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Technical viability analysis of geogrid-reinforced unpaved roads in cyclic loading test

E.S. Ferreira, Catholic University of Brasilia, Brasilia, Brazil,
G.M.D. Vieira, Catholic University of Brasilia, Brasilia, Brazil,
M.V. Souza, Catholic University of Brasilia, Brasilia, Brazil,
I.A.M.G. Góngora. Catholic University of Brasilia, Brasilia, Brazil.

ABSTRACT

Although the study on the use about geosynthetics is quite recent, considering the beginnings of geotechnical engineering, the positive results obtained with its application in several works make this theme increasingly developed. Aiming at improving the technical viability of unpaved roads, this work proposes the use of a type of geosynthetic, the geogrid, in a comparative study between different unpaved road simulations. This type of road is known to constitute over 89% of Brazilian roads, denoting its relevance. In the study, road simulations involving embankments with steel slag and gravel 1 were performed on large equipment that applies cyclic loading, which in turn resembles vehicle crossing on a real road. With an analysis of the data obtained, it was found that the roads containing or geosynthetic had a greater number of cycles when put load, which represents, under real conditions, the increase of road life.

1. INTRODUCTION

Unpaved roads, also popularly known as “dirt roads”, are roads that have no surface treatment, bitumen or Portland cement (Oda et al., 2001). However, problems may be linked to these structures such as excessive dust, sinking wheel tracks and potholes, often due to lack of periodic maintenance (Santos et al., 1988).

Since unpaved roads make up 89% of Brazil’s road network, according to the National Transportation Confederation – (CNT,2018), it is noteworthy to develop solutions that optimize the life of these roads. Oda et al (2011) he adds that while many believe that the solution to the problems of unpaved roads comes down to asphalt paving, such an implementation is costly and with proper maintenance would be possible to solve such situations. One solution found to reduce ongoing maintenance costs is to reinforce the structure using industrialized materials such as geosynthetics.

According to Brazilian Standard NBR ISO10318-1 (2018), geosynthetics are products derived from polymeric materials, synthetic or natural, used in various areas of engineering with the functions of drainage, filtration, protection, reinforcement, separation, surface erosion control, barrier, and stress relief. In this context, the geogrid was adopted for the development of this study, due to the tensile strength it provides an interaction with the soil.

The concern with the environment is currently known to be of great relevance, so this study also brings an analysis of the viability of using steel slag (EA) as a backfill material on unpaved roads. Steel slag is a waste generated in steel productions during the iron refining process, being found in abundance in the country. Therefore, employing it in civil construction emerges as a possibly viable option in environmental, technical and/or financial matters. According to Motz and Geiseler (2000), the most important properties of the steel co-product are bulk density, shape, resistance to fragmentation (resistance to impact and crushing), strength, water absorption, resistance to freezing and thawing, volume stability and resistance to abrasion and polishing.

Finally, in view of these demands, the following study aims to analyze the performance of unpaved roads through laboratory tests, using large equipment that simulates the passage of vehicles through the application of cyclic loading in the road. In the comparative study four roads were simulated, two consisting of (EA) as backfill material: with and without geogrid reinforcement. And two made of gravel 1 as backfill material: with and without geogrid reinforcement. All have sand subgrade.

2. MATERIAL AND METHODS

2.1 Backfill Material: Steel Slag

The EA used in this work was obtained from a deposit in Minas Gerais (Brazilian state) and underwent previous treatment before being used in the tests. The treatment of EA is extremely important because its expandability, which depends on its mineralogical composition, can cause loss of strength and disintegration (OLUWASOLA et al., 2014). Since there is no standard or criterion of EA, it is important to study the mineralogy and micro-roughness of the material.

According to Raposo (2005) apud Anderson (1984); Tosticarelli et al., (1985); Gumeri et al., (2000); Kuehn et al., (2000); Robinson (2000); Thomas (2000); Azevedo (2001); Geyer (2001) one of the preventive treatments for the expansion of solid state EA is the disposal of the material in an outdoor patio where it is crushed and stacked. After this procedure, EA can be treated by exposure to weather in conditions of temperature and humidity, called *weathering* and which may be accompanied by water spray over time.

The initial treatment of EA performed in this study was through the crushing of the material, whose largest particle diameter resulted in (through the material in ¾" sieve), particle size similar to gravel to the purpose of comparing laboratory tests. The crushed EA then underwent aa water washing procedure and was disposed on the canvas. Figures 1, 2 e 3 express the treatment of EA.

Figure 1. EA crushing.

Figure 2. EA wash with water.

Figure 3. EA arranged on canvas.

2.2 Backfill Material: Gravel 1

The gravel used in this research was commercially known as number 1, which has a maximum grain diameter of 19mm and whose origin is limestone and comes from the Guapó quarry, located in the state of Goiás.

2.3 Subgrade Material: Sand

In the subgrade layer of the pavement structure, loose sand was used, whose characteristics are presented below in Table 1 and Figure 4.

Test	Kid aggregate
	Sand
Specific Mass per *Chapman* bottle (g/cm^3)	2,57
e natural	0,51
e maximum *e* minimum	0,73 0,49
Dr(%)	89,8
C	0,000
θ	36,8˚

Table 1. Sand properties

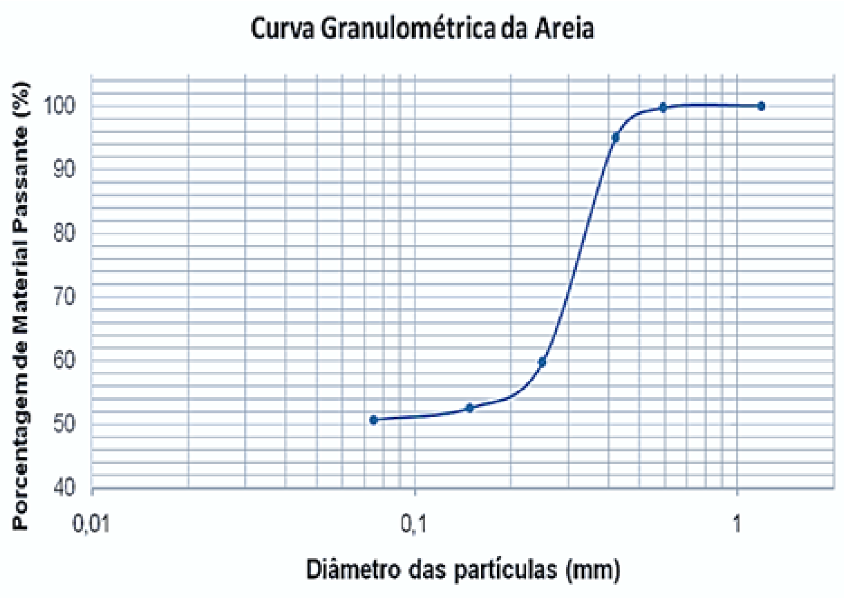

Figure 4. Sand particle size curve

2.4 Reinforcement Material: Geogrid

For the present study, it was determined the use of the geogrid, which still according to the NBR ISO10318-1 is a type of geosynthetic that has a planar polymeric structure consisting of an open mesh of tensile-resistant elements, which can be joined by extrusion, welding or interlacing and whose openings are larger than the constituent elements.

In this case, the geogrid, geosynthetic of interest for this work, has the functions of reinforcement and separation (of materials, when it is desired that they do not meet or mix). According to Vertematti (2015), the increase in the structural capacity of the granular layer with the use of geogrids occurs through four main mechanisms: interlocking, tensile stress, confinement, and separation, explained below:

- Geogrid application can provide or increase interlocking between grains at the subgrade interface by inhibiting aggregate lateral movement;
- improves "abrasion resistance" with low deformations in the base layer;
- Provide uniform aggregate confinement at the subgrade interface. The increased confinement of non-cohesive materials in this region provides increased strength and resilient modulus of granular materials, enabling a reduction in granular layer thickness and total deflection of the structure;
- May inhibit aggregate penetration into the subgrade while maintaining the thickness of the granular layer;

In addition to the above features, the use of geogrid is also very efficient in reducing wheel tracks on flexible pavements. Figure 5 below shows the geogrid used in the work and Table 1 summarizes the main features of it.

Figure 5. Geogrid used in the study (Góngora 2015)

Geogrid Properties	
Mesh Opening (mm x mm)	18,4 x 21,0
Equivalent Opening (mm)	19,66
Manufacturing Material	Poliéster
Tensile Strength MD (Manufacturing Direction) (kN/m)	109
Rigidity modulus at 5% deformation MD (Manufacturing Direction) (kN/m)	893

Table 1. Properties of the geogrid used in the study (Góngora 2015)

2.5 Equipment

For the development of this study, we used large equipment located in the geotechnical laboratory of the University of Brasilia (UnB). The equipment was built to meet Góngora's work (2015), to simulate vehicle traffic on unpaved roads by applying cyclic loads.

The equipment is consist of a cylindrical tank that has 1m of internal diameter and 0,52m of height. Thus, to better represent a part of the unpaved road in small size, 30cm was used as the thickness of the embankment layer, with EA and gravel 1 and 22cm of sand subgrade. The geogrid used in the reinforcement tests was introduced at the interface between the subgrade layer and the embankment for anchoring. The following figure shows the arrangement of the equipment.

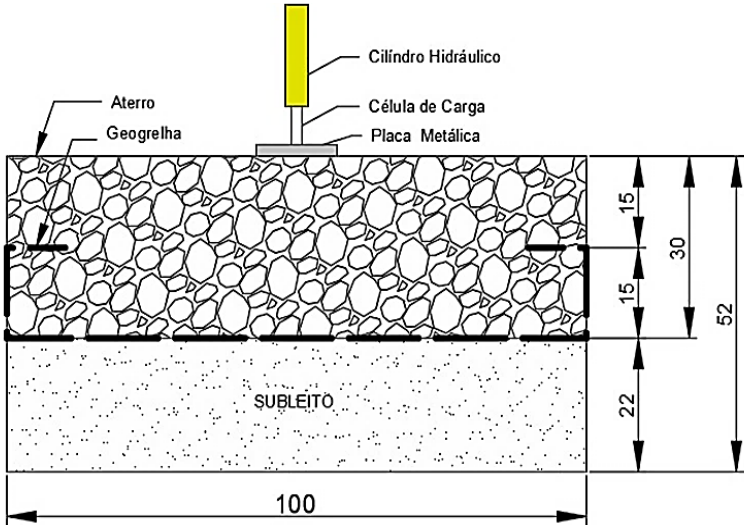

Figure 6. Arrangement of equipment used for cyclic loading tests

The test consists of successive loads on a rigid plate of 0,20m diameter to simulate the wheel load of an 80KN axle load vehicle. Cyclic loading, carried out through a hydraulic system, was applied through loads of approximately 18KN to produce a maximum pressure of 560kPa – in general, Brazilian pavements are sized to withstand this pressure, which is the project load – on the surface. The load application frequency was 1Hz, simulating vehicle traffic.

Several authors such as Cancelli et al. (1996), Perkins et al. (1999), Leng (2002), Abu-Farsakh et al. (2010), Góngora (2011) among others, made tests using systems similar to the one used in this work. Ibrahim et al. (2017) evaluated different geosynthetic placement positions, between the base and subgrade interfaces, which he called B0, 1/3 of the base layer, B1 / 3h, ½ of the base layer, B1 / 2h and on the surface, Bh. Figure 7 shows one of the strain gauge measurements, revealing that the geosynthetic road at 1/3 of the base has the lowest deformations for the same applied stress compared to other arrangements.

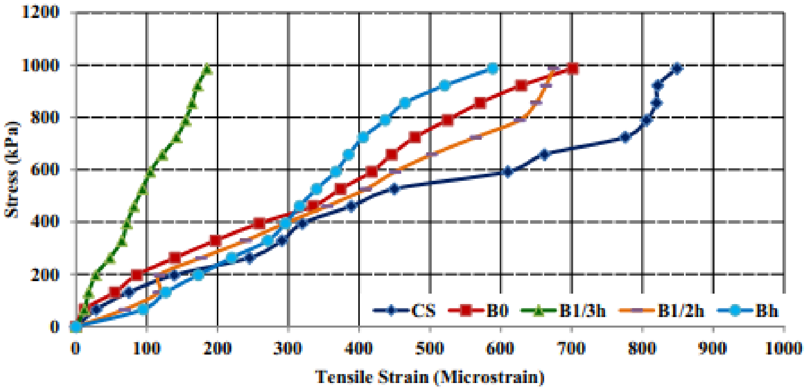

Figure 7. Stress versus measured strain at the middle depth of the base layer for all cases

However, in this work, the positioning of the geogrid between the base and subgrade layers was chosen due to its ease of execution and not being the focus of the article. The real focus assessed the use of geosynthetics and alternative material.

2.6 Instrumentation

The load cell was placed to measure the load applied by the hydraulic cylinder, while the displacement meters measured the plate settlement
. For the monitoring of the tests was used a data acquisition system manufactured by the company LYNX, model ADS 2000. The data acquisition system was operated by AqDados 7 software, thus enabling the acquisition of data from the channels.

2.7 Cyclic Loading Tests

2.7.1 Equipment preparation

Prior to the start of the tests, it was necessary to wrap the inner part of the cylindrical tank (shackle) with plastic and Vaseline to reduce the lateral friction between the soil and the equipment (Figure 8).

Figure 8. Preparation of cylindrical tank

2.7.2 Subgrade layer preparation

The subgrade layer was simulated with loose sand. To obtain this state of the material, a condition in which it has a higher void index and lower carrying capacity, the sand was deposited at a height of approximately 10cm. The sand was arranged in two layers of 12 and 10cm.

2.7.3 Reinforcement preparation (geogrid)

As explained in item 2.5, the geogrid used in the work was placed between the subgrade and embankment layers. The material was cut to a diameter of 1,50m and embedded in the backfill layer. Figure 9 shows the development of geogrid placement in the equipment.

Figure 9. Geogrid installation

2.7.4 Preparation of the backfill layer

The backfill with EA was deposited in 3 layers of 10cm, where for each layer slight compaction was performed with the help of a metal plate with a diameter smaller than the inside diameter of the tank and the load application equipment. The total layer resulted in 30cm, thickness commonly used on roads.

2.7.5 Displacement meter installation

As shown in figure 10 below, it is possible to observe the displacement meter installed on a plate supported on the road surface. Three displacement meters were installed, two of them close to the load application axis, on the edges of the metal plate and the side of the road surface.

Figure 10. Displacement meter installation

2.7.6 Execution of the test

After test preparation and instrument installation, the test was started by switching on the load application system. As some tests can withstand a large number of cycles, the maximum stopping load of 75mm or 270.000 cycles has been established as a test interruption criterion. This step was called the first load stage.

After the completion of the first stage of loading, the second stage begins, which consists of restoring the region where the sinking occurred, taking care to maintain the same compaction conditions of the previous test. The interruption criterion used was the same as in the first stage. This backfill restoration was performed to simulate what happens in the maintenance of unpaved roads.

3. RESULTS

3.1 Analysis of Displacements in the First Stage of Loading

According to the laboratory tests with cyclic loading, it was possible to construct the graphs of displacement versus the number of cycles, which represents the sinking of the road and the number of cycles supported by it. Figure 11 below shows the results for the first loading stage of the 4 tests performed: BSR (Gravel without reinforcement); BCR (Gravel with reinforcement); EACR (Steel slag with reinforcement) e EASR (Steel slag without reinforcement). The tests BCR, EASR e EACR did not reach the maximum displacement of 75mm, thus, the curvature of the tests and the number of cycles were determinant parameters for the finalization of the first loading stage.

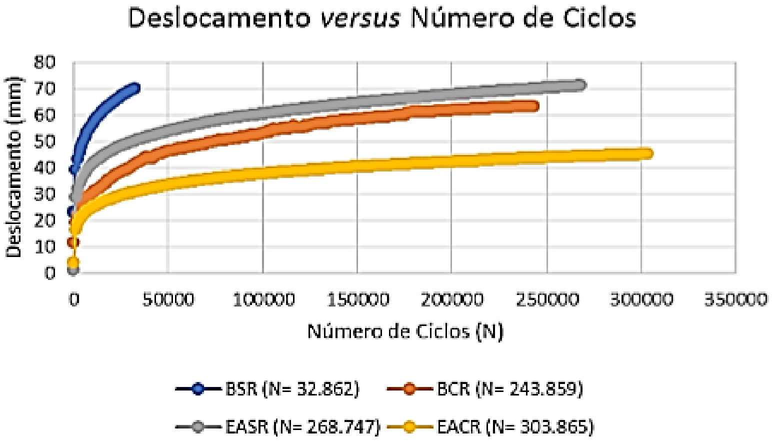

Figure 11. Loading plate vertical offsets (mm) *versus the* number of load cycles (N) – First load stage

In figure 12 below the results for the first loading stage, were placed such that the number of cycles for the 4 test types was evaluated over the same cycle range as the conventional test, BSR, which withstood 32.862 cycles. Thus, it was possible to more clearly evaluate the behavior of the curves in the different tests.

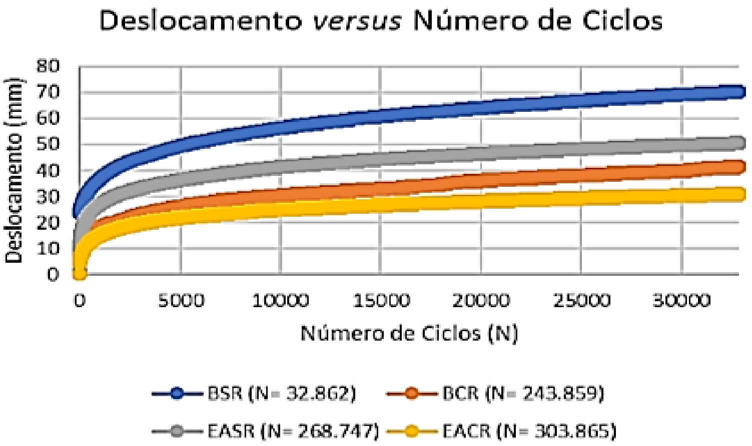

Figure 12. Loading plate vertical offsets (mm) *versus* the number of load cycles (N) – First load stage - Para N = 32.862

3.2 Analysis of Displacements in the Second Stage of Loading

Figure 13 below shows the displacement values and the number of cycles obtained in the second load stage for the 4 types of tests performed. It is noteworthy that the stopping criterion of this stage was N= 270.000 cycles. From the results, it was possible to realize that the EASR and EACR tests presented the best performances since they presented the lowest deformation values for the same number of cycles. Comparing the results to the conventional road, BSR, which showed a maximum displacement of 63,09mm, the BCR test reduced the road sink by 35,24%, while for the EASR and EACR tests there was a reduction of 58,74% and 70,33%, respectively.

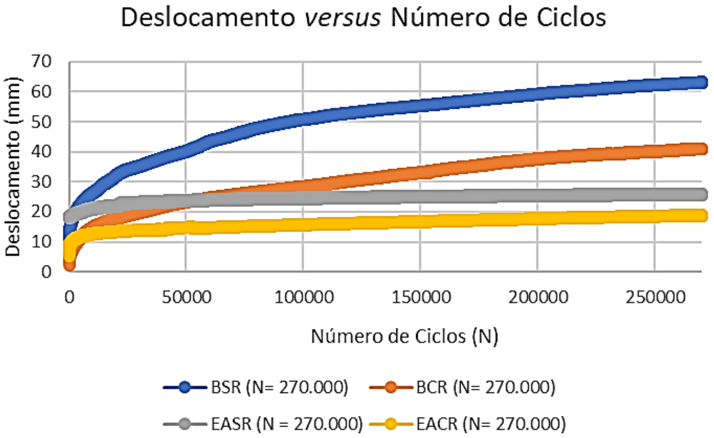

Figure 13. Loading plate vertical offsets (mm) *versus* the number of load cycles (N) – Second load stage

3.3 Cyclic Loading Test Efficiency Factors

In order to analyze the efficiency of the materials used and the respective reinforcements, the Efficiency Factor (E), was calculated for each test performed. E is calculated by the ratio between Nr (number of cycles supported in each test) and Nu (number of cycles supported by the road to be compared). For the results of this study, which did not reach the 75mm displacement, it was necessary to calculate a Modified Efficiency Factor (E*), calculated through the following equation 1, as studied by Góngora (2015):

$$E^* = \frac{Nr}{Nu}\frac{\rho u}{\rho r} \quad [1]$$

Where Nr is the number of load repetitions in the reinforced test when it is discontinued, Nu is the number of load repetitions at the end of the non-reinforced test, ρu plate settlement at the end of the non-reinforced test and ρr is the plate settlement in the reinforced test when discontinued.

In the first situation shown in Table 2 below, modified efficiencies were performed for the tests BCR, EASR, and EACR by comparing them to the conventional test BSR.

Test	Nr (cycles)	Nu (cycles)	ρu (mm)	ρr (mm)	E*
BCR	243859	32862	70,39	63,12	8,28
EASR	268747	32862	70,39	71,65	8,03
EACR	303865	32862	70,39	45,47	14,31

Table 2. Modified efficiency for first load stage compared the conventional system

Table 3 below shows the values of the modified efficiencies when compared to the conventional second stage loading system.

Test	Nr (cycles)	Nu (cycles)	ρu (mm)	ρr (mm)	E*
BCR	270000	270000	63,09	40,86	1,54
EASR	270000	270000	63,09	26,03	2,42
EACR	270000	270000	63,09	18,72	3,37

Table 3. Modified efficiency for second load stage compared the conventional system

The modified efficiency values of the reinforced tests and the non-reinforced tests for each aggregate were also compared. Table 4 below shows the results for the first loading stage.

Test	Nr (cycles)	Nu (cycles)	ρu (mm)	ρr (mm)	E*
BCR	243859	32862	70,39	63,12	8,28
EACR	303865	268747	71,65	45,47	1,78

Table 4. Modified efficiency of geogrid reinforced tests for the first loading stage

Table 5 shows the modified efficiency values of the reinforced tests of each aggregate for the second loading stage.

Test	Nr (cycles)	Nu (cycles)	ρu (mm)	ρr (mm)	E*
BCR	270000	270000	63,09	40,86	1,54
EACR	270000	270000	26,03	18,72	1,39

Table 5. Modified efficiency of geogrid reinforced tests for the second loading stage

4. DISCUSSION AND CONCLUSIONS

Through the analysis of the cyclic loading test results, it was possible to verify the technical viability of the use of EA on unpaved roads. The increase in the number of cycles obtained in the EA tests, when compared to the conventional system (use of unreinforced gravel) revealed a better efficiency of the road and the consequent increase of the service life. This result may be even more relevant when using geosynthetic reinforcement, the values obtained showed a significant improvement in the mechanical properties of the road. It was also observed that the efficiency values obtained in the BCR test were close to the EASR test results, which also demonstrates the viability of the EA.

In addition, it is noteworthy that the application of EA on the road would result from the reuse of a waste, which would generate environmental and often economic gains. Also, as evidenced by the increased life of this road, there would be fewer maintenance costs over the years. However, the importance of previous treatment of EA before its use is emphasized due to its high expansive content, avoiding problems such as the appearance of cracks.

It is suggested that other types of analysis be performed on the subject of this study, using the simulation with cyclic loading on a paved road that has as lateritic soil subgrade and reinforcement with different types and sizes of geosynthetics. Also, make an economic viability study between the use of EA and gravel.

It is also recommended that simulations of cyclic loading tests be performed through modeling in an area software.

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