THE ROLE OF THE INTERMEDIATE STRESS ON FAILURE DIRECTION

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The directions of faults are often suggested to correspond to the Coulomb failure criterion. In these analyses, only the maximum (σ_1) and least principle (σ_3) stresses control fault formation and their orientation. However, it has been demonstrated that the intermediate stress (σ_2) plays a major role in rock failure and that the Coulomb failure criterion is not accurate under true 3-D loading conditions. Alternative criteria for failure, as Drucker-Prager, Wiebols-Cook, Hoek-Brown, Lade, Mogi and others were suggested to include all stress components but did not attempt to predict the direction of failure with respect to the principle stress orientation. We numerically simulate rock failure using damage-rheology mechanical model that describes the accumulation of damage intensity as a function of the ongoing deformation that eventually leads to macroscopic brittle failure. Our criterion for the onset of damage accumulation is described as $\xi = I_1/\sqrt{I_1} > \xi_0$, where I_1 and I_2 are the first and second strain invariants, and ξ_0 is the critical strain invariants ratio which corresponds to the internal friction in the stress failure models. We run a set of simulations in which only σ_2 is varied between simulations while σ_1 and σ_3 remain the same. Nucleation and propagation of the faults were driven by fluid injection at the center of the simulated rock volume. Results show that the angle between the fault and σ_1 changes from oblique (~35^0) at $\sigma_2=\sigma_3$ to vertical (0^0) at $\sigma_2=\sigma_1$ (figure 1). Although all local failure where in shear mode of deformation and there was no tensile stress in the systems, the nearly vertical fault structure at $\sigma_2=\sigma_1$ is similar to tension regime or axial splitting. Keeping σ_1 and σ_3 constants and increasing the intermediate stress component from low values $\sigma_2=\sigma_3$ to $\sigma_2=\sigma_1$ significantly affects the proximity to failure. The mean stress ($\sigma_m=(\sigma_1+\sigma_2+\sigma_3)/3$) increases with σ_2, while the differential stress ($\sigma_1-\sigma_3$) remains the same. This stabilizes the rock and drives the state of stress farther from failure conditions. Therefore, stress shadowing that promotes only one conjugate direction is more significant at low intermediate stress values. At high intermediate stresses shadowing is weak and both conjugate directions are constantly active giving an average vertical fault direction. Interpreting fault patterns without considering the intermediate stress can lead to wrong conclusions regarding stress directions and failure mechanisms.

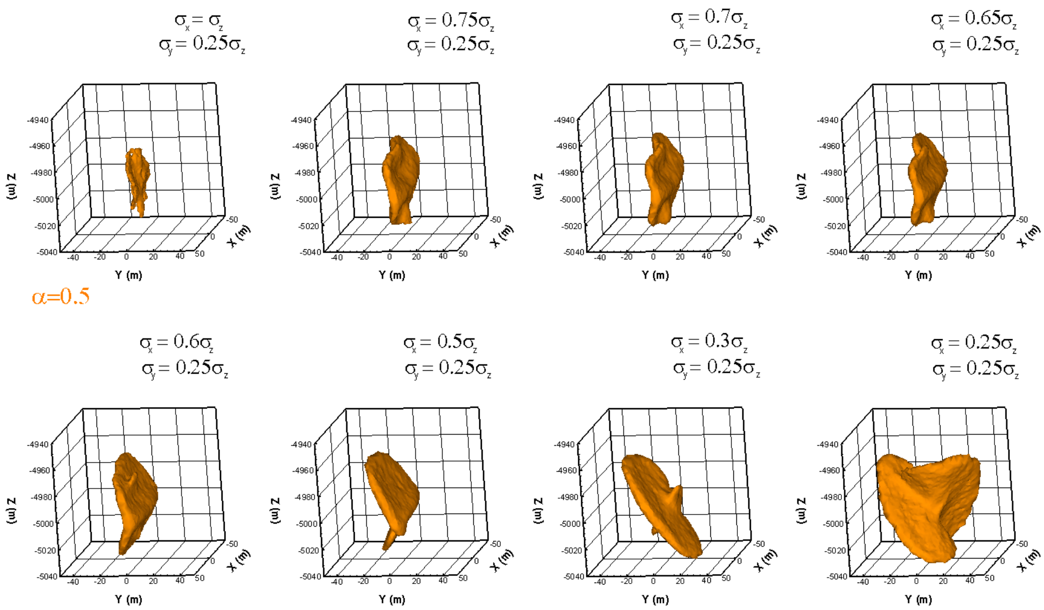

Figure 1. Iso-damage (a=0.5) surfaces for the simulated faults. σ_1 and σ_3 are the same for all cases. Direction of faults change with respect to σ_2.