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Green system for erosion control and stabilization as an alternative to shotcrete: A case study of Bogotá - Villeta highway slope

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Abstract

Stability and Erosion problems were found in several slopes on the Bogota – Villeta road. Most of them has been managed with conventional solutions. Specifically on the 60 kilometer, an unstable slope has presented frequent material falls including considerable size rocks generating a landslide mechanism. This phenomenon jeopardizes security conditions, generate blockages on the road and in the worst case put human's life in risk.

Due to rain regime, soil type (mainly highly weathered rocks), high and steep slope, exposure conditions and the continuous action of wind and rain, a suitable solution should be execute for stabilize and control erosion process. Initially a conventional shotcrete and bolts solution was proposed. Looking for a green alternative, which would integrate with the landscape, provide stability, stop falling material and give protection against erosive agents, a mixed solution between turf reinforcement mats (TRM), meshes, bolts and wires was carried out.

This kind of solutions offers many advantages, which will prevent landslides in the future by avoiding a failure mechanism. 6 and 10-meter bolts will offer slope stability and Mats will not allow fine material fall, while meshes and ½" wires will sustain the fall of debris and larger materials. Finally, this mixed alternative provides the proper environment for slope revegetation, which will further reduce the erosive process.

Key Words

Stabilization, Erosion Control, Turf Reinforcement mats, mesh, bolts.

1 INTRODUCTION

Slope stability is one of the most important concerns in engineering, particularly in infrastructure projects such as roads and highways. There are many techniques for evaluation of the slope stability and exist several technologies, materials and procedures for guaranteeing that stability.

Additionally, slopes soil erosion is another big issue because as a natural process, could be one of the causes of slope instability. Erosion consist in particles of soil, which are moved by wind and water, and displaced to another location. When erosion occurs on slopes, it may create a failure mechanism starting with gullies, furrows, following by debris fall and local detachments. At the end, an instability would be originated and significant landslides may occur.

The slope analyzed in this paper is located 60km from Bogota. Its morphology and geometry is a result of human intervention when the highway was constructed in 2010. The slope remained exposed for several years. It was not necessary to intervene until intense periods of rain appeared, including La Niña phenomenon in 2010 and 2011. These extreme weather events accelerated and triggered a series of instabilities on the slopes of the Bogotá-Villeta road.

Initially, conventional bolts and shotcrete was proposed to stabilize and control erosion. Nevertheless, as an effort to keep a green environment in the area and reduce hydraulic alterations on the slope, an alternative solution was implemented by using geosynthetics, meshes and wires.

2 OBJECTIVES

This paper presents a non-conventional solution for stabilization and erosion control. Through the case study of the slope on the road to Villeta, the advantages of the system will be shown.

Materials used on the slope will be described, mainly the most important components of the solution as the turf reinforcement mat (TRM), mesh and bolts.

A photographic record and report about re-vegetation, which is one of the principal purposes of this kind of solution, is made.

3 STUDY AREA CHARACTERISTICS

The study undertaken is based on a specific activity carry out by “Sabana de Occidente” concession on the Bogota – Villeta Road under the supervision of the National Infrastructure Agency (ANI) of Colombia.

3.1 Location

The study site is located at the 60km on the road that from Bogota city leads to Villeta in Cundinamarca department.

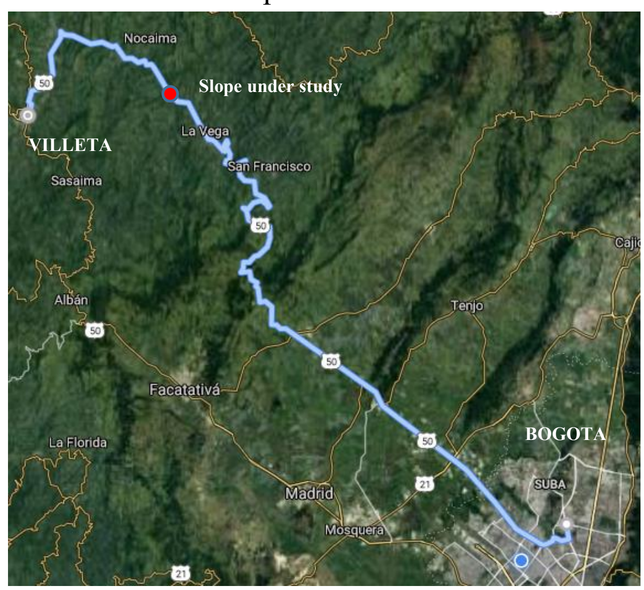

Figure 1. Bogotá-Villeta road and slope location

The general project involves the maintenance of an 80-kilometer road, rehabilitation works on the pavement structure and safety guarantee for road users. It implies occasional activities and civil works for keeping the infrastructure in optimal service state.

3.2 Climate Condition

The studied area is located at 1,200 meters above sea level. It is classified as a tropical climate. Most months of the year are marked by significant rainfall. The short dry season has little impact. The rainfall is 1600 mm per year. The average temperature is 22 ° C.

From the winter season of La Niña Phenomenon of 2010 and 2011, a series of unstable sites were activated that affected the normal operation of the road. Funds from government were designated for studies and design for stabilizations.

Once more, in 2017, due to the winter season presented in the first months of the year, new failure mechanisms of some sectors of the corridor were activated, in particular the critical point in kilometer 60.

Precipitations causes the continuous release of material from the slopes and consequently may lead to landslides, which fall to the highway generating permanent risk for the users.

Figure 2. Debris fall.

3.3 Geological and geotechnical model

From the soil exploration and geotechnical characterization by specialized test, the geological and geotechnical model for the instability was determined.

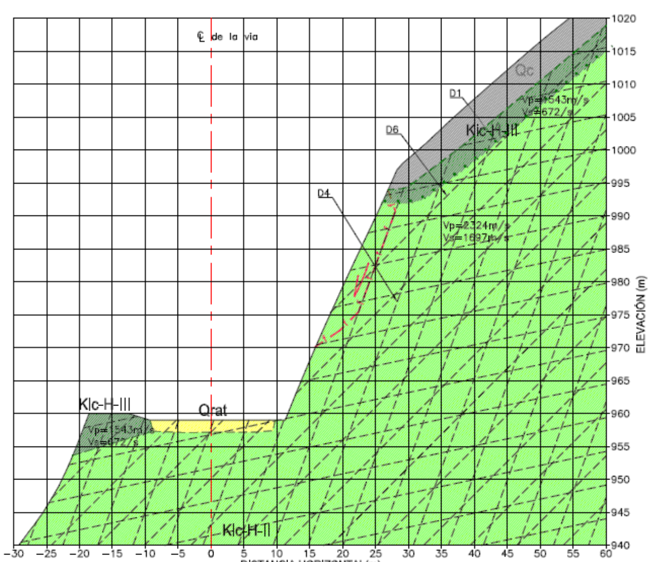

Figure 3. Slope initial condition (K60) and debris drop.

The stratigraphic profile found on the site is described below:

1. Anthropic filling (Qrat): Slime and gravel of gray lutites that make up the road structure
2. Colluvial Deposit (Qc): Pale yellow slime of loose compactness.
3. Moderate weathered rock (Horizon III): gray Arcillites with oxidations and open discontinuities.
4. Weakly weathered rock (Horizon II). Dark gray arcillites with some fractures.

Figure 4. Slope initial condition (K60).

In some places, cuts in sedimentary rocks of the Capotes Formation are evident. Siltstones, mudstone and calcareous mudstones are identified. These rocks have been affected by tectonic events associated with the lifting of the Central Mountain Range throughout geological time. Consequently, they reflect a strong fracturing, high porosity and secondary permeability of the massif.

Figure 5. Very fractured calcareous mudstone.

3.4 Phenomenon description

Based on the structural characteristics of the rock mass and the direction of the cutting slopes, some geotechnical failures such as wedges, planners and topping are generated.

Exogenous agents trigger those failures. Water infiltration from precipitation generates failure surfaces along the fractures, weathers the rock, erode non-competent rocks, and leave negative blocks that could fall to the road.

From the previous conditions that generate instability in the sector, some predominant typologies are identified, which correspond to blocks detachment associated with the discontinuities arrangement of the rock mass.

On the other hand, there are some material detachments from accumulation sectors located on the mid-slope. Those sectors are high-threat sources, since these small matrix-supported deposits have a very low degree of consolidation and mass displacements may occur when they are saturated by precipitation or by the effects of gravity itself and the constant impact by surface erosion.

Figure 6. Rock Blocks fall to the road.

3.5 Slope stability Assessment

Several methods of calculating slope stability based on the balance of forces, moments or energy are used. Most often, the methods based on the assumption that failure occurs towards slip surface. The shape of slip surface depends mainly on the physical and mechanical properties of soils or their arrangement in the profile. The stability analysis in question takes into account the families of discontinuities that predominate in the sector and the cutting slopes directions. This structural data was analyzed using the DIPS V5.1 software to determine the failures associated with each of these slopes.

The analysis indicates that the wedge failure is the critical condition, even more than the planar failure, because a greater bolts capacity is required.

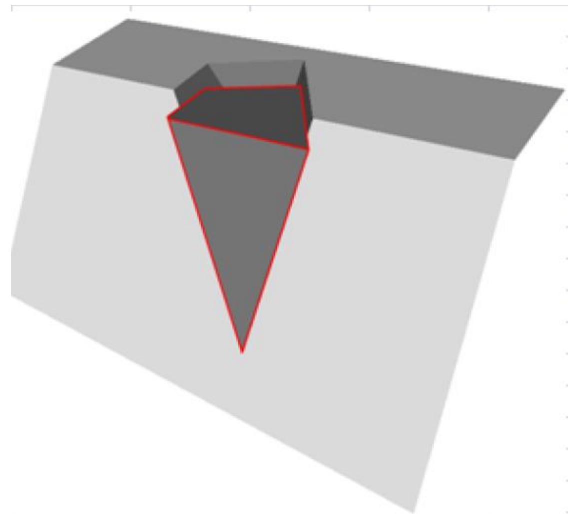

Figure 7. Wedges Modelling by using specialized software.

4 GREEN SOLUTION

The engineering analysis based on the discontinuities information and the rock mass characterization, was focused on the most frequently phenomenon at the site: debris flow and wedge failure.

The green solution was design for one of the slopes on the Bogotá-Villeta highway. Every single component of the system has an important function for stabilization or erosion control.

Figure 8. General view of the slope intervened by green system

4.1 Bolts

The length of the bolts is determined by the wedge width with high probability of falling identified in the planar or wedge failure modeling.

The assessment showed a wedge width of 3.3m, for which a bolt length of 10m is recommended. Furthermore, the bolts separation is given by the geometry of the critical wedge. The analysis indicates that bolts are required horizontally and vertically every 2.4m.

21-ton design capacity and 1in diameter bolts were used in the arrangement previously described.

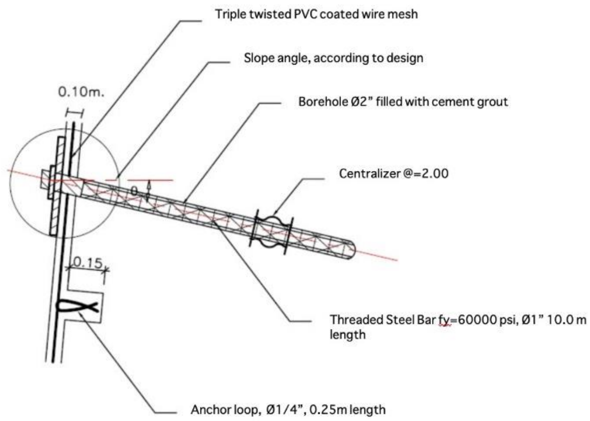

Figure 9. 10m bolt detail

Figure 10. 15cm x 15cm steel plate and hexagonal nut

4.2 Turf Reinforcement mats TRM

Considering the erosion potential of the analyzed slope that is determined by four basic factors: soil characteristics, vegetative cover, topography, and climate. A geosynthetic mat was specified for control erosion in the slope surface.

Figure 11. Permanent and 100% UV stabilized fibers mat

These types of mats are suitable when natural vegetation, by itself, is not able to withstand flow conditions, and provide sufficient protection for long-term erosion neither.

Additionally, this type of TRM not only retain soil moisture that helps promote seed germination, but it allows small deformations due to its flexibility and the free transit of water, so it is not exposed to premature damage due to excess hydrostatic pressure as in the case of concrete.

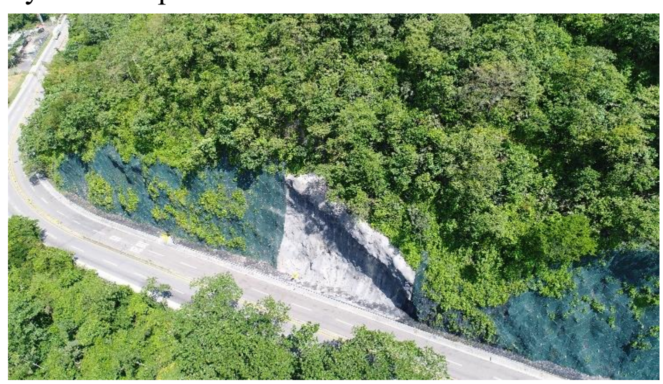

Figure 12. TRM installed over the erodible surface vs conventional concrete solution.

4.3 Steel Mesh and Wires

The mesh is a two-dimensional element, composed of high resistance wires arranged in a hexagonal configuration, whose flexibility allows easy adaptation to the slope morphology. It is a retention element used in slopes formed by residual soil, with a high presence of blocks from weathered rock and with frequent fall of debris and landslides of medium-sized material.

Figure 13. Steel and PVC coated mesh

The mesh used for this specific slope consist in a galvanized steel triple torsion and PVC coated mesh. The element is responsible for keeping soil particles in place and preventing mats damage due to strengths caused by surface detachments.

Additionally, wires were used among the bolts, allowing load transferring from the mesh towards the bolts around.

Figure 14. Steel and PVC coated mesh.

4.4 Drainage elements

It is fundamental to guarantee optimal drainage conditions over the entire slope. Free water flow is the optimal condition in the slope surface for avoiding hydrostatic pressures. At the top, flow must be control and driven carefully.

Two specific structures were design for that purpose. A concrete dissipation structure and a flexible waterproofed ditch with 0.75mm geomembrane at the crest of the slope.

Figure 13. Concrete drainage system.

5 RESULTS

The Green alternative was successfully implemented over 1km length of the unstable site and more than 60m high slopes. Some results obtained are:

- Vegetation was promoted in areas where site conditions allowed it.
- Generation of a complete erosion control system
- Evasion of material migration
- Slope surface protection
- Prevention of further serious problems caused by erosion, such as furrows and gullies that can create a slope failure mechanism.
- Lower maintenance costs.
- Stabilization.

5.1 Re-vegetation

It refers to improve the establishment and performance of grass cover on slopes in combination with the vegetation roots to offer sufficient mechanical strength and protection against erosion agents.

Four months after de system implementation, 25% of the slope surface was cover with vegetation. It is expected to continue growing in the near future.

Figure 14. Re-vegetation process

6 CONCLUSIONS

Climatic factors combined with the erosion activity as rain, wind, watercourses and groundwater are major causes of slope deformations. Winter periods with extreme rainfall events increased the number of slope instabilities on the Bogota-Villeta highway.

The green stabilization alternative provides an attractive and environmentally compatible system to protect slopes against surficial erosion and shallow mass movement. It is found that green system can be a cost-effective, sustainable, functional, environmentally superior solution; being more aesthetic, economical and flexible design method than conventional solutions.

Slope failure due to erosion is a common problem along the highway. Green system is an alternative environment friendly solution to the problem. A mixed solution with geosynthetics and bolts can be used as an overlay on the exposed slopes for reducing erosion of the soil mass. It will also increase the stability of the slope.

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