Exploring frictional velocity dependence as a mechanism for slow earthquake rupture

Julia Krogh and Chris Marone
Department of Geosciences, Pennsylvania State University, University Park, PA, USA

Earthquakes fail through a spectrum of slip modes ranging from slow slip to fast elastodynamic rupture. Slow earthquakes, or slow-slip events, represent fault slip behaviors that involve quasi-dynamic, self-sustained rupture propagation. To better understand the mechanisms that limit the slip speed and propagation rates of slow slip, we focus on a particular parameter: the critical frictional weakening rate of the fault surface, $k_c$. When $k_c$ is approximately equal to $k$, the elastic loading stiffness of the fault, complex fault slip behaviors including slow-slip events are observed. If $k_c$ has a negative dependence on slip velocity, acceleration during the coseismic phase could decrease $k_c$ until it approximates $k$, terminating in a slow earthquake. Here, we describe the results of laboratory experiments designed to quantify the dependence of $k_c$ on frictional slip velocity. We conducted double-direct shear experiments in a biaxial shearing apparatus with 3 mm-thick fault zones composed of quartz powder to simulate fault gouge. We focus on step decreases in slip velocity from 300 to 3 m/s that were performed for a range of normal stresses, from 10 to 20 MPa, which we know to be near the stability transition from stable to unstable sliding defined by $k/k_c \sim 1.0$. Under stable conditions, rate-state friction modeling was used to determine $k_c$ for each velocity step. Our data provide direct insight on the stability transition associated with $k_c(V)$, including experiments for which slow-slip instabilities grew larger and faster throughout velocity-step sequences. Ultimately, both numerical modeling and observational data indicate that the velocity dependence of $k_c$ is an important parameter when considering the mechanisms of slow earthquake nucleation.