Assessing the Financial Feasibility of Slope Protection Through the use of Geocell With Recomposed of Infertile

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Abstract

Soils that have small load capacity need to have their mechanical characteristics improved in order to portray parameters that provide safety to the desired works. The geocells were developed to obtain a cellular confinement system used for reinforcement, protection and coating of slopes, similar to a beehive, which can be filled with soil, granular materials or concrete. However, the present work presents economic viability methods between the projected concrete and the geotextile. With the methodology, it was considered that the alternative use of geocell promoted savings of 35% compared to the projected concrete. The results indicated by tables that compose the projected concrete coatings and geocells were made available by the executing company. Finally, the method was applied to the soil-cement satisfactorily serving the execution, mechanical and economic aspects.

Keywords: Geocells; Slope revestment; Economic viability;

1. Introduction

The mobilities and different aspects of synthetic products succeed in stimulating the application in the great varieties of Geotechnical Engineering, assuming various roles related from mechanical characteristics such as protection, reinforcement, confinement and erosion control, hydraulic domains that stand out: drainage, soil filtration and waterproofing. It is also noted that geosynthetics present the obligation of separation avoiding the mixing of materials.

However, the handling of materials in engineering works currently obeys some type of design criterion, the particularization is made according to the assignment requested through the conditions established by the work, the basic properties are divided into: physical, mechanical and hydraulic, known geosynthetic attributions as “materials of the future”.

In sloping landfill works, the insertion of a landfill geosynthetic component provides a global division between stresses and alterations, enabling the patronage of solutions that demonstrate great difficulty and with low compacted landfill volume.

The article reports events of a work by which synthetic materials were used to explain geotechnical problems, carried out to restore a slope after its rupture. The work is inherent, convenient due to the application of various geosynthetics to an event. Restoration of the slope on the lateral surface of a landfill was carried out with a retaining wall, enveloped soil, geotextile blanket, plus compacted soil-cement to promote greater strength, improving soil mechanical performance designed to meet the primary requirement imposed by the landlord. of the work: restoration of the slope.

2. Literature Revision

In this real chapter will be foundations that refer to the addition of the study on the use of geocell occupied with concrete to harden the soil for the recomposition of the slope, with the foundation of authors who have handled or have been handling theories in order to improve the development of the project. In this theoretical foundation, the following arguments interpreted the origin of soils, tropical soils, slope, geosynthetics, geocells and projected concrete.

2.1 Soil Emergency

Soil mixtures formed by inorganic materials and organic decomposed part waste, for humans, the formation of soil there is one of the most respectable weathering products. Soils are the result of a composition between freely moving particles in intermediate spaces usually filled with water and air [1]. The founder further ensures that such behavior requires the particles that made it up as well as the chemical formation of its original rock.

According to [2], soil is considered a natural material consisting of mineral and / or organic compounds distributed in layers of varying thickness, differing from its original material by morphological, physical, chemical, mineralogical and biological genres.

[3] assure that the soil in its origin until evolution has ancestry, mainly of the weathering (rainwater and temperature), of the components that cause it of the animal and vegetal organisms that help changing the physical and chemical characteristics of the relief.

According to the author [1], debris soils are qualified by their heterogeneity, evidenced by the mother rock, resorting to their complex characterization starting from laboratory tests, an occasion in which specimens delineated from the same origin may follow different properties.

Whereas transported soils can vary greatly in structure and are more inconsolate than residual soils, and according to [4] claim to depend on different transport agents such as waterways (river and alluvium), gravitational force established with the action of the waters (runoff and talus), the force of the tides (marine sediments) and the action of the wind (wind soils).

2.2 Tropical Soils

They occur in locations that point to tropical and humid climate genres. Tropical soils are generally situated between the imaginary lines that cut horizontally from the northern hemisphere and the southern hemisphere, their properties may vary due to the geological or pedological process characteristic of humid tropical regions [5].

The behavior of tropical soils may reveal distinct reactions in relation to the hydraulic and mechanical behavior conducive to the laterization or latolization process where cations are leached, due to the large residual concentration of iron and aluminum oxide.

According to [5], lateritic conduit soils conceive in the superficial stratum of drained areas, defined by the color in which the red and yellow hues prevail. Its density can range from 2 to 10 meters.

A soil that depicts lateritic performance acquires, when condensed under ideal conditions, increased base capacity and low loss of capacity when immersed in water [6].

2.3 Taludes

According to [7], explains that the consolidation of the slope with the method applied on a slope of land, modified or natural, with the intention of improving its strength aspects, in the event of a possible weakness in the slope, necessary measures to be taken stabilization avoiding a tragic episode.

Slopes are understood as surfaces that cut off a solid earth, rock or both. According [8], they can be natural, cases of the slopes or slope, or synthetic, as the slopes of cuts and embankments. Figure 1 shows the terminology commonly adopted.

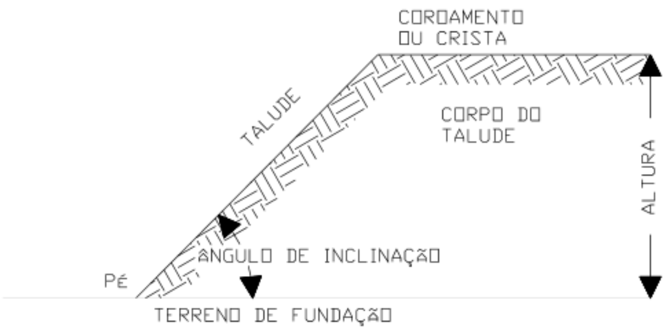

Figure 1 - Terminology usually adopted.

Source: CAPUTO (1988).

The natural slope presents an intensity in its inclination angle from a certain origin of exposed soil notorious to the time. According to [9], in soils composed of individually detached particles in the dry (non-cohesive) state, this angle practically coincides with the internal friction angle, and in cohesive soils (clays), which are quite impermeable, theoretically equals 90º.

[10] report that the vegetation layer is capable of producing favorable or unfavorable results in slope stability, for example: the presence of the canopy reduces the volume of water reaching the slope surface, the tree stems generate a preferential path. water flow, the root system can act as reinforcement and / or preferential infiltration path, the vegetation cover increases the weight on the slope.

[8] mentions that generally causes of slipping are the increase in weight of the slope (including the applied loads) and the decrease in shear strength of the material where the former is classified as external and the latter as internal.

The table pictured below in Table 1 consists of numerous problems associated with artificial and natural slopes. The many forms of its occurrence are pointed out and the essential causes influence the emergence of this problem.

Theoretically, a slope is subjected to three types of eminent forces: weight strength of its constituent materials, force due to water drainage and force due to shear strength. These three forces must be in equilibrium, as the first two add up and drive the ground mass down the slope, and the third tends to curb this movement [12].

Table 1 - Types of problems related to the slopes, forms of their occurrence and the main causes responsible for the occurrence.

TYPES OF PROBLEMS	OCCURRENCE	MAIN CAUSES
EROSION	• On slopes and embankment (In solution and differential); • Longitudinal along the platform; • Located and associated with drainage works (ravines and gullies); • Internal in landfill (piping)	• Drainage deficiency; • Surface protection deficiency; • Surface water concentration and / or groundwater interception; • Deficiency or lack of internal drainage
SURFACE DEGREGATION	• Surface stacking on cutting slope; • Superficial; • Deep; • Various shapes and dimensions;	• Drying or wetting of material; • Presence of expansive mineral clay or material deconditioning; • Steep slope of slope • Energy Relief; • Soil and rock discontinuity
CUTTING SLIP	• Superficial on natural cuts or slopes; • Deep cuts; • Shapes of varying dimensions; • Large and generalized talus body movement; • Reaching the Landfill Edge; • Reaching the landfill body	• Soil saturation; • Evolution by erosion • Talus body cut; • Drain change; • Inadequate edge compaction
LANDFILL	• Hit the landfill body;	• Foundation deficiency; • Drainage deficiency; • Surface protection deficiency; • Poor material quality; • Inadequate compression; • Slope slope.
REACH ON LANDFILL	• Vertical platform deformation.	• Foundation deficiency; • Drainage deficiency; • Manhole length; • Inadequate compression
BLOCK FALL	• • Usually in free fall	• Action of water and roots on rock mass discontinuity.
BLOCK BEARING	• Rolling block movement on natural cuts or slopes	• Erosion of the base.

Source: [11].

However, there is a technical standard that determines the conditions required for the study and mastery of the stability of slopes and consecutive slopes of cuts and embankments performed on slopes. It is [13], which also encompasses the conditions for studies, design, execution, control and observation of stabilization works.

2.4 Origin of Geosynthetics

According to [14], geosynthetics appear in the history of construction with the first attempts to reinforce soils used to stabilize marshy soils with tree trunks and small shrubs. These applications date from 3,000

BC and have advanced with the emergence of road stabilization by mixing soil or paving with stone blocks. The first citation of the use of fabric in construction was the reinforcement of road pavements in the United States in the year 1926. However, geosynthetics only began to be used systematically name of the twentieth century, after the emergence of synthetic polymers in the 1940s.

[15] reports that the evolution of soil reinforcement led to the beginning of geosynthetic production in the 1950s, due to the emergence of synthetic polymers in the previous decade. Geosynthetics therefore came to be employed due to the conversion of the textile industry in the Netherlands in the 1960s. But it was in the 1970s that geosynthetics established themselves as a building material with the emergence of needled nonwoven geotextiles.

According to [14], the motives that led to the great and rapid advance of geosynthetics were: manufactured for controlled environments; can be put in quickly and effectively, can dodge the use of raw materials (possibility of using recycled materials), circumvent the use of structures with difficult dimensions, their use is more economical than using more traditional solutions, make possible construction on soils that would not normally be considered adequate are introduced at competitive prices.

According to [16] geosynthetics are already being widely applied in various construction works. Its main reasons for its large-scale use over time include its technical advantages (speed and simplicity of application, wide range of products for various purposes), economic (low cost) and environmental (low environmental impact). Thus geosynthetics have become a great alternative to traditional building materials.

[15] reports that the evolution of the geosynthetic industry in recent years has led to an increase in supply and investment in various types of materials such as geotextiles (woven, nonwoven and knitted), geogrids, georedes, geomembranes, geocomposites and geocells. , among others. As a result, geosynthetic functions have expanded, such as drainage, filtration, protection, reinforcement, separation, surface erosion control and fluid barrier.

2.5 Geosynthetic Classification

According to [17], there were approximately five to six types of geosynthetics in 1970, however at the moment there are over 600 distinct geosynthetic products marketed worldwide. Recently, geosynthetics are most frequently acted on reinforced massifs are woven and nonwoven geotextiles, geotiras, geogrids, and tough geocomposites [18].

[19] describes the classification and certainty of the main types of geosynthetics detected in the market, among them are:

a. Geogrids - Flat open mesh composed of tensile-resistant elements joined together.

b. Geotextile - permeable, textile and flat material produced by synthetic or natural polymer. May be divided into fabric, non-woven, or knitted.

c. Geocell - Three-dimensional hexagonal-shaped polymeric structure composed of connected geosynthetic strips.

d. Geomembrane - also known as geosynthetic barrier (GBR), is used to prevent or limit fluid percolation as it has low permeability. It can be polymeric, clayey, bituminous or composite..

e. Georedes - parallel elements superimposed and interconnected with similar elements in several angles.

f. Geotubes - smooth or corrugated, rigid or flexible, perforated or grooved pipe used as conductive and draining element. Also known as geosynthetic drain pipe.

g. Geomanta - permeable, three-dimensional structure composed of interconnected elements. Also known as geofiber.

h. Geocomposite - formed by overlapping materials where at least one of them is geosynthetic.

2.6 Geosynthetic Employment Employment

For each and every geotechnical work that points out problems of rupture by soil shear, there is a need for the benefits of geosynthetics as reinforcement elements [20]. Works that lack containment structures, floor reinforcement works and staked embankments on soft soils are typical cases that require the use of geosynthetics conducive to their high strength [20]. [21] summarize the different functions that each of the major geosynthetics can perform in engineering as shown in Table 2.

Table 2 - Functions of geosynthetics employed in engineering.

Geosynthetic	Separation	Protection	Filtration	Drainage	Erosion	Reinforcement	Waterproofing
Geotextile	X	X	X	X	X	X	X
Geogrid	X	-	-	-	-	X	-
Geomembran	X	-	-	-	-	-	X
Geode	-	X	-	X	-	-	-
Clay Geocomposit	-	-	-	-	-	-	X
Geocell	-	X	-	-	X	X	-
Geotube	-	-	-	X	-	-	-
Geofiber	-	-	-	-	-	X	-

Source: [21].

The guidelines for geosynthetics used in performance-compliant works must be adhered to, suppliers deliver products to the specifications of the designers, and builders purchase products that meet these requirements, and designers specify both geosynthetics quantitatively and qualitatively. with the technical standards [21].

2.7 Geocell

In the late 1970s and early 1980s, geocells were created to support military vehicles on weak subgrade terrain [22].

The disclosed material has been prepared with the main desire to add low-resistance soil carrying capacity [23]. For [14], the geocell has as its operating source the resistance created by the lateral confinement of a load and the friction of the cell walls with the filler material, making shear breakage and lateral movement of the materials impossible.

Geocells can be produced “on site”, with the advantage of being able to dimension the desired height and length [24]. The global charge transmission system in the geocell as shown in Figure 2 works by combining cell wall resistance, passive filler resistance in adjacent cells and the frictional interaction between the filler soil and the cell walls.

Figure 2: Geocell composition: (a) High density polyethylene; (b) Polypropylene.
Source: [25].

In the manufacture of geocells there is a standardization between cell width (l) and height (h). The heights often encountered are 50, 75, 100, 150 and 200 mm. In general, when expanded, they have plates with an area of around 2.60 x 3.00 m for the minimum size and 2.60 x 6.00 m for the largest [26].
When adopting a filler material for geocells, one tends to take into account the hydraulic, environmental conditions of the supporting ground beyond the site and purpose of the work. In case of steep slopes it is feasible to fill the geocells with soil, vegetation, concrete or mortar, while for soft slopes it is possible to use sand as filler material [27].
For ENGEPOL, geocell filler materials are divided into:

- Granular material: Provides increased erosion resistance by preventing migration of downstream particles by the action of gravity and water flow. It is characterized by being flexible and durable..
- Plant material: Reinforces the soil through rooting, contributing to increased natural resistance to erosion as well as directing water flow over vegetation and reducing moisture loss..
- Concrete: As a flexible lining, the geocell provides controlled concrete cracking and piping control as cells follow the movement of the supporting soil to conform to it. Concrete filling for steep slopes and channel lining is recommended [27].

The knowledge of the geosynthetic relationship with the soil is deeply valuable, a circumstance in which the mechanical characteristics of a reinforced soil reflected the action of the mechanisms of coexistence of the constituent materials, distributing the tensions inside the set.
Increased resistance in the geocell benefits three distinct mechanisms; the confinement effect, the slab effect and the membrane effect. They are generated by the same loads applied to the ground. Although each mechanism can be verified in its own way, they are interrelated and act jointly, improving soil carrying capacity [23].
The confinement effect performs the function in two ways as shown in Figure 3, the first function is by expanding the resistance and minimizing the deformability of the geocell filler material, which is earned by the cellular mold of the geocells, in which the confining stresses in its filler material increases, leading to a compression of this material into the cells, compacting them, resulting in better strength conditions.
The second is through dissipation of the applied charges, where the induction of horizontal tensions from within the cells is distributed and shared between adjacent cells by mobilizing the passive resistance of the confined material [28]. The benefit of the confinement effect is that its process does not differ in the ground

displacements of the foundation, but in the congruent in the transmission of forces to the filler, and between it and the cell walls, as well as the strength and stiffness of the geocell. and your seams [28].

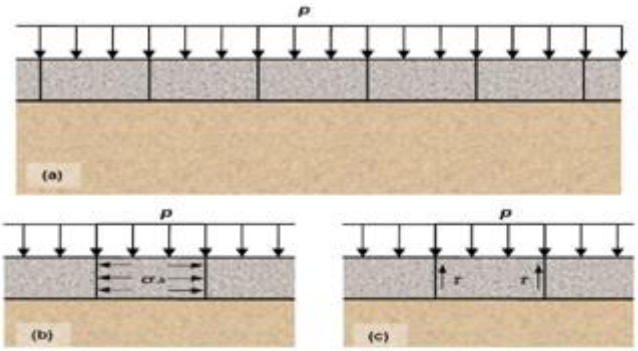

Figure 3 - Illustrative scheme of the confinement effect: (a) application of loading, (b) induction of horizontal stresses within the cell; (c) mobilization of shear stresses at the interface between the filler material and the cell wall.
Source: [23].

3. Materials and Methods

3.1 Study site

The study was developed at Av. Constelação, Aleixo neighborhood, next to the Amazon Network group as shown in figure 4, the main objective was to evaluate the financial viability of steep slope protection by using the geocell with recomposition of infertile material.

Figure 4 - Aerial view with the location of the work under study
Source: [31].

3.2 Materials Used

From the outset when the research study compares the financial feasibility analysis for slope surface protection between projected concrete and geocell reinforcement, it needed to determine the type of materials it integrated into its fill.

3.2.1 Geocells

Geocells, as they refer to manufactured geosynthetics, have a huge range of variations in their own material, such as: geometric (cell width and height) and composition material. StrataWeb geocells were used, whose material is made of high-density polyethylene (HDPE), model SW712 7.5 cm high. The properties of geocells are shown in figure 5.

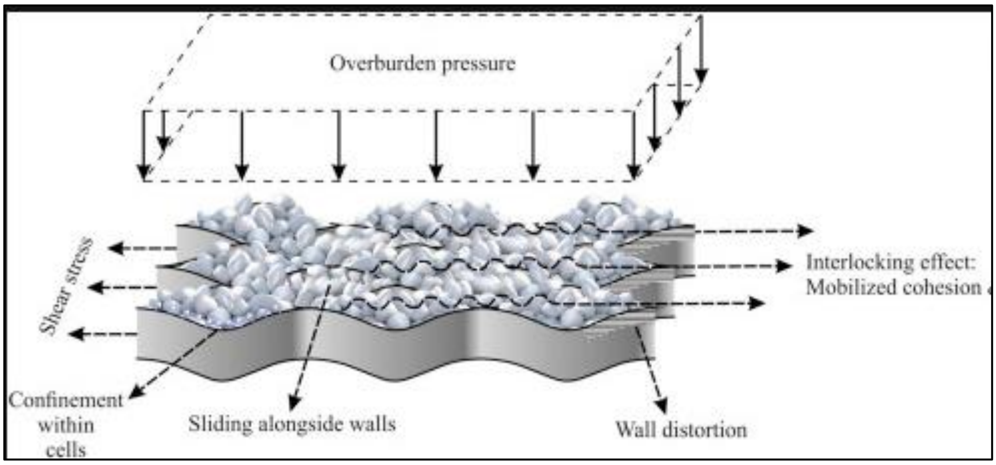

Figure 5 - Geocell technical properties
Fonte: Adapted from [29].

3.2.2 Cement

The executing company has chosen to use MIZU's Portland CP IV 32 RS cement due to its characteristics such as: higher final strength, quick grip, sulfate attack resistance (RS), low hydration heat and operational structure safety and efficiency handling and use, providing functional advantages of the product.

3.2.3 Clay

The clay being a natural material, fine grained, earthy texture with particles of fibrous or lamellar form, due to the clay-minerals, the clays in the water company grow a series of peculiarities such as: resistance, wet mechanical plasticity, shrinkage. drying, compacting and viscosity of aqueous suspensions that explain its wide range of technological applications.
Most of the clay adopted showed no trace of vegetation, an orange hue, as shown in Figure 6.

Figure 6 - Bucket discharging clay.
Source: Author.

3.2.4 Woven geotextile

The geotextile blanket known as bidim has become a useful material for construction, very conducive to its ability to accommodate various environments and the performance of various functions, such as the material is basically made of high quality fibers of polyester or polypropylene, Simple to handle and apply the geotextile blanket is ideal for works of various sizes, so the executing company chose the blanket as shown in figure 7.

Figure 7 - Woven Geotextile Blanket
Source: [30].

3.3 Solution Method.

3.3.1 Slope Rebuild.

For the reconstruction of the slope, all the soil was removed with the heterogeneous vegetal layer keeping at an oblique angle with the help of a backhoe, enabling the most favorable place to start the journey in the reconstruction of the slope as shown in the figure. 8th.

Figure 8 - (a) Moment before part of the slope falls; (b) view from another angle of the slope.
Source: Author.

The soil reconstitution process needed to carry out structural reinforcements such as excavated piles with a diameter of 30cm, where at the top a depth of 8 meters and at the bottom 4 meters were used Ø16mm gauge CA-50 steel and a retaining wall meters high with structural blocks to prevent infiltration-related disasters a horizontal drainage system with Ø75mm PVC pipe was made in the containment.

The problem with soil arises during its replacement, so it was carried out in 2 stages. In the first stage, the clay had a simple process, where every 60cm of clay placed at the site of the removed soil was compaction by means of a manual equipment and then covered by a geotextile blanket, a process that repeated until reaching height of the retaining wall. In the second stage, because the slope is very oblique, a soil-cement technique was used. After carrying out several test sequences with different soil types, they agree that increasing the cement content results in increased compressive strength and, consequently, durability regardless of the desolation.

Soil-cement are some of the low cost alternative materials, acquired by melting soil, cement and some water, in appropriate measures as shown in figure 9. In the creation of material, this mixture resembles a damp "crumbly" and , after compaction and cure, it hardens and over time gains consistency, the figure shows the elaboration of the cement soil.

Figure 9 - Soil-cement process; (a) Four 42.5kg bags of Portland CPII cement and approximately 4.2m³ of clay were used; (b) Mixing process between materials.
Source: Author.

Due to anthropogenic changes, associated with climatic conditions and an inspection with the area decisions for the control of water flow and flow with intuitive taming of the waters on the slopes, a 40cm half-cane channel drainage system was constructed between the retaining wall and the slope, a masonry retarding box was assigned before the public drainage system with the help of Ø150mm PVC material pipes.

The Geotextile mat, having ideal filtration properties and lower cost geomembrane protection with longer life in the impermeability system, determined that it would be applied to the soil-cement after compaction fixed with small clamps.

The geocells were installed on the geotextile blanket so that it covered the entire slope to the channel, to immobilize the geocells, initially established the area and soon after the four edges were fixed by staples or stems in the ground as shown in the figure. 10. In the process of filling the geocells with machined concrete of 20 Mpa obtained as a help a pump carriage and some collaborators who handled the hose and others performed the finishing on the surface.

Figure 10 - (a) application of geotextile over the slope after compaction; (b) fixation of geocells and then application of machined concrete.
Source: Author.

4. Results and Discussions

Prior to the implementation of the slope protection, the site management together with the company coordination performed a cost study comparing the systems suggested by the project author.

The processes compared were the use of machined concrete fill geocells and dry-cast concrete where all costs for such executions were included, values such as equipment leases, supplies of necessary materials as well as additional services after completion of the step such as fine cleaning and paint recovery as shown in table 3.

Table 3 - Composition for projected concrete coating

Item	Input	Und	Qnt.	Value Unit. (R$)	Value Total (R$)
01	TELCON CA-60 SCREEN FRAME Q-138	m²	446,4	13,81	6.164,78
02	DESIGNED CONCRETE 20MPa E = 5cm	m³	22,32	450,74	10.060,52

03	(MATERIAL + EQUIPMENT)	m²	446,4	60,00	26.784,00
04	CONCRETE DESIGNED - LABOR (LAUNCH)	VB	1	3.500,00	3.500,00
05	EQUIPMENT MOBILIZATION AND DEMOBILIZATION	m²	135	16,00	2.160,00
06	ACRYLIC PAINTING - NEAR BUILDINGS	m²	195	8,20	1.599,00
				Value TOTAL (R$)	**50.268,30**

Source: Executing Company (2019).

Due to the geometry and characteristics of the slope, the practical regulations on admission of the geocells and the low cost as shown in table 4 have been replaced by filter-capable fabric geocells.

Table 4 - Composition for geocell coating.

Item	**Input**	**Und**	**Qnt.**	**Value Unit. (R$)**	**Value Total (R$)**
01	GEOCELL	m²	446,4	19,15	8.548,56
02	GEOTEXTILE BLANKET	m²	892,8	4,50	4.017,60
03	STEEL WIRE 10mm - CLAMPS	Kg	185,1	6,13	1.134,66
04	MACHINED CONCRETE 20MPa - SUPPLY	m³	31,25	385,00	12.031,25
05	MACHINED CONCRETE 20MPa - LAUNCH	m³	31,25	160,01	5.000,31
06	GEOCLEULA MOUNTING AND FIXING AND GEOTEXTILE MAT	m²	446,4	4,80	2.142,72
				VALUE TOTAL (R$)	**32.875,11**

Source: Executing Company (2019).

From the quantitative material surveys it is possible to determine the total cost for each type of coating as shown in table 5.

Table 5 - Comparison between slope coating systems.

Item	**SYSTEM**	**VALUE TOTAL (R$)**	**VALUE UNIT. (R$)**	**DIFFERENCES BETWEEN SYSTEMS**	
				VALOR	PORCENTAGEM
01	DESIGNED CONCRETE COATING	50.268,30	112,61	**R$ 38,96**	**34,60%**
02	GEOCELL CLEANING WITH CONCRETE PREVENTION	32.875,11	73,65		

Source: Author (2019).

Through the results, it was possible to compare economically the solution presented and conclude that the techniques would meet the slope conditions and also economic, increasing the profit margin of the contractor. Geocell-coated slope protection solution becomes more viable than projected concrete coating.

6. Final Considerations

In this paper a technical and cost analysis of the geocell use for slope protection was conceived. Choosing a mechanical protection process should involve all studied and efficient solutions, budget checking varies considerably, resulting in a weighted topic when it comes to solution preference.

One of the objectives to be highlighted is that the costs raised refer to one square meter of the slope. Thus, the cost divergences between the solutions tend to be numerous, when enlarged by the proportion of a given work. However, financial feasibility studies are key and reputable in order to extend parameters when choosing the most appropriate circumstances.

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