22 Laboratory Investigations into Micromechanical Mechanisms Controlling the Onset of Stick-slip Instabilities

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Introduction

Improving our understanding of the factors controlling spontaneous shear rupture nucleation on a frictional fault would help better define the important physical processes contributing to earthquake rupture and faulting. Our current laboratory investigations (Selvadurai and Glaser, 2013) quantify the local stress states on a laboratory fault, which control the transition from stable (quasi-static) to unstable (dynamic) sliding. We propose that the initiation of the unstable phase occurs at the displacement incongruities where compliant, ‘creeping’ segments of the fault transition into stiff, ‘locked’ sections. These transition regions can exhibit swarms of smaller earthquakes, localized in time and space, prior to the larger subsequent earthquake. Similarities between our laboratory results (specifically the acoustic emission measurements), and those observed in geological settings are briefly described here.

Laboratory Facilities

The laboratory model consisted of two sandblasted Poly(methyl methacrylate) (PMMA) surfaces pressed together by a normal stress ($\sigma$) and then sheared at a constant velocity ($v_p$) in a direct shear configuration. Figure 2.22.1 provides a general view of the direct shear apparatus where the PMMA base plate and slider block measured 950 x 950 x 60 mm and 400 x 80 x 10 mm, respectively. A non-contact eddy current sensor array, mounted near the interface, measured the slow, quasi-static motions near the fault and, in nature, are evident in GPS and InSAR data. To measure the relatively quick dynamic stress changes, an array of 16 piezoelectric acoustic emission (AE) sensors were placed along the underside of the base plate; drawing parallels to seismometers deployed in the field. The AE sensors have been accurately calibrated using known source-time functions induced by glass capillary fractures. During the application of the normal pressure, contacting asperities are formed due to the interaction between the two randomly rough surfaces. These interactions are believed to be consistent with processes occurring on natural geological faults. A pressure sensitive film (FUJI™ prescale 12-50 MPa) was used to initially localize, quantify, and measure the heterogeneous normal stresses resulting from the population of asperity contacts.

Laboratory Procedure

Details of the experimental facilities, procedure and material properties of the PMMA are given by Selvadurai and Glaser (2013). Briefly, the fault was firstly characterized using the pressure sensitive film by compressing it throughout the interface using a known nominal stress ($\sigma$) for a controlled amount of time ($t_{load}$) at a known reference location. Using the electro-mechanical shear actuator, the rigid loading platen was driven at a set-point velocity ($v_p$) to simulate far-field tectonic actions.

Current experimental suites employed constant velocities ranging from 0.010 to 0.030 mm/s but only the results from the faster loading rate, $v_p = 0.030$ mm/s, will be presented here. Shear stress ($\tau_f$), normalized over the nominal interface area, measured between the loading platen and shear actuator, increased gradually and slow, aseismic ‘creeping’ displacements were observed using the non-contact sensors until a ‘mainshock’ occurred. The mainshock was characterized by a sizable decrease in the bulk shear force (~50-70% drop from maximum) coupled with rapid, coseismic displacements in the direction of applied shear.

Experimental Observations: Foreshocks Preceding the Mainshock

Detectable physical changes, such as ground deformations associated with the premonitory movements are difficult (if not impossible) to detect using current geodetic and seismic sensing tools. On some natural faults, smaller earthquakes have occurred within a region tens of kilometers of the eventual hypocenter of the larger earthquake, weeks to seconds beforehand. The physics and mechanics of these ‘foreshocks’ are not well understood with respect to their influence on the larger mainshock.

In Figure 2.22.2, while loading the fault slowly ($v_p = 0.030$ mm/s) prior to the mainshock, we observe small dynamic emissions detected using the AE array.

During these ‘foreshock’ emissions, there was no discernible drop in the bulk shear force ($\tau_f$) sustained by the fault, but they must represent changes in local stress states due to some physical phenomena which we are currently investigating.

Spatio-temporal distributions can also be analyzed. Location and timing of the foreshocks were determined from first arrival P-waves using multiple AE sensors and are shown in Figure 2.22.3. The size of the circular region represents the spatial error associated with the p-wave location algorithm. Locations...
of the foreshocks have been superimposed over the initial contact measurements provided from the pressure sensitive where the hotter (red) colors indicate contact and the cooler (blue) represents zero stress or no initial contact.

**Preliminary Discussion**

Observational seismology has, in some cases, observed foreshock sequences preceding larger mainshock events (e.g., Dodge et al., 1995) not dissimilar to our preliminary laboratory results. While the scale of the two results are distinctly different (in both space and time) we have currently begun an investigation that employs similar techniques and models to characterize our experimental findings. These techniques may help develop scaling relations from the laboratory to the field that have been difficult to characterize in the past. These foreshock bursts may be useful contributors to short-term earthquake probability estimates (Chen and Shearer, 2013).

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**References**

