RIGA TECHNICAL UNIVERSITY
The Faculty of Building and Civil Engineering
Institute of Transportation Engineering

Viktors Haritonovs

PERMANENT STRAIN DEVELOPMENT DYNAMICS FOR ASPHALT PAVEMENT MATERIALS

Transport and Traffic Science

Land Transport and Infrastructure Sector (P-06)

Summary of Doctoral Dissertation

Scientific Advisor
Dr. sc. ing., Professor
Juris-Rihards Naudžuns

Riga, 2010

UDK 625.85(043.2)
Ha 548 p

Haritonovs V. Permanent Strain Development Dynamics for Asphalt Pavement Materials. Summary of Doctoral Dissertation.-R.: RTU, 2010.-31.lpp.

EIROPAS SOCIĀLAIS FONDS EIROPAS SAVIENĪBA

This work has been supported by the European Social Fund within the project „Support for the implementation of doctoral studies at Riga Technical University”.

Scientific Novelty

1. To investigate road pavement strain properties at large traffic loads, unconventional asphalt mixtures – dense graded asphalt AC 11 with Martin steel slag aggregate and stone mastic asphalt SMA 16 with modified bitumen - have been developed.
2. For the first time among the papers devoted to asphalt pavement permanent strain modelling, the Promotion Thesis provides the equivalent single-axle load *ESAL* estimation equation for the period with maximally high road pavement performance temperatures. The equation is made on the basis of the comprehensive evaluation of the traffic load, air temperature and asphalt pavement high performance temperature which are characteristic for local circumstances.
3. The offered methods of permanent strain prediction are based on the viscous-elastic system *VESYS* estimation model with *ESAL* values specified for the hot period (spring-summer). It allows predicting permanent strain by considering traffic load expressed in *ESAL* units and local climatic conditions. Rutting prediction is done to timely select the asphalt pavement which is durable and appropriate for the specific weather conditions and traffic load.
4. The concept of the asphalt pavement quality provision system, which summarises all processes and their quality provision measures, has been developed to determine the existing deficiencies in the quality provision system and to eliminate them in practice.

Urgency of the Subject

Asphalt pavement longitudinal deformation (rutting) is the most significant defect of carriageway. Such road damages considerably reduce the service life and carrying capacity of asphalt pavement, traffic safety and comfort level, increase the road pavement operation and maintenance expenses. They negatively influence several branches of Latvian national economy: transport and communication (I), mining industry and quarry development (C), construction (F), and forestry (A). To eliminate such damage, a large section of asphalt pavement has to be renovated, which requires considerable financial investments and is hard to be implemented in the current economic situation. This indicates to the fact that the urgent problem is to predict and minimise road pavement permanent strain within the range of possibility. Such prediction must be based on the existing traffic load and specifics of climatic conditions.

The State Strategic Framework Document (VSID) for the period of 2007–2013, in accordance with the current situation analysis, establishes deficiencies of the roads operation, for instance, a large number of road accidents, the unsatisfactory condition of the roads and their depreciation which can lead to loss of competitiveness in provision of transit services [1].

The Promotion Thesis has been elaborated with account of requirements of the currently effective technical regulations of Latvian transport structures “Road Specifications 2010” and the State Standards (LVS). The experimental part has been prepared by using new performance test methods for Latvian circumstances – the wheel tracking (rutting) formation test and the uniaxial and triaxial cyclic loading test.

Practical Significance

The useful in practice and convenient methods of asphalt pavement strain development prediction have been elaborated on the basis of the traffic load and the climatic conditions characteristic for Latvia. The permanent strain development dynamics have been analysed for conventional and modified asphalt mixtures. For the first time, the traffic load characteristic for Latvian circumstances has been expressed in equivalent single-axle load (*ESAL*) units. The new asphalt performance testing methods have been approbated and recommended for Latvian circumstances. The pavement quality provision system developed at the RTU Civil Engineering Science Centre has been submitted to the Riga City Council Transport Department for practical application. The obtained results can be used for improving the road-building technical regulations "Road Specifications 2010".

Aim and Tasks of the Promotion Thesis

The aim of the Promotion Thesis is to develop asphalt mixes by using conventional and unconventional raw materials and to determine their strain development dynamics by using for this purpose the developed methods of predicting the road pavement permanent strain on the basis of comprehensive evaluation of external factors.

Tasks of the Promotion Thesis

1. To analyse the mechanism of asphalt pavement permanent strain formation, the existing prediction methods and main (internal and external) factors influencing the strain.
2. To determine properties of the steel manufacturing byproduct – Martin steel slag, as an aggregate, and to compare them with properties of conventional granite, diabase and dolomite aggregates.
3. To mutually compare properties of the unmodified bitumen binder B70/100 and the styrene-butadiene-styrene SBS polymermodified binder.
4. To develop and manufacture the AC and SMA asphalt mixtures by using conventional and unconventional aggregates, as well as modified and unmodified bitumen binders. To compare the results and to evaluate their conformity to requirements of the technical regulations.
5. To determine strain properties of the developed asphalt mixtures by means of the cyclic loading and wheel tracking tests. To evaluate the results obtained by different methods.
6. To statistically process the observation data – the traffic load and external air temperatures characteristic for Latvian circumstances - and to analyse the asphalt pavement high performance temperature dynamics.
7. To adapt the methods of the equivalent single-axle load (*ESAL*) estimation for the intensively loaded Latvian streets and roads and to develop the *ESAL* estimation equation for the period with the maximally high performance temperatures.
8. By using strain properties of the asphalt mixtures obtained in the laboratory, the *VESYS* model, the load of heavy transport vehicles expressed in *ESAL* units, as well as, by considering the specific features of local climatic circumstances, to investigate permanent strain accumulation of the developed asphalt mixtures.

9. To develop a concept of the asphalt pavement quality provision system for the intensively loaded Latvian streets and roads to allow performing systematic evaluation.

Approbation of the Thesis and Publications

The Promotion Thesis results have been provided in the following scientific publications:

1. V. Haritonovs, J. Smirnovs, J. Naudžuns "Prediction of Rutting Formation in Asphalt Concrete Pavement". The Baltic Journal of Road and Bridge Engineering Vol. 5. Nr. 1. Vilnius, 2010.
2. V. Haritonovs, J. Smirnovs, J. Naudžuns "Study of the Dynamics of Permanent Deformations for the AC and SMA Asphalt Mixtures". RTU Zinātniskie raksti. Būvzinātne. Sērija 2. Sējums 10. Rīga, 2009.
3. V. Haritonovs, J. Smirnovs, J. Naudžuns "Investigation of the Dynamics of Permanent Deformations for the AC 11 Asphalt Mixtures". RTU Zinātniskie raksti. Būvzinātne. Sērija 2. Sējums 9. Rīga, 2008.
4. V. Haritonovs, E. Skuķis, J. Smirnovs, J. Naudžuns „Asfaltbetona paraugu mehānisko īpašību izmaiņa atkarībā no slogošanas ātruma un temperatūras". RTU Zinātniskie raksti. Arhitektūra un būvzinātne. Sērija 2. Sējums 8. Rīga, 2007.
5. V. Haritonovs, J. Naudžuns, J. Smirnovs. „Maršala testa piemērotība risu veidošanās dinamikas izpētei". RTU Zinātniskie raksti. Arhitektūra un būvzinātne. Sērija 2. Sējums 7. Rīga, 2006.
6. V. Haritonovs, J. Naudžuns "Investigation of Rutting Formation". The 26th International Baltic Road Conference Proceedings, 28–30 August, 2006. Kuressaare, Estonia (an article in the conference theses publication).
7. V. Haritonovs, J. Naudžuns, J. Smirnovs „Bitumena saistvielas fizikālu un novecošanās īpašību analīze". RTU Zinātniskie raksti. Arhitektūra un būvzinātne. Sērija 2. Sējums 6. Rīga, 2005.
8. V. Haritonovs, J. Naudžuns, J. Smirnovs. „Ceļa segu risu veidošanas cēloņu noteikšana". Civil Engineering 2005. International Scientific Conference Proceedings. Jelgava, 2005.
9. V. Haritonovs, A. Veikšāns, J. Smirnovs „Šķembu mastikas asfaltbetona ABS-16 īpašību izpēte". RTU Zinātniskie raksti. Arhitektūra un būvzinātne. Sērija 2. Sējums 4. Rīga, 2003.

The Promotion Thesis results have been announced at the following international scientific conferences:

1. RTU 50. International Scientific Conference. V. Haritonovs, J. Smirnovs, J. Naudžuns "Study of the Dynamics of Permanent Deformations for the AC and SMA Asphalt Mixtures". 13 October 2009. Riga.
2. 27th International Baltic Road Conference. V. Haritonovs, J. Naudžuns, J. Smirnovs "Prediction of Rutting Formation in Asphalt Concrete Pavement". 24–26 August, 2009. Riga, Latvia.

3. RTU 49. Starptautiskā zinātniskā conference. V. Haritonovs, J. Smirnovs, J. Naudžuns „Paliekošu deformāciju veidošanās dinamikas izpēte asfaltbetona maisījumiem AC 11”. 13. oktobris 2008. gads, Rīga.
4. RTU Jauno Tehnoloģiju un inovācijas conference. V. Haritonovs. J. Naudžuns „Asfaltbetona paliekošu deformāciju veidošanās dinamikas izpēte ar trīsaksiālu cikliskās spiedes testu”. Rīga, 2008. gada 19. septembris.
5. RTU 48. Starptautiskā zinātniskā conference. V. Haritonovs, E. Skuķis, J. Smirnovs, J. Naudžuns „Asfaltbetona paraugu mehānisko īpašību izmaiņa atkarībā no slogošanas ātruma un temperatūras”. 13.oktobris 2007. gads, Rīga.
6. RTU Jauno Tehnoloģiju un inovācijas conference. V. Haritonovs. J. Naudžuns „Risu testa piemērotība SMA asfaltbetona paliekošu deformāciju dinamikas izpētei”. Rīga 2007. gada 26. septembris.
7. RTU 47. Starptautiskā zinātniskā conference. V. Haritonovs, J. Naudžuns, J. Smirnovs „Maršala testa piemērotība risu veidošanās prognozēšanas izpētei asfaltbetona segās”. 9. – 13. oktobris 2006. gads, Rīga.
8. 26th International Baltic Road Conference. V. Haritonovs, J. Naudžuns “Investigation of Pavement Rutting Formation”. 28–30 August 2006, Kuressaare, Estonia.
9. RTU 46. Starptautiskā zinātniskā conference. V. Haritonovs, J. Naudžuns, J. Smirnovs “Bitumena saistvielas fizikālo un novecošanās īpašību analīze”. 13.–15. oktobris 2005. gads, Rīga
10. International Scientific Conference of Civil Engineering 2005. V. Haritonovs, J. Naudžuns, J. Smirnovs “Determining the Reasons for Formation of Pavement Rutting”. 26– 27 May, Jelgava, 2005.
11. RTU 45. Starptautiskā zinātniskā conference. J. Naudžuns, J. Smirnovs, V. Haritonovs „Asfaltbetona segu deformāciju pētījumi”. 14. – 16. oktobris 2004. gads, Rīga.

Practical Implementation

1. Riga Streets, Transport Structures and Transport Management Development Concept for 2008 – 2018. Chapter 2.5, Riga, 2007. Ordered by: the Riga City Council Transport Department.

CONTENT OF THE THESIS

INTRODUCTION

Introduction provides characteristics of the object of the research – asphalt concrete - from chemical, physical and mechanical aspects. The current situation on the roads and in Latvian transport industry has been described, and urgency of the problem, the necessity to eliminate deficiencies and the economic effect have been substantiated. The aim and tasks of the Thesis have been formulated.

Object of the Research

Asphalt concrete is a typical composite material which is formed by two main components with a completely different origin – bitumen (organic binder) and stone material (mineral aggregate). Bitumen, being a binder of asphalt concrete, contains, at least, four main components, which are of organic origin and have a large range of molecular mass, volatility, structure and other properties. Aggregates are also formed of various chemical compounds, but of inorganic origin. Asphalt concrete can fulfil the anticipated functions only when a sufficiently strong adhesion link exists between its components which depends on properties of the components and technologies of their manufacturing and laying [2]. Professor I. Leonovch characterises the asphalt concrete structure as a multi-component conglomerate system which mineral part is in the bitumen binder medium, forming a uniform monolith [3].

Physical properties of asphalt pavement are characterised by three main components of volume – bitumen, mineral material and voids. Mechanical properties of asphalt pavement depend on properties, quantity and proportion of these main components. The following volumetric parameters characterise the quantity and proportion of main components in the compacted asphalt pavement: voids (V_a), voids in mineral aggregate (VMA) and voids filed with bitumen (VFB).

Current Situation on the Roads and in Latvian Transport Industry

Significant changes took place on the roads and in Latvian transport industry during the last nineteen years. Due to transition from the earlier used GOST standards to the *FAS* (*Finnish Asphalt Specification*) methods and, starting from 2004, to the European Norms (EN), the quality provision requirements have changed. Alongside with changes of the technical documentation, compositions of asphalt mixtures changed as well. In place of the А, Б, В, Г and Д asphalt mixtures, designed in accordance with the GOST methods [5], the SMA and AC mixtures, designed in accordance with the “Road 94” requirements until 2004 and in accordance with the “Road Specifications 2005” [6–7] requirements from 2004, started to be used for the asphalt pavement wear course. These mixtures, being new for Latvian conditions, have been the object of investigation of the world’s leading researchers for more than forty years. These new types of asphalt mixtures, in contrast to simple or conventional compositions, have specific requirements. They need a new approach to design and manufacturing of the mixtures. By using technologies, raw materials and experience currently available with the manufacturers, the SMA and AC asphalt mixtures made and laid in Latvia show unsatisfactory strain properties, and, furthermore, the traffic intensity is increasing with every year (see Fig. 1).

Alongside with development of the road-building materials industry in the world, requirements to quality of raw materials and asphalt concrete are growing as well. The range of asphalt concrete raw materials, modifiers and reinforcement materials has become larger. It must be noted that volumes and costs of the road-building works have considerably increased in recent years. However, asphalt concrete and bitumen binder modifiers have not been extensively used, due to the fact that such mechanical indices of asphalt concrete performance properties as, for instance, the permanent strain formation slope, fatigue and stiffness, have not been included in the effective technical requirements of recent years. As a result, asphalt concrete designed and manufactured in Latvia, having low stability to strain under the heavy traffic load, do meet requirements of the technical specifications. However, the consequence is such that asphalt pavement longitudinal deformations or ruts on wheel tracks are observed on more than a half of the streets and roads which have been reconstructed in recent years and are intensively loaded.

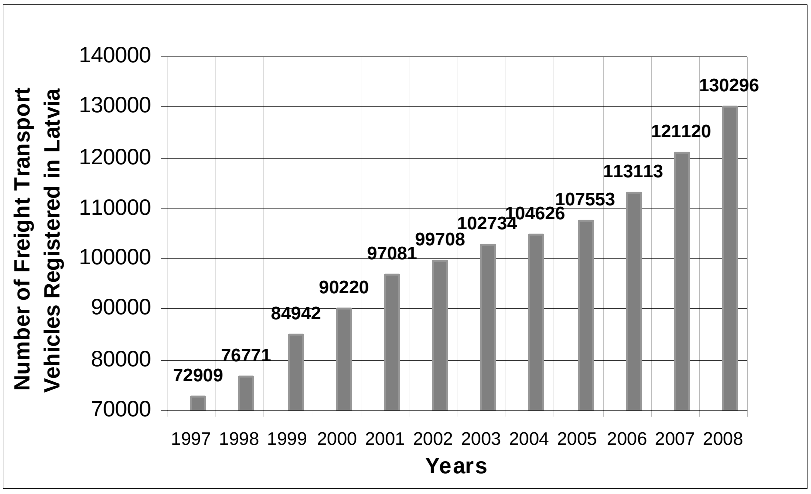


Fig. 1. Number of Freight Transport Vehicles Registered in Latvia [8–9]

LITERATURE SURVEY

The second chapter is devoted to survey of the literature which provides new and the already known (classical) modelling methods of stress and strain of road pavement layers, as well as description of advantages and deficiencies of these methods. The mechanics of pavement permanent strain formation has been analysed: the condition of the stress strained asphalt pavement under the static and rolling wheel load is described, stress distribution in one layer and multilayer systems, and the mechanism of permanent strain formation. Asphalt mixture design methods have been described and compared.

Permanent strain on a road or street is the main reason for hydroplaning of cars. In accordance with researches of a number of scientists, ruts with the depth of ≥ 13 mm become dangerous, when the driving speed exceeds 80 km/h [10]. Minimisation of such road pavement construction damage allows significantly improving traffic safety and convenience. Therefore, it is required to develop methods of permanent strain estimation (based on models and results of previous researches), in order to timely predict and perform the road infrastructure repair. There are several theories and methodologies that explain and describe asphalt concrete permanent strain. The main of these are:

- linear and nonlinear resilience theory [11];
- viscoelastic methodology (rheology models) [12];
- elasto-viscoplastic methodology[13];
- micromechanical methodology [14–15];
- permanent strain equations obtained as a result of the laboratory research [16–18].

Prediction of asphalt concrete stability is complicated due to many factors that influence its properties. The main of these are a variable load rate and its loading frequency, as well as considerable dependence of the properties from the temperature and the load [19]. Development of a mechanical model for asphalt pavement by evaluating all factors that influence its mechanical properties is very complicated. It is possible either to shorten a large number of influencing factors, leaving some of the most important ones, or to make time-consuming tests for determining other parameters and to summarize them in one model. The largest deficiency of this method is the considerable cost of equipment and experimental work. The most perspective methods are based on the correlation "number of vehicle loading cycles – strain", where the number of cycles is expressed as equivalent single-axle load (*ESAL*). To maximally approach to the real operation conditions, analysis of the functions equations must be based on the parameters obtained from performance tests. It means that manufacturing and loading of specimens, close to the real road or street pavement loading, must be provided in the laboratory circumstances. By participating in several research programmes, the RTU Civil Engineering Science Centre has attracted resources to obtain the performance test equipment, this way providing an opportunity to investigate the dynamics of asphalt concrete permanent strain development in the laboratory circumstances.

By summarising information on asphalt pavement permanent strain, starting from selection of raw materials and up to pavement usage, it has been established that by now there is no single approach to investigation of permanent strain development dynamics (comprehensive evaluation of external factors, prediction models, testing methods). There is no quality provision system or method, which is convenient for practical application, developed for road pavement.

Up to now, no practical experiments have been made for comparing strain properties of conventional and unconventional mixtures with Martin steel slag (MTS) aggregates to use this waste efficiently. At present, large MTS waste reserves are being formed in the manufacturing industries of Latvia and Europe (their current total available reserves at the Joint Stock Company "Liepājas Metalurgs" are approximately 5 million m^3).

Pursuant to this analysis, chief trends and parameters of the research which influence mostly permanent strain formation in asphalt pavement have been determined:

- asphalt pavement high performance temperature research;
- traffic load research and introduction of *ESAL* units of measurement in permanent strain research;
- *ESAL* estimation equation development for the high performance temperature period;
- permanent strain development prediction by means of performance test methods – wheel tracking and cyclic loading tests;

- development of research objects – conventional and unconventional asphalt mixtures and comparison of their properties;
- development of the quality provision system concept.

DESIGN OF ASPHALT MIXTURES, THEIR PHYSICAL AND MECHANICAL PROPERTIES

The third chapter contains description of test methods used in the Promotion Thesis. Properties of experimental specimens and their raw materials have been compared. Methods of designing asphalt mixtures are described. The Promotion Thesis problem solution includes usage of unconventional aggregates and modified binders, which are resistant to plastic or permanent deformations, to develop asphalt mixtures (See Fig. 2).

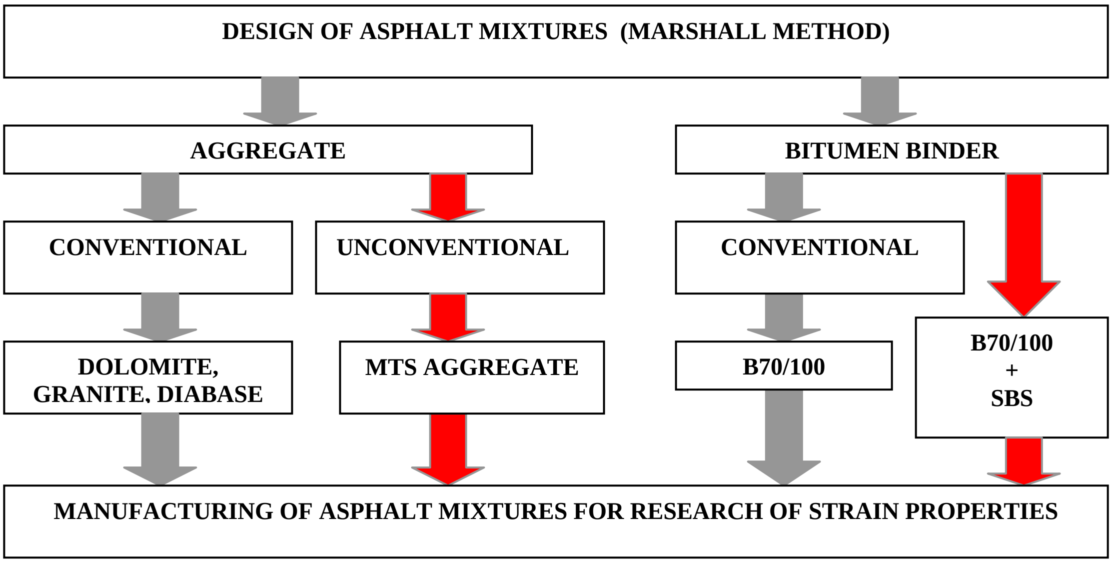


Fig. 2. Selection of Raw Materials:
=> – conventional raw material; => – unconventional raw material

Selection of Asphalt Concrete Raw Materials

Asphalt mixtures are manufactured by using conventional (B70/100) and unconventional SBS polymermodified bitumen (PMB) binders. Latvian experience shows that asphalt mixtures with bitumen B70/100 demonstrate unsatisfactory strain properties, even when they meet requirements of local technical regulations – "Roads Specifications 2010" (CS 2010). For this purpose, properties of bitumen binders B70/100 and PMB have been investigated. By comparing the obtained results, it has been established that PMB binder has lower penetration (at the temperature of +25 °C), the higher softening point temperature and the higher Frass breaking point temperature (See Fig. 3.a).

Asphalt concrete aggregates have been selected to contain the main natural stone materials which are used for asphalt concrete manufacturing – dolomite, granite and diabase (conventional aggregates). Properties of conventional aggregates and Martin steel slag (MTS) aggregates have been investigated and their conformity to the

CS 2010 requirements has been evaluated. When comparing the obtained results, it has been established that the MTS aggregate has lower resistance to fragmentation (LA=10 and NT=4), better form (Flakiness index) (FI=3) and less filler (< 0.063 mm = 0.1%; Fig. 3.b). The obtained results allow putting forward a hypothesis that, by using MTS aggregates in manufacturing asphalt concrete, a material resistant to large loads will be obtained, having a large internal friction angle of its mineral skeleton, as well as excellent adherence of car tyres with road pavement will be provided.

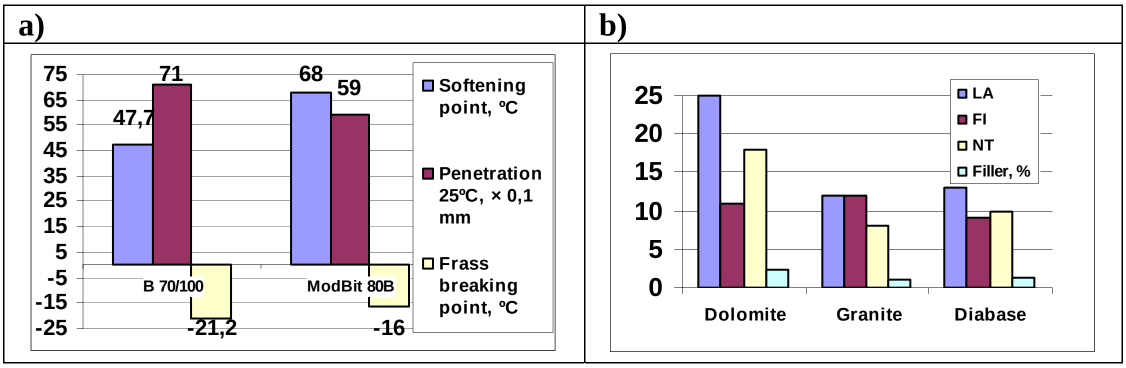


Fig. 3. Comparison of Properties of Bitumen Binders (a) and Aggregates (b)

Design of Asphalt Mixtures

SMA and AC mixtures have been designed in accordance with the Marshall method, by using conventional and unconventional raw materials. In total, seven asphalt mixtures have been made, two of them having unconventional raw materials – AC 11/Ref asphalt mixtures with MTS aggregate and bitumen B70/100 and SMA 16/Mod with granite aggregate and PMB binder (See Table 1). Analysis of physical properties of asphalt mixtures (the compaction degree), which is characterised by three volume parameters – voids (V), voids in mineral aggregate (VMA) and voids filled with bitumen (VFB), has been made (See Fig. 4). The binder content has been optimised and conformity of the mixtures to the CS 2010 requirements has been evaluated. When analysing properties of the designed specimens, it has been established that volume parameters of the AC test specimens meet the CS 2010 requirements. It is important to note that the SMA 16/Modbit test specimen, in case of the optimum binder content, demonstrate 4.7% large voids, which exceeds the upper limit stipulated by the technical regulations – 3.5%.

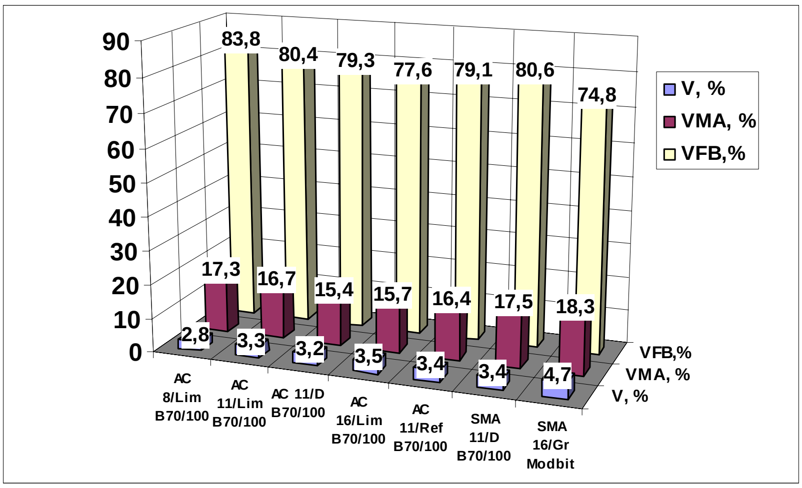


Fig. 4. Physical Properties of Asphalt Mixtures

Table 1

AC and SMA Asphalt Mixtures

Asphalt Mixture Type	Aggregate Fraction d–D (mm), 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/D[5)]	–	–	21.9	7.6	1.9	60.2	3.8	4.6	–
AC 11/Ref[6)]	14.0	29.8	–	–	–	42.9	6.5	6.8	–
AC 16/Lim	20.9	29.5	–	–	1.0	37.1[2)]	6.6	4.9	–
AC 8/Lim	–	–	–	27.2	15.0	42.2[1)]	9.4	6.1	–
SMA 16/Mod	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

Figure 5 provides a summary of mechanical properties of the test specimens: compressive strength of the specimens under the static load at the temperature of 60 °C (Marshall stability) and displacement at the moment of deterioration (Marshall flow), at the compaction degree of the specimens with the optimum binder or bitumen content (See Table 1). Marshall specimens are 63.5 ± 2.5mm high cylinders with the diameter of 101.7 mm. When comparing the obtained results, it has been established that the AC 11/Ref specimen, in comparison with other materials, has much larger Marshall stability – 13 kN. It is to be noted that mechanical properties of all test specimens conform to the CS 2010 requirements.

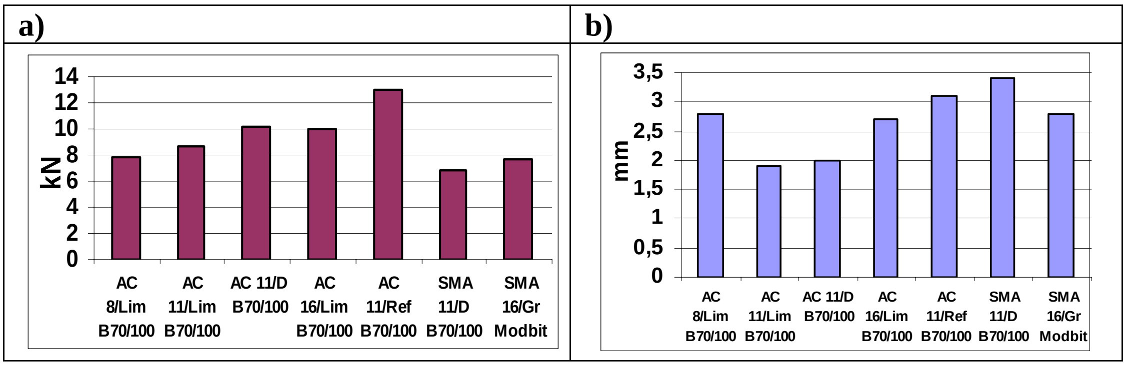


Fig. 5. Mechanical Properties of Asphalt Mixtures: Marshall Stability (a) and Marshall Flow (b)

Methods of Investigating Strain Properties

Methods for investigating strain properties of asphalt specimens have been selected in such a way as to achieve and solve the aims and tasks set in the Thesis, i.e. to determine and compare strain properties of the manufactured asphalt mixtures with the help of the methods, which ensure manufacturing of specimens, testing environment and loading, maximally close to the real road pavement performance circumstances (performance testing methods, See Fig. 6).

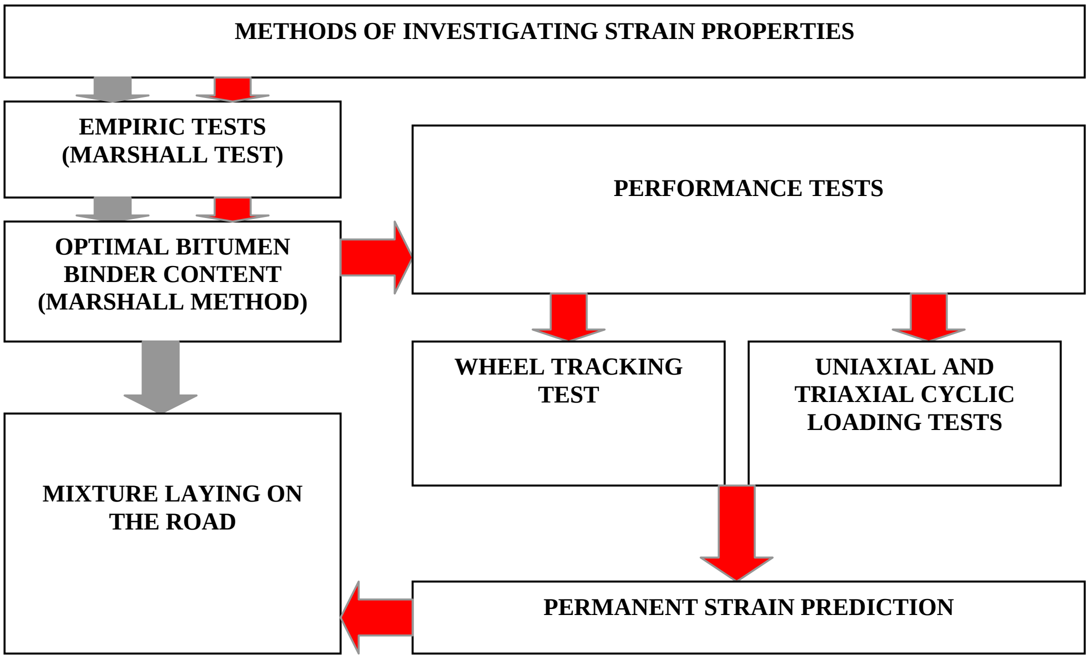


Fig. 6. Permanent Strain Research Methods Used in the Thesis:
=> – without evaluation of performance properties;
=> – with evaluation of performance properties

The following performance test methods have been used during the experiments: the wheel tracking test (*WTT*), the uniaxial cyclic compression test (*UCCT*) and the triaxial cyclic compression test (*TCCT*) (See Fig. 7.a and 7.b). The *WTT* method determines the wheel pressing depth and the permanent strain rate under the 700 N large load of the rotating wheel with the speed of 26.5 cycles per minute. The test was performed in a heat-chamber at the temperature of 60 °C. Asphalt concrete strain properties have been determined for the rectangular shape specimens with the base area of 305×305 mm. Thickness of the tested specimens conforms to that of the pavement surface layer – 40 mm (See Fig. 8.b). The *UCCT* and *TCCT* tests determine permanent strain of asphalt cylindrical specimens and the strain speed at cyclic loading by applying several thousand loading cycles to the specimens. In the triaxial loading case, horizontal confining stress has been applied to the specimens. It limits lateral deformation of specimens and, in comparison with the uniaxial loading, the triaxial one is much closer to the real road pavement performance circumstances. The stiffness modulus has been determined for the cylindrical specimens (h=40 mm, Ø≈100 mm; See Fig. 8.c) cored from asphalt concrete slabs by using the indirect tension loading system (See Fig. 7.c).

a) b)

c)

Fig. 7. Performance Tests:
a) uniaxial and triaxial cyclic loading tests; b) wheel tracking test;
c) indirect tension test

a) b) c)

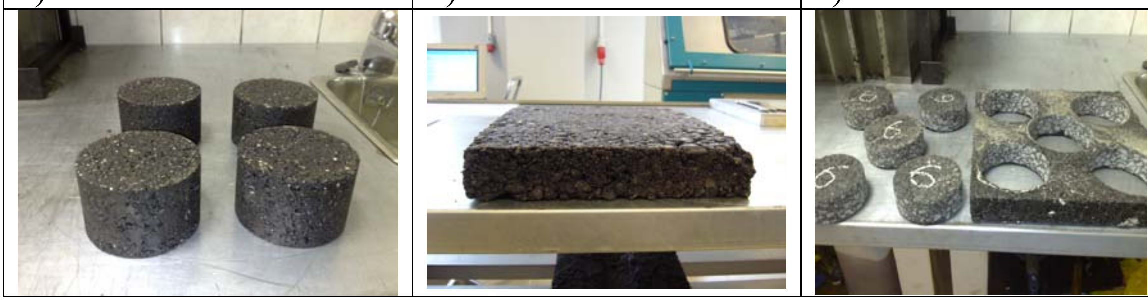


Fig. 8. Asphalt Concrete Specimens:
a) Marshall specimens; b) asphalt concrete slab; c) cylindrical specimens cut from asphalt slabs

PERMANENT STRAIN REASONS AND METHODS OF THEIR EVALUATION

The fourth chapter provides analysis of external factors causing asphalt concrete permanent strain – temperature and transport load. A certain concurrence of these factors – transport load and pavement temperature – leads to the accelerated permanent strain formation in asphalt pavement. The actual temperature of asphalt pavement changes depending on the air temperature, which, in its turn, depends on the season, time of the day and specifics of local climatic circumstances. The Promotion Thesis provides statistical processing of the observation data – transport load and external air temperatures which are characteristic for Latvian circumstances. Stiffness moduli and plastic deformations of asphalt concrete specimens have been determined experimentally at high asphalt pavement performance temperatures. The asphalt pavement high performance temperature and the equivalent single-axle load (*ESAL*) have been calculated for the hot (spring-summer) period in Latvia at the heavily loaded Riga detour road A4.

Temperature Influence Evaluation

Pursuant to the research of strain properties of asphalt specimens, the temperature has been determined at which asphalt pavement plastic deformation rapidly increases (the resilient modulus decreases). Fir this purpose, elastic and plastic deformations of the test specimens have been determined at different temperatures – from +20 °C to +60 °C. As the obtained results show, rapid reduction of the resilient modulus and increase of plastic deformation is observed at the temperature exceeding + 40 °C (See Fig. 9). Asphalt specimens made of unconventional raw materials – SMA 16 with polymermodified bitumen ModBit 80B and AC 11 with Martin steel slag (MTS) – demonstrate a larger resilient modulus at the chosen test temperatures, in comparison with conventional mixtures. Among conventional unmodified asphalt mixtures, the best strain properties have been demonstrated by AC 16 with dolomite and SMA 11 with diabase aggregates.

a) **b)**

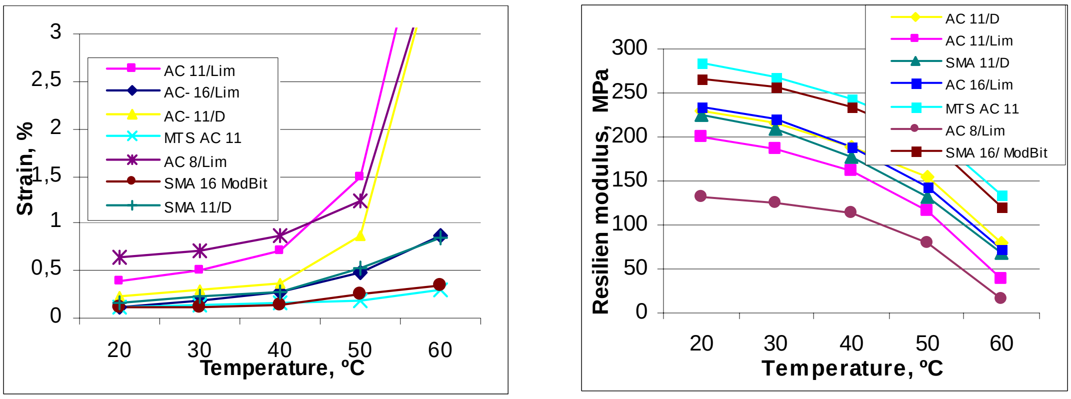


Fig. 9. Asphalt Concrete Plastic (a) and Elastic (b) Deformations at Different Temperatures

By using the empiric correlation of Professor Kiriukin, which is appropriate for Latvian climatic circumstances – the temperature range of -35ºC to -40 ºC (1) [20], and the 2001–2008 air temperature data obtained by the State Limited Liability Company "Latvian Environment, Geology and Meteorology Centre") [21], the number of days a year has been determined when the asphalt pavement surface temperature exceeds +40 °C (See Table 2):

$$T_v = -0{,}0306 \cdot T_{\max}^2 + 3{,}8071 \cdot T_{\max} - 39, \qquad (1)$$

where T_v – asphalt pavement surface temperature, °C;

$T_{\max}$ – maximal air temperature at the chosen region, °C.

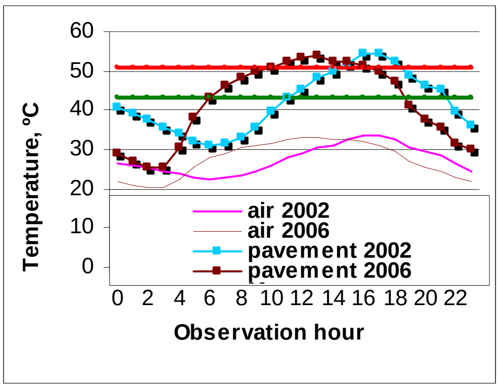
Table 2

Number of Days a Year when the Asphalt Pavement Temperature Exceeds +40 °C

Month	Number of Days a Year with the Asphalt Pavement Temperature > 40 °C							
	2001	2002	2003	2004	2005	2006	2007	2008
April	1	–	–	–	–	–	–	No data
May	4	9	5	4	5	1	6	No data
June	5	10	4	4	7	11	10	No data
July	20	19	23	11	23	23	4	No data
August	8	31	11	16	12	14	11	No data
September	–	6	2	–	4	1	–	No data
Total	**37**	**75**	**45**	**35**	**51**	**50**	**31**	No data

In accordance with the analysis of the air temperature data appropriate for Latvian climatic circumstances and the asphalt pavement high performance temperature, it has been established that asphalt pavement permanent strain can develop during the period of April to September from 7.00 to 21.00 (See Fig. 10.a). The annual average daily traffic ($AADT$) during this period is maximal (See Fig. 10.b).

a)



b)

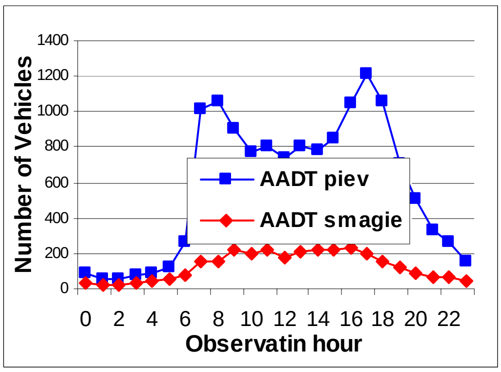


Fig. 10. Dynamics of Changing External Factors:
a) Asphalt Pavement Temperature; b) Traffic Intensity

Traffic Load

Traffic axle load, intensity and driving speed are the second most important external factor influencing permanent strain. To predict the rate of permanent strain formation, comprehensive evaluation of the traffic load and intensity has been made.

To estimate the road pavement load carrying capacity, the equivalent single-axle load ($ESAL$) concept has been developed, when road pavement damages can be expressed with the help of the $ESAL$ value depending on the axle load [22]. The admitted axle loads vary in different countries: in the USA – 8.2 tons over tandem axle, whereas, in France, Spain and Belgium – 13 tons [23–24]. The admitted axle load in Latvia is 11.5 tons. As road pavement is subjected to different traffic loads with various configuration of axle types, the load equivalence factor has been introduced and estimated ($EALF$) [22] to evaluate influence of any axle load effect (equivalent to the 11.5 t heavy axle) by using "the fourth power law" (2):

$$EALF = \left(\frac{AL_i}{AL_j} \right)^4 , \tag{2}$$

where AL_i and AL_j is axle load in tons for vehicles of **i** and **j** axle categories.

It has been established that the traffic intensity measurement unit currently widely used in Latvia – the annual average daily traffic intensity ($AADT$) - is very general and does not allow estimating axle loads precisely. To investigate the dynamics of asphalt pavement permanent strain development in the thesis, the number of axle (equivalent to the 11.5 t axle) loading cycles during the pavement designed (service) period has been predicted for each weight category of heavy vehicles. It is offered to express the traffic load characteristic for Latvian circumstances in $ESAL$ units of measurement by using the following correlation:

$$ESAL = f_i \cdot G \cdot AADT \cdot 365 \cdot N_i \cdot EALF_i , \tag{3}$$

where $ESAL$ – equivalent single-axle load (unit of measurement: the number of vehicle axle (equivalent to the 11.5 t axle) loading cycles during the road pavement service period);

f_i – design lane factor;

G – traffic intensity growth factor;

$AADT$ – annual average daily traffic intensity during the first year of asphalt pavement performance;

N_i – number of axles on each vehicle in axle category i;

$EALF_i$ – load equivalency factor for axle category i.

The traffic intensity and load data have been obtained from the traffic statistics station (SUS), which is located at the Riga detour road A4 (Baltezers – Saulkalne). As, due to the Latvian variable weather circumstances and unpredictable economic situation, external factors causing permanent strain can significantly differ from the ones observed during previous years, several assumptions based on these observations have been introduced:

- average annual traffic growth – 2%;
- asphalt pavement service life in accordance with the project – 20 years;

- number of days a year with asphalt pavement high performance temperature – 2%;
- rutting takes place during the period of April to September from 7.00 till 21.00, when asphalt pavement temperature may reach and exceed the critical performance temperature – +40 °C;
- during the period of April to September the $ESAL$ value is 55% of the annual value, and from 7.00 till 21.00 it is 85% of the daily value.

By assuming the annual traffic growth value (2%) and the designed pavement service life (20 years), the traffic growth factor (during 20 years) has been calculated:

$$G = \left[(1+r)^n - 1\right]/r = 24{,}30, \tag{4}$$

where G – traffic growth factor;

$r = \frac{i}{100}$ – traffic average annual growth rate;

i – traffic growth rate a year – 2%;

n – designed pavement service life in years.

For $ESAL$ calculation, vehicles on the Riga detour road A4 have been divided with an hour interval, based on the vehicle weight category and number of axles. The analysis of the vehicle division data on the detour road A4 shows that 74% are two-axle cars, 4% - two-axle trucks, 1% - six-axle and three-axle trucks, 4% - four-axle trucks and 16% five-axle freight trucks.

By using the earlier determined parameters – $AADT$, $EALF$, G and the two-way lane number coefficient f_i = 0.5, the total $ESAL$ for each vehicle weight category has been calculated (See Table 3).

Table 3

$ESAL$ and its Calculation Parameters

Vehicle Axle Number	Lane Number Coefficient, f_i	Growth, G	$AADT$ (number)	$EALF$, f	Group $ESAL \times 10^{-6}$	Total $ESAL \times 10^{-6}$
2 axles	0.5	24.3	10,000	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	

For further calculation, the $ESAL$ value must be determined for the period when rutting takes place – hot spring-summer months with asphalt pavement high performance temperature. In accordance with the earlier introduced assumptions, the $ESAL$ calculation correlation has been made for the period with asphalt pavement high performance temperature:

$$ESAL_0^{hp} = ESAL_0 \cdot a_1 \cdot a_2 \cdot a_3 = 6452 \tag{5}$$

and

$$ESAL_0 = \sum ESAL_i / G = 0{,}69 \times 10^6, \tag{6}$$

where $ESAL_0^{hp}$ – equivalent single-axle load during the period with pavement high performance temperature;

$ESAL_0$ – equivalent single-axle load during the first asphalt pavement service year;
a_1, a_2 – parameter which includes the season and the number of days a year with asphalt pavement high performance temperature;
a_3 – parameter which includes the number of hours a day with asphalt pavement high performance temperature;
G – traffic intensity growth factor.

PERMANENT STRAIN AND ITS PREDICTION

In the fifth chapter, test specimens have been experimentally tested with the help of the performance testing methods (*UCCT*, *TCCT* and *WTT*). Plastic deformations have been determined and deformation rates have been calculated. Permanent strain development has been predicted by determining the functional correlation constants of permanent strain prediction.

Cyclic Loading Test

The research described in the previous chapter has determined the highest performance temperature of asphalt pavement – ≥ +40 °C at which fast decrease of the resilient modulus of asphalt specimens is observed. Permanent strain (See Table 1) has been determined for the specimens on the cyclic loading equipment *UCCT* and *TCCT* at the temperature of +40 °C, +50 °C and +60 °C. The specimens have been cyclically loaded with the 100 kPa load and 0.5 Hz frequency. Duration of one cycle is 2 s (1 s – loading and 1 s – unloading). In the triaxial loading, the specimens have been applied the horizontal confining stress of 50 kPa.

When comparing the results obtained at different temperatures, it has been established that:

- at +40 °C after ~ 500 loading cycles all specimens have the expressed stabilisation zone (the strain rate is constant) without disintegration (See Fig. 11.a);
- at +50 °C after ~ 2500 loading cycles disintegration starts for the AC 11/Lim specimens (See Fig. 11.b);
- at +60 °C disintegration is observed for the specimens AC 11/Lim, AC 11/D and AC 8/Lim (See Fig. 11.c).

When analysing the triaxial test results, it has been established that the disintegration zone is observed at none of the specimens. However, the total strain of the AC 11/Lim and AC 8/Lim specimens after ~ 3600 cycles is 1–1.2%, which is several times larger than for other test specimens: for the AC 11/Ref and SMA 16/Mod specimens with an unconventional aggregate – 0.1%, for the conventional SMA 11/D, AC 16/Lim and the AC 11/D specimens – 0.3% (See Fig. 11.d). Following analysis of the obtained “number of loading cycles - strain” correlation, it has been established that the AC 11/Lim and AC 8/Lim specimens have larger strain rate at the axial and triaxial loading.

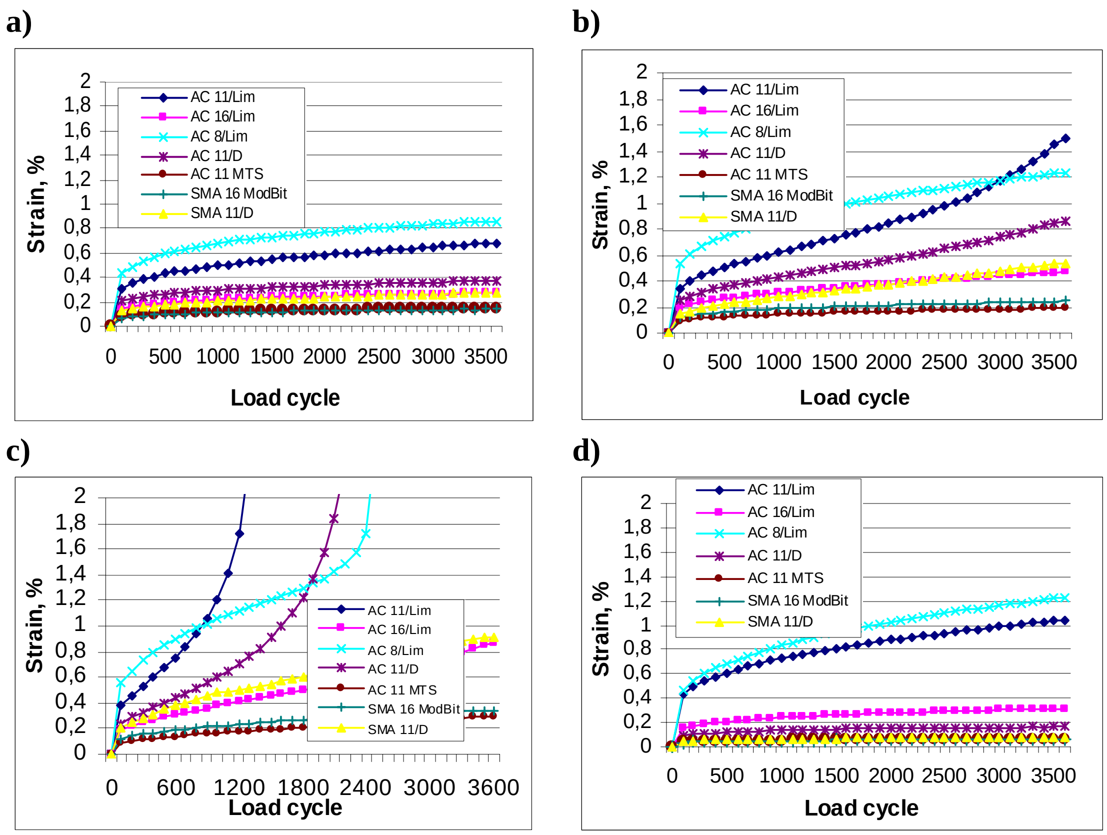


Fig.11. Cyclic Loading Test Results:
a) axial test +40 °C, 100 kPa, 0.5 Hz; b) axial test +50 °C, 100 kPa, 0.5 Hz;
c) axial test +60 °C, 100 kPa, 0.5 Hz; d) triaxial test +60 °C, 100/50 kPa, 0.5 Hz

Wheel Tracking Test

Permanent strain has been determined experimentally for test specimens with the help of the *WTT* method (wheel tracking test). The most significant difference of this test from the *UCCT* and *TCCT* methods is the form of specimens (See Fig. 8.b) and application of the load to surface of the specimens by a moving wheel with the load of 700 N (See Fig. 7.b). The contact surface of the wheel and the specimen is 19 cm^2. The equipment determines pressing of the wheel into the specimen (relocation) up to 20 mm. Duration of the test is 20 000 cycles with the load of 26.5 cycles per minute.

The obtained results (the “number of loading cycles - strain” correlation) demonstrate similar graphic tendencies both at axial, and triaxial cyclic loading – the largest plastic deformations appear for the AC conventional asphalt concrete mixtures, and the lowest deformation is demonstrated by SMA 16/Mod (See Fig. 12). It is important to note that the SMA 11/D conventional mixture has demonstrated the second best result.

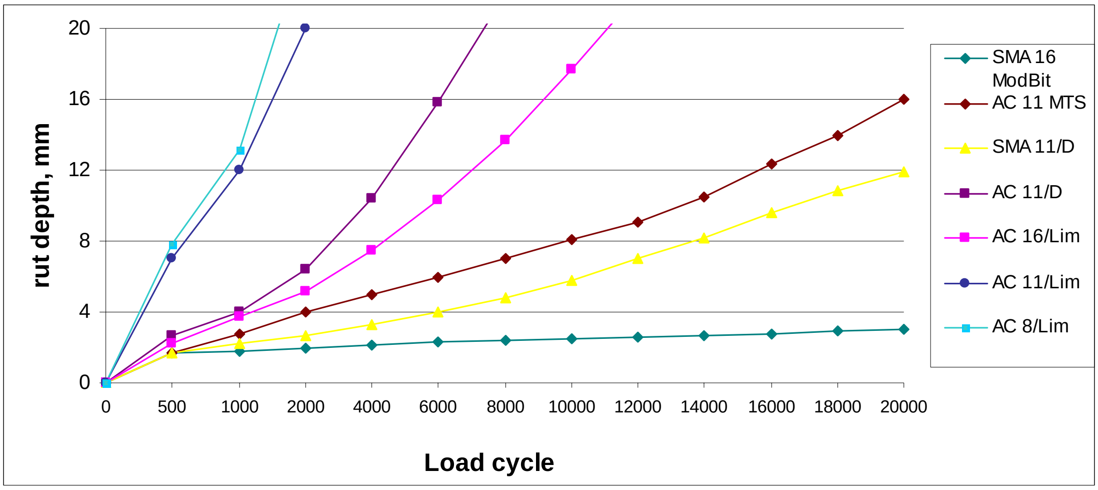


Fig. 12. Wheel Tracking Test Results

The experimentally obtained correlation "number of loading cycles - strain" has been analysed. The wheel tracking slope has been calculated by using the formula:

$$WTS_{air} = \frac{\varepsilon_{n1}^{p} - \varepsilon_{n2}^{p}}{n_1 - n_2}, \qquad (8)$$

where WTS_{air} – wheel tracking slope, mm/1000 cycles;

ε_{n1}^{p}, ε_{n2}^{p} – plastic deformation after n_1, n_2 loads;

n_1, n_2 – number of cyclic loads at the start and finish of the creep curve stabilisation.

Table 4 provides summary of the researched indices of asphalt specimens WTS_{air}. It is noted that since 2010 the strain rate has been regulated by the CS 2010 requirements [25] in Latvia, hereto the maximal WTS_{air} classification in accordance with the LVS EN 13108-1 standard is one. When comparing the calculated strain rates, it has been established that only three test specimens (AC 11/Ref, SMA 16/ModBit, SMA 11/D) have $WTS_{air} < 1$. It is important to note that the SMA-16/ModBit mixture with $WTS_{air} = 0.06$, in accordance with the new CS 2010 requirements, is appropriate to be laid on the streets and roads with intensive traffic, i.e. where the traffic intensity $AADT > 3500$ (See Table 4).

Rutting of the researched asphalt mixtures has been investigated by using the power functions which is a mathematical model of the permanent strain prediction [26–27]:

$$\varepsilon_p = a \cdot N^b, \qquad (9)$$

where ε_p – permanent strain, mm;

a, b – material constants;

N – number of loading cycles.

The a parameter characterises permanent strain increase at $N = 1$, whereas the b parameter – the strain increase rate.

Table 4

Strain Rates of Asphalt Mixtures

Mixture Type	Maximal WTS_{air} Category in accordance with LVS EN 13108-1 (mm/1000 loading cycles)	Actual WTS_{air} Category (mm/1000 loading cycles)	Requirements of "Road Specifications 2010"			
			AADT < 500	AADT 501–1500	AADT 1501–3500	AADT >3500
AC 11/Lim	1.00	5.79	1.0	0.8	0.5	0.3
AC 11/D		3.11				
AC 11/Ref		0.56				
AC 16/Lim		1.5				
AC 8/Lim		6.87				
SMA 11/D		0.49				
SMA 16/ModBit		0.06				

Accumulation of plastic deformation (ε_{pn}) from the number of traffic loading cycles ($ESAL$ units) is expressed by the relation (10) [17]:

$$\varepsilon_{pn} = \frac{\partial \varepsilon_p}{\partial N} = \frac{\partial}{\partial N}(aN^b) = ab \cdot N^{b-1} . \qquad (10)$$

By cyclically loading the asphalt specimens, elastic and plastic deformations appear. By assuming the elastic deformation (ε_r) in cyclic loading as a constant value and introducing the prediction parameters $\mu = \frac{ab}{\varepsilon_r}$ and $\alpha = b - 1$, a model equation of the viscoelastic system (*VESYS*) has been obtained:

$$\frac{\varepsilon_{pn}}{\varepsilon_r} = \mu \cdot N^{\alpha} \text{ jeb } \varepsilon_p(N) = \mu \cdot \varepsilon_r \cdot N^{\alpha} . \qquad (11)$$

By analysing the *WTT* test results (See Fig. 12) and applying the linear correlation curve methodology, as well as by considering the experimentally determined resilient modulus of asphalt specimens, a mathematical model (11) parameters μ and α have been calculated. The obtained results are summarised in Table 5. The μ parameter characterises the relation of plastic and elastic deformations, whereas the α parameter – the permanent strain increase rate.

Table 5

Model Parameters for Permanent Strain Prediction

Material Parameter	Asphalt Mixtures						
	AC 11/Lim	AC 8/Lim	AC 11/D	AC 11/Ref	AC 16/Lim	SMA11/D	SMA 11/D_Mod
E, MPa	17.5	16.4	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	6.13
μ	0.16	0.17	0.08	0.47	0.17	0.35	8.95
α	0.629	0.695	0.745	0.524	0.617	0.458	0.172
Thickness, mm	40						

$^{*)}$ ε_p at 1700 cycles. $^{**)}$ ε_p at 5000 cycles. $^{***)}$ ε_p at 10 000 cycles.

To enable prediction of permanent strain, the following assumptions have been used:

- rutting appears on roads or streets in accordance with the "number of loading cycles - strain" correlation, which is obtained by performing the permanent strain laboratory research with the help of the *WTT* method;
- rutting appears only in the asphalt concrete surface layer and is not related to strain properties of the bottom layers, i.e. ruts are not the structural or impress result;
- the surface layer has no temperature gradient, the temperature is constant in the entire material;
- the traffic load expressed in *ESAL* units is 16.7 million during twenty years (See Table 3);
- rutting appears at the temperature of +40 °C and higher (See Fig. 9).
-

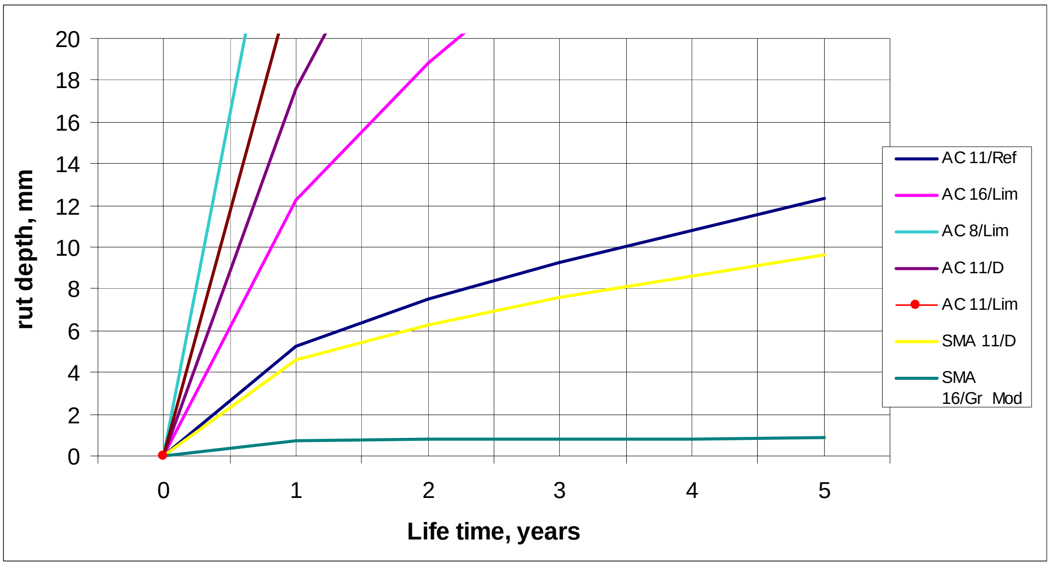


Fig. 13. Permanent Strain Formation Dynamics (loading circumstances of the Riga detour road A4)

By considering the earlier determined resilient modulus of the asphalt specimens, depth of ruts and their rate results, permanent strain parameters and external factors of permanent strain formation – local climatic circumstances and traffic load expressed in *ESAL* units of measurement for the pavement high performance temperature period, the theoretical dynamics of rut development for the Riga detour road A4 (See Fig. 13) has been determined. By comparing the obtained results for seven asphalt mixtures designed during the research, it has been determined that the conventional dense graded AC mixtures have ruts ≥ 13 mm deep, which becomes dangerous and may cause hydroplaning when the driving speed exceeds 80 km/h, and this will be reached already during the first year of the road pavement service (See Fig. 13). It is important to note that, among three best specimens, there is one conventional SMA 11/D mixture with the diabase aggregate. This confirms that also unmodified bitumen is appropriate for manufacturing SMA mixtures, if, prior to manufacturing it, a thorough calculation of its grading composition is made.

CONCEPT OF THE QUALITY PROVISION SYSTEM

In the fourth chapter, the asphalt pavement quality provision system has been developed on the basis of the analysis of the obtained results and recommendations have been provided for minimising rutting. The aim of the analysis is to discover deficiencies in the existing quality provision process.

It has been established that, irrespective of the clearly understandable mechanics, the recommended specifications and general conformity of the asphalt pavement layer formation stages to the quality requirements, at some renovated road pavement sections of the Latvian roads ruts appear after a short period of payment service. In order to avoid this, a concept of quality provision system of asphalt pavement has been developed in the thesis which is the quality provision algorithm of the entire process and, thus, allows tracing its every procedure (See Fig.14) [28].

By analysing separate stages of the developed concept of the quality provision system (See Fig. 14) and the results obtained in the promotion thesis, it has been established that:

1. Under the impact of large traffic loads, considerable plastic deformations appear in the dense graded AC asphalt mixtures, which are traditional for Latvian conditions. However, in accordance with recommendations of associations of the world's leading asphalt concrete manufacturers *EAPA*, *NAPA* and *AASHTO*, AC and SMA mixtures are appropriate for pavement of heavily loaded sections of streets and roads [29–31, 6].
2. Asphalt concrete raw materials are classified and testing methods are selected in accordance with requirements of the European standards (LVS EN 13043 for aggregates, LVS EN 12591 for road bitumen, LVS EN 14023 for PMB bitumen), and conformity of the classified raw materials is determined by considering the local requirements of "Road Specifications 2010".
3. Since 1994 asphalt mixtures in Latvia have been designed in accordance with the Marshall method. It has been scientifically proven that optimisation of the bitumen quantity with the help of the Marshall method gives similar results as the latest *SUPERPAVE* method and the classical Hvim method [18].
4. In accordance with the CM Regulations No. 181, asphalt concrete, bitumen binder and mineral material are included into the regulated sphere, which is subjected to

the compulsory evaluation of conformity of products, processes and services, as determined by the government [32]. In this system, the manufacturer must test the asphalt concrete type (product testing prior to offering it on the market), develop the production process control system and periodically test the material. It is important to note that the type testing standard LVS EN 13108-20 includes different performance testing methods, which have been used in the promotion thesis (*WTT*, *UCCT* and *TCCT*), whereas, the *WTT* method, according to requirements of the technical regulations "Road Specifications 2010", has been included only since 2010. Therefore, asphalt mixtures manufactured in Latvia have low strain properties, though they meet requirements of the local technical regulations.

5. The asphalt mixture quality control in Latvia is performed in accordance with the LVS EN ISO/IEC 17025:2005 standard method at an independent accredited laboratory (third party) [33–34]. Methods and requirements of the standards (LVS EN) are used for the quality control, determining physical and mechanical properties of the asphalt mixture and cored specimens. It is important to note that the manufacturer's and the third party laboratory accredit the methods which are stipulated by the local regulations, i.e. without performance testing. Reliability of the results provided in the Promotion Thesis is ensured through usage of the accredited *WTT* method.
6. When analysing the influence of the transportation and laying processes of the manufactured material on the road pavement quality, it has been established that they are not regulated. However, the LVS EN 13108-21 standard recommends developing the mixture transportation procedure to minimize segregation. It is important to note that the material laying quality depends on:
   - properties of the laid asphalt concrete layer (temperature, thickness, homogeneity of the layer);
   - properties of asphalt concrete and raw materials (asphalt concrete type, aggregate form and texture, grading and bitumen viscosity);
   - weather circumstances (air and base layer temperature, wind speed);
   - road-roller type (static, pneumatic or vibration roller) un speed of rolling;

7. Quality control of the laid mixture is performed by determining properties of the asphalt core specimens (permanent strain since 2010). It is important to note that the obtained results do not pertain to the entire road or street pavement, but only to the specific places where the specimens have been taken. Still, at present there are several progressive non-destructive methods developed in the world for determining the compaction degree for the entire road pavement layer.
8. One of the reasons for rutting is the necessity to open traffic at the reconstructed section as soon as possible. Opening a road for traffic must not be allowed until the moment, when payment is cooled down and bitumen is sufficiently condensed and structured. The minimum recommended time prior to opening a road for traffic is 12 hours [35]. The rate of cooling down depends on properties of the material and raw materials, thickness of the layer, air temperature and wind speed. It is important to note that the researched specimens were tested in 24–48 hours after their compaction (requirements of the EN standards).

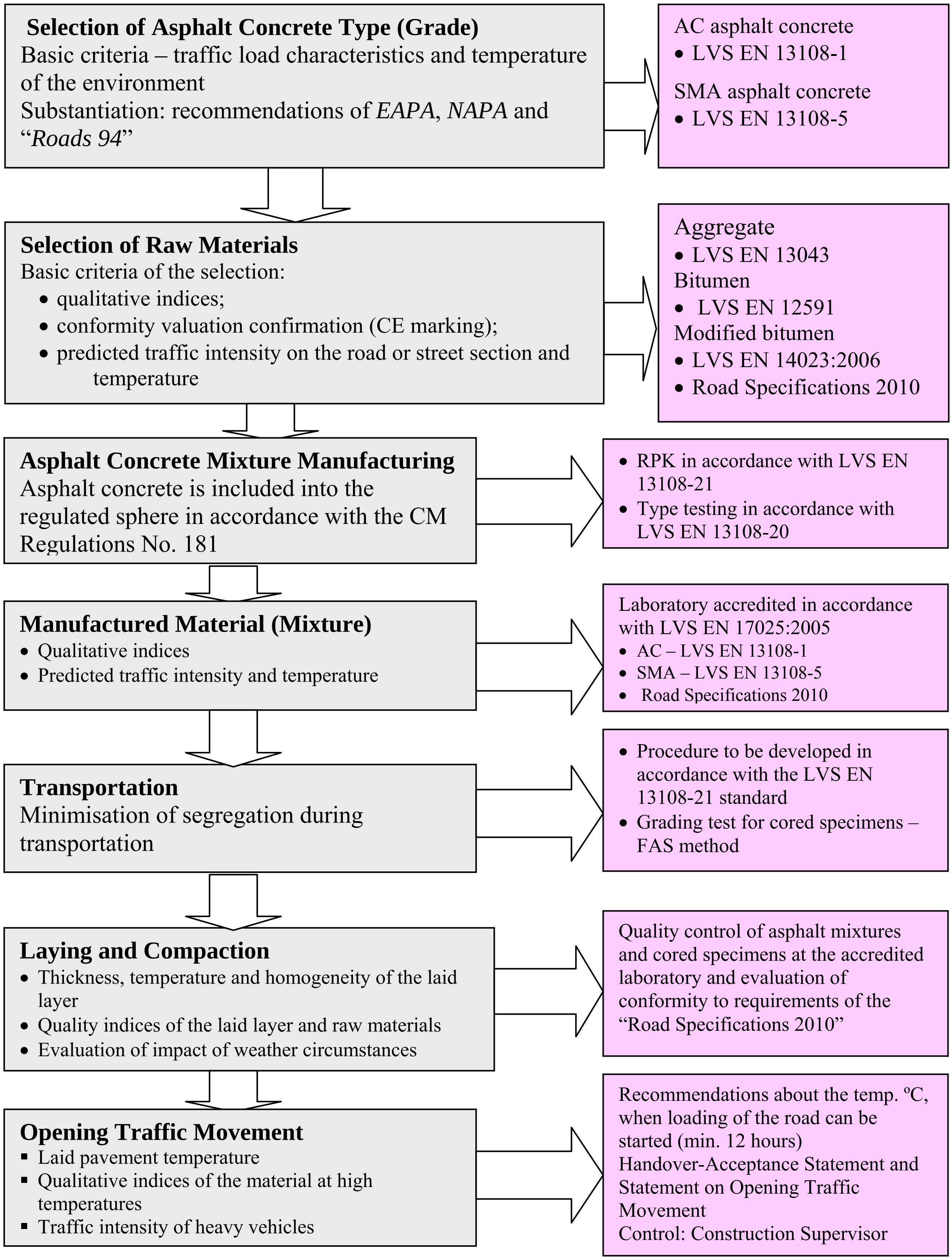


Fig. 14. Concept of the Asphalt Pavement Quality Provision System:
[grey] – processes and procedures; [pink] – quality provision measures

The aforesaid certifies that, irrespective of some positive properties of the SMA and AC asphalt mixtures, there is no sufficient experience of their practical usage on the Latvian streets and roads. Their usage on the Latvian roads and streets demonstrate that the result is not satisfactory – the inadmissible ruts appear. The Promotion Thesis, by analysing the developed stages of the quality provision system – selection of the asphalt concrete type, requirements to raw materials, design and the manufactured material quality control, offers some **recommendations** which implementation could minimise rutting on the newly built Latvian streets and roads:

- improvement of requirements of the technical regulations "Road Specifications 2010" – approbation of new methods for performance testing and their introduction for quality control of asphalt mixtures and cored specimens;
- providing CE marking, which certifies that asphalt conforms to the EU directives, i.e. the manufacturing process control has been elaborated and certified, and main functional properties of the materials are periodically determined at low and high temperatures, in accordance with the asphalt concrete type testing standard LVS EN 13108-20;
- observation of the *AASHTO* and *NAPA* recommendations with regards to manufacturing and laying of the SMA and AC mixtures, i.e., by using qualitative aggregates and modified bitumen, strictly observing the material supply sequence, temperature and duration of mixing at manufacturing, mixing of the mixture at the start and finish of laying, thoroughly following the procedure of rolling (the road-roller type, temperature, rolling speed, etc.);
- development of the procedure of asphalt mixture transportation and laying of each asphalt mixture type;
- introduction of the methods determining progressive compaction for quality control of the entire road pavement layer;
- collection of informative data (thickness of the road pavement structure and its separate layers, asphalt concrete type, etc.);
- development and introduction of the vehicle weight control system.

CONCLUSIONS

1. When investigating the rutting process, properties of the steel manufacturing by-product – Martin steel slag (MTS), as an aggregate, have been experimentally determined: its resistance to fragmentation (LA = 10 and NT = 4), the Flakiness index (FI = 3) and the filler content (< 0.063 mm = 0.1%). The results confirm the higher quality of the MTS aggregate, in comparison with conventional aggregates: dolomite (LA = 25, NT = 18, FI = 11, < 0.063 mm = 2.4%), granite (LA = 12, NT = 8, FI = 12, < 0.063 mm = 1.1) and diabase (LA = 13, NT = 10, FI = 9, < 0.063 mm = 1.4%).
2. Properties of the unmodified bitumen binder B70/100 and the SBS polymermodified bitumen binder have been experimentally determined. The results confirm the higher indirect viscosity indices of the modified bitumen binder at high performance temperatures (penetration at 25 °C = 59×0.1 mm, the softening point temperature = 68 °C), in comparison with B70/100 (71×0.1 mm and 59 °C), though the Frass breaking point temperature is higher - –16 °C (–21.1 °C for B70/100).
3. Two unconventional asphalt mixtures have been created: AC 11/Ref with the Martin steel slag (MTS) aggregate and SMA 16/Mod with the SBS modified bitumen aggregate, as well as five mixtures with conventional aggregates: AC 11/Lim, AC 8/Lim and AC 16/Lim with dolomite, AC 11/D and SMA 11/D with diabase. To determine the optimum content of the aggregate, the volumetric analysis (V, VMA and VFB) has been done with the help of the Marshall method. With the optimum content of the aggregate, SMA 16 has larger content of permanent voids – 4.7%, and the AC 11 mixture with the MTS aggregate has larger resistance when being statically loaded at the temperature of 60 °C (Marshal stability) – 13 kN.
4. By using modern performance test methods (*UCCT* and *TCCT*), plastic deformation values have been experimentally determined for unconventional (etalon mixtures) and conventional asphalt mixtures. By analysing the obtained results, it has been established that at similar testing circumstances under cyclic axial and triaxial loads, the conventional asphalt mixtures, in comparison with the etalon mixtures, demonstrate 3–10 times larger plastic deformation. No deterioration zone has been established for the unconventional mixtures. Under triaxial load at +60 °C, permanent strain is 0.1%, which is three times less than that of the SMA 11/D and AC 16/Lim (0.3%) mixtures and more than ten times less than that of the AC 11/Lim, AC 11/D and AC 8/Lim mixtures (1.2%).
5. When analysing the wheel tracking slope WTS_{air} (mm/1000 cycles) obtained by means of the wheel tracking test (*WTT*), it has been established that for three asphalt mixtures – AC 11/Ref, SMA 11/D and SMA 16/ModBit – the wheel tracking slope is less than one (WTS_{air} = 1 is the maximum category of the LVS EN 13108-1 standard). However, only the SMA-16/ModBit mixture with WTS_{air} = 0.06, in accordance with requirements of the “Road Specifications 2010”, is appropriate for being laid on the streets and roads which are intensively loaded with traffic, i.e. where traffic intensity *AADT* > 3500. The unconventional AC 11/Ref mixture has WTS_{air} of 0.56, WTS_{air} of the conventional SMA11/D is 0.49, and the wheel tracking slope WTS_{air} of other conventional AC mixtures is 1.5 to 6.86.
6. The equivalent single-axle load (*ESAL*) calculation correlation has been made for the traffic load and climate conditions characteristic for Latvian circumstances. It

has been proven that the unit of measurement used for traffic statistics in the researches of permanent strain formation dynamics in Latvia – the annual average daily traffic intensity (*AADT*) – is very general and inappropriate for investigating the permanent strain formation dynamics. It is required only for the *ESAL* value calculation.

7. By using the data obtained from the traffic statistics station (SUS) on the Riga detour road A4, as well as the air temperature data for the period of 2001–2008, the equivalent single-axle load value has been estimated for the period with the road pavement high performance temperature. As in the future the traffic intensity data may differ from observations of recent years, the *ESAL* value is estimated on the basis of several assumptions: the annual traffic intensity increase is 2%, the asphalt pavement service life is 20 years, and the number of days a year with asphalt pavement high performance temperature is 2%. These assumptions are based on observations of the recent years and the results of many experiments.
8. Methods based on the *VESYS* calculation model with the *ESAL* values calculated for the hot (spring-summer) period has been offered which allows, by considering the traffic load expressed in *ESAL* units and the local climatic conditions, to predict permanent strain in the laboratory circumstances. By predicting permanent strain of the conventional and etalon mixtures characteristic for Latvian circumstances, it has been established that the conventional AC mixtures have ruts ≥ 13 mm deep, which is dangerous when the driving speed exceeds 80 km/h, and this will be reached already during the first year of the road pavement service.
9. Asphalt pavement quality provision system has been developed and, by analysing its separate stages related to selection of the asphalt mixture type, manufacturing, design and quality control, recommendations have been provided to minimise rutting on Latvian streets and roads.
10. It has been demonstrated that SMA mixtures may be made also of unmodified bitumen, if thorough calculation of the grading composition is made prior to the manufacturing and qualitative aggregates are used.

LITERATURE

1. Valsts Stratēģiskais ietvardokuments 2007.–2013. gada periodam. LR Finanšu ministrija. – 2007. – 38 lpp.
2. Dzenis M. Vīksne A. Bitumenu un pildvielu adhēzija un asfaltbetona degradācijas cēloņi. Atskaite Rīgas pilsētas Domes Satiksmes departamentam, 2002.
3. Леонович И.И., Шумчик К.Ф. Дорожно-строительные материалы. – Минск: Вышейшая школа, 1983. – 399 с.
4. Brown E. R., Prithvi S. Kandhal, Jungna Zhag. Perfomance Testing For Hot Mix Asphalt. National Centre for Asphalt Technology. NCAT Report 01–05. November 2001. – 72 p.
5. ГОСТ 9128-84. Смеси асфальтобетонные дорожные, аэродромные и асфальтобетон. Технические условия. 1997. – 41с.
6. Ceļš 94. Vispārējie ceļu būves tehniskie noteikumi. 6. daļa. Bituminētās segu konstrukciju kārtas. Zviedru Nacionālā ceļu administrācija. Tehniskais departaments. Autoceļu būves un grunts sekcija. Tulkojums Latviešu valodā 1999. – 174. lpp.

7. Autoceļu specifikācijas 2005. Apstiprinātas LR Satiksmes ministrijā Autosatiksmes departamentā Tehniskajā komisijā ar 2005. gada 14. jūlija rīkojumu Nr.13.1-10/1. – 137 lpp.
8. Ceļu satiksmes drošības direkcija (CSDD): Statistika / Internets. – http://www.csdd.lv/
9. Ceļu satiksme drošības direkcija (CSDD). Transportlīdzekļu statistikas kopsavilkums Latvijā no 1995. līdz 2004. gadam. 2005. Rīga. – 3. lpp.
10. Erkens. S. Asphalt concrete response – Determination, Modeling and Prediction. Delft University.- Delft: Press Science 2002. – 202 p.
11. Lapsa. V. Jaunākas būvmateriālu mehāniskās pārbaudes. – Rīga, Avots, 1981. – 163 lpp.
12. Sides, A. Uzan, J., Perl, M. A. Comprehensive Viscoelasto-Plastic Characterization of Sand-Asphalt Compressive and Tensile Cyclic Loading// Journal of Testing and Evaluation, Vol. 13, No. 1 – 1985. – 57–65 pp.
13. Chang, K.G and Meegoda, J.N. Micromechanical simulation of hot mix asphalt// Journal of Engineering Mechanics, Vol. 123, No. 5 1997. – 495–503 pp.
14. Attoh-Okine, N.O. Potential application of geometrical modelling to stressstrain behaviour of asphaltic concrete layers in flexible pavement// Proceedings of the Fifth International Conference on Bearing Capacity of Roads and Airfields, Trondhiem, Norway, 1998.
15. Park, S. and Lytton R. Effect of Stress-Dependent Modulus and Poisson's Ratio on Structural Responses in Thin Asphalt Pavements// Journal of Transportation Engineering, ASCE, Vol. 130, No. 3, 2004. – 387–394 pp.
16. Park, Seong-Wan. Prediction of Layer Rutting on Pavement Foundations Based on Stress Dependency// Journal of KGS Vol 21. Nr. 7 Septemper 2005. – 345 p.
17. Kenis, W. and Wang, W. Calibrating Mechanistic Flexible Pavement Rutting Models from Full Scale Accelerated Tests// Proceedings of the Eighth International Conference on Asphalt Pavements.- Seattle, Washington, 1997. – 663–672 pp.
18. Baladi, Gilbert Y., Lyles Richard W., Harichandran Ronald S. Asphalt Mix Design: An Innovative Approach// The 67th Annual Meeting of the Transportation Research Board, National Research Council, Washington, D. C., January 11–14, 1988. – 26 p.
19. Romain J.E. Rut Depth Prediction in Asphalt Pavements// Proceeding of Third International Conference on the Structural Design of Asphalt Pavement Vol.1. London –1992. – 205–210 pp.
20. Kiryukhin G.N. Asphalt Mixture Design on the Criteria of Shear and Crack Resistance of the pavement// CD Proceedings of the ISAP 2002 - 9th International. Conference on asphalt pavements Copenhagen, Denmark,. August 17–22, 2002.
21. Latvijas Vides, ģeoloģijas un meteoroloģijas aģentūra: Informatīvie materiāli – meteoroloģija / Internets.-http://www.meteo.lv/public/30116.html
22. Technical Circular TC01-04 Pavement Structure Design Guidelines Ministry of Transportation. Geotechnical, Materials, & Pavement Engineering. British Columbia February 2004. – 18 p.
23. Bačova K. Influence of traffic load on asphalt pavement structure// Proceedings of IIV International Conference Durable and Safe Road Pavement. – Kielce, Poland, 8–9 May 2001. – 187–192 p.

24. Pachowski J., Kraszewski C. Analysis of rules of road pavement destructive loads evaluation under road traffic// Proceedings of IIV International Conference Durable and Safe Road Pavement. - Kielce, Poland, 8–9 May 2001. – 307–315 pp.
25. Ceļu specifikācijas 2010. Apstiprinātas ar 2009. gada 7. septembra Satiksmes Ministrijas rīkojumu Nr. 01.01 - 03/173. Rīga, 2010.
26. Rabbira Gabra. Permanent Deformation Properties of Asphalt Concrete Mixtures. Department of Road end Railway Engineering. - Norwegian University of Science and Technology NTNU Dissertation 2002. – 201 p.
27. Eisenmann J, Himler A. Influence of Wheel Load and Inflation Pressure on the Rutting Effect at Asphalt Pavement – Experiment and Theoretical Investigations// Proceedings of Sixth International Conference on the Structural Design of Asphalt Pavement, Vol. 1. - Ann Arbor, 1987. – 392–403 pp.
28. Rīgas ielu, transportbūvju un satiksmes vadības attīstības koncepcija 2008.–2018. gads, sadaļa 2.5, Rīga, 2007. Pasūtītājs – Rīgas Dome Satiksmes departaments.
29. National Asphalt Pavement Association (NAPA). HMA Pavement Mix Type Selection Guide. Information Series 128. 2002. – 4–5 p.
30. European Asphalt Pavement Association (EAPA). Heavy Duty Surfaces: The Argument For SMA. Netherlands, Breuklen, 1998. – 40 p.
31. National Asphalt Pavement Association (NAPA). Designing and Constructing SMA Mixtures – State of the Practice. Quality Improvement Series 122. 2002. – 47 p.
32. MK noteikumi Nr. 181 Būvizstrādājumu atbilstības novērtēšanas kārtība reglamentētajā sfērā ar grozījumiem – MK noteikumi Nr. 142. no 17.02.2009.
33. Standartizācijas, akreditācijas un metroloģijas centrs SIA: Akreditētās produktu sertifikācijas institūcijas/ internets. – http://www.latak.lv/.
34. LVS EN ISO/IEC 17025:2005 Testēšanas un kalibrēšanas laboratoriju kompetences vispārīgās prasības.
35. Asphalt Institute. The Asphalt Handbook. Manual Series No. 4 (MS-4), 1989. 12–27 pp.