Evaluation and testing of hydro-mechanical models describing slump failure and liquefaction potential.

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INTRODUCTION

It is important to explain and specify how landslides transform into rapid and dangerous debris flows (The Slide2Flow process). Different mechanisms has been identified which explain this dangerous transition.
We have developed 2 modelling concepts to describe the fluidization process which are based on undrained loading effects during displacement of a slump.

OBJECTIVE

The objective of this work is to test 2 concepts of the Slide2Flow process on slumps which occurred in secondary scarps of the Super Sauze earth flow .

FIELD OBSERVATIONS

The ***1999 slump*** on the clay rich slow moving Super-Sauze earth flow developed in a secondary scarp. The slump *completely liquefied* into a muddy debris flow. A volume of material of 135 $m^3.m^{-1}$ (corresponding to a total volume of 2500 m^3), failed suddenly (estimated velocity 1-2 m per minute) from the secondary scarp of the earth flow, and flowed rapidly over a large distance (120 m) on the earth flow slope.

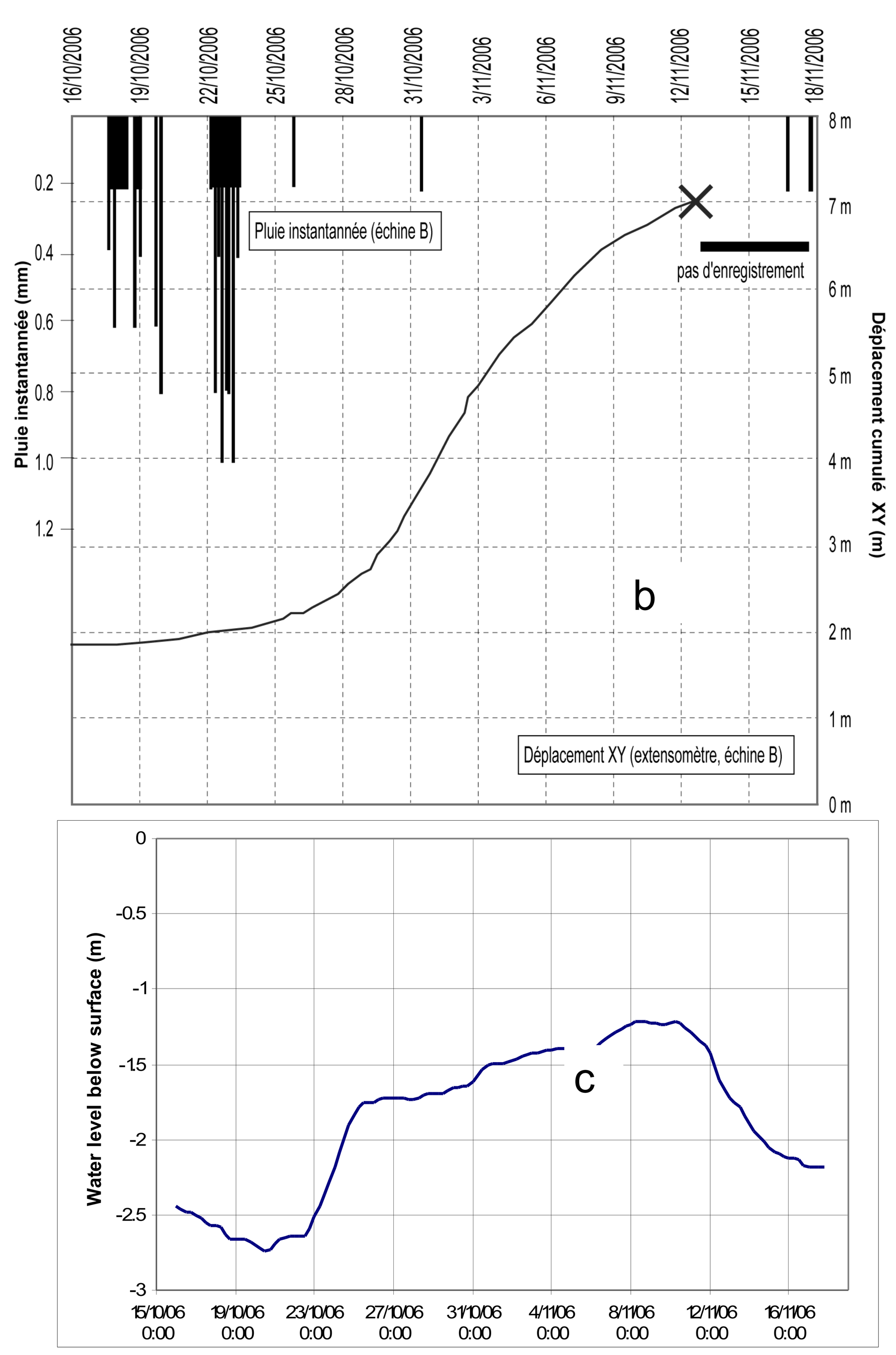

Figure 1. Failure history of the 2006 slump

The ***2006 slump*** on the Super Sauze earth flow, could be monitored in more detail (Figure 1). Figure 1a shows that the slumped material remained for a larger part in the source area and *practical no liquefaction was observed after failure*. Figure 1b gives more details about the failure process. The main displacement took place in the period 25/10/2006 until 12/11/2006, which is around 18 days. The displacement measured in the lower part during that period was about 5 m (Figure 1b) The groundwater level during this failure period varied between -1.75 and -1.25 m (Figure 1c)

MODEL DESCRIPTION

Two undrained loading models have been developed and tested to describe the potential for the Slide2Flow process (Figure 2).
The strain controlled model assumes that during failure of the slump excess pore pressure is generated by compression or extension due to differences in displacment S of the slices i+1, i, i-1… within a slump. We assume that, during the differential movement of the slices, the most important dominant strain component (ε_{xx}) is in the horizontal direction which can be calculated as follows (eq.1) :

$$\varepsilon_{xx} = -\frac{(\Delta S_{i+1}\cos\alpha_{i+1} - \Delta S\cos\alpha_i) + (\Delta S\cos\alpha_i - \Delta S_{i-1}\cos\alpha_{i-1})}{b_i} \qquad (1)$$

Excess pore pressure Δu can be calculated by Skempton's law (eq 2):

$$\Delta u = (1+A)\Delta\sigma_x = (1+A)\varepsilon_{xx}E \qquad (2)$$

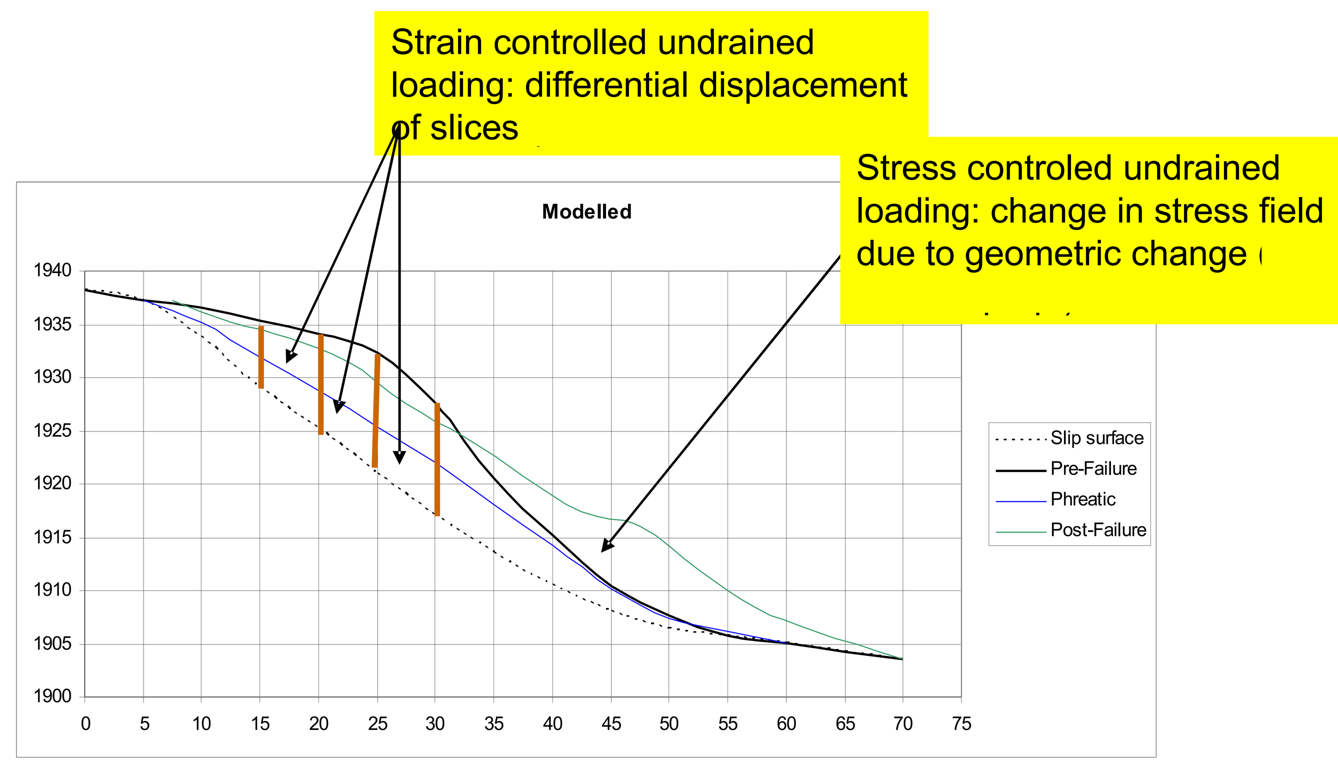

Figure 2: Two concepts of undrained loading to describe liquefaction potentials in relation to displacement of a slump.

where A is Skempton's pore pressure coefficient and E the Young's modulus. The dissipation of excess pore pressure is obtained by calculating the degree of consolidation for uniform distribution of excess pore pressure in a half closed layer.

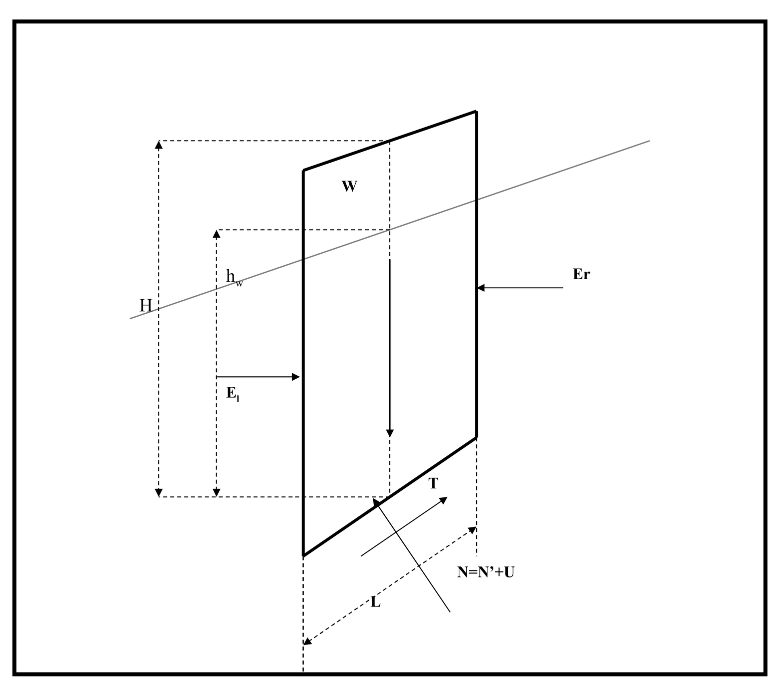

Figure 3. Forces working on a slice of a slump.

The stress controlled model assumes that excess pressure is generated, by a change in the stress field in term of total stress (force) T and N (see Figure 3) in each slice caused by the change in geometry of the slump during movement. Included is the pore pressure dissipation module. Equations 3 and 4 translate these changes into respectively changes into the total principal stresses and into changes in excess pore pressure (Δ u) according to Skempton.

$$\Delta\sigma_1 = (\Delta T\sin(45+\tfrac{1}{2}\varphi) + \Delta N\sin(45-\tfrac{1}{2}\varphi))/L$$
$$\Delta\sigma_3 = (\Delta T\cos(45+\tfrac{1}{2}\varphi) - \Delta N\cos(45-\tfrac{1}{2}\varphi))/L \qquad (3)$$

$$\Delta u = \Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3) \qquad (4)$$

MODELLING RESULTS

Figure 3 shows the development of pore pressure during movement calculated with the *strain controlled model* for the 1999 slump . It shows pore pressure distribution and the successive liquefaction of the slices in the lower part of the moving block in relation to the mean displacement of the slices. The figure shows for example that slice no 6, 5 and 4 liquefied (r_u=1) after a displacement of respectively of 0.09, 0.14 and 0.48 m. The *strain controlled model* was not able to explain the total liquefaction of the slump. In our simulations, about half of the Super-Sauze slumping mass of 1999 liquefied, while observation showed a nearly 100 % liquefaction. With the *stress controlled model* nearly the same amount of liquefaction volume could be simulated but after a larger displacement of 3.1 m

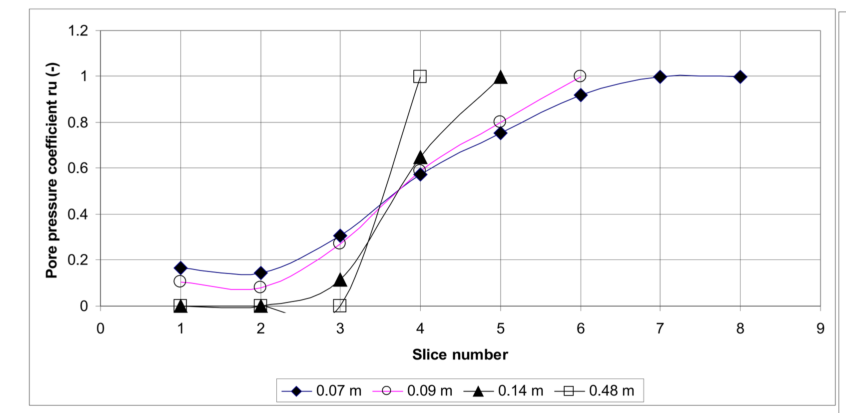

Figure 3. Pore pressure distribution for each slice of the 1999 slump after different displacements with the *strain controlled model*

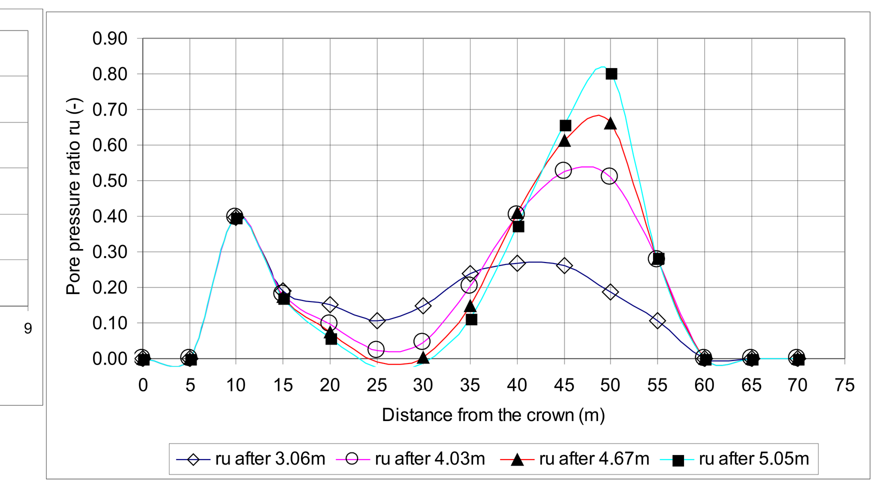

Figure 4. Pore pressure distribution for each slice of the 2006 slump after different displacements with the *stress controlled model*

The 2006 slump shows a mean displacement of about 5 m in 18 days. In this case observations showed no significant liquefaction. However the *strain controlled model* calculated already the beginning of liquefaction in the lower part of the slump after a displacement of 0.05 m. This is about the same result as obtained for the 1999 slump

Figure 4 shows the distribution of the pore pressure during displacement (resp. after 3.1, 4.0, 4.7 and 5.1 m) calculated with *stress controlled model*. The Figure shows an increase in excess pore pressure in the lower part. However the slump stopped after 5.1 m before liquefaction could take place (see Figure 4). Pore pressure have risen pretty high at the toe, which may explain some weakening and larger run-out of material than was modelled (compare Figure 5a with Figure 5b)

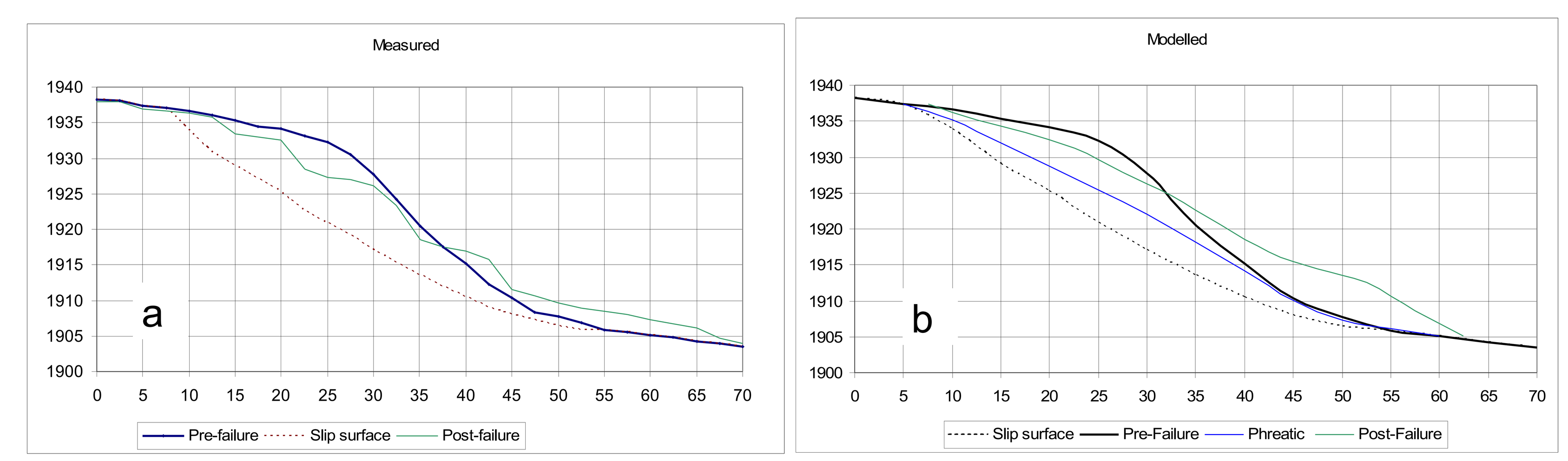

Figure 5. A comparison between measured (a) and modelled (b) displacement after 18 days, using the *stress controlled model* of the 2006 slump at Super Sauze, which showed no liquefaction. (See Figure 4).

Conclusions

Two slumps developed on secondary scarps of the Super Sauze mudslide respectively in 1999 and 2006, which could be analyzed in more detail. The 1999 slump completely liquefied into a debris flow, while the 2006 slump stopped after 18 days with a displacement of 5 m and without liquefaction. The *stress controlled model* seems to describe better the failure processes in terms of displacement in relation to liquefaction than the *strain controlled model.*