Influence of geosynthetic reinforcement on unpaved road performance after surface maintenance

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ABSTRACT: A great part of the world's road network consists of unpaved road. They allow the transportation of several important products from agriculture, mining, forestry and other industries, besides providing access to inhabitants of isolated communities to services in larger cities. Despite its importance, overloading and poor maintenance services may cause frequent traffic disruptions in these roads with important economic losses and social impacts. Geosynthetic reinforcement can improve the performance of unpaved roads on weak subgrades, increase its life and reduce maintenance costs. This paper investigates the performance of unpaved roads on compressible subgrade using a large scale equipment under laboratory conditions. Cyclic load was applied to the road to simulate traffic conditions. Different geogrid reinforcements were used at the fill-subgrade interface. After a target rut depth has been reached, the road surface was repaired and a new loading stage was applied. This aimed at assessing the influence of the presence of the reinforcement on the behaviour of the road after surface maintenance. The breakage of the fill material (gravel) was also quantified after each test. The results obtained showed the significant influence of the reinforcement on road performance as well as on the reduction of breakage of fill material particles in comparison with the unreinforced case.

Keywords: Geosynthetics, Unpaved Roads, Reinforcement, Surface Maintenance

1 INTRODUCTION

Unpaved roads represent more than 80% of the Brazilian road system and are very important for the country's economy for providing transportation of products from the agriculture, mining and forestry industries, among others. In addition, they provide access to social services in larger cities for members of remote communities. Such roads are commonly constructed on weak soils, which accelerates surface rutting, causes traffic disruption and increases maintenance costs. Geosynthetics can be used as reinforcement in several geotechnical engineering works, such as pavements, embankments on soft soils, retaining walls and also unpaved roads on weak subgrades. In the latter case, geosynthetic reinforcement can reduce the stresses transmitted to the weak subgrade, provides lateral confinement to the fill material and reduces rut formation, which leads to better road performance, life increase and less maintenance costs.

Due to its characteristics, unpaved roads need to be constantly maintained to provide good and continuous traffic conditions. However, few researches can be found in the literature dealing with the benefits of geosynthetic reinforcement in unpaved roads after surface maintenance. On this regard, contributions from the presence of reinforcement at the fill-subgrade interface can be found in Palmeira (1981), Palmeira (1998) and Leng (2002) in the case of roads constructed on soft clays. Palmeira and Antunes (2010) presents results of large scale laboratory tests on unpaved roads also showing the benefits of geosynthetic reinforcement in roads constructed on weak unsaturated subgrades and discuss cost issues related to the use of reinforcement in this type of work. Palmeira and Gongora (2015) shows improved performance of unpaved roads built on loose sand subgrade and discuss relevant physical and mechanical properties of geogrids for this type of application. It is important to point out that to the knowledge of the authors the beneficial effects of the reinforcement presence in case of road maintenances is not considered in the evaluation of reinforcement cost-effectiveness in unpaved roads on weak subgrades on a routine basis, nor in the reduction of operational costs throughout the road life.

This paper presents a study on the performance of unreinforced and reinforced unpaved roads subjected to cyclic loading after surface maintenance by means of large scale laboratory tests aiming at identifying relevant properties of the types of geosynthetics typically employed as reinforcement in unpaved roads on weak subgrades and how they interact with fill and subgrade materials.

2 EQUIPMENT AND MATERIALS

2.1 *Equipment employed*

The testing apparatus used in the research described in this paper consisted of a large and rigid tank, 1000 mm internal diameter and 550 mm high, where the layers of fill and subgrade materials were constructed. A cylinder connected to a hydraulic system applied the load on a rigid platen (200 mm diameter) resting on the fill surface in order to a maximum vertical stress of 566 kPa (typical tire pressure in Brazil) to be achieved at a frequency of 1 Hz. Figure 1 shows a typical view of the equipment during one of the tests performed. A load cell and displacement transducers measured the loads and displacements of the loading platen, respectively. Displacement transducers were also used to measure vertical displacements along the fill surface. Electric total pressure cells were installed at different locations in the subgrade to assess the vertical stresses transmitted to that layer. These cells were calibrated immersed in the same soil used in the subgrade to increase measurements accuracy. A data acquisition system (Lynx ADS 2000) connected to a microcomputer was employed to acquire and process the data from the instrumentation. Part of the results obtained in the research programme are presented and discussed elsewhere (Palmeira and Gongora 2016 and Gongora and Palmeira 2016).

Figure 1. Equipment used in the tests.

2.2 *Materials*

A clean sand with particle diameters varying between 0.2 and 2.0 mm was used as subgrade material. The choice of a sand layer instead of a soft saturated clay subgrade was twofold. Firstly, it aimed at simulating roads constructed on loose sandy subgrades for which solutions of soil improvement would be expensive or unpractical. Secondly, the main objective of the research was to identify and evaluate relevant physical and mechanical reinforcement properties in this type of geosynthetic application. In this context, the use of a sandy subgrade makes sample preparation and testing much simpler than in the case of saturated clay subgrades, besides allowing a greater number of tests to be performed. The subgrade layer was prepared under a loose state (relative density of 30%) using the sand rain technique. The relevant geotechnical properties of the sand employed are presented in Table 1. The thickness of the subgrade was equal to 220 mm and it is acknowledged that larger thicknesses would represent more realistically field condition. However, as explained in the case of the choice of the type of subgrade material, a smaller subgrade thickness was more practical for the purposes of the research, as it would also facilitate test preparation and allow a greater number of tests to be performed. Tests with similar subgrade material and thicknesses based on the same considerations aforementioned can be found in the literature (Brown et al. 2007, Cancelli et al.1996, Hussaini 2012 and Wu et al. 2015, for instance).

Table 1. Properties of the subgrade soil.

Property	Value
Coefficient of uniformity	2.6
Specific gravity of soil solids	2.69
Relative density (%)	30
California bearing ratio (%)	1.6
Cohesion (kPa)	0
Unit weight (kN/m^3)	16.7
Friction angle (°)	31

The fill material was 300 mm thick and consisted of gravel with 90% of its mass with particles with diameters varying between 1.5 and 21 mm. The average particle diameter (D_{50}) of the fill material was equal to 10.5 mm and its coefficient of uniformity equal to 7.7. Static compaction (in 3 layers, 100 mm thick each) was used to obtain the target density of the fill material. The main properties of the fill material are summarized in Table 2. Figure 2 shows schematically the soil layers in a typical test.

Table 2. Properties of fill material.

Property	Value
Average particle diameter (mm)	10.5
Maximum particle diameter (mm)	19.0
Coefficient of uniformity	7.7
Specific gravity of soil solids	2.65
Relative density (%)	83
Los Angeles abrasion (%)	34
Cohesion (kPa)	0
Unit weight (kN/m3)	17.3
Friction angle (°)	43

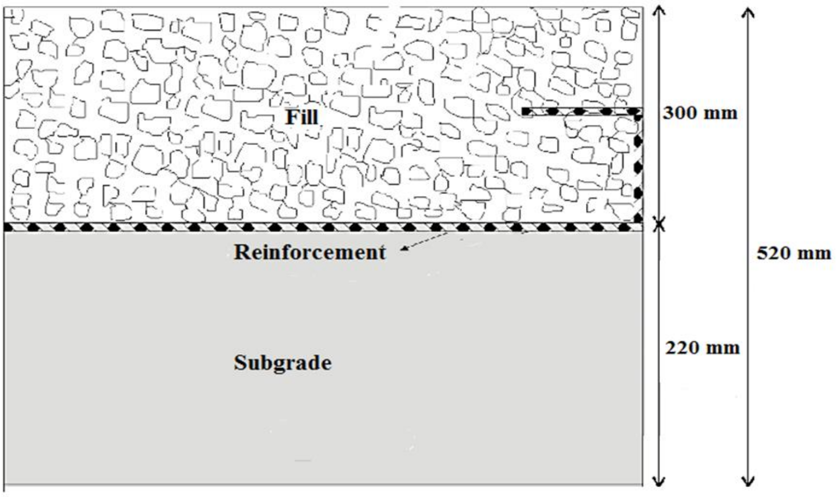

Figure 2. Soil layers setup in a typical test.

Six different geogrid products were used as reinforcement, whose main physical and mechanical properties are presented in Table 3. Geogrids G1 to G4 are uniaxial products, whereas the other grids are biaxial ones. The choices of the geogrids aimed at testing products with a wide range of tensile stiffness and fill particle diameter to equivalent grid aperture ratios. The equivalent grid aperture value is defined as the geometric mean of the aperture dimensions (Hussaini 2012). So, values of geogrid equivalent aperture between 12.8 mm and 32.2 mm were investigated. Geogrids with tensile stiffness values at 5% strain (J_5)

obtained in wide strip tensile tests (ASTM D6637) between 417 kN/m and 1165 kN/m were tested. The Aperture Stability Modulus (ASTM D7864) varied between 0.029 N-m/deg and 0.107 N-m/deg. The extremities of the geogrid reinforcement were folded (Fig. 2) to provide anchorage. Observations during and after the tests confirmed that the anchorage procedure adopted was successful.

Table 3. Reinforcement properties.

Property	**Geogrid (G1)**	**Geogrid (G2)**	**Geogrid (G3)**	**Geogrid (G4)**	**Geogrid (G5)**	**Geogrid (G6)**
Aperture dimensions (mm)	18.4 x 21	23 x 35	15 x 11.6	18.5 x 14.1	26 x 40	11x 15
Tensile strength MD / Tensile strength XMD (kN/m)(1)	109/30	92/92	18/18	142/30	38/38	43
Tensile stiffness at 5% strain (kN/m) (1)	893/300	811	417	1165/300	474	474
Aperture stability modulus (N-m/deg.)(2)	0.033	0.074	0.040	0.036	0.107	0.029
Equivalent aperture dimension, a_{eq} (mm)	19.7	28.4	13.2	16.2	32.2	12.8
Polymer Type	Polyester	Polyester	Polypropylene	Polyester	Polypropylene	Polypropylene

Notes: (1) ASTM D6637, (2) ASTM D7864

Additional information on materials and testing methodology can be found in Gongora (2015) and Gongora and Palmeira (2016)

3 RESULTS

3.1 *Vertical displacements of the loading plate*

Figure 3 shows displacements of the loading plate versus number of loading repetitions (N) for the first loading stage, which was the one where the load was applied immediately after the construction of the fill. The maximum target plate settlement of 75 mm was achieved after N equal to 2810 in the unreinforced case. In the reinforced tests, geogrids G1, G2 and G4 were the ones that performed best, with N varying between 204,135 and 340,068, depending on the geogrid considered. It should be noted that these were the stiffest grids tested (Table 3). For this loading stage it was noted that the values of tensile stiffness and ratio between equivalent aperture dimension and particle diameter were more relevant than other grid properties (Palmeira and Gongora 2016). Besides, no correlation between geogrid performance and geogrid Aperture Stability Modulus was observed. Further information and discussions on the performance of unreinforced and reinforced roads during the 1st loading can be found in Palmeira and Gongora (2019).

The results of plate settlements versus N for the 2nd loading stage, after the 1st repair of the fill surface, are presented in Figure 4. In the unreinforced case, the target settlement was reached after 84,042 load repetitions. In the reinforced tests, grids G1 and G2 were the ones for which the smallest plate settlements were obtained, and in these cases, as well as for grids G4 to G6, the tests were ended at N equal to 270,000 because the trend of results indicated that the target plate displacement of 75 mm would be reached for much larger values of N. Grid G1 was the one with the best performance in the 2nd loading stage. Larger values of N in unreinforced and reinforced tests in comparison with the results obtained in the 1st loading stage (Fig. 3) were to some extent due to the compaction of the sandy subgrade at the end of the 1st loading stage. Increases of the membrane effect in the reinforced tests must also have contributed to improved reinforcement performance in the 2nd loading stage.

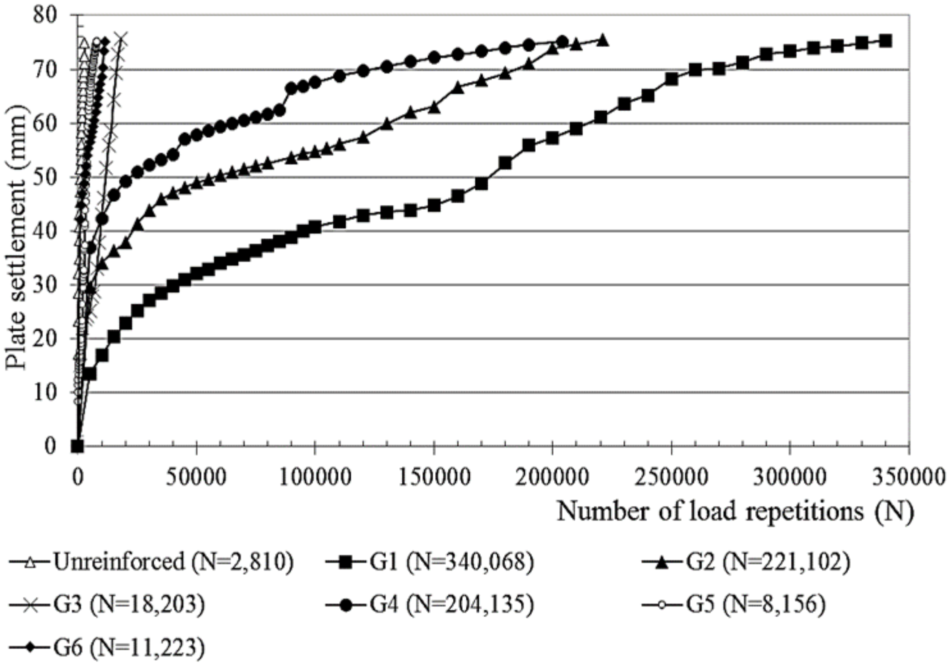

Figure 3. Plate settlement versus number of load repetitions-1st loading stage

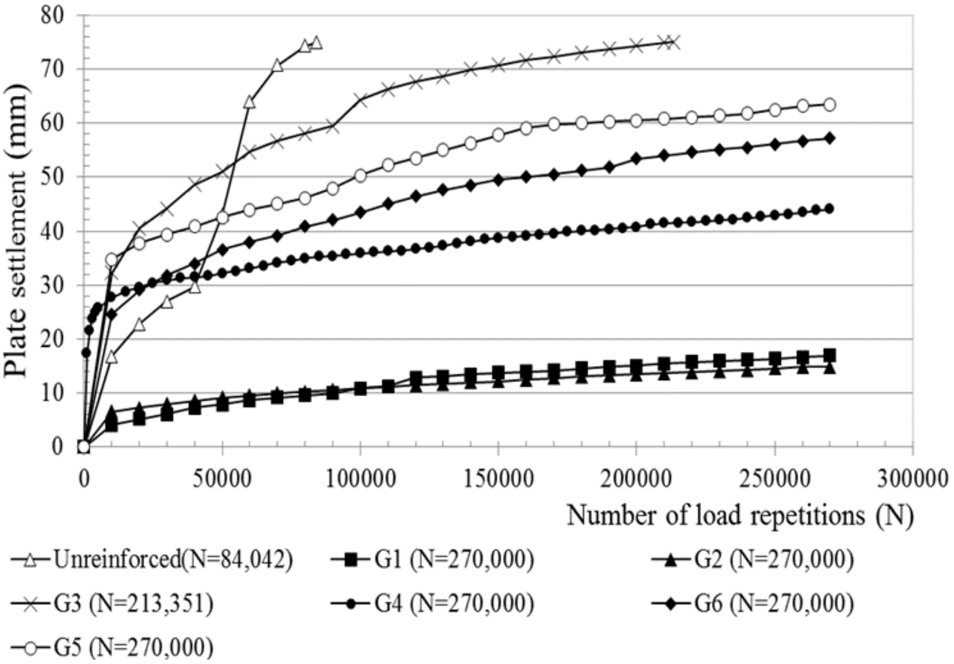

Figure 4. Plate settlement versus number of load repetitions-2nd loading stage, after surface repair

3.2 *Influence of some reinforcement properties*

In this study the mechanical properties of the reinforcements considered were the tensile stiffness and the Aperture Stability Modulus (ASM). Other properties were considered in detail in Palmeira and Gongora (2016) and Gongora and Palmeira (2016). Figure 5 presents the performance of the reinforced roads in terms of TBR (Traffic Benefit Ratio) *versus* ASM for the 1st loading stage. TBR is defined as the ratio between the numbers of load repetitions in unreinforced and reinforced tests for a given rut depth. The rut depth considered in the present work was equal to 75 mm. No correlation between TBR and ASM can be noted from the results obtained. The same lack of correlation was noted for the results of the 2nd loading stage, as shown in Figure 6. These results show that for the conditions of the tests carried out the value of ASM did not influence reinforced road performance. Similar observations can be found in Cuelho *et al*. (2014).

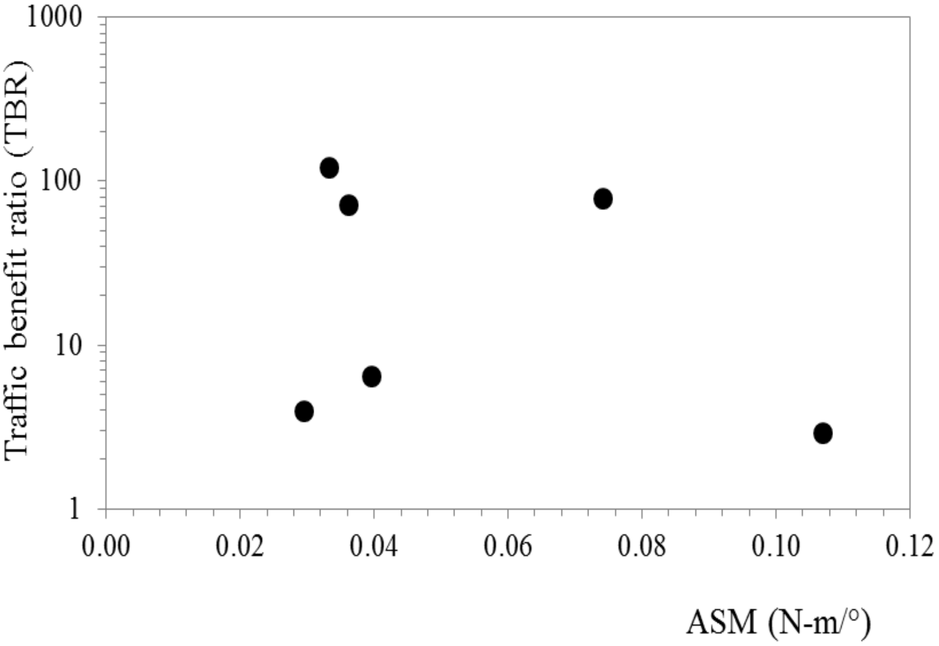

Figure 5. TBR versus geogrid ASM - 1st loading stage

Figure 7 shows the variation of TBR with geogrid tensile stiffness ($J_{5\%}$) for the 1st and 2nd loading stages. Despite the scatter in both cases (though less for the 1st loading stage), a consistent trend of TBR increasing as $J_{5\%}$ increases can be noted. The results confirm that the tensile stiffness is an important parameter for road performance but not the only one. Further investigations (Palmeira and Gongora 2016) showed that best reinforcement performance was also associated with grids with ratios between equivalent aperture (a_{eq}) and uniform fill average particle diameter (D_{50}) close to 2 and equivalent aperture and uniform fill maximum particle diameter (D_{max}) close to 1. Similar findings were obtained by Brown et al. (2007) and Hussaini (2012). Thus, a large tensile stiffness, although desired, may not be sufficient for good geogrid performance if fill-geogrid interaction is poor. Palmeira and Gongora (2016) discuss the influence of physical and mechanical properties on geogrid performance in unpaved roads.

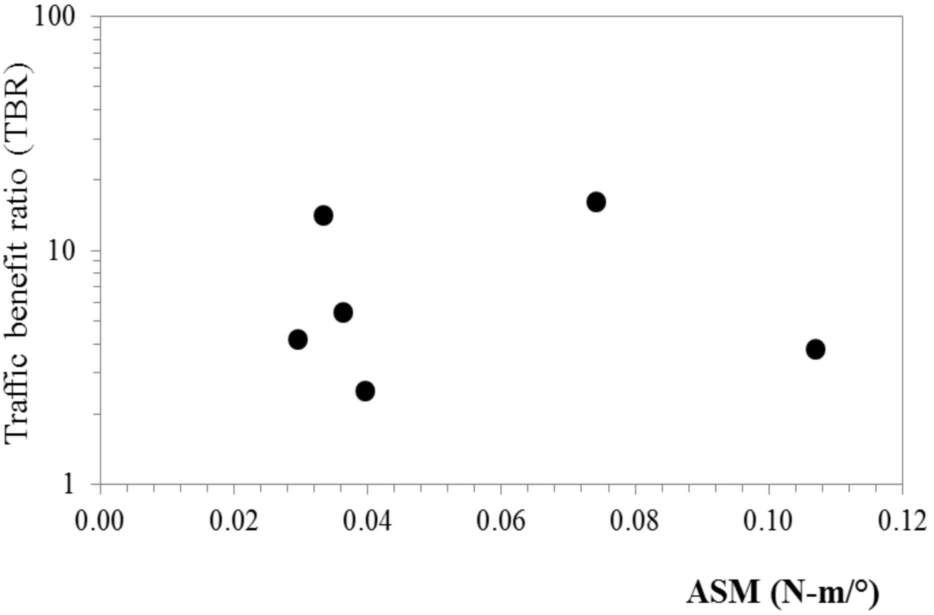

Figure 6. TBR versus geogrid ASM - 2st loading stage

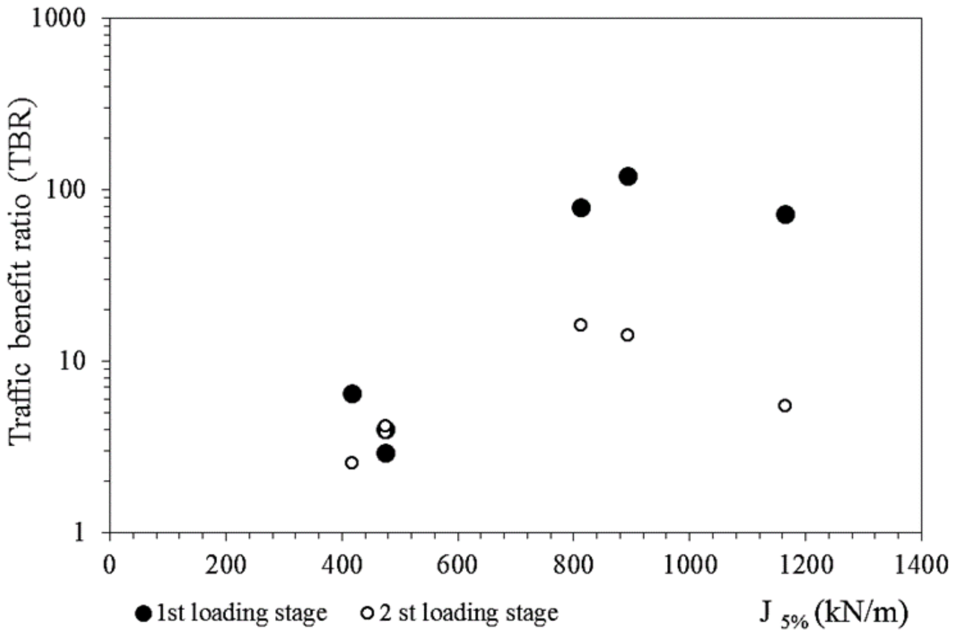

Figure 7. TBR versus geogrid tensile stiffness – 1st and 2nd loading stages

3.3 *Fill particle breakage*

The method proposed by Marsal (1967) was employed to evaluate the level of fill particles breakage at the end of the tests. According to this method, the percentage of broken particles can be calculated by:

$$B_g = \Sigma(\Delta W_{ki} - \Delta W_{kf}) \qquad \text{for } \Delta W_{ki} - \Delta W_{kf} > 0 \qquad (1)$$

Where B_g is the percentage (by weight) of fill broken particles, ΔW_{ki} and ΔW_{kf} are the initial (before breakage) and final (after breakage) fractions of the sample weight corresponding to a given range of fill particle dimensions, respectively, and n is the number of ranges of particle dimensions for which $\Delta W_{ki} - \Delta W_{kf} > 0$.

For particle breakage evaluation fill samples were collected at the surface (Position 1) and at the fill-subgrade interface (Position 2) at the end of the tests. Table 4 presents the values of B_g obtained, where it can be seen significant less particle breakage in the reinforced roads, particularly for the tests reinforced with geogrids G1 and G2. Less fill particle breakage and greater load spreading angles along the fill thickness were also associated to ratios a_{eq}/D_{max} close to 1 (Gongora and Palmeira 2016).

Table 4. Percentage of fill broken particles.

Test	**Position**	**Bg (%)**
Unreinforced	1	25.3
	2	27.8
G1	1	4.8
	2	4.2
G2	1	5.1
	2	4.9
G3	1	10.7
	2	11
G4	1	8.1
	2	7.5
G5	1	17.8
	2	18.5
G6	1	14.7
	2	15.4

4 CONCLUSIONS

This paper presented and discussed results of large scale tests performed on unreinforced and geogrid reinforced unpaved roads. The main conclusions obtained are summarized as follows.

- The presence of the reinforcement significantly improved the performance of the road both in the 1st loading stage and after surface maintenance.
- For the conditions of the tests, the geogrid tensile stiffness and the ratio between grid equivalent aperture dimension and fill particle diameter were important parameters for good reinforcement performance. Thus, the intensity of fill-geogrid interaction cannot be underestimated. No correlation between geogrid performance and grid aperture stability modulus was observed.
- Significant less breakage of fill particles was obtained in reinforced roads in comparison to the unreinforced one. Less breakage was also associated with large values of tensile stiffness and optimum ratio between equivalent aperture dimension and fill particle diameter.
- The results obtained show the beneficial effects of reinforcement on unpaved road performance after surface maintenances. This benefit should be considered in cost-effective analysis on the use of geosynthetics in such applications.
- Further research is being carried out to a better understanding on the performance of geosynthetic reinforced roads on weak subgrades.

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