Influence of inherited structural heterogeneities and alteration on gravitational slope failure: Physical and numerical modelling.

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1. Introduction

Gravitational slope failure is known to be influenced by several factors among which structural heterogeneities (*Pan et al.,* 1994; *Bois et al.,* 2008) and alteration/weathering processes (*Hill and Rosenbaum*, 1998; *Hall and André*, 2001) are assumed to play a dominant role. However, the relative influence of these processes is still not understood and requires more studies. In this paper we report results of both 2-D physical and numerical modelling of the La Clapière landslide (Alpes-Maritimes, France). These two techniques are very complementary. The physical modelling is very well suited to study the influence of a large/realistic number of structural heterogeneities on gravitational failure initiation and propagation in large strain conditions. The numerical modelling is a powerful tool for quantitative investigation of the processes that are difficult to simulate in the laboratory. The alteration and its influence on slope failure is one of such processes. The comparison between physical and numerical models and field observations provide constraints on the relative influence of these parameters on a gravitational destabilisation.

2. Modelling techniques

The physical modelling technique is given in *Chemenda et al.* (2005). It is based on the use of original analogue material *Slope*1 possessing low internal friction and quasi-brittle properties with strain softening. The initially homogeneous slope model is fabricated by pouring a melt of *Slope*1 into a rigid box at a temperature of 50°C. Then fractures/faults are produced in the model by cutting it using a special procedure described in (Bois et al., 2008). The final model is loaded into a vertical accelerator table. The latter consists in a mobile platform that can be uplifted up to 2 m and then released. After the release, the platform falls down with the gravity acceleration and then is rapidly but smoothly decelerated to zero velocity when it comes into contact with a progressive shock absorber. During this phase the model undergoes a strong vertical deceleration (up to 500 m/s^2) oriented in the same direction as the gravity. The deceleration/acceleration cycles are repeated until model failure and beyond.

The numerical modelling technique used to simulate the rock alteration effect is presented in *Chemenda et al.* (2009). Computations were performed on the finite difference, time-matching dynamic code FLAC 3D. The model is initially homogeneous with Hooke–Mohr–Coulomb properties and parameter values in accordance with the available data: $E = 20$ GPa, $\nu = 0.23$, $\rho = 2700$ kg/m^3, $\phi = 30°$; the initial cohesion is set to 10 MPa (*Merrien-Soukatchoff et al.,* 2001; *Willenberg,* 2004). The topography is derived from a SRTM digital elevation model file. The resolution of the model is 20 m. Roller-bounder conditions are imposed to the model lateral sides and bottom (Fig. 3a). After an elastic consolidation, the cohesion value was progressively decreased during cycling to simulate the effect of degradation of the rock strength due to alteration.

3. Results

The physical modelling was applied to investigate the influence of the geometry of pre-existent faults at depth. Two sets of experiments have been carried out with six listric faults (Figs. 1 and 2). In the first set, the inflexion depth of the faults was limited to the valley floor level (Fig. 1a), while in the second set, the inflexion depth was greater (Fig. 2a). In both cases the general deformation pattern is characterized by the formation of a deep master fault delimitating a Deep Seated Gravitational Slope Deformation (DSGSD) (Figs. 1b and 2b). Gravitational "superficial" deformation at the toe of the slope is however different in the two tested configurations. In the first one a forming sliding plane leads to the formation of a deep seated landslide (DSL) (Fig. 1b) very similar to the current active La Clapière Landslide. On the contrary, in the second configuration the toppling of the units delimitated by pre-existing faults is observed (Fig. 2b). The kinematics of the rupture is thus strongly influenced by the geometry of the faults at depth. This factor seems to control the deformation both at the topographic surface and depth (mainly at the toe of the slope). The mobilized volume is approximately the same in both cases.

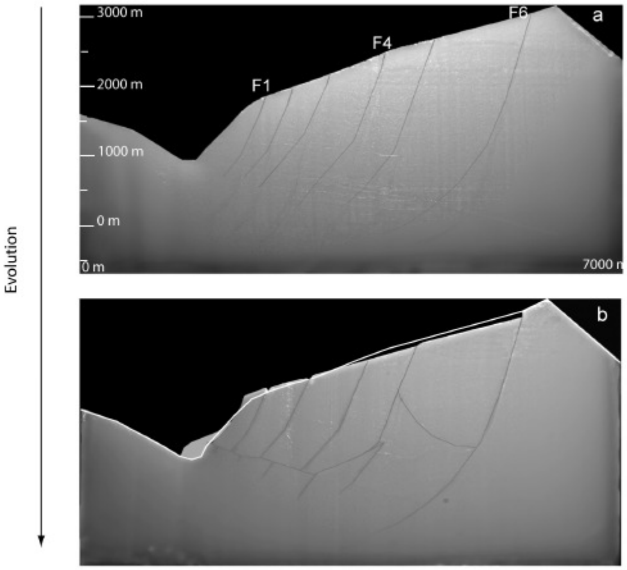

Figure 1. Evolution (two stages) of the model with 6 shallow listric faults (modified after (Bois et al., 2008).

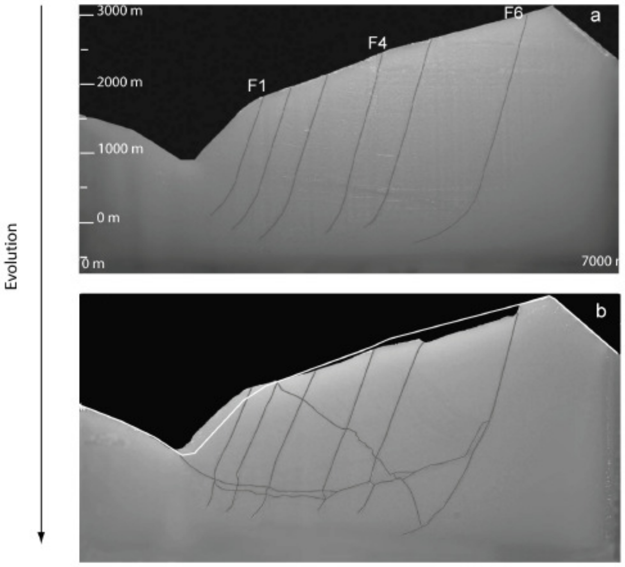

Figure 2. Evolution (two stages) of the model with 6 deeper listric faults (modified after (Bois et al., 2008)

The numerical models show a result of a combine effect of alteration and the first order topography, which result in a rupture of the model at depth and formation of a DSGSD (Fig. 3c). With further alteration/weathering, the lesser wavelength topography features also start influencing the destabilization but at smaller scale, which causes the formation of a DSL (Figs. 3d to 3h).

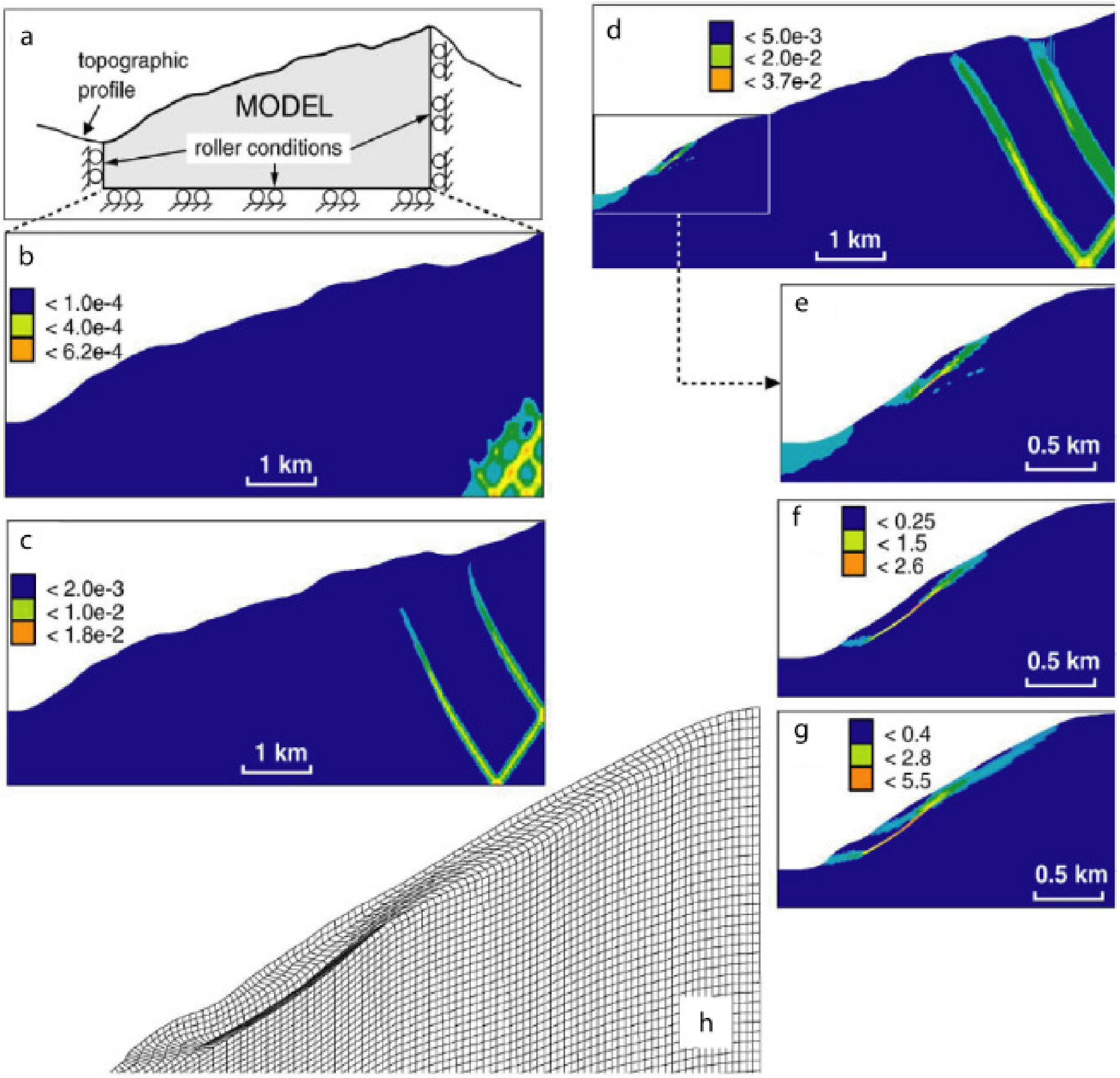

Figure 3. Evolution of the numerical model under gravity force and with progressive reduction of the cohesion. (a) Setup; (b) to (g) Stages of the model evolution; (h) Deformed grid corresponding to the stage (g) and showing the bending (toppling) of the initially vertical grid lines. Colour palettes correspond to the accumulated inelastic deformation representative of the material damage degree (after Chemenda et al., 2009).

4. Discussion and conclusion

Our modelling approach based on coupled physical and numerical modelling technique represents a powerful tool in analyzing different-scale rock mass rupture taking into account pre-existing large scale structural heterogeneities and alteration/weathering processes.

On the one hand, the physical models show that the geometry of faults at depth strongly influences the kinematics of slope failure (trigger DSLs and toppling of the hillside) through a deformation control both at depth and at surface. On the other hand, the numerical models evidence that the alteration/weathering processes combined with the first order topography result in the gravity-driven failure at depth and the formation of DSGSD. The combined effect of alteration/weathering and the second order topography causes formation of DSLs. The reported modelling results need to be completed by the field observations of the relation between pre-existent faults/fractures and destabilisation of a slope. Rock properties characterization as a function of depth and time (alteration) is also of a fundamental importance.

5. Bibliography

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