"Green" reinforced soil walls using geosynthetics: an alternative for ecological and environmental projects

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Keywords: Reinforced soil walls, woven geotextile, green walls, reinforcement, geosynthetics

ABSTRACT: For some projects the environmental and landscaping requirements have obliged the engineers and architects to look for novel methods of constructing retaining walls and slopes. The "Green" walls and slopes are constructed from soil reinforced with geosynthetics and facades made from UV-degradable sacks filled with organic material and vegetation to have a natural appearance This article provides a detailed description of the designs of the "Green" reinforced soil walls and slopes. These designs incorporate the use of various geosynthetics, including woven geotextiles to reinforce the soil, geodrains for the drainage both behind and within the walls, and permanent Turf Reinforcement Mats (TRMs) to protect the wall facade from erosion. Also presented are details of the construction process needed to ensure the stability of the wall. The article concludes with an analysis of the "green" reinforced soil walls highlighting the economic, technical and environmental advantages.

1. INTRODUCTION

Retaining soil walls and slopes reinforced with Geosynthetics present an alternative to traditional retaining wall solutions, such as walls of reinforced concrete or soil embankments in their natural angle of repose. Reinforced soil walls are challenging the more traditional constructions due to their economic competitiveness and their green environmental credentials. Additionally, the introduction of soil walls or slopes has permitted the construction of retaining walls in places where the load capacity of the foundation soil is not sufficient for rigid walls, or where there are space restrictions preventing the construction of soil fills or soil embankments at their natural angle of repose.

Geosynthetic reinforced soil walls or slopes are also attractive solutions because of the flexibility they provide, as their design can be adapted to suit a wide range of different loads, solicitations, geometries, landscape features and environments. Increasingly urban housing complexes and new tourist developments are emphasizing ecological awareness and care for the environment in their construction, and Geosynthetic reinforced soil walls are used as they meet the construction goals.

For these types of projects we have developed a system for building "green" walls or slopes, which are geotextile reinforced soil slopes which have a uniform covering of vegetation on their facade to give a natural appearance. The resulting slope is attractive and as strong and robust as the traditional solutions which use concrete, block or stone facades.

The facades, of the so-called "green" walls, are made from UV-degradable sacks filled with organic soil and vegetation. Once the facade is finished, these sacks are covered with a permanent erosion control mat (Turf Reinforcement Mat) to guarantee the growth and development of the vegetation on the wall facade. The facade inclination for this type of structure must be no more than 80 degrees with respect to the horizontal, to guarantee the development of the vegetation on the wall facade. When the inclination is 70 degrees or less, the structure is analyzed as a reinforced soil slope and for inclinations between 70 degrees and 80 degrees, the structure is calculated as a reinforced soil wall.

The maximum height recommended for the "Green" reinforced wall or slope is 12 m in one block. If the height is greater than 12 m, it is recommended to design a wall or slope with different terraces, and a berm of 1m minimum between terraces. For example, for a 18 m wall, it is recommended to design 3 terraces each one of 6 m height with a 1 m berm between each terrace.

2. DESIGN METHODOLOGY

2.1 Overview

Soils have a high resistance to compressive forces but they give way easily under the application of tensile forces.

However, soils may be reinforced with other materials, such as Geotextiles, which are specially designed to absorb tensile forces. Therefore, where we have a soil wall needing to resist both compressive and tensile stresses we can obtain a structure of much greater resistance by including a suitable Geotextile within the soil mass. The extra strength provided is principally due to shear stresses produced by the friction between the Geosynthetic material and the adjacent layers of soil.

Various design methodologies exist for the reinforcement of soil walls using Geosynthetics. In our case, we use the methodology proposed by Robert M. Koerner (in "Designing with Geosynthetics", 4th Ed) and by Robert D. Holtz, Barry R. Christopher, Ryan R. Berg (in "Geosynthetic Engineering"). Fundamental to this methodology are the design principles of Whitcomb y Bell (1979), which state that you don't consider hydrostatic pressure in the design calculations and the active failure surface should be a plane surface defined by the Ranking methodology.

2.2 Stages of the Design Methodology

The design methodology for soil walls or slopes reinforced with Geosynthetics consists of three stages:

- Stage 1: Internal stability. In this stage the vertical space between layers is calculated as well as the correct length of reinforcing required to achieve the necessary resistance. The calculations must be based on the technical specifications of the Geosynthetic being used.
- Stage 2: External stability. In this stage the design must be reviewed to ensure adequate external stability. This stage analyses the overall structure using the Limit Equilibrium approach to verify the safety factors of Base Sliding, Overturning and Bearing Capacity.
- Stage 3: External conditions. In this stage the type of wall facade is specified and the conditions of drainage and sub-drainage analysed.

3. DESIGN FOR A "GREEN" REINFORCED SOIL WALL OR SLOPE

In order to describe the process of design for a Geosynthetic reinforced soil retaining wall or slope we will use the example of a slope designed and constructed in Costa Rica in January 2008. This slope was designed to have an erosion resistant facade of vegetation and for this it is referred to as a "green" reinforced soil slope.

3.1 Initial conditions

For the example of the reinforced soil slope that is described in this document, a stability failure of the initial slope occurred in October 2007 (October being the rainiest month in Costa Rica). Because of the failure, part of the road collapsed and some of the areas of the project had no access.

The failure was a landslide, typical of the soils of this region, which are a lateritic type, with a red color. When pore pressure increases the tear strength of this type of soils reduces, and it produces movement of the soil mass. The landslide was produced because of the saturation of the soils, due to the intense and almost constant rain of the previous months.

As a solution to the landslide, it was proposed to construct a Geotextile reinforced soil slope with a facade of vegetation, using the "Green" wall methodology. It was also important to construct a drainage system at the base and the rear of the slope. For this drainage we used a Gecomposite Drain as is described in section 3.5.

A superficial drainage system was necessary over the retaining slope and the terrain beside the slope, to control and avoid infiltration of water in the slope.

3.2 Design considerations

Geometry dimensions:

- Variable heights = 3.30m, 4.00m y 6.00m.
- Maximum height = 6.00m. (This is the height critical for the design.)
- Base = 0.8H (80% of the height) = 4.80 m.
- Total length = 80 m
- Facade inclination = 70 degrees (with respect to the horizontal)

Loads:

- Surcharge Load = 19.62 kN/m^2
- Vehicle loads on the wall were considered

Fill Material: reinforced soil

The fill material must meet or exceed these conditions:

- Properties of fill material (reinforced soil):

  - Cohesion : 0.98 kN/m^2
  - Friction Angle : 28°
  - Unit weight: 16.67 kN/m^3

- Minimum requirements for fill material (reinforced soil):

  - Plasticity Index < 10
  - Maximum particle size 75mm
  - Passing sieve #200 < 25% in weight
  - Laboratory CBR > 10%
  - Tested CBR expansion 0%
  - Organic material content 0%

- Minimum requirements for the compaction of the fill material:
  - Determined optimum humidity and unit weight using the Modified Proctor
  - Compaction minimum 95% of the Modified Proctor

- Seismic acceleration in order to analyse pseudo-static = 0.20g

- Reduction factors and Overall Safety factors:
  - FR_{DI} = 1.5 for installation damages
  - FR_{CR}= 2.2 for creep
  - FR_{QD} = 1.0 for chemical degradation
  - FR_{BD} = 1.0 for biological degradation
  - FS_G = 1.3 factor of overall safety

- Reinforcement Woven Geotextiles used in design:

Woven Geotextile T2400: Class 1 – Standard Specification AASHTO M288-05
- Wide – Width resistance (ASTM D-4595) = 41 kN/m

Woven Geotextile TR4000: Class 1 – Standard Specification AASHTO M288-05
- Wide – Width resistance (ASTM D-4595) = 64 kN/m

3.3 Analysis results for internal stability

The internal stability analysis is made using in-house software for the design of soil reinforced walls. In this analysis the space between layers is defined as well as the type of Geotextile to be used and the length of Geotextile necessary for each layer. The results for the exemplar wall are:

- 13 layers of 0.20m with Geotextile TR4000
- 9 layers of 0.20m with Geotextile T2400
- 4 layers of 0.40m with Geotextile T2400

3.4 Analysis for external stability

For the analysis for external stability a number of factors must be taken into account. These factors include the, geotechnical characteristics of the foundation, backfill and reinforced soils as well as the static and dynamic conditions of the wall. For the purposes of this article, which is to highlight the overall design and construction process, the details of this stage are not important and so they are not included here.

3.5 Wall drainage and sub-drainage systems

- Wall drainage at the base and rear

  Adequate wall drainage can be achieved using a Geodrain at the rear of the wall and a drainage trench at the base. The trench should have a transverse section of 0.40 m x 0.30 m, with a perforated drainage tube of 4 inches in diameter. The Geodrain should be hung in strips 2 m wide, with 1 m spacings between the strips to prevent a failure surface at the rear. The 2 m wide strips of Geodrain should cover the full height of the wall.

- Internal wall drains

  As with other types of wall it is recommended to include internal drains in order to remove any water that infiltrates the wall. One option for the internal drains is to use strips 0.5 m wide of Geodrain, with a length that is 2/3 that of the wall base. The drains should be put each 1.50 m (both horizontally and vertically).

3.6 Facade of UV degradable sacks, vegetation and turf reinforcement mat

In order to achieve a wall facade of uniform vegetation the following steps need to be followed:

Polypropylene sacks filled with organic rich soil are used as the base for the final covering of vegetation. The placement of these sacks in the wall facade should be carried out at the same time as the compaction of each layer of soil. This option is the most economic and represents a major construction benefit as it means that it is not necessary to use formwork at any stage in the construction process.

The sacks should only be filled to a third of their volume so that the soil filled part of the sack is 0.20 m in height, 0.35 m in width and 0.30 m in depth. The quantity of organic rich soil in each sack should be 0.021 m^3 (0.20x0.35x0.20 m^3).The sacks however need to be larger than this so that there is approximately 0.50 m of sack length at one end without filling which can be used as an anchorage when the soil is compacted over it. The connection between the Geotextile and the sacks is provided by gravity, and which is guaranteed by the soil compacted over the empty part of the sack.

To use this method of construction successfully it is very important that the vegetation is installed as soon as the wall construction is complete. Sacks must not be left exposed (without the benefit of a vegetative covering) for any more than a week. To ensure the correct growth of the vegetative covering a permanent erosion control mat (Turf Reinforcement Mat) must be placed on the outer surface of the wall. The principal functions of this mat are to improve the growing conditions for the vegetation and prevent the erosion of the organic material in the sacks.

- Permanent erosion control mat (TRM435) used:

  - Tensile strength (ASTM D-6818) = 2.6 kN/m
  - Thickness (ASTM D-6525) = 8.9mm
  - Color = Green

4. CONSTRUCTION PROCESS

The following photos show the details of the construction process for our “green” retaining soil wall, reinforced with a woven Geotextile.

Figure 1. Initial state: Failure of the existing soil and road

Figure 2. Preparation of the site for the construction of the wall

Figure 3. Wall Drainage Systems

Figure 4. Installation of sacks (filled to a 1/3 of their volume with organic soil) in the façade

Figure 5. Installation of the woven geotextile and spread of the fill soil

Figure 6. Compaction of the soil: density greater than 95% of Modified Proctor

Figure 7. Facade of the wall with sacks filled with organic soil

Figure 8. Vegetation seeds installed in each sack

Figure 9. Installation of the permanent erosion control mat: TRM435

Figure 10. Vegetative state of the facade two months after construction

5. CONCLUSIONS

We have shown how "green" reinforced soil walls can be constructed from soil reinforced with Geosynthetics. An attractive vegetative facade is created by the use of UV-degradable sacks filled with organic rich soil and a permanent erosion control mat to protect the wall facade. These "green" walls are technically and economically attractive solutions for all retaining walls, but particularly for projects where the landscaping and the natural appearance of the walls is important.

From an economic perspective the walls are attractive as the cost of a reinforced soil wall is generally lower in comparison with traditional structures. Natural fill soil walls or embankments use a large amount of material in their construction but reinforced soil walls can be constructed with steeper slopes substantially reducing the amount of material needed, and so the wall cost. Whereas, when compared to rigid structure walls, the reinforced soil walls are usually cheaper due to the relative cheapness of the materials being used.

From a technical perspective the walls are attractive as all the construction materials are easily obtainable and the construction techniques used do not need any highly specialized equipment or workforce. Following the steps outlined in this article a "green" reinforced wall may be built by anyone with basic construction skills. Additionally, the reinforcement of the soil with Geosynthetics guarantees an improvement of the wall safety factor, in static and dynamic conditions, over that of a natural fill soil wall or embankment.

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