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Section: Roads and Railways

Functioning conditions and required properties and state of asphalt concrete pavement of motor roads and their construction

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Abstract

The state of asphalt concrete (AC) pavement and its construction, predetermined by the distress level *D*, largely depends on the functioning conditions. The factors predetermining the functioning conditions and service life of AC pavement and its construction are discussed in the present article: traffic loads, local climate and weather conditions, local soils (their properties), and other local factors (soil water horizon and moisturizing conditions, etc.). It is shown that the state of the road pavement and the road pavement construction (RPC) expressed in the distress level, the roughness of AC pavement and RPC strength, expressed by strength coefficient K_{st}, largely depends on the componential composition of the upper layer of asphalt concrete pavement and its physical and mechanical properties.

Keywords: motor road; asphalt concrete (AC) pavement; road pavement construction (RPC); functioning conditions; pavement state; distress level; service life.

1. Introduction

The project of management and development of Lithuanian national roads for 2002–2015 schedules fundamental improvement of motor road infrastructure. In order to achieve this purpose, it is necessary to ensure sufficiently good properties of asphalt concrete pavement (ACP) and road pavement construction (RPC): relevant roughness of ACP, low degree of ACP and RPC disintegration, and relevant strength of RPC and cohesion between the wheels of vehicles and pavement. It is also necessary to determine the permissible quality, exploitation and strength indices for ACP and RPC and ensure the service life of ACP and RPC.

Lithuania is far behind the developed countries in the density and technical level of the network of motor roads. At the beginning of 2013, the length of national roads was 21 242 km. Only 13 895 km (65.4%) of them had asphalt concrete cover. The length of the roads of category E was 1 511 km and the length of the roads of category I and higher categories was 575 km including 417 km of main roads (MR) [1].

Under the conditions of increasing number of vehicles (1.29 million in 2000 and over 2.24 million in 2013) and the portion of heavy-weight multiaxial cargo vehicles, it is very important to evaluate the ACP and RPC functioning conditions and to correctly forecast the future state of ACP and RPC and factual service life taking into account the actual quality of asphalt concrete and strength of RPC. These data are necessary for scheduling the timely ACP and RPC repairs in order to ensure safe, convenient and fast transportation of passengers and cargo, i.e. to ensure the required pavement roughness.

2. Investigation of Objective ACP and RPC Functioning Conditions

Asphalt concrete pavement and road construction (RC) function under objective local road exploitation conditions which depend on many factors: properties of ACP and of materials used for the layers of RPC, soil properties in the road bed (RB), various climate factors (number of sunny and rainy days, snow cover duration, time spans with negative and positive air temperatures, depth of frozen ground, duration of spring thaw, annual number of passages from negative to positive (and vice versa), etc.), traffic loads, local groundwater horizon (LGH) and soil moisture, and exploitation conditions (roughness, RCP strength, etc.) of ACP and RPC (Fig. 1) [2–3].

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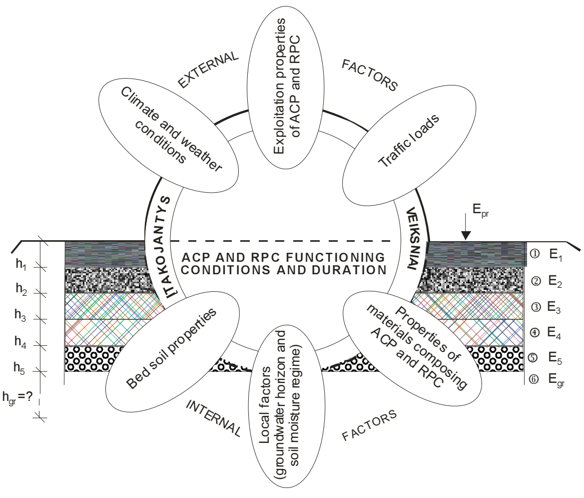

Fig. 1. Model of interdependence between the factors predetermining ACP and RPC functioning conditions and duration: ①–⑤ – RPC layers (① and ② – upper and lower layers of ACP; ③ and ④ road-metal (RM) or gravel (G) road bed layers; ⑤ – protective cold-resistant sand (S) (or other material) layer); ⑥ – road bed (RB) soil; E_1– E_5 and h_1– h_5 – respectively, elasticity modules of the indicated RPC layers and thickness of these layers; E_{gr} and h_{gr} – respectively, elasticity module of road bed soil and equivalent thickness of active zone [2–3]

The values of the analysed indices (E_1– E_5, h_1– h_5 and E_{gr}) except h_{gr} can be chosen (or determined) using the normative documentation on the requirements for road pavement construction and taking into account the RPC materials and soil of locality where the road is already built or scheduled. Index E_{pr} project module of RPC elasticity can be derived based on the established dependences and forecasting future (after 10–20 years) project traffic intensity N_{pr} (index $E_{pr} \geq K_{st} \cdot E_r$, E_r – the required elasticity module of RPC determined by evaluation of N_{pr}, and K_{st} – RPC strength coefficient). Index h_{gr} can be derived from the following interdependence:

$$h_{gr} = h\frac{\left(E - E_{pr}\right)}{\left(E_{pr} - E_{gr}\right)}, \tag{1}$$

h – capacity of RPC layers (in this case $h = h_1 + h_2 + ... + h_5$); E – average weighted elasticity module of RPC layers:

$$E = \frac{E_1 h_1 + E_2 h_2 + ... + E_5 h_5}{h_1 + h_2 + ... h_5}. \tag{2}$$

Index h_{gr} shows the equivalent thickness of RB soil when at soil elasticity module E_{gr} RPC project elasticity module will be E_{pr} (Fig. 1):

$$E_{pr} = \frac{E_1 h_1 + E_2 h_2 + ... + E_5 h_5 + E_{gr} h_{gr}}{h_1 + h_2 + ... h_5 + h_{gr}}. \tag{3}$$

The long-term experience of road exploitation shows that service life of asphalt concrete (before repair) in the road pavement usually is considerably shorter than the service life of the road construction (RC) (RPC with RB soil) before the major repair and a few times shorter than the service life of the road before reconstruction because the possible service life of asphalt concrete in the road pavement always is shorter than that of flexible road construction and considerably shorter than the possible service life of road.

The recently increasing impact of heavy multiaxial vehicles on the road pavement and its construction in Lithuania have been intensifying their disintegration and reducing their service life. Results of researches carried out in many countries show that rutting of ACP has been markedly increasing. This is a very important challenge to AC quality showing that shear stress-resistant (frame) AC must be used in the roads with heavy traffic.

In the course of time asphalt concrete in the road pavement disintegrates under the impact of the following factors [2],see Fig. 1):

Destructive impact of vehicles (especially heavy-weight cargo vehicles) causing fatigue cracks and subsequently a network of cracks:

Meteorological conditions:

a) *Sudden weather cooling in winter*. When cooling velocity reaches the value $v_t = 6 - 10$ °C/h , transverse cracks in the pavement appear.
b) *Frequent changes of meteorological conditions, i.e. temperature swings from positive to negative (when ACP temperature t frequently passes the limit t* = 0 *°C).* In Lithuania, these temperature changes occur 60–80 times per year and more (autumn–winter–spring season). Under these conditions, the road pavement begins to crack and later

crumbles away; especially when asphalt concrete in the pavement is insufficiently thickened or when its resistance to erosion is poor.

c) *Solar radiation.* Solar radiation beats up the ACP (on a clear day when air temperature reaches $t > 30$ °C the ACP heats up to 60–70 °C) causing the following:

rapid aging of the pavement due to rapid evaporation of volatile fractions of bitumen contained in the asphalt concrete leading to cracking of the pavement in 3–5 years;

reduction of elasticity module of ACP resulting in softening and reduction of the strength of RPC. There may appear patches of „blurred" bitumen because its volume increases filling the hollows and then rising to the pavement surface;

reduction of asphalt concrete resistance due to shear stress produced by vehicles (especially the heavy-weight ones) resulting in the appearance of ruts, waves, displacements and potholes. Displacement of the upper layer of ACP with respect to its lower layer (in cases of weak cohesion between the layers) may cause transverse cracks,

Insufficient strength of RPC. The insufficient strength of RPC causes transverse cracks and fractures in the ACP. In the course of time, disintegration of ACP reduces the strength of ACP and RC even more. Due to insufficient strength, the whole RPC or its part under the ACP becomes very sensitive to:

a) *destructive impact of vehicles* (heavy-weighed ones in particular),
b) c*limate factors*. Under the impact of *negative temperatures*, in the poorly cohered layers composed of low filtration capacity materials (when filtration coefficient is lower than 3 m/day) the water rising to the ACP (above the frozen ground zone) may form ice lenses with higher volume than that of the water (before freezing) contained in the layers. Due to this, the ACP may bulge out and then crack. *Surplus of atmospheric water* reduces elasticity of road bed soil (especially that of clay).

Groundwater impact. Shallow groundwater and spring thaw water reduce elasticity module of RB soil.

A nature of interaction between the factors influencing the asphalt concrete pavement roughness, rutting, degradation extent, structural strength and condition is random, thus, their effect values vary randomly (stochastically) without exceeding certain limits. Some of these factors the are air temperature, solar radiation, 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).

The service index of road pavement roughness $Y_{\mathrm{IRI}}^{(1)}$ 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 $Y_{\mathrm{IRI}}^{(\mathrm{cr})}$. The critical limit of $Y_{\mathrm{IRI}}^{(\mathrm{cr})} \geq 2.5$ m/km is exceeded later. The service index of road pavement rutting $H_{\mathrm{v}}^{(1)}$ 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 $H_{\mathrm{v}}^{(\mathrm{cr})}$. The critical limit of $H_{\mathrm{v}}^{(\mathrm{cr})} \geq 40$ mm is exceeded later.

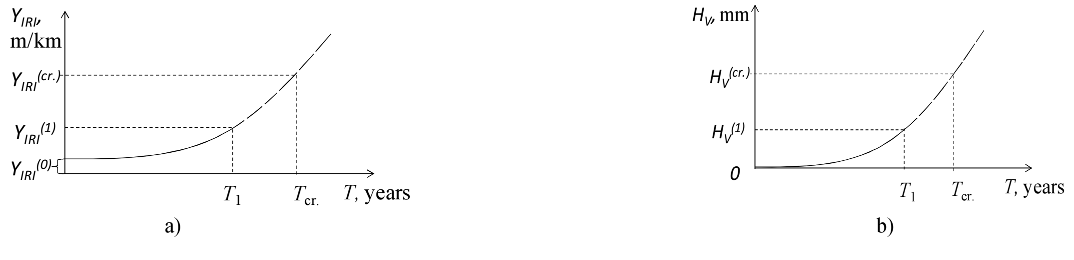

Fig. 2. Graphical model of the change in the service indices of road pavement roughness and rutting in the course of time

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

a) b)

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. Required Properties and Quality of ACP and RPC and Their Rational Service Life

Results of our investigations [2] and the ones obtained by other authors prove that expected quality and service life of ACP and RPC can be best modelled by asphalt concrete resistance to tension by bending R_l, elasticity modules of pavement and other construction layers (pavement asphalt concrete – E_a, road bed layers: road-metal – E_{sk}, sand – E_{sm}, etc.), RPC strength coefficient K_{st}, and fatigue resistance of asphalt concrete N_a. The values of indices R_l, E_a and N_a can be derived using the common formulae with respect to the chosen type and sort (composition and structure) of asphalt concrete. By modelling asphalt concrete composition (composed of chosen required materials and bitumen), the values of indices R_l, E_a, N_a and E_{sk} and forecast the future quality of ACP and RPC (after one, two and n years) [2–4] are derived.

For modelling the quality of ACP it is convenient to determine the physical and mechanical properties of asphalt concrete. Our investigations show that the pavement distress level D (%) determined using formula 1 [2] is well modelled by the following indices: AC resistance to compression at +50 °C R_{50} and absorptive power W.

$$D = -11.82 + 20.3\,R_{50}, \quad (\text{determ. coefficient } R^2 = 0.902) \tag{4}$$

$$D = 27.5 + 12.27\,W^2 + 30.1\,W, \quad (R^2 = 0.884) \tag{5}$$

In many developed West European countries and in the USA, it has been reported that AC functioning in the road pavement is modelled by the following indices: stability P, plasticity Pl, residual porosity LA according to R_l, E_a, N_a, etc. It has been proved by many authors that the values of the mentioned indices depend on the structure and composition of AC. Our investigations show that AC composition is a decisive factor for pavement roughness Y, pavement quality (distress level D), RPC strength (strength coefficient K_{st}), and absorptive power W:

$$D = 539 + 13.48\,B^2 - 170.4\,B, \quad (R^2 = 0.980) \tag{6}$$

$$Y = 1218 + 19.83\,B^2 - 246\,B, \quad (R^2 = 0.672) \tag{7}$$

$$K_{st} = -34.93 - 97.47\,(B/MM)^2 + 119.56\,(B/MM), \quad (R^2 = 0.792) \tag{8}$$

$$W = 26.7 + 48.2\,(MM/SK) - 0.064\,MM^2 - 114.3(B/SK) + 8.36(B/MM) - 9.6\,B - 1.12\,B^2, \quad (R^2 = 0.810) \tag{9}$$

B, MM and SK in (5–9) are portions (%) of bitumen, grains finer than 0.071 mm and grains coarser than 5 mm in ACP respectively.

The expected service life T_k of RPC is ensured when its factual elasticity module E_f is $E_f \geq E_{pr}$, and E_{pr} is $E_{pr} \geq E_r$. The factual elasticity module of RPC E_f reduces in the course of time: at first at a slower rate which is gradually increasing. The increasing traffic intensity N requires higher factual elasticity module E_f of RPC which can be increased by strengthening the RPC (building a new upper layer of ACP). When in the course of time the reducing minimal

RPC elasticity module $E_f^{(\min)}$ equals the required elasticity module E_r (provision $E_f^{(\min)} = E_r$) and continues to reduce further ($E_f^{(\min)} \le E_r$), the rational service T_k life of RPC comes to an end and the RPC requires a prompt major repair.

Our investigations revealed that the distress level D of RPC is closely related with pavement roughness Y and RPC strength, described by strength coefficient K_{st}, whereas D values depend on the service life T of ACP. The derived correlation regression dependencies showed close mutual links of analysed indices (the values of determ. coefficients R^2 ranged from $R^2 = 0.828$ to $R^2 = 0.996$). It was also determined that pavement distress level D is a generalized index of the state and quality of ACP and RPC. Its values $D_1 = 5-8\%$, $D_2 = 8-16\%$ and $D_3 > 16\%$ were taken based on criteria of determining the rational service life of ACP before the operative and preventive (intermediate) repairs and RPC before major repairs. We also determined the rational RPC strength coefficient K_{st} for national roads of different categories with monolithic ACP: $K_{st} = 1.5-1.6$ for main roads; $K_{st} = 1.4-1.5$ for roads of category I; $K_{st} = 1.3-1.4$ for roads of category II; $K_{st} = 1.2-1.3$ for roads of category III; K_{st} = 1.1–1.2 for roads of category IV; K_{st} = 1.05–1.1 for roads of category V. It is recommended to repair the monolithic (asphalt concrete, ferro-concrete, etc.) pavement and RPC of these roads when the values of RPC strength coefficient K_{st} are: $K_{st} = 0.95-1.00$ for main roads and roads of category I; $K_{st} = 0.90-0.95$ for roads of categories II and III; $K_{st} = 0.85-0.90$ for roads of category IV and $K_{st} = 0.80-0.85$ for roads of category V. Implementation of these recommendations for repairs of ACP and RPC of the Lithuanian national roads would ensure the required pavement roughness and conditions for safe, comfortable and fast transportation of passengers and cargo. On time ACP and RPC repairs (within rational timeframes) would also contribute to savings.

4. Conclusions

1. A decisive influence on the functioning conditions and service life of ACP of motor roads and RPC is produced by the following factors: traffic loads (heavy-weight vehicles in particular), local climate and weather conditions, local soils (their properties) and other local conditions (shallow groundwater horizon, soil moisture regime and road pavement construction conditions – whether the road is built on an embankment or in an excavation, etc.).
2. The functioning conditions and service life of ACP and RPC also depend on the factors related with qualification and experience of road constructors and technologists: chosen materials for building RPC (the following indices of chosen materials are of major importance: values of elasticity modules and thickening coefficients, filtration coefficient of sand, etc.), capacities (project and factual) of layers, roughness of ACP (mostly dependent on the technologist), etc.
3. Investigations revealed that the state and service life of ACP and RPC is best reflected by the pavement distress level D and the state of RPC is also well reflected by its strength expressed in the strength coefficient K_{st}. The article contains recommendations on the critical values of pavement distress level D indicating the necessity for operative and preventive repairs of ACP and major repair of RPC. Critical values of RPC strength coefficient K_{st} indicating the necessity of immediate major repairs of RPC (by building a new ACP) are recommended for roads of different categories.
4. Implementation of given recommendations on the regularity of repairs of ACP and RPC of Lithuanian national roads would ensure the required conditions for safe, comfortable and fast transportation of passengers and cargo and would contribute to savings allotted for RPC repairs.

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