

**STUDY OF THE DYNAMICS OF PERMANENT DEFORMATIONS FOR THE AC AND SMA ASPHALT MIXTURES****AC UN SMA ASFALTBETONA MAISIĀJUMU SASTĀVU PALIEKOŠO DEFORMĀCIJU VEIDOŠANĀS DINAMIKAS PĒTĪJUMS****Viktors Haritonovs**, M.sc.ing

Rigas Technical university

Construction Science Centre Researcher

Address: Azenes street 16/20 – 222, Riga Latvia

Phone: +37126412568

E-mail: [yh@e-apollo.lv](mailto:yh@e-apollo.lv)**Juris Naudžuns**, Prof., dr.sc.ing

Riga Technical University, The Institute of Transportation

Riga, Azenes st. 16/20

Phone: +37167089287

E-mail: [naudzuns4@bf.rtu.lv](mailto:naudzuns4@bf.rtu.lv)**Juris Smirnovs**, Prof., dr.sc.ing

Riga Technical University, The Institute of Transportation

Riga, Azenes st. 16/20

Phone: +37167089278

E-mail: [smirnovs@bf.rtu.lv](mailto:smirnovs@bf.rtu.lv)

*Keywords: asphalt concrete, modified bitumen, permanent deformation, rutting, wheel tracking test, equivalent single-axle load*

## **1. Introduction**

Permanent deformations or rutting is the main type of damage to the asphalt concrete pavement in Latvia. To eliminate it, a large section of the asphalt pavement must be renovated, which requires a lot of financial investment. In the current economic situation, this is inadmissible. In order to solve this problem, the in-depth laboratory study of deformation properties of the asphalt concrete composition is required. Since 2007 the Construction Science Centre of the Riga Technical University has been participating in the State Joint Stock Company “Latvian State Roads” research programme “Research on Application of New Technologies”, where this theme is included. Within the framework of the project, the Riga Technical University has acquired modern equipment to study the dynamics of appearance of permanent deformations. By applying the new technologies in Latvian circumstances, it is possible to timely evaluate the deformation properties of the asphalt concrete mixture composition prior to its being laid on the road, by manufacturing the asphalt concrete specimen close to the real circumstances and loading them on a road or a street, as well as to elaborate the asphalt concrete mixture compositions, which are resistant to rut formation.

## **2. Aim and Tasks of the Research**

Aim of the research: To investigate stability to strain of the asphalt concrete mixture compositions applied for the surface of Latvian streets and roads under the heavy transport load, by considering the local climatic circumstances.

To achieve this aim, the following tasks have to be solved:

- 1) Designing of the asphalt concrete mixture composition with the traditional aggregate and the modified and unmodified bitumen binder.
- 2) Investigation of the temperature and transport loads characteristic for Latvian circumstances, as the main external factors influencing formation of permanent deformation.
- 3) Determining the deformation properties of the asphalt concrete specimens in the laboratory circumstances by the standard testing methods of the performance properties – the Wheel Tracking tests, in conformity with LVS EN 12697-22, and the cyclic pressure test, in conformity with LVS EN 12697-25.
- 4) Investigation of the dynamics of appearance of permanent deformations with the help of the VESYS model

### 3. Methodology

Asphalt concrete is considered to be a very complicated material. Analysis of the asphalt concrete properties is made difficult due to many factors, which influence these properties, the main of these being: there is no constant load amount and its operation frequency, as well as the properties change considerably depending on the temperature and load nature. In accordance with researches of some scientists, the asphalt concrete mechanical properties are the function of the load amount and temperature [1]. Therefore, elaboration of a mechanical model for the asphalt concrete pavement, with observation of all factors influencing mechanical properties, is very complicated. There is a possibility of either to reduce a large amount of the influencing factors to several most important ones, or to perform the time consuming tests for determining other parameters and to summarise them in one model. The material models can be divided into three groups [2]:

1. rheological models;
2. empiric correlation equations based on the experimental stage monitoring results;
3. functional equations directly based on laboratory test results.

Plastic deformations from the repeated heavy transport load increase exponentially against the upper deformation boundary ( $\varepsilon = 20\text{mm}$ ). Growth of deformations from the cyclical load is non-linear. The internationally recognized VESYS method is chosen for permanent deformation prediction during experimental testing on the Wheel tracking equipment, as well as on the cyclical press equipment, in accordance with the EN 12697-25 method. The VESYS model states that the ratio of vertical plastic strain per cycle,  $d\varepsilon^p/dN$ , to the resilient strain,  $\varepsilon_r$ , is an exponential function of the number of load cycles,  $N$  (Equation 1) [3].

$$\frac{1}{\varepsilon_r} \cdot \frac{\varepsilon^p}{dN} = \mu \cdot N^{-\alpha}, \quad (1)$$

where:

$\varepsilon^p$  - permanent deformation, mm

$\varepsilon_r$  - elastic or/ resilient deformation, mm

$N$  - the number of load applications, cycles

$\mu$  - parameter representing the constant of proportionality of strains, and

$\alpha$  - parameter indicating the rate of decrease.

The material parameters  $\mu$  and  $\alpha$  are determined from the following expression:

$$\mu = \frac{a \cdot b}{\varepsilon_r}, \quad (2)$$

where:

$a, b, \varepsilon_r$  - constants determined from testing,

$\alpha = 1 - b$

Asphalt slabs are manufactured by the roller compaction machine in accordance with the EN 12697-32 standard method. Mechanical properties of the asphalt specimens manufactured in the laboratory are similar to those of the field compacted asphalt. For each type of asphalt, three slabs are made: two for the Wheel Tracking test and one for determining the resilient modulus. Thickness of the specimens corresponds to that of the field compacted asphalt layer, i.e. 40 mm. The wheel tracking test is performed in accordance with the EN 12697-22 standard method. The equipment in the laboratory circumstances simulates the asphalt slab specimen load, which is close to the actual heavy transport load on the asphalt pavement. Testing is performed at  $+50^\circ\text{C}$  – the warming up temperature of the asphalt pavement surface during the hottest summer days [4]. The resilient modulus is determined by the indirect tensile test method in accordance with the EN 12697-26 standard method.

#### 4. Properties of asphalt concrete and raw materials

##### 4.1. Bitumen

Comparison of properties of the binders and evaluation of their conformity to requirements of the Roads Specifications 2005 [6], which are the technical specifications for construction of Latvian streets and roads, are summarised in Tables 1 and 2. The modified bitumen binder has a lower penetration and the higher softening point temperature, the larger kinematic viscosity, but the lower fragility temperature, in comparison with the conventional bitumen binder B70/100.

**Table 1**

Comparison of Properties of the Bitumen Binders B70/100 and ModBit 80B

Bitumen properties	Results		Standard
	B 70/100	Modbit 80B	
Penetration 25°C, × 0,1 mm	71	59	LVS EN 1426
Softening point, °C	47,7	68	LVS EN 1427
Paraffin wax content, %	1,1	-	LVS EN 12606
Kinematic viscosity 135°C, mm <sup>2</sup> /s	322	350	LVS EN 12595
Flash and fire points, °C	320	349	LVS EN 22592
Frass breaking point, °C	-21,2	-16	LVS EN 12593
Solubility in toluol, %	99,27	-	LVS EN 12592
Dynamic viscosity 60°C, Pa/s	146	-	LVS EN 12596
Density, g/cm <sup>3</sup>	1,0066	-	LVS EN ISO 3838
Resistance to hardening under the influence of heat and 135°C			
Mass change	-0,050	0	LVS EN 12607
Penetration 25°C, × 0,1 mm	72,2	40	LVS EN 1426
Softening point, °C	51,8	71	LVS EN 1427
Softening point change, °C	4,1	3,0	LVS EN 1427

##### 4.2. Aggregate

The asphalt concrete aggregate is selected in such a way as to include the main natural stone materials applied in manufacturing of asphalt concrete in Latvia - dolomite, granite and diabase. The aggregate has its main physical and mechanical properties determined. Requirements of the Roads Specifications 2005 regulate conformity of the aggregate categories for construction of Latvian streets and roads depending on the motor road operation conditions, for instance, traffic intensity (See Table 3). Distribution of the aggregate properties into categories is provided in the LVS EN 13043 Standard: "Aggregates for Bituminous Mixtures and Surface Treatments for Road, Airfields and Other Trafficked".

**Table 2**

Evaluation of the Bitumen B 70/100 Conformity to Requirements of the LVS EN 12591 Standard

Index		Standard	Requirement		Results		Evaluation
			Convent.	Mod.	Convent.	Mod.	
Penetration 25°C, × 0,1 mm		LVS EN 1426	70-100	50-70	71	59	Conforms
Softening point, °C		LVS EN 1427	43-51	> 53	47,7	67,7	Conforms
Paraffin wax content, %		LVS EN 12606	≤ 2,2	-	1,1	-	Conforms
Frass breaking point, °C		LVS EN 12593	≤ -10	> -15	-21,1	-16	Conforms
Solubility in toluol, %		LVS EN 12592	> 99,0	-	99,27	-	Conforms
Kinematic viscosity 135°C, mm <sup>2</sup> /s		LVS EN 12595	> 230	-	322	-	Conforms
Flash and fire points, °C		LVS EN 22592	> 230	> 235	320	349	Conforms
Elastic reverse, %		LVS EN 22592	-	> 50	-	88	
Hardening LVS EN 12607-1	Mass change %		≤ 0,8	< 0,5	-0,050	0	Conforms
	Permanent penetration, 25°C, × 0,1 mm	LVS EN 1426	> 50	> 35,4	72,2	40	Conforms
	Elastic reverse, %	LVS EN 22592	-	> 50	-	84	Conforms
Storage stability	Softening point change, °C	LVS EN 13399	-	< 5	-	1,9	Conforms
	Penetration change 25°C, × 0,1 mm		-	< 9	-	6	Conforms

#### 4.3. Compositions of the asphalt concrete mixtures

Five compositions of the dense graded asphalt concrete mixture AC and two compositions of the stone mastic asphalt SMA with the traditional aggregate and one reference mixture AC 11 with the Martin steel slag aggregate have been designed (See Table 4). The optimal bitumen binder composition for the asphalt concrete mixtures has been determined with the help of the Marshall method

**Table 3**

Conformity of the Coarse Aggregate to the Requirements of the  
Roads Specifications 2005 at AADT > 3500

Index	Standard	Requirement		Result				Evaluation
		Dense graded AC	Stone mastic SMA	Lim	D	GR	MTS	
Flakiness index	LVS EN 933-3	≤ 15	≤ 15	11	9	12	3	Conforms
Resistance to fragmentation (Los Angeles)	LVS EN 1097-2	≤ 20	≤ 20	25	13	12	18	Lim does not conform
Magnesium sulphate test	LVS EN 1367-2	≤ 18	≤ 18	6	0,9	-	2	Conforms
Filler < 0,063mm	LVS EN 933-1	≤ 2	≤ 2	2,4	1,4	1,1	0	Lim does not conform
Nordic test	LVS EN 1097 - 9	≤ 10	≤ 10	18	13	8	4	Lim and D does not conform

**Table 4**

Compositions of the Dense Graded Asphalt Concrete Mixture AC and SMA

Asphalt Concrete Mixture Type	Aggregate fraction d-D, mass %							Bitumen	
	11-16	5-11	8-11	5-8	2-5	0-5	Dolomite powder	B70/100	ModBit
AC 11/Lim <sup>3)</sup>	-	37.7	-	-	11.3	37.7 <sup>1)</sup>	7.6	5.7	-
AC 11/Gr <sup>4)</sup>	-	-	51.5	20.7	51.5 (70% 0-2) (30% 2-5)		3.9	4.7	-
AC 11/D5 <sup>5)</sup>	-	-	21.9	7.6	1.9	60.2	3.8	4.6	-
AC 11/Ref <sup>6)</sup>	-	29.8	-	-	-	42.9	6.5	6.8	-
AC 16/Lim	20.9	29.5	-	-	1.0	37.1 <sup>2)</sup>	6.6	4.9	-
SMA 16/Gr	39,9	-	28,3	9,5	-	14,1	7,3	-	5,9
SMA 11/D	-	-	51,7	17,9	0,9	15,1	8,5	5,5	-

<sup>1)</sup> Natural washed sand<sup>2)</sup> Crushed sand<sup>3)</sup> Lim - dolomite<sup>4)</sup> Gr - granite<sup>5)</sup> D - diabase<sup>6)</sup> Martin steel slag

## 5. Results

For the designed AC and SMA asphalt concrete mixture compositions, the deformation curves - permanent deformation growth is obtained on the Wheel Tracking testing equipment, depending on analysis of the cycles. Table 5 provides summary of the material parameters  $\mu$  and  $\alpha$ , deformation and resilient modulus for the asphalt concrete specimen types used in the experiment.

The obtained results allow determining the maximum wheel tracking slope mm per 1,000 load cycles for the asphalt concrete specimens used in the research. Categories of the maximum wheel tracking slope mm per 1,000 load ( $WTS_{air}$ ) cycles are given in the EN 13108-1 standard. The maximum EN 13108-1 Standard  $WTS_{air}$  category is  $WTS_{air}1$ , which means that the maximum wheel tracking slope per 1,000 cycles is 1mm. The estimated  $WTS_{air}$  categories are provided in Table 6.

**Table 5**

Asphalt Concrete Deformation Parameters  $\mu$  and  $\alpha$

Material parameter	Asphalt Concrete Mixture Compositions						
	AC 11/Lim	AC 11/Gr	AC 11/D	AC 11/Ref	AC 16/Lim	SMA 11/D	SMA 11/D_Mod
E, MPa	11,5	33,4	32,2	115.3	55.8	68,6	164
$\varepsilon_p$ , mm	20 <sup>**</sup>	13,1 <sup>*</sup>	14,0 <sup>*</sup>	11,2	16,5 <sup>***</sup>	7,61	3,0
$\varepsilon_r$ , [ $10^{-2}$ ] mm	58,4	43,2	31,9	13,2	32,1	23,5	3,13
$\mu$	0,008	0,003	0,01	0,45	0,02	0,52	2,54
$\alpha$	0,933	0,9830	0,977	0,470	0,825	0,446	0,201
Specimen, mm	50						

\*\*\*<sup>\*)</sup>  $\varepsilon_p$  per 10,000 cycles

\*\*<sup>\*)</sup>  $\varepsilon_p$  per 5,000 cycles

\*<sup>\*)</sup>  $\varepsilon_p$  = 20 mm per 1,700 cycles;

**Table 6**

Wheel Tracking Slope  $WTS_{air}$

Asphalt Concrete Mixture Type	$WTS_{air}$ factual (mm/1,000 load cycles)
AC 11/Lim	3,11
AC 11/Gr	2,57
AC 11/D	6,87
AC 11/Ref	0,49
AC 16/Lim	1,5
SMA 11/D	0,56
SMA 16/Gr_ModBit	0,06

To determine the daily, weekly, monthly and annual growth of permanent deformations, the traffic intensity data expressed in ESAL units are required, as the parameter N from 1. equation is equal to the amount of ESAL units. ESAL is determined from the following equation:

$$ESAL = f_i \cdot G \cdot AADT \cdot 365 \cdot N \cdot F, \quad (3)$$

where:

$ESAL$  -equivalent single-axle load;

$f_i$  - design line factor;

$G$  -growth factor;

$AADT$  - first year annual average daily traffic;

$N$  - number of axles on each vehicle;

$F$  - load equivalency factor for vehicle.

If accepting that the asphalt concrete pavement design period on the A4 detour road (Baltezers – Saulkalne) in accordance with the project is 20 years and the annual traffic growth is 2%, the growth factor  $G$  will equal to:

$$G = \left[ (1 + r)^N - 1 \right] / r, \quad (4)$$

where:

$$r = \frac{i}{100};$$

$i$  - growth rate = 2%

There are 16% of the five-axle tracks on the A4 detour road. The amount of cars is 74% percent; still, their damage effect is very small, as the axle of one truck is equivalent to axles of 8,000-10,000 cars. Intensity of the annual average daily traffic (AADT) on the A4 detour road is 10,000. Knowing the load equivalency factors for vehicles, AADT and the growth factor, the total ESAL is determined (See Table 8).

**Table 8**

Total ESAL Estimation Parameters

Number of tracks axles	Design line factor, $f_i$	Growth factor, $G$	$AADT$	Load equivalency factor for vehicle, $f$	ESAL in each group, $\times 10^6$	Total ESAL $\times 10^6$
2 axles	0,5	24,3	10000	0,007	0,2	16,7
3 axles				1,05	0,46	
4 axles				1,50	2,7	
5 axles				1,76	12,5	
6 axles				1,82	0,8	

$ESAL$  for the first year -  $ESAL_0$  equals to:

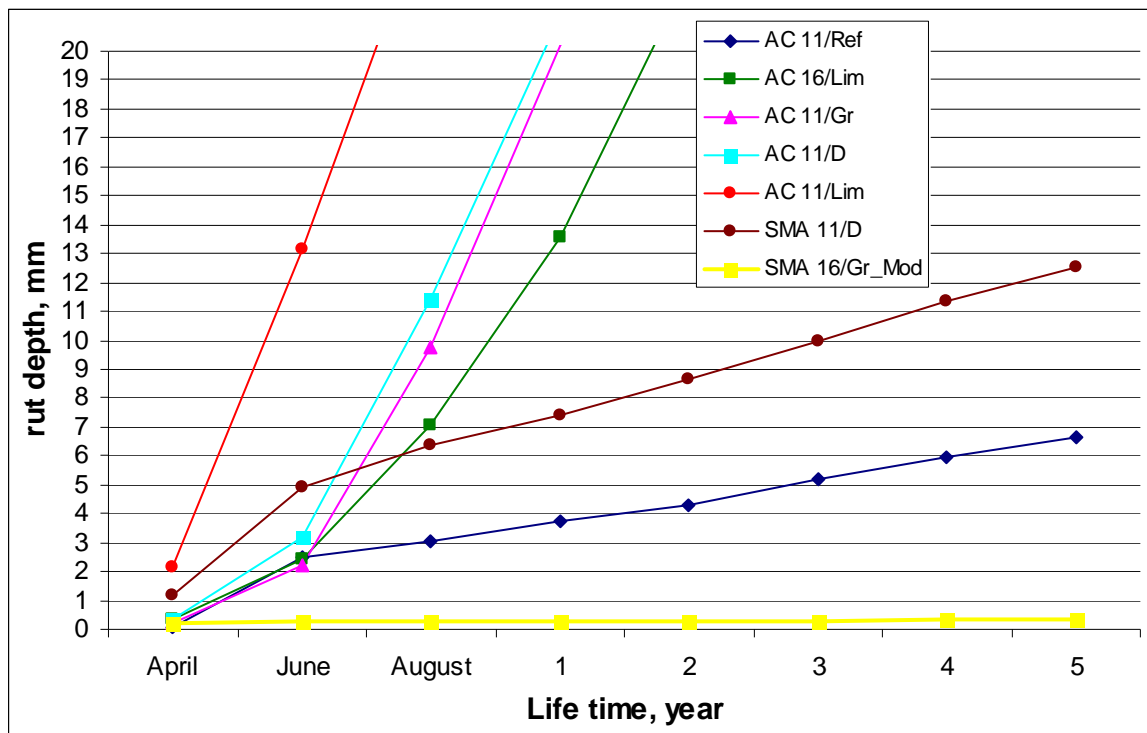
$$ESAL_0 = \sum ESAL_i / 24,3 = 0,69 \times 10^6 \quad (5)$$

$$Daily\_traffic = ESAL_0 / 365 = 1890 \quad (6)$$

The rut formation is assumed to take place during the period of April to September from 7<sup>00</sup> - 21<sup>00</sup>, when the asphalt pavement temperature can reach the high performance temperature - > 45°C.  $ESAL$  for the period of April to September is 55% of the annual value, and from 7<sup>00</sup> till 21<sup>00</sup> it is 85% of the daily value. Percentage of the days with the high performance temperature during this period is 2%



[7]. The annual *ESAL* with the high pavement performance temperature is 6452. By using 2.equations, the rut formation dynamics has been determined (See Fig. 1).



**Fig. 1.** Theoretical development of the rut depth on the A4 road

## 6. Conclusions

- 1) In accordance with the obtained results, the maximally allowed rut depth on the asphalt pavement with the unmodified conventional bitumen is 25 mm (in Lithuania, for instance, it is 20 mm) is reached already during the first operation year of the asphalt pavement layer.
- 2) When performing the prediction research of permanent deformations, the climatic circumstances characteristic for Latvia and the transport load expressed in ESAL units have been taken into account.
- 3) The standard category  $WTS_{air}$  of the conventional asphalt concrete mixture exceeds one.
- 4) To achieve the more reliable results, validity of the method must be performed, for instance, comparison of the results obtained experimentally with the laboratory research

## References

1. Erkens. S. Asphalt Concrete Response (ACRe) – Determination, Modeling and Prediction. Delft University Press Science, Delft 2002.
2. Blab Ronald, Gagliano Barbara, Kappl Karl Models for Permanent Deformation for Bituminous Bound Materials in Flexible Pavement // Proceedings of Final Reports from Sustainable and Advanced Materials for Road Infrastructure SAMARIS Conference SMA-05-DE11 2004. Lausanne, Swiss 2006.
3. Park. S. Effect of Stress-Dependent Modulus and Poisson's Ratio on Rutting Prediction // Journal of Korean Geotechnical Society, KGS, Vol. 23, Nr.3. March 2007, p. 15-24.

4. VAS Latvijas Valsts ceļi [Elektroniskais resurss], 2009 - Autoceļu specifikācijas 2009 - <http://www.lvceļi.lv/LV/?i=107&DirID=42>. Resurss aprakstīts 2009 gada 15.maijs
5. Sivapatham P., Beckedahl H.J. Asphalt pavements with innovative polymer modifications for long life time and low maintenance costs // Proceedings of 33rd CSCE Annual Conference, June 2-4. 2005, Toronto, Canada, TR 198
6. Haritonovs V., Naudžuns J., Smirnovs J. Ceļa segu risu veidošanās cēloņu noteikšana // Starptautiskās zinātniskās konferences „Būvniecība 2005” zinātniskie raksti LLU Jelgava 2005 Latvija. P.52-58.
7. Latvijas vides, ģeoloģijas un meteoroloģijas aģentūra [Elektroniskais resurss], 2008 - <http://www.meteo.lv/public/30116.html> – Resurss aprakstīts 2008 gada 20.decembris

**Haritonovs V., Smirnovs J., Naudžuns J AC un SMA asfaltbetona maisījumu sastāvu paliekošo deformāciju veidošanās dinamikas pētījums.**

*Asfaltbetona segums reālos apstākļos pakļauts atkārtotai laikā mainīgai transporta slodzei. Atkārtotas slodzes iedarbības rezultātā segumā parādās gan elastīgās, gan plastiskās deformācijas. Plastisko deformāciju uzkrāšanās vienā vai vairākos slāņos noved pie paliekošo deformāciju jeb risu veidošanās. Šīs deformācijas veids samazina satiksmes drošības un ērtību. Pētījuma mērķis ir risu veidošanās dinamikas izpēte blīvā (AC) un šķembu mastikas asfaltbetona (SMA) maisījumu sastāviem. Pētījums veikts izmantojot standarta ekspluatācijas īpašību testēšanas metodi – riteņu sliežu veidošanās tests. Eksperimentālās pārbaudes veiktās pieciem AC, diviem SMA asfaltbetona maisījuma sastāviem un vienam references maisījumam ar martenkrāsns tēraudkausēšanas sārņu pildvielu. Maisījumu izgatavošanai izmantota tradicionālā bitumena saistviela B70/100 un modificētais bitumens Modbit 80B. Rezultāti parāda tradicionālo asfaltbetonu maisījumu sliktu deformatīvo noturību zem smagas transporta slodzes, salīdzinājumā ar AC references un SMA modificēto maisījumu sastāviem. Risu veidošanas dinamikas izpētes rezultāti zem intensīvās smaga transporta slodzes izmantojot VESYS metodi parāda, ka pieļaujama risu dziļums 25mm tradicionāliem asfaltbetona maisījumiem tiks sasniegts jau pirmajā asfaltbetona seguma kalpošanas gadā*

**Haritonovs V., Smirnovs J., Naudžuns J Study of the dynamics of permanent deformations for the a AC and SMA asphalt mixtures.**

*Asphalt pavement in actual circumstances is subjected to the repetitive and changing transport load. As a result of the repetitive load impact, both elastic and plastic deformations occur to the pavement. Accumulation of plastic deformations in one or several layers leads to appearance of permanent deformations or rutting. This type of deformations reduces safety and convenience of traffic. Aim of the research is investigation of the rutting dynamics on the dense graded AC and stone mastic SMA asphalt mixtures. The research has been made by using the standard performance test method - wheel tracking test. Five compositions of the dense graded asphalt concrete mixture AC and two compositions of the stone mastic asphalt SMA with the conventional aggregate and one reference mixture AC 11 with the Martin steel slag aggregate have been used in the experiment. The B70/100 unmodified bitumen and SBS modified ModBit 80B has been used for the investigated mixtures. The results have shown poor strain stability of the conventional mixtures with unmodified bitumen under the heavy transport load, in comparison with the reference mixture AC-11 and SMA with modified bitumen. The results of investigating the rutting dynamics under the intensive heavy transport load have shown that the allowed rut depth 25mm is reached already during the first year of the asphalt pavement exploitation.*

**Харитонов В., Смирнов Ю., Науджунс Ю. Исследование динамики образования остаточных деформаций на асфальтобетонных смесях AC 11 и SMA 11.**

*В реальных условиях дорожное покрытие подвергается циклической нагрузке, которую создаёт транспорт. Под воздействием нагрузки в дорожном покрытии возникают упругие и пластические деформации. Накапливание пластических деформаций в одном или нескольких слоях дорожного покрытия, приводит к остаточным деформациям, т.е. к образованию колеи. Этот вид деформации дорожного полотна уменьшает безопасность дорожного движения и комфорт участников движения. Целью исследования является определение динамики образования колеи в плотных AC и щебнемастичных SMA асфальтобетонных покрытиях. Исследование проведено используя стандартный метод тестирования эксплуатационных свойств - тест на определение образования колеи (Wheel*

*Tracking test*). Для испытания было изготовлено 5 составов плотного асфальтобетона типа АС и два щебнемасличных асфальтобетона типа SMA с доломитным, гранитным и диабазным заполнителями, а также один состав АС на заполнителе из шлаков мартеновской стали (MTS). Для изготовления составов был применен не модифицированный В70/100 и модифицированный битум Modbit 80В. Результаты испытания выявили низкую деформационную устойчивость составов на традиционном заполнителе и битуме по сравнению с эталонными составами – АС 11 с заполнителем MTS и SMA 16 с модифицированным битумом. Результаты исследования динамики образования колеи под воздействием интенсивной нагрузки тяжёлого транспорта, используя метод VESYS, показали, что допустимая глубина колеи в 25 мм для традиционных составов асфальтобетона будет достигнута уже в первый год эксплуатации асфальтобетонного покрытия.