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EMBANKMENTS ON SOFT SOILS - THE ROLE OF GEOGRIDS

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ABSTRACT

The construction of embankments on soft soils is a technically feasible option and has been adopted frequently by geotechnical engineering. To this purpose, geosynthetics - and especially geogrids - have been successfully used as reinforcements in earth works where soft soils are present. This paper discusses the use of geogrids as reinforcement in infrastructure works, where the presence of soft soils is a challenge for the definition of a road layout and for its economic viability. The method adopted in the present study consists on the development of some numerical modeling using a specific geotechnical software, simulating the execution of compacted embankments over clayey soil of low consistency, with and without the presence of geogrids, and studying the influence of the number of reinforcing layers, following the specifications of *British Standard BS 8006/2010 - Code of practice for strengthened-reinforced soils and other fills*.

KEYWORDS: Geogrids; Embankments; Numerical Modeling; Multiple layers

RESUMO

A construção de aterros em solos moles é uma opção tecnicamente viável e tem sido adotada frequentemente pela engenharia geotécnica. Para esse propósito, os geossintéticos - e especialmente as geogrelhas - têm sido utilizados com sucesso como reforços em obras de terra onde solos moles estão presentes. Este artigo discute o uso de geogrelhas como reforço de obras de infraestrutura, onde a presença de solos moles é um desafio para a definição do traçado da rodovia e para sua viabilidade econômica. O método adotado no presente estudo consiste no desenvolvimento de algumas modelagens numéricas, utilizando um software geotécnico específico, simulando a execução de aterros compactados sobre solo argiloso de baixa consistência, com e sem a presença de geogrelhas, e estudando a influência do número de camadas de reforço, seguindo as especificações da Norma Britânica BS 8006/2010.

1. INTRODUCTION

Physical and numerical modeling are used in geotechnical engineering as tools to fill knowledge gaps in cases where the observation of prototype behavior presents a high complexity degree and requires a long observation time to obtain conclusive results. In conventional physical modeling, it is not possible to reproduce the level of stresses acting in the field, which compromises the interpretation of the experiments, especially in quantitative terms. In addition, it is important to note that research using reduced models have some limitations, although allow the repetition of tests and the control of boundary conditions more easily than when studying a real scale geotechnical problem (CAMPOS AND SOUSA, 2014).

When it is used numerical modeling, focus of this article, it is necessary to know the materials’ properties directly involved in the problem and also the mathematical models that satisfactorily represent the behavior of these materials. A lot of real cases of geotechnical works had their design studies recently based on numerical models. Assis and Oliveira (2017) point out that, when well executed, numerical models provide useful observations with predictions of complex systems, helping in understanding the modeled problem and in the associated risk assessment.

In this scenario, the present paper makes use of numerical models to study the problem of embankments on soft soils found in various regions in Brazil, considering the use of geosynthetics - more specifically geogrids - to ensure the bearing capacity and the stability of embankments. According to Xu et al. (2016), particularly in the road constructions, embankments on soft ground foundations often face post construction settlement problems and poor overall stability. The use of geosynthetic reinforcement isolated or in combination with base treatment can solve these problems and bring the desired embankment performance and stability.

The construction of embankments on soft soils has become the most viable option for geotechnical engineering. The traditionally used solution - total soft soil removal - besides making the project more expensive, has a great environmental impact, because it involves the exploration of deposits and depends on areas for putting the soft soil off. With technological advances, soft soil can be kept in earthworks foundations, since some soil characteristics - such as high deformability and low bearing capacity - are observed.

The use of geosynthetics as soil reinforcement can increase the safety factor of a construction. Furthermore, it allows higher embankments, in a short period of time and with steep slopes, and also brings a better tension distribution in the soft soil layer. The geosynthetics are attractive in cases which there are a thin layer of soft soil, as compared to the large of the embankment base. This situation has been frequently observed in projects of roads in Brazil.

2. USE OF GEOGRIDS

English Standard BS 8006 (first published in October 2010) explains the working mechanism of reinforced soil. When the soil mass is subjected to a compressive stress, tensile stresses may arise. If reinforcement layers are inserted into the soil mass, while maintaining the applied compression loads, the deformations tend to reduce as a result of the additional confining stress arising from the soil-reinforcement contact, as shown in Figure 1. Among the options of using reinforced soil, the above standard highlights 5 possibilities in foundation area (Figure 2), in which the present article addresses the case where reinforcement is employed to improve the bearing capacity of a soft compressible soil layer.

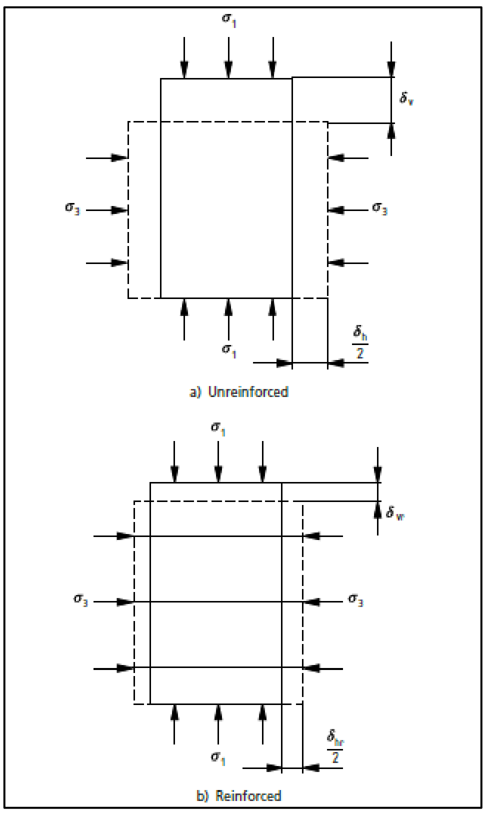

Figure 1 – Reinforced ground mechanism (BS 8006, 2010).

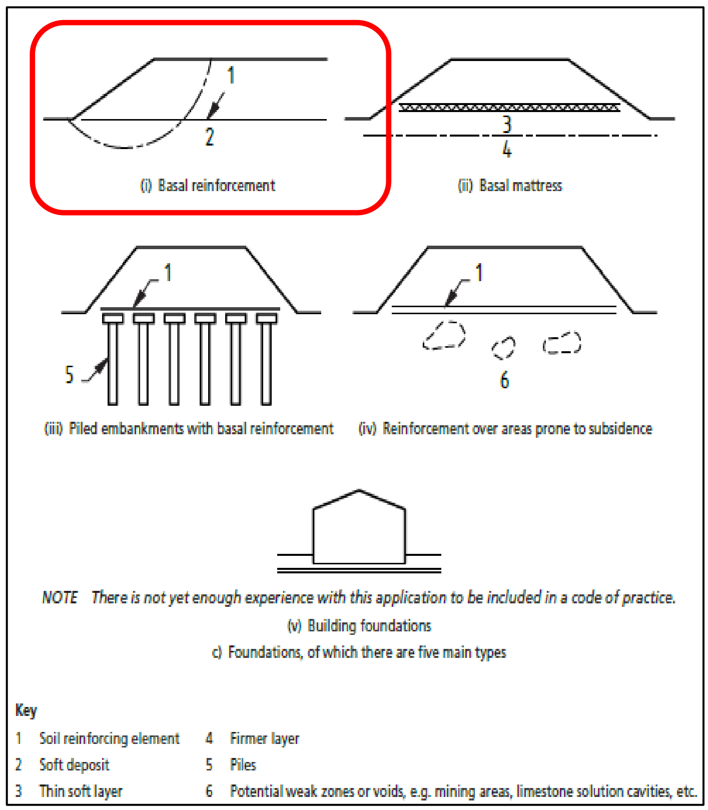

Figure 2 – Reinforcements application (BS 8006, 2010), highlighting the solution studied in this article.

Avesani Neto and Futai (2016) point out that, provided the reinforcement surface is sufficiently rough, the relative ground movement to the reinforcement will generate shear stresses at the interface, which induce tensile forces in the reinforcement material. The external effect of this interaction is the reduction of deformations when compared to the soil mass without reinforcements. In this context, geogrids are commonly used for soil reinforcement because they have elements with high strength and tensile stiffness. In order geogrid plays its soil reinforcing role, it is necessary not only to correctly design the requesting design efforts, but also to specify them in a correct way, taking into account all their relevant properties such as tensile strength, elongation under traction, rate of deformation, tensile stiffness modulus, creep behavior, resistance to installation stresses, resistance to environmental degradation, mechanical interaction with the surrounding soil and reduction factors.

Among the features of the geogrids available on the market are the high tensile strength, low creep, ease installation and also the wide range of products to meet the specificities required by the different projects. In the present study were chosen the geogrids with the characteristics shown in Table 1. The choice was based on the analysis of different projects and public information of road works in Brazil.

Table 1. Characteristics of geogrids.

Geogrid nº	Tensile Strength kN/m	Stiffness kN/m
1	100	2.500
2	200	5.000

3. NUMERICAL MODEL

Based on observations and available bibliographic information about embankments on soft soils in road constructions, some hypotheses for a hypothetical model through numerical modeling were established:

- ✓ Hypothesis 1: the soft soil layer is 2m thick and consists of homogeneous and isotropic material. The water level is 0,5 m under the surface of this layer;
- ✓ Hypothesis 2: the soft soil is positioned above a stiff, homogeneous and isotropic clayey soil;
- ✓ Hypothesis 3: the embankment has a total height of 5 m and consists of granular material, also homogeneous and isotropic;
- ✓ Hypothesis 4: the construction of the embankment takes place in compacted layers of 25 cm thickness each one. The distance between geogrid layers is of 50 cm;
- ✓ Hypothesis 5: the analysis are carried out considering drained behavior for the embankment granular soil and undrained behavior for the clayey soils;
- ✓ Hypothesis 6: soils use elastoplastic constitutive model with Mohr Coulomb failure criterion;
- ✓ Hypothesis 7: there is instability when the construction takes place without geosynthetics as a soft soil reinforcement element; and
- ✓ Hypothesis 8: an interface reduction factor (R_{inter}) of 0,8 was adopted.

The geotechnical model used in the analysis is shown in Figure 3.

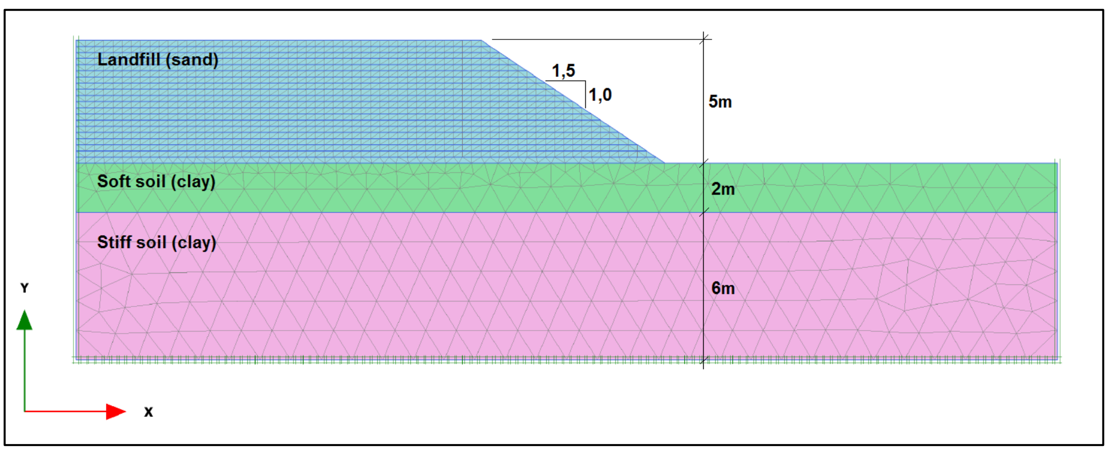

Figure 3 – Geotechnical model used in numerical analyses.

Limit equilibrium methods for stability analysis of geosynthetics reinforced embankments on soft soils are usually employed in problems involving relatively simple geometries and materials. More complex situations require the use of more elaborate numerical models, which allow the displacements and deformations forecast of all materials involved (PALMEIRA AND ORTIGÃO, 2015). The limit equilibrium methods are also useful for calculating the safety factors and they are usually used in the preliminary phase analysis of a project, because in these analyses the mobilized strength in geosynthetics is adopted to be the same as its tension strength. In real situations it is possible to verify these equality only if the soils deformations are bigger than the soil-reinforcement failure ones (PALMEIRA, 2018).

The analyses carried out in this paper aimed to verify the stability conditions of the embankment slopes. These analyses were performed using the Plaxis 2D geotechnical software. The safety calculation type is an option available in Plaxis to compute global safety factors. In the safety approach the shear strength parameters (c – cohesion and tanϕ – tangent of the friction angle) are successively reduced until failure of the structures occurs. Thus the Safety Factor is calculated dividing the available strength by the strength at failure. Despite the great relevance in geotechnical design, the soil consolidation was not contemplated in this paper.

To perform the stability analysis it is necessary to establish the shear strength parameters of the soils. These parameters were obtained through bibliography and are shown in Table 2.

Table 2. Soils characteristics.

Soil type	Friction angle (degree)	Cohesion (kPa)	Modulus E (kPa)	Specific weight (kN/m^3)
Soft soil (clay)	0	10	6.000	16
Stiff soil (clay)	25	30	45.000	18
Embankment (sand)	30	5	30.000	19

Once the shear strength parameters of the soils involved were established, the global stability analysis of the embankment on soft soil was carried out by means of the strength reduction using finite element method (FEM). Figure 4 shows the result of the first simulation (in terms of plastic points), with no reinforcement layer, which indicates the embankment failure still in the construction phase, with a thickness of the order of 4,0 m. This result confirms the previously established Hypothesis 7 in which the stability is not achieved without the presence of external reinforcement elements and also with just one layer of the least rigidity geogrid adopted.

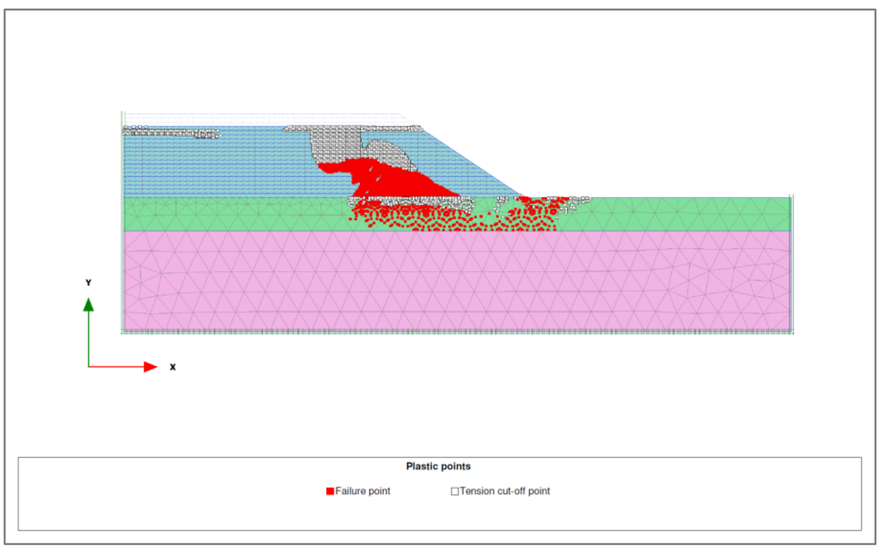

Figure 4 – Case 1 - embankment failure occurs in the construction phase, without the presence of the geogrid.

Seven different situations were analyzed after the confirmation that the embankment achieves the failure without any reinforcement. Table 3 shows the difference between these seven models, and the results of numerical model are discussed on the next item of this paper.

Table 3. Numerical models - different cases analyzed.

Case	Number of geogrid layers	Tensile Strength (kN/m)	Stiffness (kN/m)
1	1	100	2500
2	2	100	2500
3	3	100	2500
4	1	200	5000
5	2	200	5000
6	3	200	5000
7	3	200 (base) 100 (other layers)	5000 (base) 2500 (other layers)

4. RESULTS OF NUMERICAL MODELS

Figure 5 shows the plasticized points observed in the simulation of Case 1, in which the soil mass is reinforced with just one layer of geogrid with stiffness equal to 2.500 kN/m. In this situation, the failure occurred with 4,5m high embankment. Figures 6 to 11 show the total displacements observed in the simulations of Cases 2 to 7, at the last construction phase.

The results indicate that when the number of geogrid layers is increased, using the same stiffness at all the layers, a reduction of the maximum displacements is noted and these displacements are concentrated near the base of the soft soil layer. However, as shown in Table 4, the safety factors values don´t change significantly. Taking in account the examples of Cases 2 and 3, it is possible to note a reduction of 28,5% in the maximum displacements and an increase of just 7,7% in the safety factor value.

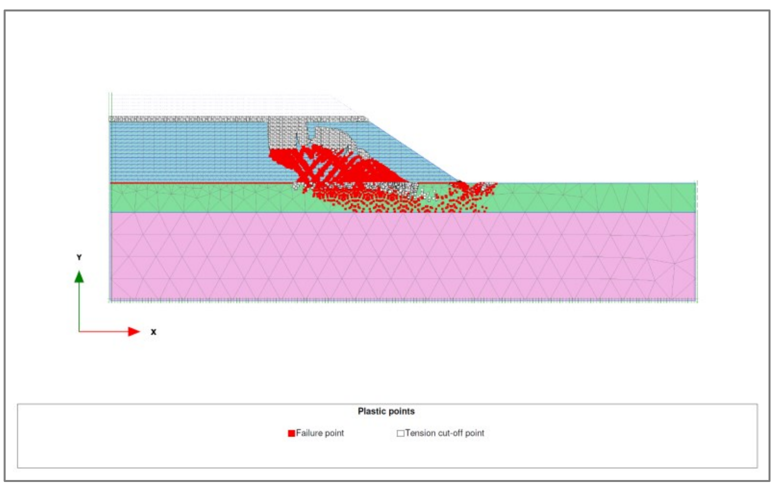

Figure 5 – Case 1 – one geogrid layer with a stiffness value of 2.500 kN/m.

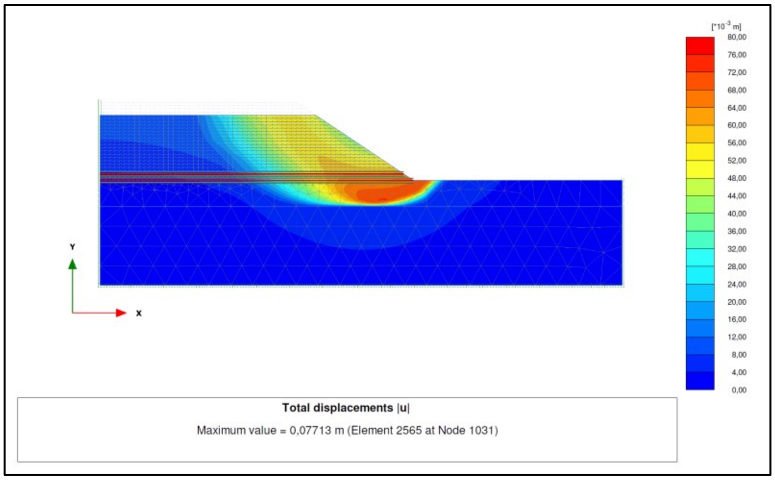

Figure 6 – Case 2 – two geogrid layers with a stiffness value of 2.500 kN/m.

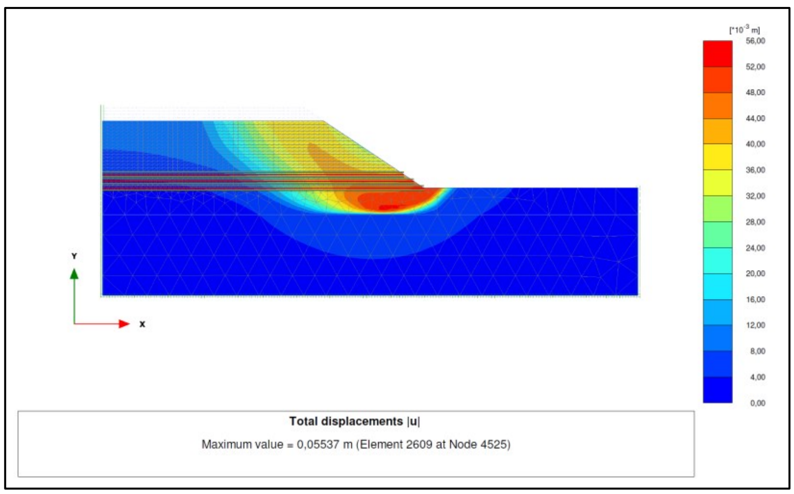

Figure 7 – Case 3 - three geogrid layers with a stiffness value of 2.500 kN/m.

A comparative analysis of the simulation results in Cases 2 and 5 (the same number of geogrid layers but with different stiffness) shows a significant reduction of the displacements – more than 46% - when the stiffness is increased; at the same time, the safety factor increases more than 12%. This same behavior is observed in Cases 3 and 6, in which a comparative analysis results in a 20% higher safety factor.

The results of Case 7 – geogrids with different stiffness – indicate that this case can represent a feasible solution in a lot of real situations, because it can brings resource savings for the construction work without reducing its performance. The use of higher stiffness geogrids near the top of soft soil brings a better performance in terms of a global failure, although it results in greater displacements when compared to the situation in which rigid geogrids are used in all layers.

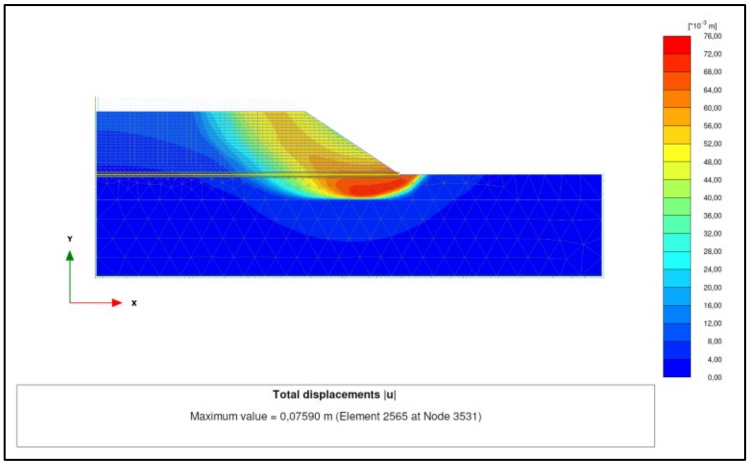

Figure 8 – Case 4 - one geogrid layer with a stiffness value of 5.000 kN/m.

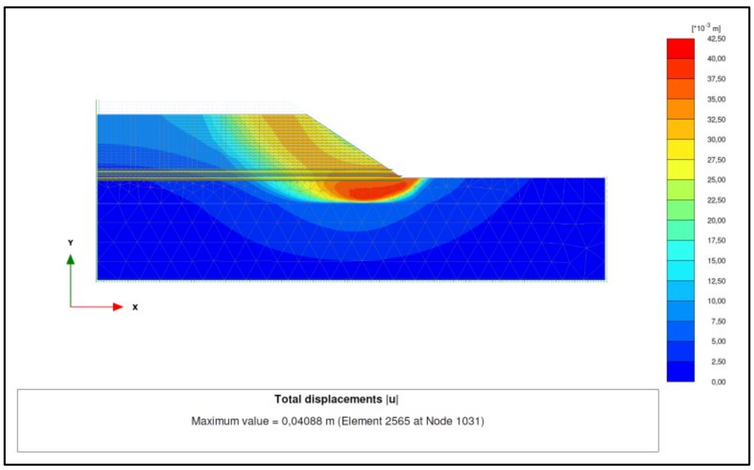

Figure 9 – Case 5 - two geogrid layers with a stiffness value of 5.000 kN/m.

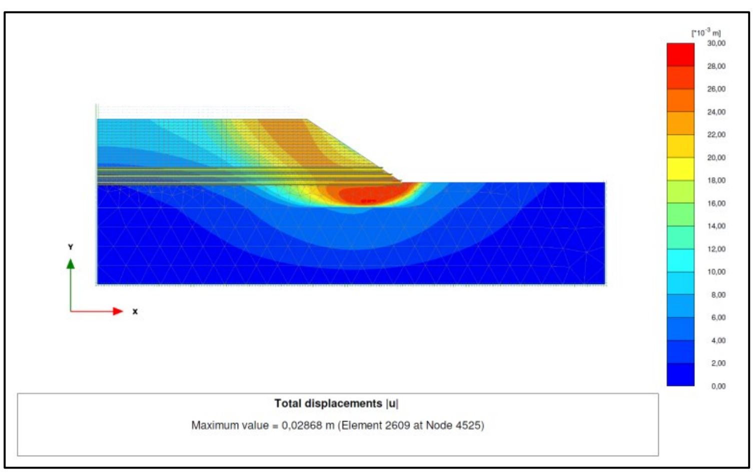

Figure 10 – Case 6 - three geogrid layers with a stiffness value of 5.000 kN/m.

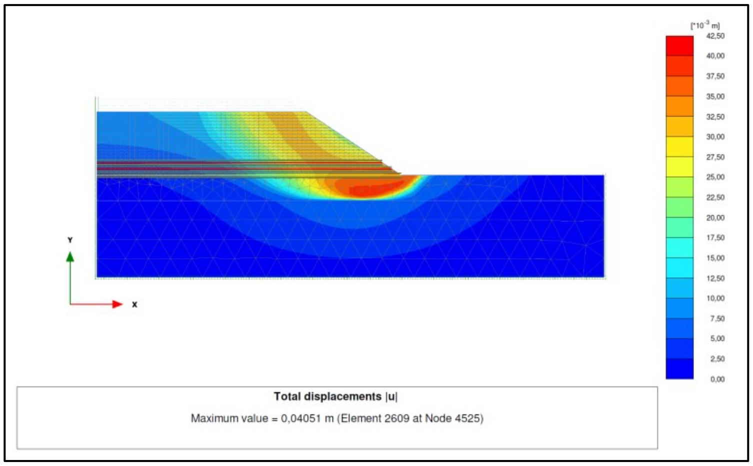

Figure 11 – Case 7 - one geogrid layer with a stiffness value of 5.000 kN/m and two of 2.500 kN/m.

Table 4. Numerical models – results.

Case	Nº Geogrid Layers	Tensile Strength (kN/m)	Stiffness (kN/m)	Maximum Displacement (cm)	Safety Factor
1	1	100	2500	Failure	---
2	2	100	2500	7,7	1,184
3	3	100	2500	5,5	1,276
4	1	200	5000	7,6	1,248
5	2	200	5000	4,1	1,418
6	3	200	5000	2,9	1,537
7	3	200 (base) 100 (other layers)	5000 (base) 2500 (other layers)	4,1	1,503

English Standard BS8006 (2010) discusses the use of multiple layers of geogrid (two or more) in the embankment reinforcement. This standard highlights that field observations show that in cases with higher displacements – bigger than the height of embankment divided by 25 – and different geogrids are used, the reinforcement layer with more tensile strength tends to concentrate the acting forces. Similarly, when two layers of the same tensile strength are used, the bottom layer – near the surface of soft soil – tends to receive greater tensions. The tension distribution between the geogrid layers is not well known so far; this factor motivated the present research. Due to the low level of knowledge about the multiple layers reinforcement behavior in a soil mass, the English Standard recommends the use of just one layer of high stiffness, whenever possible. In cases that just on layer is insufficient to resist to all the tensions, the standard established a design criterion considering geogrids with the same stiffness.

Due to the lack of national standards about the use of geosynthetics in soil reinforcement, BS8006 is used as a reference to the projects. The practice of Brazilian engineering is focused on innovation and new solutions for old problems, aiming to reduce deadlines and costs. For this reason, additional studies and field tests need to be promoted among geotechnical engineering professionals and researchers to better understanding the behavior of soil mass reinforcements using multiple layers of geogrid.

5. CONCLUSIONS

The numerical simulations of a hypothetical case, using a reduced number of sceneries (only seven cases), suggests that the use of multiple layers of reinforcement can be a good alternative solution for constructions on soft soils, because it furthers the reduction of displacements and the increase of the safety factor. Values of displacements and safety factors depend on the combinations between the different types of materials available on the market nowadays.

In general, the results of numerical models show that as greater as the number of geogrid layers smaller will be the total displacements and a greater safety factors will result. The results also indicate that an economical solution, with a similar performance, can be obtained using geogrids with higher stiffness – which are more expensive - only in the bottom layer. Additional numerical simulations, some reduced physical models and field monitoring in real works must be encouraged to provide a better understanding and promote an appropriate use of geosynthetics technology through multiple geogrids layers, in order to lead to an optimized and safe design solutions. Specific standards can also be elaborated to guide the new projects.

The results obtained bring new knowledge for a better optimization of the engineering projects, with the adoption of an appropriate solution that can minimize the costs of the works without, however, impacting on the safety and in the schedule of the execution and operation phases of road works.

Finally, it is important to register that different hypothesis in numerical simulations can result in different values for the safety factors. So the results here presented are only valid for the cases studied.

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