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A Plastic Formulation of Rate and State Dependent Friction: Emergence of Slip Transients and Earthquakes

Luc Lavier and Xinyue Tong

UT Austin, Institute for Geophysics, Department of Geological Sciences, Austin, United States (luc@jsg.utexas.edu)

We develop a numerical model for lithospheric deformation that can simulate both long term tectonic (LTT) behavior and the seismic cycle. We implement a finite element formulation of rate-and-state dependent friction with a Mohr-Coulomb elastic plastic yield and plastic flow criterion. The resulting numerical technique can simulate the deformation processes from milliseconds to 100k years. The model takes into account the velocity weakening and strengthening effects by using a velocity dependent friction law that is a function of a-b. The state variable is simulated by the effects of the plastic strain history on the shear stress over the thickness of the shear zone. We test our formulation on a simple stick-slip experiment at tectonic scale with a single fault of finite thickness and uniform friction properties. By varying both the length of the fault zone and the value of a-b we can reproduce fast and slow earthquakes that follow both theoretical and observational scaling relationships. In addition, the model suggests that slow slip transients differ from earthquakes because most of the mechanical work is spent accumulating inelastic strain (i.e. fractures) while earthquakes use the mechanical work to slip frictionally over the fault interface defined by the Mohr-Coulomb criterion. We then use our newly developed method to study the slip behavior of semi-brittle shear zones.