the simulated results of the crack path has not yet been fully addressed. For that, the coupled equations of the motion and a new implicit gradient damage formulation are introduced to govern the deformation of the solid and the evolution of the damage. The resulting nonlocal damage evolution equation featuring the growth of diffusive crack is integrated with a characteristic length scale to eliminate the common mesh-bias issue in FEM implementation. For the derivation of the material constitutive and local damage laws, a novel SED function based on the energy limiter theory for brittle crack growth problems under the small strain regime is developed.

Based on Chapter 4, it is presented in Chapter 5 a new double nonlocal damage theory based on the energy limiter idea for mixed-mode brittle failure in rocks. The key of the double model is that it differentiates damage behavior in the materials into mode I and mode II failure with the introductions of double nonlocal damage evolution equations, i.e., one nonlocal damage equation is set for mode I fracture while the mode II crack is modeled by the other one. Thus, the tensile and shear cracks are distinguished by the two damage evolution equations. Finally, the damage effects of the two modes are then combined into the introduced constitutive law.

In Chapter 6, it aims to extend the formulation in Chapter 4 for simulating failure at finite strain in rubbery structures with the consideration of rate-dependent crack-growth characteristics. For that, the rate-independent damage model in Chapter 4 is extended to the rate-dependent one. The current extension from small to finite deformation fracture simulations includes two main parts. Firstly, the SED function with the energy limiter is rewritten for large strain cases by adopting the modified neo-Hookean hyperelastic model. The material constitutive law with local damage involving is then derived from the developed energy limiter-based hyperelastic SED function. Secondly, the diffusive crack evolution is set under the Lagrangian configuration with the introduction of a rate-dependent crack propagation term integrated with an artificial viscosity parameter.

Chapter 7 presents an implicit gradient-enhanced energy limiter-based damage formulation for ductile failure simulation. Basically, the main work is to focus on the modification of the material constitutive and local damage laws introduced in Chapter 4 for the elastic brittle failure analysis to elasto-plastic-damage simulations. While for the smeared crack updating, the rate-dependent formulation in Chapter 6 is employed. For that purpose, first, the SED function is modified for ductile failure description. Then, the corresponding material constitutive and local damage laws are consequently defined. For a representative study, the elastoplastic deformation is presently limited to the von Mises plastic model for an isotropic body under the small strain regime with linear and nonlinear isotropic hardening laws. In this part, other than numerical experiments, it will present a consistent procedure to determine the value of the length scale from reference experimental tests. To the best knowledge of the author, it will show, for the first time in the literature, that the length scale parameter is an actual physical scalar of the simulated problem.

Next, in Chapter 8, a new energy limiter-based implicit gradient-enhanced damage model for fracture analysis in quasi-brittle media is developed. In other words, it will extend the model in Chapter 4 to quasi-brittle damage descriptions. For that, a novel energy limiter-based formulation for quasi-brittle damage is developed. Basically, the new SED function towards quasi-brittle fracture is developed for the derivations of the material constitutive law and local damage variable. To further improve the performance of the developed formulation, the definition of von Mises energy is also introduced in this work. In the chapter, the formulated model will also be applied to practical problems of corrosion cracks in reinforced concrete (RC) structures. The application demonstrates the ability of the theory in dealing with multiple crack growth in RC caused by corrosion.

Finally, in Chapter 9, the main conclusions and future work drawn from the Ph.D. thesis are presented.