The evolution of fault strength and gouge properties with shear strain: Insights from particle dynamics simulations

Morgan, J.K.[1,2] and Guo, Y.[1]

(1) Rice University, Houston, TX, USA
ph. (713) 348-6330 ; fax (713) 348-5214 ; email morganj@rice.edu
(2) Harvard University, Cambridge, MA, USA
ph. (617) 496-4375 ; fax (617) 496-1240

Fault slip is accompanied by substantial fault rock damage and grain comminution, which can strongly influence the overall strength and behavior of the fault zone. Changes in wall rock damage and gouge thickness over time will also control the long-term fault zone evolution. We simulate the break down of fault blocks using particle dynamics methods in two-dimensions (2-D) to examine this evolution and its consequences on fault strength and behavior under a range of normal stresses (σ_n) corresponding to different fault depths, and a range of uniaxial compressive strengths (σ_{ucs}) corresponding to varying lithologies. The fault blocks were generated by adding elastic bonds between adjacent circular particles and deformed in a direct shear configuration.

Under most stress and strength conditions, initial loading generates extensional microfractures within the wall rocks at a high angle to the pre-existing planar fault surface. Initially, the gouge zone thickens rapidly, as grains plucked from the wall rocks accumulate within the fault. Once the thickness of the gouge is great enough to separate the wall rocks, wall rock wear and damage decreases, and deformation is accommodated primarily by shearing within the existing fault gouge. Gouge grains also undergo progressive fracture and size reduction with shear.

The presence of fault gouge decreases fault strength compared to that associated with slip on the planar fault surface. However, fault strength evolves with shear strain due to changes in gouge thickness and grain characteristics. The balance among grain plucking, grain size reduction, and gouge thickening depends on the ratio of σ_n / σ_{ucs}. If this ratio is high, gouge grains are rapidly crushed, forming a relatively thin layer of weak, fine-grained fault gouge that cushions the wall rocks from further plucking. This results in a progressive decrease in fault strength with strain. If this ratio is low, comparatively large, angular gouge grains persist, grinding along the walls to pluck new grains, further increasing the thickness of the gouge. This causes a gradual increase in fault strength with shear strain.

The implications of such variations in gouge thickness and fault strength the ratio of σ_n / σ_{ucs} are significant. First, this demonstrates that there is no universal relationship between gouge thickness and shear strain, as the former is strongly dependent on both fault depth and wall-rock lithology. Second, for a uniformly strong lithology, deeper portions of a fault zone will undergo rapid softening as fault gouge forms and degrades, whereas shallower portions of the fault will experience a gradual increase in strength as coarse, immature fault gouge accumulates. Such temporal and spatial heterogeneities in fault strength may result in changes in fault activity, and possibly seismicity, over time.