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Analyse pluriscale des lois de couplage hydro-mécaniques dans les milieux rocheux à perméabilité de fractures par confrontation entre expérimentations in situ (site expérimental de Coaraze) et modélisations numériques.

Coupled hydromechanical processes in heterogeneous fractures networks - In situ characterization and numerical simulations

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*In this thesis, coupled hydraulic and mechanical processes in a heterogeneous fractured rock mass are studied by a combination of hydromechanical field experiments and numerical modelling. An investigation methodology for in situ characterization of hydromechanical couplings within a well-connected and high-permeability fractures network is presented. The method was applied to an unconfined aquifer nested in a shallow fractured carbonate reservoir rock at the Coaraze Laboratory Site, in Southern-East France.*

*In a large-scale analysis of the fractured rock mass hydromechanical behavior, field and numerical investigations show that the coupling between fluid flow and deformation is simultaneously governed by a dual-permeability hydraulic behavior and a dual-stiffness mechanical behavior. From various field and numerical tests, the following fluid flow and hydromechanical conceptual scheme was established. First, a transient flow only occurs in the high-permeable faults. Second, when a steady-state flow is reached in faults, water flows from faults to low-permeable bedding planes. Intact rock matrix is practically impervious. Connectivity between discontinuities is high. When fluid pressure changes occur within the fracture network, the hydromechanical coupling is direct in the high-permeable faults where a pressure change induces a deformation change. No direct hydromechanical coupling occurs within the low-permeable zones where deformation does not present direct correlation with pressure changes. This means that mechanical deformation of bedding planes and of the rock matrix is induced by the faults deformation. In surface of the rock mass, deformation field evolution is first controlled by the hydromechanical reactions in the high-permeable faults and then by the poro-elastic effects in the rock matrix.*

*Single fracture hydromechanical behavior was evaluated by a series of hydraulic-pulse-injection testing and high-frequency hydromechanical measurements with innovative fiber-optic borehole equipment. Fracture hydromechanical response is monitored measuring simultaneously change in fluid pressure and fracture mechanical normal-displacement. Hydromechanical response is simultaneously monitored in two measuring points spaced about 1 m apart within the plane of a sub-vertical fracture. Initial hydraulic aperture and normal stiffness of the pressurized fracture were determined by hydromechanical numerical back-analysis. High-frequency measurements allow well constraining fracture hydromechanical behavior. Observed fluid pressure-versus-normal displacement curves show a characteristic loop-shaped evolution in which the paths for loading (pressure increase) and unloading (pressure decrease) are different. By matching the loop behavior, modelling indicates that the pulse pressure increase portion allow determining the fracture hydromechanical properties while the pulse pressure decrease portion is strongly influenced by the hydromechanical effects within the surrounding fractured rock mass. A sensitivity study shows that the key parameters to coupled hydromechanical processes in such fractures system are the fracture initial hydraulic aperture and normal stiffness, the stiffness of the rock matrix and the geometry of the surrounding fractures network as well as the internal geometry of the fracture.*

*In addition, numerical analyses indicate that the fluid flow is channelized within the fracture, and the amount of contact areas caused by channeling effect has a significant impact on the coupled hydromechanical effects. Moreover, numerical modelling highlights that the effective stress law conventionally used to describe the relationship between effective stress, total stress and fluid pressure is insufficient to restore hydromechanical behavior of the low-permeability fractures in which a pressure increase does not induce a deformation change. A modified law taking into account the percentage of contact surfaces within the fracture planes should be implemented.*

*The results of this study indicate that, within a well-connected and highly-permeable fractures network, the single fracture hydromechanical behavior must be analyzed considering the deformability of the surrounding fractured rock mass. A misinterpretation leading an error of several orders of magnitude in the determination of fractures properties can be avoided using a methodology based on hydraulic-field tests coupled to high-frequency hydromechanical measuring and modeling techniques.*

Key words: Fractured rock masses, Discrete fracture network, Hydromechanical coupling, Stress, Fluid flow, Channeling, Field experiments, High-frequency hydromechanical measurements, Fiber-optic sensors, Coupled hydromechanical modelling, Distinct Element Method, Finite Element Method.