The influence of loading path on fault reactivation: a laboratory perspective

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Despite natural faults are variably oriented to the Earth’s surface and to the local stress field, the mechanics of fault reactivation and slip under variable loading paths (sensu Sibson, 1993) is still poorly understood. Nonetheless, different loading paths commonly occur in natural faults, from load-strengthening when the increase in shear stress is coupled with an increase in normal stress (e.g., reverse faults in absence of the fluid pressure increase) to load-weakening when the increase in shear stress is coupled with a decrease in normal stress (e.g., normal faults). According to the Mohr-Coulomb theory, the reactivation of pre-existing faults is only influenced by the fault orientation to the stress field, the fault friction, and the principal stresses magnitude. Therefore, the stress path the fault experienced is often neglected when evaluating the potential for reactivation. Yet, in natural faults characterized by thick, incohesive fault zone and highly fractured damage zone, the loading path could not be ruled out. Here we propose a laboratory approach aimed at reproducing the typical tectonic loading paths for reverse and normal faults. We performed triaxial saw-cut experiments, simulating the reactivation of well-oriented (i.e., 30° to the maximum principal stress) and misoriented (i.e., 50° to the maximum principal stress), normal and reverse gouge-bearing faults under dry and water-saturated conditions. We find that load-strengthening versus load-weakening path results in clearly different hydro-mechanical behavior. Particularly, prior to reactivation, reverse faults undergo compaction even at differential stresses well below the value required for reactivation. Contrarily, normal faults experience dilation, most of which occurs only near the differential stress values required for reactivation. Moreover, when reactivating at comparable normal stress, normal faults (load-weakening path) are more prone to slip seismically than reverse fault (load-strengthening path). Indeed, the higher mean stress that normal fault experienced before reactivation compacts more efficiently the gouge layer, thus increasing the fault stiffness and favoring seismic slip. This contrasting fault zone compaction and dilation prior to reactivation may occur in different natural tectonic settings, affecting the fault hydro-mechanical behavior. Thus, to take into account the loading path the fault experienced is fundamental in evaluating both natural and induced fault reactivation and the related seismic risk assessment.