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Gravitational rock slope failure and associated fracturing: New insights from geological analysis and numerical modeling

Stephane Bouissou (1), Romain Darnault (2), Alexandre Chemenda (3), and Yann Rolland (4)

(1) Université de Nice Sophia-Antipolis, Laboratoire Géoazur, UMR 6526, 250 rue A. Einstein, 06560 Valbonne, France , (2) Université de Nice Sophia-Antipolis, Laboratoire Géoazur, UMR 6526, 250 rue A. Einstein, 06560 Valbonne, France, (3) Université de Nice Sophia-Antipolis, Laboratoire Géoazur, UMR 6526, 250 rue A. Einstein, 06560 Valbonne, France, (4) Université de Nice Sophia-Antipolis, Laboratoire Géoazur, UMR 6526, 250 rue A. Einstein, 06560 Valbonne, France

Gravitational slope failure is known to be influenced by several factors among which structural heterogeneities and alteration/weathering processes are assumed to play a dominant role. The relative influences of these factors as well as the massive gravity induced fracturing are however still misunderstood. We address this problem using geological analysis and numerical modeling of the Argentera massif (French southern Alps) along the Tinée Valley. The eastern side of the valley is subjected to active landsliding and is composed of metamorphic weathered units. These units are affected by tectonic fracture sets related to Oligocene-Miocene thrust tectonics. In order to analyze massive fracturing evolution during gravitational rock slope failure we performed an accurate fracturing analysis along the slope (from the toe to the crest) around two landslides. We chose the advanced La Clapière landslide active for sixty years and the initiating Isola Landslide. In addition to the well known tectonic fracture sets, we observed in both cases a new family of vertical fractures parallel to the valley. These fracture families have been only observed at the elevations corresponding to those of the landslides. They have different orientation in the both sites because of the valley rotation. In the case of the La Clapière advanced landslide, the density of this fracture set parallel to the valley is high at the toe of the slope and decreases upwards along the active landslide. To find out whether the identified fracture sets parallel to the valley are related to the gravitational failure processes, we performed a numerical modeling. We used the finite difference two-dimensional homogeneous model with Hooke–Mohr–Coulomb properties and topography of the La Clapière cite derived from DEM. The principal factor defining the gravity-driven destabilization of the model is a gradual reduction in the cohesion. This reduction simulates a degradation of the material properties with time due to weathering/alteration processes. The model properties are not only time but also strain-softening controlled by the hardening modulus strongly influencing the material faulting/fracturing attributes. The inelastic deformation first occurs at mountain scale and results in normal faulting causing crest sagging. Later, the failure process is concentrated in the lower part of the slope. It corresponds first to the formation of sub vertical fractures/faults affecting the shallow part of the slope and corresponding well to the fracture sets indentified in the field. Then evolution of inelastic deformation leads to the formation of a localized shear rupture subparallel to the slope surface at a depth of ca. 100 m. This corresponds to the initiation of the La Clapière landslide and its propagation upslope. Numerical modeling thus shows that the fracture sets parallel to the valley are of gravitational origin.