VILNIUS GEDIMINAS TECHNICAL UNIVERSITY

Matas BULEVIČIUS

INFLUENCE OF THE PROPERTIES OF FLEXIBLE ROAD PAVEMENT STRUCTURE ON THE SERVICE INDICES OF WEARING COURSES

SUMMARY OF DOCTORAL DISSERTATION

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Scientific Supervisor

Prof Dr Kazys PETKEVIČIUS (Vilnius Gediminas Technical University, Technological Sciences, Civil Engineering – 02T).

The dissertation is being defended at the Council of Scientific Field of Civil Engineering at Vilnius Gediminas Technical University:

Chairman

Prof Dr Donatas ČYGAS (Vilnius Gediminas Technical University, Technological Sciences, Civil Engineering – 02T).

Members:

Prof Dr Habil Juozas ATKOČIŪNAS (Vilnius Gediminas Technical University, Technological Sciences, Civil Engineering – 02T),

Dr Habil Valentinas BALTRŪNAS (Nature research centre, Technological Sciences, Physical Sciences, Geology – 05P),

Assoc Prof Dr Artūras KERŠYS (Kaunas University of Technology, Technological Sciences, Transport Engineering – 03T),

Prof Dr Alfredas LAURINAVIČIUS (Vilnius Gediminas Technical University, Technological Sciences, Civil Engineering – 02T).

Opponents:

Prof Dr Žilvinas BAZARAS (Kaunas University of Technology, Technological Sciences, Transport Engineering – 03T),

Prof Dr Habil Henrikas SIVILEVIČIUS (Vilnius Gediminas Technical University, Technological Sciences, Civil Engineering – 02T).

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Address: Saulėtekio al. 11, LT-10223 Vilnius, Lithuania.

Tel.: +370 5 274 4952, +370 5 274 4956; fax +370 5 270 0112;

e-mail: doktor@ vgtu.lt

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Matas BULEVIČIUS

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Mokslinis vadovas

prof. dr. Kazys PETKEVIČIUS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, statybos inžinerija – 02T).

Disertacija ginama Vilniaus Gedimino technikos universiteto Statybos inžinerijos mokslo krypties taryboje:

Pirmininkas

prof. dr. Donatas ČYGAS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, statybos inžinerija – 02T).

Nariai:

prof. habil. dr. Juozas ATKOČIŪNAS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, statybos inžinerija – 02T),

habil. dr. Valentinas BALTRŪNAS (Gamtos tyrimų centras, fiziniai mokslai, geologija – 05P),

doc. dr. Artūras KERŠYS (Kauno technologijos universitetas, technologijos mokslai, transporto inžinerija – 03T),

prof. dr. Alfredas LAURINAVIČIUS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, statybos inžinerija – 02T).

Oponentai:

prof. dr. Žilvinas BAZARAS (Kauno technologijos universitetas, technologijos mokslai, transporto inžinerija – 03T),

prof. habil. dr. Henrikas SIVILEVIČIUS (Vilniaus Gedimino technikos universitetas, technologijos mokslai, statybos inžinerija – 02T).

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Adresas: Saulėtekio al. 11, LT-10223 Vilnius, Lietuva.
Tel.: (8 5) 274 4952, (8 5) 274 4956; faksas (8 5) 270 0112;
el. paštas doktor@vgtu.lt
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Introduction

Topicality of the problem. Modern research methods of road pavement structures and the currently used computer programs are based on the theory of elasticity. This theory is most widely used in the model of road pavement structures where load transferred by the wheel tyre to the road pavement causes stresses and strains in the pavement structure. In Lithuania, the structural layers of road pavement are selected according to the requirements of the currently valid normative documents, based on the research results of materials used in pavement structural layers and on engineering practice.

Until now, no methodology has been developed which would help to sufficiently accurately assess the required pavement structural strength and to select the optimum thickness of pavement structural layers based on the quality indices of materials used. Today, Lithuania has a validated methodology, described in the Regulations for the Design of Standardized Road Pavement Structures KPT SDK 07, to select pavement structure based on only the design load A and there is no methodology to design pavement structure by determining thickness of the layers based on the quality indices of materials used.

It is especially topical to as accurately as possible predict the change in road pavement condition during its service life by taking into consideration thickness of pavement structural layers and the quality indices of materials used in the layers. Having studied and determined those quality indices there is a possibility to extend the service life of asphalt concrete pavements and to reduce the pavement repair and maintenance costs. It is topical to develop mathematical models which would enable to predict the change in pavement service indices based on the quality indices of pavement structural layers and of materials used in the layers.

Research object. Thicknesses of road pavement structural layers, quality indices of materials used for constructing the layers, traffic volume and loads, asphalt concrete pavement degradation extent D_D, service life, rut depth H_V and asphalt concrete roughness Y_{IRI} according to the International Roughness Index *IRI*.

Aim and tasks of the work. The aim of the work is to develop mathematical models for the prediction of service indices of asphalt concrete pavements of the main roads taking into consideration the structural properties of flexible road pavements and traffic volume. If they are used, the models developed would enable to predict the values of service indices (roughness and rutting) of asphalt concrete pavements after 5 years of their operation. This 5-year pavement service life corresponds to its period of warranty, therefore, the new models could be used for selecting rational flexible pavement structures for the main roads.

The following tasks were solved to achieve the aim of the work:

1. To analyze main factors influencing the service indices of asphalt concrete pavements and to determine their reasons.
2. To determine the interaction between asphalt concrete pavement composition and the quality indices of mixture materials.
3. To study regularities of the change in asphalt concrete pavement roughness and rut depth.
4. To determine the interaction between the quality indices of materials used in pavement structural layers and asphalt concrete pavement roughness and rut depth.
5. To select two rational flexible pavement structures for the main roads (for the different traffic volume) based on the quality indices of materials used in their structural layers.

Research methodology. The following research methods were used in this paper: graphical modelling; mathematical analytical; mathematical statistical; experimental in-situ: measurements of traffic volume, road pavement roughness, rut depth, road pavement degradation extent, thickness of pavement structural layers; experimental laboratory: testing of the quality indices of materials used to lay pavement structural layers.

Scientific novelty

1. For the first time the service indices of asphalt concrete pavement were predicted based on the following parameters of flexible pavement structures of the main roads: the actual thickness of structural layers and the actual quality indices of the materials used in those layers, also the actual traffic volume. The developed models for the prediction of service indices of asphalt concrete pavement (if they are used) allows predicting the pavement quality indices for a 5-year period.
2. The interaction was studied between the quality indices of road construction materials and their effect on road pavement condition.
3. Depending on the traffic volume, a variation in pavement service indices was studied and having analyzed the properties of materials used in pavement structures and the thicknesses of structural layers, mathematical models for the prediction of service indices of asphalt concrete pavement were

developed and rational road pavement structures were presented.

Practical value. The following measures were suggested to predict and improve the service indices of asphalt concrete pavements on the main roads of Lithuania:

1. Mathematical models are suggested for predicting the service indices of flexible road pavement structures. Knowing the quality indices of materials used in pavement structural layers and thickness of the layers, the models (if they are used) allow to select the rational road pavement structure and to extend its service life.
2. After extension of the service life of road pavement structure and the actual time intervals between its repair, the budget funds of the Republic of Lithuanian (from the Road Fund, other), allocated to the construction and repair of roads, will be used more rationally.

Defended propositions

1. Flexible road pavement structures can be reasonably strengthened knowing the quality indices of materials used in their layers. After strengthening of road pavement structures their service life is extended, therefore, having made economic calculations, the economic benefit of pavement strengthening can be determined.
2. Having developed mathematical models for the determination of service indices of asphalt concrete pavement and its structures (based on thickness of the layers and on the quality indices of materials), there is a possibility to predict the values of pavement service indices for a 5-year period.
3. Having predicted the most likely values of pavement service indices, there is a possibility to suggest rational road pavement structures.

The scope of the scientific work. The work consists of general characteristic, 4 chapters, conclusions, list of literature, list of publications and addendum. The total scope of the dissertation is 124 pages, 40 pictures, 18 tables and 4 addenda.

1. Analysis of research in the field of flexible pavement structures with asphalt concrete pavement

Research by the Lithuanian scientists showed that Lithuanian motor roads by their service and strength indices (pavement roughness, rutting, pavement structural strength, etc.) are not able to withstand the continuously growing axle loads. Therefore, after the year 1990, when the volume of improvement, repair and strengthening works decreased, condition of road pavements started to worsen, the amount of potholes and ruts increased and the structural pavement strength (according to the Relative Strength Index SNC) started to decrease.

Many foreign and Lithuanian scientists came to a conclusion that heavy vehicles make not only negative impact on pavement evenness but also press out pavement ruts, and such defects reduce traffic safety.

Some scientists state that the newly laid pavement structure exposed to a continuous impact of heavy vehicles shall be strengthened anew after seven-eight years. The research studies by Lithuanian scientists indicate that the new pavement structures would serve for the projected time if more expensive technologies of pavement strengthening are applied, new materials are used and thicker pavement structural layers are laid. The studies have determined that a proper use of Pavement Management System (PMS) allows saving about 20 % of funds allocated to road maintenance and repair.

Many scientists all over the world affirm that the most important road pavement service index is its roughness which is commonly expressed by the International Roughness Index *IRI*. The condition of roads is good if their pavement roughness Y_{IRI} varies from $Y_{\text{IRI}} \leq 1.5$ to $Y_{\text{IRI}} \leq 2.5$ m/km, and the roads are treated extremely rough if their roughness index $Y_{\text{IRI}} \geq 12$ m/km.

In the West European countries, USA and other post-industrial countries the special systems have been created to manage road pavement condition. The best-known are HDM and MEPDG. Those systems allows predicting pavement condition parameters taking into consideration the modulus of elasticity of pavement structural layers, their thickness, material strength, climatic and environmental conditions, traffic composition, traffic volume, etc.

Review of the scientific works show that the properties of road pavement structure, the change in its service indices and the factors influencing this change were studied by the scientists of many countries. Many of them have proved that the pavement service life depends on its structural strength, the properties of materials used, the impact of heavy vehicles, climatic, environmental and other factors. Also, there are many complex pavement performance prediction models, however, no universal model has been created yet allowing to assess all the factors influencing the service life of road pavement structure.

2. Main principles in the design of flexible road pavement structures

Asphalt concrete pavements and their structures serve under individual (local) conditions which depend on the following factors: the properties of materials used in pavement and its structural layers, the properties of subgrade soil, thickness of the layers and their compaction degree, climatic conditions, vehicle loads and local conditions (groundwater level, local irrigation conditions), on the properties of asphalt concrete pavement and its structure (the pavement service indices: roughness Y_{IRI}, rutting H_V, degradation extent D_D, pavement structural strength, etc.

Fig. 1 shows the model of interaction between the factors influencing the service conditions and properties of asphalt concrete pavement structure. The model studies the main factors having the most significant influence on roughness, rutting, degradation extent, structural strength and condition of asphalt concrete pavement.

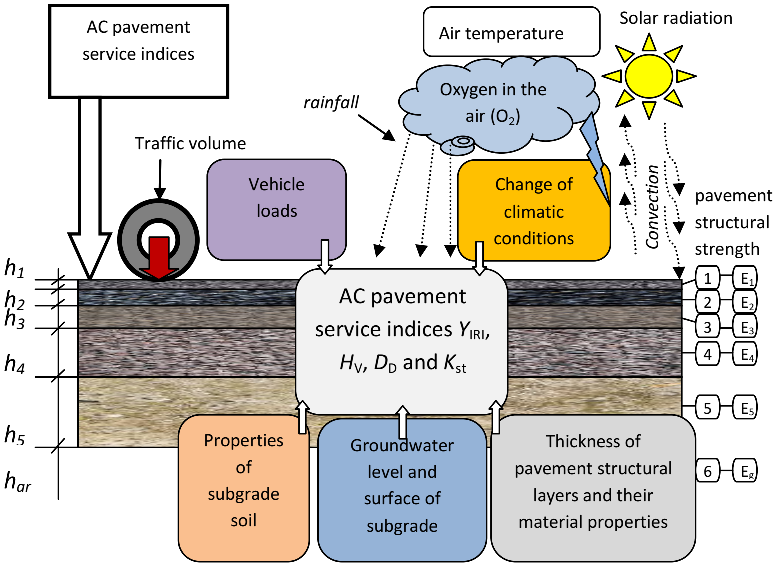


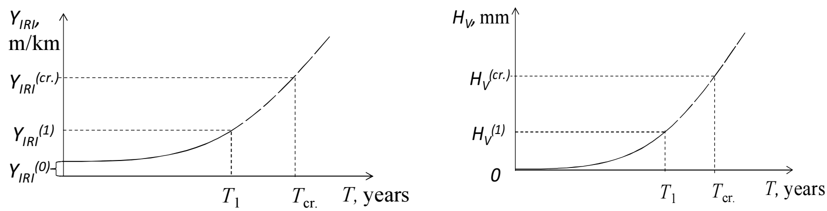
Fig. 1. The model of interaction between the factors influencing the asphalt concrete pavement roughness, rutting, degradation extent, structural strength and condition: 1–5 – pavement structural layers (1 – asphalt concrete wearing course, and 2 – asphalt concrete base courses; 3 – asphalt concrete road base; 4 – crushed stone or gravel sub-base; 5 – frost-blanket course from sand or other material); 6 – subgrade soil; E_1–E_5 and h_1–h_5 – moduli of elasticity and thicknesses of pavement structural layers, respectively; E_{gr} and h_{gr} – modulus of elasticity and equivalent thickness of the active zone of subgrade soil, respectively

The factors given in Fig. 1 are not constant (determinated). A nature of their action is random, thus, their effect values vary randomly (stochastically) without exceeding certain limits. Some of these factors are of periodic nature:

their values repeat periodically during the day (in the morning, in the evening and at night), also in the certain season of the year (in spring, summer, autumn and winter). The mentioned factors are air temperature and solar radiation forming a yearly balance of solar radiation. Another factors vary (within certain limits) completely randomly (the values of the majority of them vary according to the normal law): wind (its speed); amount of precipitation, vehicle loads; quality indices of asphalt concrete pavement and other pavement structural layers (thickness and compaction coefficient), composition of asphalt concrete of the pavement, physical, mechanical and other quality indices; grading of the materials of unbound pavement structural layers, and other quality indices; grading of subgrade soils, moisture and other indices of quality and strength.

Many of the above factors have a complicated effect on the service indices of asphalt concrete pavements (roughness Y_{IRI}, rutting H_v, degradation extent D_D), on pavement structural strength and its condition – very frequently asphalt concrete pavement and its structure are affected by several factors at the same time, therefore, it is very complicated to identify the effect of each of them.

Figs. 2 and 3 gives graphical models of the change in road pavement structure in the course of time (Fig. 2a, b; Fig. 3a, b).

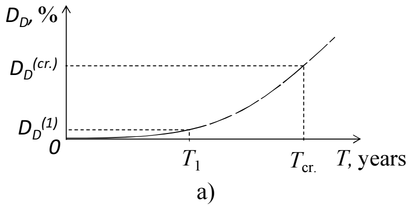


a) b)

Fig. 2. Graphical model of the change in the service indices of road pavement roughness and rutting in the course of time

The service index of road pavement roughness $Y_{IRI}^{(1)}$ varies up to 1.5–1.6 m/km in a shorter than the first time interval between repairs T_1 and does not exceed the critical limit $Y_{IRI}^{(cr)}$. The critical limit of $Y_{IRI}^{(cr)} \geq 2.5$ m/km is exceeded later. The service index of road pavement rutting $H_v^{(1)}$ varies within the limits of 6–7 mm in a shorter than the first time interval between repairs T_1 and does not exceed the critical limit $H_v^{(cr)}$. The critical limit of $H_v^{(cr)} \geq 40$ mm is exceeded later.

The change in the pavement degradation extent $D_D^{(1)}$, given in a graphical model (Fig. 3a), before the time interval between repairs T_1 when $D_D^{(1)}$ is very low (< 3 %) and does not exceed the critical limit $D_D^{(cr)}$. The critical limit of degradation extent $D_D^{(cr)} \geq 16$ % is exceeded later. The structural strength coefficient $K_{st}^{(1)}$ exceeds the critical limit $K_{st}^{(cr)} \leq 0.8$ only after the first time interval between repairs T_1.



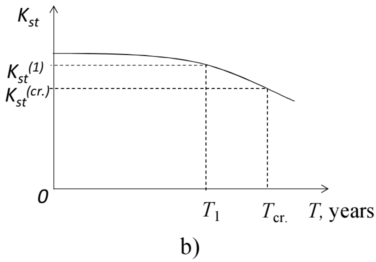


Fig. 3. Graphical model of the change in degradation extent and structural strength coefficient in the course of time

All the above discussed indices according to the tendencies presented vary up to the critical values even before the first time interval between repairs. The worsening of indices is caused by different factors which act as a complex. Under Lithuanian conditions ruts in pavement wearing courses are caused by technological spoilage or improper carcass of asphalt concrete mixture. Under the effect of wheel loads on asphalt concrete wearing course, the shear forces τ decrease, contacts between aggregates worsen, the in-between gaps appear causing initiation of ruts, however, they are not reflected in the underlying non-monolithic layers. Under the effect of the moving wheel the pavement deflects and later comes back to its initial position. Under the cyclic loads of vehicle wheel, as well as aggressive climatic factors, a fatigue of road pavement structure appears. Due to the reduced pavement structural strength the vehicle loads are transferred to the underlying structural layers what results in the decrease of strength in the whole pavement structure. In case if the critical strength index $K_{st}^{(cr)}$ is exceeded, road pavement roughness increases causing pavement defects.

3. Research in the structural layers and their material properties

For the research purposes the main road Kaunas–Marijampolė–Suvalkai (Via Baltica) was selected, the second road by the highest indices of traffic volume, reconstruction of the study sections of which was implemented in 2005. Experimental research was carried out in the laboratory and in-situ. Research methodology consisted of two major parts: testing the quality indices of materials used in road pavement structures in the laboratory and measuring pavement service indices after road reconstruction (Fig. 4).

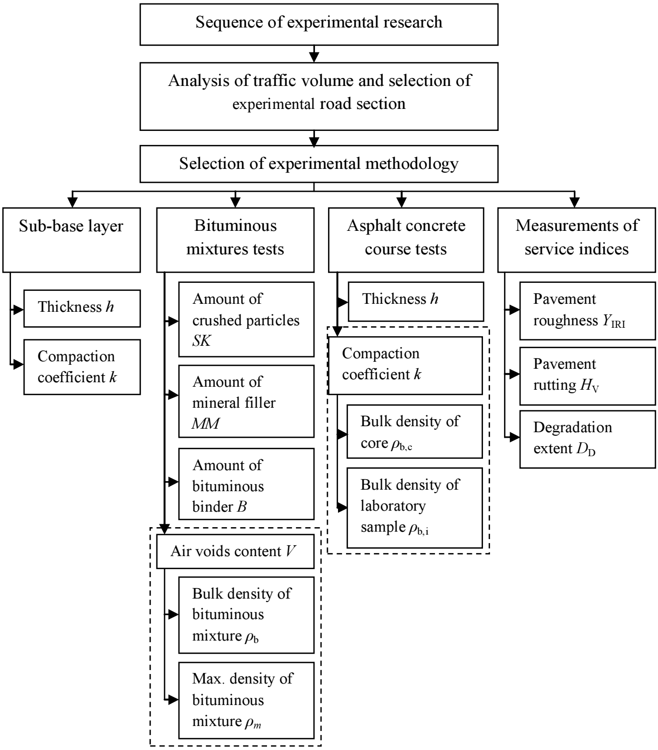


Fig. 4. The scheme of the sequence of experimental research

Having divided the road into sections with the same structural and geometrical pavement characteristics two experimental sections were selected. The length of the first experimental section is 6.8 km, of the second – 4.5 km. The experimental road sections were selected in a way that their Annual Average Daily Traffic (*AADT*) was different, while, the road pavement structures and the materials used were as similar as possible.

In 2007, measurements of pavement roughness Y_{IRI}, rut depth H_{v} and degradation extent D_{D} were carried out on the study road. The in-depth investigations of road pavement condition were carried out using the mobile road surface tester. The samples taken from the road were tested in the laboratory.

The statistical analysis was based on the testing results of asphalt concrete samples (mixtures and cores) taken from the same road sites (20 in the first section and 18 in the second section) and on the measurement results of pavement service indices.

For the obtained research results the inter-correlations were calculated and mathematical models were developed (regression equations of linear dependence 1, 2, 3, 4) for the prediction of road pavement condition (service indices Y_{IRI} and H_V).

Mathematical models for the prediction of service indices of asphalt concrete pavement were developed as follows: (1, 2) for the first experimental road section with the total $AADT \leq 30\,000$ veh./day and (3, 4) for the second experimental road section with the total $AADT \leq 10\,000$ veh./day:

$$Y_{IRI}=0.114\cdot V_S+0.203\cdot B_S+0.446\cdot SK_S+0.014\cdot MM_S+0.267\cdot B/MM_S-0.075\cdot V_{AS}-0.287\cdot B_{AS}-0.151\cdot SK_{AS}+0.023\cdot MM_{AS}-0.321\cdot B/MM_{AS}-0.318\cdot V_{PS}-0.136\cdot B_{PS}+0.085\cdot SK_{PS}-0.321\cdot MM_{PS}+0.068\cdot B/MM_{PS}+0.351\cdot k_S-0.147\cdot k_{AS}+0.093\cdot k_{PS}-0.289\cdot h_S+0.01\cdot h_{AS}+0{,}071\cdot h_{PS}-0.066\cdot h_{Sk}+0.214\cdot h_{\check{S}AS}, \text{ where } R^2=0.69, \quad (1)$$

$$H_V=0.118\cdot V_S-0.078\cdot B_S+0.467\cdot SK_S+0.023\cdot MM_S-0.069\cdot B/MM_S+0.072\cdot V_{AS}+0.117\cdot B_{AS}+0.33\cdot SK_{AS}+0.023\cdot MM_{AS}+0.104\cdot B/MM_{AS}+0.078\cdot V_{PS}+0.212\cdot B_{PS}+0.055\cdot SK_{PS}-0.119\cdot MM_{PS}+0.082\cdot B/MM_{PS}+0.325\cdot k_S+0.042\cdot k_{AS}+0.014\cdot k_{PS}+0.299\cdot h_S+0.017\cdot h_{AS}-0.184\cdot h_{PS}+0.104\cdot h_{Sk}-0.522\cdot h_{\check{S}AS}, \text{ where } R^2=0.83, \quad (2)$$

$$Y_{IRI}=0.134\cdot V_S-0.142\cdot B_S-0.05\cdot SK_S-0.124\cdot MM_S+0.044\cdot B/MM_S+0.117\cdot V_{AS}-0.033\cdot B_{AS}-0.257\cdot SK_{AS}+0.027\cdot MM_{AS}-0.056\cdot B/MM_{AS}+0.303\cdot V_{PS}+0.09\cdot B_{PS}-0.179\cdot SK_{PS}+0.212\cdot MM_{PS}-0.223\cdot B/MM_{PS}-0.126\cdot k_S-0.161\cdot k_{AS}-0.162\cdot k_{PS}+0.175\cdot h_S+0.217\cdot h_{AS}+0.115\cdot h_{PS}+0.533\cdot h_{Sk}+0.409\cdot h_{\check{S}AS}, \text{ where } R^2=0.69, \quad (3)$$

$$H_V=0.458\cdot V_S+0.166\cdot B_S+0.065\cdot SK_S+0.012\cdot MM_S+0.082\cdot B/MM_S-0.144\cdot V_{AS}-0.124\cdot B_{AS}+0.308\cdot SK_{AS}+0.056\cdot MM_{AS}-0.256\cdot B/MM_{AS}+0.277\cdot V_{PS}+0.326\cdot B_{PS}-0.289\cdot SK_{PS}+0.37\cdot MM_{PS}-0.154\cdot B/MM_{PS}-0.24\cdot k_S+0.022\cdot k_A-0.011\cdot k_{PS}-0.189\cdot h_S+0.24\cdot h_{AS}-0.123\cdot h_{PS}+0.07\cdot h_{Sk}-0.08\cdot h_{\check{S}AS}, \text{ where } R^2=0.85, \quad (4)$$

where Y_{IRI} – International Roughness Index, m/km, H_V – rut depth of the road pavement, mm, V_S, V_{AS}, V_{PS} – the index of air voids content in the mixture of respective asphalt concrete layer (S – asphalt concrete wearing course, AS – asphalt concrete base course, PS – asphalt concrete road base), B_S, B_{AS}, B_{PS} – binder content in the mixture of respective asphalt concrete layer, SK_S, SK_{AS}, SK_{PS} – the amount of retained aggregate on the 2 mm diameter sieve of respective asphalt concrete layer, MM_S, MM_{AS}, MM_{PS} – the amount of aggregate passing through the 0.09 mm diameter sieve of respective asphalt concrete layer, B/MM_S, B/MM_{AS}, B/MM_{PS} – the ratio of binder and mineral filler in asphalt concrete mixture of respective asphalt concrete layer, k_S, k_{AS}, k_{PS} – compaction index of respective asphalt concrete layer, h_S, h_{AS}, h_{PS}, h_{Sk}, $h_{\check{S}AS}$ – thickness of respective pavement structural layer.

Having implemented statistical calculations of the study indices of road pavement structure a schematic model for the sequence of predicting the road pavement service indices was developed (Fig. 5).

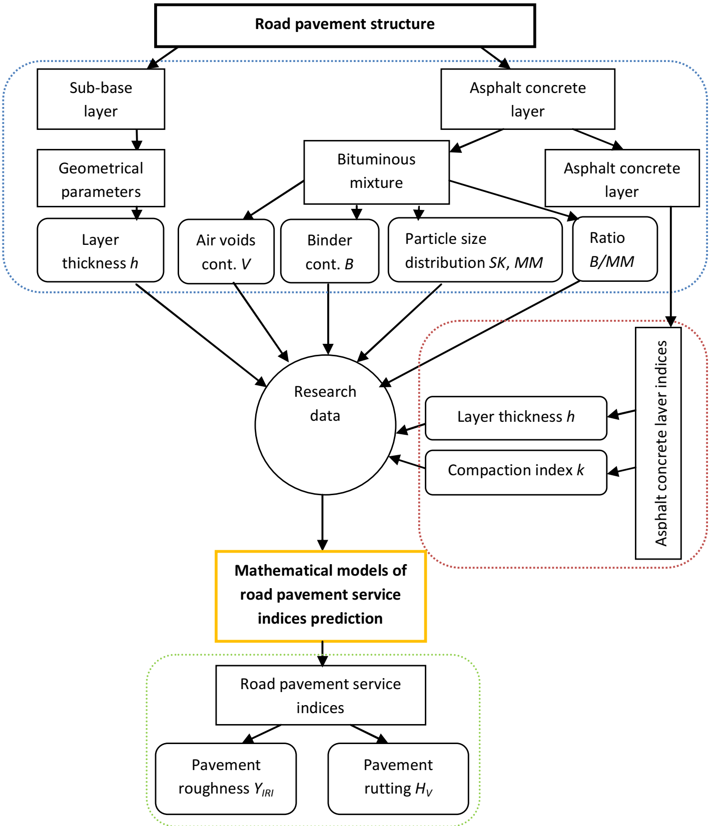


Fig. 5. Schematic model for the sequence of predicting the road pavement service indices

In the developed mathematical models the values of determination coefficients R^2 vary from $R^2 = 0.69$ to $R^2 = 0.85$.

4. Analysis and evaluation of the properties of structural layers, their materials, and selection of rational structures

Coefficient of determination ($R^2 = 1$), obtained during regression analysis, enabled to use the standardized regression coefficients as sensitivity indices.

Fig. 6 gives the calculated sensitivity indices of Y_{IRI} equation for the first and second experimental road sections. Fig. 7 gives the calculated sensitivity indices of H_V equation for the first and second experimental road sections.

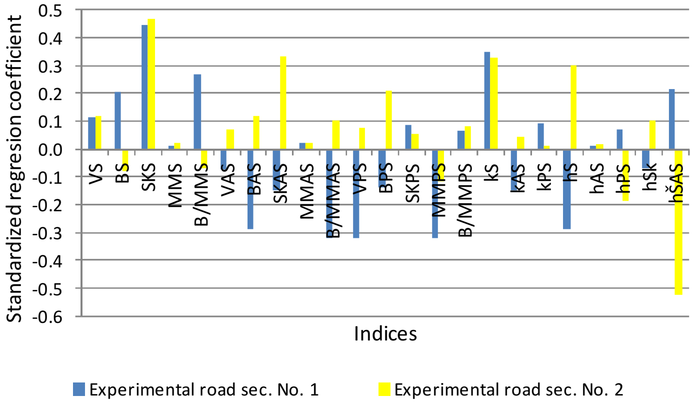


Fig. 6. Results of probabilistic sensitivity analysis of pavement roughness modelling for the first and second experimental road sections

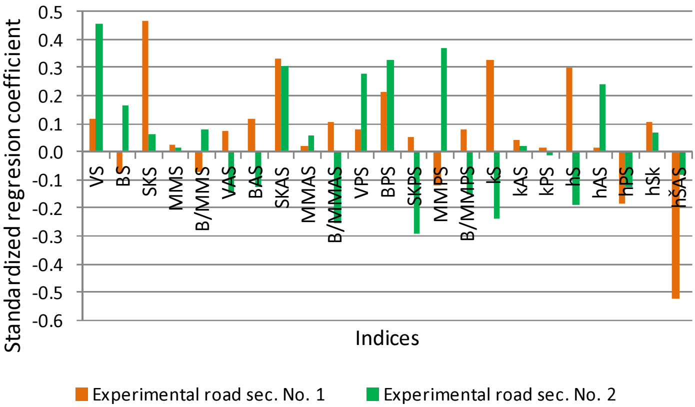


Fig. 7. Results of probabilistic sensitivity analysis of rut depth of the road pavement modelling for the first and second experimental road sections

Having calculated the uncertainty of mathematical models, the limits were determined where the values of pavement quality indices vary. When modelling rational road pavement structure the values of predicted road pavement indices were determined at a reliability degree α = 0.05.

Uncertainty analysis for the results of developed equations (1, 2, 3, 4) was carried out in a probability technique with the help of Monte Carlo method. For the analysis, in a random order 1000 index values were selected from their probability distribution and modelling of the generated values was carried out.

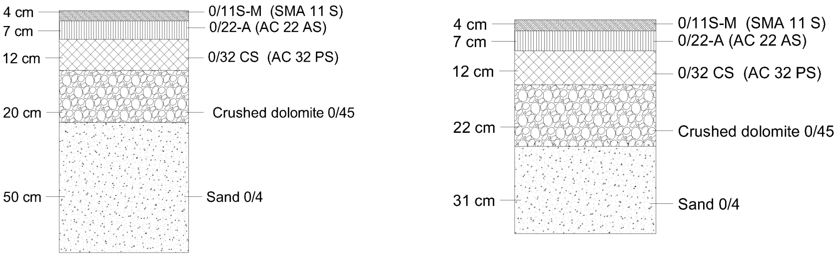
Based on the determined cumulative functions (presented in the dissertation) it could be stated that according to the calculated mathematical models for the prediction of road pavement service indices, at a 0.95 reliability the index Y_{IRI} will get the value $Y_{IRI} \leq 1.6$ m/km, and the index $H\text{v} \leq 7$ mm in the first experimental road section. Correspondingly, it could be stated that at a 0.95 reliability the index Y_{IRI} will get the value $Y_{IRI} \leq 1.6$ m/km, and the index $H\text{v} \leq 4$ mm in the second experimental road section.

Having calculated the costs of structures with the generated values of the indices of road pavement structures and having grouped them by the lowest price, the rational pavement structures were obtained that are given in Table 1.

Table 1. Statistically calculated rational road pavement structures

Experimental road section	The first		The second		Design values
AADT, veh./day	≤ 30 000		≤ 10 000		
Index	Y_{IRI}	H_V	Y_{IRI}	H_V	
Pavement structural layer	Thickness of pavement structural layer, cm				
SMA 11 S	4	4	4	4	4
AC 22 AS	7	7	7	7	8
AC 32 PS	12	12	12	12	14
crushed dolomite 0/45	20	16	22	22	30
sand 0/4	50	49	31	31	40
cost, Lt excluding VAT/m^2	234.68	227.16	231.84	231.84	261.93

The modelled rational road pavement structures for the main roads are given in Fig. 8: (a) for the main roads with the $AADT \leq 30\,000$ veh./day, (b) for the main roads with the $AADT \leq 10\,000$ veh./day.



a) b)

Fig. 8. The modelled rational road pavement structures for the main roads

The results obtained show that the suggested rational road pavement structures guarantee the sufficiently good and comfortable traffic conditions after 5 years of pavement service life.

General conclusions

1. When predicting the values of service indices pavement roughness and rut depth of asphalt concrete pavements of the main roads (for a five-year period) the use of mathematical models (regression dependences) is suggested to predict the mentioned indices. The following coefficients of determination were obtained – 0.69 for the determination of road pavement roughness and 0.83 for the determination of pavement rutting, where annual average daily traffic is not greater than 30 000 veh./day, 0.69 for the determination of road pavement roughness and 0.85 for the determination of pavement rutting where annual average daily traffic is not greater than 10 000 veh./day.
2. Sensitivity analysis of the linear regression equations for the prediction of service indices road pavement roughness and pavement rutting of asphalt concrete pavements showed that:
   - uncertainty of the pavement roughness index for the first experimental road section can be most efficiently reduced by revising the uncertainty value of retained aggregate of the asphalt concrete wearing course on the 2 mm diameter sieve and thickness of the wearing course of asphalt concrete pavement, and uncertainty of the pavement rut depth index – by revising the uncertainty value of parameters retained aggregate of the asphalt concrete wearing course on the 2 mm diameter sieve and thickness of the frost-blanket course;
   - uncertainty of the pavement roughness index for the second experimental road section can be most efficiently reduced by revising the uncertainty value of parameters thickness of the aggregate base and

the frost-blanket course, respectively, and uncertainty of the pavement rut depth index – by reducing uncertainty of the voids content index of the wearing course of asphalt concrete pavement.

3. Based on the developed mathematical models for the prediction of service indices of asphalt concrete pavement in case where annual average daily traffic is not greater than 10 000 veh./day the pavement roughness index will get the value not greater than 1.6 m/km and the rut depth index – the value not greater than 4 mm at a 95 % reliability, in case where annual average daily traffic is not greater than 30 000 veh./day the pavement roughness index will get the value not greater than 1.6 m/km and the pavement rut depth index – the value not greater 7 mm, at a 95 % reliability.

4. Having made calculations two rational road pavement structures were selected:

- for the main roads with annual average daily traffic not greater than 10 000 veh./day after 5 years of service life the asphalt concrete pavement roughness index will be not greater than 1.6 m/km, and the rutting index – not greater than 4 mm, at a 95 % reliability;
- for the main roads with annual average daily traffic not greater than 30 000 veh./day after 5 years of service life the asphalt concrete pavement roughness index will be not greater than 1.6 m/km, and the rutting index – not greater than 7 mm, at a 95 % reliability.

5. Having calculated construction costs of the selected rational road pavement structures for the main roads, it was determined that:

- construction cost of the selected rational road pavement structure where annual average daily traffic is not greater than 10 000 veh./day is 11.5 % lower compared to the construction cost of the design road pavement structure;
- construction cost of the selected rational road pavement structure where annual average daily traffic is not greater than 30 000 veh./day is 10.4 % lower compared to the construction cost of the design road pavement structure.

6. With the help of uncertainty analysis the following limit values of pavement roughness and pavement rutting were determined: representatively not greater than 1.6 m/km, and 4 mm, where annual average daily traffic is not greater than 10 000 veh./day; as well as representatively not greater than 1.6 m/km, and 7 mm, where annual average daily traffic is not greater than 30 000 veh./day, at a 95 % reliability. This critical road pavement roughness value (1.6) may be used for first (highest) supervisory level. The results obtained show that the suggested rational road pavement structures guarantee

the sufficiently good and comfortable traffic conditions after 5 years of pavement service life.

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About the author

Matas Bulevičius was born on 17 June 1981 in Jonava.

In 2003, he received the Bachelor's degree in Civil Engineering at Vilnius Gediminas Technical University, Faculty of Environmental Engineering. In 2005, he received the Master's degree in Civil Engineering at Vilnius Gediminas Technical University, Faculty of Environmental Engineering. In 2003–2011, Matas Bulevičius worked in JSC Problematika, in Concrete and Soil Testing Division of the Testing Laboratory. At present he takes a position of the Head of Testing Laboratory of JSC Problematika.

KELIŲ TAMPRIOSIOS DANGOS KONSTRUKCIJŲ SAVYBIŲ ĮTAKA JŲ VIRŠUTINIO SLUOKSNIO EKSPLOATACINIAMS RODIKLIAMS

Mokslo problemos aktualumas. Šiuolaikiniai kelių dangos konstrukcijų (KDK) tyrimo metodai ir taikomos kompiuterinės programos pagrįstos tamprumo teorija. Ši teorija plačiausiai taikoma kelių dangos konstrukcijos modelyje, kai nuo automobilio rato perduodama apkrova kelių dangai dangos konstrukcijoje sukelia įtempius ir deformacijas. Lietuvoje kelių dangos konstrukcijų sluoksniai parenkami laikantis šalyje naudojamų norminių dokumentų reikalavimų ir naudojantis KDK sluoksnių medžiagų tyrimų rezultatais bei sukaupta inžinerine patirtimi.

Iki šiol dar nesukurta metodika, kurią taikant būtų galima gana tiksliai įvertinti reikiamą KDK stiprį ir parinkti optimalius KDK sluoksnių storius, įvertinus naudojamų jiems įrengti medžiagų kokybės rodiklius. Lietuvoje pastaraisiais metais norminiu dokumentu „Automobilių kelių standartizuotų dangų konstrukcijų projektavimo taisyklės KPT SDK 07“ yra įteisinta metodika tik KDK pagal projektinę apkrovą A parinkti, o reikiamos metodikos KDK projektuoti, nustatant sluoksnių storius pagal šių sluoksnių medžiagų kokybės rodiklius, nėra.

Ypač aktualu kuo tiksliau prognozuoti kelių dangos būklės kitėjimą jos funkcionavimo laikotarpio metu, įvertinant kelių dangos konstrukcijos sluoksnių storius ir šių sluoksnių medžiagų kokybės rodiklius. Ištyrus ir įvertinus šiuos kokybės rodiklius, siektina prailginti kelių asfaltbetoninės dangos funkcionavimo trukmę ir sumažinti KD remontų ir priežiūros sąnaudas. Aktualu sudaryti matematinius modelius, kurie leistų prognozuoti kelių dangos eksploatacinių rodiklių kitėjimą pagal KDK sluoksnių ir jų medžiagų kokybės rodiklius.

Tyrimų objektas. Tyrimų objektas: kelių dangos konstrukcijų sluoksnių rodikliai, šiems sluoksniams įrengti naudojamų medžiagų kokybės rodikliai, priemonių eismo intensyvumas ir apkrovos, asfaltinės dangos suirties mastas

D_D, funkcionavimo trukmė, provėžų gylis H_V ir asfaltinės dangos lygumas pagal tarptautinį rodiklį IRI – Y_{IRI}.

Darbo tikslas ir uždaviniai. Parengti magistralinių automobilių kelių asfaltbetonio dangos eksploatacinių rodiklių prognozės matematinius modelius, atsižvelgiant į tampriosios dangos konstrukcijos savybes ir transporto priemonių eismo intensyvumą. Darbo tikslui pasiekti buvo sprendžiami šie uždaviniai:

1. Išanalizuoti automobilių kelių asfaltbetoninės (AB) dangos eksploatacinius rodiklius veikiančius svarbiausius veiksnius ir jų susidarymo priežastis.
2. Atlikus tyrimus, nustatyti AB dangos komponentinės sudėties ir AB mišinių medžiagų kokybės rodiklių sietį.
3. Ištirti AB dangos lygumo ir provėžų gylio kitėjimo dėsningumus.
4. Nustatyti dangos AB, kitų KDK sluoksnių medžiagų kokybės rodiklių ir AB dangos lygumo bei provėžų gylio sietį.
5. Parinkti dvi racionalias magistralinių kelių tampriosios dangos konstrukcijas (skirtingam transporto priemonių (TP) eismui) įvertinus jos sluoksniams naudojamų medžiagų kokybės rodiklius.

Tyrimų metodika. Darbe taikyti šie tyrimų metodai: grafinio modeliavimo; matematiniai analiziniai; matematinės statistikos; eksperimentiniai natūriniai automobilių keliuose: transporto priemonių eismo intensyvumo matavimo, kelių dangos lygumo matavimo, provėžų gylio matavimo, kelių dangos suirties masto matavimo, dangos konstrukcinių sluoksnių storio nustatymo; eksperimentiniai laboratoriniai: KDK sluoksniams įrengti naudojamų medžiagų kokybės rodiklių tyrimo.

Mokslinis naujumas

1. Pirmą kartą asfaltbetonio dangos eksploataciniai rodikliai prognozuojami įvertinus šiuos magistralinių kelių tampriosios dangos konstrukcijos parametrus: konstrukcinių sluoksnių faktinius storius ir šių sluoksnių medžiagų faktinius kokybės rodiklius, taip pat transporto priemonių (TP) faktinį eismo intensyvumą. Gauti asfaltbetoninės dangos eksploatacinių rodiklių matematiniai modeliai leidžia prognozuoti kelio dangos viršutinio sluoksnio eksploatacinius rodiklius penkerių metų laikotarpiui.
2. Ištirta kelių tiesyboje naudojamų medžiagų kokybės rodiklių tarpusavio sąveika ir jų įtaka kelių dangos būklei.
3. Įvertinus TP eismo intensyvumą, ištirtas kelių dangos eksploatacinių rodiklių kitėjimas, o išanalizavus esamas kelių dangos konstrukcijų medžiagų

savybes ir sluoksnių storius, pateikti kelių dangos eksploatacinių rodiklių prognozės matematiniai modeliai ir pateiktos racionalios kelių dangos konstrukcijos.

Praktinė vertė. Pasiūlytos šios priemonės Lietuvos magistralinių kelių AB dangos eksploataciniams rodikliams numatyti ir pagerinti:

1. Pasiūlyti matematiniai modeliai tampriosios kelių dangos konstrukcijos (KDK) viršutinio sluoksnio eksploatacinių rodiklių prognozei atlikti. Šie matematiniai modeliai (juos taikant) leidžia, žinant KDK sluoksnių medžiagų kokybės rodiklius ir sluoksnių storius, parinkti racionalias kelių dangos konstrukcijas ir prailginti KDK funkcionavimo trukmę.
2. Prailginus KDK funkcionavimo trukmę ir jos faktinius tarpremontinius laikotarpius, bus racionaliau panaudojamos Lietuvos Respublikos biudžeto (kelių fondo ir kitos) lėšos, skirtos automobilių kelių tiesybos ir remonto darbams.

Ginamieji teiginiai

1. Tampriosios kelių dangos konstrukcijas motyvuotai sustiprinti galima žinant jų sluoksnių medžiagų kokybės rodiklius. Sustiprinus kelių dangos konstrukcijas, pailgėja jų funkcionavimo trukmė, todėl, atlikus ekonominius skaičiavimus, galima nustatyti KDK sustiprinimo ekonominę naudą.
2. Parengus kelių AB dangos ir jos konstrukcijų eksploatacinių rodiklių nustatymo (pagal sluoksnių storius ir jų medžiagų kokybės rodiklius) matematinius modelius, galima numatyti dangos eksploatacinių rodiklių vertes prognozuojamam penkerių metų laikotarpiui.
3. Numačius kelių AB dangos eksploatacinių rodiklių labiausiai tikėtinas vertes, galima pasiūlyti racionalias kelių dangos konstrukcijas.

Darbo apimtis. Darbą sudaro įvadas, 4 skyriai, išvados, literatūros sąrašas, publikacijų sąrašas ir priedai. Bendra disertacijos apimtis – 124 puslapiai, 40 paveikslų, 18 lentelių ir 4 priedai.

Pirmajame skyriuje išnagrinėti įvairių šalių mokslininkų atlikti automobilių kelių asfaltinės dangos bei jos konstrukcijos eksploatacinių rodiklių ir jų funkcionavimo trukmės tyrimai.

Antrajame skyriuje pateikti teoriniai tyrimai AB dangos bei jos konstrukcijos funkcionavimo salygoms, eksploataciniams rodikliams ir KDK sluoksnių medžiagų savybėms nustatyti.

Trečiajame skyriuje pateikta atliktų tyrimų metodika, AB dangos eksploatacinių rodiklių bei KDK sluoksnių medžiagų savybių bei jų sieties tyrimai. Taip pat pateikti KDK sluoksniams naudojamų medžiagų fizinių bei mechaninių ir geometrinių rodiklių tyrimai.

Ketvirtajame skyriuje pasiūlyti magistralinių automobilių kelių asfaltbetonio dangos eksploatacinių rodiklių prognozės (penkerių metų) laikotarpiui matematiniai modeliai. Parinktos dvi racionalios magistralinių kelių tampriosios dangos konstrukcijos TP eismo intensyvumui iki 10 000 aut/parą ir TP eismo intensyvumui iki 30 000 aut/parą.

Bendrosios išvados

1. Magistralinių kelių asfaltinės dangos eksploatacinių rodiklių (dangos lygumo ir vėžėtumo) vertėms (penkerių metų laikotarpiui) prognozei atlikti pasiūlyti šių rodiklių prognozės matematiniai modeliai (regresijos priklausomybės). Gauti šie priklausomybių determinacijos koeficientai: 0,69, vertinant kelių dangos lygumą ir 0,83, vertinant kelio dangos vėžėtumą, kai vidutinis metinis paros eismo intensyvumas neviršija 30 000 aut./parą; 0,69, vertinant kelių dangos lygumą, ir 0,85, vertinant kelio dangos vėžėtumą, kai vidutinis metinis paros eismo intensyvumas neviršija 10 000 aut./parą.
2. Atlikus asfaltinės dangos eksploatacinių rodiklių – dangos lygumo ir vėžėtumo, prognozės tiesinių regresinių lygčių jautrumo analizę, gavome, kad:
   - pirmojo kelio ruožo dangos lygumo neapibrėžtį efektyviausiai galima sumažinti, tikslinant: viršutinio sluoksnio asfaltbetonio mineralinės medžiagos likučio ant 2 mm skersmens akelių sieto kiekio ir asfaltbetonio dangos viršutinio sluoksnio storio neapibrėžties įvertį, o kelio dangos vėžės gylio rodiklio rezultatų neapibrėžtį – tikslinant viršutinio sluoksnio asfaltbetonio mineralinės medžiagos likučio ant 2 mm skersmens akelių sieto kiekio ir apsauginio šalčiui atsparaus sluoksnio storio neapibrėžties įvertį;
   - antrojo kelio ruožo dangos lygumo neapibrėžtį efektyviausiai galima sumažinti tikslinant skaldos pagrindo ir apsauginio šalčiui atsparaus sluoksnio storių neapibrėžties įvertį, o kelio dangos vėžės gylio rodiklio neapibrėžtį – mažinant asfaltbetonio viršutinio sluoksnio tuštymių kiekio rodiklio neapibrėžtį.
3. Pagal sudarytus kelių asfaltinės dangos eksploatacinių rodiklių prognozės matematinius modelius (po penkerių kelių dangos konstrukcijos eksploatavimo metų), esant vidutiniam metiniam paros eismo intensyvumui ne didesniam kaip 10 000 aut./parą, dangos lygumo rodiklis įgis vertę ne didesnę, kaip 1,6 m/km, o dangos vėžės gylio rodiklis – vertę ne didesnę, kaip 4 mm, esant 95 % tikimybei, esant vidutiniam metiniam paros eismo intensyvumui ne didesniam kaip 30 000 aut./parą, dangos lygumo rodiklis įgis vertę ne didesnę, kaip 1,6 m/km, o rodiklis H_V – vertę ne didesnę, kaip 7 mm, esant 95 % tikimybei.

4. Atlikus skaičiavimus parinktos dvi racionalios kelio dangos konstrukcijos, kurios garantuoja:

- magistraliniams keliams, kurių vidutinis metinis paros eismo intensyvumas neviršija 10 000 aut./parą, po penkerių eksploatavimo metų, asfaltinės dangos lygumo rodiklis bus ne didesnis, kaip 1,6 m/km, o vėžėtumo rodiklis ne didesnis, kaip 4 mm, esant 95 % tikimybei;
- magistraliniams keliams, kurių vidutinis metinis paros eismo intensyvumas neviršija 30 000 aut./parą, po penkerių eksploatavimo metų, asfaltinės dangos lygumo rodiklis bus ne didesnis, kaip 1,6 m/km, o vėžėtumo rodiklis ne didesnis, kaip 7 mm, esant 95 % tikimybei.

5. Atlikus magistralinių kelių parinktų racionalių dangos konstrukcijų įrengimo kainų skaičiavimus, nustatėme, kad:

- parinktos racionalios kelio dangos konstrukcijos, kai vidutinis metinis paros eismo intensyvumas neviršija 10 000 aut./parą, įrengimo kainą, lyginant su projektinės kelio dangos konstrukcijos įrengimo kaina, yra 11,5 % mažesnė;
- parinktos racionalios kelio dangos konstrukcijos, kai vidutinis metinis paros eismo intensyvumas neviršija 30 000 aut./parą, įrengimo kainą, lyginant su projektinės kelio dangos konstrukcijos įrengimo kaina, yra 10,4 % mažesnė.

6. Atlikus neapibrėžties analizę, buvo nustatytos kelio dangos lygumo ir vėžėtumo ribinės vertės: kelio dangos lygumui 1,6 m/km, o vėžėtumui 4 mm, kai vidutinis metinis paros eismo intensyvumas neviršija 10 000 aut./parą, ir dangos lygumui 1,6 m/km, o vėžėtumui 7 mm, kai vidutinis metinis paros eismo intensyvumas neviršija 30 000 aut./parą, esant 95 % tikimybei. Šią lygumo ribinę vertę galima taikyti aukštam priežiūos lygiui. Gauti rezultatai rodo, kad pasiūlytos racionalios kelio dangos konstrukcijos garantuoja pakankamai geras eismo salygas keliuose po penkerių kelio dangos eksploatavimo metų.

Trumpos žinios apie autorių

Matas Bulevičius gimė 1981 m. birželio 17 d. Jonavoje.

Vilniaus Gedimino technikos universiteto Aplinkos inžinerijos fakultete 2003 m. įgijo statybos inžinerijos bakalauro laipsnį, 2005 m. – kelių inžinerijos mokslo magistro laipsnį. 2003–2011 m. dirbo AB „Problematika“ bandymų laboratorijoje, Betono ir gruntų tyrimų skyriuje. Šiuo metu eina AB „Problematika“ bandymų laboratorijos vadovo pareigas.

Matas BULEVIČIUS

INFLUENCE OF THE PROPERTIES OF FLEXIBLE ROAD PAVEMENT STRUCTURE ON THE SERVICE INDICES OF WEARING COURSES

Summary of Doctoral Dissertation
Technological Sciences, Civil Engineering (02T)

Matas BULEVIČIUS

KELIŲ TAMPRIOSIOS DANGOS KONSTRUKCIJŲ SAVYBIŲ ĮTAKA JŲ VIRŠUTINIO SLUOKSNIO EKSPLOATACINIAMS RODIKLIAMS

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Vilniaus Gedimino technikos universiteto
leidykla „Technika“,
Saulėtekio al. 11, 10223 Vilnius,
http://leidykla.vgtu.lt
Spausdino UAB „Ciklonas“
J. Jasinskio g. 15, 01111 Vilnius