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Characterization and analysis of a translational rockslide on a stepped-planar slip surface

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ABSTRACT

In 2014 a small stepped-planar rockslide blocked a road near the town of San Germano Chisone in northwest Italy. Photographs of the rock cut that failed above the road were taken before and after the rockslide occurred. Some photos were acquired with the assistance of a UAV. These photos were used to conduct a forensic analysis of the rockslide. With the aid of photogrammetry software, it was possible to characterize the slope geometry and the larger geological structures that influenced the slope behaviour. A stepped-planar slip surface and the shape of the slabs of rock that failed were defined by discontinuities and these were well documented in the 3D photogrammetry models. The effective dilation angle was estimated from an assessment of the roughness of the discontinuity surfaces forming the slip surface. The stability of the rockslide was analysed as a stepped-translational failure mechanism. A two-block force equilibrium model of the rockslide was developed. With this analytic model, both deterministic and probabilistic methods were used to study the influence of water pressure as well as time-dependent shear strength degradation along the discontinuities and corrosion of rockbolts. The analysis suggests that the rockslide was caused by a combination of inadequate rock support, time-dependent shear strength degradation, and water pressure in the joints resulting from above average rainfall.

1. Introduction

In the spring of 2014, a rock cut located at 44.902075° latitude, 7.229345° longitude in northwest Italy experienced a rockslide. The rockslide occurred above Provincial Road 168 near the municipality of San Germano Chisone in the province of Torino (Fig. 1). For several days, the rockslide debris completely blocked the only road to the town of Pramollo and its 200 inhabitants (Giordan et al., 2015a). A few days before the rockslide, warning signs occurred such as smaller rockfalls as well as the opening of a wide and continuous tension crack that isolated a moving mass of rock that was approximately 28 m long and 8 to 9 m wide. As the instability phenomena worsened, the San Germano Chisone mayor issued an order in accordance with the Provincial Civil Protection to close the road. Technicians were monitoring the situation when at approximately 17:20 on March 7, 2014, an unstable mass with an estimated volume of 700 to 800 m^3 of rock slid down onto the road. After the debris was removed, additional rock support was installed on the remaining slope and the road was repaired and repaved. Evidence of the slope and road repair can be seen in Google Earth at the coordinates listed above.

Video recordings and photos were taken before, and then after the rockslide as part of a routine slope monitoring and field assessment process. These images were key to the documentation and analysis of the rockslide. This case history demonstrates how ordinary field photographs (and video recordings) of a rock slope can be used to extract quantitative data concerning the slope geometry and structural geology, which in turn can be used to analyse the slope stability. Photographs can be a rich source of quantitative data. Almost all the data presented in this case history were derived using only the images and the resulting 3D models of the slope constructed with photogrammetry and structure-from-motion software. While the focus of the paper is on the case history of a stepped-planar rockslide, a brief description of the data collection i.e., photographs and their subsequent analysis is also presented.

Translational failure mechanisms are often assessed when performing slope stability assessments of rock slopes, however, the published literature has surprisingly few well-documented case histories for stepped-translational failures. The published literature contains examples of large-scale slope failures where the slip surfaces consist of multiple steps such as those that have occurred in the Canadian Rocky Mountains (Cruden, 1976; Sturzenegger and Stead, 2012) and elsewhere (Oppikofer et al., 2011; Sepúlveda et al., 2012). For smaller scale stepped-translational rock slope failures along highway and railway rock cuts and in open pit mines and quarries, the literature is

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Fig. 1. Location of San Germano Chisone in northwest Italy.

quite sparse. One example is work by Farmer and Gavshon (1978) for a stepped-translational failure in a quarry. To fortify the literature in this area, this paper documents a stepped-translational failure and presents an analysis of the rock slope for various scenarios involving water pressure, shear strength loss, and varying rock support.

The documentation of this stepped-path translational rockslide can be used by other modellers to study the rockslide behaviour. The geometric data presented here are key input to analyses that can be conducted using tools such as finite element models (Shamekhi and Tannant, 2015), discrete element methods (Wang et al., 2003; Mejía Camones et al., 2013; Huang et al., 2015), rock failure process analysis (Zhang et al., 2006), and numerical manifold analysis techniques (An et al., 2014; Wong and Wu, 2014; Zheng et al., 2014). While the literature contains numerous examples of hypothetical slopes or of laboratory-scale rock specimens, there are very few studies on actual stepped-path rockslides. This case history offers modellers an opportunity to analyse a real rockslide. The supplemental materials (3D models and photos) to this paper provide additional geometric details.

2. Fieldwork and image processing

Just a few hours before the rockslide occurred, a series of photographs and videos were taken of the rock cut. Some photographs were taken from the road elevation while a video of the area was taken from above the road with a small multi-rotor UAV carrying a camera. After the rockslide occurred, more photographs were obtained; again, some were taken from the road elevation and others taken in the air using a UAV. Some distinctive points on the slope were surveyed to provide ground control for processing the acquired before and after failure photographs. The slope was photographed again in October 2014, after rock slope stabilization had been completed with new rockbolts, mesh and cable lacing. The photographs along with surveyed ground control points provided a useful quantitative dataset of the rockslide.

Fig. 2 shows the rock slope immediately before and after the rockslide, as well as several months after the event, in October 2014. As described by Giordan et al. (2015a,b), the dataset of images and videos recorded by the drone were very useful during the first phases of emergency response to this rockslide and led to a timely decision to close the road. After the collapse, the images were used to analyse the new condition of the rock slope and to help design rock stabilization works. For the first surveys, over 400 image frames were extracted from a video shot of the pre-failure slope with a GoPro Hero 3 Black camera mounted to a multi-rotor UAV. After the slope failed, photos were taken with the same GoPro camera and UAV. Months later, after the slope was repaired, a Canon EOS M camera mounted on a different UAV was used. The average ground resolution for the different sets of photos ranged from 1 to 3.5 cm/pixel.

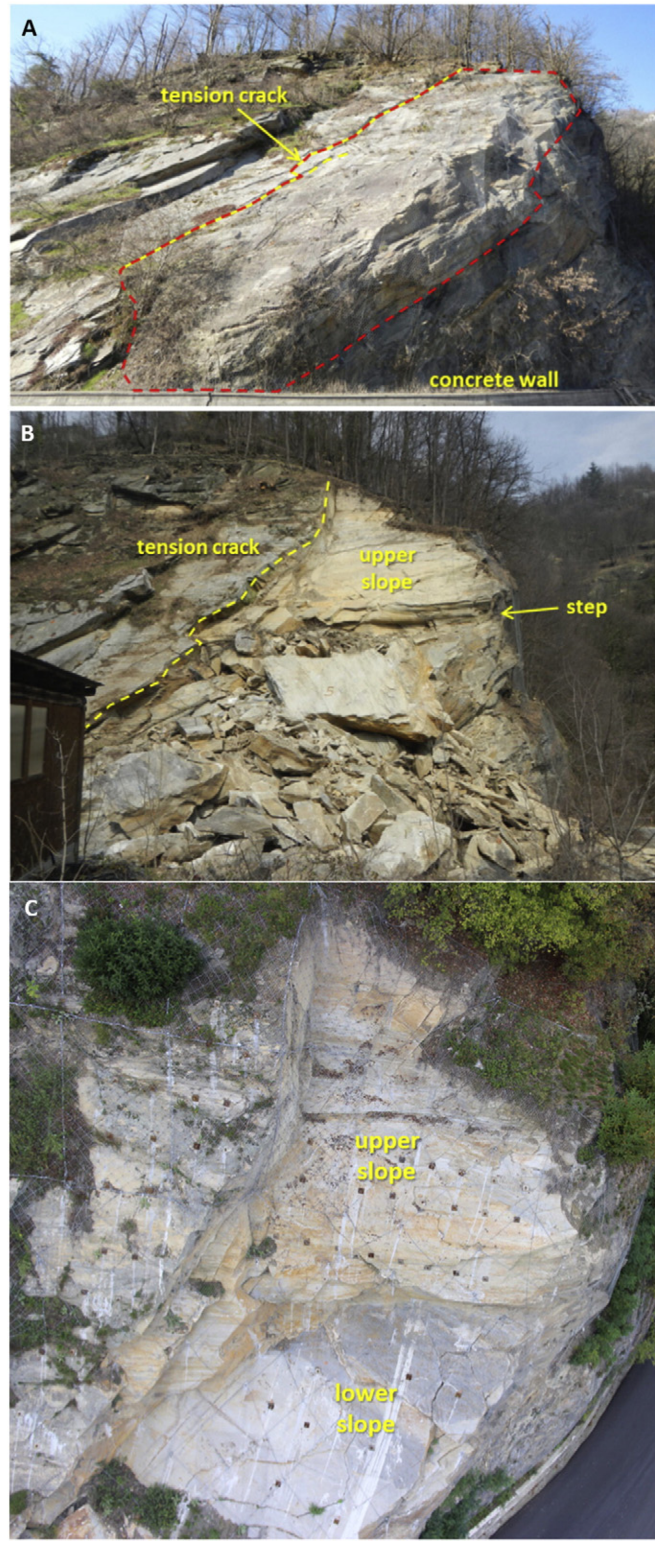

Fig. 2. Rock slope (a) one day before, (b) immediately after, and (c) several months after the rockslide event.

The acquired images were processed in photogrammetry software. Pix4D software (Pix4D, 2015) was used to construct detailed point clouds using the photos taken by the UAVs. Additional terrestrial photos acquired with a Nikon AW100 camera were also used. 3DM Analyst