Influence of fracture sets and topography on gravitational destabilization of slopes: New insights from 2-D and 3-D physical modelling.

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1. Introduction:

Gravitational rockslope failure generally results from the interplay of several factors, among which topography and structural heterogeneities are known to play a dominant role (*Pan et al.,* 1994; *Bois et al.,* 2008). A link between structural heterogeneities orientation and initial topography of the slope has been clearly established (*Cruden and Hu,* 1996; *Cruden,* 2003). The influence of the initial topography on the gravity-driven activation of fractures and on failure processes is however still misunderstood. To address this issue we performed properly scaled both 2-D and 3-D physical modelling of the Randa area. Our goal was not to reproduce the well documented 1991 Randa rockslides sequence, but to study the influence of a realistic initial topography by the comparison between 2-D and 3-D modelling results on activation of realistic fracture sets.

2. Modelling procedure:

A slope model is created by pouring a melt of the analogue material *Slope*1 into a rigid box at a temperature of 50°C. *Slope*1 is a low frictional elasto-brittle-plastic analogue material with strain softening (see (*Chemenda et al.*, 2005) for more experimental details). In order to create the fractures a series of openings cut in the opposite lateral sides of model box are used to position taut strings. After cooling to a temperature of 20°C, at which the crystallized material is strong enough to be easily handled without damage, strings are moved along the slots to cut *Slope1* and produce fractures, and then are removed. Surfaces of 3-D models are produced using a negative of the desired topography. Once the model is prepared it is loaded into a vertical accelerator table. The latter consists of a mobile platform that can be uplifted up to 2 m and then released. During its free fall the model reaches a maximum velocity of 6 m/s. The platform is then rapidly but smoothly decelerated to zero velocity when it comes into contact with a progressive shock absorber of 5 cm stroke. During this phase the model undergoes a strong vertical deceleration (up to 500 m/s^2). This deceleration acting in the same direction as the gravity is repeated until failure develops, usually ca. 100 loading cycles.

3. Results:

The influence of the density of fractures has been studied using 2-D physical models (Fig. 1). Two distinct initial configurations have been tested: A highly pre-fractured model with some continuous joints (Fig. 1a to 1c) and a slightly pre-fractured model with continuous joints (Fig. 1d to 1f). In this last configuration the continuous joints are the same as in the first one.
In both experiments the irreversible deformation tends to localize first on the most persistent/continuous joints (Figs. 1b and 1d). Then, in the advanced deformation stages, the two configurations lead to a comparable mobilized volume but with very different kinematics (Figs. 1c and 1f). In the highly pre-fractured configuration, two successive rockslides were observed. In the slightly pre-fractured configuration a new master fracture/fault form and

conduct to the formation of a deep seated landslide. These demonstrate that the fracture density is a first order parameter controlling the kinematics of the rupture.

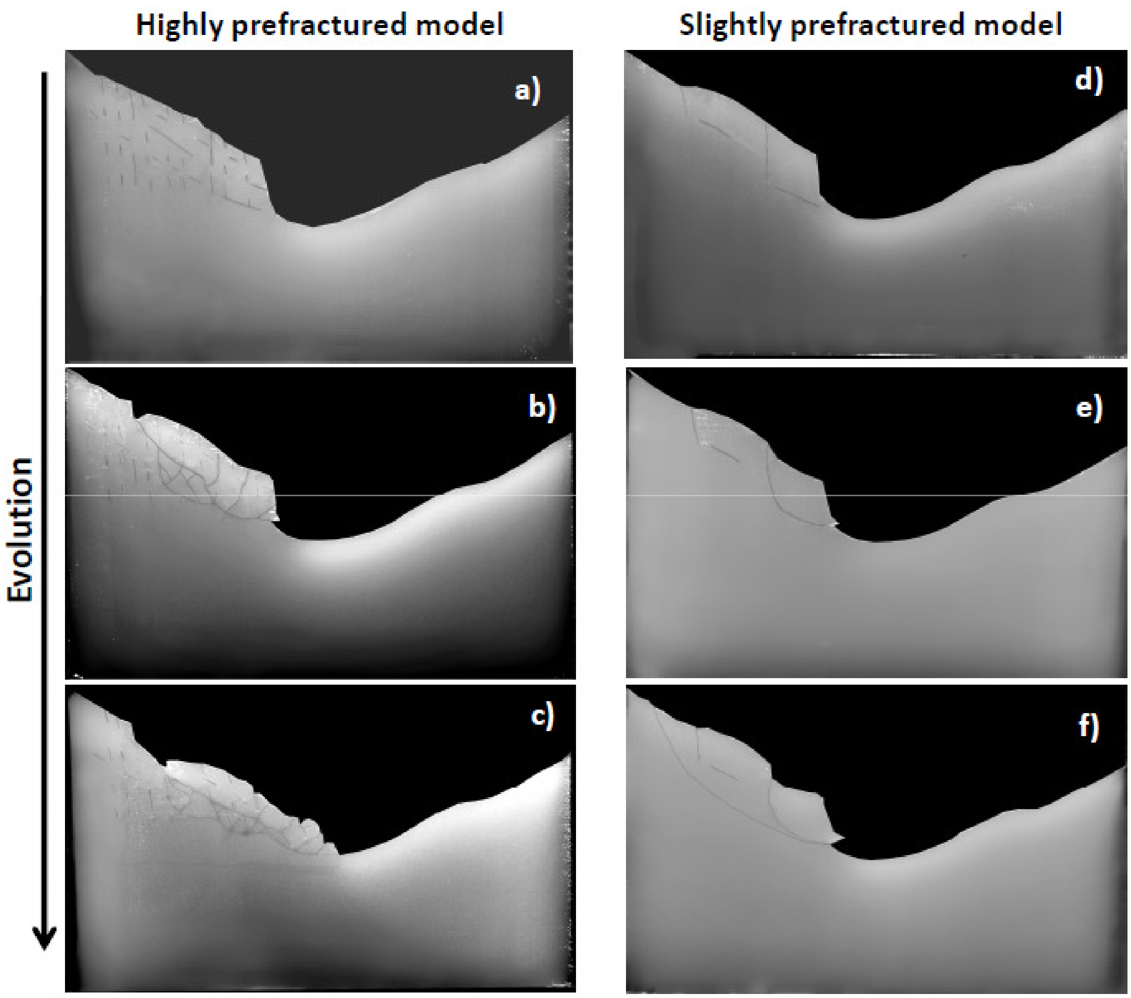

Figure 1. (a) to (c) Evolution of the highly pre-fractured model in cross-section. In this case the fractures (that are assumed to correspond to those initiated the two Randa rockslides) are longer than others: (a) Initial stage, b) Early deformation stage (after 100 loading cycles), and (c) Advanced deformation stage (after 120 loading cycles). (d) to (f) Evolution of the slightly pre-fractured model: (d) Initial stage, (e) Early deformation stage (after 100 loading cycles), and (f) Advanced deformation stage (after 120 loading cycles).

To test the influence of the topography on gravitational slope failure, 3-D physical models have been performed using DTM data (Figs. 2a and 2c). Again a slightly fractured model (2 sets of fractures affecting the model) and a highly fracture model (5 sets of fractures) have been investigated.

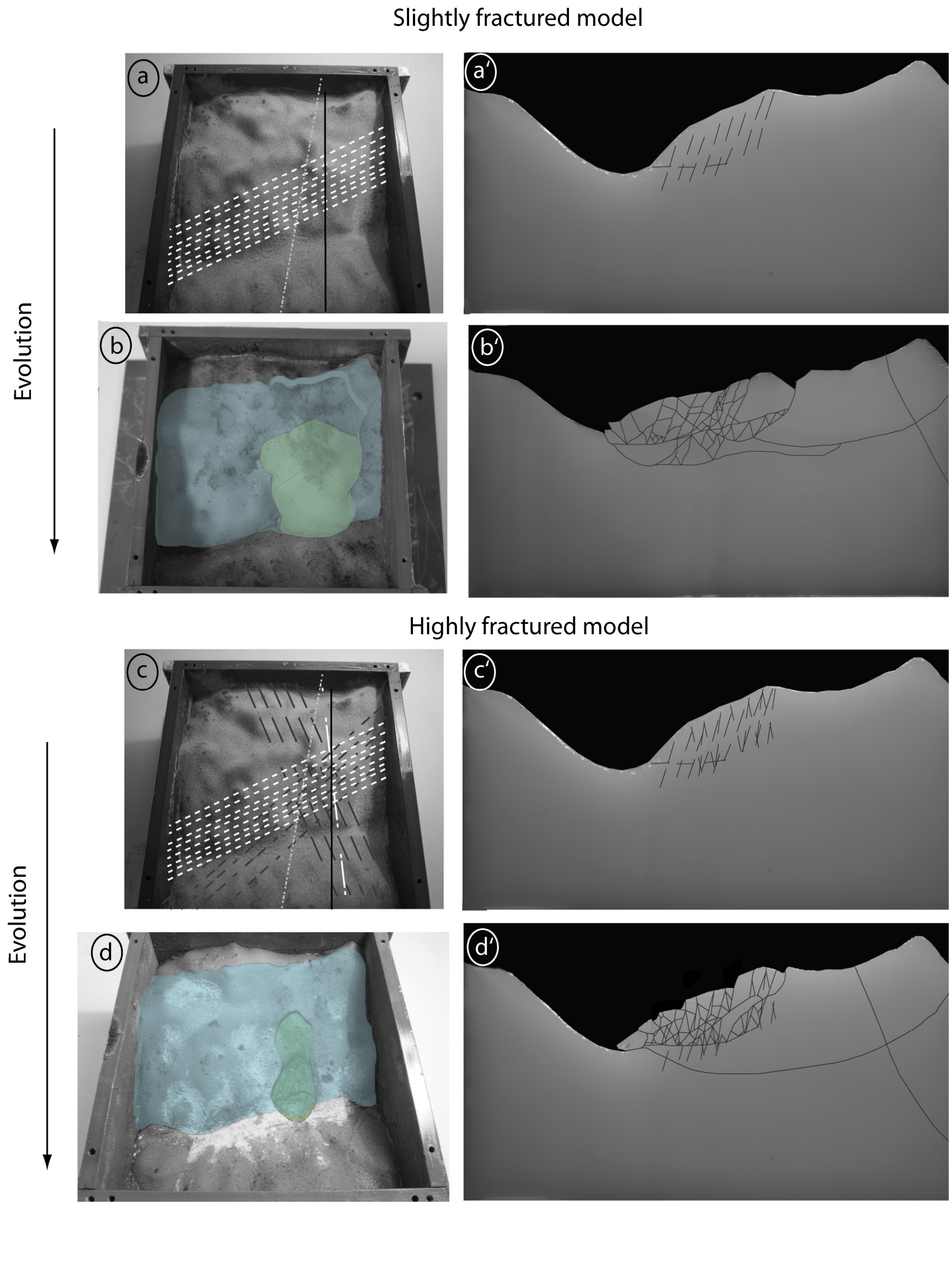

Figure 2. Evolution of the slightly (a to b') and highly (c to d') fractured models (views from above and in cross section.

Results show that for both slightly and highly fractured models the long wavelength topography predefines the formation of a Deep Seated Gravitational Slope Deformation (in blue in Figs. 2b and 2d), characterized in the cross sections by two deep master faults (Figs. 2b' and 2d'). Furthermore, in both cases a shallower rupture is generated on the slope (in green in Figs. 2a and 2c) due to the effect of the shorter wavelength topography.
The main difference between the two presented models is again the fracture pattern and the kinematics of the forming quasi-rigid blocs. Indeed, in the slightly fractured model the deformation of the model leads to the activation of a Deep Seated Landslide (Fig. 2b) sliding coherently down in the valley (Fig. 2b'), while the highly fractured model shows the formation of two retrogressive rockslides (Figs. 2d and 2d') involving a smaller volume than in the slightly fractured case.

4. Discussion and conclusion:

Our modelling approach provides an efficient tool for analyzing large scale and large strain rock mass rupture in the presence of pre-existing fracture sets. In both 2-D and 3-D models, the kinematics of the rupture associated with DSL or retrogressive rockslides has shown to be sensitive to the fracture density. Conversely, the mobilized volume appears to be only slightly influenced by this parameter. The two tested fracture pattern densities in 3-D models resulted in a comparable general deformation of the entire massif: a DSGSD has been obtained in both cases. The initial slope morphology has a major influence on the DSL/rockslide location (green on Fig. 2b and 2d) whatever the fracture density. This is due to the stress concentration effect exerted by the second order topography (*Kinakin and Stead,* 2005; *Bachmann et al.,* 2006). 3-D models have shown that the mobilized volume is very sensitive to initial topography (especially second order topography) combined with fracture orientation.

5. Bibliography:

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