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Title: YEARLY REPORT FOR THE PERIOD Jan. 2019 – Feb. 2020 IC Project: w19_hossfault "Modelling of stick-slip behavior in sheared granular fault gouge & nonlinear elasticity behavior in cracked solid"

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Scientific and Programmatic Impact:

Low frequency earthquakes, non-volcanic tremor, and acoustic emissions are examples of weak seismic signals that may help detect major seismic events, i.e., earthquakes. In a laboratory setting, in which stick-slip events are simulated, acoustic emissions are detected far from the stick-slip events. In both, field and laboratory scale cases, the acoustic emission signals are sourced or detected in a volume remote from the volume that spawns the earthquake. Therefore, it is relevant to establish the causal relationship between signals detected on passive, remote monitors and the dynamics of the elastic structures that launch important seismic events. The work conducted under this IC allocation allowed us to utilize a numerical model that let us follow this causality, i.e., examine and connect the dynamics in a granular system (fault gouge), to signals detected on passive remote monitors. It was demonstrated that stress chains are key in the dynamics of granular systems and that their evolution is the source of the acoustic emission.

In relation with the previous work, it has been established that plate motion near a fault gouge layer, and the elastic interplay between the gouge layer and the plate under stick-slip conditions, are key to understanding the dynamics of sheared granular fault systems. The investigation conducted during this IC allocation focused on determining the influence of normal load, driving shear velocity and plate stiffness on the velocities and displacements in the direction parallel to the shear directions. The simulations show that at the moment slip events occur the velocities of the media located at both sides of the gouge layer are proportional to the normal load and may be inversely proportional to the square root of the plate's shear modulus, whereas the driving shear velocity does not show distinct influence on the plate velocities. Additionally, large slips are generally associated with large macroscopic friction coefficient drops, and for the models subjected to smaller normal loads, larger shear velocity and stronger plate stiffness, the same magnitude of slip could cause larger drop of macroscopic friction coefficient. The simulations address the dynamics of a laboratory scale fault gouge system and may help reveal the complexities of earthquake frictional dynamics.

The code – HOSS – has been developed in Geophysics Group in LANL during the past fifteen years and is used to simulate the stick-slip behavior of granular fault gouge. One of the key feature of HOSS is that it is superior to pure finite element method and discrete element method and can provide very detailed evolvement information of granular fault gouge. Additionally, its parallel computing capability makes large scale earthquake gouge simulation possible. Taking these facts into account, and also because few other fully parallel FDEM code exists, this IC project allows LANL to stay at the forefront of earthquake gouge and granular material simulation in the world.

Financial Impacts:

Present Sponsors: LDRD Office

Future (potential) Sponsors: LDRD Office, Basic Energy Science Office, Office of Science.

Summary of Computational Effort Accomplished:

We used ~4 M CPU hrs for earthquake gouge 2D simulation on Badger and Grizzly, mainly focus on investigating the influence of different normal loads, shear velocity and plate stiffness on the stick-slip behavior of granular fault gouge. The simulated data show very good stick-slip phenomenon, which provide plenty of very useful information for us to further unveil the mystery of energy and stress evolution during the earthquake cycles. The data have been sent for machine learning purpose to predict earthquakes. The allocation was also used to run simulation of 3D laboratory experiments on marble samples and to run impact simulations of experiments conducted by NASA.

Publications/Presentations:

1. Viet Chau, Esteban Rougier, Zhou Lei, Earl E Knight, Ke Gao, Abigail Hunter, Gowri Srinivasan, Hari Selvi Viswanathan. Modeling of High Strain Rate loading Experiments in Westerly Granite Using the Combined Finite-Discrete Element Method. AGU Fall Meeting 2019.
2. Ke Gao, Esteban Rougier, Robert A Guyer, Paul A Johnson. Stick-Slip Induced Near Gouge Plate Motion in Sheared Granular Fault. AGU Fall Meeting 2019.
3. Viet Chau, Esteban Rougier, Zhou Lei, Earl E Knight, Ke Gao, Abigail Hunter, Gowri Srinivasan, Hari Viswanathan. Numerical analysis of flyer plate experiments in granite via the combined finite–discrete element method. Computational Particle Mechanics. https://doi.org/10.1007/s40571-019-00300-w.
4. Ke Gao, Robert A Guyer, Esteban Rougier, Paul A Johnson. Plate motion in sheared granular fault system. Under review in Earth and Planetary Science Letters. 2019.
5. V Chau, E Rougier, Z Lei, E Knight, K Gao, A Hunter, G Srinivasan, H Viswanathan. Modeling of Plate Impact Experiments in Westerly Granite Using the Combined Finite-

Discrete Element Method. 53rd US Rock Mechanics/Geomechanics Symposium. New York, USA. June 2019.

6. Ke Gao, Robert Guyer, Esteban Rougier, Christopher X. Ren, Paul A. Johnson. From Stress Chains to Acoustic Emission. Physical Review Letters, 123(4): 048003, 2019.
7. Ke Gao, Esteban Rougier, Robert A Guyer, Zhou Lei, Paul A Johnson. Simulation of crack induced nonlinear elasticity using the combined finite-discrete element method. Ultrasonics, 98:51-61. 2019.
8. E Rougier, Z Lei, B Euser, M Froment, S Kedar, EE Knight, CS Larmat. The Numerical Road to Determination of Fracture Role on Impacts as Seismic Sources: Finite-Discrete Modeling of Impacts. Lunar and Planetary Science Conference. The Woodlands, TX. 2019.

Financial Impact by Fiscal Year. FY19: LDRD $200k. FY20: Office of Science $100k. Additionally, work conducted under this Institutional Computing allocation was aimed at program development; internal funding connected to this is projected to become available FY21.