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Fault Frictional Stability in a Nuclear Waste Repository

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Exploitation of underground resources induces hydro-mechanical and chemical perturbations in the rock mass. In response to such disturbances, seismic events might occur, affecting the safety of the whole engineering system. The Mont Terri Rock Laboratory is an underground infrastructure devoted to the study of geological disposal of nuclear waste in Switzerland. At the site, it is intersected by large fault zones of about 0.8 – 3 m in thickness and the host rock formation is a shale rock named Opalinus Clay (OPA).

The mineralogy of OPA includes a high content of phyllosilicates (50%), quartz (25%), calcite (15%), and smaller proportions of siderite and pyrite. OPA is a stiff, low permeable rock ($2\times$10-18 m^2), and its mechanical behaviour is strongly affected by the anisotropy induced by bedding planes.

The evaluation of fault stability and associated fault slip behaviour (i.e. seismic vs. aseismic) is a major issue in order to ensure the long-term safety and operation of the repository. Consequently, experiments devoted to understand the frictional behaviour of OPA have been performed in the biaxial apparatus “BRAVA”, recently developed at INGV.

Simulated fault gouge obtained from intact OPA samples, were deformed at different normal stresses (from 4 to 30 MPa), under dry and fluid-saturated conditions. To estimate the frictional stability, the velocity-dependence of friction was evaluated during velocity steps tests (1-300 μm/s). Slide-hold-slide tests were performed (1-3000 s) to measure the amount of frictional healing. The collected data were subsequently modelled with the Ruina’s slip dependent formulation of the rate and state friction constitutive equations. To understand the deformation mechanism, the microstructures of the sheared gouge were analysed.

At 7 MPa normal stress and under dry conditions, the friction coefficient decreased from a peak value of $\mu_{peak,dry}$ = 0.57 to $\mu_{ss,dry}$ = 0.50. Under fluid-saturated conditions and same normal stress, the friction coefficient decreased from a peak value of $\mu_{peak,sat}$ = 0.45 to $\mu_{ss,sat}$ = 0.34. Additionally, it has been observed that the weakening distance D_w is smaller under fluid- saturated conditions ($\sim$4 mm) compared to dry conditions ($\sim$6 mm).

Results showed a linear decrease of both peak friction and steady state friction when normal stress increases. When fluid- saturation degree of gouges is reduced, gouge samples underwent a transition from velocity strengthening to velocity weakening behaviour, thus indicating a potentially unstable frictional behaviour of the fault. Furthermore, under both saturated and dry conditions, the frictional healing rate showed a low recovery of the friction coefficient under different holding times.

Our experiments indicate that the frictional behaviour of Opalinus Clay is characterized by complex processes depending upon normal stress, sliding velocity, and saturation degree of the samples. This complexity highlights the need for further experiments in order to better evaluate the seismic risk during long-term nuclear waste disposal within the OPA clay formation.