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Steady-state friction during earthquake slip: Fact or myth?

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The rupture front of an earthquake propagates along a fault while activating countless patches. Each patch undergoes intense deformation variations from rest before the front developing to acceleration, weakening, deceleration and healing. While it is unlikely that steady-state stage would materialize in such history during rise-time, the modeling of earthquake rupture is almost exclusively based on friction measurements conducted under steady-state condition. An alternative approach is presented here.

Experimentally, the friction strength of a fault is determined by its relations to the slip-distance and slip-velocity, and these relations are implicitly assumed to be rock properties. Recent observations however, show that these relations strongly depend on the slip-velocity history. Consider three styles of velocity loading: Impact (abrupt increase followed by gradual deceleration), constant (steady velocity), and ramp (gradual increase followed by abrupt deceleration). Chang et al. (2012) found that running the same sample (Sierra White granite) under different velocity loading yielded different relations: Impact loading had much shorter critical weakening distance (0.03 m for impact and 1-3 m for constant), and drastic dynamic weakening under high velocity ($V > 0.1$ m/s), whereas dynamic strengthening was observed under $V > 0.05$ m/s for constant velocity. Similar behavior was recently observed for an experimental fault made of syenite under impact and ramp loading. Further, under impact velocity, the period of velocity increase (acceleration) overlaps the period of fault weakening. This correlation is not unique and similar weakening-acceleration associations were reported in stick-slip experiments (Ohnaka & Yamashita, 1989), rotary shear (Goldsby & Tullis, 2011), and Kolsky impact shear experiments (Yuan & Prakash, 2008). These studies greatly differ from each other in slip distance, normal stress, acceleration, and slip-velocities with the outstanding commonality of impact velocity loading.

Analyses of seismic data (e.g., Tinti et al., 2005) and numerical simulation of earthquake rupture (e.g., Day et al., 2005), indicate that the early slip of a fault patch is characterized by intense acceleration. Based on these experimental and modeling results we conclude that dynamic frictional strength, which is determined in steady-state experiments, is not necessarily relevant to fault strength during earthquakes. More relevant experiments should be conducted under impact loading that better fits high velocity rupture propagation.