

Proof of the effectiveness of asphalt reinforcement and evaluation of the applicability into an existing design method

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ABSTRACT: The service life of asphalt pavements depends on various factors according to the current standard design methods. The material characteristics, layer thicknesses, climatic conditions and the intensity of the traffic load are the most decisive factors that influence the dimension of asphalt pavements. Based on this, various proofs of calculation methods are developed in accordance with the fatigue characteristics and rutting depth behavior of the asphalt as well as deformations of the substructure. Despite the positive experience obtained from globally increasing construction sites over the last 40 years and from the extensive and successful research projects, the asphalt reinforcement has unfortunately not been sufficiently taken into account in the design of asphalt pavements. Different design approaches are established based on controlling the horizontal movements induced as a result of dynamic stresses in the form of retardation or in many cases to prevent (restrict) propagation of reflective cracks in recently constructed layers. In addition, studies have shown that reduction of the strain in the area of the tensile zone (e.g. bottom of asphalt layer) significantly increases the durability of the pavement and the service life of the project. Accordingly, this research aims at numerical investigation of the mechanical behavior of the reinforced asphalt layers in terms of deformation and stress distribution in the pavements. Within this framework, a series of numerical finite element calculations will be conducted to study the factors those contribute to reduce the fatigue behavior of the reinforced asphalt pavements in terms of service life or the permissible loads.

Keywords: asphalt reinforcement, overlay rehabilitation, numerical analysis, design method

1 INTRODUCTION

The different distress forms of asphalt pavements depends on one or combination of several factors e.g. an unsuitable mix design, poor construction methods, insufficient thicknesses or environmental conditions and high traffic. Near the permanent deformation, fatigue cracking is one of the most and serious distress forms in flexible pavements.

The general and textbook explanation and definition of fatigue cracking states that the fatigue initiates mainly under the wheel path at the bottom of the asphalt layer and then propagates up to the top (bottom-up-cracks). The repeated and excessive loading, the possibly insufficient or poor conditions of the supporting Sub-Base or Sub-Soil cause high tensile strains at the bottom of the HMA layer (Huang, 1993). The initial distress in form of fatigue cracks occurs in this area (tension zone). This failure form with deep structural origins, often described as an accumulation and connection of micro cracks (Dong Wang et al, 2013). However, such mechanism can be significantly delayed by reducing the tensile strains at the bottom of the asphalt base layer. Several researches and numerical analyses have shown that the limiting of these strains (see Figure 1) can help to control the fatigue cracking.

From the performance point of view, the pavement life extends by limiting or decreasing of this distress form. One way to achieve this target is to increase the thickness of the pavement structure. Thick pavements can help to limit the initiation and propagation of fatigue cracking by reducing the maximum strain at the tension zone (Al-Qadi et al, 2008). Another way by the use of Geosynthetics as asphalt reinforcement grid made of polyester (Hilpert et al, 2016).

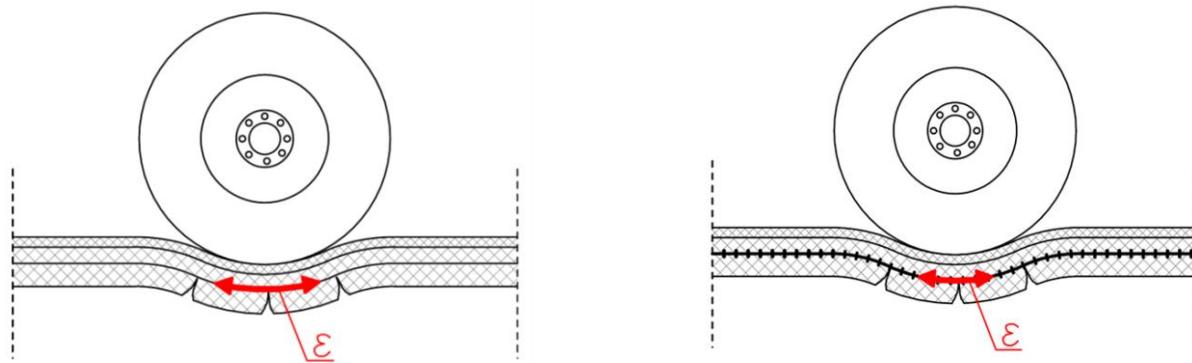


Figure 1. Horizontal strain control using asphalt reinforcement grid

The rehabilitation of asphalt pavements using asphalt reinforcement grids is a recognized and accepted method in many road authorities over the world. In order to investigate the contribution of the asphalt reinforcement grid in enhancing the mechanical behavior of the system, this paper focuses on the performance of the flexible polyester grids based on numerical calculations. The main objectives are to compare the stress-strain behavior of unreinforced and reinforced asphalt pavement by the presence of the interlocking (see Figure 2) between the existing asphalt surface and the new asphalt layer and to generate a kind of improvement factor for further researches, investigations and design methods. Furthermore, to compare the mechanical behavior of the asphalt pavement using asphalt reinforcement grids and stress absorbing interlayer by the loss of the interlocking (using e.g. Nonwoven). In both cases, the bonding effect by friction and adhesion is present and considered in the numerical analysis. Nevertheless, the full bonding is an effect that can be achieved only within the asphalt layer body and not in the interface areas.

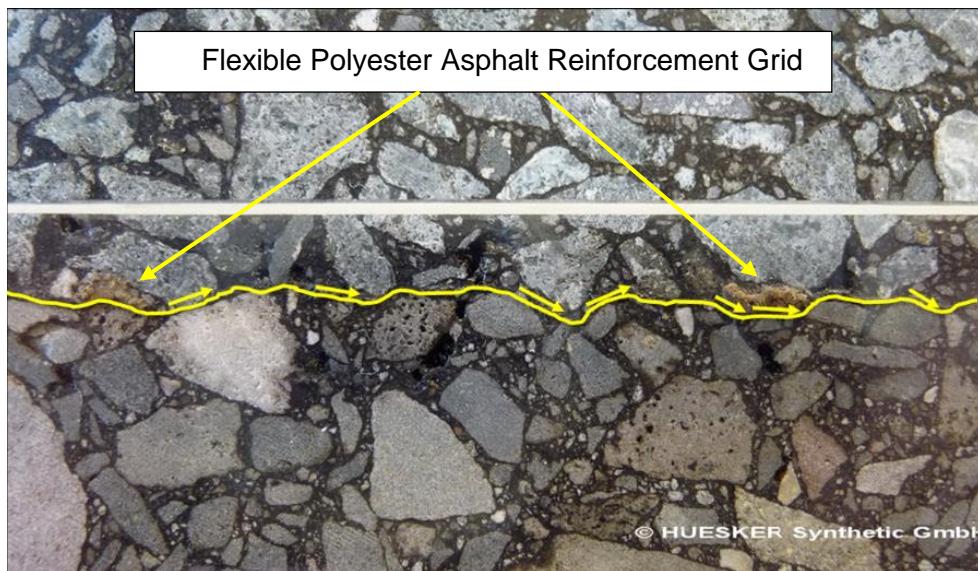


Figure 2. Interlocking between 2 asphalt layers by the use of a flexible asphalt reinforcement grid made of polyester

Several researches investigated in the past the improvement factor of the asphalt reinforcement grid. A research program using dynamic fatigue tests performed at the Aeronautics Technological Institute in Sao Paulo, Brazil (results published by Montestruque et al., 2004) shows that the improvement factor moves between 4.45 and 6.14 by the use of asphalt reinforcement grid made of Polyester. Thom (2003) found that the life of a new flexible pavement can be extended to 2.5 – 3.0 times when the grid is installed at the bottom of asphalt.

Keeping all these aspects in mind, the influence of the bonding between the two asphalt layers (i.e. base course and surface asphalt layers) has not received sufficient attention. According to the literature, the bonding between the layers that consists of three main components as (i) friction, (ii) adhesion, and (iii) interlocking, strongly depends on the type of the geosynthetic material (e.g. nonwoven or geogrids), the interaction flexibility of the reinforcement (i.e. to provide an appropriate interlocking between the layers) and the size of the apparatus. Therefore, this research aims at numerical investigation of the effect of the bonding between the reinforcement and the asphalt layers on the strain reduction at the bottom of the

surface asphalt layer. The strain reduction factor can be interpreted as an indication factor to evaluate the prolongation of the durability of the reinforced pavement structure.

2 NUMERICAL ANALYSIS

The commercially available finite element (FE) package *PLAXIS*^{2D} is adopted to the numerical calculations. As the distribution of the stress and strain in the multilayer system at very small deformations is aimed to be studied, the linear elastic constitutive model is employed to address the mechanical behavior of the material (i.e. asphalt and soil) in the system. The numerical analyses have been idealized by assuming an axisymmetric condition in which the symmetry line passes through the center of the loading area. The schematic shape of the reinforced pavement structure considered in the present study is shown in Figure 3. As seen, two observation sections namely section A-A (at the center of the load) and B-B (at the edge of the load) are considered to evaluate the distribution of the stress and strain at two critical positions.

To avoid considering unrealistic full bond between the asphalt surface and base course, two interface layers have been assigned to the contact surfaces between the reinforcement and asphalt layers at top and bottom. The interfaces obey the Mohr-Coulomb elastic-perfect plastic. The dilative behavior of the interface is ignored in this study. To accommodate the aging effect in the old base course (BC) asphalt layer, the stiffness of the old BC asphalt layer is assumed to be higher than the newly installed surface layer. Nevertheless, the bonding strength of the reinforcement with the bottom layer is assumed to be lower than the bonding between the reinforcement and the recently installed surface asphalt layer.

In order to study the behavior of the pavement layer with and without asphalt reinforcement, a series of numerical analyses have been conducted. In these calculations, the strength properties of the contact between the new and old asphalt layers namely the cohesion and friction angle have been considered to vary. Apparently, various interlayer cohesion and friction angles refer to the type of the asphalt reinforcement. For instance, low friction angle mainly refers to asphalt reinforcements that restrict the interlocking between the grains of the asphalt at the top and bottom of the contact surface while the larger friction angle denotes the geogrid asphalt reinforcement with larger opening size that permit the perfect interlocking between the asphalt grains at two sides of the geogrid. Additionally, the variable interlayer cohesion is attributed to the variation of the adhesion between the new and old asphalt layers.

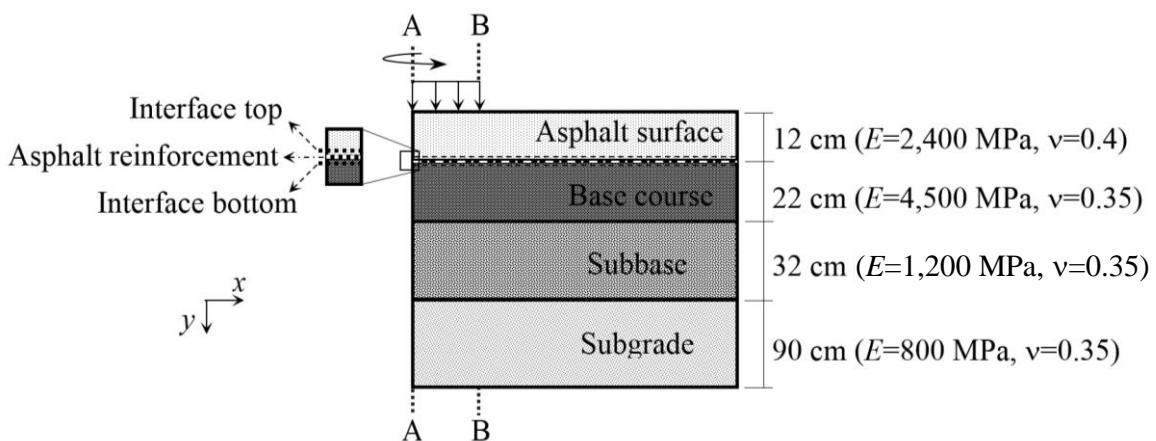


Figure 3. Reinforced pavement structure and the observation sections

The traffic loads acting on the surface of asphalt pavement include centric vertical load is applied as the uniform vertical pressure of 662 kPa over the circular area with the radius of 10 cm. The combination of the parameters for the top and bottom interfaces in the present study is tabulated in Table 1.

Table 1. Tables placed below caption.

Inter layer friction angle (deg.) Top interface /bottom interface	Interlayer cohesion (kPa) Top interface	Interlayer cohesion (kPa) Bottom interface
25/20, 30/25, 35/30, 40/35	75	50
	100	75
	150	100
	200	150

3 RESULTS AND DISCUSSION

In this section, the distribution of the stress and strain in the pavement structure (surface and BC asphalt layers) under the centric vertical pressure is shown for two observation cross sections. In the following figures, the legend 40-200 refers to the most appropriate adhesion, friction (e.g. 40 mm opening size) and interlocking (e.g. Polyester grid with proper interaction flexibility) between the BC and surface asphalt layers (e.g. friction angle and cohesion of 40° and 200 kPa between reinforcement and asphalt surface layer, respectively). It is to be noted that according to Table 1, bonding combination of 40°-200 kPa for the top interface corresponds to friction angle and cohesion of 35° and 150 kPa for the bottom interface (bonding between the reinforcement and the BC asphalt layer). Nevertheless, legend 25-75 states the least friction (e.g. 25°) and cohesion (e.g. 75 kPa) between the reinforcement and asphalt surface layer (that correspond to friction and cohesion of 20° and 50 kPa between the reinforcement and BC asphalt) which is most likely for the stress absorbent geotextile layer (e.g. nonwovens).

3.1 Stress and strain distribution in the reinforced pavement

Figure 4 illustrates the range of the variation of the stress and strain distribution patterns in different directions (e.g. x and y) in the reinforced pavement structure with lowest and highest bonding strength at the contact between the reinforcement and the asphalt that can be referred to nonwoven geotextile and geogrid with appropriate interaction flexibility and 4 cm apparatus size, respectively.

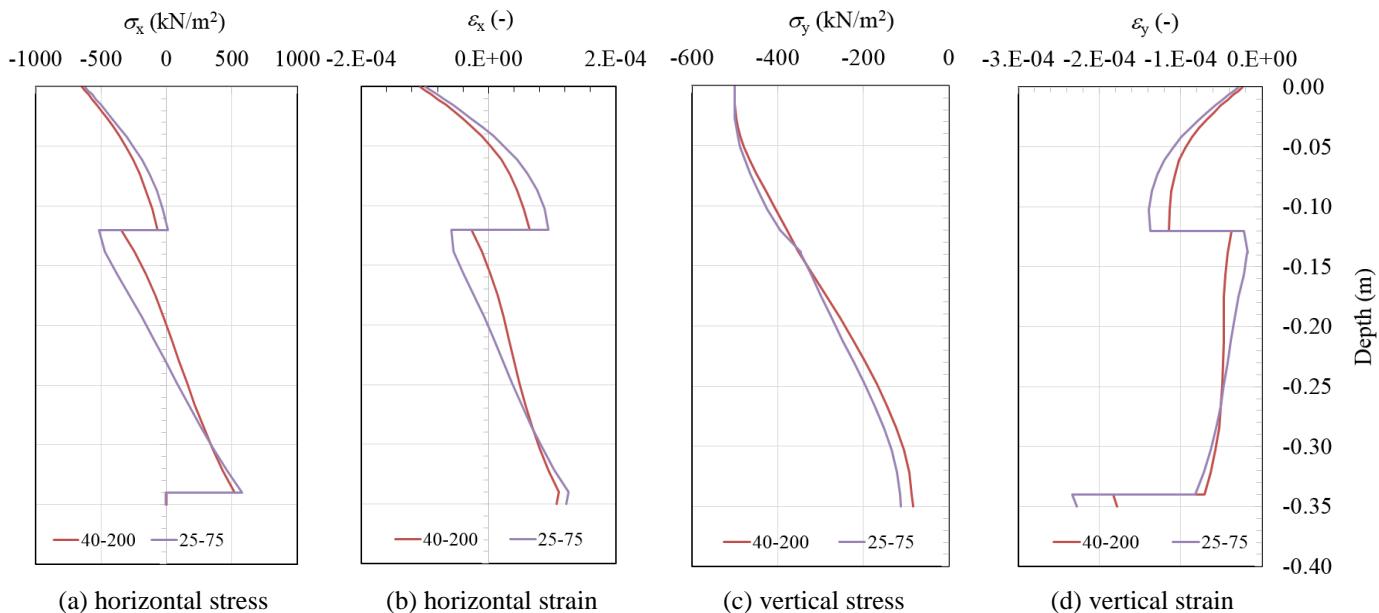


Figure 4. Variation of the stress and strain in depth on observation section A-A for reinforced pavement structure

As seen in Figure 4, the shear strength of the contact between two asphalt layers (bonding) plays a significant role not only in the stress and strain distribution in the pavement structure but also in the uniformity and integrity of layers. Apparently, the formation of the crack in the pavement structure strongly depends on the stress and strain level in the layers due to the traffic load. The high strains (and also stresses) at the bottom of the asphalt surface due to high dynamic traffic loads can result in quick generation and therefore upward propagation of the fatigue cracks. On the other hand, the higher stress and strain de-

development in the contact between the pavement layers trigger the slip failure between the pavement layers. As seen in Figure 4a, a strong bonding between the base course and asphalt surface leads to a remarkable decrease in the deviation of the horizontal stress (σ_x) between the top and bottom asphalt layers. Figure 4b illustrates the significant reduction in the range of the variation of the horizontal strain between the layers. As a matter of fact, the strain difference at the contact between layers and specially the variation of the direction of the strain at top and bottom of the contact can significantly weaken the interlayer bonding and provoke the slippage and separation of the layers. Consequently, such a disparate behavior at the top and bottom of the reinforcement would significantly decrease the life time (durability) of the pavement. Figure 4c shows that the distribution of the vertical stress at the center of the load is not significantly affected by the mechanical properties of the interlayer bonding.

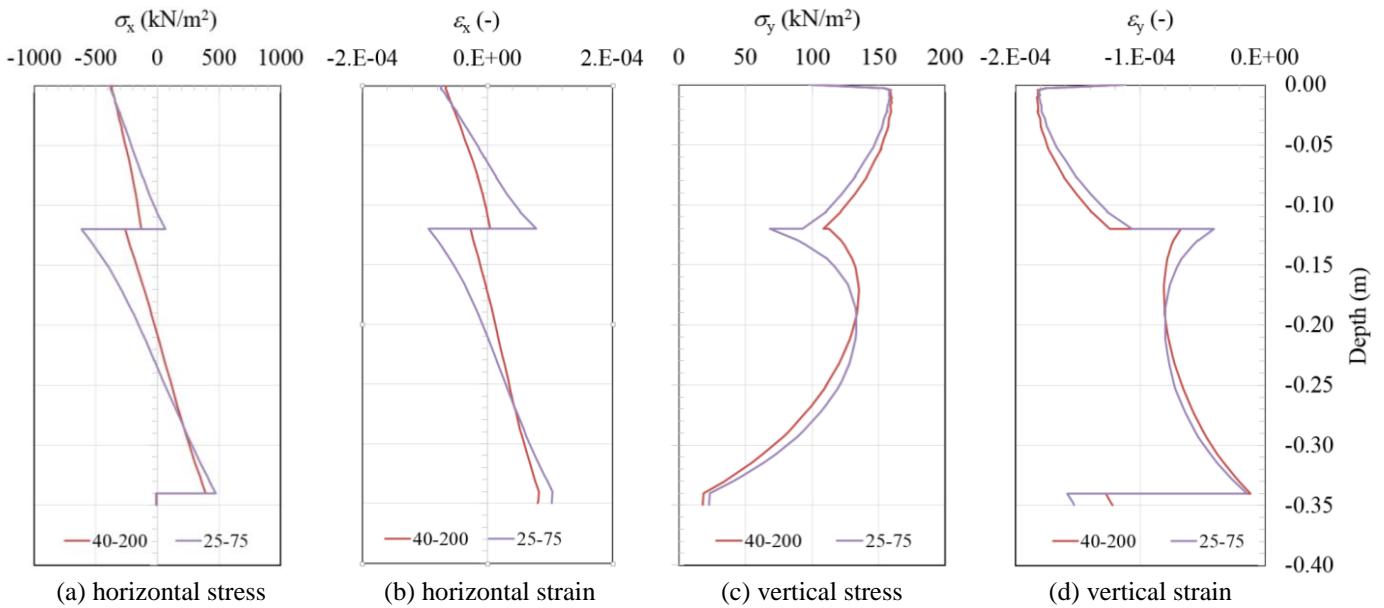


Figure 5. Variation of the stress and strain in depth on observation section B-B for reinforced pavement structure

Figure 5 shows the distribution of the stress and strain in the pavement structure on a cross section the passes through the edge of the surface load (B-B). As seen, the contribution of the bonding properties of the reinforcement can be more pronounced on section B-B. Figures 5a and 5b show that poor bonding due to inappropriate interlocking and adhesion between the layers cause a significant contrasting stress and strain at the top and bottom of the base course and surface asphalt layers at the edge of the loading area. As shown, the relevant bonding properties has solved the problem of stress and strain reverse at the top and bottom of the contact. The reverse of the horizontal stress at the bottom of the surface asphalt and the top of the base course layer indicates variation of the modes of behavior from tension (on top of the contact) to the compression (at the bottom of the contact surface). Such a frequent exchange in the mechanical behavior of the two adjacent layers under the dynamic traffic load results in accumulation of the plastic strain at that contact and weaken the interlayer bonding. However, when an asphalt reinforcement with appropriate interaction properties (e.g. interlocking and adhesion) is used to reinforce the pavement structure, the exchange in the mode of the deformation at the contact surface disappears due to having no change in the direction of the strain at top and bottom of the contact. Therefore, the risk of reduction of the bonding strength and disintegration of the asphalt layers due to the traffic load at the operation becomes uncritical. However, for the reinforced pavements with low interlocking properties, this is still the case.

According to the results presented in Figures 4 and 5, four different scenarios for the pavement structure can be introduced to study the stress and strain distribution in the pavement system as (a) unreinforced pavement with relatively high bonding where the friction angle and cohesion of the upper and lower interfaces are 35°-200 kPa and 30°-150 kPa, respectively; (b) reinforced with nonwoven geotextile with low bonding properties as 25°-75 kPa and 20°-50 kPa for friction and cohesion of upper and lower interfaces, respectively; (c) reinforced pavement with geogrid having average interlocking (e.g. polyethylene and polypropylene) and friction (e.g. 20×20 mm size of the apparatus) in which the friction and cohesion of the upper and lower interfaces are 30°-150 kPa and 25°-100 kPa, respectively; (d) reinforced pavement with geogrid having appropriate bonding properties (e.g. polyester with 40×40 mm size of the apparatus)

where the friction and cohesion of upper and lower interfaces are 40°-200 kPa and 35°-150 kPa, respectively. Results of the analyses for these scenarios are presented in Figure 6.

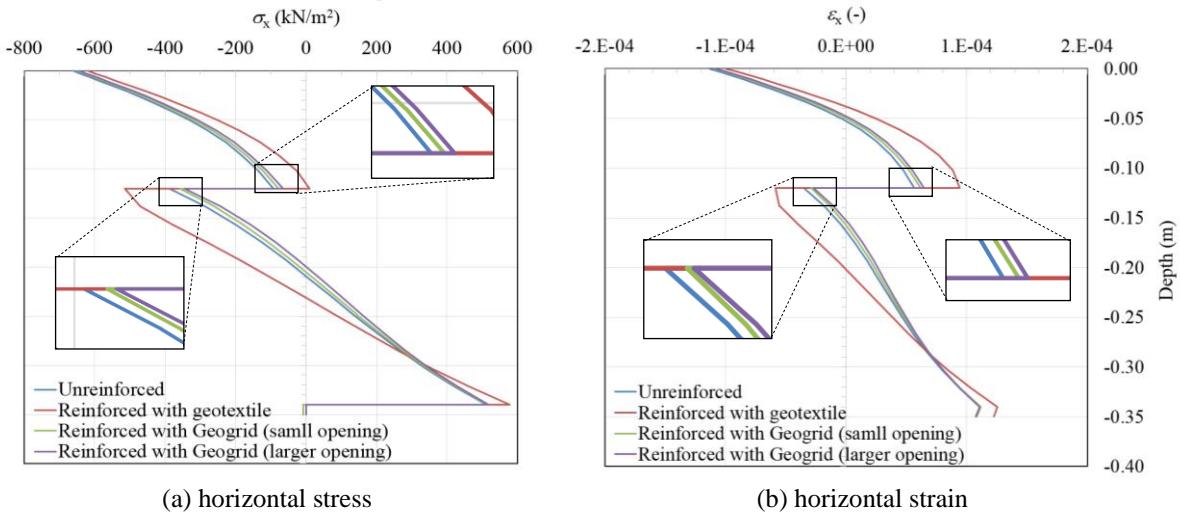


Figure 6. Variation of the stress and strain in depth for various reinforced and unreinforced pavement structures on observation section A-A

According to Figure 6, the unreinforced system will absolutely perform better in comparison to the pavement that is reinforced with the geotextile with poor bonding properties. A comparison between different curves for different scenarios reveals that the lowest horizontal stress and tensile strain is developed when the pavement is reinforced with geogrid with relevant interlocking properties and opening size (proper bonding). Although the difference between the reinforced pavements with geogrid lower bonding seems to be small, the accumulation of the strain due to the cyclic traffic load becomes more crucial. For instance, as shown in the literature, 20% reduction in the strain at the bottom of the asphalt surface can prolong the durability of the layer up to 3 times (Beyer, 2014).

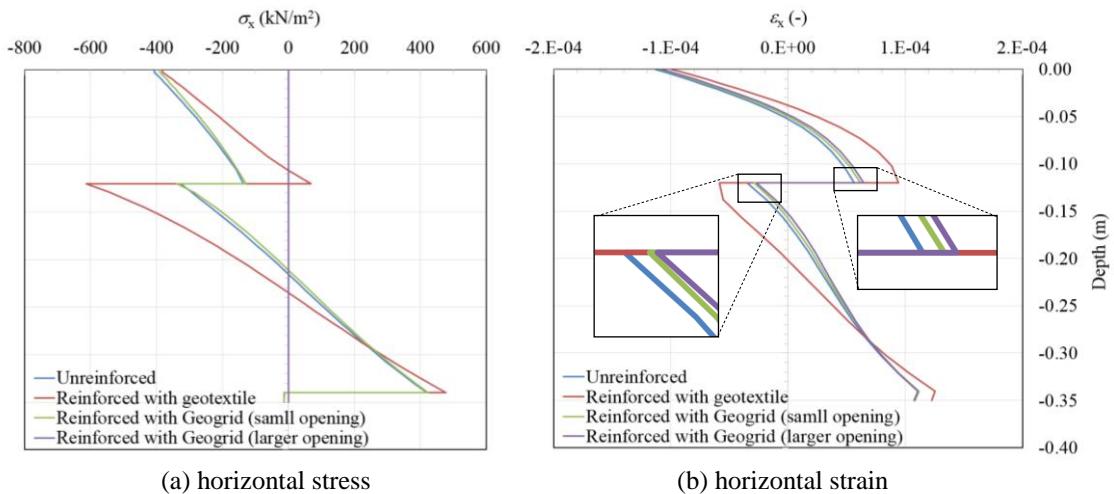


Figure 7. Variation of the stress and strain in depth for various reinforced and unreinforced pavement structures on observation section B-B

Figure 7 shows the distribution of the horizontal stress and strain for different scenarios on section B-B that crosses through the edge of load. As seen, the pavement reinforced with geotextile with poor bonding has an extremely unfavorable performance due to large deviation of stress and strain at top and bottom of nonwoven. The horizontal stress is in acceptable range for the other scenarios (e.g. unreinforced and reinforced with geogrid). Figure 7b, depicts the contribution of the geogrid with different interlocking properties to reduce the horizontal strain at the contact. Similar to cross section A-A, the geogrid with appropriate bonding (interlocking and adhesion) can reduce the unfavorable strains in the pavement structure.

3.2 Strain factor at the bottom of the asphalt surface layer

As mentioned before, the slip failure between the asphalt layers and also the fatigue-induced damage in the pavement structure is function of the strain in the system. Several studies have shown that the strain

factor as the ratio between the strain at the bottom of the surface asphalt in the reinforced system (with different bonding properties) to the strain at the same position in unreinforced system can be used as an indicator to predict the contribution of the reinforcement in extension of the life time (durability) of the pavement structure.

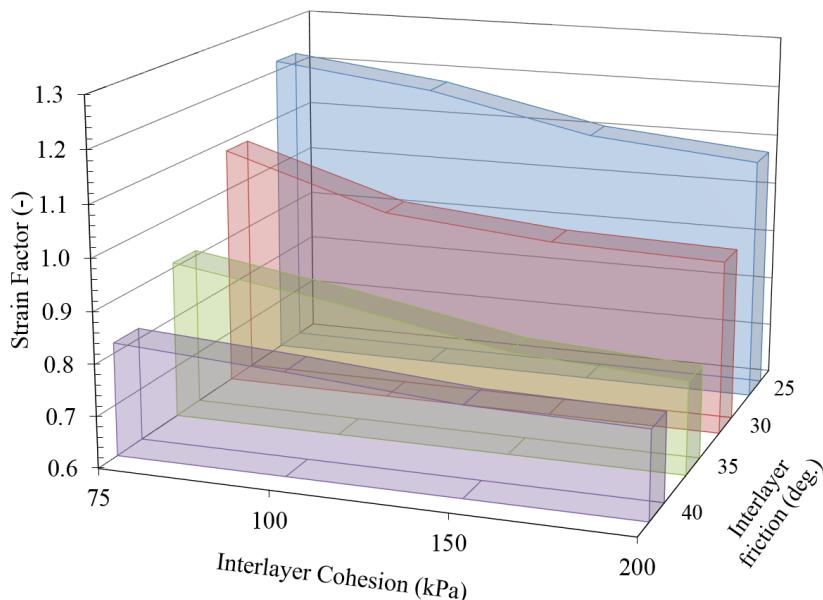


Figure 8. Variation of the strain reduction factor for various bonding conditions

Figure 8 shows the variation of the strain factor for variable bonding properties as the function of the interlayer friction and cohesion of the interface between the reinforcement and asphalt surface (i.e. friction, interlocking and adhesion). It has to be noted that the strain factor above the unity refers to an increase in the strain in the bottom of the surface asphalt layer due to poor bonding that shows the negative role of the layer in comparison to unreinforced pavement. In contrast, the strain factor less than unity demonstrates the favorable effect of reinforcement (with appropriate bonding) to reduce the strain at the bottom of the asphalt layer. According to Figure 8, the strain factor significantly decreases with an increase in both interlayer friction (interlocking due to the interaction flexibility and relevant size of openings) and interlayer cohesion (appropriate adhesion between the layers). The poor interlocking between the top and bottom asphalt layers (friction angle equal to 25°) leads to strain factor larger than 1. Therefore, it can be concluded that durability of the pavement will be reduced in comparison with the unreinforced pavement with average to good bonding conditions. For the reinforced pavement with friction angle about 30° (i.e. reinforced pavement with geogrid with small opening size), the reduction factor is above unity for poor adhesion (cohesion=75 kPa) while the reduction factor remain close to 1 (slightly smaller) for the better adhesions (cohesion>75 kPa). It can be obviously seen in Figure 8 that the strain factor remains always less than 1 for higher friction angles ($\geq 35^\circ$). For the friction angle equal to 35°, increase in the interlayer cohesion results in lower strain factor. However, the strain factor becomes minimum and independent of the interlayer cohesion when the friction angles is equal to 40°.

4 CONCLUSION

A number of FEM calculations carried out to evaluate the effect of the bonding between the asphalt reinforcement on the distribution of the stress and strain in the pavement structure. Different bonding is attributed to the type of the geosynthetic layer (e.g. nonwoven or grid), type of the raw material in terms of flexibility and stiffness (e.g. polyethylene, polypropylene, polyester) and the size of the apparatus for grids (e.g. 20×20 mm or 40×40 mm). Based on the analyses conducted in present study, the following conclusions can be drawn:

- A significant improvement in pavement behavior is obtained by applying of reinforcement grid with larger aperture size of 40×40 mm in the tension zone at the bottom of the surface asphalt layer. The horizontal strains are significantly lower compared to unreinforced pavement system, pavement with nonwoven stress absorbing layer and pavement reinforced with geogrid with improper interlocking.
- Using the nonwoven geotextile as stress absorbing membrane instead of reinforcement grid restricts proper interlocking between the asphalt layers and allows higher strains in the contact area. This can

have a negative effect on the necessary required bonding (risk of slippage effect) and thus on the durability of the asphalt pavement system (decrease of the service life).

- The reduction of the strain at the bottom of the surface asphalt layer strongly depends on the type of the asphalt reinforcement grid and its apparatus size. The strain at the bottom of the asphalt layer becomes less than 1 when the geogrid is used to reinforce the pavement while it becomes minimum when the asphalt geogrid made of polyester polymer with proper interaction flexibility and larger size of apparatus is used to reinforce the pavement.
- The use of the asphalt reinforcement should minimize the deviation of the stress and strain at the bottom of the asphalt surface layer and the top of the base course asphalt. Thus the system performs more uniformly and reduces the risk of the slippage between the layers and also the reflection of the cracks from base course to the surface.

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