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Micromechanical computational modeling of secondary consolidation and hereditary creep in soils

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Abstract

A computational modeling of a fluid-saturated deformable porous media characterized by two levels of hydrodynamics (flow in micro and macropores) is proposed based on a micromechanical analysis of dual porosity systems, i.e., media locally characterized by a porous matrix composed of permeable cells containing micropores and the surrounding system of macropores, void spaces or bulk flow paths (e.g., fissured rock or aggregated soil). The homogenization technique is applied to upscale the constitutive and geometric information available in the fine structure to the field scale leading to a microstructure model of dual porosity type, wherein the poroelastic cells act as distributed sources/sinks of mass and momentum to the global macroscopic medium. The theory provides a rigorous derivation of some secondary compression and hereditary creep effects in soils due to the delayed drainage of the fluid within the micropores under consolidation. Application of the Green's function method reduces the dual porosity system to a single-porosity viscoelastic integrodifferential system of Volterra type in which the constitutive law for the macroscopic stress tensor is given in terms of an hereditary integral with memory. A two-level finite element method is proposed to solve the coupled micro–macro governing equations of dual porosity type. Numerical experiments are performed showing the strong potential of the proposed formulation in solving consolidation problems with microstructure.

Keywords: Microstructure; Dual porosity; Secondary consolidation; Creep; Homogenization; Two-level finite element method

1. Introduction

The development of theories to model fluid flow in saturated, deformable, porous media as a coupled flow-deformation process began with Terzaghi [52] and Biot [8]. Essentially, Terzaghi and Biot developed linear poroelastic models based upon phenomenological approaches conducted at the field scale. These models are now well established and numerous works have provided a theoretical basis for Biot's theory. For example, the classical theory of poroelasticity has been rigorously reproduced by applying the mixture theory approach to an elastic two-phase solid–fluid mixture [15], or by upscaling the local pore scale problem where the solid is considered linearly elastic and the fluid is assumed to be Stokesian (see [5,61]).

The classical theory of poroelasticity applies to porous media with single structure, i.e., a two-phase system composed of the fluid-saturated wide void spaces and impermeable elastic solid phase. On the other hand many types of porous media exhibit two hierarchical geometric structures with properties radically different from each other. For example, a fissured rock is composed by a number of porous and permeable blocks or cells separated from each other by a developed system of highly permeable fissures. Aggregated or cracked soils (e.g., montmorillonite swelling clays) possess a similar structure wherein porous soil aggregates (clay clusters) are surrounded by an interconnected network of cracks or wide void spaces (macropores). The cohesive aggregates play the whole of the matrix blocks in the fissured medium and have a

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