NUMERICAL MODELING OF FLEXIBLE PAVEMENT STRUCTURES REINFORCED WITH GEOSYNTHETICS

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ABSTRACT

The general evolution of the finite element method also led to the development of the numerical modeling of flexible pavement structures by finite element method. Numerical modeling techniques represent an opportunity to understand the mechanics of flexible pavement structures reinforced with geosynthetics. Experimental studies over the past years have shown the benefits of geosynthetics use as reinforcement materials of flexible pavement structures. The paper presents results from finite element modeling, on the state of stress and strain analysis of a flexible pavement structures reinforced with geosynthetics in different versions of their location. The study highlights the reinforcement function of geosynthetic materials and determine optimum layout of geosynthetic within reinforced asphalt overlays. It follows that the use of geosynthetic materials to reinforce asphalt layers of flexible pavement structures has a positive effect on their bearing capacity, leading to increased calculus traffic volume that it can support a road.

1. INTRODUCTION

Experimental studies over the past years have shown the benefits of geosynthetics use as reinforcement materials of flexible pavement structures (Diaconu and Burlacu, 2004 [1]; Diaconu and Răcănel, 2005 [2]; [3]; Diaconu, Lazăr et al., 2007 [4]; Romanescu, Lazăr et al., 2009 [5]).

Existing design solutions, in most cases empirical, are unable to take into account many variables that influence the benefit derived from the geosynthetic reinforcement.

Advanced numerical modeling techniques are an opportunity to understand the mechanics of these systems and provide simplified numerical formulations incorporating the essential features necessary to predict the behavior of geosynthetic reinforced flexible pavement structures.

1.1. Numerical modeling of flexible pavement structures

With the general evolution of the finite element method is developed also the numerical modeling of flexible pavement structures by finite element method.

The first programs used in common practice frequently consist in two-dimensional axisymmetric models with linear or nonlinear elastic properties of the materials in the composition of pavement structure layers. Programs like AXYDIN and MICH-PAVE have been developed based on this pattern [6].

1.2. 2D axisymmetric finite element modeling

The paper uses a 2D axisymmetric finite element model for the state of stress and strain analysis of flexible pavement structures, which was developed using a computer program based on Finite Element Method (FEM) (Romanescu and Lazăr, 2008 [7, 8]; Romanescu and Lazăr, 2009 [9]).

In finite element method analysis of flexible pavement structures, the area of interest (road structure and subgrade) is discretized into a number of finite elements with vehicle load on top of the model.

The pavement structure layers have been modeled with 2D finite elements of axisymmetric solid type, of quadrilateral form, with eight nodes in isoparametric formulation, available in the library of the LUSAS computer program [10].

2. CALCULATION ASSUMPTIONS

2.1. Layout variations of the geosynthetic material

In this study different variants of geosynthetic positioning within the reinforced flexible pavement structure (Table 1) were analyzed to see the influence of this aspect to the state of stress and strain. Variants analyzed are as follows:
- Variant I: classical reinforcing of the existing pavement structure without geosynthetics;
- Variant II: reinforcing with the geosynthetic layout between the existing pavement structure and new layers of reinforcement;
- Variant III: reinforcing with the geosynthetic layout between new clothing course and new base course, so between the binder and bituminous anrobat.

Table 1 - The geosynthetic layout

Material in pavement structure layer	Layer thickness, cm		
	Variant I	Variant II	Variant III
Asphalt concrete, BAR 16	4	4	4
Binder, BAD 25	5	5	5
Geosynthetic	-	-	0,5
Bituminous anrobat, AB 2	6	6	6
Geosynthetic	-	0,5	-
Existing bituminous layers	18	18	18
Granular material, Ballast	25	25	25
Natural subgrade type P5	∞	∞	∞

2.2. Deformation characteristics of materials

The characteristics of materials what are included in pavement structure layers are listed in Table 2.

Table 2 - Material characteristics of pavement structure

Material in pavement structure layer	Thickness, h, cm	Dynamic elasticity modulus, E, MPa	Poisson's ratio, μ
Asphalt concrete, BAR 16	4	3600	0,35
Binder, BAD 25	5	3000	0,35
Bituminous anrobat, AB 2	6	5000	0,35
Geosynthetic	0,5	20000	0,35
Existing bituminous layers	18	3000	0,35
Granular material, Ballast	25	168	0,27
Natural subgrade type P5	∞	70	0,42

2.3. Type of analysis

The three variants of reinforced flexible pavement structures are subjected to an axisymmetric analysis type. The following assumptions were made:
- measure units: N, m, kg, s, ºC;
- meshing was performed with axisymmetrical isoparametric finite elements;
- all the pavement structure layers work in the elastic domain;
- the layers are perfect bonded at the interface;
- the 115 kN standard axle loading is applied on the tire contact area (footprint);
- the state of stress is an axisymmetrical one;
- the model resting is also axisymmetrical.

3. FINITE ELEMENTS ANALYSIS RESULTS

After conducting the analysis of three different pavement structures has resulted the state of stress and strain in the linear elastic behavior stage.

It was intended to estimate the response of each pavement structure in its critical points corresponding to the design criteria of the existing romanian rules:
ε_r (E_x) = horizontal strain at the bottom of the asphalt layers;
ε_z (E_y) = vertical strain at the top of the subgrade;
and, as a novelty, at the edge of the tire footprint
τ_{rz} (S_{xy}) = shear stress at the bottom of the binder course.

In figures 1, 2 and 3 are presented comparatively the variations in the axis of loading, throughout the depth of pavement structures, of the three design parameters presented above, corresponding to each geosynthetic layout variant.

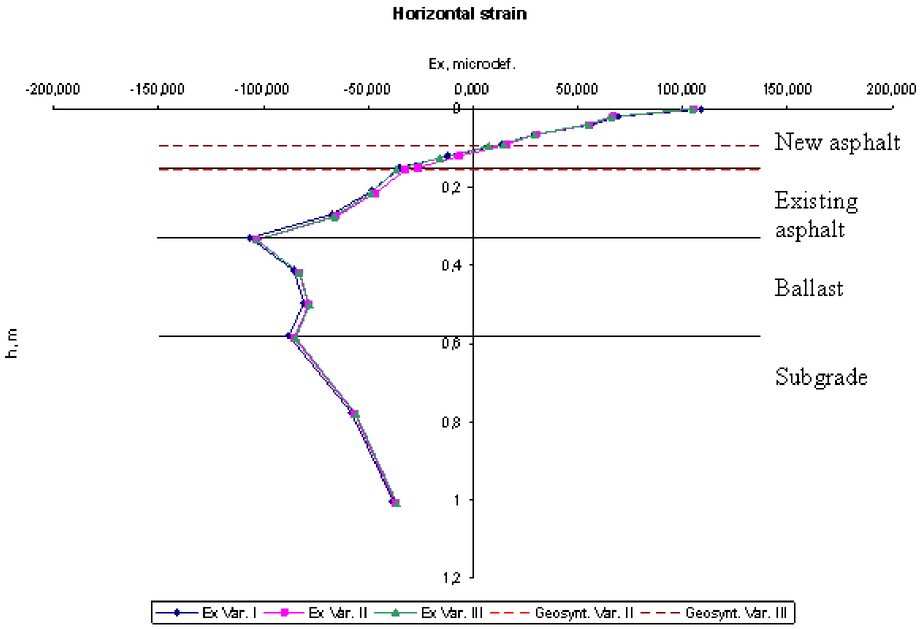

Figure 1 - Strain variation in horizontal direction;
Signs convention: (-) tension; (+) compression

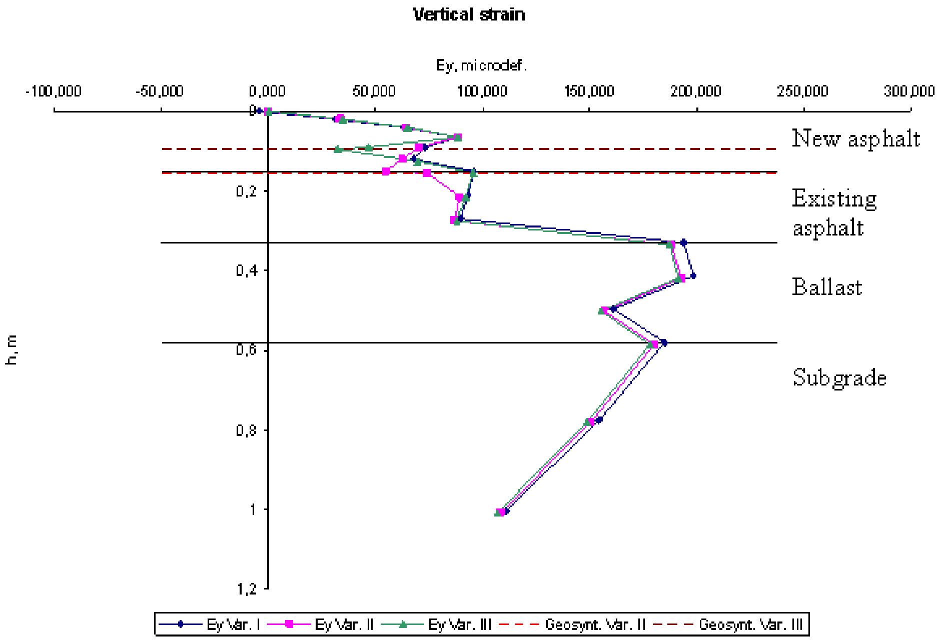

Figure 2 - Strain variation in vertical direction;
Signs convention: (-) tension; (+) compression

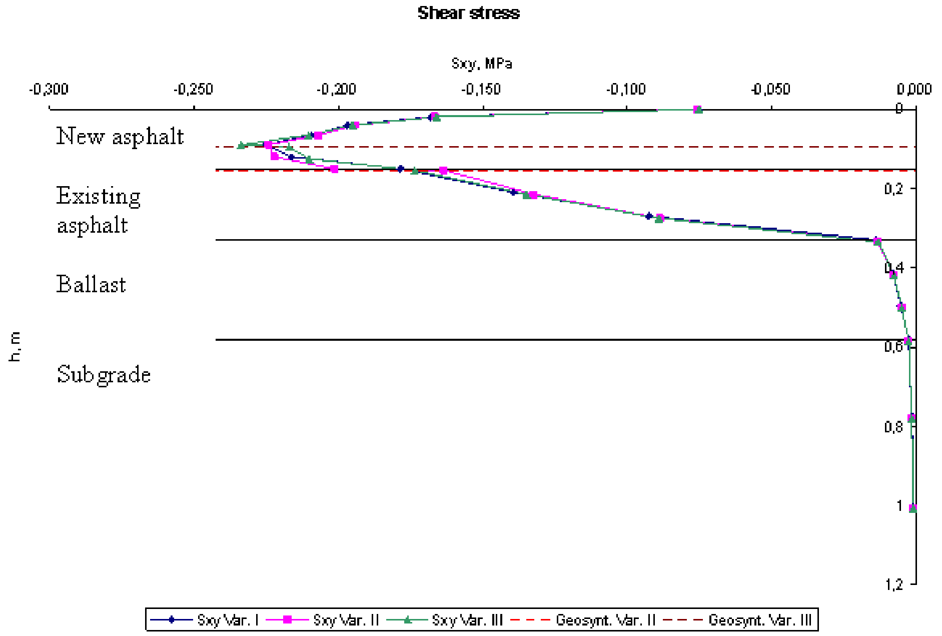

Figure 3 - Shear stress variation

For a more comprehensive representation on the behavior of flexible pavement structures reinforced with geosynthetic materials, still have examined the following parameters:

σ_r (S_x) = horizontal tensile stress;

σ_z (S_y) = vertical compressive stress;

and also, deflection basin, where

δ (D_y) = elastic deformation at the surface of the pavement structure (deflection).

Results are presented graphically in the following figures (4, 5 and 6).

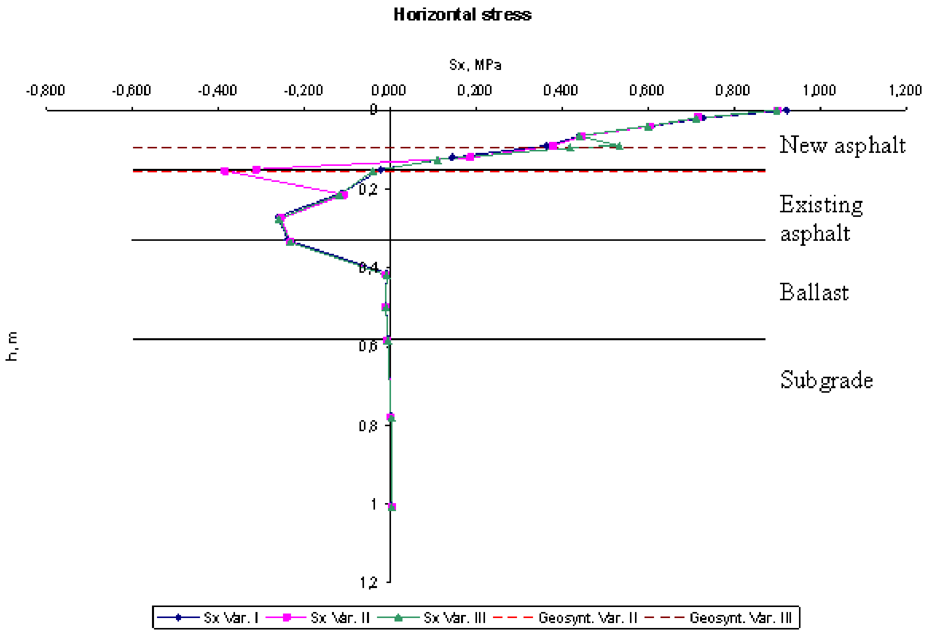

Figure 4 - Horizontal stress variation

From Figure 4 it is noted that at the bottom of asphalt layers reinforced with geosynthetic material occurs stresses with maximum values. These stresses concentration highlight the increased of the armed asphalt layers stiffness.

This indicates the geosynthetic beneficial effect of reinforcing the asphalt layers.

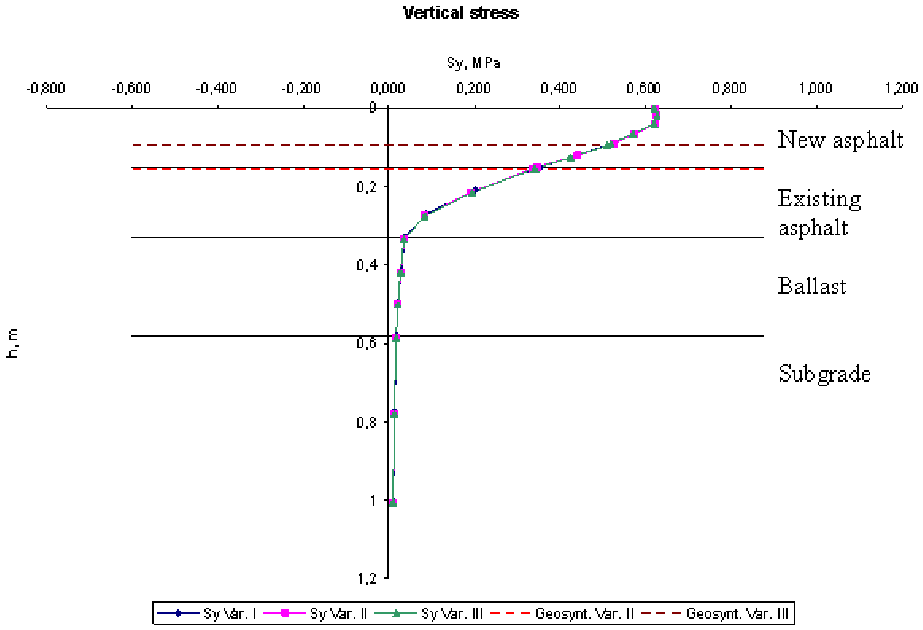

Figure 5 - Vertical compressive stress variation

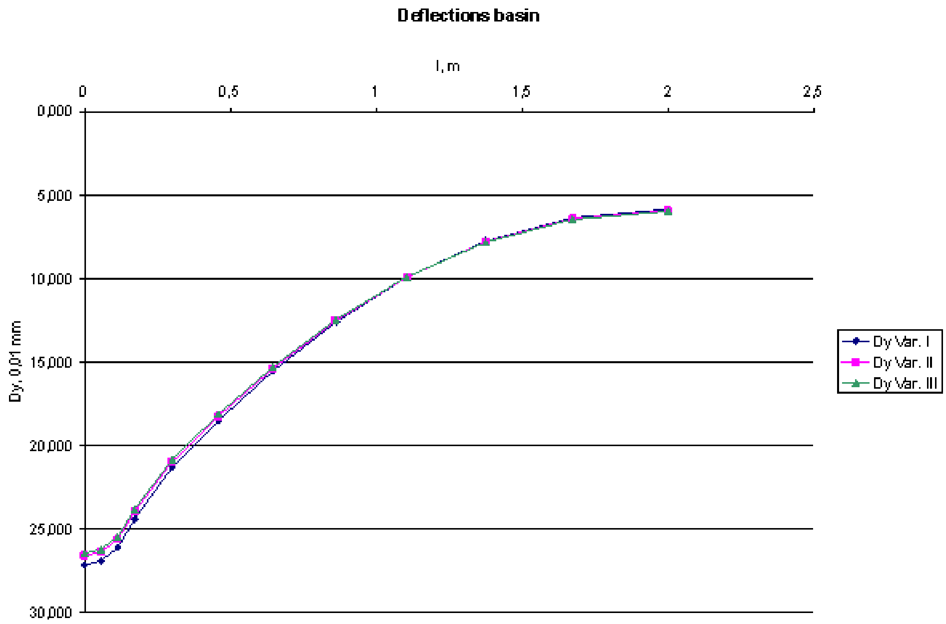

Figure 6 - Deflections basin

4. PERFORMANCE OF THE ANALYZED PAVEMENT STRUCTURES

Verification of reinforced flexible pavement structures variants was done in accordance with the romanian regulations “Reinforcement bituminous layers design normative of flexible and semirigid pavement structures. (Analytical method), indicative AND 550-99”. After calculations have resulted the values listed in Table 3. Allowable values are given in Table 4.

Table 3 - The values of strains

Layout variant of the geosynthetic material	Horizontal tensile strain at the bottom of the asphalt layers, ε_r, microdef.	Vertical compressive strain at the bed road level, ε_z, microdef.
Variant I	-106,50	185,02
Variant II	- 103,18	180,11
Variant III	- 103,50	178,21

Table 4 - Allowable values corresponding to the design criteria

Layout variant of the geosynthetic material	Admissible calculus traffic, $N_{c,adm}$, m.s.a. of 115 kN	Admissible vertical compressive strain at the bed road level, $\varepsilon_{z,adm}$, microdef.
Variant I	3,82	213,05
Variant II	4,33	213,05
Variant III	4,28	213,05

Considering the behavior under traffic of reinforced flexible pavement structures, results that these could handle a traffic volume of standard axle of 115 kN, corresponding to traffic class T1 - Very hard, according to the romanian regulations CD 155-2002.

Romanian current methods of design and reinforcement of flexible pavement structures takes into account only the fatigue behavior of asphalt mixtures and neglect their reaction to other important phenomenon to which these are subjected in service ie creep.

Shear stresses that influence the creep phenomenon, are the main generation cause of rutting distress type. For this reason, it was aimed also the evaluation of this parameter.

The research found that the shear stresses are manifested at the edge of the wheel - road surface contact and at the interface between the asphalt clothing and base course.

Below (in Table 5) are presented the values obtained for shear stress and tensile stress manifested in the asphalt layers.

Table 5 - Values of shear and tension stresses

Layout variant of the geosynthetic material	Shear stress at the bottom of the binder course, τ_{rz}, MPa	Horizontal tensile stress at the bottom of the asphalt layers, σ_r, MPa
Variant I	- 0,225	- 0,239
Variant II	- 0,224	- 0,232
Variant III	- 0,234	- 0,232

CONCLUSIONS

The studies on determining the optimal layout of the geosynthetic revealed that its location directly on the existing pavement structure (Variant II) is more appropriate to reduce the resulting stress and strain state and to an increase of admissible calculus traffic of about 13%.

Results that the use of geosynthetic materials to reinforce the asphalt layers of flexible pavement structures has a beneficial effect on their bearing capacity, issue also highlighted of the deflections basin (Figure 6).

Since the geosynthetics works well in tensioning applications, in the present study we examined also the influence of their presence in the composition of pavement structures on the shear stresses that occurs in asphalt mixtures.

It was found that the shear stresses values indicate once more the Variant II as the optimal geosynthetic layout.

How to locate the geosynthetic material on thickness of asphalt layers can bring the optimum results in taking repeated loading from traffic.

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