Towards Earthquake Rupture Simulations with High Resolution Fault Zone Models

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Granular systems are ubiquitous in our everyday experience and they control the physics of many natural phenomena that are societally relevant such as slope failures (e.g. landslides and man-made embankment) and earthquakes. Furthermore, grain transportation, pouring, packing and flowing are essential processes in many industrial fields such as food, pharmaceutical, and construction material industries. Developing tools for understanding the dynamics of granular flow, at different strain rates, pressures, and temperatures, is thus of crucial importance for optimization of resources in the industry as well as development of improved hazard models for our built environments. In this talk I will report on our recent progress in computational modeling of granular dynamics with a special focus on applications related to multiscale earthquake physics.

To that end, I will first introduce a model for deformation and failure in gouge materials within fault zones that is based on the Shear Transformation Zone (STZ) theory, a non-equilibrium statistical thermodynamics framework to describe plastic deformation in amorphous materials. The primary ingredient of the theory is that inelastic deformation occurs at rare and local non-interacting soft zones known as the shear transformation zones. The larger the number of these STZs the more disordered the material is. I will discuss an implementation of this theory in 2D and 3D finite element model of amorphous material under general loading conditions. We examine conditions under which a localized shear band may form and show that the initial value of disorder (or the degree of ageing) plays an important role. In particular our simulations suggest that if the material is well aged, the behavior is more brittle and the plastic deformation is localized. On the other hand, a more disordered material will have a more ductile response and the plastic deformations will be distributed more broadly. Furthermore, we show the rich nature of the localization bands that includes Reidel, Boundary and Y-shears and show that the persistence of these bands depends not only on the pressure and strain rate but also on the rate of change of strain rate. We compare the predictions of our model with reported experimental and field observations.

In the second half of the talk, I will introduce a novel hybrid numerical scheme that couples bulk methods (like finite difference) with boundary methods (like the spectral boundary integral equation model) for efficient computational modeling of complex fault zones with near fault nonlinearities or heterogeneities. Our end goal is to incorporate our physics based models of fault gouge within elastodynamic simulations using this newly developed hybrid approach to explore for the first time the effects of small scale physics (such as complex shear band nucleation and propagation) on rupture nucleation, propagation, arrest and seismic wave radiation.