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Non-local formulation for transport and damage in porous media

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Abstract

We present a novel damage-poroelastic model for analyzing the failure response of porous media in geomechanics applications. In this new approach, a gradient non-local permeability that leads to non-local transport and consequently non local damage, is introduced. Damage evolution is a function of an equivalent strain measure that is computed from non-local permeability using an inverse permeability-strain constitutive relation. A monolithic, mixed finite element method is proposed to solve the coupled system with a displacement-pressure-regularized permeability ($u - p - \tilde{\kappa}$) element formulation. The system is linearized and solved using Newton's method and a backward Euler scheme is used to evolve the system in time. A consistent Jacobian matrix and residual vector are derived analytically and a bilinear damage model is used to evolve the damage. Numerical examples considering hydraulic fracture problems in 1-d and 2-d and damage enhanced consolidation are presented and discussed. The proposed non-local model results are compared with local damage-permeability models. While the local models are shown to suffer from mesh dependence and non-physical spurious oscillations in strain, permeability and fluid pressure evolution, the proposed model is reliable and seems to overcome all these limitations.

Key words: Poroelasticity, non-local damage, gradient, non-local transport, hydraulic fracture

1. Introduction

The science that concerns the mechanical behavior of porous fluid-filled solids, "poroelasticity", is currently a prominent research topic. The study of poroelasticity is essential to many applications, including: rock mechanics [1, 2], geotechnical engineering[3, 4], hydraulic fracture [5–8], hydrology [9–11], biomedical engineering [12, 13], glaciology [14, 15] and others.

Poroelasticity deals with a multi-physics problem, involving the mechanical behavior of a porous solid skeleton and the fluid flow within the solid, approaching the porous medium as the superimposition of two continua [16]. The earliest efforts which coined the theory of poroelasticity are attributed to Terzaghi [17] and Biot [18], more than half a century ago. These theories

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