Mesoscale in-situ study of Thermo-Hydro-Mechanical processes with some example applications to landslides and active seismic faults

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Since several years, an innovative protocol has been developed by the Geosciences Azur to in situ study coupled effects between fluids and rocks at the mesoscale and over a broad band of frequencies. This new protocol, called HPPP, consists of a 3-meter probe, containing high-frequency (f = 120 Hz) fiber-optic sensors that allow the synchronous monitoring of fluid pressure and rock deformation variations in a small injection chamber isolated between two inflatable packers. The probe is lowered in a borehole to a specified depth where the pressure pulse is injected from the surface either in an isolated single fracture or in matrix. Observed deformation versus pressure curves show a characteristic loop-shaped evolution in which the pressure increase and decrease paths are different. A finite-difference model based on the Biot-Gassmann theory of poroelasticity was implemented to analyse the effects of the fracture, the surrounding rock properties and the stress conditions on the quasi-static response of the fracture to the pressure pulse. By matching the entire loop-shape curve, it appears that the pulse pressure increase portion allows the fracture hydromechanical properties to be determined while the pulse pressure decrease portion is strongly influenced by the hydromechanical effects within the surrounding rock mass. The key parameters to coupled hydromechanical processes in such a typical matrix-fracture volume are the initial hydraulic aperture and normal stiffness of the fracture, the stiffness of the rock matrix and the geometry of the surrounding porous network. When fluid pressure changes occur within such a complex multi-porosity system, the hydromechanical coupling is direct in the highly permeable pores (faults) where a pressure change induces a deformation change. No direct hydromechanical coupling occurs within the lower permeability zones where deformation not directly correlated with pressure changes is related to the effective stress changes induced by direct coupled effects in the high permeable elements.

This fundamental approach was then applied (i) to analyze stress transfers in a regional over-thrusting fault zone in carbonate rocks (ii) to analyze hydromechanical effects on fractured slope stability. In the case of the seismically active fault zone, fluid pressure and strain changes were simultaneously monitored in the damage zone and protolith. Data show that strains are first controlled by the hydromechanical behavior of the most permeable discontinuities. Then, fluid diffusion in the rock matrix induces significant strain and stress transfers in the damage zone where the intensely fractured matrix is low-stiff and high-permeable compared to the protolith's matrix. Those contrasted protolith-damage zone flow-stress coupled effects were reproduced at 10 km depth using numerical simulations. The high strain of the damage zone compared to protolith and the hydraulic diffusivity contrasts in the protolith - damage zone - core system may induce a high static stress accumulation and an extended creep slip of the fault core. In the case of the fractured rock slope, a nonlinear correlation between hydraulic and mechanical discontinuities properties is proposed. A parametric study shows that slope deformation depends primarily on HM effects in a few highly permeable and highly deformable discontinuities located in the basal saturated part of the slope. Thus, the entire slope deformation can be reproduced with a simplified HM slope model, with those few discontinuities embedded in continuous zones with equivalent properties. Periodic free water-surface movements cause local strain accumulations related to the contrasting HM behaviour for high and low-permeable elements of the slope.