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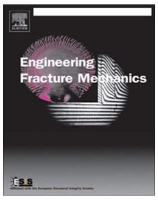

2D coupled HM-XFEM modeling with cohesive zone model and applications to fluid-driven fracture network

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ABSTRACT

The present work focuses on a new numerical model for the fully coupled hydro-mechanical analysis of groundwater flows through poroelastic saturated media. In particular, the presence and eventual propagation of fluid-driven fractures is accounted for within a non-regularized cohesive zone model. In this paper, the fracture propagation is considered as a reactivation process: the fracture already exists and evolves (*i.e.* opens or closes) on a pre-defined path initially constrained. The Talon-Curnier constitutive law is considered for the fracture interfaces and its expression has been adapted to the hydro-mechanical coupling related to the fracture evolution. The fluid pressure inside the fracture is governed by the lubrication equation. The momentum-stress balance equations involving fluid flow and deformation of the solid porous matrix are derived within the framework of the generalized Biot theory. The extended finite element method (XFEM) is preferred to a standard finite element spatial discretization in order to easily handle the presence and evolution of discontinuities in the porous medium. A set of four Lagrange multipliers is introduced to prevent spurious oscillations of the numerical solution at the interface. Comparisons between numerical results and theoretical solution assess the validity of the model presented in this paper. In addition, the hydro-mechanical interactions between neighboring fractures and the effects of the permeability of the porous medium are investigated. We also demonstrate the capability of our model to handle non-planar fracture paths.

1. Introduction

The permeability of rocks is widely affected by the presence of fractures as they establish preferential paths for fluid flow. Natural fractures are then a critical factor for determining the hydro-mechanical behavior of geological formations. As a consequence, leakage or detrimental spreading (of pollutants, fluids, etc.) can locally or regionally occur. In engineering studies, those aspects have to be considered. For nuclear waste storage in deep layers, implantation of storage cells modifies the *in situ* stress field and generates fractures [1], increasing significantly the hazards associated to potential radionuclides leakage. The scenario of leakage across the cavity seal through fractures or reactivated faults is then a matter of great concern. Similarly, metal deposits resulting from supergene weathering of ultramafic rocks [2], are strongly constrained by the development and extension of pre-existing fracture networks which participate to mineralization, modifiying the porous structure

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Nomenclature

b	Biot's coefficient
C_L	leak-off coefficient
$\mathcal{C}$	dimensionless leak-off coefficient
$\mathcal{C}_i$	dimensionless leak-off coefficient for fracture (Pi) or (Ci) $i \in \{1,2,3\}$
E	Young's modulus
E'	plane strain modulus
G_c	cohesive energy
H	generalized Heaviside function
K_c	fracture toughness for mode I
K'	effective toughness
K^{int}	intrinsic permeability
$\mathcal{K}$	dimensionless toughness coefficient
$\mathcal{K}_i$	dimensionless toughness coefficient for fracture (Pi) or (Ci) $i \in \{1,2,3\}$
lsn	normal level-set
L_r	augmented Lagrangian
$\boldsymbol{M}$	mass flux
$\boldsymbol{n}$	outward normal to the domain boundary
$\boldsymbol{n_c}$	outward normal to the fracture
p	pore pressure field in the porous medium
p_f	fluid pressure field inside the fracture
q_i	Lagrange multipliers (hydrodymamical part) $i \in \{1,2\}$
Q_i	injection rates $i \in \{0,1\}$
r	augmented ratio
t	time
$\boldsymbol{t_c}$	total cohesive stress
t_{c_n}	normal total cohesive stress
$\boldsymbol{t'_c}$	effective cohesive stress
t'_{c_n}	normal effective cohesive stress
$\boldsymbol{u}$	nodal displacement field
$[\![\boldsymbol{u}]\!]$	nodal displacement jump
$\boldsymbol{W}$	mass fluid rate
x	horizontal coordinate
y	vertical coordinate
$\boldsymbol{\beta}$	augmented multiplier
γ	fluid mobility
$\boldsymbol{\delta}$	local displacement jump
δ_c	critical opening
δ_{eq}	equivalent displacement jump
δ_n	normal local displacement jump
$\boldsymbol{\lambda}$	Lagrange multiplier (mechanical part)
μ	dynamic viscosity
ν	Poisson's ratio
ρ	fluid density
σ_c	critical stress
σ_0	confining stress
ϕ	eulerian porosity

and leading to perturbations in the pore pressure as well as in the *in situ* stress field. Similar processes have been reviewed by Das et al. [3] concerning magmatic intrusions and hydrothermal processes that participate to extension and segregation of trace elements [4–6]. Both are examples of natural hydraulic fractures. In the field of petroleum engineering, stimulation techniques like hydraulic fracturing are commonly used for low permeability reservoirs in order to increase their permeability and make them economically exploitable [7]. A high pressure flow is injected in the well, causing fracture opening and propagation. Both the fracture front and the fluid front propagate simultaneously [8,9], depending on the rock toughness and fluid viscosity [10,11]. To better understand and simulate all of these phenomena, developing and implementing more efficient and reliable numerical models would be beneficial.

Among all current available numerical methods, the finite element method (FEM) is one of the most convenient and is the most widely used. Modeling fracture propagation or thermo-hydro-mechanical problems have been successfully conducted with numerical models based on zero-thickness interface elements within the classical FEM (see for example [12]).