A dynamic modeling procedure for estimating flow-induced seismicity in fluid-saturated faults

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The paramount role of pore fluid pressure during earthquake nucleation and dynamic rupture deserves further comprehension. Earthquake ruptures in poroelastic media encompass complex phenomena, including stick-slip frictional instabilities, thermal processes and hydromechanical couplings. A numerical simulation that couples fault poromechanics, rock poroelasticity and inertial effects is required in order to understand the elastodynamic issues on the rupture of induced earthquakes. Our numerical model includes fully-coupled hydromechanical, frictional and dynamic features; analyses the effects of both poroelasticity and the viscous material properties on the characterization of injection-induced earthquakes. We assume a rate-and-state frictional law for the fault and the Kelvin-Voigt constitutive model for the rock.

We simulate the whole earthquake sequence, both the interseismic and dynamic rupture phases, and quantify the differences between the rupture events whether the dynamic approach is considered or not. So we elucidate the key question of whether quasi-dynamic models are able to faithfully reproduce the main features of induced earthquakes obtained in dynamic simulations. The viscoelastic constitutive relation for the solid domain implies a dissipative term that affects the overall response and allows us to simulate the physical process of seismic wave attenuation. Furthermore, viscous dissipation avoids spurious high-frequency oscillations during wave propagation. The inclusion of inertial terms enables the model to account for the incremental fluctuations of both pore pressures and the stress field during dynamic rupture, which may shed light on the mechanisms that control the dynamic triggering on nearby faults.

Fig. 1: Left: Acceleration map during the first rupture of an induced earthquake on a 4km long strike-slip fault. This plot results from a dynamic model, which includes inertial terms, a visco-poroelastic domain and a saturated poroelastic medium with a tectonic ratio of two. Large peak values of accelerations may be reached during rupture. Right: Influence of the viscosity in the model results. We plot the evolution of the friction coefficient since the beginning of the injection. Regardless of the value considered in the calculations for the coefficient of viscosity, the friction value for first rupture is nearly the same. However, the viscosity entails a delay in the occurrence of the second rupture.