KINEMATICAL BEHAVIOR OF SLOW-MOVING LANDSLIDES IN THE VARVED CLAYS OF THE TRIEVES PLATEAU (FRANCE).

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INTRODUCTION

Slow-moving landslides show complex mechanical and fluid interactions. They show among others: non linear intrinsic viscosity of the shear zone, or undrained loading effects leading to local de- and accelerations and the generation of excess pore pressure. The parameterization of hydrological and geomechanical factors by field and laboratory tests to describe the movement patterns of these landslides is difficult. It is a challenge to model the accurate reproduction of the de- and acceleration of these landslides and particularly, to forecast catastrophic surges.

OBJECTIVE

The aim of this work is to analyse the relation between groundwater fluctuations and displacement velocity (and especially the role of excess pore pressure) on a deep-seated landslide in varved clays.

THE MONESTIER DU PERCY LANDSLIDE

The "Monestier-du-Percy" landslide is one of several landslides located in the Trièves Plateau in the French Alps (Fig. 1) characterized by the outcrop of varved clays; these clays are finely laminated glacio-lacustrine deposits dating from the Pleistocene (Wurmian) period. Around hundred landslides have occurred in the last century within this area. The landslides are rotational or translational slides which present slip surfaces at different depths from relatively shallow ones (4 to 8 m) to more deeper ones (20 to 40 m).

The "Monestier-du-Percy" landslide is an old landslide which has been suddenly reactivated on the 9th April 1978. It affects an area of approx. 0.9 km^2 on a relatively low-gradient slope (15°). The hill slope is characterized by a hummocky topography of successive small scarps in the medium part, and by a plateau with a vast swamp at the top above the main scarp (Fig.2)

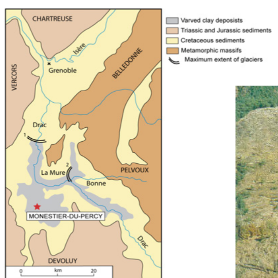


Fig. 1: Geology of the Trièves Plateau and location of the Monestier-du-Percy landslide.

Fig. 2: Aerial view of the Monestier-de-Percy landslide in 1981.

Important movements occurred after the crisis during a period of 4 days. The geomorphological analysis (indicators of movements) of several orthorectified aerial photographs from 1948, 1973, 1981, 1993 and 2003 indicates also cumulated displacements of ca. 20m over the period 1948-1981 (Fig. 3) and displacements of 2 to 3 meters on the period 199&-2003. The landslide geometry has been reconstructed by seismical soundings and geotechnical boreholes (Giraud et al., 1980). Two inclinometers and one piezometer were also installed in 1994. The landslide is a characteristic translational slide, with a slip surface relatively parallel to the topographic slope, at a depth of around -16m (Fig.4)

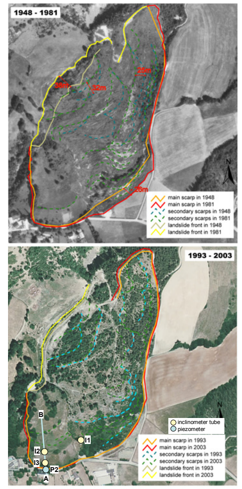


Fig. 3: Geomorphological indicators of landslide activity over the periods 1948-1981 and 1993-2003, and location of geotechnical profile.

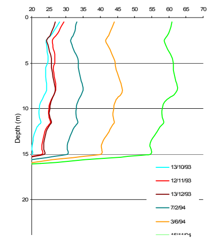
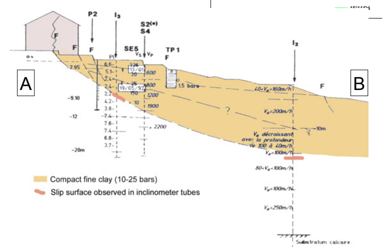


Fig. 4: Displacement profile at inclinometer I2 over the period 1997-1999, and geotechnical profile used for the mechanical modelling.



MODEL DESCRIPTION

Velocity with depth is related to the excess shear strength by means of the constitutive relationship for Coulomb viscous flow. With this relationship, the velocity was calculated at each depth and integrated numerically. Excess shear stress, $\tau - \tau_0$, for the inferred slip plane (16m below surface) was calculated in two ways under the assumption that the cohesion was zero and the strength only dependent on the angle of internal friction ϕ:

$$\frac{T_i}{l_i} = \frac{1}{\eta}\frac{\delta v}{\delta z} + \frac{S_i}{l_i} \quad (1)$$

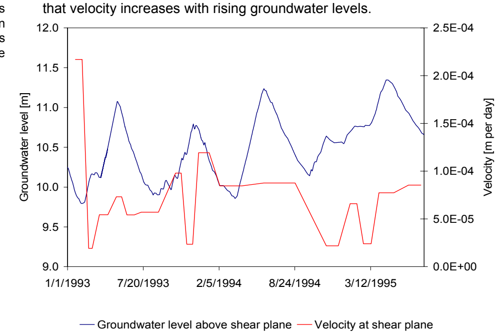
(Eq. 1) From the resistance and driving force per slice of Janbu's method, applying the overall safety factor to each slice;

$$\frac{D_i + P_i}{l_i} = \frac{1}{\eta}\frac{\delta v}{\delta z} + \frac{S_i}{l_i} \quad (2)$$

(Eq. 2) From the Coulomb resistance and viscosity terms of the equation of motion that has to equate the gravity force and earth pressure terms for viscous flow (e.g. no inertia).

where for slice i: S_i is the resistance force, T_i is the driving force according to Janbu, η is the dynamic viscosity, $\delta v/\delta z$ is the velocity gradient over depth z, l_i is the length of the slip surface in slice I, D_i is the gravity force, P_i is the pressure force, S_i is the Coulomb resistance force.

Fig. 5: Groundwater levels and velocity over time at inclinometer I2. There is bad correlation between the time series and no indication that velocity increases with rising groundwater levels.



MATERIAL PROPERTIES

We related observed displacements to the excess shear stress as a result of pore pressure fluctuations. Our analysis involved the following steps: (1) the viscosity of the material was taken from laboratory experiments (2.5 10^{+8} kPa s);

(2) this viscosity was used to obtain the angle of internal friction ϕ by back-fitting the observed displacement profiles assuming that the cohesion was zero (Fig. 6)

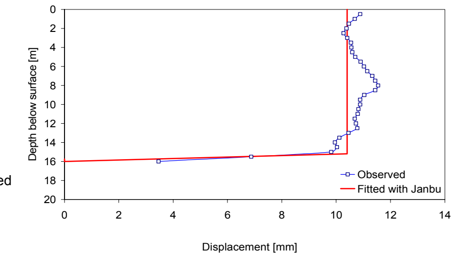


Fig. 6: Observed and calculated displacements over the period 7/2/94 – 3/6/1994

MODELLING RESULTS

The two models of excess shear stress (Janbu, equation of motion) showed little differentiation in the fitted displacement profiles and the back-calculated friction angle. The landslide is very sensitive to fluctuations in the groundwater level (between 10 & 11.2 m) and the resulting range in friction angles is small (between 20.7 & 22.3°; Fig. 7).

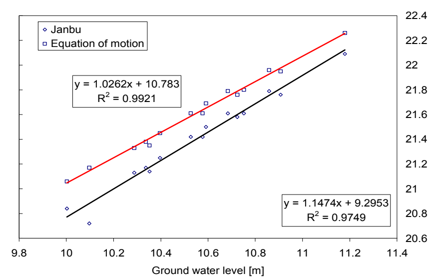


Fig. 7: Calibrated ϕ–values with Janbu and the equation of motion in relation to measured groundwater levels.

The models have limited predictive capacity given the poor relationship between the observed GWLs and displacements. The good fit of the friction angle and GWL for a constant viscosity (Fig. 7) provides a clue towards the internal mechanisms that could operate at the site. At higher groundwater levels, displacement appears to be regulated by the development of additional strength.

This can be quantified as an apparent friction angle (ϕ') that increases due to the generation of negative excess pore pressures (Eq. 3). The overall lowest friction angle was selected as the offset value ϕ_0 (Fig. 7). The other calibrated ϕ-values in Fig. 7 are considered as apparent friction angles (ϕ'). Given these values the excess pore pressure coefficient r_u and thus the excess pore pressure can be calculated with Eq. 3.

$$\tan\phi' = (1 - r_u)\tan\phi_0 \quad (3)$$

where ϕ' is the apparent friction angle, r_u is the excess pore pressure coefficient and ϕ_0 is the off-set of the friction angle.

Excess pore pressure varied, depending on the groundwater height, between -1.0 and -24.3 kPa. The generation of this excess (negative) pore pressure can be explained as a result of dilatation during movement in this part of the landslide.

CONCLUSIONS

The displacement velocity in deep-seated varved clays landslides seems to be not only controlled by the viscous and Coulomb resistance of the material but also by the generation of excess (negative) pore pressure during movement.

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