CONSTRUCTION SCIENCE
ISSN 1407-7329 BŪVZINĀTNE 2008-7329

INVESTIGATION OF THE DYNAMICS OF PERMANENT DEFORMATIONS FOR THE AC 11 ASPHALT MIXTURES

PALIEKOŠU DEFORMĀCIJU VEIDOŠANĀS DINAMIKAS IZPĒTE ASFALTBETONA MAISĪJUMIEM AC 11

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Keywords: asphalt mixture, rutting, rut depth, Wheel Tracking test, Wheel Trackin slope

Introduction

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. With accumulation of water in the road rut, possibility of vehicle hydroplaning increases, thus, reducing the quantitative value of the road friction coefficient and facilitating occurrence of emergency situations. As the asphalt pavement is the most expensive road construction material, prediction of permanent deformations is of big importance. It allows planning the road infrastructure repairs timely and cost efficiently.

Aim and Tasks of the Research

Aim of the research is investigation of the rutting dynamics on the AC asphalt mixtures with the help of the Wheel Tracking testing method.

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

1. Designing of the asphalt mixtures
   - AC 11 reference mixture with the martin steel slag aggregate (AC 11/Ref)
   - AC 11 with the granite aggregate and the surface active substance (AC 11/Gr)
   - AC 11 with the diabase aggregate (AC 11/D)
   - AC 11 with the dolomite aggregate (AC 11/Lim)

   The conventional bitumen B 70/100 (See Table 1) is used for the asphalt mixtures.
2. Manufacturing of slab specimens with the segmental roller compactor [1].
3. Determining deformational properties with the help of the Wheel Tracking testing method [2].
4. Assessment of the rut formation dynamics by using the VESYS (viscoelastic pavement system)method [3]

Table 1. Compositions of Asphalt Mixtures

Raw material fraction d-D	Compositions of asphalt mixtures, mass %				
	AC 11/Lim	AC 11/Gr	AC 11/D	AC 11/Ref	AC 16/Lim
11-16	-	-	-	-	20.9
5-11	37.7	-	-	29.8	29.5
8-11	-	51.5	21.9	-	-
5-8	-	20.7	7.6	-	-
2-5	11.3	51.5 (70% 0-2) (30% 2-5)	1.9	-	1.0
0-5	37.7 [1)]		60.2	42.9	37.1
Dolomite powder	7.6	3.9	3.8	6.5	6.6
Bitumen B70/100	5.7	4.7	4.6	6.8	4.9

[1)] Natural washed sand

Methods

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.

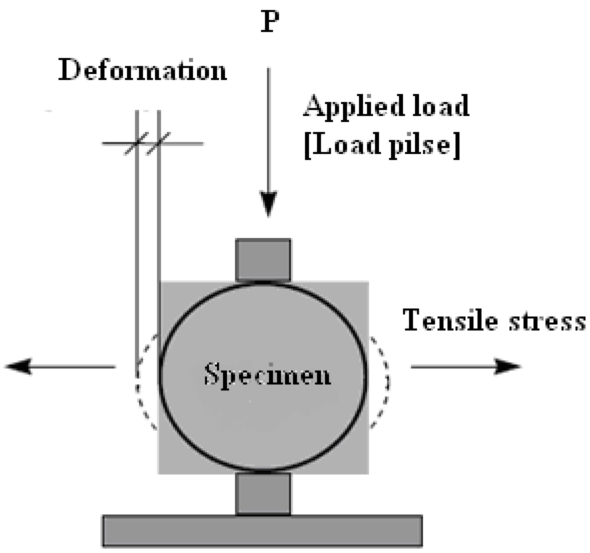

Fig. 1. Type of the cylindrical specimen (core) load [6]

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.

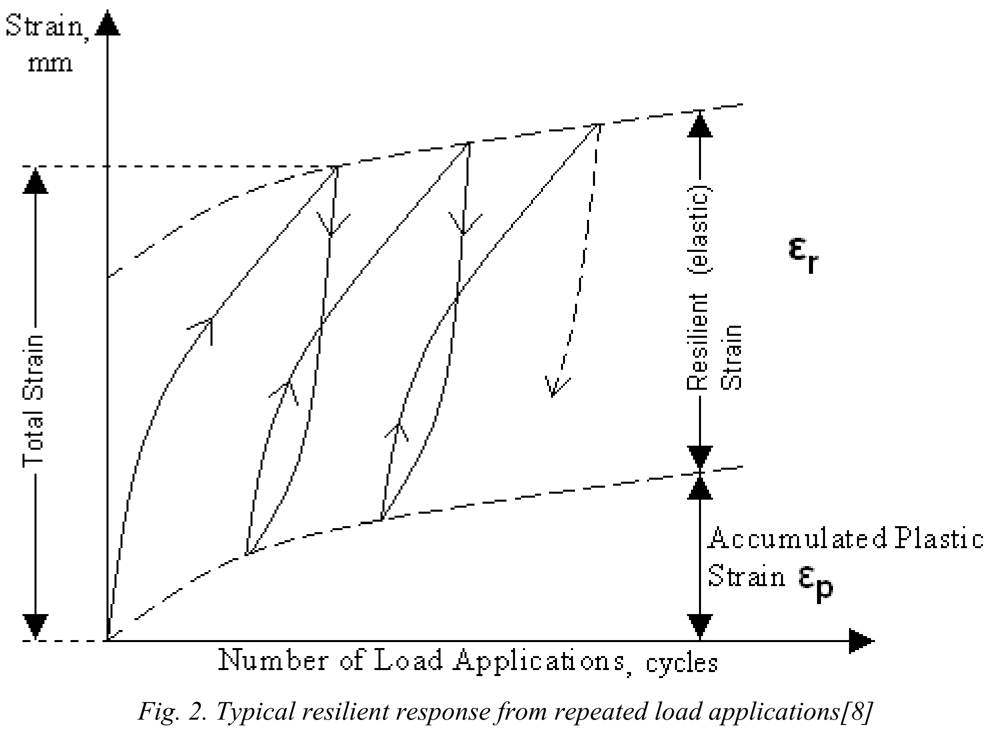

Fig. 2. Typical resilient response from repeated load applications[8]

Results and Discussion

Material parameters μ and α, the deformation and resilience modulus for asphalt specimens of the AC 11/Lim, AC 11/Gr, AC 11/D, AC 11/Ref and AC 16/Lim types used in the experiment are summarized in Table 2. The α parameter is determined from the deformation – cycles charts (See Fig.3) and the μ parameter from the following formula:

$$\mu = \frac{\varepsilon_p}{\varepsilon_r \cdot N^{\alpha}}, \quad (3)$$

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

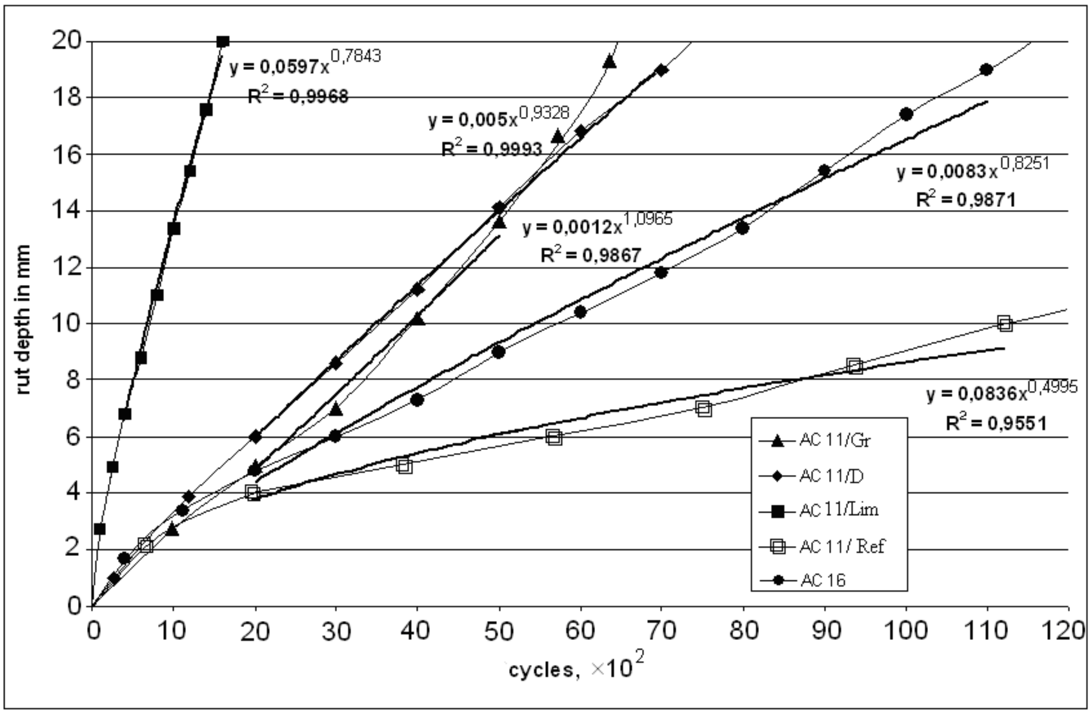

Fig. 3. Development of Rut Depths

Table 2. Calculation of deformation and material parameters μ and α

Material parameters	Asphalt mixtures				
	AC 11/Lim	AC 11/Gr	AC 11/D	AC 11/Ref	AC 16/Lim
E, MPa	11.5	33.4	32.2	115.3	55.8
ε_p, mm	20**	13.1*	14.0*	6.1*	9.2*
ε_r, $[10^{-2}]$mm	58.4	43.2	31.9	11.2	32.1
μ	0.10	0.0026	0.016	0.77	0.025
α	0.7843	1.0965	0.9328	0.4995	0.8251
Specimen, mm	40				

**) ε_p for 5,000 cycles
*) ε_p = 20mm for 1,700 cycles

The obtained results allow determining the rate of rutting after 1,000 cycles (the maximum wheel tracking slope mm per 1,000 load cycles) for the asphalt specimens used in the research. The maximum wheel tracking slope mm per 1,000 load (WTS_{air}) cycles category are provided in the EN 13108-1 standard [9]. Indices of the AC 11/Gr, AC 11/D, AC 11/Lim, AC 11/Ref and AC 16 WTS_{air} specimens are summarized in Table 3. The maximum WTS_{air} category of the EN 13108-1 standard is $WTS_{air}1$, which means that the maximum wheel tracking slope per 1,000 cycles is 1mm. The reference mixture AC 11/ref corresponds to the $WTS_{air}0.50$ standard category. However, WTS_{air} for other AC 11 mixtures exceeds the maximum standard category – $WTS_{air}1.00$ several times.

=Table 3. Wheel Tracking Slope WTS_{air}

Asphalt mixture type	WTS_{air} Max. EN 13108 -1 category (mm/1000 load cycles)	Actual WTS_{air} (mm/1000 load cycles)
AC 11/Gr	1.00	3.11
AC 11/D		2.57
AC 11/Lim		6.87
AC 11/Ref		0.49
AC 16		1.44

The heavy transport load on the asphalt pavement is the main cause for appearance of permanent deformations. Road Tests of the American Association of State Highway and Transportation Officials (AASHTO) showed that the damaging effect of vehicle loads can be expressed by a number of equivalent single axle loads (ESAL). In accordance with this document, the traffic intensity is anticipated for 20 years [10]. Table 4 provides the data summarized by ESAL for one of the Riga streets with the especially expressed permanent deformations resulting from the intensive public transport load – the descent from the Vanšu Bridge, the "Ķīpsala" stop. Asphalt pavement looses its capacity to resist shear stresses in the period when the pavement surface temperature is up to 35^0C [12] In accordance with the Latvian Environment, Geology and Meteorology Agency data [13], it is established that there can be up to 27 days with high surface temperature during a year. In Germany, for comparison, there are about 42 such days on average [11].

Table 4. Traffic Intensity in ESAL Units for the Descent and Ascent to the Vanšu Bridge

Axles	$ESAL^{13\text{-}19}$ 1))	$ESAL_{2004\text{-}2007}$ 1)		Annual average $ESAL^{13-19}_{May-Sept}$ (47 ^{0}C)
		$ESAL^{13-19}_{May-Sept}$ 2)	$ESAL^{13-19}_{May-Sept}$ (47 ^{0}C)3)	
2	206	157,590	5,562	7,587
3	75	57,375	2,025	

1) $ESAL^{13\text{-}20}$ - equivalent single axle loads during the time from 11^{00} – 19^{00}

2) $ESAL^{13-19}_{May-Sept}$ - equivalent single axle loads from May to September during the time from 11^{00} – 19^{00}

3) $ESAL^{13-19}_{May-Sept}$ (47^0 C) equivalent single axle loads from May to September during the time from 11^{00} – 19^{00} for the covering surface temperature above 47^0 C.

By taking into account the resilient modulus, the μ and α material parameters and the rutting test results, the rut depth development has been calculated by means of the VESYS method (Equation 4)

$$\varepsilon^{p}(N) = \varepsilon_{r} \cdot \mu \cdot N^{\alpha} \quad (4)$$

where

$\varepsilon^{p}(N)$ - rut depth, mm, after the N load cycles.

Allowable rut depth may be limited by both safety and structural considerations. Pavement failure is defines as a rut depth of 19-20mm, however ruts deeper than 10mm could cause hydroplaning or loss of skid resistance. The depth of maximum allowable rutting in Latvia is 25 mm. Strain stability of asphalt mixtures of the AC 11 types with different aggregates at high operating temperature and traffic intensity corresponding to descents from the Vanšu Bridge differs considerably (See Fig.4). In accordance with the obtained results, the reference mixture AC 11/Ref is stable to strain, whereas the AC 11/Lim mixture forms large road pavement ruts already during the first months of operation.

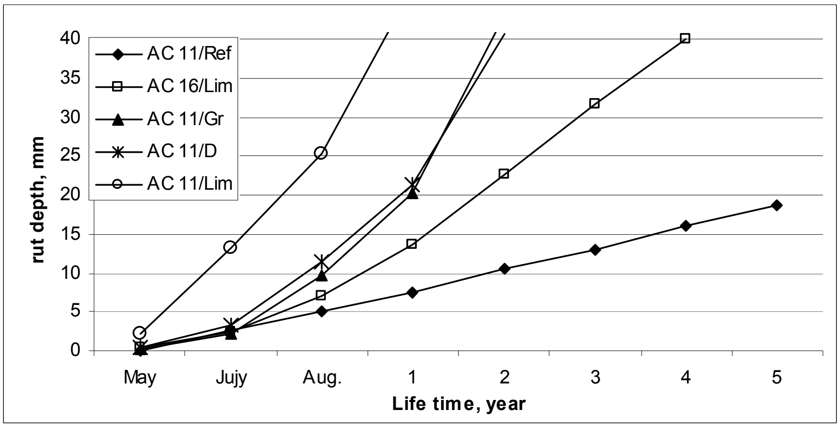

Fig.4. Development of rut depth

Conclusions

1. The AC 11/Gr, AC 11/Lim, AC 11/D and AC 16 asphalt mixtures exceed the standard maximal wheel tracking slope category of $WTS_{air}1{,}00$.
2. The AC 11/Ref reference mixture corresponds to the wheel tracking slope category of $WTS_{air}0{,}50$.
3. Service life of the asphalt pavement with the AC 11/Lim asphalt mixture, having the dolomite aggregate, at the traffic intensity corresponding to the descent from the Vanšu Bridge, in accordance with the obtained results, does not exceed 1 year. However, service life of the AC 11/Ref reference mixture, for the same traffic intensity, in accordance with the results, exceeds 5 years.
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.

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Haritonovs V., Smirnovs J., Naudžuns J Paliekošu deformāciju veidošanās dinamikas izpēte asfaltbetona maisījumiem AC 11.

Līdz šīm asfaltbetona kvalitātes nodrošināšanas sistēmā Latvijā bija iekļauts vienīgi Maršala (Marshall) tests, kas paredzēts nosacītu deformācijas radītāju – deformatīvās stabilitātes un plūstamības ar konstantu saspiešanas ātrumu 50mm/min pie 60ºC temperatūras noteikšanai. Latvijā trūka standarta metodes, kas laboratorijas apstākļos spētu nodrošināt reāliem apstākļiem līdzīgu asfaltbetona paraugu izgatavošanu un slogojumu. Asfaltbetona deformatīvo īpašību prognozēšanai lielu loma ir slodzes pielikšanas ātrumam, darbībās ilgumam un pielikšanas frekvencei. Pētījums veikts izmantojot ekspluatācijas īpašību (performance test) standarta testēšanas metodi Wheel Tracking test. Eksperimentā ir izmantoti četri asfaltbetona maisījuma sastāvi – AC-11/Lim (ar dolomīta pildvielu aggregate), AC-11/D (diabaza pildviela), AC-11/Gr (Granita pildviela) un no martenkrāsns tēraudkausēšanas sārņiem ir izgatavots references maisījums AC-11/Ref. Visiem pētāmiem maisījumiem ir izmantota B70/100 nemodificēta bitumena saistviela. Rezultāti parāda tradicionālo (conventional) maisījumu – AC-11 ar dolomīta, granīta un diabāza slikto deformatīvo noturību zem smagas transporta slodzes, salīdzinājumā ar references maisījumu AC-11/Ref. Risu veidošanas dinamika izpētes rezultāti zem intensīvās smaga transporta slodzes izmantojot VESYS metodi parāda, ka pieļaujamais risu dziļums 25mm tiks sasniegts jau pirmajā asfaltbetona seguma kalpošanas gadā.

Haritonovs V., Smirnovs J., Naudžuns J. Investigation of the dynamics of permanent deformations for the AC 11 asphalt mixtures.

Up to now, the system securing asphalt quality in Latvia includes only the Marshall test, which anticipates the conventional deformation indicator – determination of strain stability and flowability with the constant compression rate of 50mm/min at the temperature of 60ºC. There is lack of standard methods in Latvia, which in the laboratory circumstances could provide manufacturing and loading of asphalt specimens similar to real circumstances. Large role in predicting the asphalt deformation features is played by the load application speed, impact duration and application frequency. The research has been made by using the standard performance test method - the Wheel Tracking test. Four compositions of asphalt mixtures have been used in the experiment – AC-11/Lim (with the dolomite aggregate), AC-11/D (the diabase aggregate), AC-11/Gr (the granite aggregate) and the AC-11/Ref reference mixture made of the martin steel slag. The B70/100 unmodified bitumen binding agent has been used for all the investigated mixtures. The results have shown poor strain stability of the conventional mixture – AC-11 with dolomite, granite and diabase, under the heavy transport load, in comparison with the AC-11/Ref reference mixture. The results of investigating the rutting dynamics under the intensive heavy transport load, by using the VESYS method, have shown that the allowed rut depth 25mm is reached already during the first year of the asphalt pavement usage.

Харитоновс В., Смирновс Ю.,, Науджунс Ю. Исследование динамики образования остаточных деформаций на асфальтобетонных смесях АС 11.

До 2008 года в систему обеспечения качеством асфальтобетонного дорожного покрытия в Латвии был включен тест Маршала, определяющий условные деформационные свойства асфальтобетона: стабильность и текучесть при постоянной скорости нагрузки 50мм/мин и температуре $60^{0}C$*. Существовала объективная необходимость в стандартном методе, который в лабораторных условиях обеспечил бы изготовление образцов асфальтобетона и их нагрузку, приближенную к реальным условиям на дороге. Для прогнозирования деформационных свойств асфалтобетонного покрытия в лабораторных условиях большое значение имеет метод изготовления и характер испытания образцов – скорость приложения, длительность и частота нагрузки Иследование произведено используя стандартный метод исследования эксплуатационных свойств асфальтобетонного покрытия на образование колеи – Wheel Tracking test. Для испытания было изготовлено 4 состава плотного асфальтобетона типа АС 11 с доломитным, гранитным, диабазным заполнителями и из шлаков мартеновской стали (MTS). Для всех составов был применен не модифицированный битумен B70/100. Результаты испытания подтверждают низкую деформационную устойчивость составов на традиционном заполнителе по сравнению с референтным составам (MTS). Допустимая глубина колеи в 25мм для традиционных составов при интенсивном движении грузового и общественного транспорта в жаркие летнии дни будет достигнута в первый год эксплуатации асфальтобетонного погрытия.*