Coulomb Failure Stress and triggered seismicity: The consequences of fault zone damage

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Predictive models for the stress triggering of earthquakes have been built on the concept of Coulomb Failure Stress (CFS). CFS is the change in proximity of a given 'target' fault to the Mohr-Coulomb shear failure criterion due to changes in stress induced by slip on a neighbouring 'source' fault. Stress triggering models, often based on Okada's elastic dislocation solution for a fault in an isotropic elastic half-space, form the basis of many seismic hazard assessments, e.g. the Coulomb software package from the USGS.

A common assumption in CFS models of stress triggering is that of constant apparent friction. Apparent friction is a term used to combine frictional strength and effective stress contributions to the localised stress changes at the target fault. Beeler et al. (2000) and Cocco & Rice (2002) have both explored the underlying mechanics of apparent friction, and considered isotropic and anisotropic poroelastic effects in fault zones. We know that fault zones are inherently anisotropic in their physical properties, in part due to arrays of sub-parallel cracks and fractures in their damage zones (Faulkner et al., 2006; Mitchell & Faulkner, 2009). We can model the mechanical influence of these crack patterns using anisotropic poroelasticity (Sayers & Kachanov, 1995; Wong, 2017). For short-term effects, we can consider the target faults responding as 'undrained' poroelastic materials (constant fluid mass, varying pore fluid pressure), and for longer-term deformation we can use the 'drained' case (constant pore fluid pressure, varying fluid mass). We have built a new open source software tool called CFSape (Coulomb Failure Stress anisotropic poroelasticity), using MATLAB. The tool includes a GUI to collect source and target fault parameters, select among alternative poroelastic boundary conditions, and specify the required outputs.

Calculations using CFSape show that the possible consequences of ignoring anisotropic poroelasticity at the target faults are highly significant. Faults which appear stable (locked) under either of the typical assumptions of constant apparent friction or isotropic poroelasticity are predicted to fail when anisotropic poroelasticity is incorporated. The converse is also true: apparently 'risky' faults are predicted to be stable. The model predictions confirm the theoretical finding of Cocco & Rice (2002) that in the extreme case of perfectly fault-parallel cracks at the target fault, an assumption of constant apparent friction is generally valid. However, this begs the critical question: what is the correct or best value of the Skempton coefficient (isotropic case), or the Skempton tensor (anisotropic case), for these models? We urgently require more and better experimental data on the anisotropic poroelastic response of rocks, measured under likely crustal conditions of true triaxial stress. We need data for both the Skempton (undrained) and Biot (drained) tensors to apply better constraints for short- and long-term seismic hazard assessments due to stress triggering of earthquakes.