GEOTEXTILE SEDIMENT BARRIERS FOR EROSION CONTROL IN TROPICAL SOILS

Ennio M. Palmeira[1], Rideci J.C. Farias[2] & Jose C. Carvalho[3]

[1] *University of Brasilia., Brasilia, DF, 70910-900, Brazil (e-mail: palmeira@unb.br)*
[2] *Brazilian Environmental Institute-IBAMA, Brasilia, DF, Brazil. (e-mail: rideci.farias@ibama.gov.br)*
[3] *University of Brasilia. Brasilia, DF, 70910-900, Brazil (e-mail: camapum@unb.br)*

Abstract: Erosion can cause significant damages to the environment as well as to construction located in areas prone to such events. Gullies can reach impressive dimensions and their repair can be very expensive and time consuming. In the central part of the Brazilian territory, soils may be highly sensitive to surface and deep erosion mechanisms. In this context, geotextiles can be used in works to control or minimize erosive processes. This paper describes a study on the use of barriers for sediments (silt fences) for erosion control. Large laboratory tests using a flume 6 m long, 1 m high and 0.4 m wide were performed on different types of nonwoven geotextiles and soil slurries. The slurries were prepared using soils collected from large erosions in the Federal District, Brazil. Four types of geotextiles and 3 types of soils were used in the tests under varying values of runoff discharges. The flow rate passing through the geotextile and the upstream slurry level rising with time were measured as well as the sizes of the soil particles that piped through the geotextile and the permittivity of the geotextiles after the tests. The laboratory tests aimed to investigate the use of light and cheap nonwoven geotextiles, with particular reference to their retention capacity. Besides the laboratory experiments, full-scale silt fences were constructed in some gullies and their performance was monitored after some raining seasons. The results obtained showed good performance of the light geotextiles tested, with favourable implications for the construction of low cost erosion control works using such materials.

Keywords: Geosynthetic, Geotextiles, Erosion Control, Large Scale, Filtration.

INTRODUCTION

Soil erosion can cause severe damages to the environment as well as economic losses related to the reduction of agricultural production and damages to infrastructure, for instance. Losses of fertile soil due to runoff can cause reductions in crop productions, increase of sediments in rivers and lakes and considerable environmental damages, which are commonly very expensive to be repaired in an advanced state of the erosive process. Civil engineering works such as roads and reservoirs can be affected by sediment transportation by runoff. When the erosive process is not halted or controlled, large soil masses can be eroded which may yield to the formation of large gullies. The soils in the central region of Brazil can be very sensitive to erosive mechanisms and large erosion damages can occur close to or even in large cities of this region. As an example, Figure 1 shows a large gully near the city of Brasilia, Federal District, Brazil.

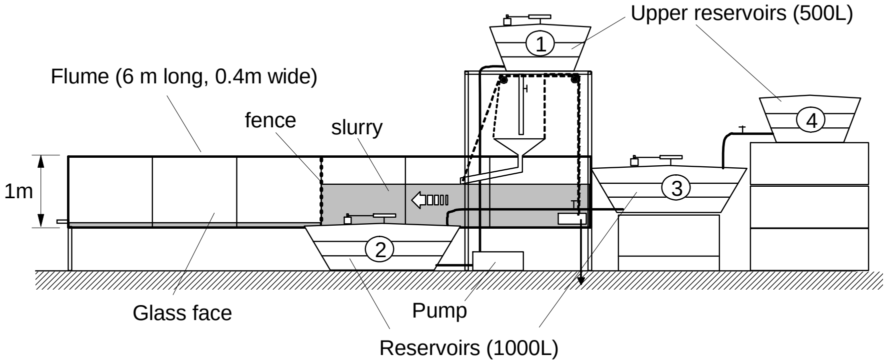
Figure 1. Large gully close to the city of Brasilia, Brazil

Erosion control structures can be built using geosynthetics. Geomats, geocells and geotextiles can be employed for this type of problem and works on design procedures and geosynthetic installation can be found elsewhere (Wyant 1980, AASHTO 1990, Richardson and Middlebrooks 1991, Holtz *et al.* 1997, Koerner 1998). Barriers or embankments incorporating geotextiles can also be used to retain or control sediments transported by runoff and several works on the applications of geosynthetics in erosion control can been found in the literature (Hoover 1982, Legge 1990, Sansone and Koerner 1992, Palmeira and Farias 2000, Bhatia *et al.* 2002). Most of these works can be considered as index tests, not necessarily representing accurately the mechanisms prevailing in the field. This paper presents and discusses the results of large scale tests to evaluate the performance of geotextiles as barriers for sediments. The use of light non-woven geotextiles in silt fences for low cost erosion control works is also investigated.

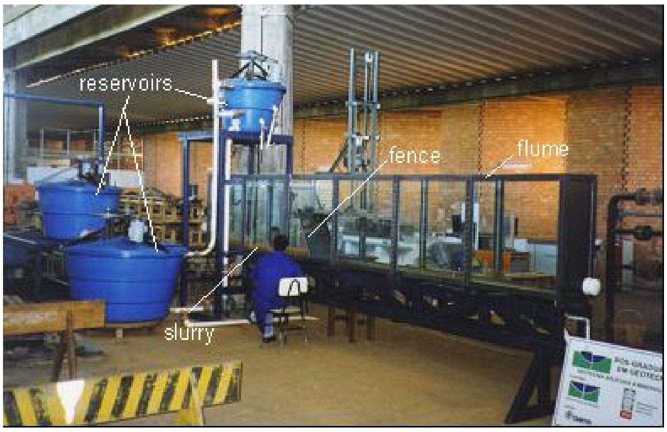
EQUIPMENT AND MATERIALS USED IN THE EXPERIMENTS

Testing Equipment

A large scale flume apparatus was used in the experimental programme (Ribeiro 2000). The flume is 6 m long, 1 m high and 0.4 m wide. Figures 2(a) and (b) show the geometrical characteristics and an overall view of the apparatus during a test, respectively. The flume consists of a rigid steel structure and its side walls are made of glass (10 mm thick) to allow the observation of the sedimentation of soil particles and their accumulation at the geotextile face during the tests. The equipment is similar to that proposed in ASTM (1995a), however, its scale is larger and the slurry flow regime is imposed at a steady, rather than transient mode as proposed in ASTM (1995a). In addition, greater flow rates and testing durations can be used.



(a) Schematic view of the equipment



(b) Large flume during one of the tests performed

Figure 2. Large scale equipment used in the tests on barriers for sediments (silt fences)

Mixtures of water and soil particles produced slurries that were forced to flow along the flume length at constant flow rates. The concentration of the slurry in all tests was equal to 10g/L, which is consistent with field measurements in real erosions in the Federal District, Brazil, for the soils tested in this research programme. Four reservoirs (2 with 1000L and 2 with 500L storage capacities) formed the slurry mixing and feeding systems. The mixture of water and soil particles is made in reservoirs 3 and 4 (Fig. 2a) and conducted by gravity to reservoir 2. From reservoir 2 the slurry is pumped to reservoir 1 to feed the flume. All the reservoirs have mixers to maintain the mixture homogeneous and to avoid premature soil particle sedimentation. The slurry is fed into the flume extremity at a constant rate of flow by a fluid spreader with the same width of the flume, which allows uniform distribution of the slurry along the entire flume width. During the test the spreader elevation is automatically adjusted in order to coincide with the slurry surface level. Tap water with a pH of 7.6 was used in the tests. The slurry that passes through the geotextile can be collected at the other end of the flume for further investigations. Samples collected at different points on the fence downstream surface were subjected to grain size analyses using a laser beam grain size analyser from Malvern Instruments Ltd. (England). After the flume tests the geotextile specimens were subjected to permittivity tests (ASTM 1995b) to evaluate permittivity losses.

A rigid metal grid was used to fix the geotextile specimens to the internal flume walls in order to form a 0.9 m high barrier, perpendicular to the flume length. The flow rates used in the tests were equal to 0.250 L/s and 1 L/s. The latter value would be the expected runoff on an impervious surface with an area of 10,000m^2 (100m x 100m) caused by a precipitation of approximately 100 mm/h.

The same geotextile specimen was submitted to two stages of testing. In the first stage, the virgin (clean) geotextile was submitted to the flow of slurry for a certain period of time. At the end of this stage of testing, the geotextile was somewhat blinded and/or impregnated by soil particles that it retained during the test. A second stage of testing was carried out on the same geotextile specimen 24 hours later to evaluate the effects of soil impregnation and geotextile blinding on its performance.

Materials Tested

Three soils collected from large gullies in the central region of Brazil were used in the testing programme. Two of these soils (codes ErCel1 and ErCel2) were collected in gullies close to the city of Ceilandia, approximately 35 km from the city of Brasilia, the capital city of Brazil. The third soil was collected in a gully in the city of Anapolis, in the state of Goias, approximately 160 km from the city of Brasilia. The main characteristics of the soils tested are presented in Table 1. Soils ErCel1 and ErCel2 are typically silty soils, whereas soil ErAn is a sandy soil.

Table 1. Soil properties

Property*	**Soil ErCe1**	**Soil ErCe2**	**Soil ErAn**
G	2.80	2.71	2.73
D_{10} (mm)†	0.00036	0.00031	0.0225
D_{50} (mm)	0.0412	0.00569	0.191
D_{85} (mm)	0.259	0.0483	0.700
D_{95} (mm)	0.390	0.181	1.202
C_u	182	39	12

* G = soil particle density; D_{10}, D_{50}, D_{85} and D_{95} = diameters for which 10%, 50%, 85% and 95% of the remaining particles are smaller than that diameter; C_u = coefficient of uniformity (= D_{60}/D_{10});
† From analyses with a laser beam grain size analyser.

Four types of non-woven geotextiles from the same manufacturer were tested. These products are needle-punched geotextiles, made of continuous fibres of polyester. The main characteristics of the geotextile products are presented in Table 2. The mass per unit area of the geotextiles varied between 75 g/m^2 and 600 g/m^2 and their filtration opening sizes varied between 0.060 mm and 0.16 mm. Geotextile GA is a very light non woven material and was tested because of its low cost compared with the others.

Additional information on test equipment and methodology can be found in Farias (2005) and Farias et al. (2006).

Table 2. Characteristics of the geotextiles tested

Property	**GA**	**GB**	**GC**	**GD**
Mass per unit area (g/m^2)	76	150	300	600
Thickness (mm)	0.8	1.5	2.6	4.5
Porosity (%)	94	94	93	90
Transmissivity (cm^2/s) *	0.06	0.07	0.13	0.27
Permitivitty (s^{-1})†	5	2.6	1.5	0.9
Filtration opening size (mm) ‡	0.16	0.15	0.11	0.60
Tensile strength (kN/m) §	3.3	7	20	37

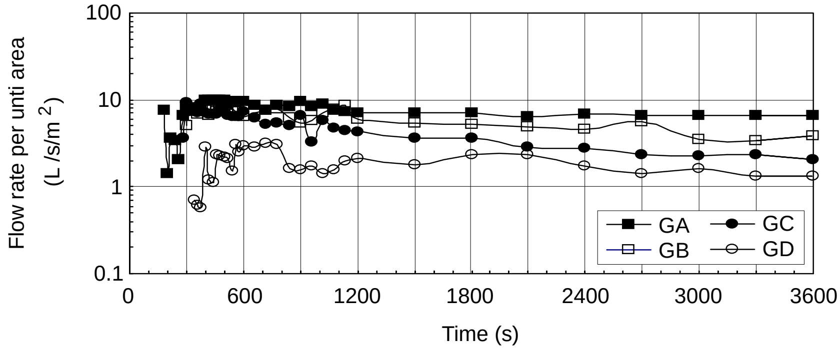
* Under 20 kPa normal stress;
† ASTM (1995b);
‡ Hydrodynamic sieving (CFG, 1986); (4);
§ Wide strip tensile tests (ASTM 1995c)

TEST RESULTS

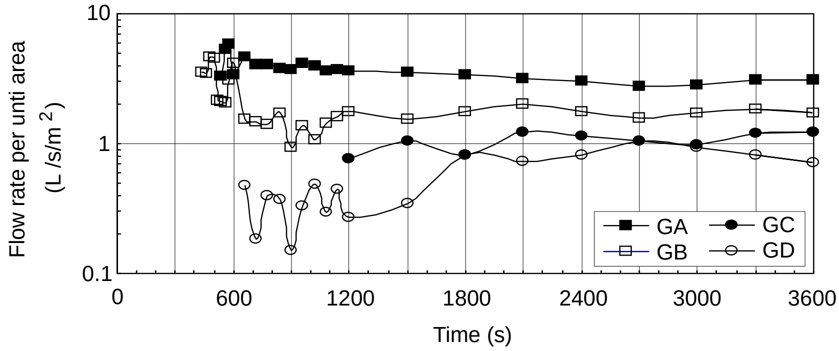
Figure 3(a) and (b) show the results of flow rates per unit area through the geotextile versus time for tests with slurry prepared with soil ErCe1 in the first (virgin geotextiles) and second (reused geotextiles) stages of the test. In these tests an inlet flow rate (Q) of 0.25 L/s was used. The lighter and more opened geotextile GA was the one presenting the smallest reduction of flow rate, whereas the thicker geotextile GD was the one with the greatest flow rate reduction. The reductions in flow rates are greater in the second stage of the test (Fig. 3b), when the geotextile was already blinded or partially clogged. Thus, the effect of the previous partial clogging of the geotextile had a marked effect in its water retention capacity, increasing the possibility of barrier overtopping.

Figures 4(a) and (b) present the variations of upstream slurry height with time for tests with soil ErCe1 and an inlet flow rate of 0.25 L/s. During the first stage of the test, stabilisation of the upstream mixture level was reached only for the tests with geotextiles GA and GB (the lighter ones). At the end of the 2nd stage of the tests the increases of upstream slurry height were significantly greater due to the partial clogging of the geotextile barrier. For this stage only the test with geotextile GA showed a clear stabilisation of the upstream fluid height at the end of the test.

The variation of slurry height with time for an impervious fence is also presented in Figures 4(a) and (b). It can be noticed that in the earlier stages of the tests the geotextile layer behaves as an impervious face, due to the difficulty of the water to penetrate the unsaturated geotextile. As time increases the behaviour of the geotextile barrier deviates from that of the impervious fence and the greater the geotextile permittivity the sooner and the greater the deviation from the impervious fence behaviour.

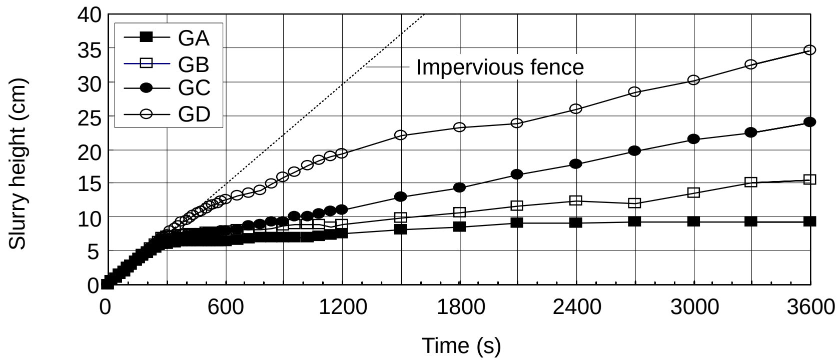


(a) 1st stage of testing (on virgin geotextile specimen)

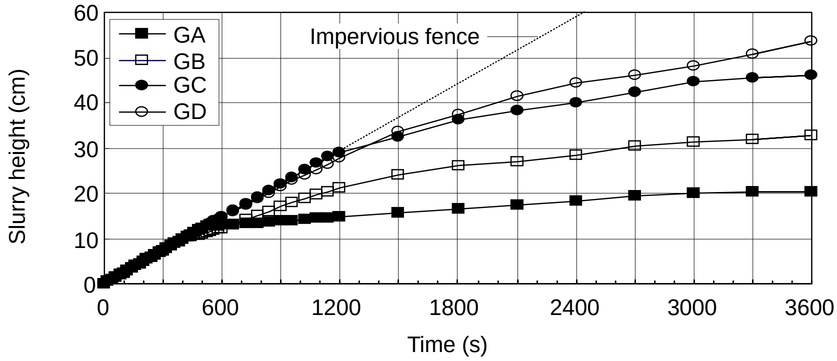


(b) 2nd stage of testing (on reused geotextile specimen)

Figure 3. Flow rate versus time for tests with soil ErCe1 – Q = 0.25 L/s



(a) 1st stage



(b) 2nd stage

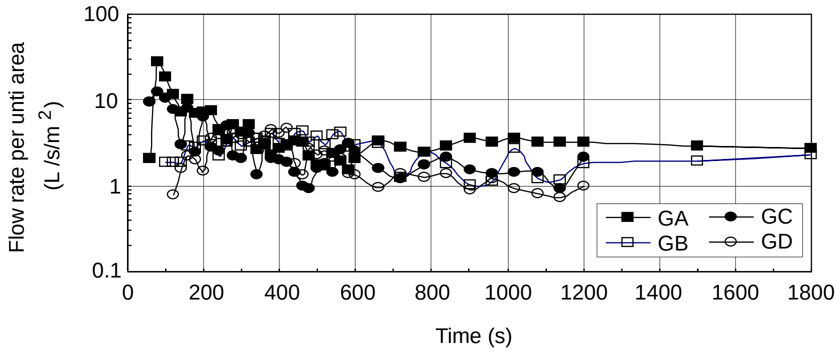
Figure 4. Slurry height versus time for tests with soil ErCe1 – Q = 0.25 L/s

Figures 5 and 6 show results of tests with soil ErCe1 and an inlet flow rate Q of 1.0 L/s. The severity of the flow conditions imposed to the geotextile increases with the increase of the inlet flow rate. For Q equal to 1.0 L/s the values of flow rates varied less with the geotextile type than in the tests with Q equal to 0.25 L/s. With respect to the results obtained at the end of the first stage of the tests with Q equal to 0.25 L/s (Fig. 3a) the results obtained for Q equal to 1.0 L/s were 64% smaller for geotextile GA and 20% smaller for geotextile GD. These results show that the performance of the thicker and less opened geotextile was not much affected by the increase of the inlet flow rate.

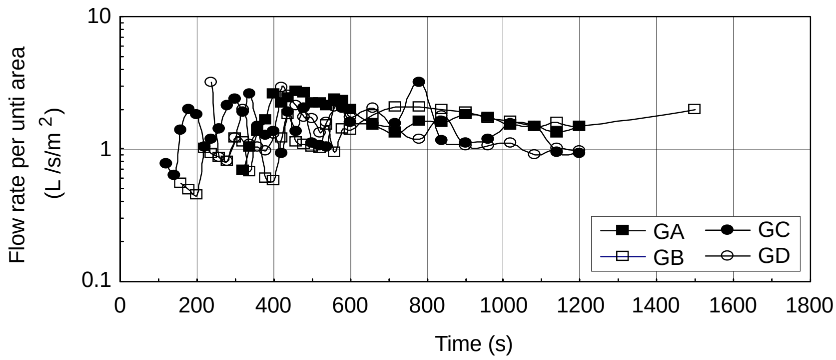
In the 2nd stage of the tests with soil ErCe1 and Q equal to 1.0 L/s the variations of flow rate per unit area were rather similar for all the geotextiles tested, as shown in Figure 5(b). In spite of the impregnation and blinding mechanisms developed in the first stage of the tests, the conditions at the end of the 2nd stage were not significantly different from those at the end of the 1st stage.

Figure 6(a) shows the variation of upstream fluid height with time in the first stage of the test with soil ErCe1 and Q equal to 1.0 L/s. For the largest inlet flow rate the pattern of variation of fluid height with time is not so dependent on the geotextile type. In these tests overtopping of the fence did not occur only for geotextile GA. As expected, the less opened the geotextile the faster the fence overtopping. For the 2nd stage of the test the patterns of variation of upstream fluid height with time were very similar for all geotextiles tested (Fig. 6b), showing the consequences of more severe blinding and impregnation mechanisms developed in the previous stage by the high inlet flow rate.

The results of the tests with slurry of soil ErCe2 were similar to those obtained in tests with soil ErCe1 for both values of Q.



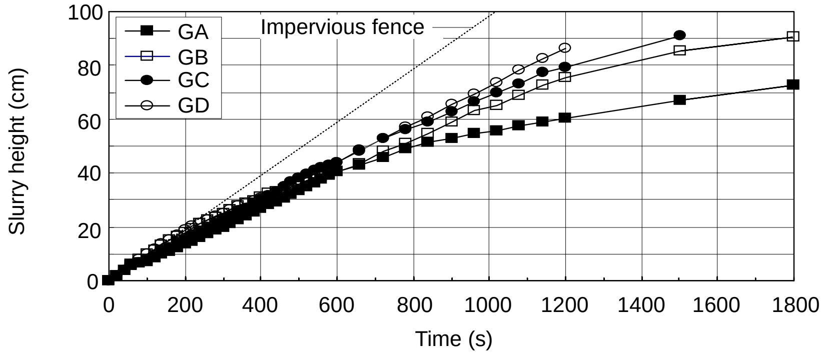
(a) 1st stage



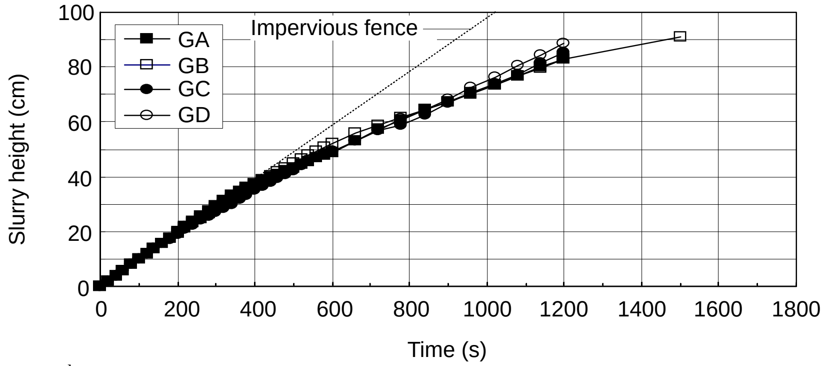
(b) 2nd stage

Figure 5. Flow rate versus time for tests with soil ErCe1 – Q = 1 L/s

Figures 7 (a) and (b) depict the comparisons between maximum diameters (d_{95}) of the particles that piped through the geotextile and geotextile filtration opening sizes (O_{95}) for each stage of the test. In this figure, for a given soil, the upper and lower values of d_{95} plotted are the values obtained for samplings at times (t) equal to 10min and 20min after the test has started, respectively. The results show that the maximum diameters of the particles that piped through the geotextiles were considerably smaller than the geotextiles filtration opening sizes in most of the cases. For the 1st stage of the test the largest piped particle diameter at t equal to 10 min was smaller than half the geotextile filtration opening size in 58% of the cases (Fig. 7a). It should be noted that the maximum diameters (D_{95}) of the particles of soils ErCe1 and ErAn were greater than the filtration opening sizes of the geotextiles (Tables 1 and 2). Globally, for the grain size and geotextile opening dimensions involved the coarser the soil the greater the diameter of the particles that piped through the geotextiles.

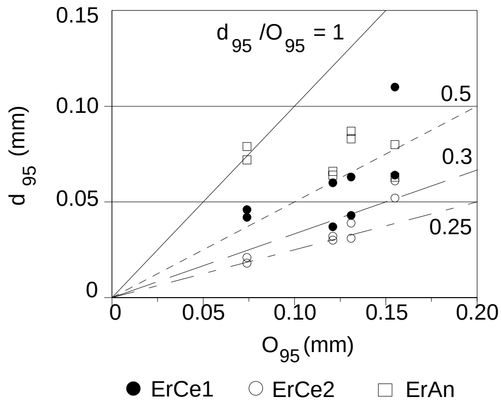


(a) 1[st] stage

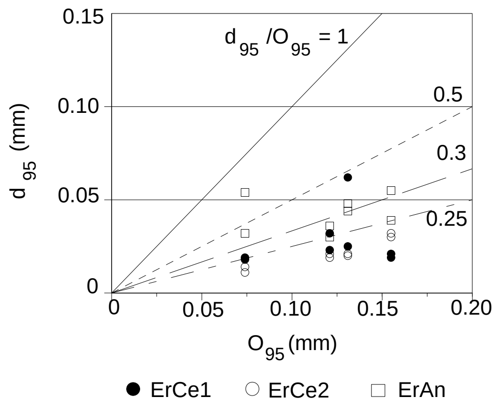


(b) 2[nd] stage

Figure 6. Slurry height versus time for tests with soil ErCe1 – Q = 1 L/s



(a) 1[st] stage



(b) 2[nd] stage

Figure 7. Largest piped particle diameter versus geotextile filtration opening size

The results in Figures 7 (a) and (b) suggest a significant increase in the retention capacity of the geotextile. The smaller particle diameters downstream of the fence might be in part due to the sedimentation of larger particles before reaching the barrier, although this is unlikely due to the high inlet flow rate in these tests. This greater retention capacity can be also explained by progressive clogging of the geotextile, which causes the obstruction of its largest constrictions, yielding to only smaller particles being able to pipe through the geotextile. This is very much so for the results obtained in the 2[nd] testing stage (Fig. 7b) when the maximum piped particle diameters were even smaller. Besides, the flow through the geotextile is not entirely normal to its plane along the entire fence height, being similar to what would occur in an under-designed chimney filter unable to allow free water flow along its length. It was observed during the tests that flow on the downstream geotextile surface occurred along a large fraction of the fence height. In this case the soil particles have to travel a distance greater than the geotextile thickness to reach the downstream region of the fence, increasing the chance of particle entrapment. Palmeira and Farias (2000) also observed greater geotextile retention capacity in fine fraction filtration tests.

After the end of the flume tests, permittivity tests (ASTM 1995b) on the geotextile layers tested were carried out. Geotextile specimens for these tests were collected from the geotextile layer at an elevation equal to the mid-height of the maximum upstream level reached by the slurry in the flume during the test. Figure 8 shows the reductions of geotextile permittivity after the tests. Reductions between 62% and 85% of the original geotextile permittivity can be observed. In general, for a given soil the thicker and less opened the geotextile the greater the permittivity reduction. All three soils considered, the thicker geotextile GD was the one presenting the greater permittivity reduction (between 80% and 85%).

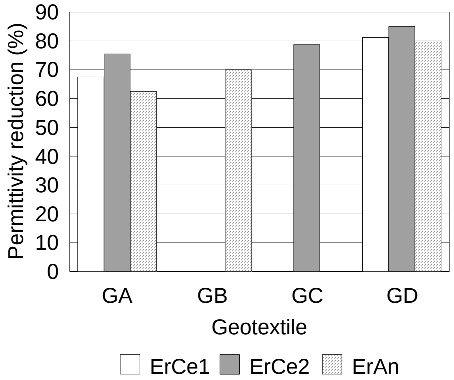


Figure 8. Geotextile permittivity reductions after the end of the tests

PERFORMANCE OF SEDIMENT BARRIERS IN THE FIELD

The laboratory tests showed that the retention capacity of non-woven geotextiles increased due to the flow conditions and impregnation by soil particles. This implies that a lighter, more opened and cheaper geotextile product might be used as barrier. However, other conditions must be taken into account in the specification of the geotextile, such as mechanical and endurance properties. When the product attends such requirements a very cost-effective and quick to install barrier for sediments can be employed. Figures 9(a) and (b) show an example of such structure designed based on the experiences carried out in the laboratory. Three barriers were built to control the erosive process in a gully close to the city of Anapolis, in the state of Goias, Brazil, in December of 2003. A galvanised wire mesh and a non-woven geotextile with mass per unit area equal to 150 g/m^2 were used in this work (Fig. 9a). The spacing between barriers was equal to 20m. Figure 9(b) shows the amount of sediments retained by one of the barrier after some days of heavy rains. The system has been performing well ever since its installation. Similar structures in other sites were also built and performed well, as reported by Farias (2005).

(a) Fence construction

(b) Sediments retained upstream the fence

Figure 9. Low cost sediment barrier to control erosive processes in gullies

CONCLUSIONS

In this paper large scale flume tests were carried out in order to evaluate the performance of non-woven geotextiles as barriers for sediments. The main conclusions obtained are summarised below.

The equipment used in the tests proved to be a useful tool to evaluate the performance of geotextiles as barrier under conditions close to those found in the field. It should be pointed out that the size of the equipment requires larger amounts of soil and water for running the tests for a sufficient long duration.

Slurry flow impairment was greater for less opened geotextiles. The performance of the thicker and less opened geotextile was less influenced by the value of the inlet flow rate.

High inlet flow rates caused greater geotextile blinding and clogging, reducing the differences between the performance of geotextile barriers in the 1st and 2nd stages of the tests. In general, for a given soil the thicker and less opened the geotextile the greater its permittivity reduction. For the largest inlet flow rate used the geotextile characteristics did not affect much the variation of upstream slurry height with time. The reduction of geotextile permittivity due to blinding or entrapment of soil particles enhance the importance of a proper hydraulic project to avoid the consequences of barrier overtopping.

The retention capacity of the geotextiles was significantly increased. This greater geotextile retention capacity can be explained by progressive clogging of the geotextile, which causes the obstruction of its largest openings, yielding to only smaller particles being able to pipe through the geotextile. In addition, the flow through the geotextile is not entirely normal to its plane along the entire fence height, making the soil particles to travel a distance greater than the geotextile thickness to reach its downstream face, increasing the chances of particle entrapment.

The results suggest that light, more opened and cheaper geotextiles may function satisfactorily in barriers for sediments provided that other relevant requirements are fulfilled.

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Corresponding author: Prof. Ennio M. Palmeira, University of Brasilia, Dept. of Civil and Environmental Engineering-FT, Brasilia, DF, 70910-900, Brazil. Tel: 55-61-32737313/Ext. 217. Email: palmeira@unb.br.

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