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A MICROSTRUCTURAL MODEL FOR HYDRAULIC CONDUCTIVITY EVOLUTION DUE TO BRITTLE DAMAGE

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Summary. A coupled approach to model damage induced by hydro-mechanical processes in low permeability solids is discussed. The solid is as described as an anisotropic brittle continuum, whose damage is characterized by the formation of nested microstructures in the form of equi-distant parallel cohesive faults characterized by distinct orientation and spacing. Faults originate once the tensile or shear resistance of the medium is attained. Secondary faults may also form in a hierarchical organization, creating a complex network of connected fractures. The particular geometry of the faults allows for the analytical derivation of the porosity and of the anisotropic permeability of the material. The approach can be used for a wide range of engineering problems, ranging from the prevention of water or gas outburst into underground mines to the prediction of the integrity of reservoirs for underground CO_2 sequestration or hazardous waste storage.

1 INTRODUCTION

Deterioration of mechanical and hydraulic properties of soil and rock masses is closely related to changes in the stress state, formation of new cracks and increase of permeability. In saturated porous media, fluid and solid phases are interconnected and their interaction is characterized by coupled diffusion-deformation mechanisms that convey an apparent time-dependent character to the mechanical properties of the material. The governing equations of the coupled problem are the linear momentum balance and the continuity equation of the fluid (mass conservation). We describe a coupled approach to model damage induced by hydro-mechanical processes in low permeability solids. Classic methods can then be applied to describe the hydraulic behaviour of the material to estimate the flow of fluids across the medium according to the presence of fluid pressure gradients.

2. THE BRITTLE DAMAGE MODEL

We describe the solid as an anisotropic brittle continuum, whose damage is characterized by the formation of nested microstructures in the form of equidistant parallel faults [1], characterized by distinct orientation $\mathbf{N}_k$ and spacing L_k (see Figure 1). Faults bound otherwise elastic matrix material. We refer to this mode of deformation as recursive faulting, and the resulting microstructures as recursive faults. The assumption of faulting separates the constitutive relations into two independent components: the behaviour of the matrix (assumed to be elastic) and the behaviour of the faults, governed by a cohesive relation in the fault initiation stage, and by Coulomb friction and contact henceforth. The faulting construction can be applied recursively in order to generate complex fault patterns. Moreover, the elasticity of the matrix can be replaced by other dissipative behaviours.

3. ANALYTICAL EXPRESSION OF DAMAGE INDUCED POROSITY AND PERMEABILIY

The fractured medium can be regarded as an anisotropic porous material, in the case that faults undergo a normal opening displacement Δ^N_k. The particular geometry of the faults allows for the analytical derivation of the porosity n of the medium, as the sum of the porosity of the matrix n^m and of the contribution of the faults,

$$n = n^m + \sum_{k=1}^{Q} \frac{\Delta_k^N}{L_k} \tag{1}$$

and of the anisotropic permeability $\mathbf{K}$ of the medium, characterized by the expression:

$$\mathbf{K} = \mathbf{K}^m + \sum_{k=1}^{Q} \frac{\Delta_k^N}{L_k} \frac{\left(\Delta_k^N\right)^2}{12} \left(\mathbf{I} - \mathbf{N}^k \otimes \mathbf{N}^k\right) \tag{2}$$

being $\mathbf{K}^m$ the permeability of the matrix.

4. APPLICATIONS

The material model has been validated against experimental triaxial tests conducted on rocks [2]. The coupled approach can be used for a wide range of engineering problems, ranging from the prevention of water or gas outburst into underground mines to the prediction of the integrity of reservoirs for underground CO_2 sequestration or hazardous waste storage. As an example of application of the dry model, we consider the progressive damaging induced in a rock mass by the drilling of a borehole with an increasing diameter. The initial stress state of the rock mass is anisotropic, and the material surrounding the borehole fail creating a typical fracture pattern that is nicely reproduced by the numerical simulations, see Fig. 2.

REFERENCES

[1] Pandolfi A., Conti S., Ortiz M. A recursive-faulting model of distributed damage in confined brittle materials. *Journal of the Mechanics and Physics of Solids* 54:1972-2003, 2006.

[2] De Bellis ML, Della Vecchia G, Ortiz M, Pandolfi A. A multiscale model of distributed fracture and permeability in solids in all-round compression, Submitted to *Journal of the Mechanics and Physics of Solids*, 2016.