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A space–time multiscale method for computing statistical moments in strongly heterogeneous poroelastic media of evolving scales

Juarez S. Azevedo[1], Márcio A. Murad[2,*,†], Marcio R. Borges[2] and Saulo P. Oliveira[3]

[1]*CETEC-UFRB, Centro, 44380-000, Cruz das Almas-BA, Brazil*
[2]*Laboratório Nacional de Computação Científica, Av. Getúlio Vargas 333, 25651-075, Petrópolis-RJ, Brazil*
[3]*DMAT-UFPR, Centro Politécnico, 81531-980, Curitiba-PR, Brazil*

SUMMARY

A new multiscale procedure is proposed to compute flow in compressible heterogeneous porous media with geology characterized by power-law covariance structure. At the fine scale, the deformable medium is modeled by the partially coupled formulation of poroelasticity with Young's modulus and permeability treated as stationary random fields represented by their Karhunen–Loève decompositions. The framework underlying the multiscale procedure is based on mapping these random parameters to an auxiliary domain and constructing a family of equivalent stochastic processes at different length scales characterized by the same ensemble mean and covariance function. The poromechanical variables inherit a space–time version of the scaling relations of the random input parameters which allows for constructing a set of multiscale solutions of the same governing equations posed at different space and time scales. A notable feature of the multiscale method proposed herein is the feasibility of solving both the poroelastic model and the Fredholm integral equation for the eigenpairs of the Karhunen–Loève expansion in an auxiliary domain with much lower computational effort and then derive the long term behavior at a coarser scale from a straightforward rescaling of the auxiliary solution. Within the framework of the finite element approximation, in conjunction with the Monte Carlo algorithm, numerical simulations of fluid withdrawal and injection problems in a heterogeneous poroelastic reservoir are performed to illustrate the potential of the method in drastically reducing the computational burden in the computation of the statistical moments of the poromechanical unknowns in large-scale simulations. Copyright © 2012 John Wiley & Sons, Ltd.

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1. INTRODUCTION

Natural porous media such as petroleum reservoirs and freshwater-bearing formations display high degree of heterogeneity in their ability to deform and conduct fluid. Although geological formations are intrinsically deterministic, field observations have shown that local properties such as hydraulic conductivity, porosity, and poromechanical parameters vary substantially in space in an apparently random fashion and produce significant impact on geomechanical predictions over all length scales. Laboratory experiments along with field data and theoretical studies have shown that large-scale

*Correspondence to: Márcio A. Murad, Mecânica Computacional, Laboratório Nacional de Computação Científica, Av. Getúlio Vargas 333, 25651-075, Petrópolis-RJ, Brazil.

†E-mail: murad@lncc.br