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Section: Roads and Railways

Performance of asphalt pavement structures in test road sections

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Abstract

The experimental pavement test road section program was carried out in 2007–2013 by the Road Research Institute of Vilnius Gediminas technical university. The road of experimental pavement structures was constructed in 2007 and still continues its operation. The road consists of 27 different pavement structures with the same class of pavement structure, but the different type and composition of materials. The experimental pavement structures were laid on the road to the query, one traffic lane is used by loaded traffic and other – by unloaded traffic. This paper presents the first experimental pavement test road section in Lithuania including pavement design, annual measurements, data acquisition and response analysis. Final results after five years of monitoring indicate the performance of typical Lithuania flexible pavement structures influenced by different traffic loads. The total number of ESAL's (100 kN) at the end of December 2013 was 480 000.

Keywords: test road; experimental pavement structures; surfice conditions; ESAL's; bearing capacity.

Nomenclature

AADT	annul average daily traffic (vehicles/day)
IRI	International roughness index (m/km)
FWD	Falling Weight Deflectometer

1. Introduction

Flexible pavements are subjected to traffic and environmental loads that are applied hourly, daily, weekly and monthly over the life cycle of the pavement. The performance of a flexible pavement, over its design or performance life, is directly related to the pavements subjected to cumulative traffic and environmental-induced stresses and strains. The most common problems in the field of road pavement exploitation are the formation of ruts, fatigue, as well as thermal cracking, deterioration, aging and water susceptibility [1].

Rutting due to permanent deformation is considered one of the most serious distress mechanisms in asphalt pavements. It causes traffic hazards by affecting vehicle steering. The factors affecting permanent deformations can be divided into traffic loading, material properties and climatic conditions [2–4]. Under the action of traffic loads, three types of stresses are formed in asphalt pavements: vertical, horizontal (tangential) and shear.

Over the years, a significant amount of effort has been spent on developing methods to objectively evaluate the condition of pavements [5]. The use of asphalt pavement is connected with various exploitation characteristics, which are becoming the main object of contemporary scientific research. The scientists of other countries made an attempt to determine the performance of road pavement structures by constructing and testing them in special test polygons. A lot of experimental investigations were made to model the performance of new materials, their mixes and the combinations of separate pavement structural layers under real conditions [6–7].

In 2003 the Experimental Rut Resistant Sections using asphalt and concrete products were placed on Sullivan Road to Idaho State Line. This section was chosen due to the high use of studded tires and the chronic rutting that occurs in Eastern Washington. It was analysed experimental sections and their performance through year two of their five year evaluation period as an experimental feature [6].

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Based on the literature overview, when modelling asphalt pavement behavior under traffic loads using the non-finite element method, the finite element method and the compound models, also when monitoring the impact of tires and/or loads on road pavements, and having made the analysis of experimental data conformity to the modelling results, it was noticed that the values obtained by computer calculations and field tests were very similar [4].

New mechanistic-empirical (M-E) pavement design methods are therefore being developed in different countries with the main purpose of adequately predicting pavement performance as a function of time. This interest has intensified research in Sweden towards performance of typical road materials under realistic loading conditions [8].

2. Road of experimental pavement structures

In 2007 near Vilnius City in Pagiriai settlement the road of experimental pavement structures was constructed. The parameters of experimental pavement structures road's transverse profile according to (STR 2.06.03:2001) corresponds to the III category (2 traffic lanes, pavement width – 7 m, roadside width – 1 m) and the III class of pavement structure class (ESAL's$_{100}$ of 100 kN = (0.8–3.0) mln). The road of experimental pavement structures, which is in total 710 m long, consists of 23 sectors of 30 m long and one 20 m long sectors. Three sectors additionally are divided into 15 m sections. The pavement structures of various types were constructed at these sectors. The experimental road was constructed on the way to gravel quarry where the empty heavy vehicle are going in and the loaded are going out. In this case, the one traffic lane of the experimental road is loaded much more than the other [9], [12].

Various materials were used for every layer of experimental road sector construction. The frost blanket layer was built from sand (0/4, 0/11); the base layer from crushed dolomite and granite (0/56, 0/32), the mix of 50% crushed granite and 50% sand and gravel, crushed gravel mix, gravel and sand mix and the reclaimed asphalt. The asphalt base layer was built from AC32PS crushed dolomite, gravel, 100% crushed gravel, 50% crushed dolomite and 50% crushed gravel; asphalt binder layer: AC16AS, AC16AS PMB crushed granite 11/16 + crushed dolomite 5/8 + (crushed dolomite and crushed granite 8/11, 50% and 50%); crushed granite 8/11 and 11/16 + crushed gravel (rest of aggregates); crushed dolomite 8/11 and 11/16 + crushed gravel (rest of aggregates); 50% crushed granite + 50% sand; 100% crushed granite; 100% crushed gravel. Asphalt wearing layer: 0/11 AC11VS, SMA11S, SMA11S PMB, Confalt [10].

The thickness and materials for every pavement construction were chosen according to reference pavement structure, which was made from 4 cm asphalt wearing layer AC11VS; 4 cm asphalt binder layer AC16AS; 10 cm asphalt base layer AC32PS; 20 cm base layer – crushed dolomite 0/56; 47 cm frost blanket layer – sand 0/11 [11].

3. Research methodology and equipment

Every year at the test road these measurements are made:

- measurement of traffic flow
- measurement of temperature and moisture in different layers of pavement structure
- measurement of rutting
- measurement of pavement roughness
- measurement of pavement transverse and longitudinal gradients
- visual assessment of pavement distress
- measurement of pavement equivalent modulus with Falling Weight Deflectometer (FWD)
- measurement of pavement deflection with Benkelman Beam
- measurement of skid resistance in asphalt wearing layer with pendulum device.

The traffic flow is measuring consistently after the first car passed after opening of the road. For the classification of traffic flow the induction loops, installed into road pavement, were used as well as the Loop profiler classificatory. All vehicle are classified in to 10 class (from motorcycles, light cars to busses) and were normed under ESAL's$_{100}$ = 100 kN.

Monitoring of pavement structure strength changes raise the need of temperature and moisture sensors installation. The moisture and temperature sensors are installed in four pavement structure sectors in different levels of pavement structure. The data of temperature and moisture is registering consistently since installation of each sensor station.

Table 1. The installation levels of temperature and moisture sensors in pavement structure sectors

Pavement structure No	Depth of temperature sensor, cm									Depth of moisture sensor, cm		
4	–	–	–	–	–	–	100	130	150	100	130	150
12	–	–	–	–	–	–	100	130	150	100	130	150
18	surface	4	8	18	38	85	100	130	150	85	110	–
24	–	–	–	–	–	–	100	130	150	100	130	150

Research of test road surface conditions (roughness of surface (IRI), ruts, transverse and longitudinal gradients of pavement surface, texture of pavement surface) were performed using a mobile laboratory RST-28. The measurements of rut depth, transverse and longitudinal gradients of pavement surface are made every 1 m, 30 values in total for each pavement structure. The average depth of the right rut, the left rut and the maximum clearance was counted at every pavement structure and the average of transverse and longitudinal gradients was counted in each structure section.

Pavement distresses by visual assessment method were defined by "Methodology for asphalt pavements defects detection". This methodology used mostly for cracking evaluation (longitudinal, thermal and structural). Visual measurements are made in each spring and autumn.

The bearing capacity of pavement structures are evaluating by non-destructive method – Falling Weight Deflectometer (FWD). Measuring with FWD the pavement structure deflection from dynamic loading is registering. Measurements are taking in 4 points of each section in the rut of the right wheel and between the ruts.

Measurements of the bearing capacity using the Benkelman beam were performed in 4 points of each section in the rut and between the ruts of both traffic lanes (the loaded and un-loaded). The Benkalman beam is nondescrutive portable test-device, which is able to record the pavement surface deflections occuring under actual truck traffic loading. These deflections are generally generated using with a loaded truck – typically 100 kN on a single axle with dual tires, tire pressure, dimension etc. Measurement is made by placing the tip of the beam between the dual tires and measuring the pavement surface rebound as the truck is moved away.

Pendulum device gives a measure of the friction between a skidding tyre and wet road surface. It provides a practical means of obtaining reliable evidence on which to take the appropriate measures to increase skid resistance. The test is performed according standard EN 13036-4. Measurements were taken on loaded and un-loaded traffic lines in each section every spring and autumn.

4. Research results

4.1. Traffic flow

During the year the traffic volume changes as well [12]. The increases in the traffic volume and loads lead to pavement deteriorations and consequently failure [13].

Annual average daily traffic (AADT) was decreasing since 2008 to 2011, in 2011 it became stabilized and till the end of 2013 it exceeded 6.7%, comparing results with 2008 data in Fig. 1. During 2013 AADT of heavy vehicles exceeded 17.7%, comparing results with 2008 data. Heavy vehicles accounted 24.9% in 2008 of the total traffic intensity, in 2009 – 17.8%, in 2010 – 17.0%, in 2011 – 14.0%, in 2012 – 12.0%, in 2013 – 27.5%.

All the heavy vehicles were rated according to ESAL's$_{100}$ = 100 kN. ESAL's$_{100}$ distribution at the time of the operation in test road is presented in Fig. 2. The test road is used by 75 000 ESAL's$_{100}$ in average annually, the total amount of ESAL's$_{100}$ from the beginning of road use till the end of 2013 was 480 000 ESAL's$_{100}$.

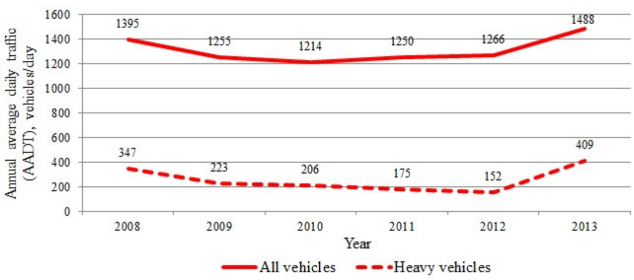

Fig. 1. Average daily vehicle traffic

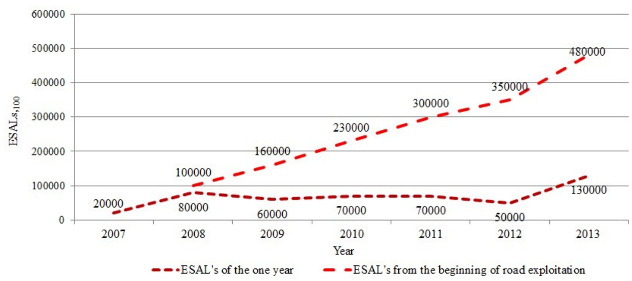

Fig. 2. Distribution of ESAL's$_{100}$ of the experimental pavement structure

4.2. Temperature and moisture distribution in pavement structure

Daily values of average temperatures and moisture in different layers of four experimental pavement structures (No 4; No 12; No 18; No 24;) are monitoring. Monitoring of pavement structure No 18 is started from 2009 and of pavement structures No 4, No 12 and No 24 from July 2013.

The highest temperature of asphalt pavement surface in structure No 18 reached +47.5 °C (in July of 2013), the lowest – –18.96 °C (in January of 2013) in Fig. 3. The temperature range of asphalt pavement surface in 2013 was 66.46 °C. Permafrost in this construction has reached a depth of 150 cm, negative temperature followed up to three months (from the middle of January till the middle of April in 2013), the lowest temperature in this depth reached –0.64 °C.

Analysing the average moisture in the subgrade (at 85 cm and 110 cm depths from pavement surface) from 1th of September 2012 to 31st of December 2013, the highest average moisture is found on the 16th of September 2013 at a 110 cm depth from pavement surface (8.43%); the lowest average moisture – on the 29th of January 2013 at a 85 cm depth from pavement surface (2.96%). Variation of moisture depends on frost depth. The lowest moisture is found when the temperature in subgrade (at a 110 cm depth from pavement surface) reaches the lowest point. Distribution of average moisture and temperature in the subgrade are presented in Fig. 4.

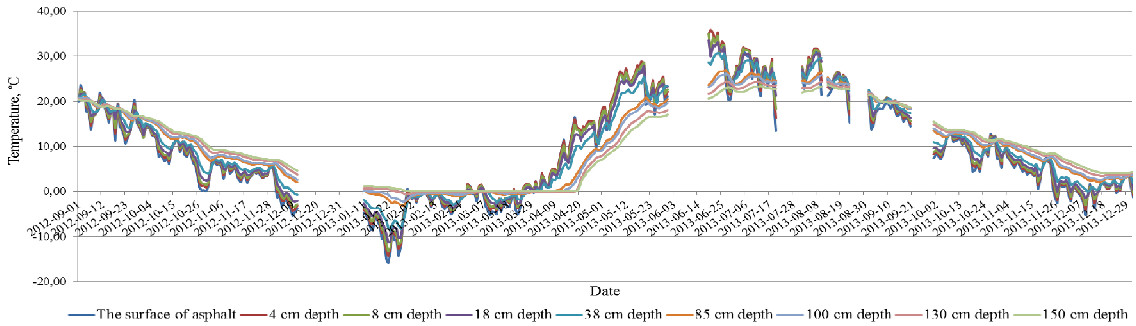

Fig. 3. Daily values of average temperatures in structure No 18

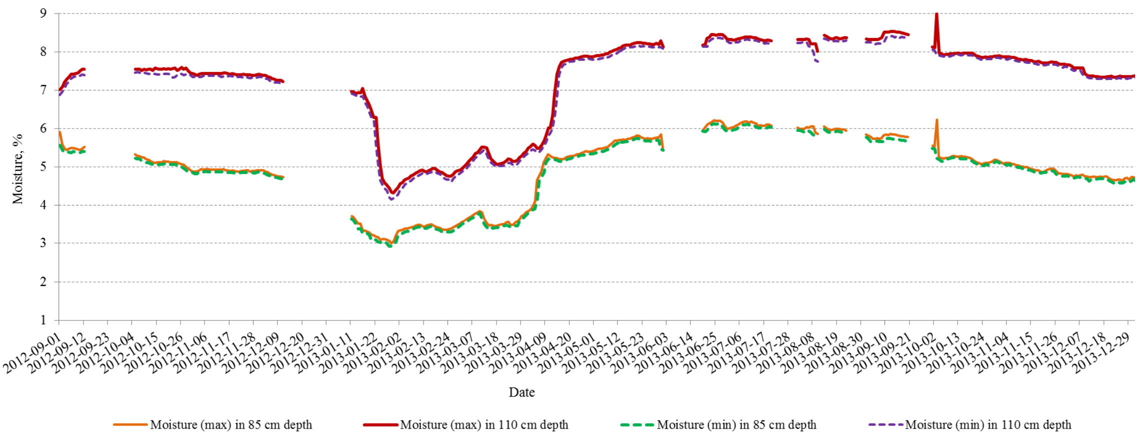

Fig. 4. Daily values of moisture in structure No 18

4.3. Visual assessment of pavement distress

Every year the cracks propagations of experimental pavement structures were measured on a test road section. Measurements of pavement structure cracking were carried out in spring and autumn. During 6 years of experimental road exploitation only longitudinal (Fig. 5b) and transverse cracks (Fig. 5a) were identified. Longitudinal cracks are running parallel to the pavement center lane, while transverse cracks extend across the center lane. The mostly transvers cracking appears in pavement structure with semi rigid wearing layer and in the 1st and last (27th) structures about 0.5 m from the joint line with the old pavement. Longitudinal cracks in a part of structures (No 3, No 5, No 10, No 11, No 12, No 13, No 14, No 22, No 23) are caused by laying technology violation of the requirements, transverse cracks attributed to temperature cracks caused by temperature fluctuations and freeze.

(a) (b)

Fig. 5. Identified cracks (a) transverse cracking in pavement structure with semi rigid wearing layer and (b) longitudinal cracking emerged by construction technology violation

4.4. Results of road surface condition

Results of road surface conditions (roughness of surface (IRI), ruts, texture of pavement surface) is in Fig. 6-8. It was noticed that the measurement data of both transverse and longitudinal gradients in loaded and un-loaded traffic lines during road exploitation was practically the same. The highest roughness of surface (IRI) on loaded traffic line according to results are in structures No 9 (3.2 m/km), No 22 and No 23 (2.5 m/km), No 27 (2.6 m/km), the lowest – in structures No 8 (0.6 m/km), No 15 (0.5 m/km), No 16 (0.6 m/km) (Fig. 6).

To increase the precision of the rut measurements (measurements of rut depth are made every 1 m, 30 values in total for each experimental pavement structure) and to get the reliable analysis results the additional statistical analysis was made. This analysis let to define that the most relevant statistical index is Median. Fig. 7 shows that the highest rut depth values are defined at ESAL's$_{100}$ = 350 000 in the 21st and 24th – 5.7 mm (asphalt wearing layer AC11VS, asphalt binder layer AC16AS, asphalt base layer AC32PS, base layer – crushed dolomite 0/56, frost blanket layer – sand 0/11 and geosynthetics between asphalt binder layer and asphalt base layer in structure 21st and geosynthetics between base layer and frost blanket layer in structure 24th); the lowest rut depth – in the 11th and 12th – 3.4 mm (where polymer-modified bitumen was used for the asphalt wearing layer and also for the asphalt wearing and asphalt binder layers). Comparing measured values with the limit values, the rut depth is not exceeding the latter ones, which is 2.5 cm for regional roads. The measurement of rutting showed that the maximum rut depths vary from 3.4 mm to 5.7 mm dependent on pavement structure type.

Fig. 8 shows that most changes of texture depth, during test road exploitation period, were in structures No 5, No 6 and No 9. During the six year of test road exploitation the texture depth mostly changed in structure No 9 (about 0.47 mm).

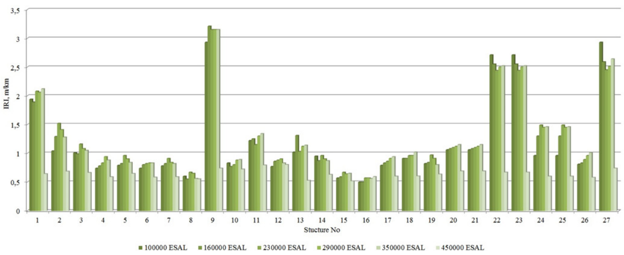

Fig. 6. Distribution of pavement structure IRI (each autumn)

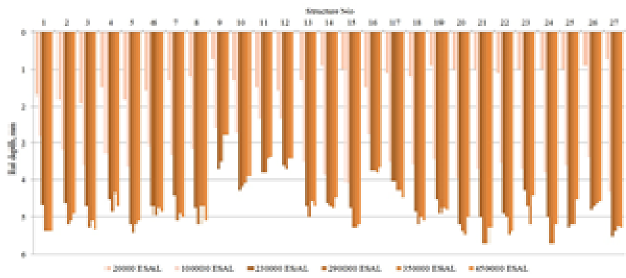

Fig. 7. Distribution of pavement structure rut depth (each autumn)

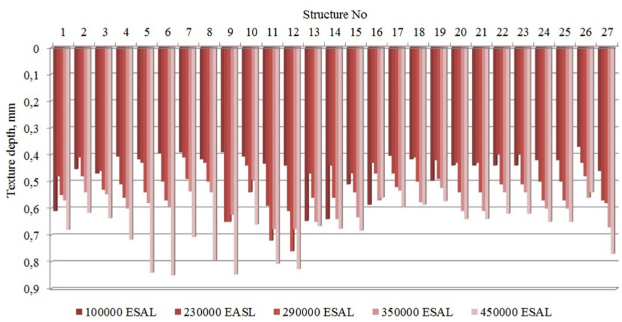

Fig. 8. Distribution of texture of pavement surface (each autumn)

4.5. Results of bearing capacity

The bearing capacity of different experimental pavement structures measured by Falling Weight Deflectometer (FWD) was increasing year by year (from 2007 to 2012). The increase in difference between Eo modulus of different pavement structures are seen after 2009 in Fig. 9. There is a tendency that from 2010 to 2012 Eo modulus differs very little. The highest values of bearing capacity of different structures measured by Benkelman Beam are in 2010, the lowest – in 2007. The values measured with FWD dependent on time vary from 570 MPa to 1100 MPa. The values measured with Benkelman Beam dependent on time vary from 350 MPa to 800 MPa in Fig. 10.

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

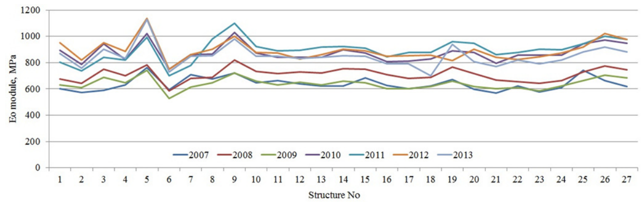

Fig. 9. Distribution of pavement structure E modulus measured with FWD (each autumn)

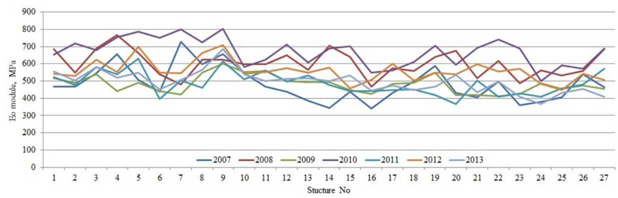

Fig. 10. Distribution of pavement structure E modulus measured with Benkelman beam (each autumn)

4.6. Results of skid resistance

The skid resistance of asphalt wearing layer of the test road are carried out in both traffic lanes – loaded and unloaded each spring and autumn. Measurements of the skid resistance are taken in the rut of right wheel (3 points) and between the ruts (2 points) in each pavement structure traffic line, totally 10 points for each pavement structure and 270 points for all experimental road. Measurements are performing with pendulum test device registering pendulum test values (PTV).

Analysis of the results of loaded traffic line skid resistance shows that values obtained in 2010 and 2011 are more less equal, but in 2012 skid resistance decreased, Fig. 11. The highest PTV values were in 13th, 14th, 21st, and 25th pavement structures, the lowest PTV were in 8th and 11th pavement structures.

Fig. 11. Distribution of pavement structure skid resistance (each autumn)

5. Conclusions

After 6 years of service of the test road the ESAl's$_{100}$ = 480 000 was achieved. Depending on the trends in the growth of heavy traffic it could be stated that in the 10th year of service the road will achieve the ESAl's$_{100}$ value of 0.8 million.

It could be stated that at present permanent deformations start to occur in experimental pavement structures caused not only by material consolidation but also different composition of pavement structures. Currently, the processes of pavement deterioration have been considerably progressing.

The use of geosynthetics in the asphalt base and binder layers of new experimental pavement structures reduces the bearing capacity and increases a probability of rutting.

A type of aggregate in the asphalt binder layer has no effect on the bearing capacity of experimental pavement structure, though significantly affects rutting. The deepest ruts were formed in the experimental pavement structure where crushed gravel was used for asphalt binder layer. The depth of ruts in 100 % granite and the granite with fine sand particles are almost identical.

The experimental pavement structure with a base layer of reclaimed asphalt (RAP) shows a large bearing capacity (the largest of all pavement structures), even larger than that of a semi-rigid pavement structure with Confalt wearing layer. A large bearing capacity is also represented by the pavement structure with 30 cm thick crushed dolomite base layer and the pavement structure with a thicker (14 cm thick) asphalt base layer.

The grading limits of frost blanket layer (04; 0/11) and crushed aggregate base layer (0/32; 0/56) have no effect on the size of bearing capacity. Bearing capacity is affected by the thickness of crushed aggregate base layer, in other words, the bearing capacity of pavement structure must be ensured by a sufficient (optimum) thickness of crushed aggregate base layer and asphalt base layer.

The bearing capacity and rut depth of experimental pavement structures with different type of aggregate used in their base layers differ only very slightly.

One pavement structure could be distinguished where the asphalt base layer is made of 100% of crushed gravel. The bearing capacity of this experimental pavement structure is one of the largest, and the depth of ruts – one of the lowest.

The smallest ruts were formed in the pavement structures where polymer-modified bitumen was used for the asphalt wearing layer and also for the asphalt wearing and asphalt binder layers.

The experimental pavement structure with the asphalt wearing layer SMA 11 S (rut depth – 4.1 mm) is not so resistant to rutting as the pavement structure with SMA 11 S PMB (rut depth – 3.4 mm).

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