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A Toy Model Investigation of the Weak-Fault Strong-Crust Problem

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There is growing evidence that many large to intermediate faults are very weak ($\mu_f < 0.1$-0.2) relative to classical lab friction measurements ($\mu_f = 0.6$-0.85, Byerlee's Law). In contrast the brittle upper crust appears to be typically strong, as shown by deep borehole stress measurements and critical-taper wedge mechanics ($\mu = 0.4$-0.8). Here we present very simple numerical modeling to illuminate how weak faults and strong crust can coexist. These models incorporate a relatively strong off-fault material with embedded weak faults as an analog of the weak-fault-strong-crust problem. The results suggest that crustal strength may be dominated by off-fault strength because off-fault deformation is required for a general deformation of a crust with imbedded weak faults.

We have developed a large, crustal-scale, 2-dimensional, discrete-element model (DEM) that represents the Earth's crust with embedded pre-existing faults at various depths within the seismogenic crust. The technique treats rock as an array of circular particles of unit thickness that are bonded in both shear and tension. This technique has numerous advantages over continuum formulations, most significantly the ability for fracture to occur when bond strength is exceeded upon loading. This occurs in an organic manner, and the direction and nature of faulting is dependent on near-field loading and material and not by pre-defined faults or interfaces. In the past these sorts of particle-based, discrete-element formulations have had difficulty simulating slip upon newly formed faults: the bumpy nature of the particle formulation creates an implicit resistance to slip and dilation that would not necessarily occur in nature. To avoid this problem we are applying a recently developed 'smooth-fault' logic to the embedded faults within the model crust. This formulation allows particles that lie upon the embedded faults to slide smoothly past one another without the effective friction and dilation that would otherwise occur.

Faults of different lengths, strengths and orientations are embedded into the model crust. They are either randomly arrayed or input as sets with similar and/or conjugate orientations. Fault maximum length and length distribution is scaled according to model size and the largest earthquake magnitude expected according to a Gutenberg-Richter power-law relationship, with fault friction an inverse function of fault length.

As our intention here is to investigate the influence of pre-existing faults within a crustal domain, we run these models to very small strains ($< 1\%$); we do not want to create suites of new faults, but rather monitor the behavior and conditions in our pre-existing faults. This does not mean that new faults will not form as the result of slip upon- and interaction between the embedded during loading.

The models are run within a servo-controlled, 2D biaxial testing environment: models are end-loaded via two rigid walls and confining pressure is supplied along the sides by two rigid servo-controlled walls. Quantities such as Young's modulus E, Poisson's ratio ν and the failure strength σ_f, among others, can be monitored continuously during the model runs. We will monitor the evolution of effective fault friction, a function of confining pressure and strength at failure, both on the embedded faults and within the intervening, initially intact crust on the verge of failure. From this simple toy model we illuminate how the stress state evolves and damage accumulates in strong crust that contains weak faults.