Slope stabilization with woven geogrids in San Bernardo Hill

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ABSTRACT: As a result of the rains that occurred during the summer of 2008 in Salta city, an important stretch of the access road to the top of San Bernardo hill was affected by debris sliding which produced an important landslide of the road in one part and the destruction of it in another. Although the importance of this road, because of being the only vehicular access to one of the most important and most visited touristic places in Salta, it had to be closed for security reasons and the impossibility of circulation for larger vehicles, causing major economic losses and important trouble to tourism. The developed project allows solving a serious problem of slope stabilization with a very low cost, even lower than any other conventional solution, with a very important advantage, specially for this moments, that is to build up a low environmental impact wall using the non-conventional bagged stone wall alternative, with soil reinforcement elements made with double twist hexagonal mesh and additional reinforcement. In this case we use woven geogrids fabricated with polyester yarns, in the range of 40-60 KN/m ultimate tensile strength. The final design gives the possibility of a quick and durable integration between the structure and the environment.

1. INTRODUCTION

The place where the intervention took place is located in San Bernardo hill, at the east side of Salta City, where access is available throughout the year by a state road named access to San Bernardo hill.

Climb to San Bernardo hill is one of the tourism attractions in the popular city of Salta, because there are important panoramic views of the city. You can go up by the access road and also by a cable car.

Due to the attractive that generates this relief road which is used by a significant number of vehicles, bicycles, and running people, this road is of great value, hence the need to preserve and maintain in terms of use throughout the year.

Figure 1. Satellite Image - Location

2. GENERAL FEATURES

San Bernardo Hill corresponds to a monoclinal structure with a strong dip (32 º) to the west, consisting of an alternation of sedimentary rocks, siliceous sandstone and shales. The last one is a fine-grained sedimentary rock, whose original constituents were clay minerals or muds, and are positioned with a sliding angle in the direction to the road which increases gravitational processes (landslides).

The intervention is located in a temperate region with torrential rainfall that occurs in summer with an average of 600 to 800 millimeters, with a maximum altitude of 1200 meters above sea level.

Vegetation cover is an important element of protection that prevents the direct action of concentrated runoff.

3. SITUATION ANALYSIS

Due to the age of the road into consideration, who has built 60 years ago, was designed according to the criteria of that time, without consideration different geotechnical aspects.

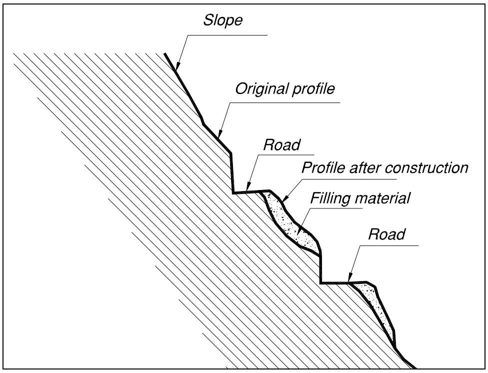

Figure 2. Profile after construction

As a result briefly above, in February 2008 due to intense rainfall (70 mm in one hour) maintained after several days, there were two landslides (D1 y D2) that hit the slopes and part of the asphalt surface in the access road to San Bernardo hill (D1 and D2).

Figure 3. Satellite Image - Lanslide D1 y D2

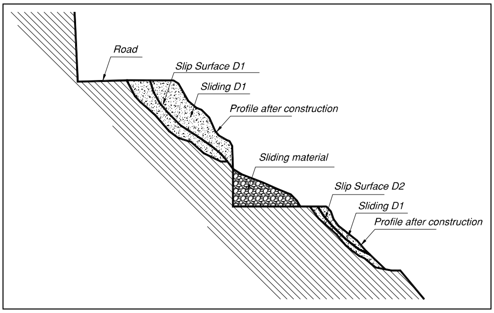

Figure 4. Profile after landslide

Figure 5. Sliding D1

Due to the lanslide the material was deposited on the road. For this reason the pavement was destroyed and the route had to be closed. Both landslides were generated for the same reasons, the difference was due to the volume of material moved.

Figure 6. Pavement structure damage

This place showed an accumulation of sliding debris over rocks with a sliding angle in the direction to the slope, the state of the rock that conforms the original outcrop, totally fractured shales, runoff is not controlled properly, allowing water pass through the cracks formed in the asphalt, which caused the saturation of the material below. All this factors were responsable for the displacement of loose material from the slope to the road, and accumulate on it.

In the case of the largest slip (D1) for the volume of the material involved, should be added the presence of a small depression where the water drains and accumulates in a micro basin developed on the slope of this sector. By the effect of the accumulation of water in a short-term, the basin overflows. Therefore, this fluid contributes to the erosion of the loose material of the slope.

Given this situation, with the road closed and significant economic losses, it was necessary to begin recovery efforts as soon as possible, waiting to start once the rainy season end.

To stabilize the slope, repair and open the road was needed a short time and a low environmental impact intervention.

The conventional concrete wall was discarded from the beginning, because of its high cost, irreversible environmental impact, small space available for construction, problems with foundation and time of construction.

Dismissed this traditional option, led to take the determination of using the non-conventional bagged stone wall alternative named Terramesh System and aditional reinforcement with woven geogrids with 40-60 KN/m ultimate tensile strength.

Terramesh units, facing and reinforcement mesh, is fabricated continuosly and therefore no separate conection to the reinforcement mesh exists

This option was adopted because, in the little space available for the construction, it let to assemble a 22 meter height wall, built up in two laddered levels as a terrace, so as to allow the placement of tree species in it, avoiding a continuous, monolithic structure that was not aesthetically appropiate. As the front section demands little space because, due to its constructive characteristics the required structural soil uses 6 m long anchorage reinforcement elements, which also once the reinforced structural soil is placed, allows to recover the lost space and also to control future sliding helping the frontal structure stability.

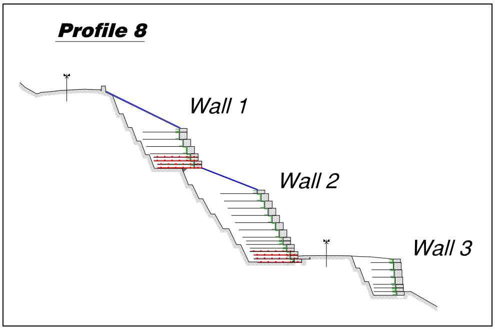

Figure 7. Final design of slope intervention

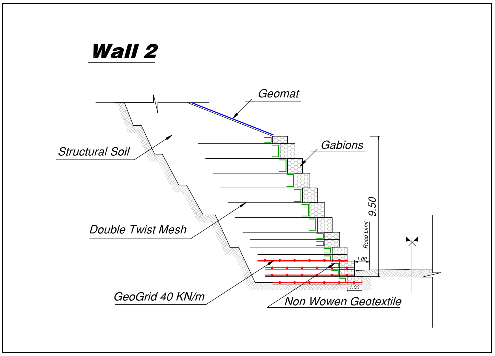

Figure 8. Detail intermediate wall

In the top part of each reinforced soil wall, a 5m slope is performed (in the highest part) with a 1:2 inclination, where it will be carried out a treatment aimed to improve the original conditions of the structural soil and to place appropriate seeds. The slope will be coated by a polypropylene geomat to reduce the concentrated runoff caused by the summer rainfalls, avoiding the formation of erosion furrows and the elimination of structural soil, allowing the development of vegetation and minimizing the visual impact in the area.

4. DESIGN PARAMETERS

Natural soil:
Cohesion: 30 KN/m^2,
Internal friction angle: 25˚.
Unit weight: 20,00 kN/m^3.

Structural soil:
Cohesion: 0 KN/m^2.
Internal friction angle: 35˚.
Unit weight: 18,00 kN/m^3.

Seismic Analysis:
Intervention was located in zone 3, by local standard NAA80
Horizontal coefficient: 0,20g
Vertical coefficient: 0,10g

Loads:
Uniform load: 20 KN/m^2, by local standard.

5. STABILITY ANALYSIS

The analysis of slope stability was performed by Macstars software. This soft has been developed to check the stability of reinforced soils, that is structures which provide the slope stability using reinforcement units that are able to absorb the tensile stress. Furthermore this program allows to conduct the stability checks using the Limit Equilibrium Method even considering unreinforced slopes.

The program allow to conduct the following calculation:
Global Stability analysis
Internal Stability Analysis
Compound Stability Analysis
Direct Sliding

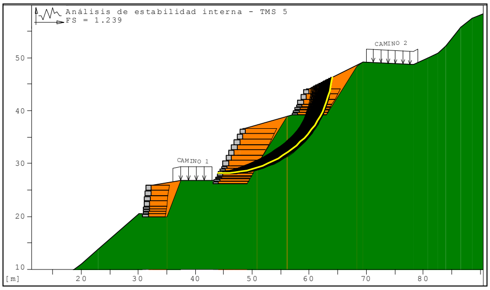

Figure 9. Software analysis – Compound stability

The adopted minimum safety coefficient are the followings:

Type of analisys	Seismic FS min	Surcharge FS min	Design FS real
Global stability	1.2	1.3	1.17
Compound stability	1.2	1.3	1.17
Direct Sliding	1.5	2.0	1.79

In all cases critical surface was appear in seismic analisys, but they are greater than the minimum required values.


Figure 10: Final picture of intermediate wall

6. CONCLUSIONS

The selected alternative, was built in a very fast time and let recovered a seventy percent of the material involved in the landslide, thereby avoiding the transfer of it to other sectors outside the area of influence of San Bernardo Hill, reducing costs and direct environmental effects

It is very important to mention, that the proposal alternative provided a rapid integration with the environment, with the addition of trees and native vegetation in order to reduce the environmental impact at the maximum.

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