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Section: Roads and Railways

Changing of technical and operational road parameters caused by traffic load and climatic factors

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Abstract

Climatic factors and car wheels are the reasons of changes in road condition: deformations of subgrade, cracks, potholes and rut appear, roughness and safety are deteriorating, and the strength of the road structure reduces. In our opinion, cracks in the road structure are of particular importance. The appearance of cracks causes the destruction of the whole road structure during the road operational cycle.

There are many classifications of cracks depending on the reasons of their occurrence as well as repair methods of cracked asphalt pavements. The main reasons that contribute pavement cracking are: 1) horizontal tensile stresses caused by an unfree deformed pavement layers on a continuous and cracked subgrade owing to temperature changes, moving vehicles and the contraction due to the aging of asphalt mixtures; 2) transverse shear stresses in the vertical plane above the crack or joint in the base layer during the vehicles passing.

We have carried out the research of the physical and mechanical properties and thermal properties of asphalt concretes, the research of the deflected mode of the pavement layers from different materials under the temperature and traffic loads using the finite element method. The results of the research on the experimental road in Pagiriai are of particular interest. These researches are original and they were carried out jointly with specialists of the Vilnius Gediminas Technical University.

During the research the relation between the loading modes of the roads and an appearance of pavement damages was established, the most stable to the formation of damages road structures were revealed corresponding to climatic conditions and traffic load conditions. The mechanisms of cracking under current conditions were revealed according to the research results; the recommendations for the upper layer material choice and the choice of activities to repair the damages were formulated. These developments will improve the performance of the road and allow to do crack repair activities more effectively.

Keywords: asphalt concrete pavement; crack; finite element method; repair; strength.

Nomenclature

FEM	finite element method
E	modulus of elasticity (MPa)
P	load (N)
l	support span (m)
f	sample deflection at midspan (m)
b	width of the specimen (m)
h	height of the specimen (m)
R	bending tensile strength (MPa)
P'	breaking load (N)

1. Theoretical research of temperature and traffic load effect on the technical and operational road condition

Asphalt concrete pavements are widely used because of several advantages: a sufficient mechanical strength, damping capacity, manufacturability, maintainability, the possibility of full mechanization of construction works, etc. At the same time, the problem of improving their shear and crack resistance remains relevant.

Climatic conditions in Belarus are unfavorable for effective maintenance due to wet winter and frequent temperature transitions through zero [1]. Overabundance of precipitation leads to the destruction of the pavement material and, if it

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contains corrosive materials, it leads to corrosion of metal bridges and other structures. Air temperature fluctuations cause crack appearance because of temperature stress, solar radiation cause premature aging of the asphalt concrete pavement due to changes in group composition of bitumen, snowdrifts and glazed frost reduce traffic safety.

The impact of the car is the main cause of road pavements destruction. Wheel transmits normal (vertical) and tangential (horizontal) stresses on the road surface. Transport wheel load causes alternate stresses appearance in the upper pavement layer. Pavement deformation in the form of transverse waves may appear with the passage of a wheel, especially at the braking sites at high temperatures. Formation of microcracks at the borders of the rut causes the further development of these cracks in winter. Braking vehicles also can cause slipping of pavement layers relative to the base. Consequently, not only difficult weather conditions during the cold season affects the formation and development of cracks in pavement layers, but also an appearance of strains in summer and an impact of the traffic load [2–3].

Cracks are the most widespread defect of asphalt concrete pavement due to fatigue stresses accumulation by the material and other factors. Cracks affect road service life negatively. The defect is in destruction of pavement continuity, and it appears due to vertical (caused by uneven subsidence of the base) and horizontal deformations under the influence of climatic factors (mainly due to temperature fluctuations), traffic load, or due to mistakes made during construction process. Thermal cracks appearing on the pavement surface and grow downwards as a fatigue cracks in the zone of convex bending of the pavement under the influence of vehicles. Reflected cracks grow from old cracks in base asphalt concrete layer and grow upward.

Crack resistance is the ability of a pavement to resist the formation of cracks under the action of traffic loads and changing climatic conditions (it is one of the pavement reliability characterizing parameters). To evaluate the crack resistance both theoretical and experimental methods can be used. In our opinion the most appropriate theoretical method is the finite element method (FEM) [4–6]. During the research, we considered the effect of external loads on the distribution of temperature and stresses in pavement layers in terms of the probability of occurrence and development of thermal and reflective cracks. Mode of deformation was estimated for sixteen different road structures. Different types of base (solid or cracked basis), presence or absence of cracks in pavement layers, repair activities of different kinds were taking into account.

1.1. Research of physical and mechanical properties of the upper layer's asphalt concrete

Physical and mechanical properties of the most materials for the modeling of the temperature and traffic load impact were set according to the mean values. But the upper layer's asphalt concrete properties were defined experimentally in order to obtain the most reliable modeling results.

The following parameters for the upper layer's asphalt concrete were determined experimentally:

- Modulus of elasticity at a temperature of 0 °C and –20 °C using the dynamic load press (central point load): it is for calculating the tensile stress
- Modulus of elasticity at a temperature of +20 °C using the dynamic load press (central point load): it is for the calculation of the maximum compressive stress
- Tensile strength in bending (to evaluate the crack resistance of asphalt concrete under the influence of temperature and traffic load)
- Thermal conductivity

Method of testing the strength characteristics of asphalt concrete consists in determining of the load required to break the sample. Modulus of elasticity and tensile strength of asphalt concrete were defined after the testing of beams (4×4×12 cm) on elastic supports at the rate of deformation of the sample of 3 mm/min. Modulus of elasticity was determined according to Eqn. (1).

$$E = \frac{P \cdot l^3}{4 \cdot f \cdot b \cdot h^3} \tag{1}$$

Tensile strength in bending was determined according to Eqn. (2).

$$R = \frac{3 \cdot P' \cdot l}{2 \cdot b \cdot h^2} \tag{2}$$

The calculation results for dense asphalt concrete for the upper pavement layer are summarized in Table 1.

Thermal conductivity was defined by laboratory tests on the NETZSCH HFM 436/3/1E LambdaTM device. Cylinders of 7.14 cm diameter and height were made from the same dense asphalt concrete mixture and were used for the test at a temperature of +20 and 0 °C. Measurement results are shown in Table 2.

Table 1. Strength characteristics of dense asphalt concrete

Property evaluation, MPa	Measurement temperature, °C		
	–20	0	+20
Modulus of elasticity	2.48	1.75	0.81
Tensile strength in bending	16.90	9.52	3.59

Table 2. The thermal conductivity of dense asphalt concrete for the upper pavement layer

Thickness, m	Measurement temperature, °C	Time to stationary mode	Thermal conductivity, W/K·m	Measurement accuracy, %
0.732	+20	1 h 27 min	0.658	±0.08
0.730	0	2 h 50 min	0.600	±0.07

The results of laboratory tests were used in setting properties of the upper asphalt concrete layer for the calculations using FEM.

1.2. Research of the mode of deformation of pavement layers under the temperature and traffic load

Five groups of design models were developed for the analysis of mode of deformation under the impact of temperature and traffic load [7]:

- before cracking in the upper asphalt concrete layer on solid or cracked base – 4 types of design models;
- after thermal and reflected cracks appearance in the upper asphalt concrete layer – 2 types of design models;
- after crack repair using different technologies – 6 types of design models;
- after repair and re-crack formation in the upper asphalt concrete layer – 2 types of design models;
- before cracking after road rebuilding with applying of a crack-interrupting layer and asphalt concrete wearing layer – 2 types of design models.

Air temperatures were taken according to data of the Republican Hydro Meteorological Center for Minsk. Traffic impact on the road surface has been modeled as a wheel load from a heavy truck KAMAZ-65117 which has the load of 115 N/axle; this load has been modeled as a pressure of 0.43 MPa to the rectangular area 28×23.8 mm.

A dense asphalt concrete, stone mastic asphalt and recycled asphalt concrete were modeled as an asphalt concrete mixture types for the upper layer.

1.3. The main results of the theoretical research

Use of FEM allowed us evaluating the effectiveness of the most common ways to repair asphalt concrete pavements with cracks: sealing, milling and sealing, milling and sealing with applying of a crack-interrupting layer (geosynthetic material), etc. Values of the maximum tensile stresses are presented in Fig. 1.

Recommendations based on the modeling results are as follows:

- cracks up to 5 mm width should be repaired by sealing with the cold or warm materials
- cracks of the average width (5 to 25 mm) should be repaired by sealing with pre-milling for a width of 10–25 mm and a depth of 15–35 mm depending on the width of the crack opening

It was proved that milling of cracks up to 20 mm width allows reducing the tensile stresses in the upper zone of the upper asphalt concrete layer by 20%.

Research of the upper asphalt concrete layer's mode of deformation using FEM also allows to estimate crack resistance of the pavement based on variation of the thickness of the road structure layers and on selection of road construction materials. We have established that

- using of geosynthetics between structural layers helps to prevent cracking
- the lowest tensile stresses are when applying standard dense asphalt concrete and reclaimed asphalt concrete for making the upper pavement layer

Confirmation of the theoretical research results were carried out on the experimental road in the village Pagiriai, Lithuania. Also the experimental research of the influence of surface cracks on the overall strength of the road structure was carried out on this road of experimental pavement structures.

2. Experimental research of temperature and traffic load influence on technical and operational road condition

Estimation of different road structures condition after five years of service under climatic and traffic load impact were made together with specialists from Road Research Institute of Vilnius Gediminas Technical University.

The results of the annual seasonal measurements of technical and operational performance after five years of service (the amount of accumulated axes ESAl's 320000) were analyzed (Figs 2–4) to find out which construction type from 27 different types is the most crack resistant and durable [8].

According to the diagnostic results the highest defectiveness was 40.0% for structure number 9, 15.2% for structure number 22, 5.7% for structure number 23, 4.3% for structure number 27, 3.33% for structure number 1. Thermal transverse cracks had been formed in two sections (Fig. 5), longitudinal technological cracks – in 6 sections, crack network – on the section with Confalt as the upper pavement layer.

Modulus of elasticity was determined using dynamic load deflectometer FWD DYNATEST 8000, roughness – using laboratory RST-28. These technical and operational parameters, as well as defectiveness and maximum rut depth were four basic parameters for the statistical cluster analysis to identify the most durable and crack resistant road structures.

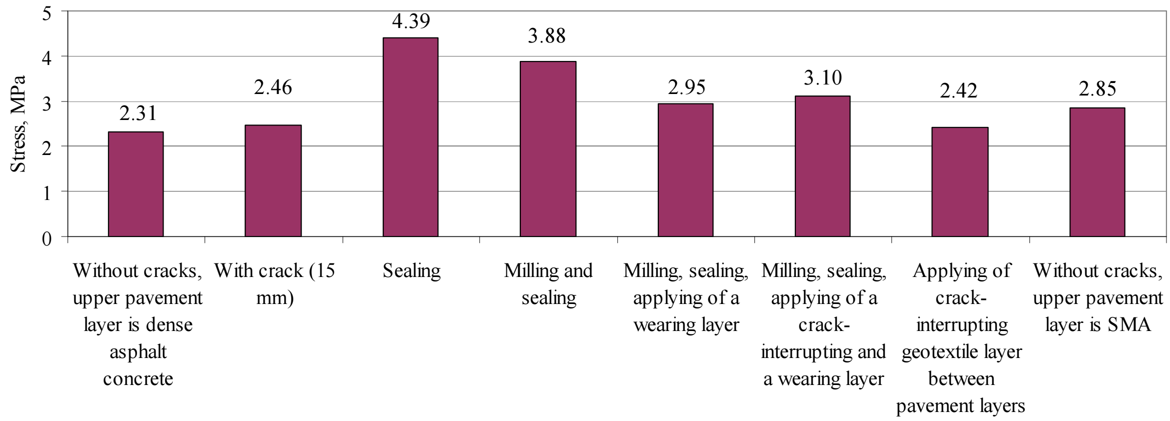

Fig. 1. The maximum tensile stress according to the results of modeling

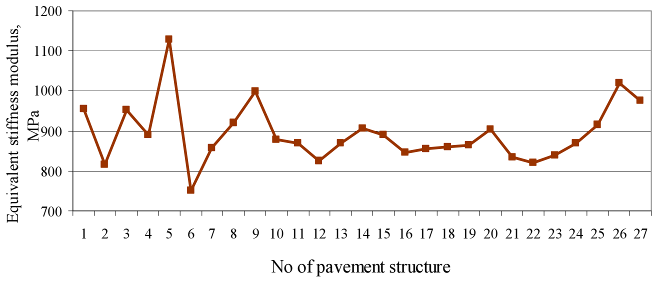

Fig. 2. Modulus of elasticity (dynamic)

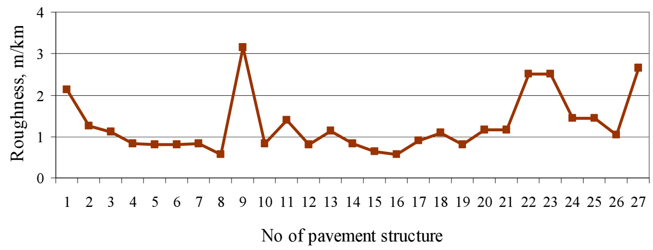

Fig. 3. Roughness according to IRI

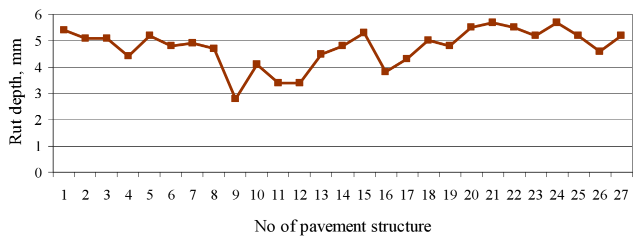

Fig. 4. Maximum rut depth

2.1. Choosing of the most crack resistant and durable road structure

A classification of the road structures of the experimental road were made using cluster analysis to estimate an efficiency of different construction types use in real climatic and traffic load conditions. K-means method of grouping has been applied as a clustering method. According to this method the object should be included to the class the distance to which is minimal. Distance is understood as the Euclidean distance.

Working principle of the method of k-means:

- making of some clustering for data, centers of gravity of the clusters are calculated;
- each point is placed in the closest cluster;

- centers of gravity of the new clusters are calculated;
- steps 2 and 3 are repeated until the clusters do not cease to change (stable configuration).

Data should be standardized before the beginning of the classification process. Elastic modulus, roughness, maximum rut depth and defectiveness were classification parameters.

Fig. 5. Thermal cracks on sections № 1 and № 27

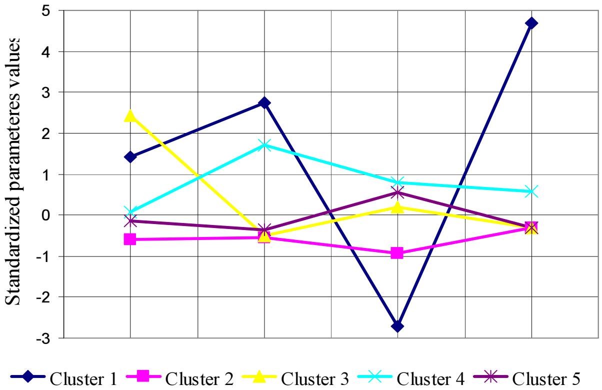

Fig. 6. Average characteristic values graph for each cluster

As a result, 27 road structures were divided into 5 clusters:

- cluster 1 – № 9;
- cluster 2 – № 4, 6, 10, 11, 12, 13, 16, 17;
- cluster 3 – № 5, 26;
- cluster 4 – 1, 22, 23, 27;
- cluster 5 – № 2, 3, 7, 8, 14, 15, 18, 19, 20, 21, 24, 25.

A graph of the mean values for each cluster is shown in Fig. 6.

The road structures of cluster number 3 are the most durable with the lowest defectiveness and rut depth: there are section № 5 (with crushed dolomite and reclaimed asphalt as a base pavement layer) and section № 26 (with crushed dolomite at the base and gravel as a filler for asphalt concrete mixture for the lower pavement layer). The road structures № 1, 22, 23 (with geogrid separating the lower and the middle pavement layers) and № 27 are also proved to be well operating over the past five years.

Both theoretical and experimental researches have shown that cracks of asphalt concrete pavements appear as a result of insufficient structural strength, inconsistencies of the materials used for road construction. It is possible to improve the overall crack resistance of asphalt concrete pavement by using stone mastic asphalt for making the upper pavement layer, and to redistribute the tensile stress (their appearance is the main factor of cracks formation) and fixing the base layers by using the reinforcement geosynthetics layers.

2.2. Program of experimental research "The effect of cracks on the strength parameters of non-rigid pavements"

The second stage of the research at the road of experimental pavement was the investigation of the influence of cracks up to 20 mm width on the overall strength of the road structure. According to the hypothesis, there are "cracks affected zones" where the actual modulus of elasticity of the entire pavement structure is reduced depending on the crack type (thermal or reflected) and crack width (Fig. 7). Determination of the width of these zones would allow making repair more appropriately.

Research has been done by deflectometer DYNATEST FWD 8000 on pavement structures № 1 and № 27 with single transverse cracks with an average width of 6 mm.

The experiment was carried out according to the scheme shown in Fig. 8. The stamp has been placed between the tracks toward the sand pit. Ten measurements were made with breaks between each measurement for 15 minutes to avoid the influence of fatigue effect. For the first measurement deflectometer's stamp was placed directly at the edge of the crack, then according to the scheme of measurements. There were made three measurements for each point.

2.3. The main results of the research of surface cracks effect on the overall strength of the road structure

The elastic modulus values (the average of the ten measurements over the entire section) for structures № 1 and № 27 are presented in Fig. 9. Average modulus of elasticity of the whole structure is 714 MPa for a section № 1 and 824 MPa for a section № 27. The length of a crack affected zone was about 1 m on each side of the crack's axis (Fig. 10).

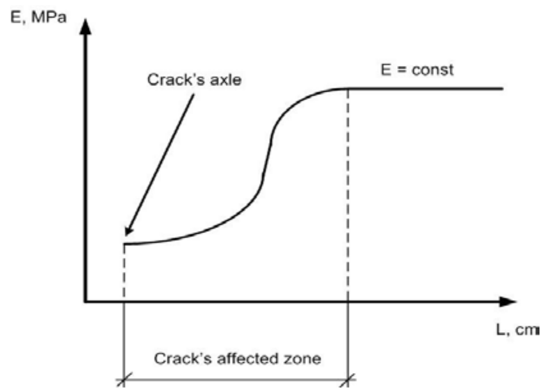

Fig. 7. Cracks affected zone

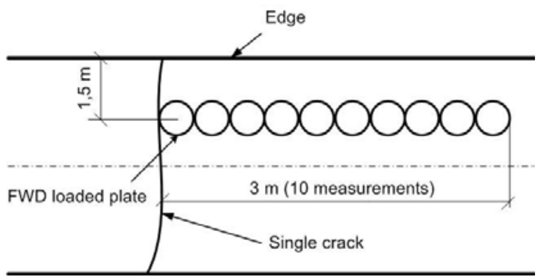

Fig. 8. The scheme of DYNATEST FWD 8000 measurements

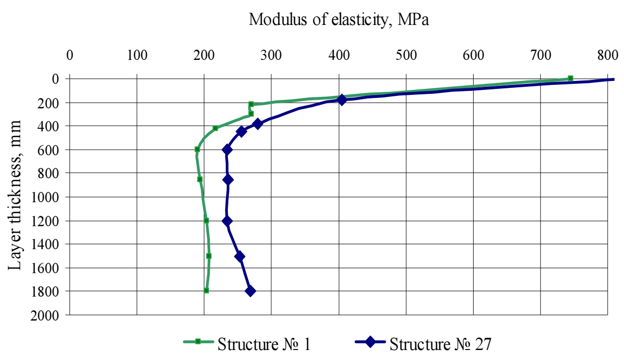

Fig. 9. Modulus of elasticity (average) for the investigated structures

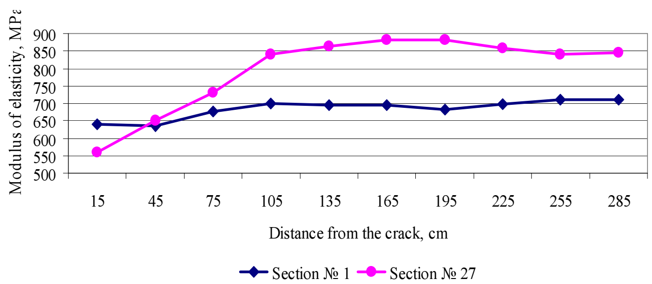

Fig. 10. Crack affected zones according to the experimental research results

Thus, the hypothesis is confirmed: there are crack affected areas within which the overall elastic modulus of the road structure is 1.1–1.3 times lower due to surface transverse cracks of the upper pavement layer.

Conclusions

1. Infiltration of water into the road structure and impact of traffic load during the service life of the road will reduce road bearing capacity and will lead to failure within a few years. Thus, the timely repair of the upper pavement layers with cracks will allow us to avoid further deterioration in the crack zone under the impact of weather, climatic factors and traffic.
2. Crack affected areas can be determined for different crack types and width. There are zones on either side of the crack where the elastic modulus of the road structure is lower. The elastic modulus is 10–30% lower within these areas for road surfaces with upper pavement layer cracks of 20 mm width.
3. Crack resistance during road service life in climatic and traffic load condition of Lithuania and Belarus could be enhanced by using of stone mastic asphalt and geosynthetics (geotextiles, geogrids, etc.) for fixing the structural layers and for redistribution of tensile stresses (which is the main factor of crack appearance and development).

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