



## Undrained loading in basal shear zones modulates the slow-to-fast transition of giant creeping rockslides

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Giant rockslides creep for centuries and then can fail catastrophically posing major threats to society. There is growing evidence that creeping landslides are widespread worldwide and extremely sensitive to hydrological forcing, especially in climate change scenarios. Rockslide creep is the results of progressive rock failure processes, leading to rock damage accumulation, permeability enhancement and strain localization within basal shear zones similar to tectonic faults. As shear zone accumulate strain, they become thicker and less permeable, favoring the development of perched aquifers. Since then, the creep behavior of mature rockslides becomes dominated by hydro-mechanical interaction with external triggers, e.g. rainfall and snowmelt. However, the mechanisms regulating the slow-to-fast transition toward their catastrophic collapse remain elusive, and statistical and simplified mathematical models used for collapse prediction are usually unable to account for the full spectrum of observed slip behaviors.

Here we couple laboratory experiments on natural rockslide shear zone material, sampled from high quality drillcores, and in situ observations (groundwater level and surface displacement) to investigate the mechanism of rockslide response to short-term pore pressure variations within basal shear zones at the Spriana rockslide (Italy). Using a biaxial apparatus within a pressure vessel, we characterized the strength and permeability of the phyllosilicate-rich shear zone material at in situ stress, as well as the rate and state frictional properties for shear rates typical of the slow-to-fast transition of real rockslides. Then we carried out non-conventional pore pressure-step creep experiments, in which shear stress is maintained at subcritical levels and pore pressure is increased stepwise while monitoring shear zone slip and dilatancy until runaway failure.

Our results, that are quantitatively consistent with in situ monitoring observations, provide a scale-independent demonstration that short-term pore pressure variations originate a full spectrum of creep styles, modulated by slip-induced undrained conditions. Shear zones respond to fluid pressure increments by impulsive acceleration and dilatancy, causing spontaneous deceleration followed by sustained steady-rate creep. Increasing fluid pressure results in high creep rates and eventual collapse. Laboratory experiments quantitatively capture the in situ behavior of giant rockslides, providing physically-based basis to improve forecasting models for giant mature rockslides in crystalline rocks.

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