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Prediction of Rutting Formation in Asphalt Concrete Pavement

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.

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.

Tasks:

- Designing of the asphalt concrete mixture composition with the traditional aggregate and the modified and unmodified bitumen binder.
- Investigation of the temperature and transport loads characteristic for Latvian circumstances, as the main external factors influencing formation of permanent deformation.
- 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.

- Investigation of the dynamics of appearance of permanent deformations with the help of the VESYS model.

PROPERTIES OF ASPHALT CONCRETE AND RAW MATERIALS

Bitumen

To manufacture the selected conventional B70/100 asphalt concrete mixture, the bitumen binder and the SBS polymer modified bitumen binder Modbit 80B are used in Latvia. Comparison of properties of the binders and evaluation of their conformity to requirements of the Motor Roads Specifications 2005 [1], 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^2/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 viscosity60°C, Pa/s	146	-	LVS EN 12596
Density, g/cm^3	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

Table 2

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

<table>
<tr><th colspan="2" rowspan="2">Index</th><th rowspan="2">Standard</th><th colspan="2">Requirement</th><th colspan="2">Results</th><th rowspan="2">Evaluation</th></tr>
<tr><th>Convent.</th><th>Mod.</th><th>Convent.</th><th>Mod.</th></tr>
<tr><td colspan="2">Penetration 25°C, × 0,1 mm</td><td>LVS EN 1426</td><td>70-100</td><td>50-70</td><td>71</td><td>59</td><td>Conforms</td></tr>
<tr><td colspan="2">Softening point, °C</td><td>LVS EN 1427</td><td>43-51</td><td>> 53</td><td>47,7</td><td>67,7</td><td>Conforms</td></tr>
<tr><td colspan="2">Paraffin wax content, %</td><td>LVS EN 12606</td><td>≤ 2,2</td><td>-</td><td>1,1</td><td>-</td><td>Conforms</td></tr>
<tr><td colspan="2">Frass breaking point, °C</td><td>LVS EN 12593</td><td>≤ -10</td><td>> -15</td><td>-21,1</td><td>-16</td><td>Conforms</td></tr>
<tr><td colspan="2">Solubility in toluol, %</td><td>LVS EN 12592</td><td>> 99,0</td><td>-</td><td>99,27</td><td>-</td><td>Conforms</td></tr>
<tr><td colspan="2">Kinematic viscosity 135°C, mm²/s</td><td>LVS EN 12595</td><td>> 230</td><td>-</td><td>322</td><td>-</td><td>Conforms</td></tr>
<tr><td colspan="2">Flash and fire points, °C</td><td>LVS EN 22592</td><td>> 230</td><td>> 235</td><td>320</td><td>349</td><td>Conforms</td></tr>
<tr><td colspan="2">Elastic reverse, %</td><td>LVS EN 22592</td><td>-</td><td>> 50</td><td>-</td><td>88</td><td></td></tr>
<tr><td rowspan="3">Hardening LVS EN 12607-1</td><td>Mass change %</td><td></td><td>≤ 0,8</td><td>< 0,5</td><td>-0,050</td><td>0</td><td>Conforms</td></tr>
<tr><td>Permanent penetration, 25°C, × 0,1 mm</td><td>LVS EN 1426</td><td>> 50</td><td>> 35,4</td><td>72,2</td><td>40</td><td>Conforms</td></tr>
<tr><td>Elastic reverse, %</td><td>LVS EN 22592</td><td>-</td><td>> 50</td><td>-</td><td>84</td><td>Conforms</td></tr>
<tr><td rowspan="2">Storage stability</td><td>Softening point change, °C</td><td rowspan="2">LVS EN 13399</td><td>-</td><td>< 5</td><td>-</td><td>1,9</td><td>Conforms</td></tr>
<tr><td>Penetration change 25°C, × 0,1 mm</td><td>-</td><td>< 9</td><td>-</td><td>6</td><td>Conforms</td></tr>
</table>

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 Motor 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 3

Conformity of the Coarse Aggregate to the Requirements of the Motor 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

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 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[3)]	-	37.7	-	-	11.3	37.7[1)]	7.6	5.7	-
AC 11/Gr[4)]	-	-	51.5	20.7	51.5 (70% 0-2) (30% 2-5)		3.9	4.7	-
AC 11/D5[)]	-	-	21.9	7.6	1.9	60.2	3.8	4.6	-
AC 11/Ref[6)]	-	29.8	-	-	-	42.9	6.5	6.8	-
AC 16/Lim	20.9	29.5	-	-	1.0	37.1[2)]	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	-

[1)] Natural washed sand [2)] Crushed sand [3)] Lim - dolomite [4)] Gr - granite
[5)] D - diabase [6)] Martin steel slag

RESEARCH METHODS OF THE DYNAMICS OF APPEARANCE OF PERMANENT DEFORMATIONS

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 [2]. 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 [3]:

- Rheological models;
- Empiric correlation equations based on the experimental stage monitoring results;
- Functional equations directly based on laboratory test results.,

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 $+50^0$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 [5]. The scheme of determining the resilient modulus is shown on Fig. 1.

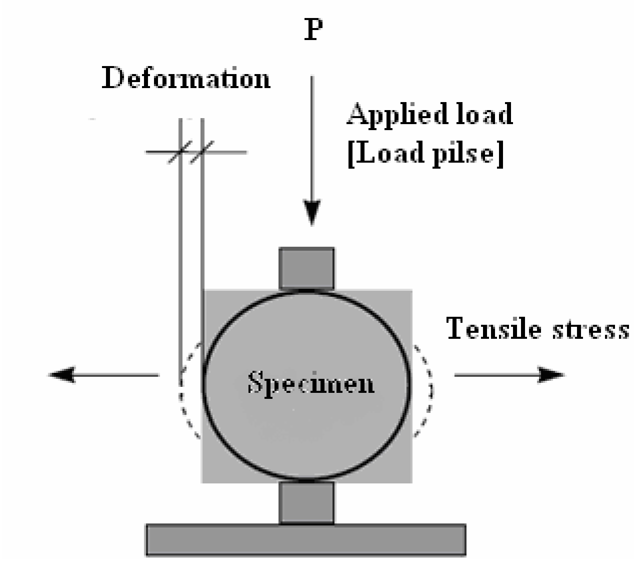

Fig. 1. Type of the cylindrical specimen (core) load [6]

The resilient modulus is determined subject to the applied load P, the horizontal deformation Δ, the specimen thickness h and the Poisson's ratio μ = 0.35 value (See Equation 1). The resilient modulus is determined at the temperature of +50ºC.

$$E = \frac{P \cdot (0{,}273 + \mu)}{\Delta \cdot t} \tag{1}$$

Plastic deformations from the repeated heavy transport load increase exponentially against the upper deformation boundary (ε = 20mm). 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 [7]. The VESYS model states that the ratio of vertical plastic strain per cycle, $d\varepsilon^p/dN$, to the resilient strain, ε_r, is an exponential function of the number of load cycles, N (See Fig. 2, Equation 2).

$$\frac{1}{\varepsilon_r} \cdot \frac{\varepsilon^p}{dN} = \mu \cdot N^{-e}, \tag{2}$$

where:

ε^p - permanent deformation, mm
ε_r - elastic or/ resilient deformation, mm
N - the number of load applications, cycles
μ - parameter representing the constant of proportionality of strains, and
α - parameter indicating the rate of decrease.

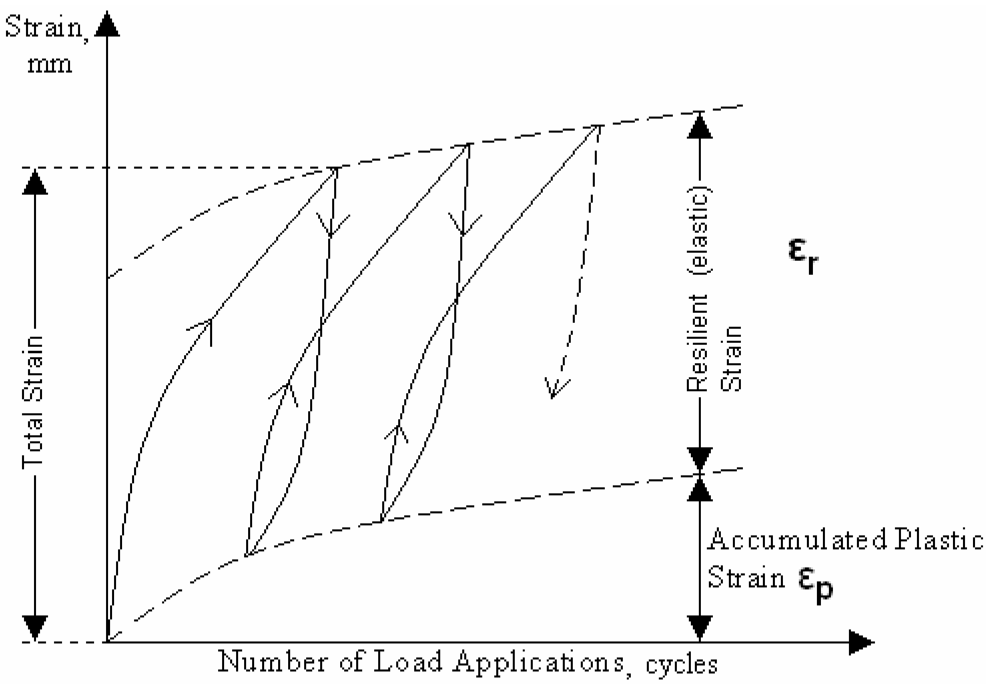

Fig. 2. Typical resilient response from repeated load applications [8]

The material parameters μ and α are determined from the following expression:

$$\mu = \frac{a \cdot b}{\varepsilon_r}, \qquad (3)$$

where:

a, b, ε_r - constants determined from testing,

α = 1-b.

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 μ and α, deformation and resilient modulus for the asphalt concrete specimen types used in the experiment.

Table 5

Asphalt Concrete Deformation Parameters μ and α

Material parameter	Asphalt Concrete Mixture Compositions						
	AC 11/Lim	AC 11/Gr	AC 11/D	AC 11/Ref	AC 16/Lim	SMA11/D	SMA 11/D_Mod
E, MPa	11,5	33,4	32,2	115.3	55.8	68,6	164
ε_p, mm	20**	13,1*	14,0*	11,2	16,5***	7,61	3,0
ε_r, $[10^{-2}]$ mm	58,4	43,2	31,9	13,2	32,1	23,5	3,13
μ	0,008	0,003	0,01	0,45	0,02	0,52	2,54
α	0,933	0,9830	0,977	0,470	0,825	0,446	0,201
Specimen, mm	50						

***) ε_p per 10,000 cycles
**) ε_p per 5,000 cycles
*) ε_p = 20 mm per 1,700 cycles;

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 [9]. 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 6

Wheel Tracking Slope WTS_{air}

Asphalt Concrete Mixture Type	WTS_{air} Max. EN 13108 -1 Category (mm/1,000 load cycles)	WTS_{air} factual (mm/1,000 load cycles)
AC 11/Lim	1,00	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 equation 2 is equal to the amount of ESAL units. ESAL is determined from the following equation:

$$ESAL = f_i \cdot G \cdot AADT \cdot 365 \cdot N \cdot F, \quad (4)$$

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:

$$G = \left[(1+r)^N - 1\right]/r = 24{,}30, \quad (5)$$

where:

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

i - growth rate = 2%

Table 7

Distribution of Vehicles on the A4 Road in Percent

Truck Class			Observation hour																								Av., %
	axles	tire	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Single –unit, %	2	4	63	68	65	57	52	54	72	85	85	75	75	73	76	72	72	74	77	84	86	83	82	80	77	72	**74**
	2	6	2	2	4	1	11	8	7	3	2	4	6	6	5	4	6	5	5	4	2	3	3	3	2	2	**4**
	3; >3	6,>6	1	2	0	1	0	1	2	1	2	2	2	2	3	2	3	2	2	2	1	1	1	0	0	1	**1**
Multiple-unit, %	4		3	9	0	8	11	6	3	3	3	5	5	5	3	5	4	5	4	3	2	3	4	2	3	8	**4**
	5		30	30	25	26	25	30	16	7	8	13	12	14	12	13	14	12	10	8	8	10	11	13	18	15	**16**
	6,>6		0	0	6	6	1	2	1	1	1	1	1	1	1	1	1	2	1	1	1	1	0	2	2	2	**1**

Table 7 provides that 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. Figure 3 provides the load equivalency factor F for the three main types of vehicles on the heavily loaded Latvian roads.

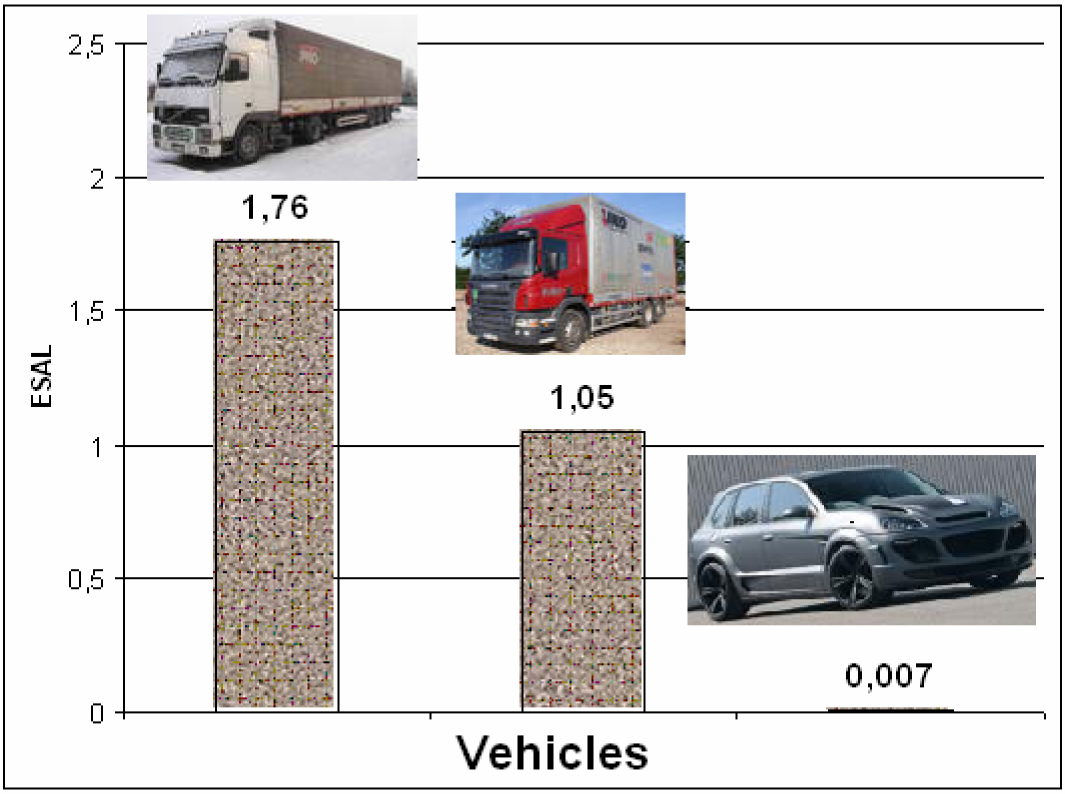

Fig. 3. Some Typical Load Equivalency Factors for Vehicles on the Heavily Loaded Latvian Roads

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:

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

$$Daily\_traffic = ESAL_0 / 365 = 1890 \quad (7)$$

The rut formation is assumed to take place during the period of April to September from 7^{00}- 21^{00}, when the asphalt pavement temperature can reach the high performance temperature - > 45^0C. $ESAL$ for the period of April to September is 55% of the annual value, and from 7^{00} till 21^{00} it is 85% of the daily value. Percentage of the days with the high performance temperature during this period is 2%. The annual $ESAL$ with the high pavement performance temperature is:

$$ESAL_0^{hp} = 0{,}69 \times 10^6 \times 0{,}85 \times 0{,}55 \times 0{,}02 = 6452, \quad (8)$$

where:

$ESAL_0^{hp}$ - equivalent single-axle load with the high pavement performance temperature - > 45^0C

By using equations 2 and 8, the rut formation dynamics has been determined (See Fig. 4).

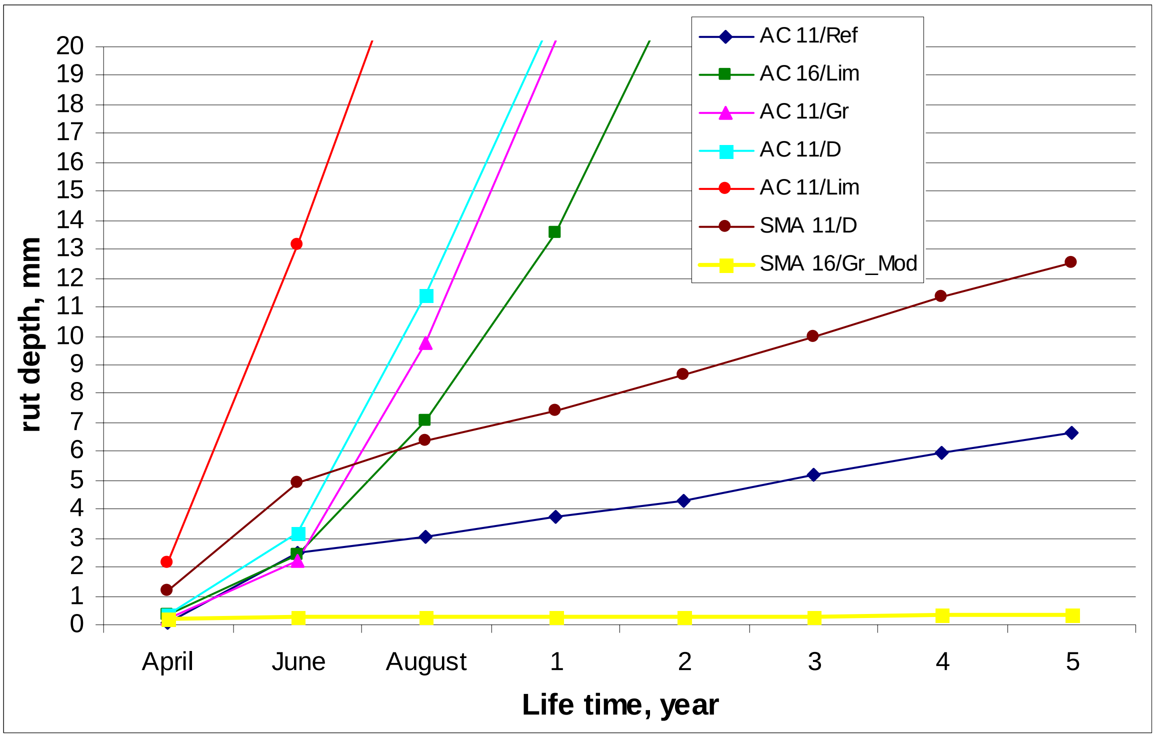

Fig. 4. Theoretical development of the rut depth on the A4 road

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.

LITERATURE

1. Autoceļu specifikācijas 2005. Apstiprinātas 2004. gada 27. februārī LR Satiksmes ministrijas Tehniskajā komisijā. http://www.lvceli.lv/LV/?i=107&DirID=42
2. Erkens. S. Asphalt concrete response – Determination, Modeling and Prediction. Delft University Press Science, Delft 2002.
3. Blab Ronald, Gagliano Barbara, Kappl Karl „Models for Permanent Deformation for Bituminous Bound Materials in Flexible Pavement", Proceedings of Final Reports from SAMARIS SMA-05-DE11 2004.
4. V. Haritonovs, J. Naudžuns, J. Smirnovs. Ceļa segu risu veidošanās cēloņu noteikšana // Starptautiskās konferences„Būvniecība 2005" zinātniskie raksti. LLU Jelgava 2005- lpp. 52-58.
5. EN 12697 – 26 Bituminous mixtures - Test methods for hot mix asphalt - Part 26: Stiffness
6. 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
7. EN 12697-25 Bituminous mixtures - Test methods for hot mix asphalt - Part 25: Cyclic compression test
8. 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.
9. EN 13108-1 Bituminous mixtures – Material specifications – Part1: Asphalt concrete
10. www. meteo.lv