PhD Thesis defense:
Numerical modeling of earthquake faults

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During coseismic slip, the energy released by the elastic unloading of the adjacent earth blocks can be separated in three main parts: The energy that is radiated to the earth's surface ($\sim$ 5% of the whole energy budget), the fracture energy for the creation of new fault surfaces and finally, the energy dissipated inside a region of the fault, with finite thickness, which is called the fault gauge. This region accumulates the majority of the seismic slip. Estimating correctly the width of the fault gauge is of paramount importance in calculating the energy dissipated during the earthquake, the fault's frictional response, and the conditions for nucleation of the fault in the form of seismic or aseismic slip. In this thesis different regularization approaches were explored for the estimation of the localization width of the fault's principal slip zone during coseismic slip. These include the application of viscosity and multiphysical couplings in the classical Cauchy continuum, and the introduction of a first order micromorphic Cosserat continuum. First, we focus on the role of viscous regularization in the context of dynamical analyses, as a method for regularizing strain localization.

We study the dynamic case for a strain softening strain-rate hardening classical Cauchy continuum, and by applying the Lyapunov stability analysis we show that introduction of viscosity is unable to prevent strain localization on a mathematical plane and mesh dependence. We perform fully non linear analyses using the Cosserat continuum under large seismic slip displacements of the fault gouge in comparison to its width. Cosserat continuum provides us with a proper account of the energy dissipated during an earthquake and the role of the microstructure in the evolution of the fault's friction. We focus on the influence of the seismic slip velocity to the weakening mechanism of thermal pressurization. We notice that the influence of the boundary conditions in the diffusion of the pore fluid inside the fault gouge, leads to frictional strength regain after initial weakening. Furthermore, a traveling strain localization mode is present during shearing of the layer introducing oscillations in the frictional response. Such oscillations increase the spectral content of the earthquake. Introduction of viscosity in the above mode, leads to a rate and state behavior without the introduction of a specific internal state variable. Our conclusions about the role of thermal pressurization during shearing of the fault gouge, agree qualitatively with newly available experimental results.

Finally, based on the numerical findings we investigate the assumptions of the current model of a slip on a mathematical plane, in particular the role of the boundary conditions and strain localization mode in the evolution of the fault's friction during coseismic slip. The case of a bounded domain and a traveling strain localization mode are examined in the context of slip on a mathematical plane under thermal pressurization. Our results expand the original model in a more general context.

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