EGU23-8771, updated on 11 May 2023
https://doi.org/10.5194/egusphere-egu23-8771
EGU General Assembly 2023

A thermo-poro-mechanical model to simulate and predict landslide evolution: a physics-based method applied to the Ruinon Landslide (Italian Alps)

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Large slope instability processes result from a complex interaction among different geological, geomorphological and climatic factors. A complex multidisciplinary approach is thus necessary to understand their behavior and develop modeling predictive tools. This work suggests a multi coupling method to predict stability and velocity of a landslide, giving critical values for measurable variables (i.e., piezometric level) up to which remediation actions can be deployed. The aim is to define a time-dependent stability criterion that links the external forcing of a landslide with its internal response through a thermo-poro-mechanical mathematical model.

The presented model is based on the assumption that most of the landslide deformation is concentrated on a basal shear band representing the sliding surface: the landslide body is deemed as a rigid block sliding on a visco-plastic shear band with thermal softening and velocity hardening. When the landslide moves, it causes friction with mechanical dissipation that raises the basal temperature and reduces the shearing resistance of the shear-band material. This process can continue up to the point when the friction coefficient decreases uncontrollably due to a thermal runaway instability and the system become unstable, even without changes in the external factors.

The model is applied to the Ruinon Landslide located in the Central Italian Alps (upper Valtellina region). It represents one of the most active cases in the alpine region, with a main sliding surface located at a depth of approximately 70 m, for a total estimated volume of about 20 Mm^3 threatening the national road SS300 that travels through the valley bottom. On the base of the available in situ monitoring data (Piezometers, Ground-Based Interferometric Radar), velocity–time curves correlate with the piezometric level trend, suggesting a key role of pore pressure as an accelerating factor for the landslide.

The workflow of the analysis involved different steps. A preliminary 3D FEM numerical analysis was performed to provide the stress-strain distribution along the slope. Then, to define the thermo-poro-mechanical behavior of the sliding surface and to calibrate the mathematical model, triaxial compression tests with thermal control were performed on rock samples representative of the shear band. The pore pressure data from in situ piezometers were introduced as input-data and the landslide basal temperature was calculated. Finally, the strain rate was simulated by the model and a process of validation was applied using field displacement histories recorded by the landslide monitoring system.

The outputs of the model well simulate the landslide velocity, reproducing the sliding behavior and its relationship with pore pressure. The developed time dependent stability criterion represents an innovative physics-based tool for analyze landslide evolution leading to early-warning and remediation strategies, that accounts for thermal and velocity sensitivity of shear band materials, as well as the effect of pore pressure in promoting the evolution of different creep stages. The validated model can be also used as a predictive tool, to forecast the behavior of landslides and establish a physically based early warning strategy taking into account future climate scenarios.