A laboratory evaluation of soil loss caused by rain in slopes with and without geomats

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ABSTRACT

Water is the main triggering agent of erosive processes in slopes. Some types of geosynthetics can be used to protect slopes, minimizing soil transport along the slope face. The study of surface erosion triggered by rain precipitation along the face of a slope can be carried out in the laboratory using rain simulator equipment. For the purpose of evaluating the amount of soil loss in a slope subjected to rain precipitation, laboratory tests were carried out in such equipment with controlled intensity and uniformity of the rain. Also, a verification of the grain size variation of the soil eroded using a laser grain size analyzer was carried out during the tests. Four types of geosynthetics materials were used. Geomat 1 was manufactured with coconut fibers, a degradable polypropylene mesh and a reinforcing screen. Geomat 2 was also manufactured with coconut fibers and a degradable polypropylene mesh. Geomat 3 was composed by natural straws and Geomat 4 consisted of a flexible mat with a metallic reinforcement. The rainfall simulation tests were performed on a segment of a slope inclined 25° with the horizontal. The soil specimens dimensions were 1.0 m x 1.0 m x 0.15 m. Tests on protected and unprotected soil were conducted. Soil losses were measured during the test at 10 minutes intervals. The results obtained show the effectiveness of soil protection against surface erosion and identifies the main factors affecting the performance of the system.

RESUMO

A água é o principal agente desencadeante de processos erosivos nas encostas. Alguns tipos de geossintéticos podem ser usados para proteger encostas, minimizando o transporte do solo ao longo da face do talude. O estudo da erosão superficial desencadeada pela precipitação da chuva ao longo da face de um talude pode ser realizado em laboratório usando um equipamento simulador de chuva. Com o objetivo de avaliar a quantidade de perda de solo em um talude sujeita a precipitação de chuva, foram realizados testes laboratoriais em tais equipamentos com intensidade e uniformidade controlada da chuva. Além disso, foi realizada uma verificação da variação do tamanho de grão do solo erodido usando um analisador de tamanho de grão a laser durante os testes. Foram utilizados quatro tipos de materiais geossintéticos. O Geomat 1 foi fabricado com fibras de coco, uma malha de polipropileno degradável e uma tela de reforço. O Geomat 2 também foi fabricado com fibras de coco e uma malha de polipropileno degradável. O Geomat 3 foi composto por palhas naturais e o Geomat 4 consistiu em uma geomanta flexível com reforço metálico. Os testes de simulação de chuva foram realizados em um segmento de uma inclinação inclinada 25° com a horizontal. As dimensões dos corpos de prova foram 1,0 m x 1,0 m x 0,15 m. Testes em solo protegido e desprotegido foram realizados. As perdas de solo foram medidas durante o teste em intervalos de 10 minutos. Os resultados obtidos mostram a eficácia da proteção do solo contra a erosão da superfície e identificam os principais fatores que afetam o desempenho do sistema.

1. INTRODUCTION

1.1 Surface Erosion

Exposed slopes are susceptible to erosive processes caused by rain precipitation. Installed erosion processes can be minimized or even avoided by installing a protective system on the slope surface. Several types of slope surface protection systems can be used, some of them incorporating geosynthetics.

According to Marques & Geroto (2015), the prevention of surface erosion is always indicated due to the high costs involved for the correction of problems due to erosive processes. As for prevention measures, there is the implementation of surface drainage, regularization and protection of areas of steep slopes, planting of vegetation and use of concrete structure. Geosynthetics can also be used in works against erosion.

The surface flow generated by rainwater runoff is directly related to the amount of water infiltration into the soil, the more water is infiltrated into the soil, the lower the surface flow. The action of surface erosion is characterized by the uniform removal of the soil along the slope and, depending on the slope, grooves can appear altering the erosion evolutionary stage (Camapum de Carvalho et al. 2006).

Real erosion, as stated by Cancelli et al. (1990), is caused more by runoff than by direct rainfall. In laboratory studies, rain simulation should take into account the flow mechanism for the analysis of erosion phenomena, which is the best way to study this phenomenon both qualitatively and quantitatively.

Menezes & Pejon (2010) state that erosive processes depend on intrinsic soil properties, infiltration and absorption capacity for different moisture contents, and that soil water retention capacity determines the degree of infiltration.

The erosion caused by rain and the consequent loss of soil from the slope is triggered by the detachment of the soil and its immediate transport, generated by raindrops impact (Touze-Foltz & Zanzinger 2016).

1.2 Rain Simulation Tests

To analyze soil behavior in a slope subjected to precipitations, rain simulation tests can be performed in laboratory considering the slope in the exposed condition and with different geosynthetic protection systems. In the field, solutions can be installed on the slope faces to verify and prove their efficiency.

Rain simulators are used for studies of runoff, infiltration and erosion processes. In this type of test the determination of rainfall specifications is important in order to characterize and control the duration of the event, the distribution of droplet sizes, the speed and intensity of the simulated rain and the quantification of eroded soil.

According to Thomaz & Pereira (2014), rain simulators vary in size, physical characteristics of the simulated rain and wetness and are often built to meet the specific needs of the job or research, with variations in the costs involved in their fabrication and operation.

Rain simulators used in laboratory tests have the advantage of controlling the factors that trigger the erosion process, making it easier to use the soil and to compare the results, as well as to perform a large number of tests (Touze-Foltz & Zanzinger 2016).

Smets et al. (2011) conducted a research with field and laboratory rain simulator trials using different types of geosynthetics and found that, despite some limitations to represent actual field conditions in the laboratory, the experiments presented results similar to those obtained in the field with regard to runoff rate and soil losses.

In a rain simulation tests performed by Thomaz (2012) indicate that, the tests that were done make the same effect of transportation of sediment as the natural event.

1.3 Geosynthetic Materials

Geosynthetics can be used in virtually any surface protection work due to the many types and technologies available. According to Costa et al. (2015), more than one type of geosynthetic can be used, depending on the work or project in question, combining the action and function of each of them in applications in geotechnical works. With the use of geosynthetics, costs and construction times can be reduced in comparison with conventional solutions.

The methods to make the control of superficial erosions can be the geosynthetic, acting in the stress distribution, avoiding deformations in the slopes and increasing the deformations of earth mass. This is because the geosynthetic makes a reduction of the localized stress, by equalizing the level of the layer or surface of stress, providing an adequate resistance to mechanical installation damages and dissipation of the stress generated (Giribola 2014).

When used for erosion control the geosynthetic product must retain the fine fraction of the transported soil or sediment and reduce runoff velocities and surface flow stresses (Marques & Geroto 2015).

Barrela (2007) states that: the geosynthetic in the erosion control function also acts as reinforcement, protection and sealing of the ground, controlling the detachment and flow of materials with due to the blockage or deviation of surface flow.

According to the results of erosion and runoff tests conducted by Cancelli et al. (1990), the effective function of geosynthetic is also soil confinement, avoiding localized slides. This is because geosynthetic materials provide a uniform distribution of runoff water so that the water flow is not strong enough to produce deep furrows, as would occur in unprotected soils.

In their studies Fernandes et al. (2009) comments that in tropical countries, such as Brazil, there is a need to improve methods for slope cover. According to the authors, studies and researches are essential for improving the use and efficiency of erosion control solutions to minimize environmental impacts caused on soil surfaces exposed to erosive processes.

In the studies made by Smets et al (2011), found that rain falling on geosynthetics contributes directly in a decrease of runoff depth, comparing with a unprotected soil.

2. MATERIALS AND METHODS

2.1 Geosynthetics

Four types of geosynthetics (Geomats 1 to 4) were used in the present research work, which are presented in Figure 1. Geomat 1 was made with coconut fibers, a degradable polypropylene mesh and a reinforcement mesh. Geomat 2 was also made from coconut fibers and a degradable polypropylene mesh. Geomat 3 was made with natural straw and Geomat 4 consisted of a flexible mesh with a metallic reinforcement. Table 1 shows some properties of the geomats used in the rain simulation tests.

Figure 1 - Details of the geomat used in the survey.

Table 1 - Properties of geomat used in the rain simulation tests.

Properties	Geomat 1	Geomat 2	Geomat 3	Geomat 4
Grammage (g/m²)	400	400	400	520
Tensile Strength (kN/m)	0.69	0.70	0.38	3.00

2.2 Soil

The soil used in the research was taken from slopes located in one of the adduction channels of Simplício Dam / Eletrobras Furnas. This dam is located on the border of the states of Rio de Janeiro and Minas Gerais.

The slopes from which the soil was extracted are located in the city of Sapucaia – RJ. According to information from Brasil (1983), the area is predominantly composed by soils with association of Red Acrisols + Red-Yellow Ferralsols.

Tests were performed to determine the geotechnical characteristics of the soil and some of these characteristics are presented in Table 2.

Table 2 - Geotechnical characteristics of the soil used in the tests

Dry density in situ (g/cm³)	Atterberg Limits		Compaction test	
	Liquid limit (%)	Plastic limit (%)	Maximum dry density (g/cm³)	Optimum water ratio (%)
1.38	44	27	1.69	17.8

2.3 Rain Simulation Equipment

This research used a portable rain sprinkler simulator; this equipment was developed by Mendes (2016) to reproduce artificial rainfall with characteristics similar to an actual rain. The equipment allow several possibilities for each type of test, such as slope inclination, spray height, intensity and uniformity of the rain etc.

Therefore, the equipment analyzes the slope runoff taking into account the slope factor, the soil water infiltration rate and the eroded material, and is composed of four parts: a metallic structure, an acrylic box, a hydraulic system and the automation system. The slope inclination can vary up to 45°. In the present study an inclination of 25° was used to avoid soil layer instability. Figure 2 shows an overview of the equipment.

The acrylic box to accommodate the soil layer has dimensions of 1.0x1.0x0.15 m, corresponding to its length, width and depth, respectively, and was made with 10 mm thick acrylic plates. In the lower part of the acrylic box there is a collector gutter that collects the eroded sediments after rain simulation. The gutter has six exits for sediment outflow, and the sediments are transported to reservoirs through plastic pipes (Figs. 2 and 3).

Figure 2 - Overview of the rain simulator equipment.

The rain was generated using a square spray sprinkler at a pressure of 70 kPa, with a rain uniformity coefficient of 70% and an intensity of 131 mm/h. The duration of the test was 1 hour. These rainfall parameters were determined before the rain simulation test were performed.

For each test the soil was compacted in the acrylic box in two layers. Tests were carried out to control the density of the compacted soil.

Firstly, a reference test was performed on the unprotected soil surface. Then tests were performed using the different mats described above. Figure 3 shows the water flow on the surface of the unprotected slope.

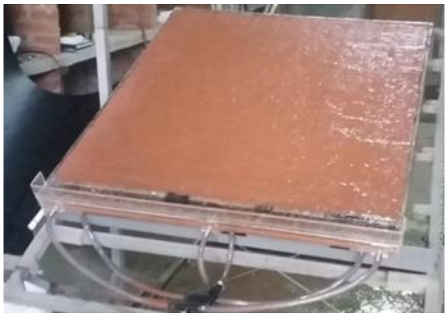


Figure 3 – Surface flow on the unprotected slope

2.4 Laser Particle Size

Specimens of eroded soil particles for grain size analyses were collected every ten minutes during the test. A Mastersizer 2000 - Malvern laser grain size analyser was used to obtain the grain size distribution of the eroded soil particles.

3. RESULTS

3.1 Rain Simulation Tests

Eroded soil and runoff water volume during the rain simulation test were assessed every ten minutes. All tests were performed under the same conditions of rain and for the same slope. Figure 4 shows the variation of accumulated soil loss with time during the one hour rain period. Under such conditions geomats 1 and 2 were the ones the performed best with regard to the reduction of soil loss.

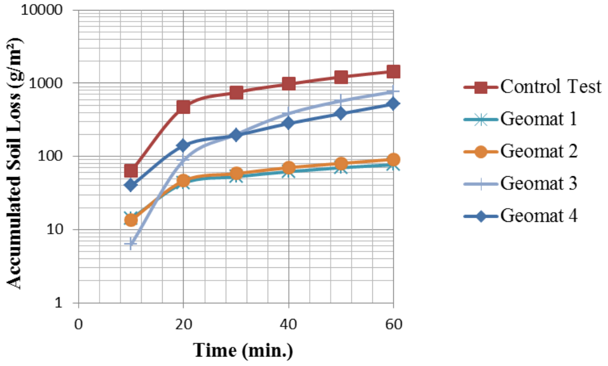


Figure 4 - Accumulated soil loss versus time during the test.

Figure 5 shows the total soil loss per unit area obtained for each protection material. In comparison with the result obtained in the reference test, it can be noted that the geomats were effective in reducing soil erosion. The most efficient mats were Geomat 1 and Geomat 2. Geomat 3 presented the worst performance, with 47% efficiency compared to the soil loss observed in the test on the unprotected soil.

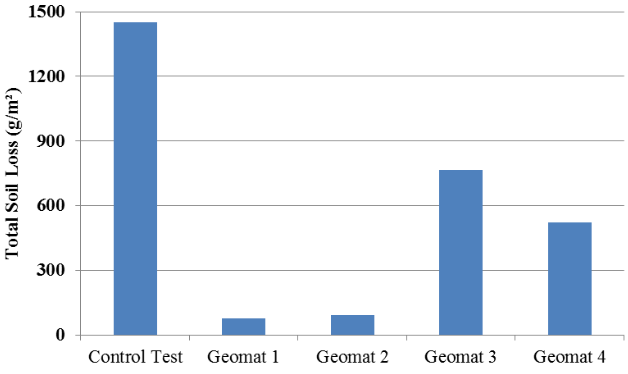


Figure 5 - Total Soil Loss from Rain Simulation Test.

3.2 Grain Size Analyses

Grain size analyses were carried out on the eroded soil. In terms of grain size, it was found that the highest percentage of carried material was composed of silt, followed by sand, as shown in Table 3. This result is consistent with the grain size distribution of the natural soil before the tests. In the soil tested is composed by 53.1% of silt, 42.7% of sand and 4.2% of clay. In the unprotected soil condition, the percentage of silt in the eroded mass was smaller than in the protected slopes, but still higher than the other soil fractions, as shown in Table 4.

Table 3 - Relative particle size distribution of eroded particles in protected slopes.

Soil Protection	Relative Composition (%)					
	Time 10 min.			Time 60 min.		
	Sand	Silt	Clay	Sand	Silt	Clay
Geomat 1	16.24	77.69	6.07	15.27	78.50	6.23
Geomat 2	21.33	73.92	4.75	21.75	73.45	4.80
Geomat 3	17.24	77.78	4.98	38.68	56.93	4.39
Geomat 4	23.41	71.80	4.79	32.16	63.25	4.59

Table 4 - Relative particle size distribution of eroded particles in an unprotected slope.

Soil Condition	Relative Composition (%)					
	Time 10 min.			Time 60 min.		
	Sand	Silt	Clay	Sand	Silt	Clay
Unprotected Soil	37.45	58.20	4.35	30.78	64.20	5.02

With the protection of the soil surface with the geomats, the amount of material carried in the sand fraction was smaller than for the bare soil condition. Thus, the geomats prevented the removal of coarser granular material. The percentage of silt was higher when the soil was protected by geomats compared to the soil without protection. It is noteworthy that this behavior can be explained because the bare soil is more exposed to splash kinetic energy, as well as the effect of runoff, which contributes to the transportation of larger particles such as sand particles.

In addition, Geomats 1 and 2 presented, respectively, greater uniformity in the experiment in relation to the different rainfall times (10 min - 60 min), which demonstrates better effectiveness of these mats compared to the others. Geomat 1 showed almost no variation in soil loss for different durations of the test (Table 3). Such behavior can be explained by the smaller spacing between coconut fibers.

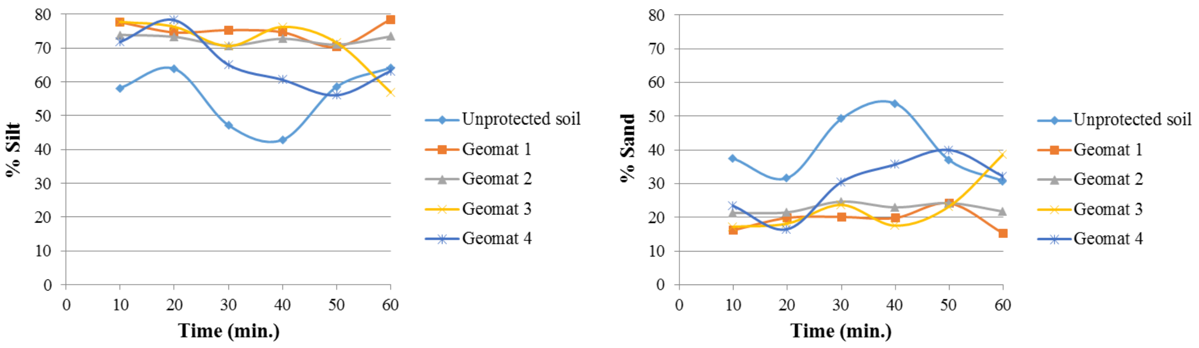
Despite smaller total soil losse, the test with Geomat 1 presented slightly greater clay loss than in the tests with the other geomats (Table 3). The clayey soil fraction is the one which presents colloidal characteristic, which is responsible for the soil chemical activities together with the organic matter (Lepsch, 2011).

Cohesion in clayey soils decreases erosion susceptibility in these soils. Sandy fractions, especially in the coarse sand range, show large porous spaces and are also less likely to be transported by runoff or detached by the splashing effect. Thus, the grain size ranges most prone to transportation are silt and fine sand, because both do not have the cohesive characteristics of clays, nor the weight of coarse sands (Bertoni & Lombardi Neto , 2010).

A comparison was made with soils by Bertoni and Lombardi Neto (2010), as the soil grain size distribution is a major factor to soil loss, mainly related with the structure. Was found that clay textures in granular soils such as Ferrasols, have a better physical condition, so they have a better resistance to water erosion than Acrisols.

Was made a comparison with soils in the region of Bertoni and Lonbardi Neto (2010), as the soil grain size distribution is a major factor to soil loss, was found that clay textured and granular soils such as Ferrasols have a better physical condition, so they have a better resistance to water erosion than Acrisols witch have clay increment in its B horizon.

Figure 6 presents the variation of silt and sand fractions in the eroded material with time. For times greater than 50 minutes the results obtained in the tests with Geomat 3 and Geomat 4 were close to those obtained in the test with the unprotected slope.



a) b)

Figure 6 - Percentage of silt (a) and sand (b) found in the eroded material during the tests.

4. CONCLUSIONS

This paper presented a study on the use of geomats for the protection of slopes subjected to rainfall. To accomplished this an equipment was constructed and tests on protected and unprotected slopes were performed. In general, all four geomats tested reduced the amount of soil eroded. In this context, Geomats 1 and 2 were the most effective ones in reducing surface erosion.

Although the amount of material eroded was also smaller in the tests with Geomats 3 and 4 in comparison with the test on the unprotected slope, these mats did not perform as well as Geomats 1 and 2. The latter mats also resulted in greater uniformity with regard to the grain size distribution of the eroded soil particles.

Further studies are in progress to a better understanding on the use of geosynthetics for the protection of slopes subjected to erosion caused by rainfall.

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5.1 REFERENCES

BARRELA, C. (2007). Aplicação de Geossintéticos no Controlo da Erosão Superficial e Costeira. Relatório 206/2007 – NGE, LNEC, Departamento de Geotecnia, Núcleo de Geologia de Engenharia, Lisboa, Portugal, 51p.

BERTONI, J. & LOMBARDI NETO, F. (2010). *Conservação do Solo*. Ícone, 7ª Edição, São Paulo, SP, 355p.

BRASIL (1983). Folhas SF. 23/24, Rio de Janeiro/Vitória: geologia, geomorfologia, pedologia, vegetação, uso potencial da terra / Projeto RADAMBRASIL. Ministério das Minas e Energia, Secretaria Geral, Rio de Janeiro, RJ, Volume 32, 775p.

CAMAPUM DE CARVALHO, J., SALES, M. M., SOUZA, N. M. & MELO, M. T. S. (2006). *Processos Erosivos no Centro-Oeste Brasileiro*. Universidade de Brasília, Editora FINATEC, Brasília, DF, 464p.

CANCELLI, A., MONTI, R. & RIMOLDI, P. (1990). Comparative Study of Geosynthetics for Erosion Control. *4th International Conference on Geotextiles*, Geomembranes and Related Products, The Hague, Netherlands: 403 – 408.

COSTA, A. H., LOPES, G. A., SOUSA, L. B., PIMENTEL, L. A. S. & ARÊDES, P. H. A. (2015). Versatilidade dos Geossintéticos Aplicada à Engenharia. *XII Simpósio de Excelência em Gestão e Tecnologia*, AEDB, Resende, RJ, 1 – 13.

FERNANDES, L. S., GRIFFITH, J. J., FONSECA, D. M., DIAS, L. E. & RUIZ, H. A. (2009). Uso de Geomantas no Controle da Erosão Superficial Hídrica em um Talude em Corte de Estrada. *Revista Brasileira de Ciência do Solo*, 33: 199-206.

GIRIBOLA, M. (2014). Como Comprar Geossintético. Construção Mercado Negócios de Incorporação e Construção, Edição 154, PINI. Disponível em: < http://construcaomercado.pini.com.br/negocios-incorporacao-construcao/154/artigo311000-1.aspx >. Accessed on 25 Aug. 2016.

LEPSCH, I. F. (2011). *19 Lições de Pedologia*. Oficina de Textos, São Paulo, SP, 456p.

MARQUES, A. C. M. & GEROTO, R. E. (2015). *Aplicações em Controle de Erosão Superficial. Manual Brasileiro de Geossintéticos*, J. C. VERTEMATTI (eds), 2ª edição, Editora Edgar Blücher, São Paulo, SP, pp. 421-456.

MENDES, T. A. (2016). Desenvolvimento de Simulador Portátil de Chuva por Aspersão para Avaliação do Coeficiente de Escoamento Superficial de Solo Vegetado para Fins Geotécnicos. Seminário de Geotecnia, Faculdade de Tecnologia, Programa de Pós-Graduação e Geotecnia, UnB, Brasília, DF.

MENEZES, M. B. M. & PEJON, O. J. (2010). Análise da Influência do Teor de Umidade na Absorção D'água e Sucção dos Solos em Estudos de Erodibilidade. *Geociências*, UNESP, São Paulo, 29(2): 211-228.

SMETS, T., POESEN, J., BHATTACHARYYA, R., FULLEN, M. A., SUBEDI, M., BOOTH, C. A., KERTÉSZ, A., SZALAI, Z., TOTH, A., JANKAUSKAS, B., JANKAUSKIENE, G., GUERRA, A., BEZERRA, J.F.R., ZHENG YI, PANOMTARANICHAGUL, M., BÜHMANN, C. & PATERSON, D. G. (2011). Evaluation of Biological Geotextiles for Reducing Runoff and Soil Loss Under Various Environmental Conditions Using Laboratory and Field Plot Data. *Land Degradation & Development*, 22: 480–494.

THOMAZ, E. L. & PEREIRA, A. A. (2014). Performance Assessment of a Microsprinkler. *Acta Scientiarum. Technology*, Universidade Estadual de Maringá, Maringá, PR, 36(2): 315-321.

THOMAZ, E. L. (2012). Runoff and Sediment Transport in a Degraded Area. *Revista Brasileira de Ciência do Solo*, 36(1): 243-252.

TOUZE-FOLTZ, N. & ZANZINGER, H. (2016). Laboratory Tests for Evaluating the Performance of Geosynthetics for Surface Erosion Control. *European Geosynthetics Conference, EuroGeo 6*, IGS, Ljubljana, Slovenia, 10p.