The use of geomaterials reinforcement techniques in road pavements subgrade

Maria Margarida Nazaré Godinho Gonçalves

Abstract

The major problem associated with the lifetime of a road surface is concerned with its maintenance. In this context and in order to optimize rehabilitation costs and increase the lifetime of pavements, techniques have been developed in recent years, for enhancing the application of reinforcement geosynthetics. This reinforcement technique consists in the application of this material at the interface between different layers of the pavement, providing a more balanced distribution of the load on its structure, to avoid a high concentration at the site where this is applied.

This paper aims to evaluate the influence of the use of geosynthetics in the design of road pavements by numerical modeling, finite element, using the ADINA software. Thus, it was possible to analyze the application of a geogrid at various depths of the pavement in various solutions where the basic parameters of the pavement structure and external factors have changed. The various solutions considered were based on parameters and values currently used in the design of flexible pavements in Portugal.

With this study, it was possible to conclude that the geosynthetic performance is directly related to the properties of the pavement structure constituent materials. Thus, the geosynthetic will have greater influence on the structure reinforcement when applied to pavements with weaker properties. In addition, it is concluded that the location of the geosynthetic is an important factor, with better results when applied on top of the subgrade. Nevertheless, technical improvements were obtained in all considered solutions.

Keywords: roads, pavements, reinforcement, geosynthetics, finite element, ADINA

1. Introduction

Roads are one of the most important systems to the development of a country, contributing to the growth of any economic and sustainable system. In the design of a road pavement is planned its durability, which over the years has undergone a considerable decrease due to the intense traffic of heavy vehicles, to climate conditions and mechanical properties of materials used in its design.

In order to combat their durability to fatigue and rutting arise geosynthetics, these come bring several advantages for road paving, such as reducing or preventing the reflection of cracks, function as a barrier preventing the rise of fine soils, reduce the thickness both of the asphalt concrete layer and subgrade course of pavement and extend pavement life acting as a reinforcement.
These days’ geosynthetics mark a significant presence in different works of Civil Engineering worldwide for the technical advantages, economic and its rapid implementation in the field. This solution can greatly enhance the performance and durability of pavements depending only on its design and convenient installation.

2. **Background**

In addition to the various functions that a geosynthetic has, this work aims to study the structural reinforcement of a pavement.

For pavement reinforcement the application of a geosynthetic may take place at various levels of the structure. To provide better soil bearing capacity of layers, when the geosynthetic is applied, the pavement will experience a more balanced tension, as illustrated in Figure 1b). Otherwise the distribution of load will occur at the concentration of its point of application, Figure 1a).

![Figure 1: Relative load magnitudes at subgrade layer level for: a) unreinforced flexible pavement; and b) geosynthetic-reinforced flexible pavement. Adapted from (Zornberg, 2013)](image)

With the use of a geosynthetic reinforcement a considerable improvement is obtained, as regards the stresses which are transmitted to deeper layers. This is due to three mechanisms resulting from the interaction with the ground geosynthetic: the lateral resistance, Figure 2a), the increase in bearing capacity, Figure 2b), and the effect of a tensioned membrane, Figure 2c).

![Figure 2: Reinforcement mechanisms induced by geosynthetics: a) Lateral restraint; b) Increased bearing capacity; c) Effect Membrane support. Adapted from (Zornberg, 2013)](image)
• **Lateral restraint (a):** this mechanism, as the name implies, is associated with the lateral restraint which is caused by friction between the geosynthetic and the aggregate. In addition, this material also functions as a tough cutting force between the interfaces. When any surface is subjected to cyclical forces (traffic), this aggregate in the granular layers tends to move laterally. Now, with the application of a geosynthetic, this strength will be directly transmitted to this. Thus, the geosynthetic acts as a barrier to lateral movements, enabling the pavement to obtain resistance to these forces. It is noted that the whole constitution of the geosynthetic is important at this stage, since the opening of the network and the constituent materials will fully contribute to the lateral resistance of the geosynthetic (Zornberg, 2013).

• **Increase of bearing capacity (b):** in addition to the mechanism explained above, the geosynthetic also provides an increase in bearing capacity of the soil, where it is applied, since it acts as an alternative rupture surface. However, this new surface, will ensure a higher carrying capacity from lowering the shear stress that is applied over the pavement (Zornberg, 2013).

• **Membrane tensioned effect (c):** Finally, the geosynthetic will support the axle load from acting as a tensioned membrane, or the reinforcement will produce a vertical reaction in order to minimize the action of the load produced by vehicles. This effect will reduce the tension transmitted to the pavement layer, giving greater bearing capacity (Zornberg, 2013).

It is also possible to calculate the reinforcement geosynthetic efficiency factor, TBR, which is a ratio between the number of load cycles to failure of the reinforced pavement and the number of load cycles to failure of the non-reinforced pavement, with the same symmetry and constituent materials.

\[
TBR = \frac{N_R}{N_U}
\]

Where: 
- \(TBR\) – Traffic Benefit Ratio
- \(N_R\) – Number of load cycles to break the reinforced pavement
- \(N_U\) – Number of load cycles to break the pavement unreinforced

For the types of existing materials the market already provides several solutions for the enhancement of pavements, especially at the level of geogrids and geotextiles, for bituminous layer pavements. The geogrids solution is more used for this purpose and has also been widely used to prevent the reflection of cracks. Geotextiles may also have other aspects such as filtering and separation, so they are a better alternative when in addition to reinforcement is also intended to stagnate at these levels. For pavements without bituminous layer, a so depth study has not been done, but in my understanding is where geosynthetics will bring many benefits once they may provide greater rigidity and bearing capacity, when applied to pavement with bad material characteristics, providing the necessary rigidity.

### 3. Numerical analysis

In addition to the cases developed in the laboratory and in the field, it has also been carried out modeling studies to test the action of geogrids and geotextiles. This analysis quantifies the information in order to understand the behavior and impact of the application of geosynthetics with different conditions on the
pavement. Different programs have been used to reproduce, by finite elements, the impact applying a geosynthetic may have when applied under different characteristics.

In this sense, it is performed a modeling by finite elements in 2D in a state axisymmetric, once it's thought to be an adequate approximation of what is intended to simulate. Such simulation reproduced the final loading as models executed by Shell and allowed to evaluate the performance of a pavement with the application of geosynthetics. The solutions were based on certain parameters and values used in the pavements designs in Portugal, thus constituting a model applied to what will be the Portuguese experience.

Figure 3 shows the dimensions used in the test model under study, which were based on the measures adopted in article formulated by (Saad et al, 2006) in 3D and thesis formulated by (Bohagr, 2013) in 2D. The parameters a, b and c vary depending on the considered solution.

![Figure 3: Geometry considered for the model in the 2D finite element in an axisymmetric state](image)

For the formulation of hypotheses, we tried to study variations on material properties, layers thicknesses, traffic actions and finally location of geosynthetics. All these considerations are important in the analysis results, to see the impact of the geosynthetic in every situation. On Figure 4 three types of pavement are considered. Table 1 and Table 2 presents parameters and properties for each type of pavement. On Table 3 and Figure 5 properties and the positions considered for the geogrid selected may be consulted.
Figure 4: Considered types of pavement: a) Pavement type 1; b) Pavement type 2; and c) Pavement type 3.

Table 1: Subgrade class, traffic class and thickness of bituminous layer of solutions under study.

<table>
<thead>
<tr>
<th>Subgrade class</th>
<th>F_1</th>
<th>F_2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic class</td>
<td>T_5</td>
<td>T_6</td>
</tr>
<tr>
<td>Pavement Type 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a1 [m]</td>
<td>0.22</td>
<td>0.18</td>
</tr>
<tr>
<td>Pavement Type 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a2 [m]</td>
<td>0.25</td>
<td>0.20</td>
</tr>
<tr>
<td>Pavement Type 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a3 [m]</td>
<td>0.23</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Table 2: Properties of the materials considered in the finite element modeling.

<table>
<thead>
<tr>
<th>Subgrade class</th>
<th>Pavement type</th>
<th>F_1</th>
<th>F_2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Concrete</td>
<td>E [MPa]</td>
<td>ν</td>
<td>E [MPa]</td>
</tr>
<tr>
<td>MD_A, MD_B or MD_C*</td>
<td>0.40</td>
<td>0.40</td>
<td></td>
</tr>
<tr>
<td>Base</td>
<td>60</td>
<td>0.35</td>
<td>120</td>
</tr>
<tr>
<td>Subgrade</td>
<td>30</td>
<td>0.35</td>
<td>60</td>
</tr>
<tr>
<td>Pavement type 2 and 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphalt Concrete</td>
<td>MD_A, MD_B or MD_C*</td>
<td>0.40</td>
<td>0.40</td>
</tr>
<tr>
<td>Base</td>
<td>120</td>
<td>0.35</td>
<td>240</td>
</tr>
<tr>
<td>Subbase</td>
<td>60</td>
<td>0.35</td>
<td>120</td>
</tr>
<tr>
<td>Subgrade</td>
<td>30</td>
<td>0.35</td>
<td>60</td>
</tr>
</tbody>
</table>

*MD_A = 3 000 MPa; MD_B = 4 000 MPa; and MD_C = 6 000 MPa

Table 3: Reinforcement geogrid properties considered in finite element modelling.

<table>
<thead>
<tr>
<th>Material</th>
<th>e_g [m]</th>
<th>E [MPa]</th>
<th>ν</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geogrid</td>
<td>0.00254</td>
<td>4 230</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Reference (Bohaghr, 2013) (Erickson & Drescher, 2001)
4. Results and discussion

After the results analysis, it was possible to conclude that all solutions brought improvements, but there were more meaningful cases than others.

Regarding the fatigue resistance criterion, when a geogrid is applied on the interface between the asphalt concrete and the base, it is observed a larger reduction of the traction strains in comparison with other solutions. It was also concluded that the thinner is the bituminous layer, the larger is the reduction of strains due to the geogrid application.

The results were quite similar on the rutting criterion but, in this case, the application of the geogrid on top of the subgrade, represented the more considerable improvements when compared with the solution without geosynthetic. Even so, it was proven that the geogrid impact is directly related to the properties of the materials: the weaker these properties are, the greater the associated improvement. This fact had already been demonstrated in other studies that were also reviewed. Figure 6 shows the variation of the vertical strains along the pavement structure for a solution without reinforcement compared to a geogrid reinforcement case. It is further noted that the results obtained for this criterion had higher expression compared to the figures for fatigue.
Figure 6: Compression strain criterion of solution 2 $M_{DA} T_7 F_1$ throughout the pavement: a) without reinforcement, $R0$; and b) with geogrid reinforcement, $R3$.

It should be noted that on the article (Saad et al, 2006) or on dissertation (Bohagr, 2013), where the same parameters were used, the assays to rutting do not express such greater impacts related to the geogrid on top of subgrade as the solutions depicted on this essay. This may be related to the material properties or the use of thinner granular courses.

Regarding the TBR values for the rutting, there was a considerable increase in the number of load cycles, with values between 33% and 55%. On Figure 7 can be observed the graphic that represents the TBR values for rutting criterion.

![Figure 7: Number of load cycles without reinforcement in relation to the number of load cycles with geogrid reinforcement for the rutting criterion of pavement type 3 with F1 subgrade class.](image)

As for the fatigue criterion, Figure 8, the values of load cycles reduction ranged between 14% and 34%. The maximum values observed correspond to the environments in which materials are of better quality,
whereas if analyzing the criterion of rutting, the maximum observed values are related to the poor quality of the materials of the pavement structure.

Figure 8: Number of load cycles without reinforcement in relation to the number of load cycles with geogrid reinforcement for the fatigue criterion of a pavement type 3 with F1 subgrade class.

In order to obtain an economic benefit by applying geosynthetics, a study was conducted that allowed the thickness of the bituminous layer reduction for the same amount of supported load cycles since it represents the biggest expense by area on the whole pavement. In this context, the BLR (Bituminous Layer Reduction) emerged and after analyzing the results it was more significant in the R1 position for fatigue criterion and on the R3 position for the rutting criterion. The values for this ratio ranged between 0.85 and 1.0 which represented between 1 and 2 cm in thickness reduction. Only five solutions were able to meet these values on the fatigue criterion. As for the rutting criterion, the values were met by all solutions, as we can observe on Figure 9.

Figure 9: BLR values between the subgrade classes for the rutting criterion of a geogrid R3 and MDA class.
**Conclusions**

In general, despite the improvements in all Portuguese based solutions, this material did not get the expected impact. If we want to increase the level of traffic on a road, the use of this material may be an added-value, given the option of increasing the bituminous layer. If this application occur in a subgrade class F1, where the soil characteristics are weaker, we will get a reduction up to 2 cm when applying the geogrid on top of the foundation layer. However, the study was just a technical analysis what means that to know if geosynthetic is viable on each situation it is necessary to make also an economic and an environmental analysis.

**References**


