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Highly plastic behavior and fluidization of gouge; implications for fault and landslide mechanics and for the generation of mud volcanoes

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We address an issue on "how low gouge friction can be with an increasing amount of pore fluid" (an unexplored problem in fault mechanics), as studied with a rotary-shear low to high-velocity friction apparatus in Beijing using host specimens of Ti-Al-V alloy with a Teflon sleeve. A friction experiment was conducted on about 1 mm-thick, smectite-rich gouge from Shionohira fault zone, Fukushima, Japan, with 80 wt% of initial pore water, at a normal stress of 1 MPa, and with velocity steps of 17 times ranging in 0.21 microns/s to 2.1 m/s. Friction coefficients at slow rates were initially 0.003 to 0.005 with abundant water, but the coefficients increased to about 0.2 owing to the loss of water during the drained tests. Gouge was squeezed out slowly from host-specimen/Teflon interface as very thin paper-like flakes during a part of the run, indicating highly plastic behavior of gouge. The initial friction was by far the lowest ever reported!

A dry high-velocity friction experiment on the same gouge (normal stress 2 MPa, velocity 2.1 m/s) revealed fluidization of gouge due to vaporized water released during decomposition of clay minerals. Friction coefficient increased to its peak ($\sim$ 0.8), followed by nearly exponential decay to a steady-state value of $\sim$ 0.2. Then the friction coefficient began to decrease almost linearly with displacement down to ca. 0.07, deviating from an exponential decay. The gouge was lost almost instantly in less than one second, terminating the run. Temperature, measured at the sliding surface, began to decrease at the onset of the nearly linear weakening, strongly suggesting dehydration of clays (endothermic reactions). We interpret the results that steam pressure increased in gouge till a limit to cause a small explosion of gouge. Gouge can fluidize!

A series of low to intermediate-velocity experiments on slip-zone materials from Kualiangzi landslide, Sichuan, China, demonstrated that the initial friction coefficient was less than 0.1 with a minimum of 0.02 when the initial pore water was greater than about 30 wt%. The landslide is moving slowly at velocities to ca. 1 cm/day on a very gentle slope with a dip angle of 1 to 3 degrees, corresponding to friction coefficients of 0.02 to 0.05. Our drained tests still could not fully reproduce this landslide and we plan to conduct undrained tests as the other extreme case.

Highly plastic behavior of gouge with very low friction may lead to extreme weakening of faults with dehydration, and mud volcanoes may also be caused by dramatic weakening of granular materials with abundant water. Fluidization of gouge can be an important mechanism for ultra-low friction of faults and landslide slip zones with degassing reactions or with vaporization of dehydrated water at low normal stresses. We have just made a gouge sample cell with O-rings and a pore-pressure gauge to refine those preliminary experiment, by conducting undrained tests with controlled amount of pore water while monitoring pore pressure. Additional data will be reported on those materials and on fine sandstone from a mud volcano in the Nankai Trough.