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3D modeling of cohesive crack growth in partially saturated porous media: A parametric study

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ABSTRACT

In this paper, the 3D cohesive crack propagation is presented in partially saturated porous media. The double-nodded zero-thickness cohesive interface elements are employed to capture the mixed mode fracture behavior. In order to describe the behavior of fractured media, two balance equations are applied similar to those employed for the mixture of solid–fluid phase in semi-saturated media, including: the momentum balance of fractured media, and the balance of fluid mass within the fracture. Crack permeability is modified based on the data obtained from experimental results to consider the roughness of fracture walls effect.

1. Introduction

Crack propagation modeling in semi-saturated porous media taking into account the water pressure effects is a new aspect in computational fracture mechanics. One of important applications of such analysis is simulation of hydraulic fracturing which has become a valuable technique for the measurement of in situ rock stresses and the stimulation of oil and gas reservoirs. The other application is related to the overtopping stability analysis of gravity dams. Modeling crack propagation in porous media involves a number of processes; namely, fracture initiation, fracture propagation, fluid flow in a deformable fracture, and fluid diffusion into the porous media.

There are a few published data available for water flow in propagating fractures. A series of experimental studies were conducted by Brühwiler and Saouma [1,2] to determine that the static pressure inside a crack is a function of crack opening. Reinhardt et al. [3] investigated the flow in concrete cracks and concluded that the permeability of cracks having an opening more than about 0.04 mm is higher than the undamaged concrete and for smaller crack widths the penetration behavior is similar to that of uncracked concrete. Slowik and Saouma [4] developed an experimental and numerical investigation on the influence of water pressure on crack propagation in concrete. From the experimental results they pointed out that the crack opening rate significantly influences the water pressure distribution. On the basis of experimental results they proposed an interface model, considering the fluid permeability as a function of crack opening displacements. However, they did not consider the roughness of fracture walls as a key parameter of fracture permeability. Barani et al. [5] proposed a new

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Nomenclature

b	body force per unit mass
$\mathbf{B}$	the matrix relating the increments of strain and displacements
$\mathbf{B}_f$	the matrix relating the increments of strain and displacements for the fractured zone
C_s	specific moisture content
C_f	cohesive material matrix for the fractured zone
$\mathbf{D}$	material property matrix of solid skeleton
D_f	material property matrix
e	hydraulic aperture
$\mathbf{G}$	compressibility matrix
$\mathbf{G}_f$	compressibility matrix for the fractured zone
$\mathbf{H}$	permeability matrix
$\mathbf{H}_f$	permeability matrix for the fractured zone
JRC	fracture surfaces roughness
k_{rf}	relative permeability of the fracture
k_n	transverse permeability coefficient of the fractured zone
k_p	longitudinal permeability coefficient of the fractured zone in p direction
k_s	longitudinal permeability coefficient of the fractured zone in s direction
k_{rm}	relative permeability of the matrix
$\mathbf{k}$	permeability tensor of the matrix
$\mathbf{k}_f$	fracture permeability tensor
K_s	bulk modulus of solid particles
K_T	bulk modulus of porous medium
K_w	bulk modulus for liquid phase
$\mathbf{K}$	stiffness matrix
$\boldsymbol{K}_f$	cohesive stiffness matrix
m	material constant
n	porosity
$\mathbf{N}_f$	shape functions of cohesive fracture element
$\mathbf{N}_u$	contact shape functions
$\mathbf{N}_p$	water pressure shape functions
p_r	reference pressure
p_w	water pressure
q_w	imposed flux
$\mathbf{Q}$	coupling matrix
$\mathbf{Q}_f$	coupling matrix for the fractured zone
S_w	water saturation
t_e	effective traction
t_n	normal component of traction vector
t_p	tangential component of traction vector in p direction
t_s	tangential component of traction vector in s direction
t_{pC}	cohesive shear traction in p direction when $t_n < 0$
t_{sC}	cohesive shear traction in s direction when $t_n < 0$
$\mathbf{u}$	displacement vector
u_n	the normal component of displacement vector
u_p	tangential component of displacement vector in p direction
u_s	tangential component of displacement vector in s direction
w	fracture width
$\dot{w}$	fracture opening rate
δ_{ij}	the Kronecker delta
δ_c	critical displacement corresponding to zero traction
δ_e	effective displacement of fracture surfaces
δ_n	normal displacement of fracture surfaces
δ_p	shear sliding of fracture surfaces in p direction
δ_s	shear sliding of fracture surfaces in s direction
γ_p	shear strain of cohesive fracture element in p direction
γ_s	shear strain of cohesive fracture element in s direction
Γ_q	external boundary for influx
Γ_t	external boundary for traction
ε_{ii}	total volumetric strain