THE ROAD OF EXPERIMENTAL PAVEMENT STRUCTURES: EXPERIENCE OF FIVE YEARS OPERATION

Audrius Vaitkus[1 ✉], Alfredas Laurinavičius[2], Rolandas Oginskas[3], Algirdas Motiejūnas[4], Miglė Paliukaitė[5], Oksana Barvidienė[6]

[1, 4, 5]*Road Research Institute, Vilnius Gediminas Technical University, Linkmenų g. 28, 08217 Vilnius, Lithuania*
[2, 3]*Dept of Roads, Vilnius Gediminas Technical University, Saulėtekio al. 11, 10223 Vilnius, Lithuania*
[6]*Dept of Hydrology, Vilnius Gediminas Technical University, Saulėtekio al. 11, 10223 Vilnius, Lithuania*
E-mails: [1]*audrius.vaitkus@vgtu.lt;* [2]*alfredas.laurinavicius@vgtu.lt;* [3]*rolandas.oginskas@vgtu.lt;*
[4]*algirdas.motiejunas@vgtu.lt;* [5]*migle.paliukaite@vgtu.lt;* [6]*oksana.barvidiene@vgtu.lt*

Abstract. The road of experimental pavement structures was constructed in 2007 and still continues its operation. The road consists of 27 different pavement structures with the same class of pavement structure but the different type and composition of materials. The experimental pavement structures were laid on the road to the query, one traffic lane is used by loaded traffic and other – by unloaded traffic. In May, 2012 totally 320 000 ESAL's (100 kN) passed the road. Annually – about 70 000 ESAL's. This article gives the research results of the bearing capacity and surface characteristics of experimental pavement structures after five years of their service.

Keywords: asphalt pavement structure, pavement distress, ruts (-ing), ESAL's, roughness of pavement, *IRI*.

1. Introduction

Over the years, a significant amount of effort has been spent on developing methods to objectively evaluate the condition of pavements (Nejad, Zakeri 2011). The use of asphalt pavement is connected with various operation characteristics, which are becoming the main object of contemporary scientific research. The most common problems in the field of road pavement operation are the formation of ruts, fatigue, as well as thermal cracking, deterioration, aging and water susceptibility (Navarro 2002). To increase the reliability of asphalt pavement, to avoid premature failure of asphalt pavement, researches should be strengthened to further study environmental influence in order to improve the quality of asphalt pavement, and enhance the ability of asphalt pavement (Yang, Ning 2011).

Surface cracking in pavements has long been regarded as the main cause of deterioration of roads because surface water penetration reduces the strength of subbase layers and results in broader cracks and potholes. Thus, surface cracking has a direct effect on pavement's quality and service life, which attracts more and more attention in recent years (Xu *et al.* 2011). Asphalt pavement is subjected to many distresses during its service life. One of the main distresses is rutting. Recently, rutting in asphalt pavements has become one of the major distress forms with the increase in traffic volume, tire pressure and axial load. It often happens within the first few years after opening to traffic. The rut is formed because of the shear stress in asphalt layer which causes large plastic deformations, so the part of the asphalt layer is imprinted into the ridge at the edges of wheel roll zone (Oscarsson 2011; Xu, Huang 2012).

Stiffness of asphalt pavement layers, as well as deflections measured by the Falling Weight Deflectometer (FWD) and the calculated equivalent stiffness modulus E_0 values depend on pavement temperature. Temperature is one of the main factors affecting road design, construction and maintenance. Therefore, Juknevičiūtė-Žilinskienė (2010) suggested a climatic zoning of the territory of the Republic of Lithuania from the point of view of road construction. Motiejūnas *et al.* (2010) made an assessment of temperature distribution in the different layers of asphalt pavement dependent on environmental temperature as well as the influence of the temperature variation on the stiffness of asphalt layers.

Asphalt mixture is a heterogeneous complex composite material of air, binder and aggregates used in modern pavement construction (Xu 2012). Modification of asphalt mix with polymer or other additives increases durability of asphalt pavement and decreases rutting (Kamaruddin *et al.* 2010; Moghaddam *et al.* 2011). Vaitkus *et al.* (2009) ascertained that the use of particular supplements in warm mix asphalt increases stiffness of the binder and at the same

time improves resistance to rutting. The material used and the thickness of frost blanket course must not only ensure the required resistance to frost of road pavement structure but also to increase bearing capacity of the structure, to distribute and reduce pressure to the subgrade surface. Vaitkus *et al.* (2012) suggested the materials for a frost blanket course and recommended that when laying a frost blanket course to take into consideration bulk density and Proctor density of the material used, as well as transportation costs.

2. Main characteristics of the road of experimental pavement structures

In 2007, near Vilnius City in Pagiriai settlement the road of experimental pavement structures was constructed. Parameters of the road of experimental pavement structures according to *STR 2.06.03:2001 Statybos techninis reglamentas „Automobilių keliai"* [Construction Technical Regulation "Motor roads"] corresponds to the road category III (2 traffic lanes, pavement width – 7 m, roadside width – 1 m) and the pavement structure class III (ESAL's of 100 kN = (0.8–3.0) mln). The road of experimental pavement structures, which is 710 m long, consists of 23 sections 30 m long and one section 20 m long. Three sections are additionally divided into 15 m sections. Pavement structures of various kinds were constructed at these sections. The experimental road was constructed on the way to the gravel quarry where the empty heavy vehicles go in and the loaded go out. In this case, one traffic lane of the experimental road is loaded much more than the other (Čygas *et al.* 2008).

Various materials were used for constructing every layer of experimental road section. The frost blanket course was built from sand (0/4, 0/11); the base course – from crushed dolomite and granite (0/56, 0/32), the mix of 50% crushed granite and 50% sand and gravel, crushed gravel mix, gravel and sand mix and the reclaimed asphalt. The asphalt base course was built from 0/32-C (AC 11 PS) crushed dolomite, gravel, 100% crushed gravel, 50% crushed dolomite and 50% crushed gravel; asphalt binder course: 0/16-A (AC 16 AS), 0/16-A$_{PMB}$ (AC 16 AS PMB) crushed granite 11/16 + crushed dolomite 5/8 + (crushed dolomite and crushed granite 8/11, 50% and 50%); crushed granite 8/11 and 11/16 + crushed gravel (rest of aggregates); crushed dolomite 8/11 and 11/16 + crushed gravel (rest of aggregates); 50% crushed granite + 50% sand; 100% crushed granite; 100% crushed gravel. Asphalt surface layer: 0/11 S-V (AC 11 VS), 0/11 S-M (SMA 11 S), 0/11 S-M$_{PMB}$ (SMA 11 S PMB), Confalt (Vaitkus *et al.* 2010).

The thickness and materials of every pavement structure were chosen according to the reference pavement structure which was built from asphalt surface layer 0/11 S-V (AC 11 VS); asphalt binder course 0/16-A (AC 16 AS); asphalt base course 0/32-C (AC 32 PS); base course – crushed dolomite 0/56; frost blanket course – sand 0/11 (Fig. 1) (Laurinavičius *et al.* 2009).
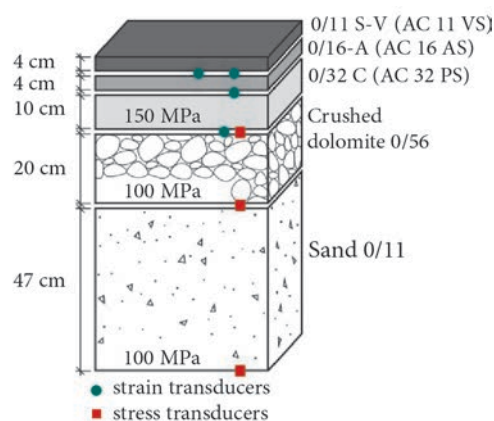

Fig. 1. Reference pavement structure (No 19)

Every year at the experimental road section the following measurements are taken:
- measurement of traffic flow,
- measurement of temperature and moisture in different layers of pavement structure,
- measurement of rutting,
- visual assessment of pavement distress,
- measurement of pavement roughness,
- measurement of pavement skid resistance,
- measurement of pavement equivalent stiffness modulus E_0 with FWD,
- measurement of pavement deflection with Benkelman Beam.

During the year the traffic volume changes (Čygas *et al.* 2011). The increase in the traffic volume and loads leads to pavement deterioration and, consequently, to the failure (Khedra, Breakahb 2011). Investigations of the test road section are performed in parallel with the determination of traffic flow. The traffic flow is recorded constantly after the opening of the road for traffic. For the classification of traffic flow the induction loops are installed into the road pavement. The volume of traffic on the experimental road test section is measured every day and data is collected week by week. Traffic flow distribution in the loaded traffic lane in 2008–2012 is presented in Fig. 2.

The assessment of the loaded traffic lane enables to define the highest traffic volume which dominates from summer to the beginning of autumn, and the lowest – in winter. When analysing the traffic volume of 2008–2012 it was determined that the highest traffic volume was in 2008. Heavy vehicles in 2008 made 23%, in 2009 – 17.5%, in 2010 – 16.5%, in 2011 – 21.8% of the total traffic volume (Čygas *et al.* 2011).

All the vehicles were rated according to ESAL's$_{100}$ = 100 kN. ESAL's$_{100}$ distribution at the time of the operation of experimental section is presented in Fig. 2. The experimental road is used by 70 000 ESAL's$_{100}$ in average annually, the total amount of ESAL's$_{100}$ from the beginning of road use to May, 2012 was 320 000. Distribution
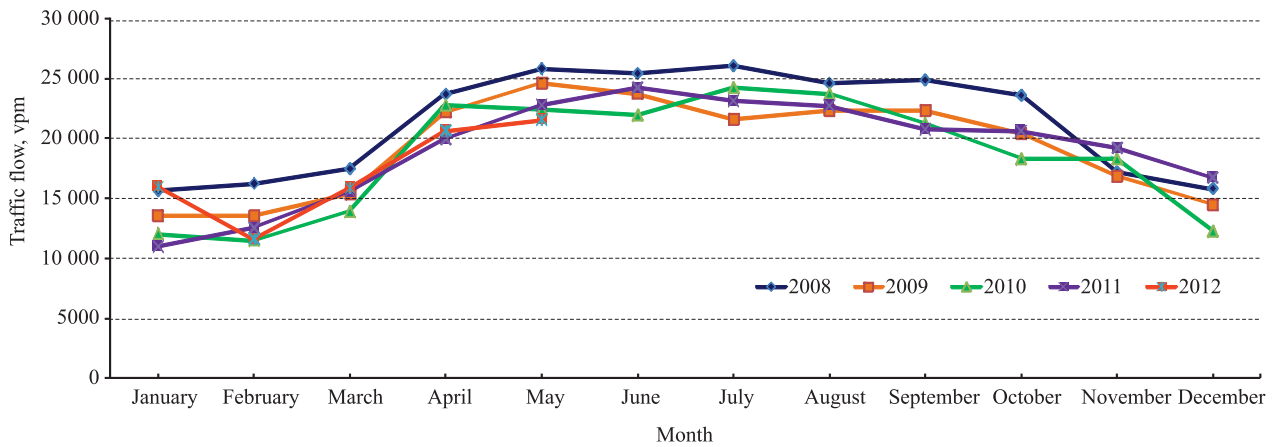
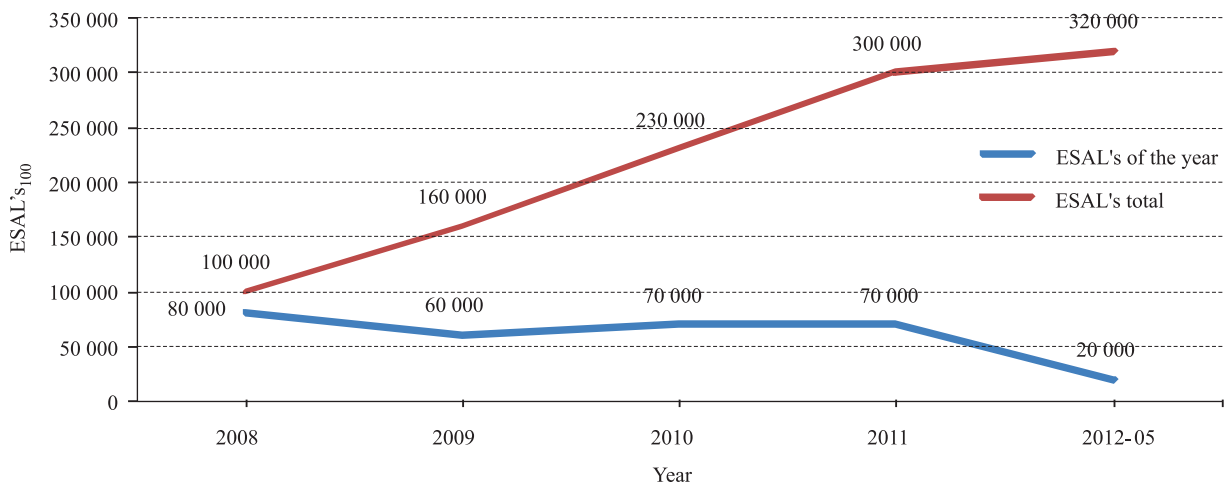**Fig. 2.** Traffic flow distribution in the loaded traffic lane in 2008–2012

Fig. 3. Distribution of ESAL's$_{100}$ of the experimental pavement structures

of ESAL's$_{100}$ of the experimental pavement structures is presented in Fig. 3.

3. Results of annual measurements

3.1. Temperature and moisture of pavement structure

Periodical investigations of strength indices and analysis of the obtained results encouraged to install temperature and moisture sensors in one of pavement structures where in 2009 seven temperature sensors of 12-Bit Temperature Smart Sensor type were installed: temperature sensor T1 was installed at the surface of the asphalt surface layer; T2 – in the asphalt surface layer (at a 2 cm depth from pavement surface); T3 – at the interface of the asphalt surface and base course (at a 4 cm depth from pavement surface); T4 – at the interface of the asphalt base course and road base (at a 8 cm depth from pavement surface), T5 – in the asphalt road base (at a 10 cm depth from pavement surface); T6 – at the interface of the asphalt road base and the crushed dolomite subbase layer (at a 18 cm depth from pavement surface) and temperature sensor T7 was erected

in the subgrade (at a 125 cm depth from pavement surface).

Analysing the highest temperature distribution in structural pavement layers in 2010–2011 the highest temperatures were found on the 17th of July at the asphalt pavement surface (+52.75 °C); in the asphalt surface layer (+52.20 °C); at the interface of the asphalt surface and base courses (+49.41 °C); at the interface of the asphalt binder and asphalt base courses (+46.13 °C); in the asphalt base course (+44.72 °C); at the interface of the asphalt base course and road base from crushed dolomite mix (+39.21 °C) and in the subgrade (+27.65 °C) on the 18th of August. Analysing the lowest temperature distribution in pavement structure layers in 2010–2011, the lowest temperatures are found on the 25th of January at the asphalt pavement surface (–21.87 °C); in the asphalt surface layer (–21.77 °C); at the interface of the asphalt surface and base courses (–20.93 °C); at the interface of the asphalt binder and asphalt base courses (–19.79 °C); in the asphalt base course (–18.88 °C); at the interface of the asphalt base course and road base from crushed dolomite

mix (–16.28 °C) and in the subgrade (–3.75 °C) on the 30th of January. The highest and the lowest temperatures of pavement structure are presented in Fig. 4.

The temperature in the surface layer of the asphalt pavement structure changes during the year from –21.77 °C to +52.75 °C, thus, the difference is more than 70 °C. It is obvious that such huge changes in the temperature of asphalt layer negatively influence the asphalt characteristics and lead to the early pavement distress. The similar situation is in asphalt binder layers. The suggestion is to use the polymer modified binders for asphalt surface and binder layers of asphalt pavement for the pavement structures of classes SV and I–III.

3.2. Bearing capacity of pavement structures

The bearing capacity of pavement structures was evaluated by two non-destructive methods – measuring pavement

response with Benkelman Beam and pavement deflections with FWD.

Benkelman Beam measures the max pavement deflection and response caused by static load of dual wheels. Measurements with Benkelman Beam are carried out two times a year in spring and autumn. Measurements are taken in 3 points of each section in the rut of the right wheel (2 points) and between the ruts (1 point). The highest mean values of equivalent stiffness modulus E measured in the rut (vary from 877 MPa to 519 MPa) at ESAL's$_{100}$ =180 000 (2010). The lowest mean values of equivalent stiffness modulus E (vary from 591 MPa to 397 MPa) at ESAL's$_{100}$ = 40 000 (2008). The distribution of equivalent stiffness modulus E of pavement structures after different number of ESAL's is presented in Fig. 5.

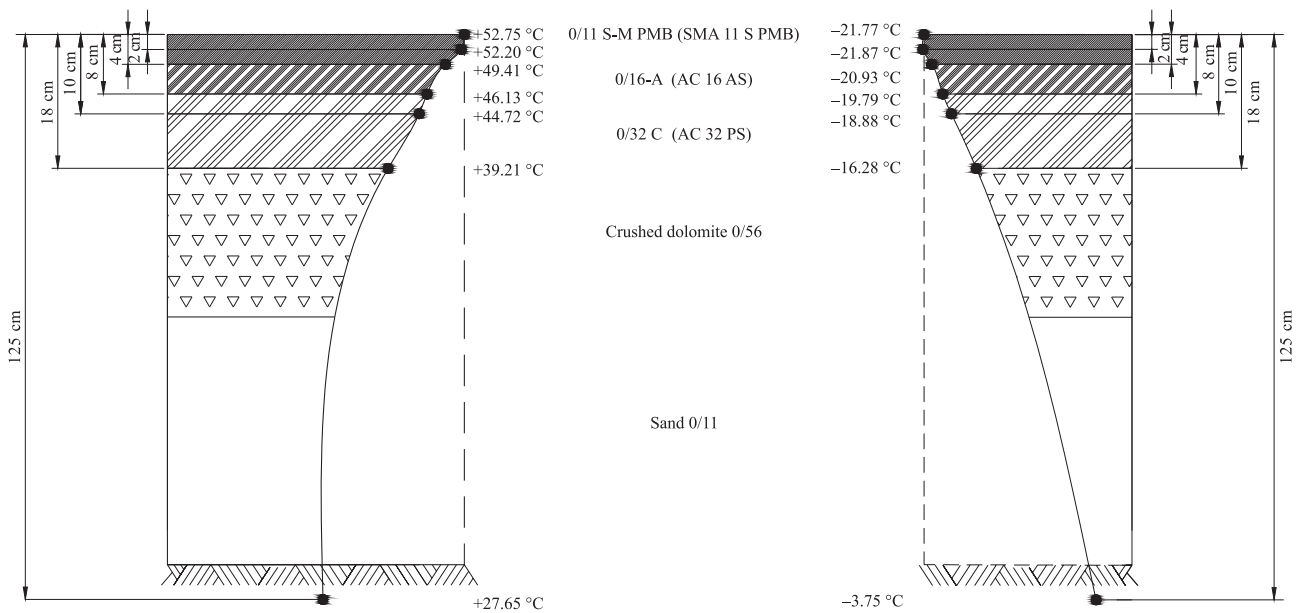When measuring with FWD the pavement structure deflections from the dynamic loading are registered.

Fig. 4. The highest temperatures in pavement structure in July and the lowest – in January
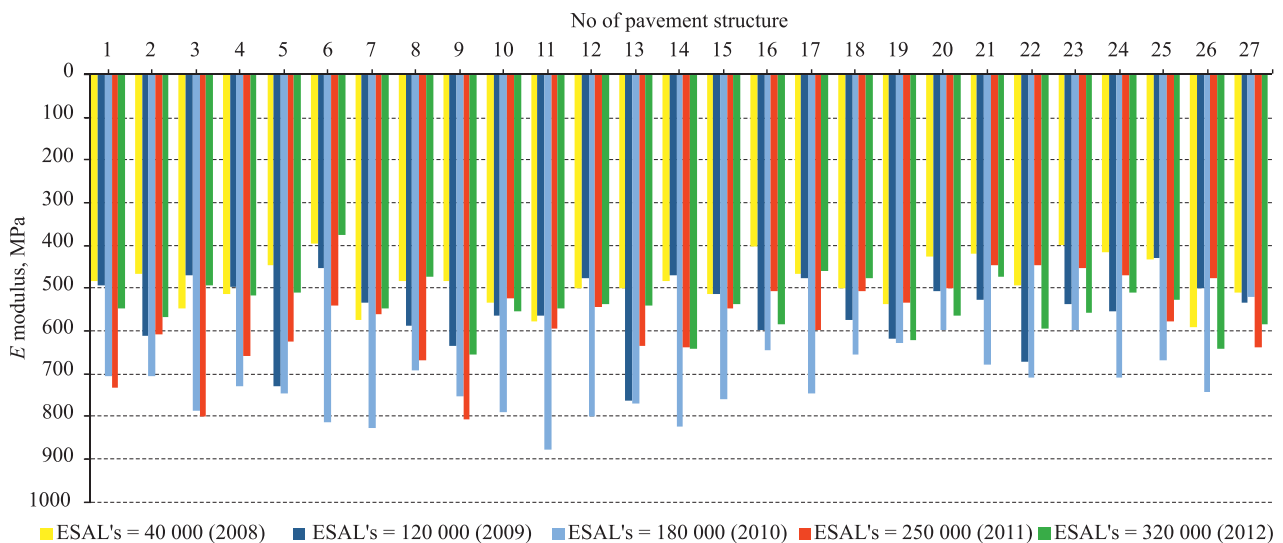

Fig. 5. Equivalent stiffness modulus E of pavement structures measured in spring with Benkelman Beam in the rut of loaded traffic lane

Measurements are taken in 4 points of each section in the rut of the right wheel and between the ruts. The mean of the rut in the right wheel is taken by 3 values. The highest mean values of equivalent stiffness modulus E_0 (vary from 1080 MPa to 753 MPa) at ESAL's$_{100}$ = 320 000 (2012). The lowest mean values of equivalent stiffness modulus E_0 (vary from 823 MPa to 612 MPa) at ESAL's$_{100}$ = 120 000 (2009). The highest bearing capacity in the loaded traffic lane at ESAL's$_{100}$ = 320 000 (2012) was represented by the pavement structures: 5, 9, 3, 17, 16, 20th – 1080 MPa (asphalt surface layer AC 11 VS, asphalt binder course AC 16 AS, asphalt base course AC 32 PS, base course – reclaimed asphalt pavement and crushed dolomite 0/32, frost blanket course – sand 0/11); 9th – 1056 MPa (asphalt surface layer – Confalt, asphalt binder course – AC 16 AS, asphalt base course – AC 32 PS, base course – crushed dolomite 0/56, frost blanket course – sand 0/11); 3th – 980 MPa (asphalt surface layer AC 11 VS, asphalt binder course AC 16 AS, asphalt base course AC 32 PS, base course – crushed dolomite 0/56, frost blanket course – sand 0/4); the lowest bearing capacity was represented by the following pavement structures: 17th – 753 MPa (asphalt surface layer AC 11 VS, asphalt binder highest bearing capacity AC 16 AS (100% granite), asphalt base highest bearing capacity AC 32 PS, base highest bearing capacity – crushed dolomite 0/56, frost blanket highest bearing capacity – sand 0/11); 16th – 764 MPa (asphalt surface highest bearing capacity AC 11 VS, asphalt binder highest bearing capacity AC 16 AS (50% crushed granite + 50% sand), asphalt base highest bearing capacity AC 32 PS, base highest bearing capacity – crushed dolomite 0/56, frost blanket highest bearing capacity – sand 0/11); 20th – 769 MPa (asphalt surface highest bearing capacity AC 11 VS, asphalt binder highest bearing capacity AC 16 AS, asphalt base highest bearing capacity AC 32 PS, base highest bearing capacity – crushed dolomite 0/56, frost blanket highest bearing capacity – sand 0/11). The distribution of equivalent stiffness

modulus E_0 of pavement structures after different number of ESAL's is presented in Fig. 6.

The analysis of results of the bearing capacity of pavement structure shows that the highest values are obtained in pavement structures where the thicker (30 cm) base highest bearing capacity of crushed dolomite was used, also where the base highest bearing capacity was constructed with reclaimed asphalt 10 cm plus crushed dolomite 10 cm. The pavement structure with semi rigid surface highest bearing capacity also showed high result. The lowest bearing capacity values were obtained in pavement structures with crushed granite and sand mix asphalt binder highest bearing capacity and also pavement structure with geosynthetics at the bottom of asphalt binder highest bearing capacity. It should be stated that the measurements by using different methods to evaluate the bearing capacity of asphalt pavement structure showed different results.

3.3. Roughness of pavement structures

Roughness of asphalt pavement structures of experimental road is measured in both traffic lanes – loaded and unloaded. Measurements are taken by the mobile road research laboratory RST-28. Roughness expressed by the international roughness index *IRI*, m/km, is presented as the mean value of 30 m taken from each pavement structure. Distribution of roughness in different pavement structures depending on the number of ESAL's is presented in Fig. 7.

Analysis of roughness is more concentrated on the changes of *IRI* in each pavement structure depending on the time of its operation and the number of ESAL's. Differences between the *IRI* of pavement structures are influenced by construction and are independent of the type of pavement structure. The collected results showed that roughness decreased after five years of road operation and after 320 000 of ESAL's, though the decrease is not sufficient, changing max 0.3 m/km.
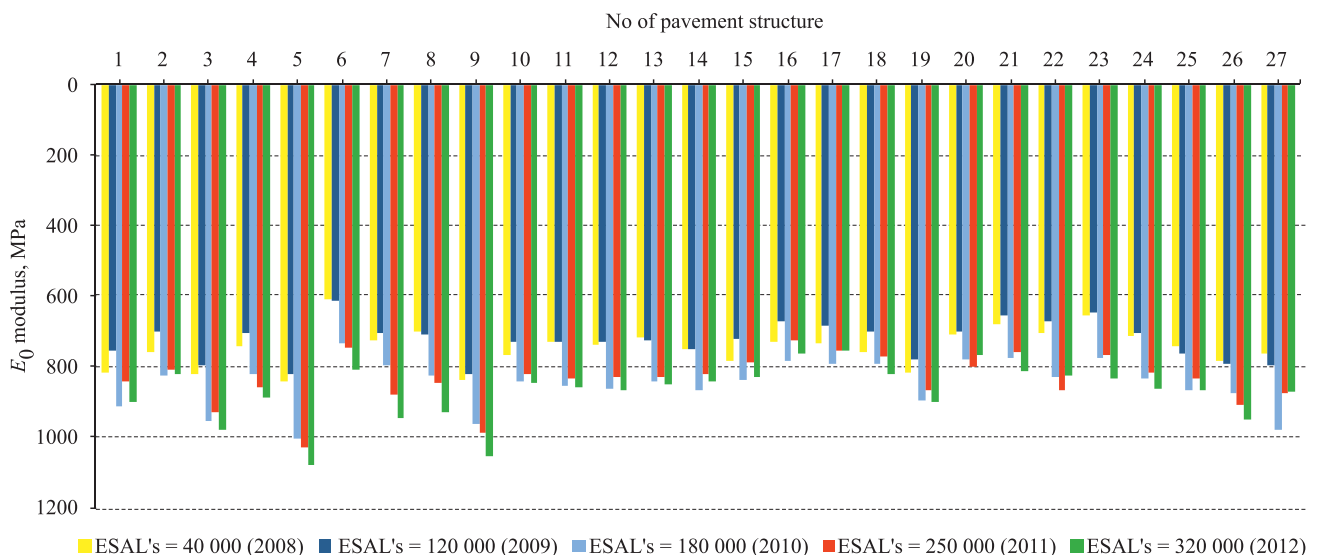

Fig. 6. Equivalent stiffness modulus E_0 of pavement structures measured in spring with FWD in the rut of loaded traffic lane

3.4. Rutting of pavement structures

The rut depth of asphalt pavement structure of the experimental road is measured in both traffic lanes – loaded and unloaded. Measurements are carried out by the mobile road research laboratory RST-28. The rut depth is measured using laser sensors which measure transverse road profile in certain intervals and ensure sufficient reliability for the definition of rut depth.

Measurements of the rut depth are taken every meter, totally 30 values for each pavement structure. The average depth of the right rut, the left rut and the max clearance was counted of every pavement structure. To increase the accuracy of measurements and to get the reliable analysis results the additional statistical analysis was made. The analysis showed that the most relevant statistical index is Median (Vaitkus *et al.* 2012). Distribution of the right rut depth of different pavement structure dependent on the number of ESAL's is presented in Fig. 8.

At first the measurements of the loaded traffic lane right rut depth were taken by the mean values in 2008 and 2009. Since 2010 the assessment of rut depth measurements, i. e. comparing the differences between the min and max values, the average of rut depth in 30 m and 20 m sections, the average of rut depth at 30 m, median and mode at different number of ESAL's$_{100}$, were taken by the median. Fig. 8 showed that the highest rut depth values are defined at ESAL's$_{100}$ = 320 000 in the 22th – 5.7 mm (asphalt surface layer AC 11 VS, asphalt binder course AC 16 AS, asphalt base course AC 32 PS, base course – crushed dolomite 0/56, frost blanket course – sand 0/11); 27th – 5.7 mm (asphalt surface layer AC 11 VS, asphalt binder layer AC 16 AS, asphalt base course AC 32 PS (50% crushed dolomite + 50% crushed gravel), base course – crushed dolomite 0/56, frost blanket course – sand 0/11); 20th – 5.6 mm (asphalt surface layer AC 11 VS, asphalt binder course AC 16 AS, asphalt base course AC 32 PS, base course – crushed dolomite 0/56, frost blanket course – sand 0/11);
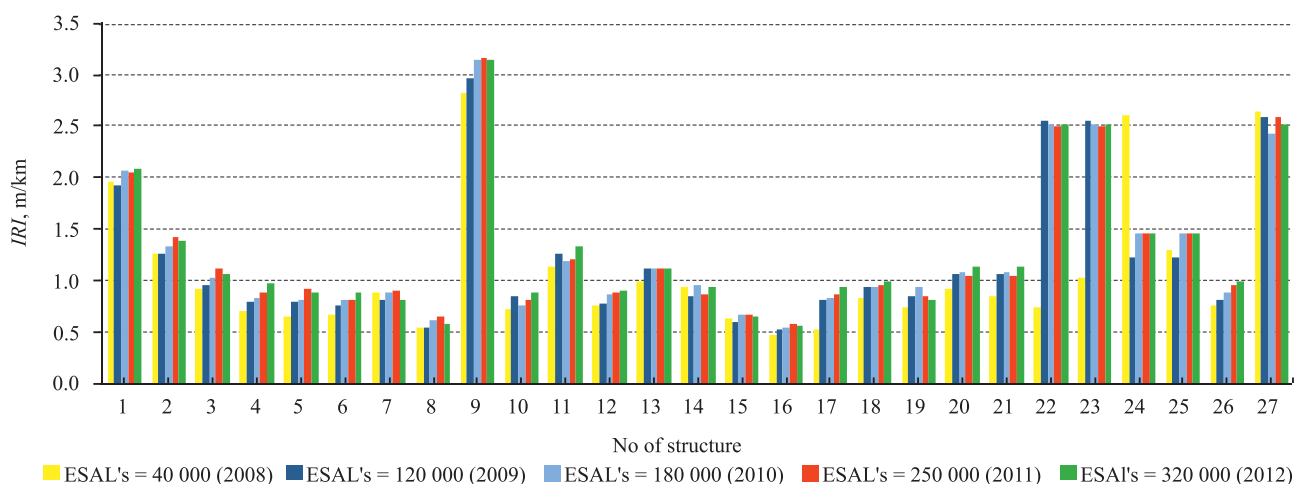

Fig. 7. Distribution of roughness in different pavement structures depending on the number of ESAL's$_{100}$
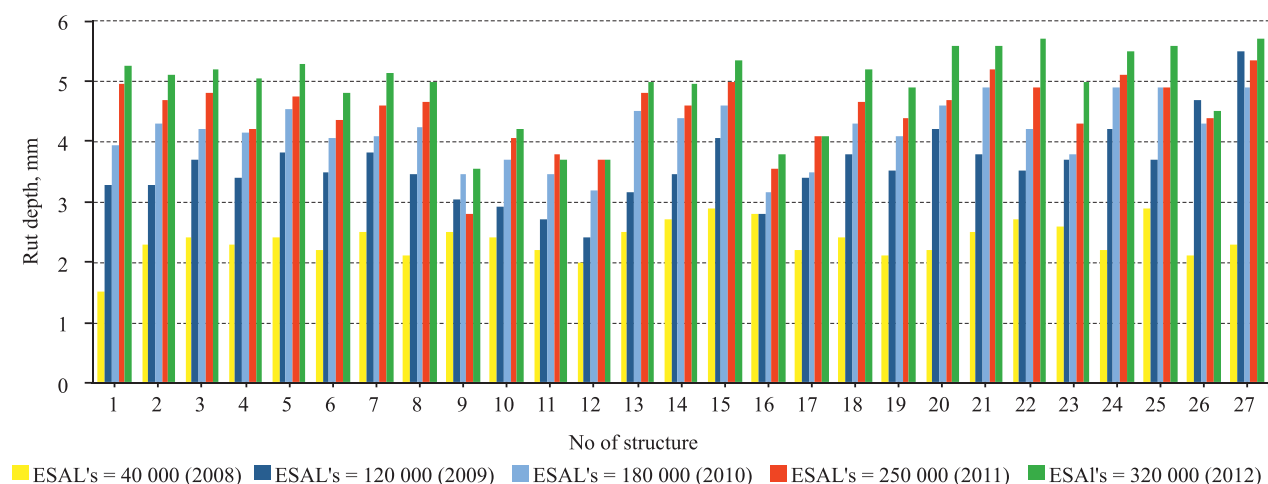

Fig. 8. Distribution of rut depth in the different pavement structures dependent on ESAL's$_{100}$

the lowest rut depth – in the 1st – 3.6 mm (asphalt surface layer AC 11 VS, asphalt binder course AC 16 AS, asphalt base course AC 32 PS, base course – gravel-sand mix 0/32, frost blanket course – sand 0/11); 12th – 3.7 mm (asphalt surface layer SMA 11 S, asphalt binder course AC 16 AS, asphalt base course AC 32 PS, base course – crushed dolomite 0/56, frost blanket course – sand 0/11); 11th – 3.7 mm (asphalt surface layer SMA 11 S, asphalt binder course AC 16 AS$_{PMB}$, asphalt base course AC 32 PS, base course – crushed dolomite 0/56; frost blanket course – sand 0/11). Comparing the measured values with the limit values, the rut depth does not exceed the limit value which is 2.5 cm for regional roads.

The measurements of rutting showed that the max rut depths vary from 3.5 mm to 5.5 mm dependent on pavement structure type. The min distressed pavement structures are those with semi rigid surface layer, also the pavement structures with stone mastic asphalt (SMA) surface layer (with PMB and without) and pavement structure with asphalt binder course with polymer modified bitumen (PMB). The max distressed pavement structures are those with geosynthetics between asphalt binder and asphalt base course, also with geosynthetics between base and subbase course. The pavement structure with the base course from crushed dolomite and crushed gravel mix also showed uncomplimentary results.

Fig. 9. Transverse cracking in pavement structure with semi rigid surface layer

Fig. 10. Longitudinal cracking caused by construction technology violation

3.5. Distress of pavement structures

Every year the distress of pavement structures was measured on the test road section. Measurements of pavement structure distress were carried out in spring and autumn. During 5 years of experimental road operation only longitudinal and transverse cracks were identified (Figs 9–10). Longitudinal cracks are running parallel to the pavement center lane, while transverse cracks extend across the center lane. The cracking mostly appears in the pavement structure with semi rigid surface layer. Longitudinal cracks are caused by the violations of construction technology, and transverse cracks are attributed to the temperature cracks caused by temperature fluctuations and freeze.

4. Conclusions

The road of experimental pavement structures in Lithuania was built to expand experimental investigations of the separate structural pavement layers under the real conditions. Analysis of the results of 5 years experimental research of the test road section showed that all 27 pavement structures still have perfect operational characteristics.

Assessment of the loaded traffic lane enabled to define the highest traffic volume which dominates from summer to the beginning of autumn, and the lowest – in winter. When analysing the traffic volume in the period 2008–2012 it was determined that the highest traffic volume was in 2008. The heavy vehicles in 2008 made 23%, in 2009 – 17.5%, in 2010 – 16.5%, in 2011 – 21.8% of the total traffic flow.

The difference of temperature in the surface layer of the asphalt pavement structure changes during the year from –21.77 °C to +52.75 °C, the difference is more than 70 °C. It is obvious that such huge changes of temperature in asphalt layer negatively influence asphalt characteristics and lead to the early pavement distress. The similar situation is in asphalt binder course. The suggestion is to use the polymer modified binders for asphalt surface and binder layers of asphalt pavement for the pavement structures of classes SV and I–III.

Analysis of the results of pavement structure bearing capacity shows that the highest values are obtained in pavement structures where the thicker (30 cm) base course of crushed dolomite was used, also where the base course was constructed with reclaimed asphalt 10 cm plus crushed dolomite 10 cm. The pavement structure with semi rigid surface layer also showed high result. The lowest bearing capacity values were obtained in pavement structures with crushed granite and sand mix asphalt binder course, and also in pavement structure with geosynthetics at the bottom of asphalt binder course.

Analysis of roughness is more concentrated on the changes of *IRI* in each pavement structure depending on the time of its operation and the number of ESAL's. Differences between the *IRI* of pavement structures are influenced by construction and are independent of the type of pavement structure. The collected results showed that roughness decreased after five years of road operation and

after 320 000 of ESAL's, though the decrease is not sufficient, changing max 0.3 m/km.

The measurements of rutting showed that the max rut depths vary from 3.5 mm to 5.5 mm dependent on pavement structure type. The min distressed pavement structures are those with semi rigid surface layer, also the pavement structures with SMA surface layer (with PMB and without) and pavement structure with asphalt binder course with PMB. The max distressed pavement structures are those with geosynthetics between asphalt binder and asphalt base course, also with geosynthetics between base and subbase course. The pavement structure with the base course from crushed dolomite and crushed gravel mix also showed uncomplimentary results.

The cracking mostly appears in the pavement structure with semi rigid surface layer. Longitudinal cracks are caused by the violations of construction technology.

Recommendations

Pavement distresses after five years of road operation emerged not only due to the environmental conditions and traffic flow but also due to the materials of pavement structure. It is recommended to proceed the research of experimental pavement structures and to evaluate the distress of pavement structures with regard to the changes in moisture and temperature of base course and subgrade.

It is recommended to use the accelerated testing methods, such as heavy vehicle simulator, to speed up the experimental research and to get the results more quickly.

Reference:

Čygas, D.; Laurinavičius, A.; Vaitkus, A.; Paliukaitė, M.; Motiejūnas, A. 2011. A Test Road Section of Experimental Pavement Structures in Lithuania (II), in *The 8th International Conference „Environmental Engineering": selected papers*, vol 3. Ed. by Čygas, D.; Froehner, K. D. May 19–20, 2011, Vilnius, Lithuania. Vilnius: Technika, 1064–1069.

Čygas, D.; Laurinavičius, A.; Vaitkus, A.; Pervenenckas, Z., Motiejūnas, A. 2008. Research of Asphalt Pavement Structures on Lithuanian Roads (I), *The Baltic Journal of Road and Bridge Engineering* 3(2): 77–83. doi: 10.3846/1822-427X.2008.3.77–83.

Juknevičiūtė-Žilinskienė, L. 2010. Methodology for the Evaluation of the Effect of the Climate of Lithuania on Road Construction and Climatic Regioning, *The Baltic Journal of Road and Bridge Engineering* 5(1): 62–68. http://dx.doi.org/10.3846/bjrbe.2010.09

Kamaruddin, I.; Madzlan, B. N.; Yasreen, G. S. 2010. The Effect of Fine Aggregate Properties on the Rutting Behaviour of the Conventional and Polymer Modified Bituminous Mixtures Using Two Types of Sand as Fine Aggregate, in *Proc. of Malaysian Universities Transportation Research Forum and*

Conferences 2010 (MUTRFC2010). December 21, 2010, Universiti Tenaga Nasional. ISBN 978-967-5770-08-1.

Khedra, S. A.; Breakahb, T. M. 2011. Rutting Parameters for Asphalt Concrete for Different Aggregate Structures, *International Journal of Pavement Engineering* 12(1): 13–23. http://dx.doi.org/10.1080/10298430903578960.

Laurinavičius, A.; Vaitkus, A.; Bertulienė, L.; Tuminienė, F.; Žiliūtė, L. 2009. Research of Experimental Road Pavement Structures in Lithuania, in *The 2nd International Conference "Environmentally Friendly Roads – Enviroad 2009"*: selected papers. October 15–16, 2009, Warsow, Poland.

Moghaddam, T. B.; Karim, M. R.; Abdelaziz, M. 2011. A Review on Fatigue and Rutting Performance of Asphalt Mixes, *Scientific Research and Essays* 6(4): 670–682. http://dx.doi.org/10.5897/SRE10.946.

Motiejūnas, A.; Paliukaitė, M.; Vaitkus, A.; Čygas, D.; Laurinavičius, A. 2010. Research of the Dependence of Asphalt Pavement Stiffness upon the Temperature of Pavement Layers, *The Baltic Journal of Road and Bridge Engineering* 5(1): 50–54. http://dx.doi.org/10.3846/bjrbe.2010.07

Nejad, F. M.; Zakeri, H. 2011. An Optimum Feature Extraction Method Based on Wavelet–Radon Transform and Dynamic Neural Network for Pavement Distress Classification, *Expert Systems with Applications* 38(8): 9442–9460. http://dx.doi.org/10.1016/j.eswa.2011.01.089

Oscarsson, E. 2011. Modelling Flow Rutting in In-Service Asphalt Pavements Using the Mechanistic-Empirical Pavement Design Guide, *Road Materials and Pavement Design* 12(1): 37–56. doi:10.1080/14680629.2011.9690351

Vaitkus, A.; Vorobjovas, V.; Žiliūtė, L.; Kleizienė, R.; Ratkevičius, T. 2012. Optimal Selection of Soils and Aggregates Mixtures for a Frost Blanket Course of Road Pavement Structure, *The Baltic Journal of Road and Bridge Engineering* 7(2): 154–159. http://dx.doi.org/10.3846/bjrbe.2012.21

Vaitkus, A.; Puodžiukas, V.; Motiejūnas, A.; Vitkienė, J.; Vorobjovas, V.; Paliukaitė, M. 2010. Long Term Research of Experimental Asphalt Pavement Structures, in *Transport Research Arena Europe 2010*. June 7–10, 2010, Brussels, Belgium.

Vaitkus, A.; Čygas, D.; Laurinavičius, A.; Vorobjovas, V.; Perveneckas, Z. 2009. Analysis and Evaluation of Compaction Properties of Warm Mix Asphalt, in *The 2nd International Conference "Environmentally Friendly Roads – Enviroad 2009"*: selected papers. October 15–16, 2009, Warsow, Poland.

Xu, Ch.; Anzhi, Y.; Liao, M.; Chunan, T. 2011. Analysis of Periodic Cracks in Surface Layer of Pavement Structures, *Engineering Failure Analysis* 18(1): 411–420. http://dx.doi.org/10.1016/j.engfailanal.2010.09.023

Xu, T.; Huang, X. 2012. Investigation into Causes of In-Place Rutting in Asphalt Pavement, *Construction and Building Materials* 28 (1): 525–530. http://dx.doi.org/10.1016/j.conbuildmat.2011.09.007

Yang, Q.; Ning, J. 2011. The Environmental Influence of Asphalt Pavement and Countermeasures, *Energy Procedia* 5(2011): 2432–2436. http://dx.doi.org/10.1016/j.egypro.2011.03.418.