Leapfrog in Computational Fracture Mechanics Enabled by Curvature-Limiting Sprain as Localization Limiter and Inspired by Gap Test

Z. P. Bažant[1]*, H. Xu[1], A. Dönmez[1], A. Nguyen[1], Y. Zhang[1]

[1] Northwestern University, Evanston, IL, USA, z-bazant@northwestern.edu

Sixty-one years after Ray Clough's epoch-making finite element analysis of cracks in Norfolk Dam [1], there is still no completely satisfactory computational model for fracture. This is evidenced by recent model comparisons with many *distinctive* [2] fracture tests—tests to be distinguished from the *nondistinctive* ones, i.e., those that can be fitted closely by very different models. The distinctive comparisons reveal dismal performance of peridynamics and severe applicability limitations of the phase-field models [3,4], as well as certain innate inadequacies of the nonlocal models of integral and gradient types. The crack band model (CBM) [5] with microplane model M7 is found to give relatively much closer fits of the test data, especially the gap test [6,7] and size effect [5], mainly thanks to its realistic crack-face boundary conditions. Yet the CBM has three limitations: 1) the width of the band front cannot be varied, 2) the damage distribution across the band cannot be resolved, and 3) regular meshes cause bias of the propagation direction. All three are overcome by the new smooth CBM (sCBM) [6]. Its idea is to limit damage localization within a band of multi-element width, equal to the material characteristic length, by restricting the displacement curvature through sprain energy density Φ, which represents energy homogenization, distinct from the standard stiffness-based homogenization. Called the sprain energy, Φ is not the strain energy. Rather, it is the Helmholtz free energy density of the third-order tensor of the curvature (or second gradient) of the displacement vector field, briefly called the sprain (a term inspired by ligament sprain in medicine). The sprain includes material rotation gradient is not expressible in terms of the strain-gradient tensor. The derivatives of Φ with respect to finite element nodal displacements yield self-equilibrated sets of in-plane nodal of body (sprain) forces resisting excessive softening damage localization. In the simplest version [8] using constant-strain finite elements, some sprain forces were applied as nodal forces of distributed body forces of adjacent elements. The ways of overcoming this programming inconvenience are outlined. The sprain forces act only during softening damage. Numerical results confirm good performance and close fits of distinctive concrete fracture tests.

References

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