LARGE GRAVITATIONAL MOVEMENT MONITORING USING A SPONTANEOUS POTENTIAL NETWORK

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Abstract

It is well-known that the main driving force of large unstable rocky slopes is gravity and that their main triggering mechanism is due to groundwater located in interstices and fractures. The understanding of hydromechanical coupling effects on landslides is generally provided by hydrological investigations, surface or boreholes monitoring and numerical modelling. However, these approaches suffer from the lack of information within the unstable area at depth. To overcome this problem, geophysical methods can bring suitable images or information at depth on a large scale.

In this study, we present different geophysical investigations (electrical, seismic, seismic noise) performed on a huge rocky landslide (Séchilienne, the Alps, France), which is extensively instrumented and monitored since 1985 (surface displacements and meteorology). The measured displacement rates vary on the rock slide from 15 cm/year to 1 m/year and appear to be correlated to water infiltration following rains. A Spontaneous Potential (SP) network has been installed since a few months for a one-year period. This network consists in 24 Pb-PbCl2 electrodes deployed both at surface (in the most active area) and in a 240-m long gallery drilled within the unstable rocky zone. We present possible correlations between time SP data anomalies, meteorological data, deduced from two rain gauges, and surface displacements.

Introduction

In crystalline formations, large gravitational movements are frequently produced following various types of failure, such as toppling, sagging, and translational or rotational sliding (Hutchinson, 1988). Sometimes, one of these mechanisms can evolve into catastrophic rockslides (Valpola, Italy, 1987, Azzoni et al., 1992; Randa, Switzerland, 1991, Noverraz and Bonnard). In the Alps, most of the large gravitational movement were probably initiated or reactivated after the retreat of the glaciers some 10,000 to 15,000 years ago (Noverraz, 1996). Depending on geological, meteorological, tectonic conditions or initial topography, these movements evolve differently and progress through periods of stabilization and reactivation. Consequently, the understanding of failure mechanism of rock slides remains a complex question, due to a lake of reliable and representative information on the geometry, rheology and kinematics of the unstable slope (Crosta and Agliardi, 2003; Moser, 2002; Noverraz, 1996). A better understanding of the dynamic behavior of these objects could only be completed through long periods of observations and investigations on various cases.

Nowadays, new geodesic techniques (GPS, laser, ERS synthetic aperture radar) are used to measure the superficial evolution of landslides presenting a high social and economical risk. Moreover advances in geophysical instrumentation and in inversion allow now following the 2D and 3D evolution of electrical and mechanical properties of landslides. These contributions, combined to numerical modeling developments, could allow a better understanding of landslides dynamic and of its sensitivity to external factors (meteorological, seismological).

Water influence is still unclear, but in some cases, evidences of correlations between rain falls and dynamic of movements were derived on monitored landslides (Alfonsi, 1997; Duranthon et al., 2003; Hong, 2005). To improve the understanding of this hydromechanical coupling, a precise and quantitative model of fluids flow variations must be derived. Unfortunately, this model is difficult to get in such highly fracture zones when only local and costly measurements are available (boreholes, piezometers, tracer tests). Consequently, hydrogeophysical methods, which are sensitive to the fluid flow (NMR, seismic, electrical, SP, IP), should be intensively used in future for this purpose. In such heterogeneous medium, electrical and SP methods are maybe the easier to deploy and monitor.

In this paper, we present a SP time monitoring of a huge rocky landslide (Séchilienne, France), which was investigated using various geophysical methods over a few years (Méric et al., 2005) and benefits from available surface displacements monitored since 1985 and a 240-m long gallery. For this, an electrodes network was deployed along different profiles to evaluate its potential and limitations to characterize hydrological properties of the Séchilienne movement. The recordings started in June 2005 and should last, at least, one year.

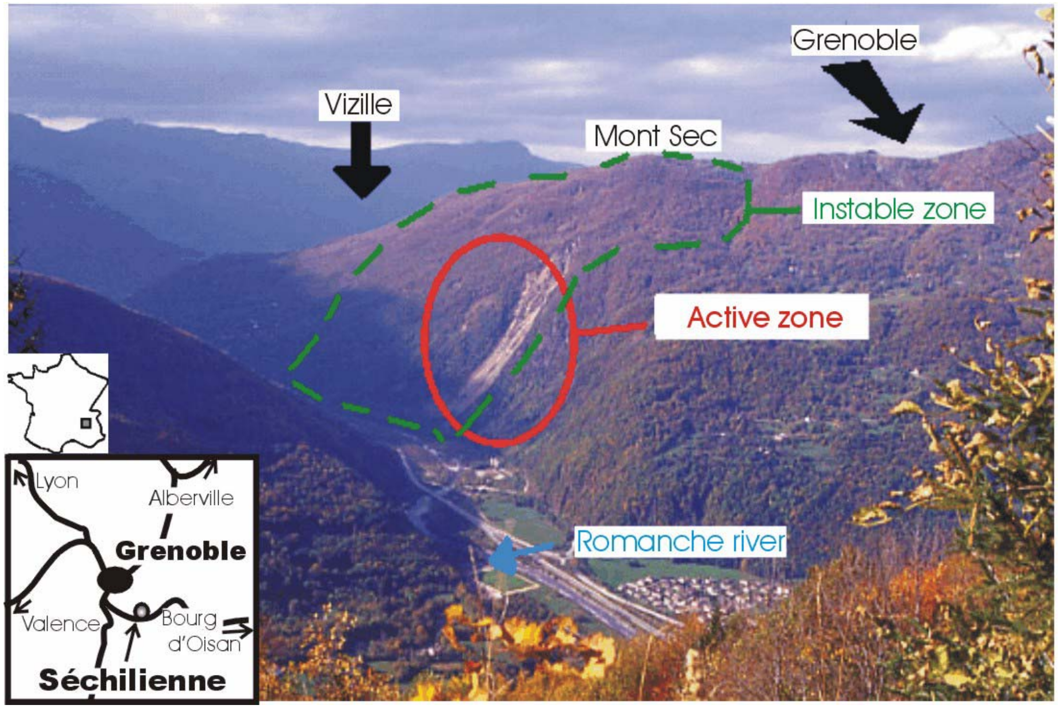

Figure 1: *Photography of the Séchilienne movement.*

The Séchilienne mass movement

Located in French Alps, the Séchilienne movement (Fig. 1) affects the south side of Mont Sec (elevation 1048 m) and is mainly composed of micaschists. The volume estimations for a rock avalanche scenario are highly variable and poorly constrained, ranging from $3 * 10^6$ m^3 to $20 * 10^6$ m^3 (Giraud et al., 1990; Antoine et al., 1994). In case of rupture of more than $3 * 10^6$ m^3 of rocks, it could generate a natural dam over the Romanche river causing flowing and downstream in case of brutal dam failure. The presence of an active fault in the vicinity of the landslide (Thouvenot et al., 2003) increases the risk.

This landslide, which is monitored since 1985, has been the subject of numerous publications concerning geology and structural analyses (Pothérat and Alphonsi, 2001), hydrogeology (Alfonsi, 1997; Guglielmi et al., 2002), geodesy (Duranthon, 2000; Evrard, 1990), numerical modeling attempts (Vengeon et al., 1996; 1999) and internal investigations with various geophysical methods (Meric et al., 2005), which allowed to better locate the limits of the fractured zones. About 50 displacement sensors and one 240-m long survey gallery (Fig. 2) showed that the displacement rate in the active zone varies from 15 cm/year to more than 1 m/year and regularly decreases to the north and to the west. Displacements and measurements conducted inside the gallery showed its internal heterogeneity consisting in a succession of rigid moving blocks delimited by highly fractured zone (Fig. 2), and that at the end of the gallery, deformation is still active (Duranthon, 2000). Local isotopic and hydrochemical analyses showed the existence of a deep saturated zone, which extends into the fractured metamorphic bedrock as well as a possible 100-m thick unsaturated zone above (Guglielmi et al., 2002). Correlations studies between rain falls and displacement rates have showed that no more than 30 mm of rain generated accelerations of the landslide within the next two days in the most active zone.

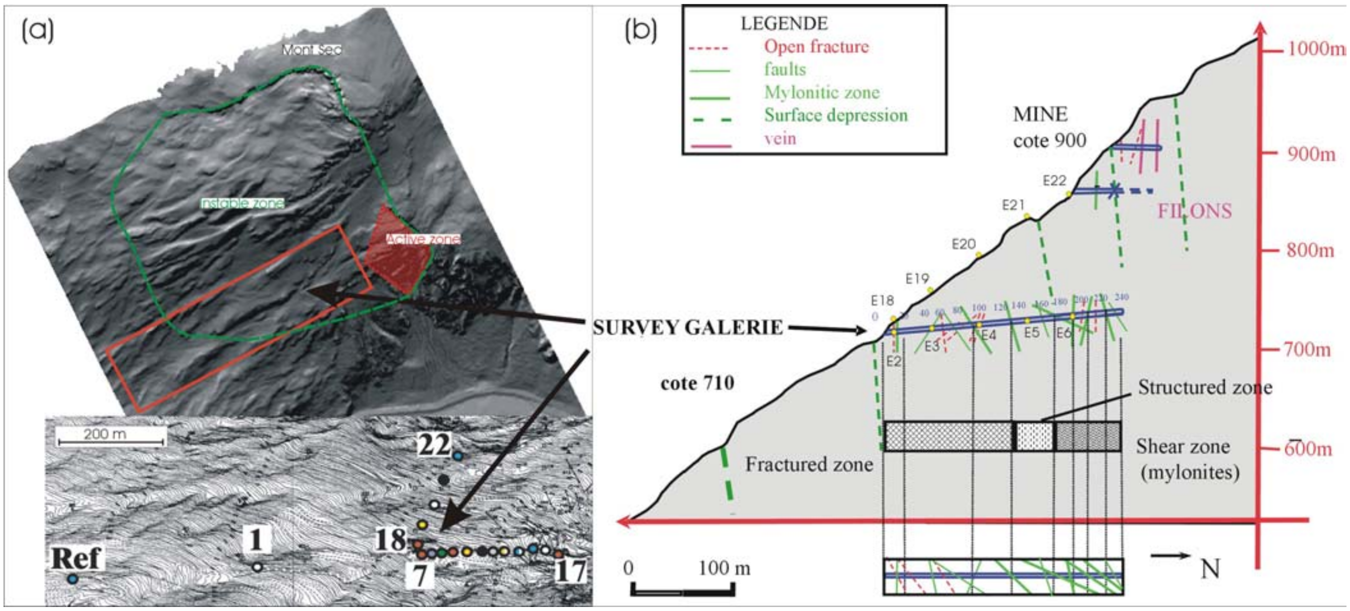

Figure 2: *(a) Map of the Séchilienne movement and location of the permanent SP monitoring network. (b) Cross-section with locations of the survey gallery and internal SP electrodes.*

Self potential network

The natural electrical field measured at the surface of the Earth represents the ground surface electric field signature of different charging mechanism occurring at depth (Patella, 1997). Electrokinetic phenomenon is the main contributor to self-potential anomalies in absence of large telluric current, electrochemical processes (e.g., Révil et al, 1999 for a quantitative description). In this case, the measured electric field anomalies are directly linked with fluid flows, but their interpretation is not always easy as the amplitude response depends on different parameters (zeta potential, conductivity, flow geometry for example). Numerous successful examples of SP mapping of volcano, piezometric surface, faults and landslides can be found in literature.

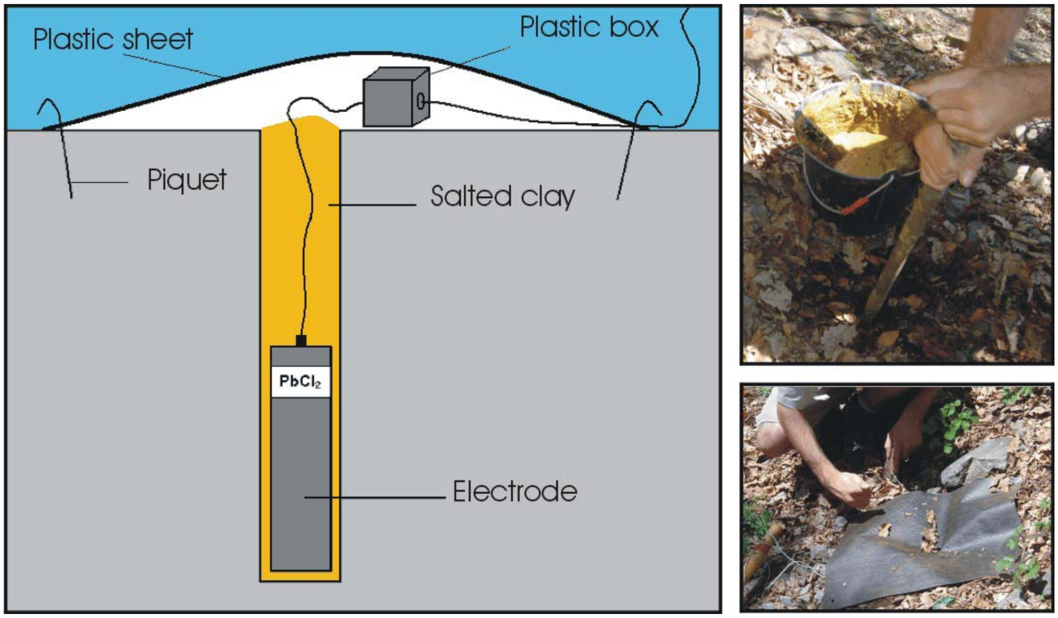

Figure 3: *Sketch and pictures of the set-up used for permanent SP monitoring.*

Méric et al. (2005) showed on a perpendicular transect performed on the Séchilienne movement that SP amplitude appear to be correlated with fracture density, and that interesting variations over time can be detected within the active zone. Consequently, we installed in June 2005 an SP monitoring network, composed of 24 Pb/PbCl2 PMS9000 electrodes (Petiau, 2000) linked to a Campbell CR10X datalogger, as well as two pluviometers and one conductivity and temperature probe. Electrodes were placed in 1-m deep holes filled with salted clays (Fig. 3), to lower temperature changes disturbances and to enhance soil/electrodes coupling effects time stability. The network is composed of:

- Two reference electrodes (1) and (Ref), which were located in a less active zone and outside the movement, respectively (Fig. 2a).
- Twelve 25-m spaced electrodes deployed along a transverse profile in the middle slope (E7-E12; E12b-E17). The 3 last electrodes were located in the most active part of the movement (Fig. 2a).
- Five electrodes (E2 to E6) deployed inside the survey gallery, in order to follow at depth transient SP anomalies (Fig. 2b).
- Five electrodes located at the landslide surface above the previous one (Fig. 2b).

The network is working since June 2006, but was affected by two interruptions due to datalogger damages generated by storms. Measurements are made every 6 seconds and time averaged over 6 minutes to decrease sensitivity on high-frequency random disturbances.

Preliminary results

To illustrate some of the main results obtained with this network, only a small part of measurements will be presented in this paper.

Figure 4 is an example of hydrological property which may be derived by following vertically SP anomalies. It shows SP measurements made on electrodes E19, E3, E21 and E5 as well as the associated rainfall. Electrodes E19 and E21 are located at the surface just right above electrodes E3 and E5 which are located inside the survey gallery (Fig. 3b). The rainfall, which begins the 27th august at 16h00 seems to produce a positive anomaly of about 5 mV on electrodes E19 (a), E3 (b) and E5(f). This anomaly is not retrieved on raw data recorded by electrode E21 (e) probably because the signal/noise ratio is too low and disturbed by high frequencies. This anomaly doesn't appear at the same time and presents different waveforms. It appeared at 20H00 the 27th august on E19 (i.e., 4H after the beginning of the rainfall), at 4H30 the 28th august on E3 (e.g. 12H30 after the beginning of the rainfall and ended at 10H00 the 28th august), at 16H20 the 28th august on E5 (e.g. 24H20 after the beginning of the rainfall, and ended at 8H00 the 29th august).

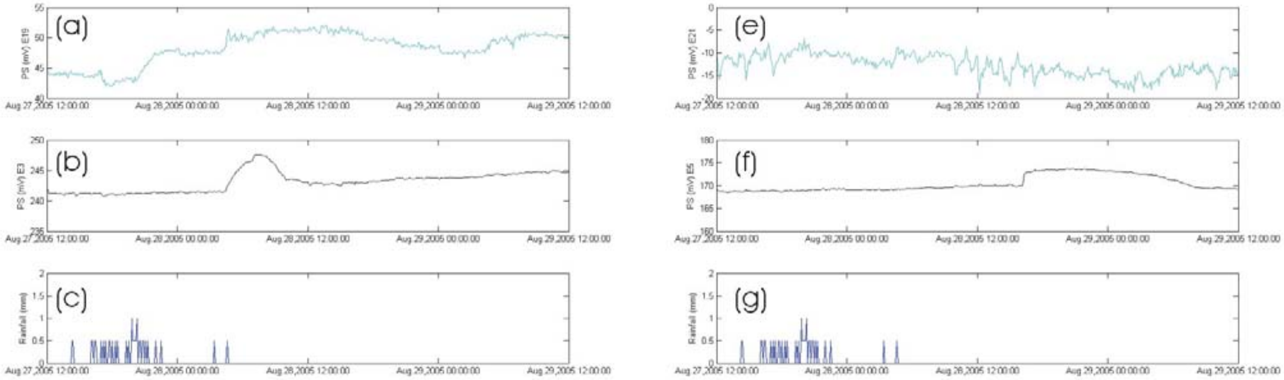

Figure 4: *SP in mV recorded (a) at E19 located above the survey gallery; (b) at E3 located inside the survey gallery just bellow E19; (c) Rainfall in millimeter; SP in mV recorded (e) at E21 located above the survey gallery; (f) at E5 located inside the survey gallery just bellow E 21; (g) Rainfall in millimeter.*

Without any signal processing, if we simply assume that anomalies observed on E3 and E5 were produced by the same rainfall of the 27th august and that water flows are purely vertical, then it is possible to compute the approximate infiltration velocity in this area. For this event, we found an infiltration speed of 3.55 m/h for E19/E3 electrode's pair and 4.8 m/h for E21/E5 electrode's pair. The fact that no anomaly was detected during the same period on electrodes E4 and E6 may be a consequence of the huge heterogeneity of the landslide and that they are placed in a less impermeable zone (low fracture density). Infiltration tests performed with different source locations should be interesting in future to study arrival times and waveforms of SP anomalies.

Figure 5 illustrate an example of large anomalies, observed almost at each location, which starts a few hours before a moderate seismic event located less than 3 km from the landslide (Magnitude of 2.9). ….

Conclusion

Time monitoring study of a given geophysical observable in landslide studies was not really developed over the recent years, but will be increasingly used in future to retrieve valuable information at depth. In order to evaluate the potential and limitations of SP monitoring networks to derived hydrological information, we installed 24 electrodes on a huge heterogeneous landslide which is also monitored (displacements). Benefiting from the presence of a 240-m long gallery drilled within the active movement, we showed that raw SP data are able to detect and follow at depth an SP anomaly generated by a rain fall event. These data permitted to derive water flow velocity within parts of the movement. We were also able to detect SP anomalies associated to a moderate earthquake. These results are still preliminary as only a few months of data were available and the experiment should at least last one year. When a longer observation period will be performed, signal processing techniques (filtering, spectrograms, intercorrelation, deconvolution, wavelet transforms) will help in qualitative and quantitative interpretation of SP anomalies and also in the study of correlations with rain falls. If needed, artificial water infiltration should also help in the understanding of waveforms, as well as numerical modeling.

Acknowledgments

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