MONITORING LANDSLIDE DISPLACEMENTS DURING A CONTROLLED RAIN EXPERIMENT USING A LONG-RANGE TERRESTRIAL LASER SCANNING (TLS)

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ABSTRACT:

A controlled rain experiment has been performed on the Super-Sauze mudslide (South French Alps) in order to better understand the hydrology and mechanics of such type of landslides. The rainfall experiment was conducted during several consecutive days on a plot of about 120 m^2. The landslide displacements were monitored by Terrestrial Laser Scanning (TLS) during 5 days from July 10-14, 2007 with one scan acquisition per day. The scans were fitted on a stable slope outside the rain area. Three techniques were used to characterize the displacements: the benchmark method, the cloud to cloud comparison method and the shaded relief image correlation method. All techniques indicate an average displacement rate of 3.2 $cm.day^{-1}$ with a slight acceleration on day 3. The benchmark method allowed to identify the direction of sliding and thus to estimate the dip of the slip surface. Information on the velocity vertical profile can also be derived from the benchmark method.

1. INTRODUCTION

In the South French Alps, the Callovo-Oxfordian clay-shales (e.g. black marls) of the Ubaye Valley present a high susceptibility to weathering and erosion. The landscape is severely affected by many shallow and deep-seated landslides. Among them, the Super-Sauze mudslide is being studied since 10 years to gain more understanding on the factors and mechanisms controlling the behaviour of landslides developed in clay shales.

The Super-Sauze mudslide (Figure 1) is a flow-like landslide characterized by a complex vertical structure associating a slip surface and a viscoplastic plug. Multidisciplinary observations (geology, geomorphology, geotechnics, hydrology; Flageollet *et al.*, 1999) provide substantial information about its geology and geometry. The mudslide material consists of a silty-sand matrix mixed with moraine debris. It extends over an horizontal distance of 850 m and occurs between an elevation of 2105 m at the crown and 1740 m at the toe with an average 25° slope. Its total volume is estimated at 750,000 m^3 and creeping velocities range from 0.01 to 0.04 $m.day^{-1}$ (Malet et al, 2002). These displacements are spatially very variable over all the mudslide, and directly correlatd with the geometry of the covered paleotopography and the presence of water. The paleotopography plays an essential role in the behaviour of the mudslide by delimiting preferential water and material pathways and compartments with different kinematic, mechanical and hydrodynamical characteristics (Malet and Maquaire, 2003). The rate of displacement is directly controlled by the hydrological regime and period of high water levels. Within most of the year, the mudslide is characterized by nearly saturated conditions.

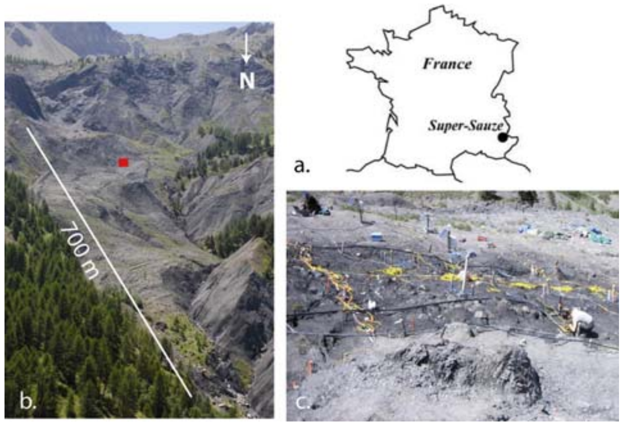

Figure 1. (a) Location of the Super-Sauze mudslide. Aerial view of the mudslide in 2007 and location of the rain experiment (square). (c) Setup of the rain experiment area

In order to better understand the factors controlling the hydrology and the mechanics of the mudslide, a rain infiltration experiment has been conducted in July 2007 (Figure 2). This experiment consisted in applying rain on a representative plot of about 120 m^2 (7 x 14 m) during 4 consecutive days. The rain consisted in water enriched in chloride and bromide and a rain intensity of 15 $mm.h^{-1}$ was applied. Geophysical (electrical

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resistivity, P-wave velocity), hydrological (soil water content, soil suction, groundwater level, water discharge, soil temperature) and hydrochemical parameters (water quality, water conductivity) were observed before, during, and after the rain experiment at several locations within the experiment plot (Figure 2). The focus of this paper is on the characterization of the landslide kinematics by using a Terrestrial Laser Scanning technology.

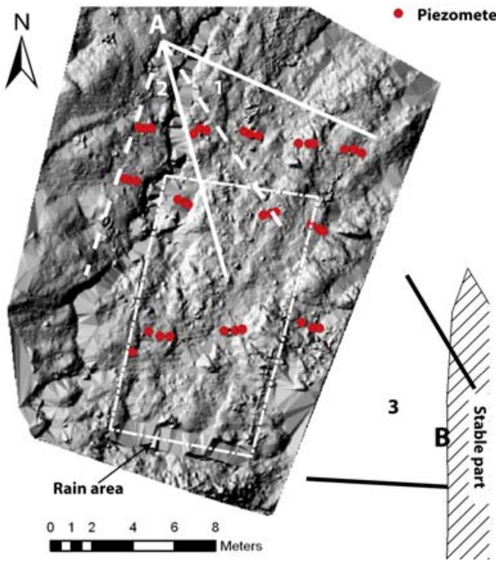

Figure 2. Map of the rain experiment plot and location of the 31 piezometers installed at different depths. Three laser scans were acquired from two viewpoints (A and B) to cover the entire rain plot.

2. METHODOLOGY OF DISPLACEMENT MONITORING

2.1 Terrestrial Laser Scanning technology

The displacement monitoring equipment used in this study is a long-range terrestrial laser scan (TLS) which principle is based on the time-of-flight distance measurements using an infrared laser (Slob and Hack, 2004). This technology is very interesting for monitoring slope displacements because it provides a rapid collection of field topographical data with a high density of points (Rosser et al., 2007; Conforti et al, 2005; Abellan et al, 2006; Monserrat and Crosetto, 2008; Oppikofer et al, 2008).

For the present study, the displacements were monitored by a Optech ILRIS-3D TLS system with a wavelength of 1500 nm. The monochromatic and nearly parallel laser beam is sent out in a precisely known direction. The pulse is back-scattered by the terrain and by several man-made objects such as the piezometer tubes installed on the site, and then recorded by the acquisition system. Knowing the speed of light, the travel time of the signal is then converted into the distance between the scanner and the object. Finally the Cartesian coordinates as well as the intensity of the beam (which is dependant of the object reflectivity) are registered. Mirrors inside the scanner allow the acquisition of a 40° wide and 40° high field of view in a single acquisition with about 2500 pts.s^{-1}. The 3D coordinates of each point are defined by its distance and direction from the scanner. The range of the used TLS is usually up to 800 m. On the field, the scanning range is difficult to evaluate because the effect of the atmosphere and soil moisture can significantly decrease the reflectivity of the target (Rosser et al., 2007). The resolution depends on the distance to the objects and on the chosen angular spacing between two spots.

1.1 Data acquisition

Displacements during the rain experiment were monitored by time series of TLS point clouds, with an acquisition per day. In order to obtain a complete topographical model of the terrain and of the objects (piezometers, benchmarks) minimizing the shadow zones, three consecutive scans from different viewpoints were carried out (Figure 2). TLS point clouds were acquired from almost the same position and orientation over 4 days from July 10-14, 2007 at noon. The rain experiment was interrupted during the scanning. Ground control points were positioned in the mudslide but outside the rain experiment plot. This ground control points consisted in white CD (diameter of of 12 cm) fixed on black and white sticks. Their positions were measured with a DGPS in order to georeference the 3D images.

For the multi-temporal analysis, it was essential to include stable areas into the scanned area (Monserrat and Crosetto, 2008). The three individual scans were then combined using first a manual alignment procedure, and second an automated iterative procedure in order to minimize the alignment error. However, each acquisition has its own reference system. Therefore, they were matched over the stable areas and compared with the reference (first acquisition). All the processing was performed with the Polyworks software (http://www.innovmetric.com).

2.2 Displacement characterization and quantification

The displacements were characterized by comparing the acquisition of the first day (reference) with the point clouds of the following days. Three methods were used to quantify the displacement from the original point clouds.

a) The benchmark method (M1): the movement of several objects (e.g. blocks of marls, piezometers, etc) allowed to precisely compute the direction of displacements because the scans from different viewpoints provide a complete 3D description of the objects. For instance, each piezometer can be modeled by fitting a cylinder on the point cloud (Figure 3). The boundaries of the cylinders were determined for 31 piezometers for each scan acquisition. The vectors between the cylinder boundaries of two consecutive dates provide the direction and the amplitude of the displacement. The rebuilding of the piezometer geometry was considered accurate if the diameter of the fitted cylinder is equal to 5±1 cm. For the area outside the rain experiment plot, a TIN (Triangulated Irregular Network) model was realized on 9 representative blocks. This technique allows to take into account the translational and rotational displacements of all the data points (Monserrat and Crosetto, 2008; Oppikofer et al, 2008).

A 4x4 matrix expresses then the affine transformation of the object geometry at different dates: 9 terms for the rotation, 3 terms for the translation (Stephens, 2000).

b) Cloud to cloud comparison method (M2a-b) : the function “shortest distance” (M2a) available in *Polyworks* consists in computing for each point of a point cloud the distance to its nearest neighbor in the reference point cloud. This method is