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Numerical Analysis of Unpaved Roads Subjected to Surface Maintenance

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***Abstract* -** Geosynthetics have proven to be beneficial in reinforcing soils, especially in problems with large deformations, such as unpaved roads built on soft soils and subjected to high loads. Due to heavy machinery traffic, this situation occurs even during the construction period of the road, in which is necessary to perform surface maintenance to the execution of the fill layers. Several experimental studies have indicated an improvement in the mechanical performance of unpaved roads when subjected to surface maintenance. The present research aimed at numerically investigate the behavior of unreinforced and reinforced unpaved roads subjected to surface maintenance. The analyses consisted of the following steps: determination of geostatic stresses in the subgrade; inclusion of the fill layer, as well as the geosynthetic reinforcement at the interface between the materials; application of a distributed load on the fill; unloading; execution of the surface maintenance from the deformed configuration of the fill; and reapplication of the load. The results indicate that the mechanical behavior of these roads will be better represented by the sequence described. Furthermore, relevant information on loads in the reinforcement and influence of material properties were obtained.

***Keywords*:** Geosynthetics, Unpaved Road, Large Deformations, Surface Maintenance, Numerical Analysis.

1. Introduction

Unpaved roads are predominant in Brazil's road modal and play an important socioeconomic role for rural dwellers, as well as for the forestry, mining, and agriculture industries. These roads, especially when made of weak subgrades and subjected to high loads, constitute a problem of large deformations, motivating the use of reinforcement alternatives such as geosynthetics. Among their benefits are an increase in the service life of the road, a reduction in construction costs by decreasing the thickness of the embankment layer, and an increase in the time required for periodic maintenance interventions [4].

The types of geosynthetics most used as reinforcement in unpaved roads are geotextiles and geogrids. Reinforcements, particularly geogrids, improve road performance mainly by enhancing the lateral confinement mechanism, guaranteed by the interlock between geosynthetic and aggregates, and by the membrane effect, mobilized from the wavy shape of the geosynthetic when subjected to large deformations [8]. In the case of geotextiles, these can also contribute as a separation element, minimizing the contamination of the fill material by subgrade fines.

Due to heavy machinery traffic, this scenario of large deformations occurs even in the road construction period, requiring continuous filling of wheel tracks during the execution of the fill layers [11]. Several authors have experimentally shown the benefits of surface maintenance on the mechanical performance of roads, particularly in reinforced cases, due to the additional traction provided in the geosynthetic [1, 5, 6, 7].

Several numerical works have evaluated the performance of geosynthetics as reinforcing elements using the Lagrangian formulation of the Finite Element Method, proposed by [2], to successfully model large deformation mechanisms [3, 9, 10]. This formulation involves updating the nodal coordinates of the elements during the analysis, although it is not restricted to this [12]. On the other hand, there are not known results of numerical analyses that consider the surface maintenance required since the road execution phase.

The objective of this research is to numerically evaluate, with and without the presence of geosynthetic reinforcement, the performance of unpaved roads built on soft soils after surface maintenance due to excessive deformation. To this end, the tests performed by [5] were simulated.

2. Experimental test

The author [5] developed a reduced model built in 1/10 scale, as shown in Figure 1. This model is basically composed of the following items: metal box with acrylic front face and dimensions of 80 cm × 22 cm × 30 cm; bottom and top drainage layer; layers of fill, subgrade and geosynthetic reinforcement; a load cell and two metal plates for load application, being one of them only used in the consolidation stage of the soft soil applied in the subgrade.

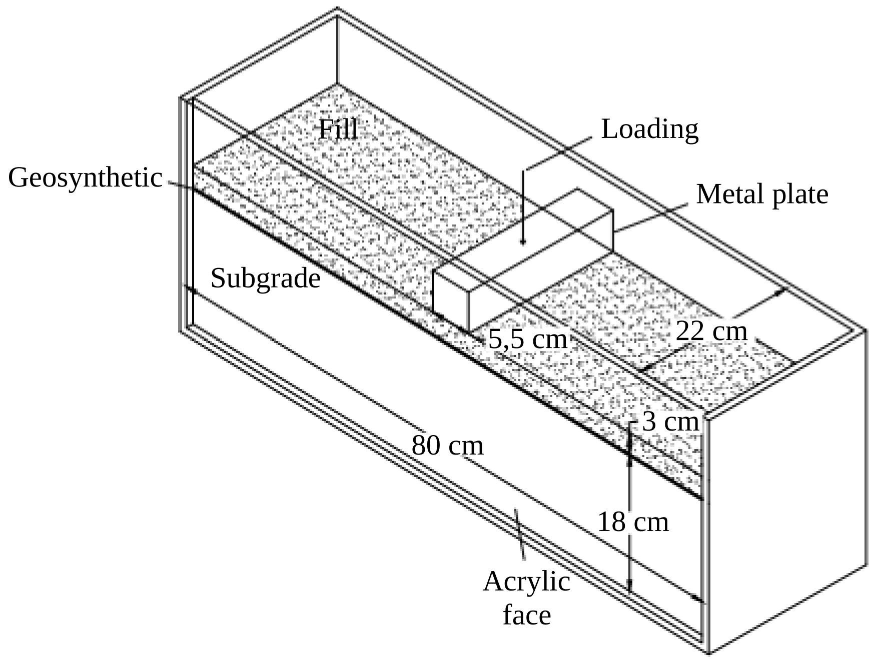

Fig. 1: Experimental model [5 – modified].

The test preparation consisted in the assembly of successive layers inside the metal box, starting with the geosynthetic that acted as bottom drainage and then the layers of subgrade, non-woven geotextile reinforcement (when applicable) and the upper drainage layer to prevent the material outflow during consolidation, which was performed using a plate that covered the entire area of the box. Next, the fill layer was applied using the "sand shower" method. The soft foundation soil was obtained by a mixture of water and kaolin, while the fill material was composed of a mixture of kaolin and fine to medium sands.

The metal plate was then positioned over the layers for the vertical application of a centered monotonic loading at a constant displacement rate of 1.5 mm/min, which ensured the undrained failure condition of the soft soil. After reaching the road's bearing capacity, the fill surface was restored with the same material used initially, thus filling the gap generated by the footing. Finally, a new loading phase was performed, analogous to the first one. The failure of the road occurred for vertical displacements of the order of 1.5 cm to 2.5 cm in the scale model.

3. Numerical simulation

Stress-strain analyses were performed under plane strain condition using the Finite Element Method by means of PLAXIS 2D software. The material properties were modeled appropriately as a function of the geometric scaling factor used.

2.1. Geometry and boundary conditions

The symmetry of the experimental model was used to represent only half of the geometry in the analyses. Horizontal displacements were restricted on the sides of the model, while at the base the displacements of both directions (vertical and and horizontal) were restricted. It was adopted a mesh with 15-node elements refined in the regions close to the load application.

The tests were simulated with and without the Updated mesh option selected, which considers the Lagrangian formulation of the Finite Element Method. The following steps were adopted: determination of the geostatic stresses in the layer corresponding to the subgrade; inclusion of the fill layer, as well as the geosynthetic reinforcement and its interface elements (in the case of analyses with reinforcement); application of a distributed load on a rigid plate on the fill surface; removal of the applied load; insertion of the surface maintenance layer; and reapplication of the load. Table 1 presents these steps numbered in sequence and detailed by calculation type of PLAXIS 2D analysis.

Table 1: Steps of the numerical analysis without reinforcement.

Stage	Calculation type	Geometry	Loading
1	K0 procedure	Subgrade	-
2	Plastic	Subgrade and fill	-
3	Plastic	Subgrade and fill	First loading
4	Plastic	Subgrade and fill	Unloading
5	Plastic	Subgrade, fill and surface maintenance	-
6	Plastic	Subgrade, fill and surface maintenance	Second loading

The geometry of the surface maintenance, activated in step 5, was defined from the deformed configuration of the fill in step 4, i.e., when only the portion of plastic deformation resulting from the applied load was present in the model. For this purpose, it was included in the initial geometry of the analysis a polygon (inactivated in the first loading step) whose corresponding material fitted the fill sinking region, in order to simulate its maintenance. Figure 2 presents the test layout at the end of step 5, for an unreinforced case, highlighting the source and destination regions of the maintenance material during the simulation. These regions were identified, respectively, by the letters "A" and "B".

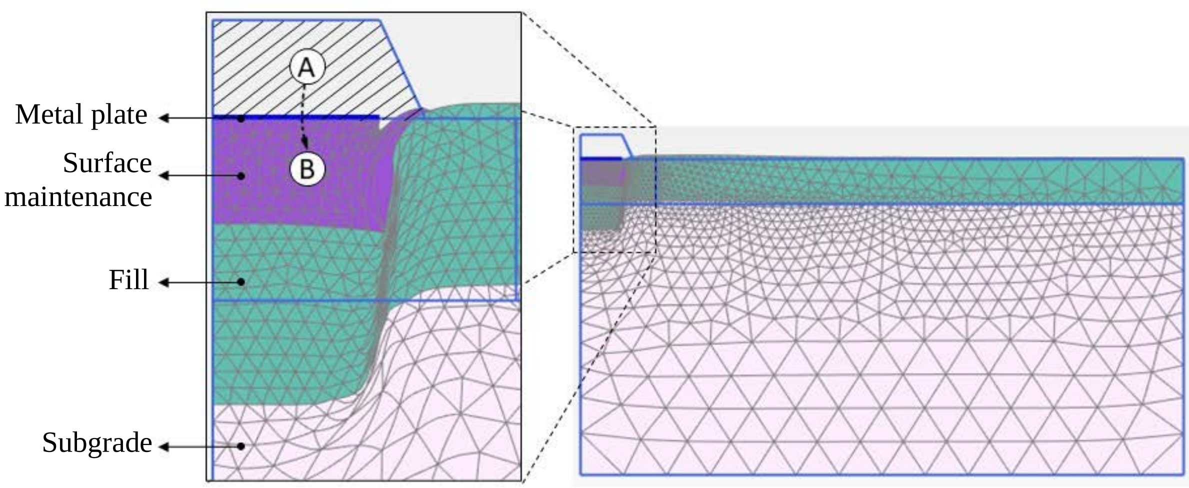

Fig. 2: Experimental model [5 – modified].

The fill and subgrade materials were represented by the elastic-perfectly plastic Mohr-Coulomb model. The values of the elastic parameters of Poisson coefficient (ν) and modulus of elasticity (E) were obtained by back analysis of tests without geosynthetic reinforcement. On the other hand, the values of cohesion (c'), friction angle (ϕ') and specific weight (γ) were obtained from the reference work. It is emphasized that, although the embankment does not consist of a cohesive material, a low cohesion value was assigned for numerical reasons.

Tables 2 and 3 show the parameters used in the soil layers. In the present work, an average value of undrained strength was used to adjust the results. The value observed at depth B' was adopted from the results of the vane test linearly increasing with depth, where B' is the base of the trapezoid of vertical stress distribution at the base of the fill layer for a spreading angle (θ) of 15°. This value was obtained by tests from [5] for unreinforced roads. Thus, the depth used in the determination of the average undrained strength was obtained by Equation 1, where "h" is the height of the fill layer and "B" is the width of the metal plate.

$$B' = B + 2 \cdot h \cdot tg(\theta) = 7.1cm \quad (1)$$

Table 2: Parameters of the fill material.

Material	c' (kN/m²)	ϕ' (º)	γ (kN/m³)	E (kN/m²)	ν
Fill	0,3	50	21	750	0,3

Table 3: Parameters of the subgrade material.

Material	Su (kN/m²)	γ (kN/m³)	E (kN/m²)	ν
Subgrade	3,3	21	205	0,49

4. Results

The road performance was represented by plots of pressure at the base of the plate (p) as a function of the vertical displacement of the road surface (δ). The pressure "p" was normalized by the characteristic undrained strength defined in the experimental test (Su), while the displacement "δ" was normalized by the width of the loading plate (B), as presented in Figures 3 and 4.

As concluded experimentally, the analyses with surface maintenance, especially those with Updated mesh option, showed higher ultimate bearing capacity when compared to the analyses without maintenance. It was also observed that the analyses with Updated mesh were more consistent with the experimental results when compared to the analyses without this function. A more pronounced difference was observed in the test with geosynthetic reinforcement, whose gain in bearing capacity is enhanced mainly by the membrane effect, mobilized at large deformations.

The results of these analyses (with the presence of reinforcement and Updated mesh option) indicated that the surface maintenance performed was responsible for an increase in the maximum strength force exerted by the geosynthetic (N_{MAX}). The value of 0.54 kN/m found in step 3 (first loading) increased to 0.80 kN/m in step 6 (second loading), as shown in Figure 5, which shows the axial force in the reinforcement for the region near the symmetry axis, by loading step. It was also observed that the geosynthetic reinforcement, although represented by the elastic model, remains tensioned after the unloading stage (N_{MAX}=0.26 kN/m) due to the plastic configuration of the fill positioned just above and the fill-geosynthetic adherence.

As for the parameters used, the undrained strength of the subgrade showed great influence on the bearing capacity achieved, as expected, showing the importance of the proper determination of this parameter.

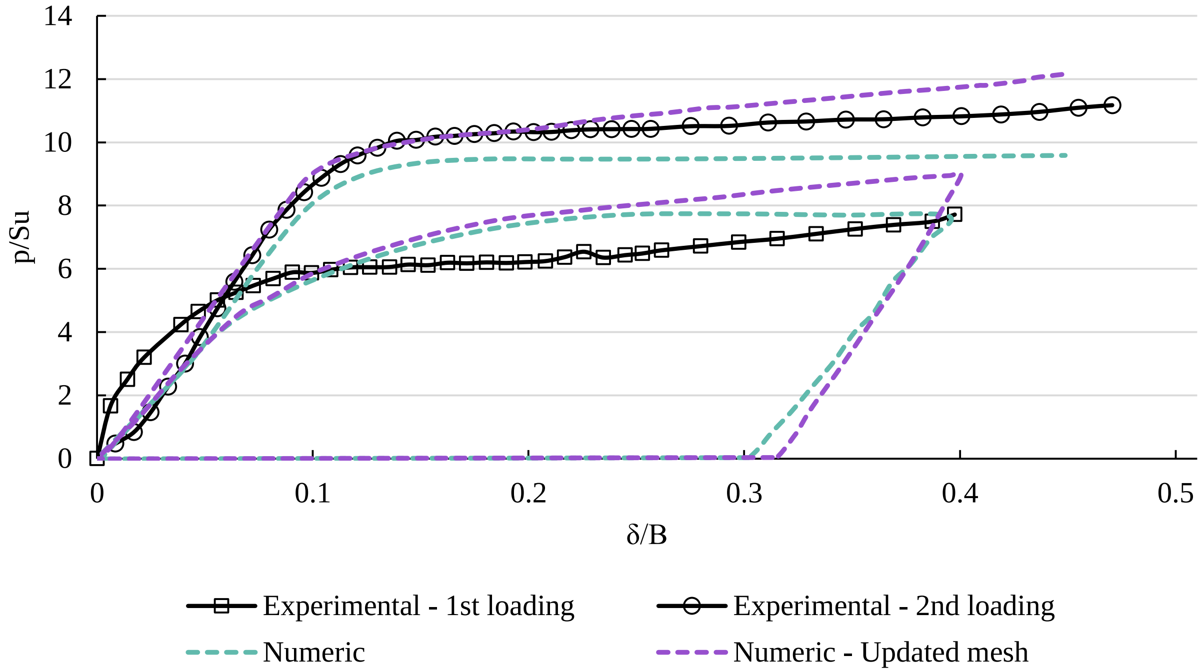

Fig. 3: Test without geosynthetic reinforcement.

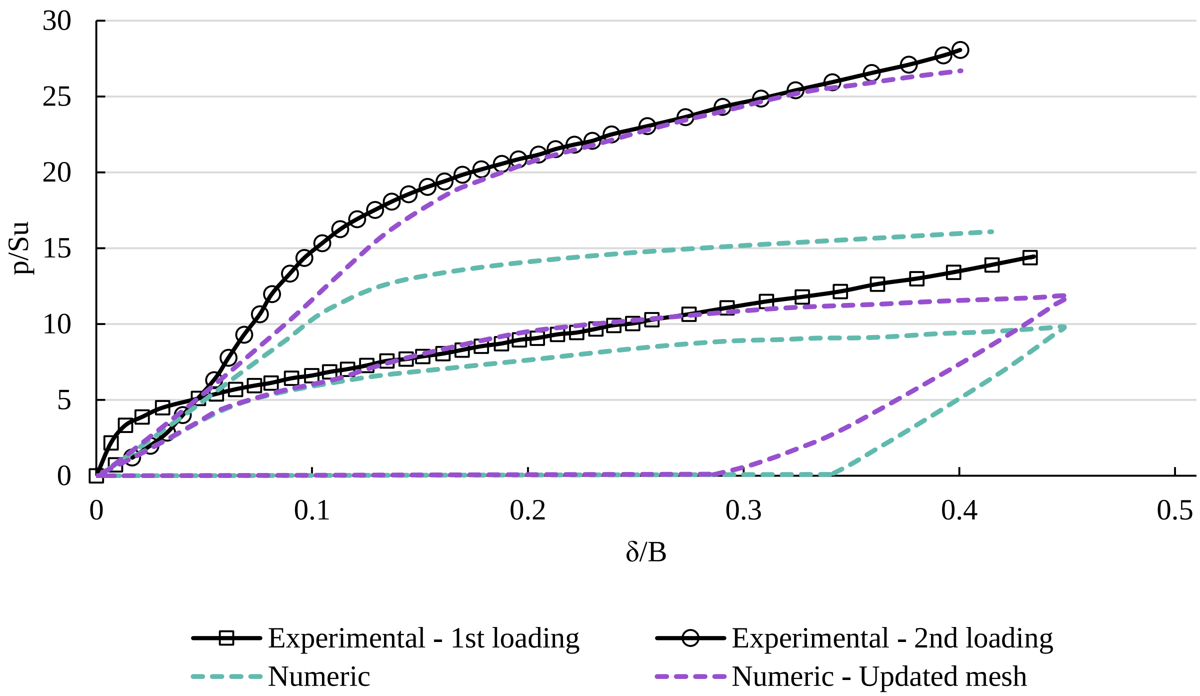

Fig. 4: Test with geosynthetic reinforcement.

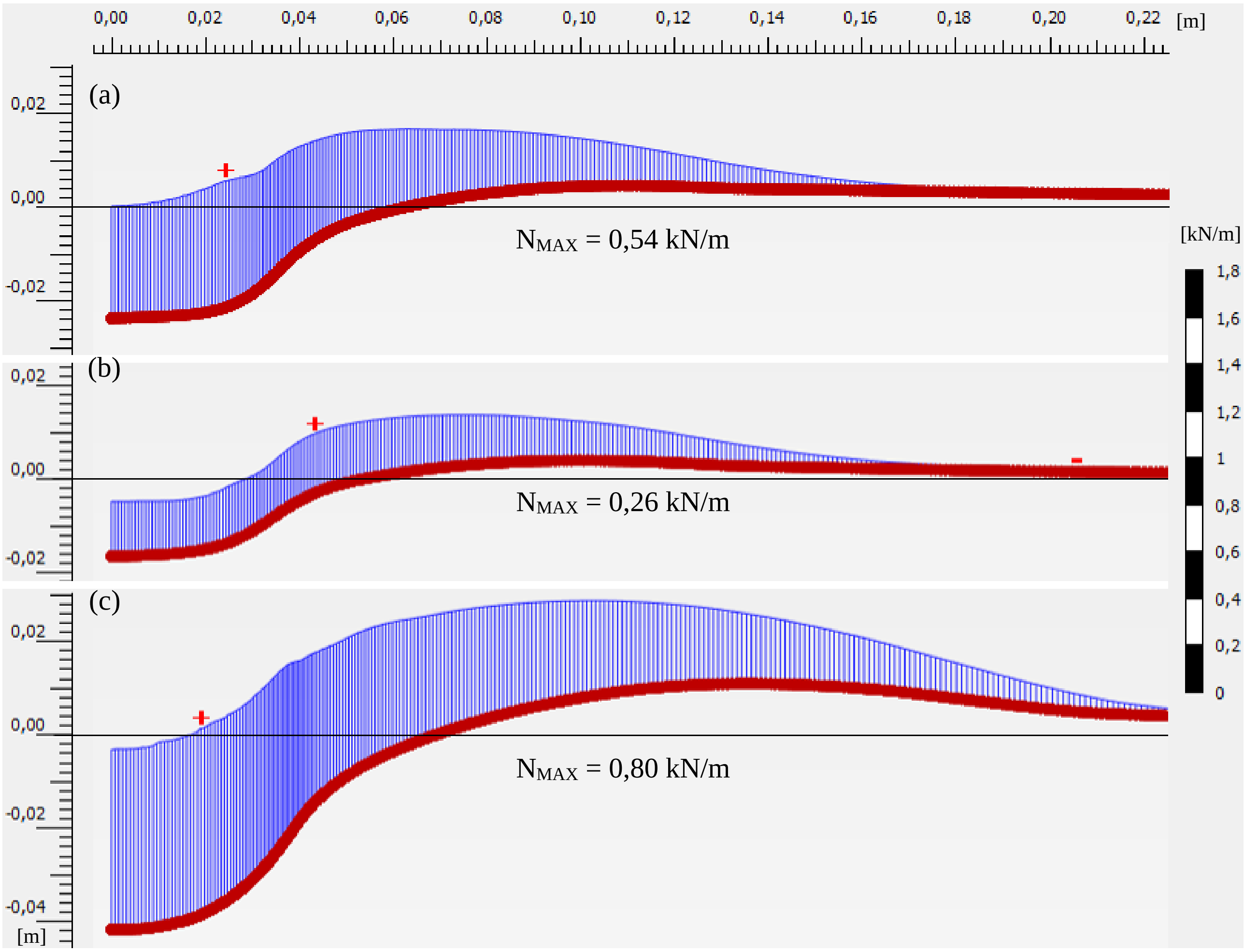

Fig. 5: Axial forces in the geosynthetic with indication of the maximum value location in the stages of: (a) first loading (step 3); (b) unloading (step 4); (c) second loading (step 6).

4. Conclusion

The present study confirmed the experimental results that indicate an increase in the bearing capacity of unpaved roads reinforced and subjected to surface maintenance. Moreover, by numerical simulation and parametric analysis it was possible to obtain relevant information such as loads in the geosynthetic, which could not be measured in the tests, and the influence of the properties of other materials.

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