Mountain Risks
2007-2010
A Marie Curie network

Decisive factors for risk management of slow moving landslides in varved clays

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INTRODUCTION

Around hundred landslides have occurred in the last century within in the Trièves Plateau in the French Alps, characterized by the outcrop of varved clays. The landslides are rotational and (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). Most of these landslides show a more or less continuous moving pattern. It is controlled among others by fluctuations of the groundwater. The velocities range in most cases between 100 and 20 mm per year. In order to take appropriate decisions in risk management especially concerning strategies for mitigation it is important to analyse the relation between groundwater fluctuations and displacement velocities and other controlling factors of these deep seated landslides in varved clays.

OBJECTIVE

The aim of this work is to analyse a feed back mechanism, which controls the movement of these slow moving landslides. Further evaluations are made about the long term evolution of these slides and the potentials for a crises. This will be done with a case study of the Monestier-du-Percy landslide

THE MONESTIER-DU-PERCY LANDSLIDE

The "Monestier-du-Percy" landslide is one of several landslides located in the Trièves Plateau in the French Alps characterized by the outcrop of varved clays; these clays are finely laminated glacio-lacustrine deposits dating from the Pleistocene (Wurmian) period. The "Monestier-du-Percy" landslide is an old landslide, which 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.

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 in the North Eastern part (Fig. 1) and displacements of 2 to 3 meters in the period 1993-2003. The landslide geometry has been reconstructed by seismical soundings and geotechnical boreholes (Giraud et al., 1980). Two inclinometers and one piezometer were installed in 1993 in the Western part. Geomorphological observations and analysis of the geotechnical drillings indicate a rotational movement in the upper part of the landslide, and a translational movement in the lower part imposed by a flattening of the slip surface down slope (Figure2). Figure 3 show example of an inclinometer profiles for different time intervals showing a concentration of the deformation in a small band at a depth around 16 m.

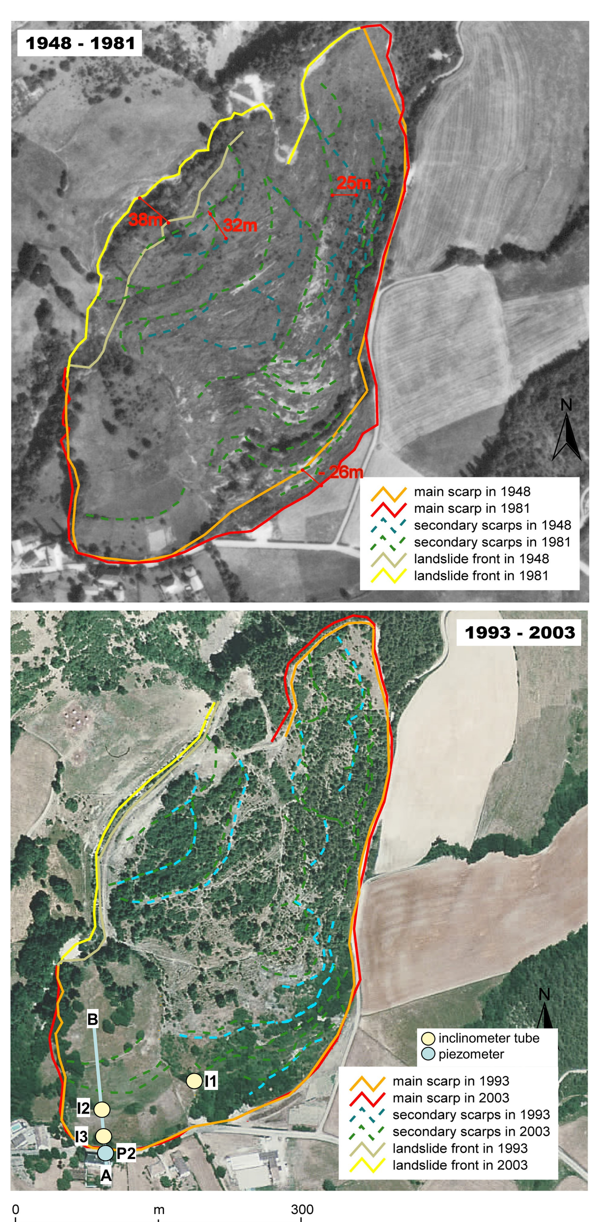

Fig. 1: Geomorphological indicators of landslide activity over the periods 1948-1981 and 1993-2003, and location of geotechnical profile.

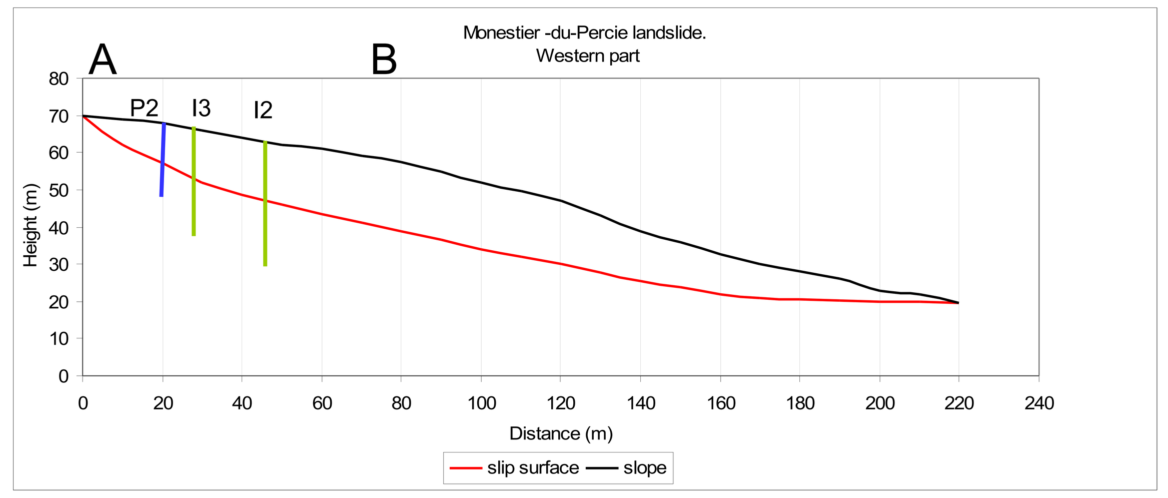

Figure 2 Cross section of the western part of the Monestier-du Percie landslide (I_2 is inclinometer; P_2 is Piezo meter)

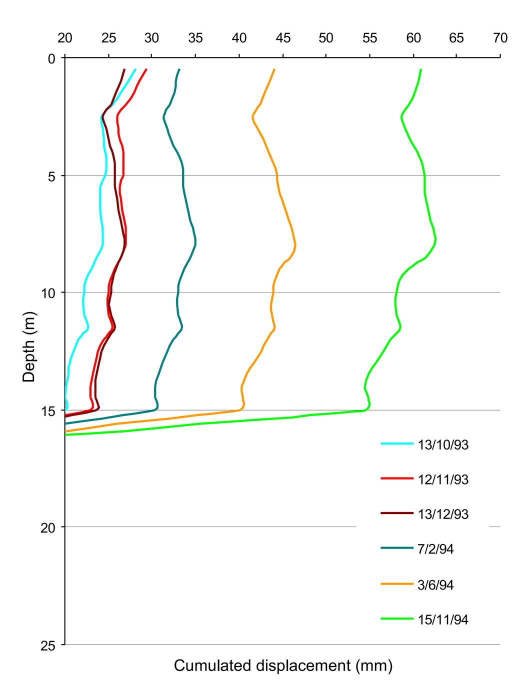

Fig.3: Displacement profiles for different time interval at inclino-meter I2 over the total period 1993-1994.

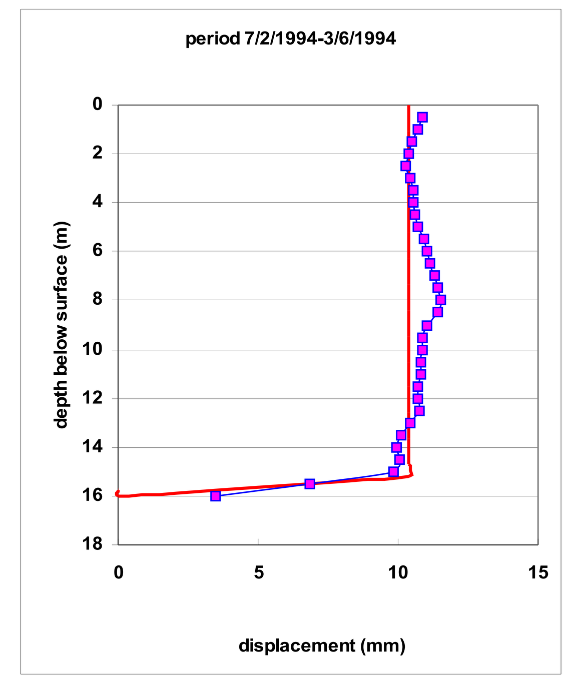

Figure 4 Observed (blue) and calculated (red) displacements at Monestier-du-Percy over time interval 7/2/94 – 3/6/1994

A HYDROMECHANICAL FEED BACK MECHANISM

In depth displacement profiles could be reconstructed, using the Coulomb viscous rheological law .(See figure 4). 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. 4). A good fit was found between mean groundwater level measured in different time intervals and the back calculated friction angle. The good fit of the friction angle and GWL for a constant viscosity 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. Figure 5 shows the relation between excess (negative) pore pressure (P_e calibrated) and the mean groundwater level for the different time interval. We developed a model which generates excess pore pressure as a function of deformation velocity in the shear zone. The model shows for each groundwater level a development of excess pore pressure towards a steady state condition. Figure 5 shows the relation between the mean groundwater level and this steady state excess negative pore pressure (P_e modelled). It does not completely explain the variation in excess pore pressure obtained by the back calculation of the inclinometer profiles (See P_e back calculated; Figure 5)

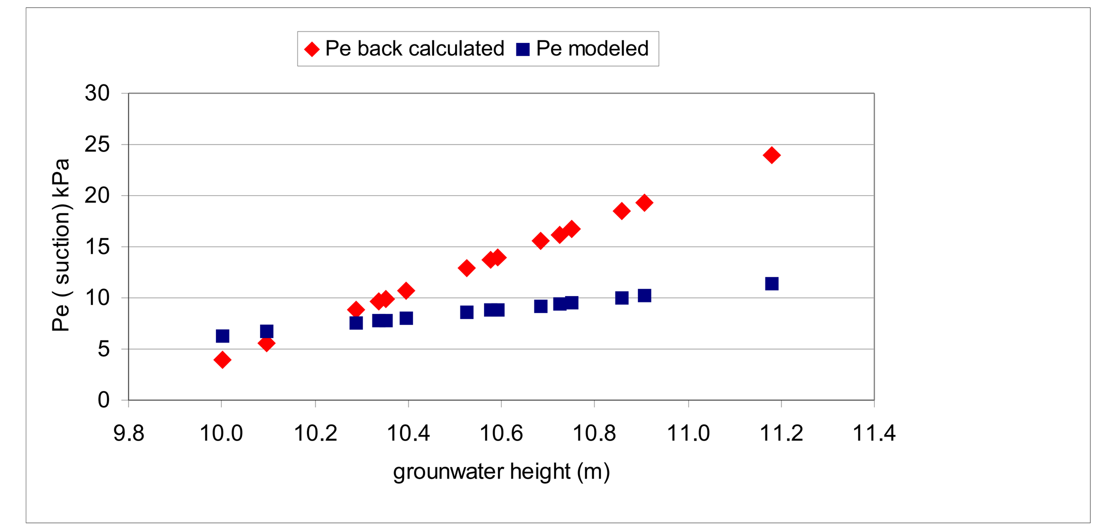

Fig. 5: Relation between mean groundwater height and generated steady state suction obtained from back calculation and modelling

LONG TERM EVOLUTION OF THE SLIDE .

Observation in the past have shown for the North eastern part that displacement velocities decrease over the years (see figure 1) . For the Western part inclinometer results showed a mean displacement of 30 mm per year for the years 1993 and 1994. the groundwater level fluctuated between -5.5 and -4.3 m below the surface with maximum heights in April-Mai and November –December. Figure 6 shows the cumulative displacement of the landslide (Western part see profile Figure 1) for the next 80 years. The long term simulation started with a mean displacement of 30 mm per year and a mean GWL of -4.95 below the surface measured during the '93-'94 period and a mean calibrated ϕ of 21.5^{0}.

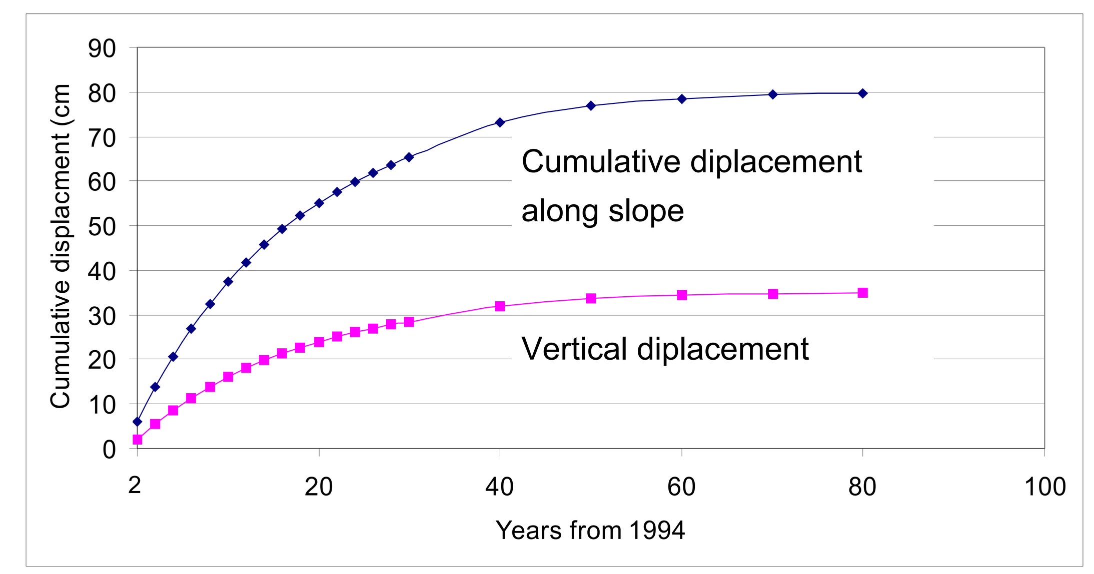

Fig. 6: Longterm cumulative displacement of the Monestier-du Percy landslide assuming steady state conditions

The graphs show under constant mean conditions a decrease in displacement due to the depletion of material in the upper part and accumulation in the lower part. It shows how the stability of the landslide is very sensitive to small displacements of material.

DISCUSSION AND CONCLUSIONS

The interpretation of short term displacements especially for early warning purposes is difficult because of the variations in the hydro-mechanical properties over time and space and a number of factors operating at the field scale. One of them is the Kinematic driven pore pressure change, which in this case works as a negative feed back mechanism on the movement.

The long term evolution seems to show a stabilizing trend due to the geometric change of the mass which however occurs very slowly. Periods of crisis are still possible due to extreme meteorological events. If groundwater height rises 1 meter above the mean level measured over the period '93-'95 velocity increases from 20 mm per year towards 360 mm per year

Viscosity was measured with a direct shear box without an imposed slip plane .These values prove to be realistic because it delivers after back calculations (see figure 5) realistic ϕ -values which were also measured in the lab) However ring shear tests with an imposed slip surface show dramatic lower viscosity values (5 10+4 kPa s). Further investigation about the hydrological system and the temporal development of rheological properties are necessary in order to take proper decision in risk management.