Combined role of the size of the microstructure and of Thermo-Hydro-Mechanical couplings on stability and fault reactivation

Ioannis Stefanou[1 *], Hadrien Rattez[1,2] and Jean Sulem[1]

[1] Navier, UMR 8205, Ecole des Ponts, IFSTTAR, CNRS, Champs-sur-Marne, France Institution, City, Country
[2] Duke University, USA

Context

Fault reactivation is a major risk in energy geotechnics. CO_2 storage, geothermal energy extraction or petroleum engineering involve the injection of fluids and the perturbation of the Thermo-Hydro-Chemo-Mechanical (THMC) equilibrium of the host rock leading, in many cases, to fault reactivation and seismicity.

Fault reactivation depends on many factors involving strain and strain-rate dependency. Here we highlight the importance of the size of the microstructure and of the various multiphyscial couplings regarding pre- and co-seismic slip. It is shown that even though the microstructure and THMC couplings concern a finer length and time scale, they affect considerably the macroscopic behavior and stability of the system.

Methods & results

We propose a micromechanical, physics-based (Cosserat) continuum model by considering the characteristic size of the microstructure and the thermal- and pore-pressure-diffusion mechanisms that take place in the fault gouge during shearing. It is shown that even for rate-independent materials, the apparent, macroscopic behavior of the system is rate-dependent. This is due to the competition of the characteristic lengths and time scales introduced indirectly by the microstructure and the thermal and hydraulic diffusivities.

Numerical analyses show that both weakening and shear band thickness depend on the applied velocity, despite the fact that the constitutive description of the material was considered rate-independent. Moreover the size of the microstructure, which here is identified with the grain size of the fault gouge (D_{50}), plays an important role and determines the slope of the softening branch of the shear stress-strain response curve and consequently influences the transition from aseismic to seismic slip.

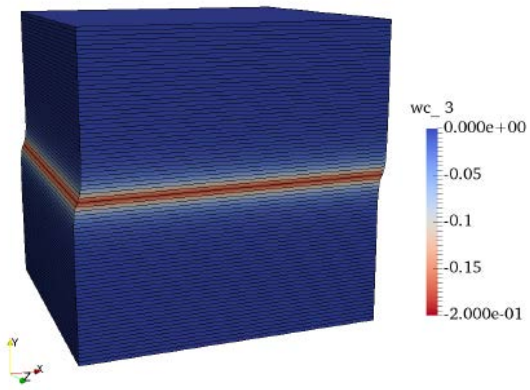

Fig. 1: Strain localization inside fault gouge (colours represent Cosserat rotations, wc_3 [rad]).

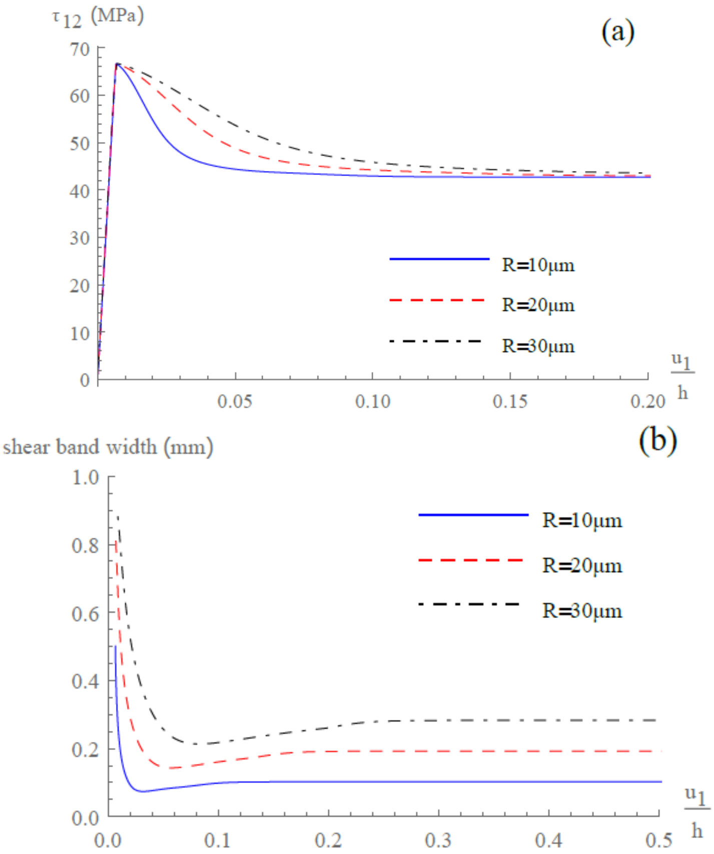

Fig. 2: Effect of grain size, R, on: (a) the stress-strain diagram and (b) the shear band thickness evolution. u_1 denotes the (seismic) slip and h the height of the sheared rock layer.

References

Dieterich, J. H. (1979). Modeling of rock friction: 1. Experimental results and constitutive equations. Journal of Geophysical Research, 84(B5), 2161. doi:10.1029/JB084iB05p02161

Scholz, C. H. (2002). The mechanics of earthquakes and faulting (Second). Cambridge

Stefanou, I., & Sulem, J. (2014). Chemically induced compaction bands: Triggering conditions and band thickness. Journal of Geophysical Research: Solid Earth, 119(2), 880–899. doi:10.1002/2013JB010342

Sulem, J., & Stefanou, I. (2016). Thermal and chemical effects in shear and compaction bands. Geomechanics for Energy and the Environment, 6, 4–21. doi:10.1016/j.gete.2015.12.004

Rattez, H., Stefanou, I., & Sulem, J. (2018). The importance of Thermo-Hydro-Mechanical couplings and microstructure to strain localization in 3D continua with application to seismic faults. Part I: Theory and linear stability analysis. Journal of the Mechanics and Physics of Solids, 115, 54–76. doi:10.1016/j.jmps.2018.03.004

Rattez, H., Stefanou, I., Sulem, J., Veveakis, M., & Poulet, T. (2018). The importance of Thermo-Hydro-Mechanical couplings and microstructure to strain localization in 3D continua with application to seismic faults. Part II: Numerical implementation and post-bifurcation analysis. Journal of the Mechanics and Physics of Solids, 115, 1–29. doi:10.1016/j.jmps.2018.03.003