

Floating anchors in landslide stabilization: the Cortiana case in North-Eastern Italy

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In order to reduce the cost of landslide stabilization works, often very high, we are always looking for new effective and more economical solutions. This work reports the case of a landslide occurred in November 2010 in the Cortiana locality (Vicenza, Italy). After a brief analysis of occurrence conditions and characteristics of the landslide, the paper presents the most important results of analyses carried out in order to design and evaluate the efficiency of some innovative interventions performed in the area, which allowed a complete slope stabilization.

Keywords: Landslide stabilization, Earth anchor, Self-drilling bar, Slope stability, Slope monitoring.

1. Introduction

Slope stabilization follows different approaches in order to reduce driving forces or increase resisting forces. The cost of remedial works is often very high. Therefore, the research of new effective solutions with low to moderate costs is a duty for all the scientific community. This paper presents the case of Cortiana landslide located in Val Maso, in the Vicenza Province (Italy). The landslide, threatening the stability of a small road that represented the only access to Cortiana hamlet, is a paleo-landslide reactivated on November 2010 due to the extreme rainfall event that hit the Italian Northeastern regions.

To have an idea of the exceptionality of the 2010 event, it is sufficient remember that, in the Vicenza Province, a maximum cumulative rainfall of about 500 mm in 3 days was observed. Moreover, rain took place after about 120-days rainy period, finding high saturation condition in the soils. It caused a catastrophic flood and the trigger of a huge number of mass movements in the Northern and Western parts of the province: the Soil Protection Division (SPD) received about 500 warn-

ings of landslides, distributed over 20 municipalities. As a direct effect of the rain, between November 2 and 3, 2010, a portion of the landslide in Cortiana collapsed and produced a small earth-flow that reached and damaged some houses downhill.

2. Cortiana landslide

The landslide is a roto-translational slide-earth/debris flow that involves eluvial/colluvial deposits and past landslide debris. It has a volume of about 200,000 m³, a maximum thickness of 20 m and is located on a slope with a mean inclination angle of about 40°. The collapse of the slope generated an earth/debris flow, which threatened the houses located in the Val Molino village, a few hundred meters downstream; the valley and the river were in danger of being blocked, the trunks acting as a cap and causing floods.

Behind the main scarp the phenomenon rapidly retrogressed by multiple rotational slides, with a sliding surface located at a depth of 15-20 m in correspondence to a thin red clay layer, at the contact between debris cover and bedrock.

In the area, the rock is constituted by the Southern Alps Crystalline Basement (Valli del Pasubio Phyllites) and by the Permo-Triassic sedimentary succession including the Val Gardena Sandstone, the Bellerophon Formation and the Werfen Formation. Some rhyolitic-dacitic volcanites are locally present as the acid products of the Upper Ladinian volcanic phase. Permian to Triassic marine-continental sediments interlay this stratigraphic unit. Colluvial/eluvial deposits are lithologically homogeneous and well sorted; the landslide debris deposits are lithologically heterogeneous with metric-centimetric blocks lost in a prevalently clayey matrix. Some normal and inverse faults related to polyphase deformations (Mesozoic and Paleogene extension and Neo-Alpine shortening) dislocate the local succession and are responsible of the different kinematics that characterize the slope.

After the landslide occurrence, SPD performed several investigations and installed a monitoring system. Geo-seismic and geo-electric surveys (Fig.1a), coupled with four boreholes, established that the bedrock was at 15-20 m of depth. Two subsequent laser-scanner surveys permitted the buildup of the 3D model of

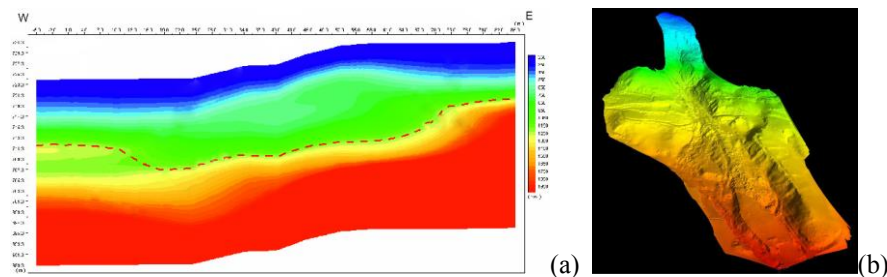


Fig. 1. Cortiana landslide: seismic tomography and identification of the sliding surface (a); 3D laserscanner model. (b).

the slope after landslide (Fig. 1b) and the reconstruction of displacements occurred between the two measurements.

Three extensometers were set in motion to measure entities of displacements after the landslide occurred and to define an alert system. In 11 months, the extensometer nr. 1 reached its maximum elongation equal to 150 cm, while the nr. 2 and 3 measured total displacements equal to 98 and 20 cm respectively (Fig. 2).

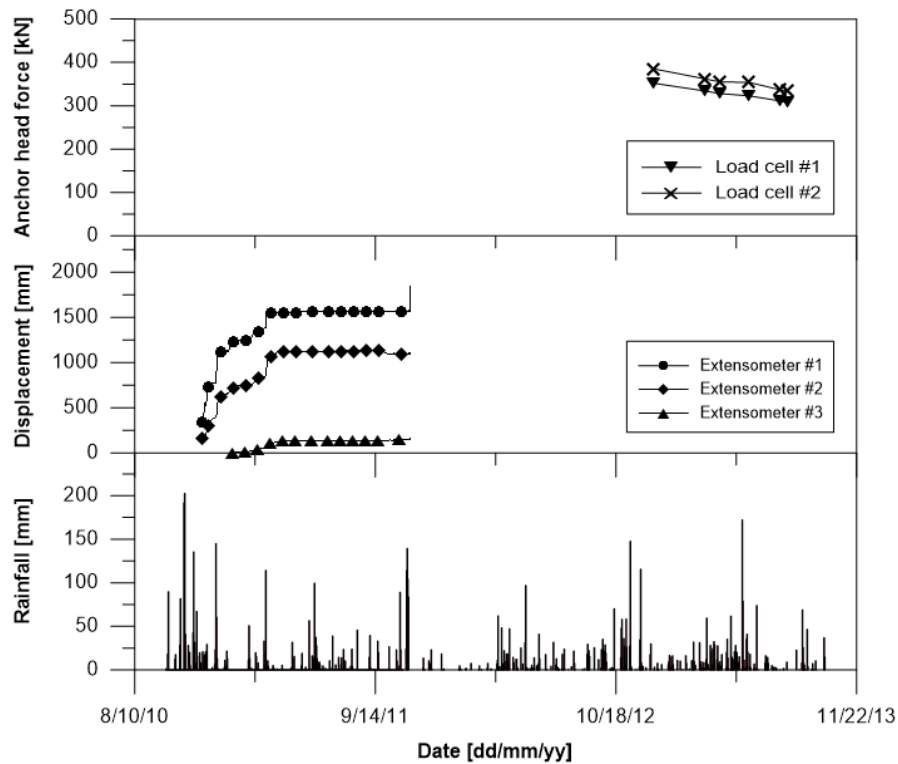


Fig. 2. Results from monitoring system (2010-2013): rainfall, displacements and anchor head force.

3. Stabilization work: floating techniques

The first landslide damaged the municipal road to the Cortiana village. Since the available funds did not seem to allow a complete consolidation of the landslide with traditional techniques, such as retaining walls or anchored micropiles, the SPD commissioned the design of remedial works with the primary purpose of ensuring the safety of the road. Instead, the geotechnical engineers proposed a solu-

tion that permitted to reach the complete stabilization of entire landslide with the same cost.

The solution provided a geosynthetic-reinforced soil (GRS) wall built at the toe, as a support for the slope remodeling. Each GRS reinforcement was anchored to the bedrock in order to guarantee the stability of the wall. A drainage system completed the stabilization of the landslide toe. This consists of a holed steel pipe installed into a trench filled with coarse material and has the aim to capture and convey downstream the water flowing from some small springs at the landslide toe.

In order to strengthen the road foundation in the upper part of the landslide, two *floating walls* and a group of *floating anchors* have been realized in the landslide main body and anchored in the bedrock.

The *floating wall* consists of two rows of self-drilling anchor bars (nails) cemented inside the hole all along their profile and externally connected with a thin shotcrete wall. Since the nails are passive reinforcement, the floating wall is a special type of soil-nailing wall that, in contrary of the traditional rigid walls, is very flexible, allowing for high deformability without damaging itself and reducing sensibly the intervention cost.

A *floating anchor* consists of a self-drilling nail, cemented inside the hole and externally connected only to a plate. In this case, three rows of floating anchors, approximately installed at landslide mid-height (Fig. 3), completed the remedial work. The advantage of floating anchor is given by the possibility to absorb by friction a part of the shear stress induced in the soil by the landslide movement. Unlike other techniques, the floating anchors do not provide a continuous facing; each anchor head connects to a 1.5 m diameter concrete plate, then bored in the soil. The plate has a tronco-conical shape, to maximize the energy dissipation by friction at the soil-concrete interface. Since the floating element is anchored in depth, it remains quite fix in space while the landslide could relatively move and, eventually submerge the plate itself. Instead of considering that condition a system disease, the occurrence of relative soil-anchor and soil-plate displacements permits to activate the friction and optimize the energy dissipation without failure of the element. Thus, we can consider floating anchors as special friction energy dissipaters.

The key feature of these passive reinforcements is that they are free to move, complying in part the movements of the slope and then finding their equilibrium position, at the same time absorbing a tensile force equal to the sum of the soil-grout interface friction mobilized along nail profile. Each anchor retains a given force (the maximum friction force explicable along the soil-grout interface), thereby reducing of an equal rate the destabilizing forces acting in the system.

In this particular case, for realizing the floating anchors, we adopted composite bars, i.e. mild steel holed self-drilling bars with one or more harmonic steel strands installed in the internal hole and connected to the nail with a low shrinkage and a high resistance cement binder. This kind of bars permits to reach higher resistance with a minor steel section and reducing the nail cost (Bisson et al., 2013).

To evaluate the expected anchor tensions and the landslide displacements necessary for the activation of these tensions we analyzed the system behaviour by mean of a 2D Finite Element Model of the landslide. The geotechnical parameters for FEM were determined by mean of a Limit Equilibrium back-analysis of the occurred landslide and some laboratory tests. The LE analysis was also used for estimating the anchoring force required to reach an acceptable slope Safety Factor and evaluating its variation with the anchor positions.

Adopting Sirive® Special S60 Composite anchor bars (60 mm-diameter bars with three 0.6" diameter strands and a minimum tensile strength of 200 ton) anchored to the bedrock and solidarized to the soil along the entire depth using cement grout, the optimized distribution resulted of three rows spaced 4.30-6.70 m and 6 m respectively in horizontal and vertical direction.

The remedial works began in late 2011 and completed in December 2012.

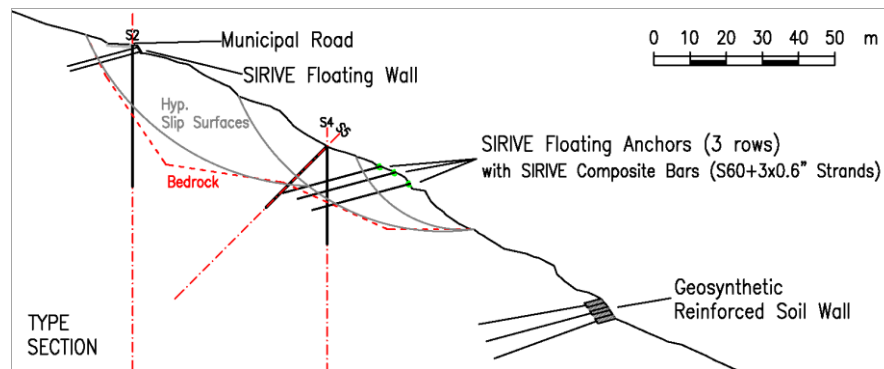


Fig. 3. Cortiana type section and stabilization works.

4. Preliminary results from monitoring system

Contemporary with execution of stabilization work, we provided to set up a monitoring system with the final aim to recognize how the floating anchors modify their setting in relation to the landslide movements.

Slope displacements and water table fluctuations are now monitored using inclinometers and piezometers. A topographical survey periodically determined the position of some selected points: in the specific, from the end of works (December 2012) the positions of the anchor heads have been monitored along with 10 points located in the stabilized slope. In addition, two load cells were applied on two anchors in order to determine the head-force adsorbed by each anchor plate in time, and three laser scanner surveys will be carried out in the next future, allowing a comparison among pre and post intervention displacement rates.

The monitoring system (Fig.2) shows that the displacements of the slope are not recognizable by the topographical tool because they are in the range of a few

centimeters, even if the spring 2013 was particularly rainy and many other landslides occurred again in Vicenza province. Moreover the displacements are smaller than those evidenced by the extensometers before the work realization.

We can only visually identify some shallow erosion due to the superficial water flow during rainfalls, also due to the absence of vegetation for slope protection.

The load cells (Fig. 2) indicate a small decrease of the head-forces in time (12.5-13%). This may denote a sort of stress relaxation in the soil close to the concrete plates. Monitoring will continue during the coming months.

5. Conclusions

Cortiana landslide proved to be a useful case study to apply and analyze the on-site behavior of Sirive® Floating Anchors. Even if the monitored period after remedial work is short we observed that the displacement rate decreased from a pre-work value of about 160 cm/y to a post-work value of 2÷3 cm/y, thus reaching a quite complete stabilization of the slope with a minor cost if compared to traditional techniques.

A complete revegetation of the slope should integrate the technique, in order to avoid shallow erosions due to surface flow and improve the quality of works.

Acknowledgements

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