A Finite-Element Method for Modeling Fracture in Disordered Media: From Single Crack Growth to Fragmentation with Application to Geomechanical Hydrofracturing

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Abstract

Structural failures resulting from extreme loading conditions are typically highly nonlinear processes involving complex material constitutive behavior, post-peak material softening, localization, new surface generation, and ubiquitous contact. Examples include penetration, fragmentation, progressive structural collapse due blast loading or seismic events, and hydrofracturing in petroleum engineering. The extent of fracturing is pervasive in the sense that a multitude of cracks are dynamically active, propagating in arbitrary directions, coalescing, and branching.

A pure Lagrangian computational method is presented that can simulate the pervasive dynamic failure of materials and structures by allowing new cohesive fracture surfaces to nucleate at the interelement faces of a random polyhedral mesh. The random polyhedral mesh is obtained from a randomly close-packed (RCP) Voronoi tessellation. The RCP Voronoi mesh possesses a number of advantageous properties including large included angles within the cells (finite-element) and a space of statistically isotropic crack paths. The a priori crack paths of the RCP Voronoi mesh are viewed as instances of realizable random crack paths within a random field representation of the continuum material properties. Mesh convergence in a pervasive fracture simulation is viewed in a distributional sense rather than at the level of a single realization. To this end a novel statistical method is presented for verifying convergence-in-distribution with mesh refinement.

Bio

Joe Bishop received his Ph.D. in Aerospace Engineering from Texas A&M University in 1996. His graduate research was in the general area of composite materials and fracture mechanics. From 1996 to 2004 he worked in the Synthesis & Analysis Department of the Powertrain Division of General Motors Corporation, performing thermal-structural analysis of internal combustion engines. Joe joined Sandia National Laboratories in 2004 in the Computational Solid Mechanics group. He has worked on various analysis projects involving earth penetration, blast effects on structures, and the coupled hydro-mechanical modeling of geologic discrete fracture networks related to CO₂ sequestration. His research interests include computational mechanics, pervasive fracture modeling, multi-scale analysis, and uncertainty quantification in highly nonlinear systems.

¹ Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy’s National Nuclear Security Administration under Contract DE-AC04-94AL85000.