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A general approach for modeling interacting flow through porous media under finite deformations

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Abstract

In the last few decades modeling deformation and flow in porous media has been of great interest due to its possible application areas in various fields of engineering such as biomechanics, soil mechanics, geophysics, physical chemistry and material sciences. Due to the high complexity and in most cases also unknown geometry of porous media on the microscale, a fully resolved model is nearly impossible to obtain, but most of the times also not necessary to answer important questions. As a consequence, one switches to a macroscopic approach. Such a mathematical description of porous media on the macroscale leads to a volume-coupled multi-field problem, wherein the interface between the two phases is not resolved explicitly. In this work we propose a numerical approach for modeling incompressible flow through a nearly incompressible elastic matrix under finite deformations. After a short overview of physical and mathematical fundamentals, the system equations are formulated and different representations are introduced and analyzed. Based on thermodynamic principles, a general constitutive law is derived, which allows the integration of arbitrary strain energy functions for the skeleton. Discretization in space with three primary variables and discretization in time using the one-step-theta method lead to a complete discrete formulation, which includes both finite deformations as well as full coupling of structural and fluid phases. Therein, we include dynamic effects, especially a time and space dependent porosity. Due to the compressibility of the solid phase, the porosity and its time derivative is not depending on the determinant of the deformation gradient only, but also on the pore pressure, which is an effect that is neglected in many publications. Considering this and also a general version of Darcys law, we derive two finite element formulations in a straightforward way, which, along with the numerical illustrations, provide a new numerical scheme for solving large deformation porous media problems.

Keywords: deformable porous media, finite deformation, poroelasticity

1. Introduction

The theory of porous media (TPM) is of great interest due to its potential application in various fields of engineering, like geophysics, civil engineering, physical chemistry, material sciences and biomechanics.

In geophysics such problems occur for example in the consolidation of aquifers, melting of ice or snow layers, or flow within magma chambers (see [1, chap. 11]). Additionally, flow and transport in fractured rock are of special interest in this field (see [2]). In civil engineering, applications of TPM include flow in porous media, e.g. while

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