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Thermo-Hydro-Mechanical simulation of a 3D fractured porous rock: preliminary study of coupled matrix-fracture hydraulics.

Abstract We present a problem involving the modeling of coupled flow and elastic strain in a 3D fractured porous rock, which requires prior homogenization (upscaling) of the fractured medium into an equivalent darcian anisotropic continuum. The governing equations form a system of PDE's (Partial Differential Equations) and, depending on the case being considered, this system may involve two different types of "couplings" (in a real system, both couplings (1) and (2) generally take place):

1) Hydraulic coupling in a single (no exchange) or in a dual matrix-fracture continuum (exchange);

2) Thermo-Hydro-Mechanical interactions between fluid flow, pressure, elastic stress, strain, and temperature (after Ababou et al. 1994 [1]).

We present here a preliminary model and simulation results with FEMLAB®, for the hydraulic problem with anisotropic heterogeneous coefficients. The model is based on data collected at an instrumented granitic site (FEBEX project) for studying a hypothetical nuclear waste repository at the Grimsel Test Site in the Swiss Alps.

Keywords: FEMLAB. Numerics. Porous fractured media. Coupled PDE systems. Darcy's law. Permeability upscaling. Dual continuum. Fluid exchange. Biot. Hydro-mechanics. Poro-elasticity.

1 Introduction

This article presents a preliminary study of fractured rock, including fracture network reconstruction and numerical flow simulations, as a first step towards a fully coupled Thermo-Hydro-Mechanical (T-H-M) analysis of a fractured granite formation located at the Grimsel Test Site (GTS, Switzerland), where the FEBEX experiment is located. FEBEX is an experiment to test the T-H-M behavior of a crystalline high-level waste repository.

The aim of the preliminary simulations presented below is to reproduce the hydraulic behavior of the fractured medium using either single or dual continuum approaches to the fractured porous rock. The macroscale continuum equations and coefficients are obtained by upscaling from the local Darcy equation (matrix) and Poiseuille-type equation (fractures) up to block scale, where each homogenized block contains ideally many fractures. But, to obtain the upscaled equations requires knowledge of the morphology of the 3D fracture network. The overall procedure can be summarized as follows.

- First, the 3D network is obtained by a statistical reconstruction method (or inversion method) based on various fracture statistics and on detailed observations of fracture traces on tunnel drifts and boreholes.
- Secondly, the domain of interest is partitioned into sub-domains, in which the fractured rock is represented as a set of single-fractured 'blocks'. The tensorial upscaled coefficients are computed at the scale of the sub-domains based on superposition approximations.
- Thirdly, the corresponding system of continuum PDE's are solved numerically for initial-boundary conditions, with a numerical mesh finer than block scale, using (here) 3D finite element PDE solvers in FEMLAB® [3].

In this preliminary paper, only the hydraulic upscaling will be applied. A set of 3D numerical experiments with either single or dual continuum equations will be presented. For this reason, the upscaling of hydraulic coefficients is briefly presented. The hydraulic simulations are performed using the FEMLAB® multiphysics software. Although the full THM model is not implemented here, the principles of coupled hydro-mechanics are still briefly explained. The THM model yields a tensorial non-orthotropic (rank 4) PDE system to be solved with FEMLAB® multiphysics.

2 Characterization of the 3D fractured medium (network)

2.1 Experimental site: geology, fracture data

GEOLOGY, TUNNEL, BOREHOLES.

The GTS is located in the southern part of the Central Aar Massif, around 400m below the surface. The rocks in this area are mostly granitic, and are