Incremental variational approach to gradient damage and poroelastic coupling of saturated media

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Abstract

We aim at investigating the full coupling between gradient damage, poroelasticity and fluid flow phenomena in saturated porous media. To this end, we first extend the thermodynamics-based Biot-Coussy theory of porolelasticity in order to incorporate gradient damage processes. Inspired by Stainier 2013 (Adv. Appl. Meca., Vol 46, pp. 69-126) in thermomechanics, we introduce the concept of kinetic porosity that allows to well clarify the interaction between skeleton deformation and fluid filtration in the connected pore space. This extension is then implemented to establish an incremental variational formulation expressed as a four-field minimization problem of an incremental total energy functional, which incorporates poroelastic energy, as well as the dissipation associated with damage evolution and fluid flow over a time increment. Moreover, by taking advantage of a suitable approximation of the kinetic porosity in the current time increment, the above mentioned minimization problem is reduced to a three-fields dependent one, involving the skeleton's displacement and damage fields, along with the fluid pressure field, which is shown to result in the equilibrium state of the saturated porous media. An incremental variational principle is thus established. Subsequently, a variational model for the fully coupled problem is consistently proposed and is numerically implemented by means of a semi-staggered optimization algorithm and the platform FEniCs. This procedure is applied in a benchmark modeling for which relevant solutions and numerical results related to hydraulic fracturing are available. The model is also employed for the evaluation of an Excavation Damage Zone (EDZ) around a waste storage underground gallery. The model is shown to be able to deliver sufficiently reliable predictions, which extends to cases involving coupled poroelastic effects or pure elastic-damage couplings.

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