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Discrete Element Method modeling and simulation of granular friction and stick-slip dynamics and the investigation of dynamic earthquake triggering

Michele Griffa (1), Jan Carmeliet (1,2), Paul A. Johnson (3), Robert A. Guyer (3,4), and Chris Marone (5)

(1) Swiss Federal Laboratories for Materials Testing and Research (EMPA), Laboratory for Building Science & Technology, Duebendorf, Switzerland (michele.griffa@empa.ch), (2) Chair of Building Physics, Institute for Building Technology, ETHZ, Wolfgang-Pauli-Strasse 15, 8093, Zuerich Hoenggerberg, Switzerland, (3) Geophysics Group, Los Alamos National Laboratory, MS D443, 87545, Los Alamos (NM), USA, (4) Dept. of Physics, University of Nevada, 89557, Reno (NV), USA, (5) Dept. of Geosciences, Pennsylvania State University, 16802, University Park (PA), USA

The mechanics and physics behind dynamic earthquake triggering remains a compelling mystery. Our objective is to shed light on the role played by the fault gouge in the frictional behavior of a fault when it is perturbed by elastic vibrations due to propagating waves. We report on a combined experimental and modeling approach.

In the experiments, sound waves are applied at the boundaries of a laboratory-scale fault model that contains thin granular layers simulating fault gouge, using a setup controlling the shear strain rate and the confining normal stress (see Johnson et al., this session). These experiments are designed for characterizing the influence of applied vibration on the stick-slip cycle typical of the fault frictional dynamics under a range of boundary conditions such as the confining (normal) load. For example, the experiments show differences for the recurrence time (the interval of time separating two successive slip events) in the absence or presence of propagating waves. It is clearly established that sound waves with amplitude exceeding a certain threshold can trigger slip events, meaning, induce a slip event out of the periodic stick-slip cycle.

Remarkably, after the sound perturbation ceases, the model fault's stick-slip cycle seems to "maintain memory" of the external perturbation, with small amplitude slip events occurring well before or after the expected, periodic, large slip events, in addition to a long time recovery of the elastic modulus over multiple event cycles.

Our numerical simulations are designed to complement the laboratory experiments, which do not provide real-time information on the granular processes during shearing. In order to investigate the microscopic mechanisms responsible for granular stick-slip and triggering of dynamic failure we have developed a representative model of the experimental configuration using the Discrete Element Method (DEM), a special type of Molecular Dynamics simulation approach based upon Contact Mechanics laws and widely used for studying granular media. This method represents the gouge as an ensemble of individual particles interacting with each other only when in contact. We have implemented the solid block shearing the granular layer at constant velocity as a lattice of bonded particles, including its surface roughness represented by bonded particles with different size.

We report results of simulated stick-slip dynamics under different normal load and shear strain rate boundary conditions, showing that shear is clearly localized in the first few layers of the model gouge close to the sliding block. We analyze the spatio-temporal evolution of the granular system, with high resolution, during the transition from the stick phase to the slip one ("unjamming transition"), triggered or not by a perturbation applied to the fault model's boundaries. The analysis is performed both in the "force domain" (statistics of the contact force amplitude and visualization of the contact force networks), where we can show the formation and disruption of force chains upon macroscopic slip, and in the "particle domain" (statistics of rolling vs sliding particles during the macroscopic slip event, evolution of the coordination number and role of shear localization).