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Reinforced steep vegetated slope 60 m height for landslide stabilization in Lona-Lases (Trento-Italy)

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ABSTRACT: Mount Gorsa versant located in Slavinac (Trento – Italy), above Lases lake, has been interested by a heavy landslide movement in a quarry area hanging over both the provincial road S.P. 71 and the same lake, with serious risks for the near built-up area and its inhabitants.This paper describes landslide stabilisation work with particular reference to a 60 meters height steep vegetated slope reinforced with high modulus PET geogrids placed at the toe of the slope to restore the containment action of landslide and to bring again the tensional state of under rock mass to the previous situation before the porphyry quarry excavation. More than 3.5 km of drainage system including 48 micro-drains have been installed to prevent the increase of pore water pressure along the sliding plane. A complete monitoring system with benchmarks, a network of inclinometers, piezometric tubes, and magnetic settlement devices has been installed to keep automatically under control the global landslide behaviour.

1 INTRODUCTION

In the mountain area near Trento there is a very intensive quarry activity for the extraction of porphyry (very hard stone) used in many building applications (pavements, walking paths etc). Mount Gorsa side above Lases lake, located in Slavinac (Trento-Italy), after quarry activity has been interested by an impressive landslide movement hanging over both the provincial road S.P. "Fersina-Avisio" and the same lake with serious risk for the near built-up area and inhabitants (Fig. 1).

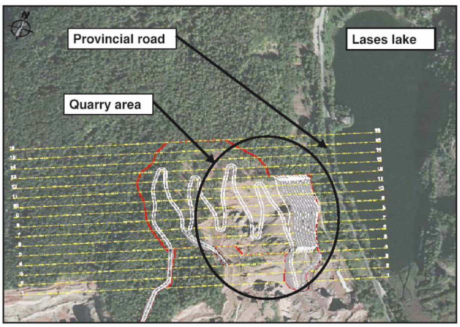

Figure 1. Aerophotogram of quarry area.

Following the exceptional meteoric events of November 2000 that caused a temporary acceleration of slope movements, the Public Disaster Prevention Department of the Province of Trento assigned to Prof. G. Barla (Polytechnic University of Torino) and Prof. A. Cancelli (University of Milano) a technical advise to study the landslide process, in order to define the guideline for final executive design of landslide stabilization and to analyse possible sceneries consequent to an increasing acceleration of landslide movement with particular reference to the evaluation of the wave effect produced by collapsing of instable rock portions into under lake.

2 HISTORICAL BACKGROUND

During summer 1976 starting signals of slope instability have been noticed while the porphyry quarry activity have been already started; landslides were attributed to:

- high steepness of slope (about 80%), high fractured condition of sub-layer, and the presence of a big size disaggregated soil layer gossan (1.00-5.00 m)
- rainfalls, excavation at the toe of slope and stresses caused by the falling down rocks during quarry extraction activity

Further sliding events have been noticed in following years and the cause has been given to the extraction activity always starting from the bottom of the quarry front.

First monitoring of landslide with cable extensometers has been done in 1996 and during three months displacements of 10-20 cm have been noted, mainly during winter months due to the prolonged period of rainfall. Geotechnical characterization of the landslide zone has been executed either with indirect (seismic investigation) and direct prospecting (destructive mechanical drilling for inclinometer and piezometric tubes) using automatic computerized log.

Slope stability analysis (limit equilibrium method back-analysis) confirmed the importance of water pore pressure pattern on the slope equilibrium conditions.

To prevent further water infiltration inside landslide body it has been decided to install a complete drainage system in the total area with drainage trenches and to waterproof all recent rupture cracks with HDPE liners.

The presence of outcropping main fault, ca. 1.50 m thick, constituted by fine sand-clay cataclasite on top of 2.00-3.00 m fractured rocks layer, and the results of further drilling test are clearly indicating a deep fault penetration. Sliding plane have been valuated at a deepness between 19.00 m and 15.00 m, but the main cause for slope instability has been reasonably assumed to be the porphyry continuity interruption above main fault due to old quarry excavation activity (Fig. 2).

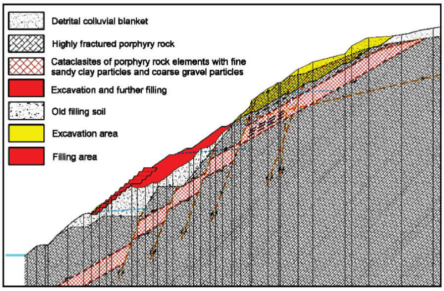

Figure 2. Slope profile showing fault and sliding planes.

3 THE SOLUTION

Global stability of the versant has been checked with polygonal Janbu method, using SLOPE/W software, considering translational rupture mechanism with main sliding plane inside cataclastic shear zone.
Three limit conditions have been examined:

- present situation: back-analysis to find relative friction angles of soil ($\phi = 35°$) with pore water pressure r_u varying from 0 to 0.10 that gives a global factor of safety FS close to 1 to justify landslide movement. Other soil parameters considered are unit weight $\gamma = 25$ kN/m^3 and cohesion c = 0.
- bottom slope filling without soil removal of upper part gives FS $\cong$ 1.2
- bottom slope filling with soil removal of upper part gives FS $\cong$ 1.3

Therefore only the third conditions, in term of global stability, was fulfilling requested FS $\geq$ 1.30 and therefore was the selected solution.

On the basis of above stability analysis supported by a detailed geotechnical investigation developed on the landslide area from year 1999 till 2003, the Consultants gave a main guideline for slope stabilization:

- restoring the containment action at the toe of the slope to bring back again the tensional state of rock mass at the previous situation before the porphyry quarry excavation
- installation of a complete drainage system around and inside the slope to prevent increasing of pore water pressure along the sliding plane.

According to indications given by the Consultants the final executive design for landslide stabilization started in 2002 and it has been based on following main points:

(1) morphological reconstruction of sliding versant by removal of soil from the upper part and its transportation to the bottom (Fig. 3)

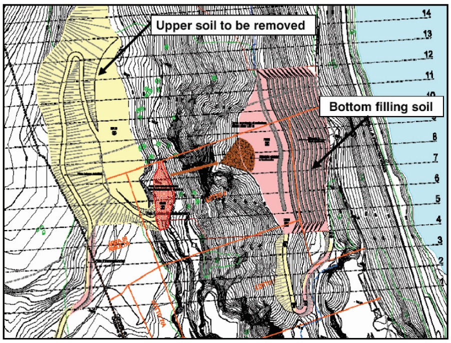

Figure 3. Removing and filling areas plan.

(2) execution of a reinforced steep slope with geogrids at the toe of the slope to allow a construction slope angle of 60° and at the same time to support the tensional above soil surcharge load. Height of the structure is 60.00 m, the face is split into a series of 5m high slopes with a 3m wide bench between each. Total length of reinforced slope is 100 m.
(3) execution of a drainage trench to collect all surface water and the installation of 48 sub-horizontal micro-drain tubes

Secondary works to complete the outline design are:

- green reclamation works for development of permanent vegetation of the area

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- falling rock barrier on top of reinforced steep slope to protect under provincial road
- instrumental automatic monitoring system with: 5 inclinometer, 6 open tube piezometers, 3 extensometers, 2 magnetic settling-meters, 25 monitoring benchmarks

4 THE REINFORCED STEEP SLOPE

Two types of PET polymeric coated geogrids have been used as structural reinforcing element of the reinforced steep slope: primary reinforcing PET geogrid with ultimate tensile strength 110 kN/m, anchor length varying from 8 to 31 meters and spacing 1.50 m, for overall and internal stability of the slope; secondary reinforcing PET geogrid with ultimate tensile strength 45 kN/m, anchor length 4.00 m and spacing 0.50 m, with the only function to guarantee local facing stability. Lost formwork made with galvanized steel mesh (15 × 15 cm, 8 mm diameter) have been used in order to achieve uniform facing with an angle of 60°. A jute biotextile has been installed between formwork and geogrids to prevent erosion of 20 cm fertile soil layer laid close the facing and to help growing of vegetation.

As filling material it had to be used exclusively the local porphyry material coming from removal of soil of the upper part of mountain sieved and crushed to obtain a proper grain size distribution. To achieve a good compaction value and to maintain under control geogrids mechanical damage, the maximum size of porphyry will be 10 cm. Due to the specific sharpness of the filling a precautionary reduction factor for geogrid mechanical damage of 1.20 has been considered for LTDS (Long Term Design Strength) calculation.

A mechanical damage test on primary reinforcing PET geogrids with porphyry filling and compaction to simulate real conditions has been performed in situ. Results of the test proved for PET geogrid a mechanical damage reduction factor of $f_{mr} = 1.14$ so it was accepted for this event being lower than the estimated conservative factor.

Figure 4 shows the typical cross section of the highest wall with two types of reinforcing geogrids used in this project.

Direct sliding check has been calculated and internal, compound and external stability check of the reinforced steep slope with Janbu method polygonal surfaces have been performed obtaining FS ≥ 1.3 according to Italian standards.

The allowable tensile strength in the reinforcement LTDS, was calculated with the method of partial factors of safety indicated by BS 8006 (1995)

$$\text{LTDS} = \frac{f_{cr} \cdot P_{ult}}{f_{mr} \cdot f_m \cdot f_e}$$

PET geogrids have characteristic shown in Table 1.

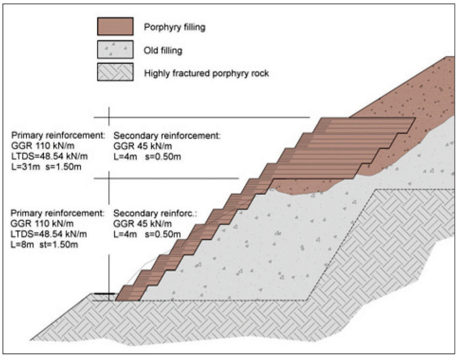

Figure 4. Cross section of reinforced steep slope 60 m height.

Table 1. Geogrids characteristics.

Material	Fortrac 45	Fortrac 110
Description	PET Woven geogrid with polymeric coating	
Tensile strength (longitudinal)	45 kN/m	110 kN/m
Elongation	≤ 12.5%	≤ 12.5%
f_{cr}: creep reduction factor (120 yrs)	0.60	0.60
f_m: reduction factor for extrap. and manufacture (120 yrs)	1.10	1.10
f_{mr}: reduction factor for mechanical damage (porphyry)	1.20	1.20
f_e: reduction factor for environmental effects (4 ≤ pH ≤ 9)	1.03	1.03
LTDS: Long Term Design Strength (120 yrs)	19.86 kN/m	48.54 kN/m

The specific characteristics and reduction factors of different geogrids were supported by certified laboratory and in situ tests.

In January 2005 the construction of the reinforced steep slope started with excavation of old filling material from quarry activity at the bottom of the slope to install first primary reinforcement geogrid layer with 8 m anchor length. At the same time the removed soil from upper top layer of quarry area has been moved down and used as filling of reinforced earth structure.

Reinforcement geogrids have been installed using wrap-around technique (Fig. 5) and heavy compaction every 30 cm thick layer of filling has been applied. Filling compressibility modules M_e, according to Swiss Standard (SNV 671307), determined with loading plate test measured under tensions between 0.15 and 0.25 N/mm^2 had to be always higher than 40 N/mm^2, while density higher than 90% of maximum Modified Proctor density according to AASHO.

Huge earthwork of ca. 750.000 m^3 excavation and ca. 300.000 m^3 filling has been executed. Total facing of reinforced steep slope is ca. 10.000 m^2 and ca. 3.5 km of sub-horizontal micro-drain have been installed.

Figure 5. Installation of primary reinforcing geogrid.

High thickness hydroseeding was sprayed on facing in progressive steps following the building of reinforced slope in height, to minimize environmental impact. An automatic irrigation plant with sprinkles installed on crest of face helped starting vegetation to grow during hot and dry summer period (Fig. 6).

Figure 6. View of slope with starting vegetation during summer 2005.

5 CONCLUSIONS

The executed project shows a very complex geotechnical problem in landslide stabilization, and the reinforced steep slope with geosynthetics proved to be in this specific situation the best solution from the technical and environmental point of view. The possibility to have a vegetated face immediately after construction reduced the visual impact of such an

Figure 7. Aerophotogram of the reinforced steep slope completed.

imposing structure from the surrounding inhabited and tourist area.

The reinforced steep slope has been completed in September 2005 (Fig. 7) and the automatic monitoring system installed is constantly measuring the behaviour of the structure and the versant.

The concept to built a strengthened slope with multiple purposes as containment of active pressure of back soil, to re-profile the versant and to contribute to general slope stability resulted very interesting and effective. Some of this ideas might be used in future for similar projects.

ACKNOWLEDGEMENTS

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