RESULTS ON LANDSLIDE MOBILITY INVESTIGATIONS ON THE RECENT TIME SCALE

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INTRODUCTION

The temporal frequency of the movement of landslides is an important aspect of landslide hazard assessment. Landslide frequency analyzes is an important tool in environmental planning.
The temporal frequency analyzes of landslide movement can be done on different scales using different methodologies. The most common approach is the statistical modelling of meteorological parameters in combination with landslide incidents. The aim is to find for a certain area and/or landslide types meteorological threshold values which are correlated with landslide incidents. Time series analyzes give information about the recurrence values of these critical meteorological thresholds and the related landslide incidents (Versace 1988).
In this chapter effort is given to the deterministic approach for understanding and predicting the frequency pattern of landslide incidents. The basic concept behind this approach is the relation between time frequency of moments of instability and critical conditions of the water balance within the landslide. Therefore a combination of more or less detailed deterministic hydrological and slope stability models may describe and predict the frequency of movements of a landslide or a group of landslides. This approach requires more detailed information about the hydrological and geotechnical parameters of the landslide material and monitoring of the water household in the field.

The here presented studies carried out in the framework of the EPOCH project are examples of such an approach: It will discuss some methodologies to determine the configuration of the slide and to monitor the water balance in the slide. It will discuss the combination of an equilibrium model and a simple hydrological models to assess the frequency of movements . The results will be compared with data on moving incidents in the past which has been obtained by dendrochronological research. The research will also show that insight in the water balance of the landslide is important for the design of remedial measures.

THE LANDSLIDE OF LA VALETTE (BARCELONNETTE)

The landslide complex north of la Valette, in the basin of Barcelonette, is one of the biggest landslides in France, totalling 3.600.000 m^3 of moved material between 1982 and 1990. The landslide originated in the "amont" of the Serre and

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Valette torrents (Fig.1). In this area clayey and permeable morainic deposits are underlaid by marly Terres Noires of the Oxfordien, which are highly impermeable. This condition favours slope instability as excessive pore water pressures will be encountered during periods of snow-smelt and prolonged rainfall. This problem is intensified by the leakage of various sources which spring from the contact between Terres Noires and Flysch into the moraine (Fig. 1).

Catastrophic movement started in the fall of 1982 when a rotational slide with a deep-seated failure plane (15-20 m) across the contact of Flysch and Terres Noires slumped down 20 percent.
This led to a reactivation of the morainic material but further dramatic development was postponed till 15th January 1988 when, after a long period of frost, sudden thaw forced oversaturated moraine to flow into the ravine of the Serre. This flow was stopped by two dams in the common lower course of both torrents at nearly 1 kilometre of its origin (Fig. 2).

This mudflow was followed by a second surge, triggered by the same mechanism, in March 1988. This flow did not only override the first but also filled the upper course of the Valette ravine. Its material however, although originating from the same moraine, seemed to be less viscous as the flow was stopped at the base of the cataract, some 250 m north of the dams (Fig.2). These flows were considered to be a serious threat to the community of St. Pons and the RTM Digne was charged to develop remedial measures to prevent further movement. First of all a basin was constructed with a capacity of 100.000 m^3 which was not reached, however.

The unloading of the morainic material in the middle part of the complex by the triggered a large planar slide with a sliding plane at the contact of the moraine and Terres Noires, at a depth of 15 to 20 m. The movement of this slide is monitored by the RTM across a survey line since 9 September 1988 (Fig.2).
Both flows stabilized during the summer but serious displacements took place during the late winter and spring of 1989 along the flows and in the moraine. Across the survey line of the RTM velocities of 0.4 m/day were reached, with an average of 0.2 m/day, which equals volumetric displacements of 881 m^3/day. At the cataract material was displaced at rates of nearly 1 m/day. As it was clear from the RTM recordings that displacement was strongly related to rainfall (Fig.3), it was decided that remedial measures should comprise extensive drainage to avoid the building up of excessive pore pressures.

These works were carried out in the summer of 1989 and 1990 and consisted of the capture of the Serre and Valette torrents and sources, deep-seated and shallow drainage in the upper, rotational slide, the flattening and drainage of the moraine in the middle part. This area was sown with vegetation to prevent raid infiltration in fissures.

In the framework of this project the Utrecht team did study the mobility characteristics of this slide.
In this limited study of 1 year the following questions were tried to be answered.
- What is the distribution of the stability over the landslide and how can the different parts influence each other?

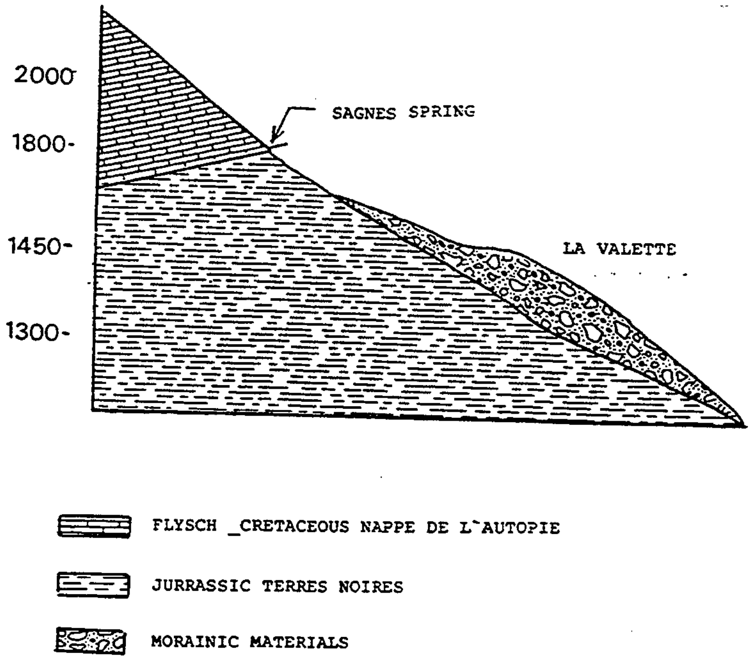

Figure 1. Schematic geological profile of the Valette landslide.

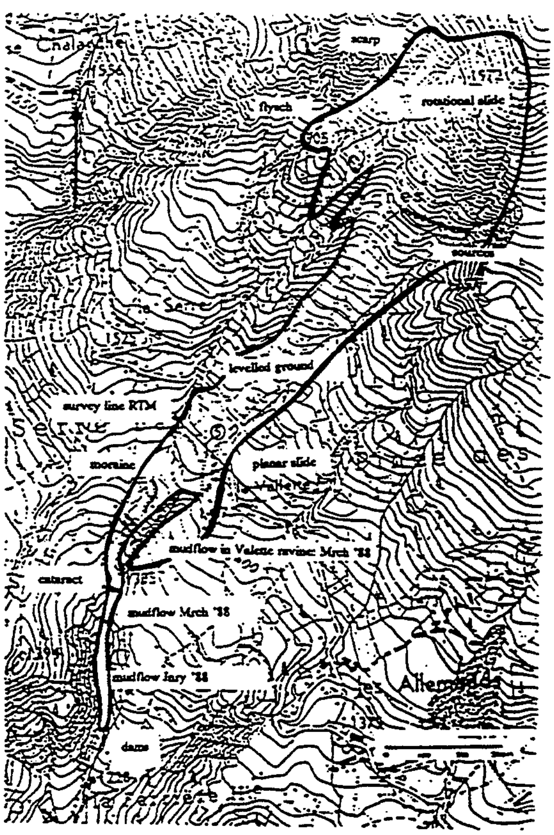

Figure 2. The Valette landslide

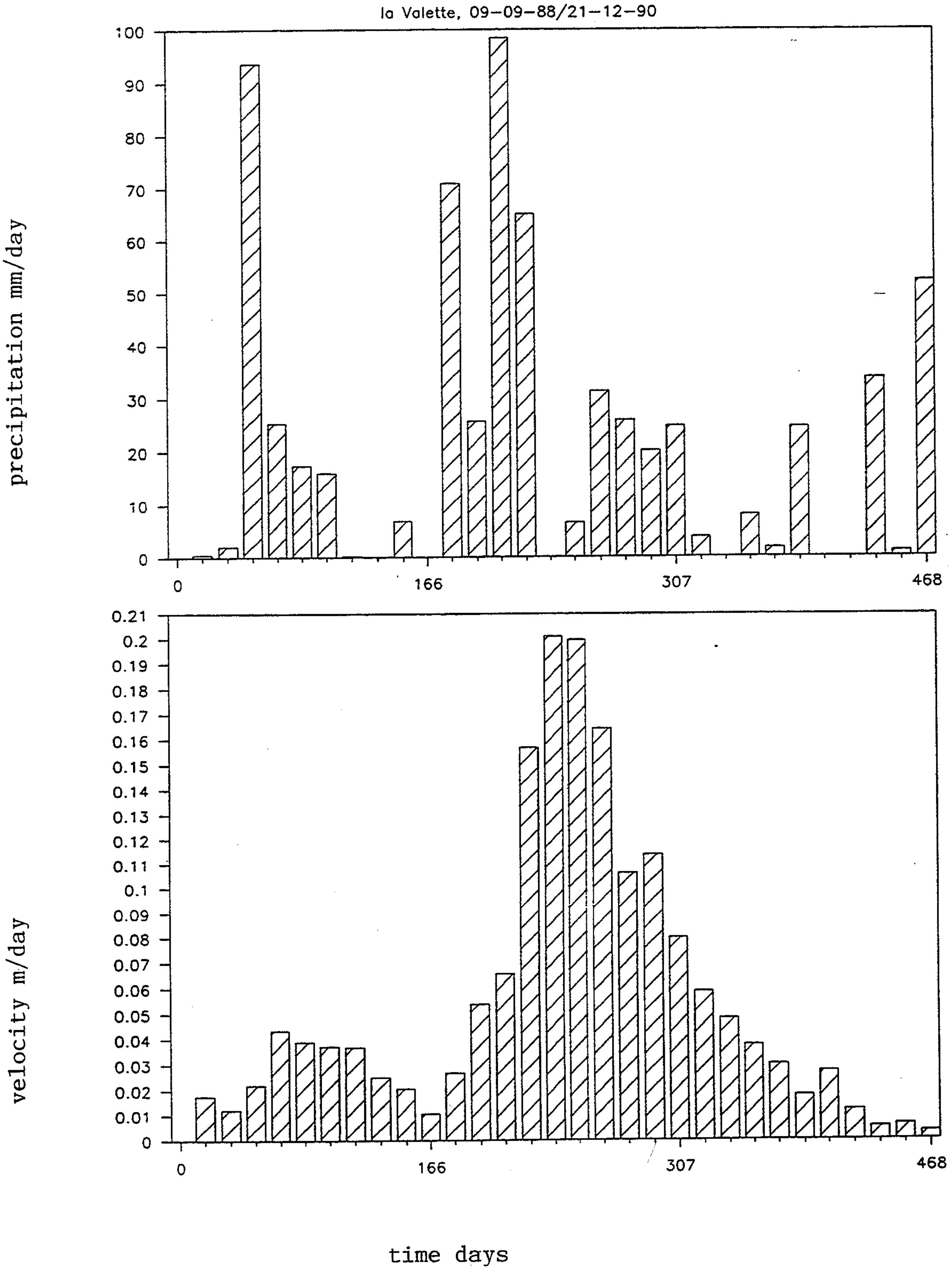

Figure 3. Daily precipitation and measured velocities (m./day) of the Valette landslide

- What are the mobility characteristics of the middle part in relation to ground water fluctuations and what are the effects of the drainage works?
- Can the tongue area be reactivated and what are the velocities which can be expected?

LAB TEST RESULTS

In order to answer these questions field work was carried out, concentrating on profiling and mapping of the landslide, the monitoring of the moisture content and of the mudflows and sampling from boreholes for triaxial and ring shear tests.
The recordings of the RTM were used to analyze the movements in the middle part.

Table 1 shows the results of the triaxial tests and the ring shear test; the letters refer to the map where the samples were taken.

area	**material**	**test**	**c_p' kPa**	**ϕ_p' °**	**c_r' kPa**	**ϕ_r' °**
M	remoulded Terres Noires	triaxial	0.00	27.55		
D	moraine	triaxial	0.00	26.88	0.00	24.44
V	mudflow Valette; March 1988	triaxial	49.07	19.78		
C	mudflow cataract; March 1988	triaxial	15.38	21.45		
C	mudflow cataract; March 1988	ring shear			2.79	14.83
O	mudflow lower course; January 1988	triaxial	0.00	25.94		

Table 1: Some strength properties of the La Valette landslide

Strained controlled ring shear tests were carried out to assess the residual strength. Five of them were tested with constant normal load of 86.1 kPa in order to assess the rate dependent strength. Figure 4 shows the result. A comparison was made between these results and other results (Part I) where it was argued that most of these graphs can be described with a log v - 1/F relation. The figure show a flatter part of the curve at lower speeds and the curve is also flatting at higher speeds . But due to the limited data of these time consuming tests (each test lasts 2 weeks) we have chosen for a straight fit, responding to the equation:

$$1/F = 0.0145261 \log(v) + 0.988870 \qquad \textbf{1}$$

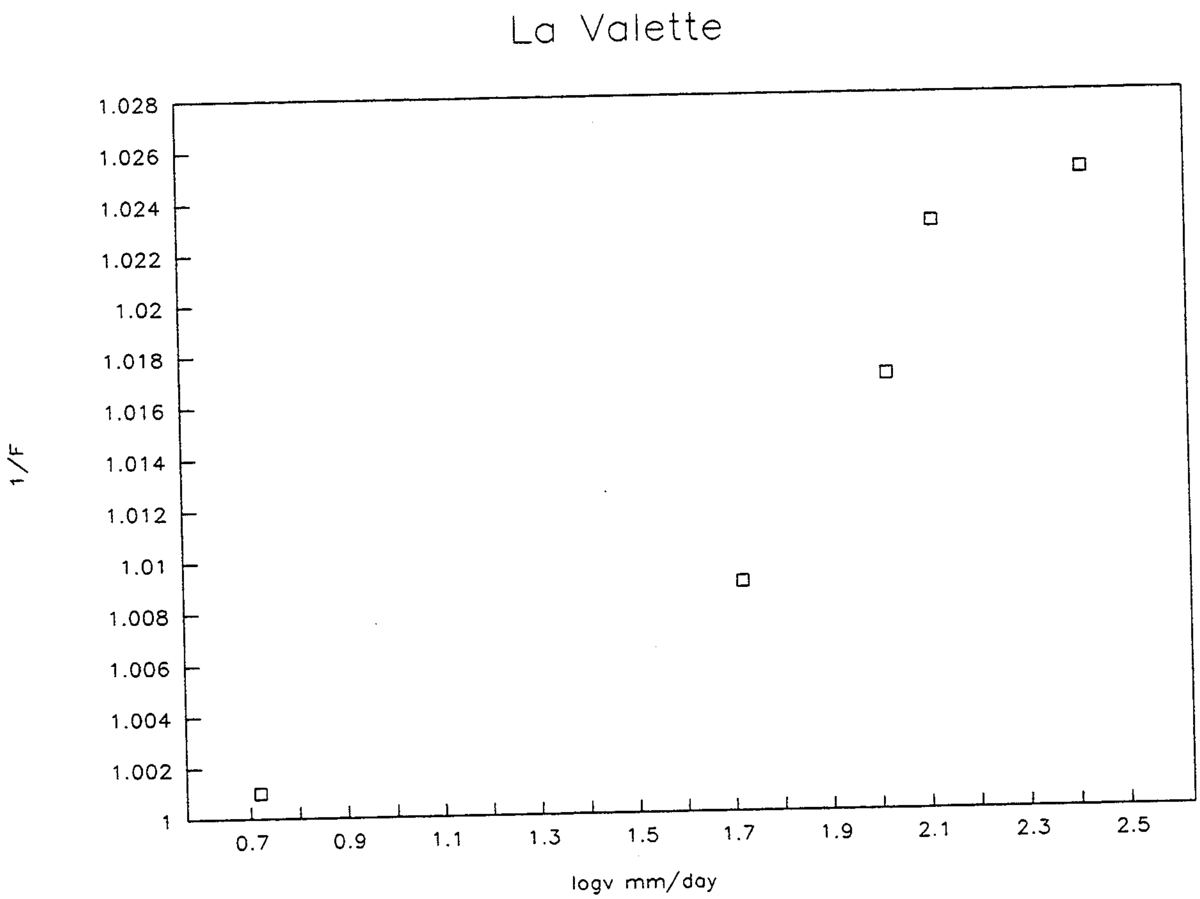

Figure 4. The inverse Safety Factor in relation with log v for Landslide material of La Valette, determined by ring shaer tests.

THE MOBILITY OF THE MIDDLE PART OF THE SLIDE

Figure 5 shows ground water changes in relation to the log velocities for the middle part of the landslide where also the measurements were taken for velocity. The depth in this middle part is 20 m. A range of velocities were chosen from 1 mm per day to 10 m per day. According to the above equation the safety factor could be calculated from the observed velocities which were reduced with a factor 0.1 to account for the difference in thickness between the slip surface in the field and the lab results. From the safety factor the ground water height could be back calculated using the infinite slope model and taking residual values obtained from 13 ring shear tests of $c' = 2.79$ kPa and $\phi' = 14.83°$ (Table 1), given a depth of 20 m and different slope angles. One can conclude from the figure that the ground water has to change 10 % from the total depth of the landslide (2 m) in order to get from beginning of movement to a catastrophic displacement of 10 m per day. The maximum velocities which were measured during the remedial works in 1989 were 0.4 m/day. Depending on the slope angle, which varies in this middle part from 8 to 14°, the beginning of movement will start at nearly zero ground water height to 18 m, 90 % of the depth. It is therefore extremely important that the ground water levels will be reduced as low as possible in order to regain strength in the slip surface due to rest and consolidation in the direction of peak strength. The residual strength in the ring shear is at its lowest value after 500 % of deformation. But the strength of the material can regained at rest condition. The peak strength was $c' = 0$ and $\phi' = 26.9°$ with a small reduction of strength after 2 % deformation to $\phi' = 24.5°$.

Unfortunately we do not have figures of strength regain which are long tests but these can be 10-20 % (Nieuwenhuis, 1991) depending on the minimum height of the ground water.

The remedial works carried out in 1988 were not sufficient and a short visit in 1993 has learned that displacements has started again (estimated distance 30 m since summer 1992) which must have reduced again the strength to a minimum value. These amount of displacement has lead to an individual slump over 50 m and a scarp displacement of 8 m in the steepest part of the cataract area at the same place where in 88 the second flow has developed. Fortunately no flow has developed probably due to limiting amount of ground water at which this slide took place.

THE STABILITY OF THE TONGUE AREA

Figure 6 shows the threshold condition and velocity condition for the flow material at the toe of the landslide which came down in January 1988. It shows that at peak strength condition and residual values after small deformation the tongue remains stable at fully saturated conditions. At residual values after large displacement measured in the ring shear apparatus the flow can become unstable at a 50% rise of the ground water. But these displacements seems very unlikely because of the very impermeable character of the flow tongue and the intensive drainage by gullying.The tongue can be considered as a dead body.

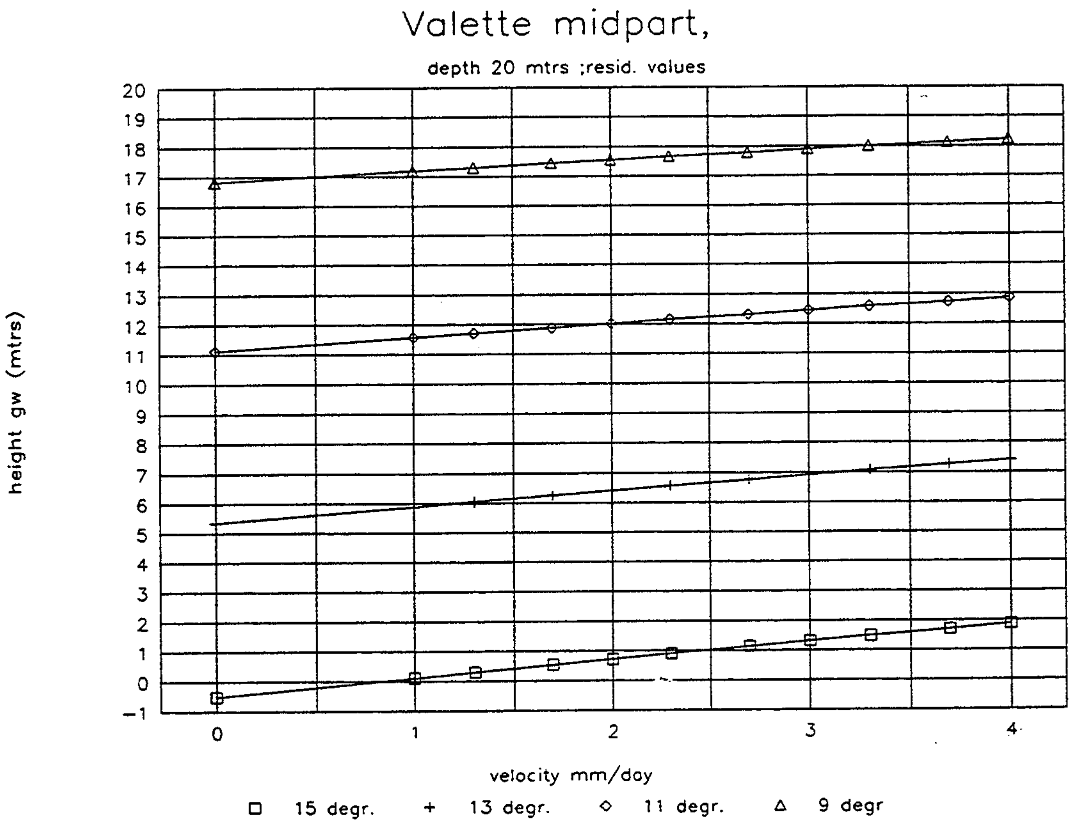

Figure 5. Ground water fluctuations against log v for the middle part of the La Valette landslide

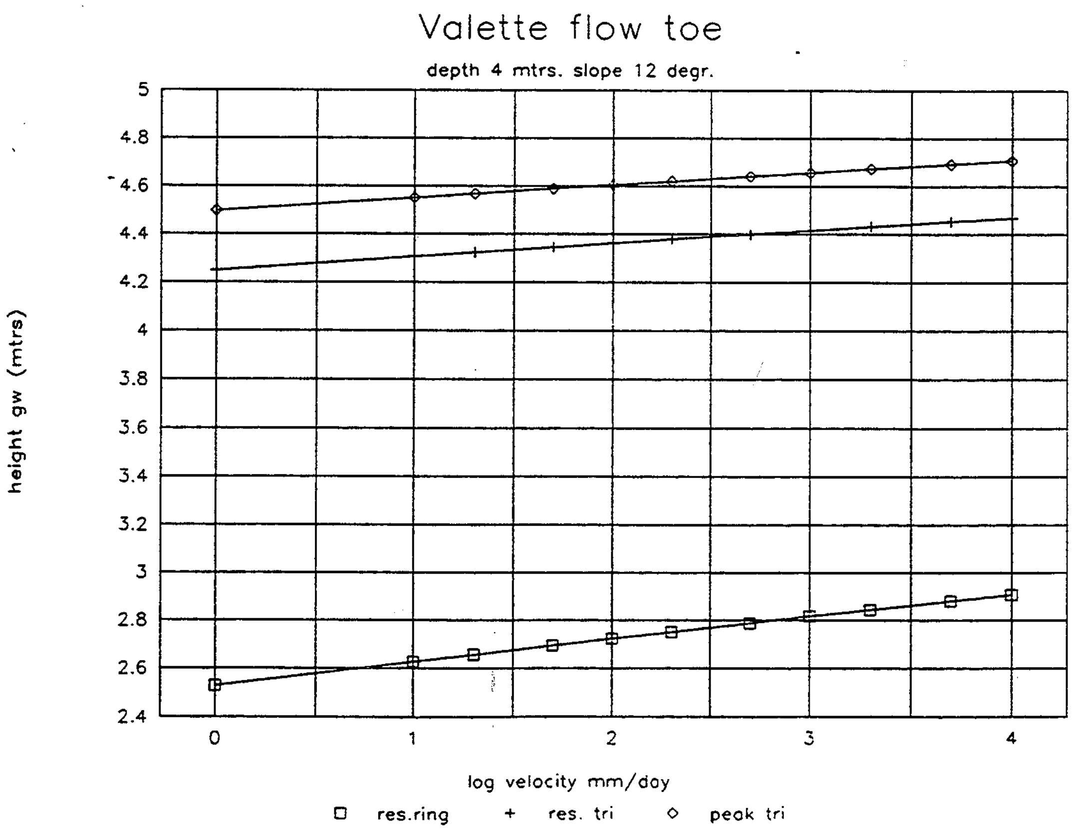

Figure 6 Ground water fluctuations against log v for the toe area of the La Valette landslide

CONCLUSIONS

The landslide started due to a block slump in 1983 in the upper part, what must have lead to higher pressure in the middle part (not analyzed here) and despite the captivation of sources at the scarp an increase in ground water fluctuations. However the strength conditions in the middle part were such that the ground water has to rise very high in the middle part in order get this part into movement. If the strength conditions in that time were at 20 degrees somewhere in the middle between the peak and residual strength the ground water has to rise to 80 % of the depth. This happened in January 1988 where a big search must have occurred and the material was pushed over the steep slope down the cataract and changed into a mud flow with a velocity of several meters per day.

The second movement in March of the same year later was not so dramatic because of its lower strength and the lower ground water heights, resulting in a stiffer earth flow.

Despite the fact that the middle part is not stable yet the movements occur at this moment at lower strength condition with lower ground water. Therefore there is less chance for liquid flow development.

The laboratory analyzes with ring shear tests have shown that the tolerance in ground water fluctuation is relatively low (only 10 %) of the depth in order to let slide pass from nearly zero velocity to a velocity of 10 m/day.

If one manages to stabilize the slide at lower shear strength, strength regain might happen which, if the drainage regime stays intact, lowers the chance for new movement. However it is strongly advised to monitor ground water fluctuation in the middle part and to take strength tests in the slip zone after the slide is stabilized in order to correlate rainfall input with ground water fluctuation after the drainage works and to follow the strength regain in the slip surface. In this case scenarios can be tested for extreme rainfall and snow conditions.

It is not foreseen that the total mass will slide rapidly downwards because the total safety factor is around 1 if all the sliding mass is fully saturated. Also local searches with flows in the middle part have become less probable because of the drainage works.

It is nearly impossible that the flows in the lower part will be reactivated because of the flat slope, the impermeable character and the deep gullies draining the flow at the toe.

THE MOBILITY OF LANDSLIDES IN THE VARVED CLAY AREA OF THE TRIEVE BASIN FRANCE

INTRODUCTION

In the Trieve basin south of Grenoble in the French Alps numerous landslides occur in Glacio-lacustrine clays. The small ones,surface 1 ha, slide plane depths 4-8