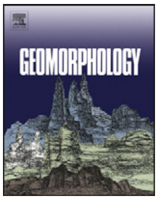
Geomorphology 253 (2016) 74–82

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph



The role of the spatial scale and data accuracy on deep-seated gravitational slope deformation modeling: The Ronco landslide, Italy

Laura Longoni *, Monica Papini, Davide Brambilla, Diego Arosio, Luigi Zanzi

Dipartimento di Ingegneria Civile e Ambientale, Politecnico di Milano, Piazza Leonardo da Vinci 32, Milano, Italy

ARTICLE INFO

Article history:
Received 18 February 2015
Received in revised form 3 September 2015
Accepted 30 September 2015
Available online 3 October 2015

Keywords:
Spatial scale
Deep-seated gravitational deformations
Large landslide
Numerical modeling

ABSTRACT

In recent decades numerical models have been developed and extensively used for landslide hazard and risk assessment. The reliability of the outcomes of these numerical simulations must be evaluated carefully as it mainly depends on the soundness of the physical model of the landslide that in turn often requires the integration of several surface and subsurface surveys in order to achieve a satisfactory spatial resolution. Merging diverse sources of data may be particularly complex for large landslides, because of intrinsic heterogeneity and possible great data uncertainty. In this paper, we assess the spatial scale and data accuracy required for effective numerical landslide modeling. We focus on two particular aspects: the model extent and the accuracy of input datasets. The Ronco landslide, a deep-seated gravitational slope deformation (DSGSD) located in the North of Italy, was used as a test-bed. Geological, geomorphological and geophysical data were combined and, as a result, eight models with different spatial scales and data accuracies were obtained. The models were used to run a back analysis of an event in 2002, during which part of the slope moved after intense rainfalls. The results point to the key role of a proper geomorphological zonation to properly set the model extent. The accuracy level of the input datasets should also be tuned. We suggest applying the approach presented here to other DSGSDs with different geological and geomorphological settings to test the reliability of our findings.

1. Introduction

Large-scale landslides are difficult to study due to the complexity of the involved geological processes and to their intrinsic spatial variability (Tibaldi et al., 2004; Chelli et al., 2006; Moro et al., 2012; Huang, 2012). Landslide analysis can be performed through the use of empirical methods, physical models and numerical models. Numerical simulations are often considered the most promising technique to study slope stability thanks to the developments in computational technology in recent decades, including the improved performance of numerical software. On the other hand, numerical simulations require detailed input datasets, which are often difficult to collect, and merging collected data to create a synthetic model is challenging. Therefore, despite their success (Dymond and De Rose, 2011), numerical models should only be used when available input data include all the relevant features to provide accurate outcomes. Generally, numerical models are aimed at: i) predicting the kinematics of the slope movements (Huang et al., 2009; Ning et al., 2011; Longoni et al., 2014); and ii) forecasting the triggering factors that may lead to failure (Della Seta et al., 2013; Camera et al., 2014). If available data are not sufficient to achieve these goals, numerical modeling is unprofitable (Goodchild, 2011).

The key point for performing efficient numerical simulations lies in the definition of geometric and geo-mechanical features of the physical model in relation to the spatial scale (Longoni et al., 2012). The choice of the spatial scale of the physical model must be carefully considered. The role of scale in geomorphology has been massively debated (Warke and McKinley, 2011): some considered the spatial scale (Zhang et al., 2011; Kerry and Oliver, 2011; Yan et al., 2011), some addressed the temporal scale (Smith, 1996; Viles, 2001; Dymond and De Rose, 2011) and others focused on how to upscale observations from microscale to macroscale (Viles and Moses, 1998; Viles, 2001; Zengchao et al., 2009). In terms of the scale choice, we acknowledge the statement by Schumm and Lichty (1965): “As the dimensions of time and space change, cause–effect relationships may be obscured or even reversed, and the system itself may be described differently”, and that by Bachmann et al. (2006): “a single landslide […] evolution will depend on what is happening at larger but also at smaller scales”. Accordingly, this paper focuses on the effect of the spatial scale and data accuracy on landslide modeling for failure forecasting. Although numerical simulations are widely employed for landslide evaluation, limited efforts have been made to critically compare the results with different spatial scales and data accuracies.

The Ronco landslide in Italy, a deep-seated gravitational slope deformation (DSGSD), is investigated as a case study. Though the analysis is site-specific, the proposed method may be useful for other large landslides. This paper starts with the description of the Ronco landslide, which reactivated after intense rainfalls in November 2002. After that

---

* Corresponding author.
E-mail address: laura.longoni@polimi.it (L. Longoni).

http://dx.doi.org/10.1016/j.geomorph.2015.09.030
0169-555X/

event, many investigations were performed based on geophysical, geomorphological and geological surveys. As a consequence, high quality data were collected and a detailed database of the landslide features was generated. We took advantage of this situation. This work aims to understand the spatial scale and accuracy required to foresee the behavior of a large landslide, and the 2002 event is used for a back analysis to define the arrangements to replicate slope behavior. First, we consider whether a global overview of the landslide is better than a local focus on the most dangerous area. Second, the accuracy of input data is discussed to define how improvements in slope characterization affects landslide modeling. The high costs of detailed investigations often prevent a complete characterization of large landslides. Therefore, numerical simulations of large landslides are usually theoretical or dedicated to representative cases. In many instances, only data for a few parameters are available; thus it is important to understand the required data accuracy level to obtain meaningful outcomes.

2. Geological setting of the case study

Many large-scale landslides are mapped in the North of Italy. The Vajont landslide (Kilburn and Petley, 2003; Panizzo et al., 2005) and the Val Pola landslides (Crosta et al., 2004; Pirulli and Mangeney, 2008) are well-known examples, and many other slopes are affected by such phenomena. The Bindo landslide (Crosta et al., 2006), Mount Letè and Mount Legnoncino landslides (Ambrosi and Crosta, 2006), and the Ruinon landslide (Agliardi et al., 2001; Del Ventisette et al., 2012) are just a few examples near the investigated Ronco landslide.

The Ronco Landslide is a DSGSD located closed to Premana, a small village in Varrone Valley 100 km North of Milan (Fig. 1). The landslide directly threatens a hydroelectric power plant and the probability that the landslide body could occlude the riverbed creating a natural dam is very high, since The Valley is very narrow close to the plant. If a dam is created, the entire upstream industrial district of Premana would be flooded (Fig. 1), while the risk of a dam break would pose a threat for the Pagnona Dam, less than a kilometer downstream, as well as Dervio City, where the Varrone River flows into Como Lake (Arosio et al., 2011). Additionally, a total reactivation of the DSGSD body may also generate direct damage to Premana Village. During a heavy rainfall event in 2002, slope displacements were recorded in the area near the hydroelectric power plant. After this partial reactivation of the landslide, it was decided to investigate the unstable slope.

The deep-seated landslide affects the entire slope (Fig. 1): the crown is located near the Paglio peak and the toe of the landslide is at 750 m a.s.l. at the bottom of Varrone Valley. Three geological units can be identified: Gneiss Chiari, Servino and Verrucano Lombardo (Fig. 2). The most important tectonic lineament of the investigated area is the Orobic Thrust (Fig. 3) (Schönborn, 1992; Blom and Passchier, 1997), where the crystalline basement (Gneiss Chiari) overthrusts the sedimentary cover (Verrucano Lombardo and Servino) as depicted in Fig. 2b. A plastic layer, hereafter named tectonic mélange, lies between the Gneiss Chiari and Servino formations. This layer has variable thickness ranging from 5 to 20 m and consists of severely deformed and altered carniole, a rock originated from the tectonization of the formations in contact. The tectonic mélange layer is generally considered a discontinuity that may act as a sliding surface within unstable slopes, as several slope failures have occurred because of such layers in northern Italy (e.g. ramp-flat of the Grigna Group in the pre-Alpine region, northern Italy; Jadoul and Gaetani, 1986).

Close to Premana Village, the Orobic Thrust has dip and dip direction of approximately 15° and 330° respectively, and outcrops near the hydroelectric power plant. The slope also features two sets of minor faults: the first one has an N–S strike and a dip of 80°, and the other has an ENE–WSW strike and a dip of 75°. The latter has 500 m spacing and is related to the Orobic Thrust as well as to the Alpine orogenesis processes, while the N–S faults, where spacing spanning between 100 and 300 m, were generated by older processes (Late Triassic) and acted as discontinuity surfaces during the Alpine orogenesis (Forcella and Rossi, 1987). A large bulged section across Piani di Ronco (i.e., the flat area located in the middle of the DSGSD; Fig. 1), together with an evident line associated with the DSGSD main scarp – probably generated by glacier debuttressing processes – are geomorphological evidences related to the instability of the slope (Fig. 3). The exceptional rainfalls in November 2002 caused the reactivation of the lowest section of the ancient deep-seated landslide and, based upon the damages to the hydroelectric power plant and the bridge located at the toe of the slope, the Ronco landslide seems to have moved approximately 30 cm during that event (Savazzi, 2005). The complexity of the geological setting (Fig. 3) and the high risk associated with this unstable slope required detailed investigations to outline the main features of the slope. Hence several survey techniques (Table 1) were employed to better characterize the rock mass (Arosio et al., 2011, 2013). As reported in Table 1, the borehole constructed in 2003 did not reach the Orobic thrust, the depth of which, based on the borehole made in 2012, is at about 120 m.

3. Geomorphological assessment

The studied area underwent the deposition of thick glacial deposits on both the valley bottom and valley flanks in the Pleistocene. During the Holocene the valley was modified because the erosion of the Varrone River deepened the valley bottom (Fig. 4). Widespread and thick landslide debris over the glacial deposits suggests that significant collapses occurred on the slope below the Paglio Peak, which were

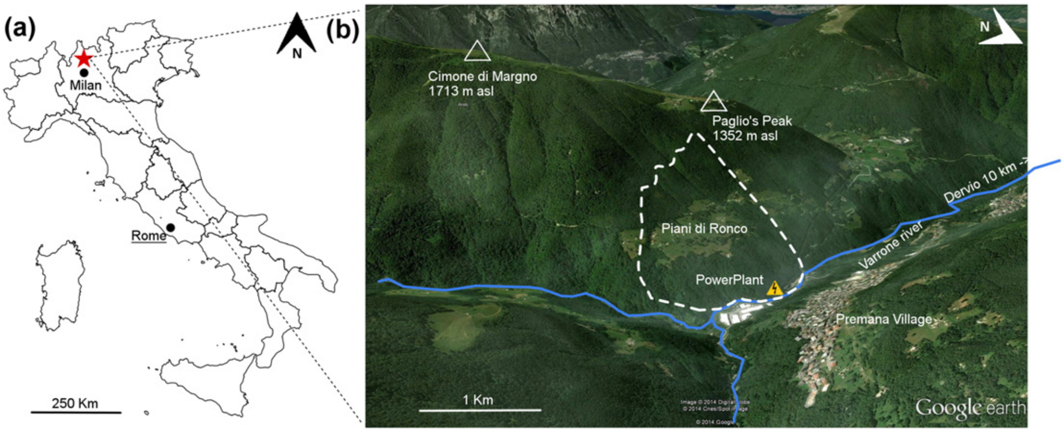


Fig. 1. Location of the study area. (a) Location of Premana Village in the North of Italy. (b) View of the study area. The Ronco landslide is on the slope facing the village, and the industrial area and the hydroelectric power plant are located at the toe of the unstable slope. The landslide is placed on the left bank of the Varrone River. The dashed line shows the limits of the DSGSD body.