Geosynthetic reinforced unpaved road performance after surface maintenance

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Keywords: geosynthetic, unpaved road, surface maintenance, geogrid, geotextile

ABSTRACT: This paper presents a study on the use of geosynthetic to reinforce unpaved roads on poor subgrades. A large equipment was used to perform the tests under cyclic loading and a nonwoven geotextile and a geogrid were used as reinforcing layers installed at the fill-subgrade interface. Three cyclic loading stages were applied in each test up to a rut depth at the fill surface of 25mm be reached in each stage. At the end of a loading stage the fill surface was repaired for the following loading stage. The results obtained show a significant contribution of the presence of the reinforcement layer in increasing the number of load cycles for a given rut depth and in reducing the stresses and strains in the subgrade, particularly when geogrid reinforcement was used. In addition, it highlights that the reduction of maintenance works due to the use of geosynthetic reinforcement may yield to significant savings in this type of problem, seldom considered in the analysis of the economics of this type of application on a routine basis.

1 INTRODUCTION

Unpaved roads are very important for the economical development of any country. In Brazil, approximately 61% of the freights are hauled by roads, with almost 90% of the total length of the road network consisting of unpaved roads (GEIPOT 2008). These roads may have traffic periodically disrupted due to lack or poor maintenance. Geosynthetic reinforcement can be used to improve the performance and the life time of unpaved roads on poor subgrades.

Several works in the literature have shown the benefits of using geosynthetic to reinforce unpaved roads on soft soils (Ramalho-Ortigao and Palmeira 1982, Palmeira and Cunha 1993, Zhou and Wen 2008, for instance). Depending on the reinforcement type, besides reinforcing the system, separation between a high quality fill material and a poor foundation soil can avoid or minimise the impregnation of the voids of the former by particles of the latter, increasing the life time of the road.

Ruts on the road surface appear after a certain number of passages of vehicles and the road surface must be repaired to allow the continuing traffic under safe and economical conditions. The less the number of maintenance work required the more economical the operation of the road. In this context, geosynthetic reinforcement can provide an important contribution to reduce road maintenance works (Palmeira 1998). This contribution is seldom considered when evaluating the costs of using reinforcement in unpaved roads.

Palmeira and Cunha (1993) have shown that the performance of the reinforced unpaved road can be significantly better than that of the unreinforced one under large rutting conditions because of the enhancement of the membrane effect after successive surface maintenances.

The efficiency of the geosynthetic as a reinforcement for a road can be quantified by the Traffic Benefit Ratio, defined as:

$$TBR = \frac{N_r}{N_u} \quad (1)$$

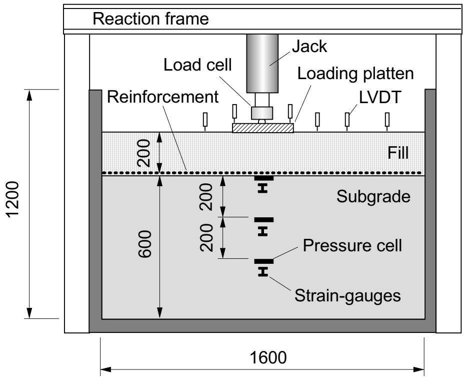
Where TBR is the traffic benefit ratio, N_r is the number of load cycles on the reinforced road for a given rut depth and N_u in the number of load cycles on an unreinforced road for the same rut depth. Values of TBR varying between 2 and 16, depending on the soil and geosynthetic characteristics have been reported (Koerner 1994).

This work presents a study on the performance of unreinforced and geosynthetic reinforced unpaved roads in large scale tests. The influence of the presence of the reinforcement after road surface maintenance is also examined.

2 EQUIPMENT AND MATERIALS

An apparatus consisting of a large steel container 1.2m high, 1.6m wide and 1.6m long, was used in the experimental programme, as shown in Figure 1 (Antunes 2008). A 300mm diameter steel plate connected to a hydraulic system provided the vertical stress of 566 kPa (correspondent to that caused by a truck axle load of 80kN) applied on the road surface with a frequency of 1Hz.

The tests were performed with three loading stages. The first one was carried out until a maximum settlement of the loading plate of 25mm was reached. Then the test was interrupted and the fill surface was repaired by adding and compacting gravel to fill the rut at the fill surface. A second stage of loading was then started up to a 25mm plate settlement had been reached, when the fill surface was repaired again for the final third loading stage.



Dimensions in mm.

Figure 1. Equipment used in the tests.

The instrumentation of the tests consisted of displacement transducers, load cell, total pressure cells and strain gauges (Fig. 1). The total pressure cells and the strain gauges were positioned at different locations along the subgrade depth to allow for the measurement of stress increments and strains during the tests (Fig. 1). A 32 channels data acquisition system (Lynx ADS 2000), connected to a microcomputer, acquired the readings from the instrumentation during the tests.

The preparation of the road foundation soil was achieved by compacting a fine grained tropical soil. The main geotechnical properties of the foundation soil are summarised in Table 1. This soil is classified as SM by the Unified Classification System (UCS) and A-7-5 according to the Highway Research Board system (HRB). The subgrade soil was compacted with a moisture content of 27% and a unit weight of 15kN/m^3 with a total final thickness of 600mm. Under such conditions the California Bearing Ratio of the foundation soil measured in the laboratory was approximately equal to 8%. A 5.5HP vibratory hammer was used for soil compaction. During foundation soil preparation, samples of the soil were taken at different depths to control layer uniformity and to check if the moisture content and unit weight specified were reached.

Table 1. Properties of the soils tested.

Property	Subgrade	Fill
D_{10} (mm)$^{(1)(2)}$	---	1.0
D_{50} (mm)	0.0021	8.0
D_{85} (mm)	0.10	14.1
Coefficient of uniformity	---	10
Soil particle density (g/cm^3)	2.69	2.72
Liquid limit (%)	56	---
Plastic limit (%)	33	---
Unit weight (kN/m^3)	15.0	18.0
Moisture content (%)	27.0	5.0
California Bearing Ratio (%)	8.0	90.0
USCS classification$^{(3)}$	CH	GW
HRB classification$^{(4)}$	A-7-5	A-1-a

Notes: (1) D_{10}, D_{50} and D_{85} = diameters of the particles for which 10%, 50% and 80% in weight of the remaining soil particles are smaller than those diameters, respectively; (2) Grain size analysis tests using dispersing agent for the subgrade material; (3) USCS = Universal Soil Classification System; (4) HRB = Highway Research Board/AASHO.

The fill material consisted of a gravel layer 200mm thick. The main properties of the gravel are presented in Table 1. The fill layer was manually compacted under optimum moisture conditions to reach a final density of 18 kN/m^3.

Two geosynthetic reinforcement materials were employed in the tests. The properties of such materials are summarised in Table 2. The biaxial geogrid is made of polypropylene, with a tensile stiffness of 600kN/m and square apertures of 40mm. The woven geotextile is also made of polypropylene, with a tensile stiffness equal to 600kN/m in both the warp and weft directions. Both geosynthetic products have the same tensile stiffness but different interaction mechanism with the surrounding soils (Palmeira 2009). In all tests performed the geosynthetic layer was positioned at the fill-foundation soil interface.

Table 2. Properties of the geosynthetics used in the tests.

Property	Woven Geotextile	Geogrid
Tensile stiffness (kN/m)$^{(1, 2)}$	600	600
Tensile strength (kN/m)$^{(2, 3)}$	80	30
Maximum tensile strain (%)$^{(2)}$	15	10
Aperture dimensions (mm)$^{(4)}$	---	40
Filtration Opening Size (mm)	0.10	---

Notes: (1) At 2% strain, (2) From wide strip tensile tests; (3) Warp and weft directions; (4) Square apertures.

3 RESULTS OBTAINED

The variation of plate settlement versus number of loading cycles for the 1st loading stage is presented in Figure 2. The 25mm plate settlement was reached for a number of cycles (N) equal to 30,720 for the unreinforced road, 282,600 for the geogrid reinforced road and 85,044 for the geotextile reinforced road. These figures yield to traffic benefit ratios (TBR, equation 1) for the geotextile and geogrid reinforced roads of 2.8 and 9.2, respectively. These values show that the geogrid was more efficient than the geotextile in restraining lateral movement of the fill material. It is interesting to notice the sudden increase on the plate settlement in the test with the geogrid for N equal to approximately 243,000. Post-test investigations showed that this behaviour was due to the breakage of gravel particles in that test, which was more severe than in the other tests conducted because of the larger number of load repetitions. The results in Figure 2 show the significant influence of the presence of geosynthetic reinforcement to improve the performance of the road, particularly for the test with the geogrid, despite gravel particles breakage.

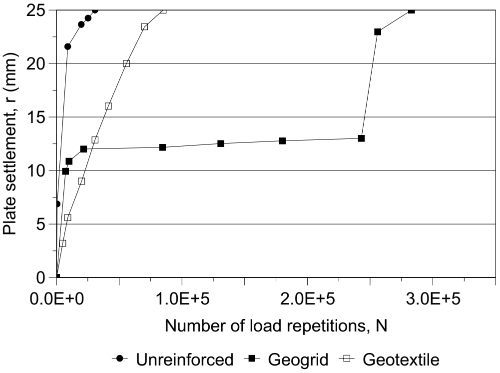
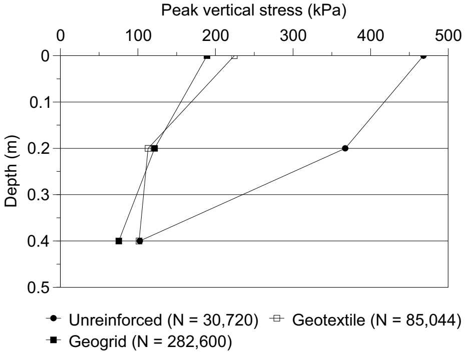
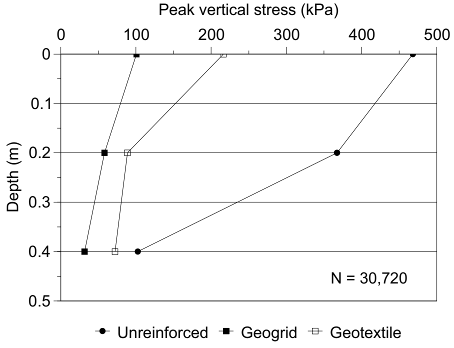


Figure 2. Plate settlement vs. number of load repetitions – 1st loading stage.

The variations of peak vertical stress with depth are depicted in Figures 3(a) and (b). Figure 3(a) shows the results obtained at the end of the tests. It is clear the benefit of the presence of the reinforcement in reducing the vertical stresses transmitted to the foundation soil, again with the best performance provided by the geogrid reinforcement. At the end of the tests the results of the geotextile and of the geogrid reinforced fills were similar, despite the better performance of the latter in terms of number of loading repetitions (N). However, one should bear in mind the influence of the breakage of gravel particles in the test with the geogrid reinforced fill, which must have influenced the values of stress increments that reached the subgrade soil. Figure 3(b) shows the comparison between vertical stress versus depth for N = 30,720 (end of the unreinforced test), where it can be seen that the presence of the reinforcement layer caused reductions on vertical stresses between 54% (test with the geotextile) and 78% (test with the geogrid) with respect to the unreinforced test. In this case, prior to gravel particles breakage, the contribution from the geogrid reinforcement in reducing vertical stress increments in the subgrade was substantially greater than that of the geotextile reinforcement. Similar benefits from the use of reinforcement were observed for the peak strains measured in the subgrade.



(a) At the end of the test.



(b) For N at the end of the unreinforced test.

Figure 3. Peak vertical stresses – 1st loading stage.

After the maintenance of the 25mm deep depression of the road surface reached at the end of the first loading stage, the second loading stage on each road was applied. Figure 4 presents the variation of plate settlement with number of load repetitions during the second loading stage, after the first repair of the road surface. The 25mm plate settlement was reached after 25,164 load repetitions for the unreinforced road, whereas for the geogrid and geotextile reinforced roads that settlement was reached for values of N equal to 210,906 and 58,698, respectively. The geogrid reinforced fill presented a stiffer response under loading since the beginning of the test. No sudden change in the curve for the geogrid reinforced road can be observed in Figure 4, as most of the gravel particle breakage occurred in the first loading stage of the test. A similar trend of results was observed for the 3rd loading stage.

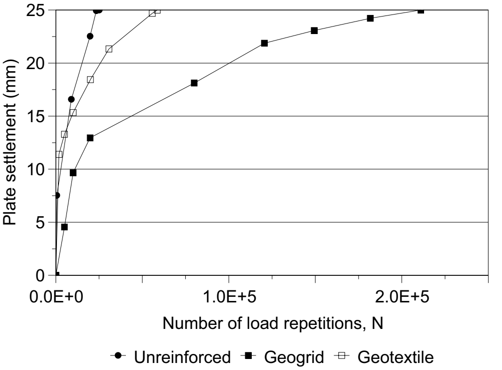


Figure 4. Plate settlement vs. number of load repetitions – 2nd loading stage.

The values of N at the end of the tests in Figure 4 yield to TBR (equation 1) values of 2.3 for the geotextile reinforced fill and 8.4 for the geogrid reinforced fill. With respect to the values of TBR obtained at the end of the first loading stage, these values indicate a 17.9% reduction for the geotextile reinforced fill and an 8.7% reduction for the fill reinforced with geogrid. Despite these reductions, the reinforced fills maintained a significantly better performance in comparison to the unreinforced one after the first surface repair.

Figure 5 shows the values of TBR for each loading stage. The TBR value for the geotextile reinforced fill is rather constant, whereas for the geogrid reinforced fill a steady reduction with the number of loading stages can be noted. These results show that even after two surface repairs, the presence of the reinforcement layer is still capable of improving considerably the performance of the fill. Under real conditions, this medium to long term benefit brought by the reinforcement has seldom been considered when evaluating the cost-effectiveness of this type of solution on a routine basis.

4 CONCLUSIONS

This paper presented an experimental study on the use of geosynthetic reinforcement in unpaved roads on poor subgrades. The results obtained showed that the presence of the reinforcement increased significantly the number of load repetitions needed for a given rut depth to be reached in comparison to the unreinforced road. The stresses transmitted to the subgrade were also considerably reduced in the reinforced roads.

The tests carried out after the maintenance of the road surface (loading stages 2 and 3) showed that the performance of the reinforced roads continued to be significantly better than that of the unreinforced one, particularly when geogrid was used as reinforcement. This highlights the benefits brought by the use of geosynthetics in this type of application.

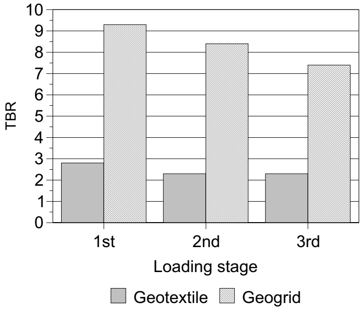


Figure 5. TBR values for each loading stage.

ACKNOWLEGEMENTS

The authors are indebted to the following institutions for their support to this research: FAP-DF, CNPq, University of Brasília and Huesker Geosynthetics for providing the products used in the tests.

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