Use of reinforced geomat in steep slopes

Chiari, V.G.,
Maccaferri do Brasil Ltda, Jundiaí, São Paulo, Brazil, victor@maccaferri.com.br

Santos Junior, P.J.
Maccaferri do Brasil Ltda, Jundiaí, São Paulo, Brazil, petrucio@maccaferri.com.br

Lima, L.L.
Maccaferri do Brasil Ltda, Jundiaí, São Paulo, Brazil, leilo@maccaferri.com.br

da Silva Duran, J.
Maccaferri do Brasil Ltda, Jundiaí, São Paulo, Brazil, jaime_s_duran_maccaferri.com.br

Ferretti, P.C.B.
Maccaferri do Brasil Ltda, Jundiaí, São Paulo, Brazil, paulo.ferretti@maccaferri.com.br

Keywords: geomat, slope, revetment, stability, vegetation

ABSTRACT: Long rainy periods and lack of maintenance can take an apparently stable slope quickly to moments of instability and subsequently moments of fast movement and collapse. This relates to a common situation in Brazil's costal regions, such as the coastal area of São Paulo state. From a geotechnical point of view, making a slope superficially stable through simple solutions provides ease of installation and adapts this condition to the application of vegetable revetment whose main characteristic is to increase resistance increments of tensile strength offered by a developed root system. The paper to be presented relates a case history which occurred in the city of São Sebastião in São Paulo's coastal region. Here, the choice of solution in vegetable coating was decisive for economic and geometric reasons because there was a residence near the "foot" of slope that made any type of retaining structure unfeasible or difficult access for equipment in this area. As the vegetation development is a function of climatic phenomena and of necessary time for root invigoration, its application is possible for some of the supporting elements for its growth. Therefore, the use of a reinforced geomat with double twist hexagonal mesh was chosen as a way of establishing slope stability and preserving the site sufficiently to allow time for vegetation growth. The most challenging points in this application have been the stratigraphic diversity of slope's soil, which demanded many types of staples to anchorage geomat and the steep inclination of slope, which complicated the installation and brought up some doubts to the development of the vegetation.

1 INTRODUCTION

The degradation of soils affects both the agricultural and natural vegetation areas and can thus be considered as one of the most important environmental problems facing us today. The soil erosion problems in Brazil are a combination of several factors impacting fragile soils and a very severe climatic regime. The challenge lies in comprehending the responsible factors which directly cause the erosion as well as recognizing that such processes are not merely physical but also socioeconomic ones. Soils suffer erosion not only due to rainfalls but also because the terrain was deforested and cultivated incorrectly.

Vegetation is an excellent defense mechanism which nature has produced to protect soil against erosion. Sometimes, however, erosive forces are too large or vegetation needs to be developed under difficult conditions and nature needs a helping hand - erosion control. The most obvious way in which vegetation stabilizes soils is by root reinforcement. The intermingled, lateral roots of plants tend to bind the soil together into a monolithic mass. The vertical root system can penetrate through the soil mantle into firmer strata below and thereby anchor the soil to the slope and increasing resistance to sliding. In this case, inert materials (like a geosynthetic) need to be brought into the solution.

Due the long rainy periods, a situation of superficial slope instability has occurred in the city of São Sebastião in São Paulo's coastal region. In the sections to follow, geotechnical engineering considerations will be presented leading to the goal of establishing a suitable factor of safety against superficial instability, applying Koerner & Soong (2005), who have used limit equilibrium and a finite slope model to analyze the superficial stability. In this case, a TRM was used to protect the slope surface against superficial erosion caused by rainfall and to promote vegetation growth.

2 EROSIVE PROCESS ON SLOPES CAUSED BY THE RAINFALL

The erosive process caused by rainfall has a global inclusion, especially in regions with a tropical climate, where the pluviometric rates are much more elevated than in other regions of the planet. In this study, we specifically focus on the Brazilian costal region. Moreover, the rainfall cycle is concentrated during some seasons, forsaking the soil of the vegetation coverage and the consequent rainfall that occurs impacts directly onto the surface of the soil, thus destabilizing it.

The mechanism of the superficial erosion caused by the rainfalls initiates through the action of the splash effect or splashing (Guerra and Guerra 1997) caused by a drop of rainwater that contacts the soil particles, which are generally given by the rupture of the aggregate. After the desegregation of the particles, soil saturation and the consequent formation of puddles, superficial flow is given, where the water performs a relatively fast trajectory and is able to transport materials of the soil by means of the hydraulics force of its flow. It can even be faster in steep slopes (above 34°), disintegrating the particles present in the soil and then causing the erosions. If the process is continuous, it originates erosions with larger dimensions, which demand a more effective solution. Figure 1 shows the entire trajectory that the rainfall water runs through just after its impact on the surface.

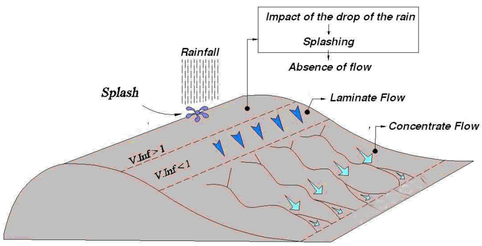

Figure1. Mechanism of the superficial erosion caused by action of the rainfall.

3 THE IMPORTANCE OF THE VEGETATION

Soil bioengineering brings together biological, ecological and engineering concepts to produce living functioning systems. The structural components initially protect the site mechanically and develop a stable, healthy environment for the plants to establish. The plant roots as fibrous inclusions, thus reinforcing the soil and increasing the resistance to sliding or shear displacement. Increased shear strength of root permeation is a function mainly of the tensile strength of the roots that must be long and frictional enough to resist pullout. This way, superficial instability and erosion can be reduced by transpiration of moisture and rainfall interception.

The vegetative coverage in slopes contributes to attenuate its erodibility rate, maintaining humidity and facilitating the infiltration of waters into the terrain. From an ecological point of view, the vegetation optimizes the hydraulic relations in soil-plant-atmosphere system; besides, it soothes temperature and humidity ends of the air close to the soil surface. From an aesthetic point of view, the vegetation reduces the visual impact with the increase of the green area and landscape improvement.

4 CASE HISTORY

The climate global change has been caused by the intensification of the greenhouse effect which is related to the increase of gases concentration in the atmosphere, causing some unforeseen phenomena in many parts of the world. Recent studies have shown that the intensity of rainfalls increases year after year, causing problems of profound and superficial erosion in slopes, specifically when they are destitute to vegetation.

One of the cases where superficial erosion was noticed due to the rainfalls was seen in a steep slope inside of a property in the city of São Sebastião in São Paulo's coastal region, Brazil (figure 2). This property was very near the "foot" of slope and it was placed in a risky situation, needing, therefore, a fast, efficient intervention. Due to this proximity, any possibility of a retaining wall utilization had been discarded to avoid the erosion. The proposal of the slope protection foresaw a search for an effective, low-cost system, besides propitiating vegetation growth. Among all the analyzed solutions for the case, it was decided that the option of utilizing a geosynthetic material was most practical, but it was necessary to perform a stability calculation in order to know whether or not the material should be reinforced.

Figure 2. Superficial erosion in the slope.

5 GEOSYNTHETIC USED FOR SUPERFICIAL EROSION PREVENTION AND CONTROL

The utilization of geosynthetics for superficial erosion prevention and control has experienced a significant advance since the 1990's, providing an adequate protection of the soils even though the local terms (steep slope, geotechnical characteristics, pluviometric indices, use and occupation of terrain, etc) show adverse and potentially deflagrated erosive processes. Basically, geosynthetics should act as retainer of the fines coming from the underlying soils or of the erodible material transported, besides having the function of resisting to the flow speeds and to the tangential efforts and absorbing the energy of the impact of raindrops.

According to Theisen (1990), geosynthetics for erosion prevention and control are classified as temporary (TERM) and permanent (PERM). The second one are subdivided in TRMs (turf reinforcement mats) and ECRMs (erosion control and revegetation mats). The TRMs are blankets of three-dimensional matrix of polymeric fibers used for the reinforcement of the vegetation already developed against the action of water speed and against the strength efforts above the maximum rated supported, besides helping it grow.

The protection exemplified in this paper is a geomat classified as TRM manufactured with an open three-dimensional synthetic mat of polypropylene joined in a double twisted hexagonal metal mesh, 2.70 mm diameter, type 8x10. This material avoids splash effect with the slope, creating a proper environment to vegetation growth. The vegetation roots anchor the geosynthetic material at the slope, and the wire mesh increases the soil strength against small displacements.

6 GEOTECHINICAL ENGINEERING CONSIDERATIONS

Cover soil sliding on slopes underlain by geosynthetics is certainly an unacceptable situation. According to Koerner & Soong (2005), the potential failure surface for veneer cover soils is usually linear with cover soil sliding with respect to the lowest interface friction layer. The potential failure plane being linear allows for straightforward stability calculation without the need for trial center locations and different radii, as in soil stability problems analyzed by rotational failure surface. Furthermore, full static equilibrium can be achieved without solving. Although this methodology being applied mostly in engineered landfills, it can be used for a superficial revetment on steep slopes.

Figure 3 illustrates the situation in the slope analyzed. The symbols used in the same figure are defined as: W_a = total weight of the active wedge; W_p = total weight of the passive wedge; N_a = effective force normal to the failure plane of the active wedge; N_p = effective force normal to the failure plane of the passive wedge; γ = unit weight of the cover soil (18 kN/m³); h = thickness of the cover soil (0.20 m); L = length of slope measured beneath geosynthetic (20.0 m); β = soil slope angle beneath geosynthetic (60°); ϕ = friction angle of the cover soil (23°); δ = interface friction angle between cover soil and the geosynthetic (23°); C_a = adhesive force between cover soil of the active wedge and the geosynthetic; c_a = adhesion between cover soil of the active wedge and geosynthetic; c = cohesion of the soil (10 kN/m²); E_a = interwedge force acting on the active wedge from de passive wedge; E_p = interwedge force acting on the passive wedge from de active wedge; and FS = factor of safety against cover soil sliding on the geosynthetic.

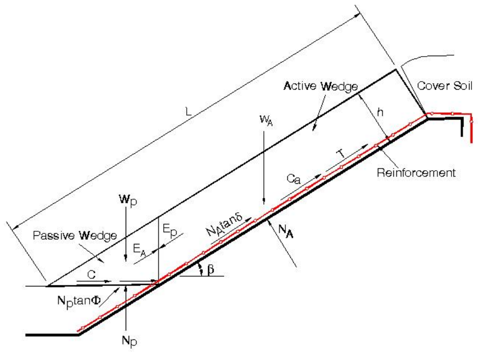

Figure 3. Slope with the use of veneer reinforcement (Koerner & Soong 2005).

The expression for determining the factor of safety is derived as follows. Considering the active wedge:

$$W_a = \gamma.h^2\left(\frac{L}{h} - \frac{1}{\sin\beta} - \frac{\tan\beta}{2}\right) = 70.75 \text{ kN/m} \quad (01)$$

$$N_a = W_a.\cos\beta = 35.38 \text{ kN/m} \quad (02)$$

$$C_a = c_a.\left(L - \frac{h}{\sin\beta}\right) = 1.98 \text{ kN/m} \quad (03)$$

The passive wedge can be considered in a similar manner:

$$W_p = \frac{\gamma.h^2}{\sin 2\beta} = 0.83 \text{ kN/m} \quad (04)$$

$$N_p = W_p + E_p.\sin\beta \quad (05)$$

$$C = \frac{c.h}{\sin\beta} = 2.31 \text{ kN/m} \quad (06)$$

The factor of safety can be arranged in the form of a quadratic equation:

$$FS = \frac{-b + \sqrt{b^2 - 4.a.c}}{2.a} \quad (07)$$

Analyzing the slope with the aforesaid characteristics:

$$a = (W_a - N_a\cos\beta)\cos\beta = 26.53 \text{ kN/m} \quad (08)$$

$$b = -[(W_a - N_a.\cos\beta)\sin\beta.\tan\phi + (N_a.\tan\delta + C_a)\sin\beta.\cos\beta$$

$$+ \sin\beta.(C + W_p.\tan\phi)] = \text{-29.17 kN/m} \quad (09)$$

$$c = (N_a.\tan\delta + C_a)sen^2\beta.\tan\phi = \text{5.41 kN/m} \quad (10)$$

Substituting the results of the equations 08, 09 and 10 into equation 09, the factor of safety FS is 0.86, which is such a low value for a final cover soil. Thus, an appropriate design option is to consider the use of veneer reinforcement with a geosynthetic material, in this case using a geomat with 50.11 kN/m of reinforcement strength due the presence of the wire mesh. Such reinforcement (induced by the wire mesh) can be considered intentional because of the inclusion of a geomat within the cover soil to purposely reinforce against instability.

Considering a reinforcement force T, acting parallel to the slope, the equations 10 and 11 can be rewritten as follows:

$$a = (W_a - N_a.\cos\beta - T.sen\beta).\cos\beta = \text{6.85 kN/m} \quad (11)$$

$$b = -[(W_a - N_a c.os\beta - T.\sin\beta)\sin\beta.\tan\phi$$
$$+ (N_a.\tan\delta + C_a.\sin\beta.\cos\beta$$
$$+ \sin\beta.(C + W_p.\tan\phi)] = \text{-14.70 kN/m} \quad (12)$$

The c item is obtained again through equation 12. The allowable value of T in the design formulation is T_{allow} which is invariably less than the as-manufactured strength of the geosynthetic material. Considering the ultimate strength as being T_{ult} (50.11 kN/m), the value should be reduced by reduction factors as installation damage (RF_{ID}=1.05) and long-term degradation (RF_{CBD}=1.05). The reduction factor of creep is not considered in this case, because the reinforcement is the wire mesh and the synthetic mat aims at avoiding soil loss.

$$T_{allow} = T_{ult}.(\frac{1}{RF_{ID}.RF_{CBD}}) = \text{45.45 kN/m} \quad (13)$$

Figure 4. Vegetation developed along the geomat revetment.

Again, the FS-value can be obtained using equation 09, resulting in an FS equal to 1.67, which it is totally acceptable. After the calculation indicates positive results, the geomat was installed along the slope (figure 4) with steel pegs of 0.50 m long in form of an "U" for fixation, respecting the average distribution of 4 (four) pegs per square meter due to its inclination.

7 CONCLUSION

Due to the hard inclination of the slope, the method used for performing calculations showed efficient results, proving, by means of safety factors, the need of a reinforced element for protection. The result of the installation was exceptional, and vegetation has been developed in just two months. In addition to the vegetation normally developed, which had been planted along the geomat, revetment in the openings of the double twisted hexagonal mesh showed a result that had been very satisfactory. Due to the access difficulty of any mechanical equipment to the slope or by the space lack for building a retaining wall, the utilization of a low-cost, reinforced geosynthetic and no need of maintenance was the ideal solution for the slope protection against the superficial erosion.

ACNOWLEGEMENTS

The authors wish to express their sincerest acknowledgements to Maccaferri America Latina.

REFERENCES

Chiari, V.G & Fracassi, G. 2008. Revitalization of San Francisco River in Brazil using geomats. *EuroGeo4, 4th European Geosynthetics Conference*, Edinburg, UK.

Guerra, A.J.T., Silva, A.S & Botelho, R.G.M. 1999. *Erosão e conservação dos solos: Conceitos, temas e aplicações*. Bertrand Brasil, Rio de Janeiro, Brazil.

Koerner, R.M. 1998. *Designing with geosynthetics*, 4th edition. Prentice Hall, New Jersey, USA.

Koerner, R.M. & Soong, T.-Y. 2005. Analysis and design of veneer cover soils. *Geosynthetics International, Special Issue on the Giroud Lectures*, 12, No 1, 28-49.

Theisen, M.S. & Carroll, R.G.,Jr., 1990. *Turf reinforcement – The soft armor alternative*, Proc. 21st Conf. Prof. Instl. Erosion Control Assoc., Steamboat Springs, CO, 255-270.

Wischmeier, W.H. & Mannering, J.V. 1969. Relation of soil properties to its erodibility. *Proceedings of Soil Science Society of America*, 33, 133-137.