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Monitoring, numerical modelling and hazard mitigation of the Moscardo landslide (Eastern Italian Alps)

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ABSTRACT

The Moscardo Torrent basin (Eastern Italian Alps) is a high-risk site, since a large roto-translational landslide might dam the torrent, with the consequence of increasing the possibility of large debris flow events, creating a threat for the infrastructures and the socio-economic activities of the villages that dot the valley below. The landslide, whose volume is estimated 2 million m^3, has been monitored since 2006 with inclinometers, electric piezometers and a GPS network. The velocity, along the entire body of the landslide, averages 1.0–1.5 cm per month. The shear surface develops at depths varying from 9 to 10 m to 55–62 m, while the groundwater table is almost constant throughout the year, despite a cumulative rainfall of the area that usually reaches 2000 mm/year. The movements were simulated in a numerical model, in order to estimate the stabilization effect obtained by different types of possible countermeasures. The simulation was carried out using FLAC 2D, with creep modelling. Visco-elasto-plastic model of the medium in the sliding zone was assumed, allowing to determine the relation between time and displacement. A 10-year displacement trend, starting from the initial situation of 2006 was simulated. Moreover, seismic conditions were taken into consideration with a quasi-static approach, by applying a horizontal acceleration. The numerical model was built and validated on the basis of the data retrieved from geological investigations, as well as from inclinometric and GPS measurements. The results show that an accurate and well-planned multidisciplinary approach can help the decision makers in the choice of the most effective engineering solution for the mitigation of landslide hazard and risk.

1. Introduction

Debris flows are widespread slope instability phenomena in the eastern Italian Alps (Marchi and D'Agostino, 2004), as the region is characterized by rugged topography, high sediment supply along headwater streams and relatively frequent heavy precipitation events (Ceschia et al., 1991; Borga et al., 2007). Moreover, the outcropping of a fractured and weathered bedrock, together with the high seismicity of the area (Querini, 1977) result in a extensive landslide activity that increase hydrogeological hazard (Takahashi, 1991). In this region it is therefore of paramount importance to map and investigate these processes and landforms throughout the territory and, among these, to identify the sites that need effective preventive measures as well as efficient countermeasure works, in order to minimize the socio-economical impact and landslide risk. The landslide risk management approach, that requires assessment and control of existing risks and of their possible evolution, is widely used to tackle with these problems (Corominas et al., 2003; Bromhead, 2005; Crozier, 2005; Jakob and Hungr, 2005; Corsini, 2008; Mayer et al., 2008).

The Moscardo Torrent basin represents a high landslide risk site, since a deep roto-translational rock slide of approximately 2 million m^3, associated with a Deep-Seated Gravitational Slope Deformation (DSGSD), might dam the torrent, with the consequence of increasing the possibility of dam breaching and large debris flow events that could affect the valley below, in case of inadequate management (Deganutti et al., 2000; Marchi et al., 2002). The slope on the right flank of the Moscardo main stream exceeded the limit-equilibrium conditions, as it results from prominent geological and geomorphological features.

In this study, a monitoring system consisting of 13 GPS benchmarks, 3 inclinometers and 3 piezometers was implemented in order to determine the landslide geometry and to measure the ongoing deformations of the slope. Stress–strain-time numerical modelling of the landslide was then carried out with a continuum two-dimensional (2D) geomechanical simulation code, based on the explicit finite difference method, FLAC2D (Fast Lagrangian Analysis of Continua, ITASCA, 2000). The code allows to simulate large displacements and strains, and both linear and non-linear material behaviors, even if yield or failure over a large area or

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total collapse occur. Modelling of coupled groundwater—deformation problems can also be accommodated.

The model of the slope was set up on the basis of underground investigation and monitoring data. Geotechnical parameters were derived by back analysis of the monitored movements.

Numerical modelling has recently become a powerful tool in the characterization of rock slope deformation, failure and post-failure (for a review see Stead et al., 2006). The results can extend the understanding of the sliding mechanisms and therefore the associated risk, together with possible mitigation actions (van Asch et al., 2007).

The potential benefits of lowering groundwater table and increasing stabilizing forces by means of structural countermeasures such as shields of drainage wells and pile-founded and anchored retaining walls were investigated. The effectiveness of the stabilizing works was proved to be very useful in the adopted risk management procedure. The numerical simulation results also provided a feedback for the cost and benefit analyses of the mitigation structures in the area.

All the activities carried out during this study highlighted that with a proper management the landslide hazard could be reduced and its socio-economical impact could be minimized.

2. Geological and geomorphological setting

The Moscardo Torrent basin is located in the eastern Italian Alps, on the north western flank of Mount Paularo, in the Udine Province (Figure 1).

According to Venturini (2002), the rock masses outcropping in the basin, that has an extension of about 5.5 km^2, are Carboniferous in age and consist in highly fractured and altered flysch, with turbiditic quartz-sandstones and gray shales ("Hochwipfel Formation"), feldspar sandstones and greenish shales with volcanic explosive breccias displaying a low grade metamorphic facies ("Dimon Formation").

This kind of bedrock appears to be very brittle and prone to erosion. Nevertheless, the lithotechnical characteristics of the bedrock itself are not the only cause of the diverse slope instability phenomena observed in the area. The whole basin is, in fact, involved in a large Deep-Seated Gravitational Slope Deformation (DSGSD), whose long-term evolution contributed to the progressive weakening of the rock mass properties, increasing both the magnitude and frequency of the collateral landslides phenomena, such as secondary slides and debris flows (Pasuto and Soldati, 1990; Agliardi et al., 2001).

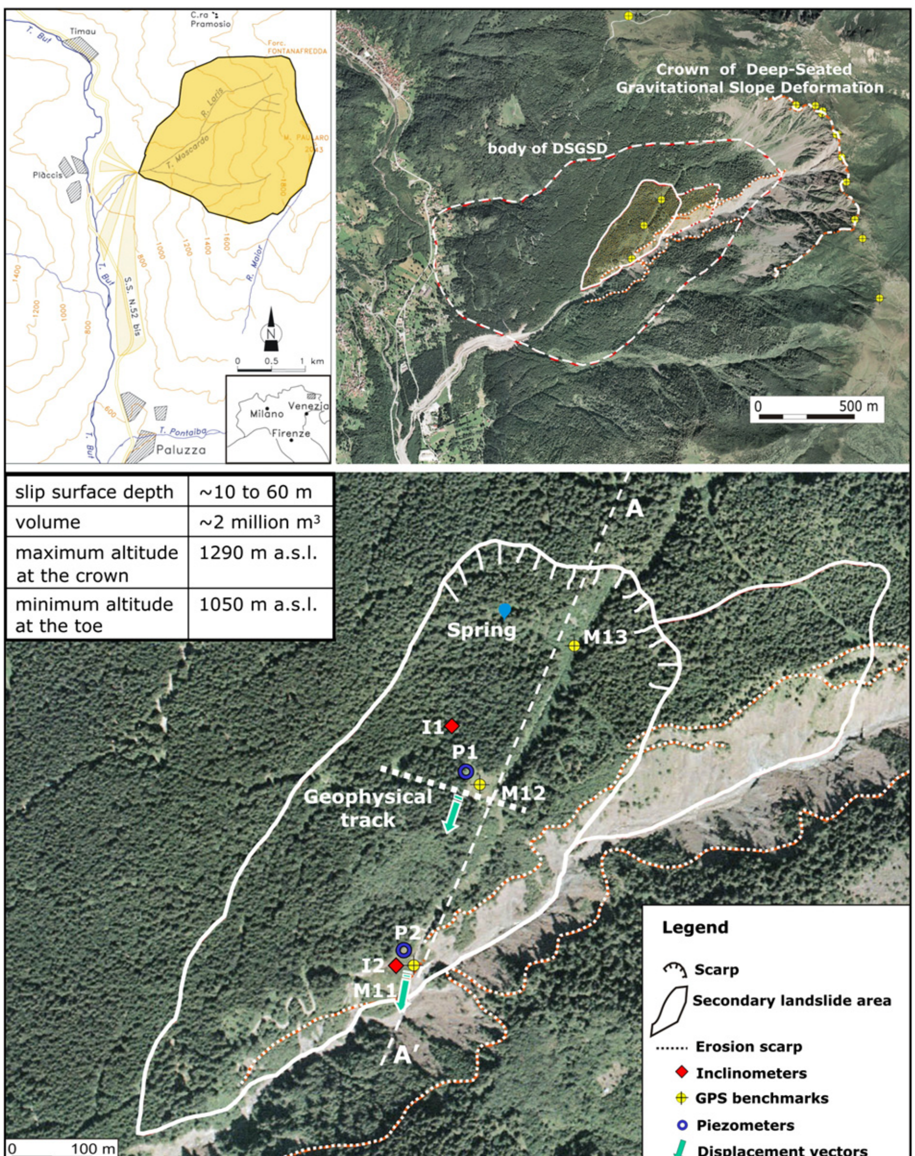

Fig. 1. Moscardo Torrent and the landslides affecting its basin, in the lower part the modeled landslide is represented.