RESEARCH AND EVALUATION OF LITHUANIAN ASPHALT CONCRETE ROAD PAVEMENTS REINFORCED BY GEOSYNTHETICS

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Abstract. The paper focuses on the main functions of geosynthetics in asphalt concrete structures; it also offers results of the research into asphalt concrete pavements reinforced by geosynthetics. The present investigation also includes evaluation of the impact of geosynthetics. The analysis has helped identify the reological parameters whose values are related directly to geosynthetics. The regressive equations help calculate the depth of ruts, if the elasticity modulus and the viscosity of asphalt concrete are given. The statistical analysis supports the validity of the equations. The conclusions at the end of the paper refer to the reliability of geosynthetics used in asphalt concrete pavements.

Keywords: geosynthetics, reinforcement, rutting, the modulus of elasticity, viscosity.

1. Introduction

Recent years have witnessed an increase in geo-synthetics used in construction industries all over the world. During the last years Lithuania has not been any exception, particularly in road construction area.

In Lithuania geosynthetics was first used for road A1 Vilnius – Kaunas – Klaipėda in 1996 [1]. The road has been so far one of the major "consumers" of geosynthetics in the country (Fig 1). This material has been mainly used to reduce reflection cracking. It is usually laid on top of the old pavement and then covered with a new asphalt concrete layer.

However, geosynthetics in road construction cannot be exclusively limited to the above functions. It can also be used in the following areas [2, 3]:

- For constructing all kinds of structures in the transport sector (walls, crash barriers, slopes, tunnels, culverts);
- For protecting the environment (slopes from erosion, liquid-proof screens);
- In road pavement structures (for improving the strength characteristics).

There are two ways of reinforcing pavement:
1. Only base is reinforced (geosynthetics is laid on in the base area).
2. Asphalt concrete is reinforced (geosynthetics is laid between two layers of asphalt concrete).

The key aim of the present research was to investigate operational features, mechanical functioning of roads reinforced by geosynthetics. Also the predicted results obtained with the help of the method of finite elements were compared with the results of experimental research [4, 5]. This research focused on the impact of reinforcement on the depth of rutting depending on the geosynthetics chosen. A dependence of the rutting depth on the type of loading and the type of geosynthetics was established. Also the fluctuations in the
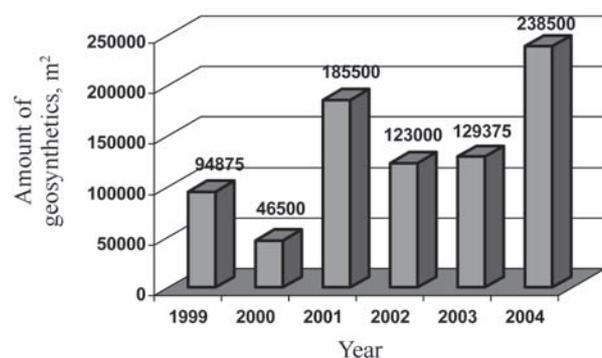

Fig 1. The amount of geosynthetics used on road A1 Vilnius – Kaunas – Klaipėda

values of stresses in different pavement layers have been quite well researched. The authors have suggested ways to evaluate the efficiency of using the materials in flexible pavements and the methodology to evaluate the impact of the materials when constructing flexible pavements.

Other authors were involved in similar research into geosynthetic-reinforced pavement structures [6, 7]. Apart from measuring the depth of rutting in the wearing course, strains were measured in deeper layers as well.

The research has attested to the dependence of rutting in the wearing course as well as deeper pavement layers on reinforcing the base by geosynthetics. The investigation has also identified the dependence of the efficiency of the geosynthetics on the strength characteristics of the frost-resistant layer.

Some authors, apart from the depth of rutting, have also identified the efficient depth of laying the material in the flexible pavement structure. Their research was based on the relative modulus of the elasticity of the road pavement as well as the strength of the embankment expressed by the above modulus of elasticity [8, 9].

Research into reinforcing asphalt concrete focused on reducing reflection cracking [10, 11]. The investigation attested to an obvious benefit obtained from geosynthetics used for that purpose.

However, very little research has been done on the impact of geosynthetic-reinforced asphalt concrete, on the development of plastic and shear strains, despite the fact that the material has been extensively used to fight the above defects.

Rutting, or wheel tracking, is one of major types of deterioration of asphalt concrete pavements. It starts at the initial stage of pavement operation and increases with heavy traffic flows. The resulting ruts enlarge expenditures for the road network maintenance and have a negative impact on the driving comfort. It also creates extra life risks. The aquaplaning is a reason of extra skidding; in winter time an icy surface contributes to increasing the breaking distance. The above reasons might lead to serious traffic accidents.

The overview of previous research has revealed that geosynthetics has an impact on the depth of rutting; however, the research was only performed on one layer of asphalt concrete with the geosynthetics reinforced base. So far no research has been conducted into the impact of geosynthetics on rutting when there are two layers of asphalt concrete and the material is laid between the wearing course and the second layer of asphalt concrete. Ruts emerging through shear strain of pavement are located in the wearing course of asphalt concrete pavement.

The problem has been in the focus of attention of researchers for years [12, 13]. However, in Lithuania so far no research has been conducted into the efficiency of geosynthetics to reduce rutting. The material has been used

on the basis of manufacturer's recommendations with no sufficient scientific substantiation.

2. Evaluation of geosynthetics used for road pavement

When used in road pavement construction, geosynthetics performs three major functions [2, 3]:

- Separation (separates different layers);
- Drainage (diverts liquids);
- Reinforcement (improves the strength characteristics of pavement or one of its layers).

Research into reinforced asphalt pavement has been conducted in the following areas:

- Residual strains;
- Reflection cracking;
- Road fatigue.

The above research aimed at substantiating the efficiency of using geosynthetics [14]. For that purpose the following parameters were employed:

1. Economic parameters: the use of geosynthetics leads to reducing the thickness of some construction layers; lower quality materials might be used.
2. Technical and operational parameters of pavement: the use of geosynthetics contributes to the increase of operation time of flexible pavements.

The main methods of investigation have remained the same; only the materials used for testing and the structure of pre-tested pavement might be different. Testing stands or testing grounds provide favourable conditions for simulation; however, the type of geosynthetics is different. Materials for road pavement are selected in accordance with the legal requirements of each country.

While researching residual strains, the following parameters were measured [15]:

- The character of rutting (plastic or structural);
- The depth of rutting in the asphalt concrete layer as well as deeper layers;
- The geometric structure of rutting;
- The loading cycle until the rutting of expected depth is achieved.

The research has attested to the fact that geosynthetics heavily influences the above strains. Its use leads to reducing the depth of rutting. Also geosynthetics-reinforced pavement can carry a higher number of loads until the rutting of expected depth is produced. The research also helped identify that the efficiency of using this type of material depends on its type. The use of geogrids leads to a better road performance than the use of geotextiles.

The efficiency of the material is assessed with reference to the layer coefficient ratio (LCR), which is used when applying American Association of State Highway and Transportation Officials (AASHTO) method in constructing flexible pavements.

The LCR values depend on the strength of the frost-resistant layer expressed in California Bearing Ratio (CBR) %. Then, the lower the strength of the layer, the higher is the impact of geosynthetics.

The LCR is calculated in the following manner:

$$LCR = \frac{SN_{REIN} \times d_{UNREIN}}{SN_{UNREIN} \times d_{REIN}}, \qquad (1)$$

where SN_{REIN} and SN_{UNREIN} refer to structural indices of geosynthetic-reinforced pavement and pavement with no reinforcement, respectively; d_{REIN} and d_{UNREIN} refer to the thickness of reinforced and unreinforced pavement base.

When researching the reinforced asphalt concrete pavement, the authors measured the rutting depth as well as the whole relative modulus of the elasticity of the flexible structure [8]. The scheme of investigation was similar to previous experimental research: on a testing stand, where loading can be transferred by a dynamic load plate test, there was a section of flexible pavement constructed which was reinforced by geosynthetics.

The modulus of elasticity of reinforced road structure is calculated by the following dependence:

$$E_{EQ.REIN} = K_R \times E_{EQ}, \qquad (2)$$

where $E_{EQ.REIN}$ is an equivalent elasticity modulus of a reinforced road structure, MPa, E_{EQ} stands for an equivalent modulus of a road structure, MPa, K_R is a "strengthening coefficient", characterising the effect of reinforcement and identified on the basis of the following dependence:

$$K_R = b_0 - b_1 \times \frac{E_{GR}}{E_D} + b_2 \times \frac{h_D}{D} + b_{11} \times$$
$$\left(\frac{E_{GR}}{E_D}\right)^2 - b_{12} \times \frac{E_{GR}}{E_D}\frac{h_D}{D} - b_{22} \times \left(\frac{h_D}{D}\right)^2, \qquad (3)$$

where E_{GR} refers to soil modulus of elasticity, MPa, E_P – stands for the modulus of elasticity of the road structure wearing course, MPa, H_P – thickness of the road structure, m, D – the diameter of the plate corresponding to the vehicle wheel track, m, b_0, b_1, b_2, b_{11}, b_{12}, b_{22} – indices obtained by a regressive analysis after conducting experimental research into road construction.

Another parameter identified in the course of investigation is a value characterising the road structure relative bearing capacity (P):

$$P = \frac{P_a}{P_0}, \qquad (4)$$

where P_A refers to pressure which remains stable for the direct dependence between the plate deflection depth and its loading (for reinforced road structure), MPa; P_0 is pres-

sure which remains stable for the direct dependence between the speed of plate deflection and its loading (for non-reinforced road structure), MPa.

The evaluation of geosynthetics in flexible road structures is related to reinforcement indices. When the base is reinforced, the indices are related to the base strength. Some researchers select the indices on the basis of their investigation according to the nomograms and depending on the pavement base strength expressed by CBR % [6, 7]. Others make use of regressive equations which include a series of parameters [8, 9].

However, the research and its evaluation are concerned with the characteristics of the lower layers. While investigating the impact of reinforcement by geosynthetics on asphalt concrete, one should focus on the nature of asphalt concrete [16]. The characteristics of asphalt concrete which might be influenced by reinforcement are determined by investigating asphalt concrete theories.

3. Key reological characteristics of asphalt concrete

Asphalt concrete is a composite material whose response depends on its input history. When investigating the functioning of asphalt concrete under repeated traffic loading, the viscoelastic theory is applied.

The materials subjected to the principle are characterised by reaction R in proportion to the initial impact I and defined by the linear principle of super-positions. The linear requirements are expressed in the following manner [17]:

In case of homogeneity

$$R\{\alpha I\} = \alpha R\{I\}, \qquad (5)$$

in case of super-position

$$R\{I_1 + I_2 + \cdots + I_n\} = R\{I_1\} + R\{I_2\} + \cdots R\{I_n\}, \qquad (6)$$

where α stands for an optional constant; symbol $\{\}$ characterises the material functioning, R – a function of the history of initial impact I.

When the reaction of the material depends on time and meets both of the above requirements, the material functioning is defined by its visco-elasticity.

The main inequalities used in the viscoelastic theory are identical in the case of elasticity; however, stresses and shifts are not identical physical dimensions. Instead, there are "pseudo-stresses" and "pseudo-shifts" used, which have the following expressions for asphalt concrete [18]:

$$\sigma_{ij}^R = E_R \int_0^t D(t-\tau)\frac{\partial \sigma_{ij}}{\partial \tau}d\tau, \qquad (7)$$

$$u_i^R = \frac{1}{E_R} \int_0^t E(t-\tau)\frac{\partial u_i}{\partial \tau}d\tau, \qquad (8)$$

where σ_{ij} refers to physical stresses, MPa, u_i – a physical

shift, m, σ_{ij} – physical stresses, MPa, σ_{ij}^R – pseudo stresses, MPa, u_i^R – pseudo shifts in m, E – elasticity modulus, MPa, D – creep compliance, m²/kN, E_R – standard elasticity modulus, adopted as a constant, MPa.

In case of shear strains [18]:

$$\tau(t) = \int_0^t \frac{1}{E}(t - \xi)\frac{\partial\gamma}{\partial\xi}\,d\xi, \qquad (9)$$

$$\gamma(t) = \int_0^t D(t - \xi)\frac{\partial\tau}{\partial\xi}\,d\xi, \qquad (10)$$

where τ – stresses varying with time, MPa, γ – strain varying with time, m, $E(t)$ – elasticity modulus, MPa, $D(t)$ – creep compliance, m²/kN, ξ – integration variable,

When making the calculating model of asphalt concrete, reology makes use of dependences of several mechanical models. For investigating the asphalt concrete as a viscoelastic material, usually Burgers' model is adopted (Fig 2) [16].
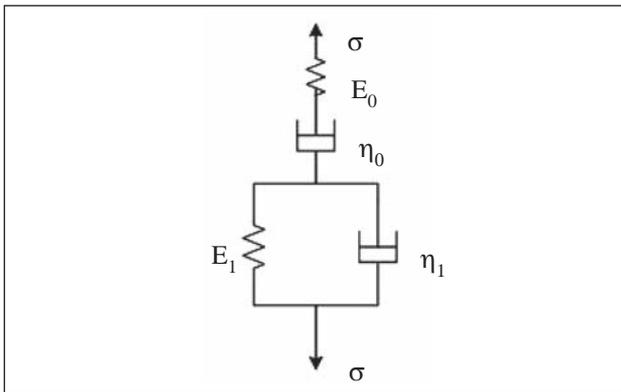

Fig 2. Burgers' reological model

The model is composite, consisting of Maxwell's and Kelvin's models and described by the following dependence:

$$\varepsilon = \frac{\sigma}{E_0}\left(1 + \frac{t}{T_0}\right) + \frac{\sigma}{E_1}\left[1 - \exp\left(-\frac{t}{T_1}\right)\right], \qquad (11)$$

where σ stands for stresses, MPa, E_0, E_1 – for the modulus of elasticity, MPa, T_0 – time of relaxation of asphalt concrete: $T_0 = \eta / E_0$, η – viscosity, MPa×s, t – time, s.

However, the most precise characteristic of visco-elastic materials is concerned with creep compliance, which can be expressed in the following manner:

$$D = \frac{\sigma}{E_0}\left(1 + \frac{t}{T_0}\right) + \frac{\sigma}{E_1}\left[1 - \exp\left(-\frac{t}{T_1}\right)\right]. \qquad (12)$$

When dealing with shear strains and stresses, we can see that the characteristics determining their values are the elasticity and viscosity of asphalt concrete.

The modulus of elasticity is the value of the elastic force of the material, expressed by the proportion of stresses and strains of the material.

Creep in asphalt concrete is a characteristic of the material determining its resistance to shear strains.

The main characteristic determining the resistance of asphalt concrete to rutting is the viscosity of asphalt concrete η_0.

4. Experimental research

An experimental research into reinforced pavement was performed at an experimental section of the city of Vilnius.

The road pavement structure consists of the following layers (Fig 3):

- asphalt layer No 1 (wearing course) – 0/11 S-M of 4 cm;
- asphalt layer No 2 – 0/16 S-A of 5 cm;
- asphalt layer No 3 – 0/22 A of 6 cm;
- base of 25 cm (crushed stone),
- subgrade of 40 cm (fine sand).

The structural layers and the materials used for constructing them are in conformity with the requirements of the Republic of Lithuania [19].

Geosynthetics was laid between the upper layer, or wearing course, and the lower layer of asphalt concrete.

In further text instead of the used materials title, arbitrary terms GT1, GT2, GT3, GT4, GT5, GT6 have been used and "any" without geosynthetic.

The experimental section has been constructed on Sept 2004. In Fig 4 the installation of geosynthetics materials in the experimental section is given.

The geosynthetic materials used are presented in Table 1.

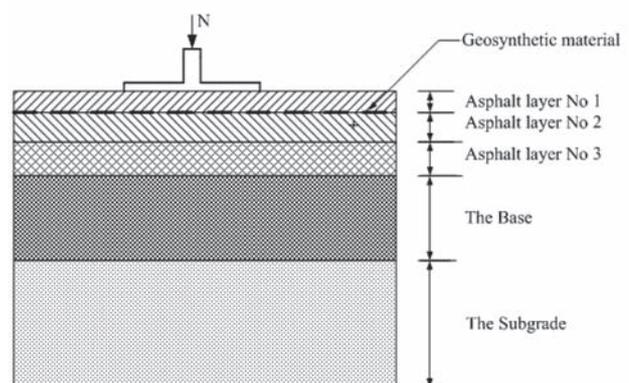The heavy traffic index VB was calculated; in the test section it amounted to 136 [19].

Fig 3. Construction scheme of an experimental section

Fig 4. The building of the experimental section

The first measurement of the depth of rutting was performed on April, 2005, the second – in Sept of 2005, together with the asphalt concrete elasticity modulus measurements.

When performing measurements, the pavement temperature was +24° C. The depth of rutting was measured with the help of a rule of 3 m. The results of the measurements are given in Fig 5.

The numbers 1 and 2 reflects the measurements of rutting in the spring and the autumn, respectively.

Table 1. Geosynthetics used

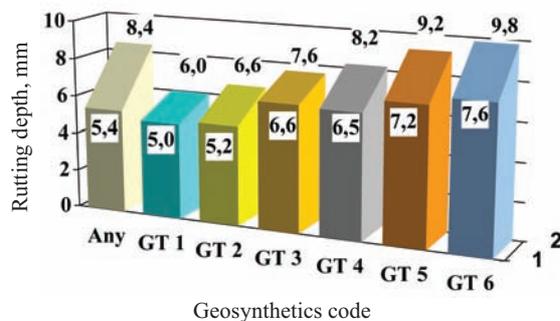| Geosynthetics	Amount of material, m^2
Geogrids	
Bitutex Stargrid Glu 50	35
HaTelit C 40/17	35
Armapal MP-50	35
Geotextiles	
Fibertex AM – 2	70
Pavegrid G-50	70
Pavemat	70

Fig 5. The depth of rutting on selected test sections after the first (1) and second (2) measurements

In the course of testing, the reological characteristics of asphalt concrete (asphalt concrete elasticity modulus E and asphalt concrete viscosity η) and the depth of rutting were determined. The tests were performed with the help of the static plate load and the 3 m rule.

When determining the viscosity of asphalt concrete, the experimental section was loaded with a static load and at equal time intervals the increase of strain was measured. When the increase could no longer be registered, the measuring stopped. The data obtained were used in the following formula:

$$\eta_0 = \frac{\int\limits_{t_0}^{t_1} \sigma(t)dt}{\Delta\varepsilon(t_0, t_1)}, \qquad (13)$$

where σ refers to constant stresses of asphalt concrete pavement, MPa, t_0, t_1 – time of loading until no strain increase is registered, s, ε – a strain during a period of time from t_0 to t_1, mm.

In addition to the above measurements, other measurements were carried out: the depth of rutting before and after the hot season, pavement strains after three cycles of loading (Fig 6).

The data of measurements and calculations are given in Table 2.

We can easily identify that before the first measurement of different sections, the depth of rutting was higher than in the section which was not reinforced.

However, after the hot season the increase in the rutting depth was highest in the section which had no geosynthetics at all.

When loading the asphalt concrete in several cycles and measuring the resulting strains, the impact of geosynthetics could be easily identified. However, the impact of geosynthetics was not positive in all cases. All types of strains with the maximum stresses and residual strains were weaker in sections where geogrids were applied. In
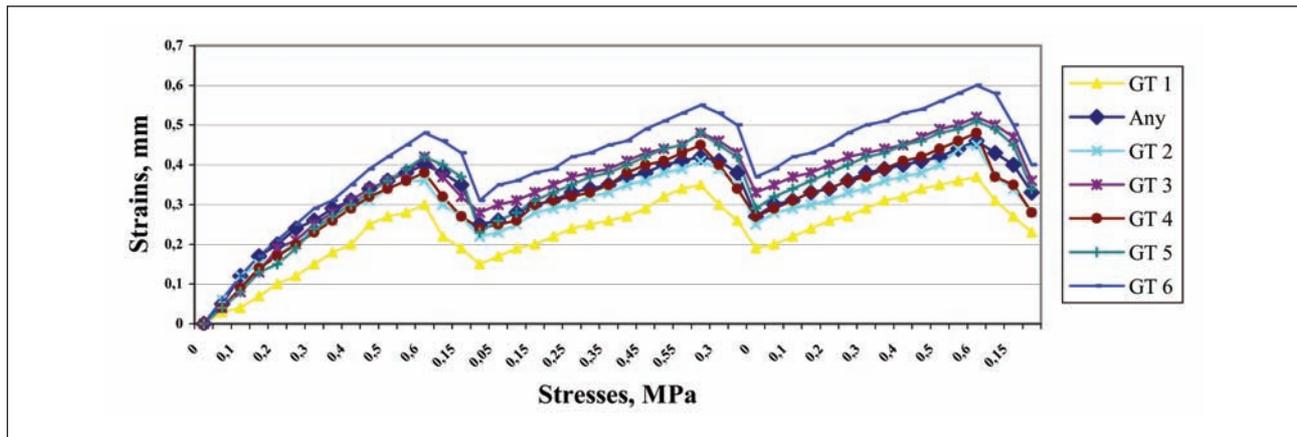
Fig 6. Asphalt concrete strains after several load cycles

Table 2. Asphalt concrete elasticity modulus and its viscosity: results of research

Experimental section number	Geosynthetics code	Elasticity modulus		Viscosity	
		E, MPa	k_E	η_0, MPa×s	$k_{\eta 0}$
00	Any	347,0	1,00	96,2	1,00
01	GT1	358,5	1,03	135,1	1,40
02	GT2	351,4	1,02	131,6	1,37
03	GT3	305,6	0,89	114,3	1,19
04	GT4	290,6	0,83	119,3	1,24
05	GT5	258,9	0,75	105,7	1,10
06	GT6	277,2	0,80	111,1	1,15

k_E, $k_{\eta 0}$ – indices measuring the changes in the asphalt concrete elasticity modulus and its viscosity, in the order of sequence.

sections with geotextiles the above strains were stronger than in sections with no reinforcement or in those reinforced by geogrids.

When performing a multiple regressive analysis, the impact of asphalt concrete elasticity and viscosity on the depth of rutting was determined (formulae 14–16):

$$S_1 = 14,191 - 0,0242E - 0,00358\eta_0, \qquad (14)$$

$R^2 = 92,3\ \%$, P – values for:

$E = 0,0038,$

$\eta_0 = 0,772,$

$$S_2 = 20,116 - 0,0197E - 0,0514\eta_0, \qquad (15)$$

$R^2 = 88,1\ \%$, P – values for:

$E = 0,040,$

$\eta_0 = 0,053,$

$$\Delta S = 5,925 - 0,00446E - 0,0479\eta_0, \qquad (16)$$

$R^2 = 70,9\ \%$, P – values for:

$E = 0,458,$

$\eta_0 = 0,0375,$

where S_1 – depth of rutting after the first measurement, mm, S_2 – depth of rutting after the second measurement, mm, ΔS – an increase in the depth of rutting, mm.

To verify, whether the resulting regressive dependences are reliable, there was a determination index used, marked as R^2.

The determination index varies from 0 to 1. The closer it is to 1, the better the graph reflects the research data.

R^2 measures the percentage of the variability in which has been explained by the fitted model. R^2 is calculated from:

$$R^2 = 100\left(1 - \frac{\sum\limits_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum\limits_{i=1}^{n}(y_i - \bar{y})^2}\right)\ \%, \qquad (17)$$

where y_i is the observed value of Y, $\hat{y}_i$ is the predicted value from the fitted model.

The adequacy of regression model verified sustaining statistical parameter F (dispersion ratio) and calculating:

$$F = \frac{S_{\bar{y}}^2}{S_{res}^2} , \qquad (18)$$

where $S_{\bar{y}}^2$ – the dispersion of regression model, S_{res}^2 – the residual dispersion.

F – value is compared with F_{CR}; if $F > F_{CR}$ – the model is adequate. Hence, all regression models are adequate (*F-ratio* > 1).

The impact of variables on the value under investigation can be determined by the value of P. The P-value reflects the impact of one or another variable on a characteristic under investigation. The value of ≤0,05 refers to a strong dependence between the variable and the characteristic under investigation.

The parameters that manifest a weaker impact on the variable can be removed from the regressive models.

Having overviewed the research results in Table 2, we can see that geosynthetics influences the elasticity and viscosity of asphalt concrete. However, with some materials the elasticity of reinforced asphalt concrete is lower than in the section that has not been reinforced. The viscosity in all sections is considerably higher than in the section that has not been reinforced. If the viscosity of asphalt concrete is compared with the increase of rutting during the hot season, we can claim that the viscosity of asphalt concrete is a crucial factor for the development of these strains when the pavement temperature is high.

5. Conclusions

1. The impact of geosynthetics is assessed in terms of reinforcement indices, which reflect changes in respective characteristics.

2. The research has proved that geosynthetics is related to the development of rutting during the hot season. There have been two reological characteristics of asphalt concrete identified which are heavily influenced by geosynthetics. The latter determines the size of strains during different seasons of the year.

3. The research has shown that the elasticity of asphalt concrete is a characteristic determining the development of rutting during the cold season. Equally the elasticity of asphalt concrete exerts an impact on maximum strains when asphalt concrete pavement is tested by the static plate load.

4. The viscosity of asphalt concrete determines the increase in the rutting depth during the hot season and the development of residual strains when the asphalt concrete pavement is tested by the static plate load,

5. On the basis of the regressive dependences, with the predicted and measured values of asphalt concrete elasticity and viscosity already known, the depth of rutting developing after a certain cycle of loading can be calculated.

6. The research has attested to the fact that the values of asphalt concrete elasticity and viscosity are higher on sections where geogrids have been used for reinforcement. Therefore, we suggest that for preventing shear strains and rutting, geogrids could and should be given preference over geotextiles.

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