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EVALUATION OF FLEXIBLE ROAD PAVEMENT CONSTRUCTION STATE USING OBJECTIVE STRENGTH CRITERIA

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Abstract. This article illustrates that by means of our methodology for evaluation of state of flexible road pavement construction (RPC) it is possible with an adequate precision for practical purposes to measure the remaining resource of pavement construction strength and to suggest in every particular case the necessary measures to stop early and speedy deterioration of road pavement. For the application of the methodology mentioned above the following objective criteria have been established seeking to determine the state of pavement and its construction: RPC strength coefficient as well as remaining resource of this strength, resistance of asphalt concrete pavement or other asphalt material to binding tension, obligatory values of fatigue resistance coefficient of those materials and allowed value of RPC deterioration extent.

Keywords: road pavement, state of pavement, flexible pavement construction, deterioration extent, heavy weight vehicle (HWV), strength criterion, remaining resource of strength, service life.

1. Introduction

Lithuania's accession to the European Union was followed by a marked inconformity between profit generated in road transport sector and damages on roads. The majority of Lithuanian roads was designed and constructed at the time when the projected axle load was 10 tonnes (100 kN). Thus nowadays the damaging effect of international transit road haulage, which is characterised by axle load ranging from 11 to 13 tonnes (110 kN – 130 kN), to road pavements and their construction in Lithuania is too big.

By means of widely applied methodologies for evaluating flexible RPC strains that result due to wheel impact on pavement VSN 46-83, VSN 52-89 and VSN 42-87 [1–3] it is difficult to make fairly precise predictions on changes in pavement construction strength and its real service life as well as to carry out accurate measurement of remaining resource of its strength and evaluate the increase in extent of fatigue failures in its solid layers. Thus it is difficult to ensure that asphalt concrete or other asphalt pavement and its construction will serve for a long time without a marked deterioration.

By means of our methodology [4–7] for evaluating the state of flexible RPC it is quite easy to measure (with an adequate preciseness for practical purposes) the remaining resource of pavement strength and to suggest in every particular case the necessary measures to stop early and speedy deterioration of road pavement: timely strengthening of pavement, construction of a new upper layer for asphalt concrete pavement, restrictions on vehicle axle load etc. For application of the methodology mentioned above the following criteria have been established seeking to determine the state of a pavement: RPC strength coefficient K_{st} as well as remaining resource of this strength, resistance of asphalt concrete pavement or other asphalt material to binding tension R_l, obligatory values of fatigue resistance coefficient of those materials N and allowed value of deterioration of pavement construction D.

Results of our research [8–13] as well as results of other researchers [14–17] indicate that it is possible to extend the real service life of road pavement and its construction by means of appropriate methodologies for determining the state of road pavement and by means of efficient measures to improve its state.

The majority of Lithuanian state roads (more than 60 % of their length) has asphalt concrete or other type of asphalt pavement. The most intense traffic is on the following main roads: Vilnius–Kaunas–Klaipėda, Vilnius– Panevėžys, Kaunas–Marijampolė, Panevėžys–Šiauliai etc. It ranges from 1000 to 39 000 vpd (vehicles per day), nearly 13 000 vpd on district roads and less than 300 vpd on regional roads. Road pavement constructions are built in places that could be characterised by varied area-specific conditions, different types of ground in roadbed, varied area-specific hydrothermal regimes and different average air temperatures. When designing roads, pavement constructions for road sections are usually chosen taking int. Account the experience in road service. However, the chosen pavement construction is not always efficient from the economic point of view because when constructed its actual service life in a road construction until major repair is shorter than a rational service life.

One of major reasons for inadequate evenness of road pavements is an often insufficient strength of RPC. Due to the lack of this strength in the 2nd road and climate zone, in which service life conditions for roadbed and pavement construction are extremely difficult and complicated, around 35 % of deteriorating pavement fail. The remaining part of deteriorating pavement (more than 65 % of such a pavement) deteriorates due to inadequate quality of materials [18]. The pavement evenness parameters mainly depend on the type of roadbases, their thickness and state. If the cohesion of upper layers in a pavement is not adequate, the service life of pavement construction reduces by 30 % [19]. In southern part of Western Europe the following failures in asphalt pavements are most common: tracks of vehicles, waves, displacements and spots of bitumen. Tracks of 1,5–3,0 cm depth may form due to vehicle loads [10]. In USA the most common type of asphalt concrete pavement failure is temperature and fatigue determined cracks except for southern states in which elastic failures dominate [10]. In Russia in 75–80 % of cases asphalt concrete pavement in the 2nd and 3rd road and climate zones deteriorates due to cracks [20].

The analysis of studies [4–6, 9, 10] indicates that in the majority of cases there is no strict linear dependence between elastic deflection, resistance of material to displacement and its resistance to settlement, thus without evaluating at least one of the above-mentioned parameters it is not possible to design rational RPC. In order to calculate the future deterioration of a pavement with an adequate preciseness for practical reasons and aiming to increase rational service life of its construction, it is necessary to make a detailed evaluation of these three most important characteristics of RPC. Analysis of other research [21–25] indicates that influence of the above-mentioned factors is very complicated because certain factors tend to influence other factors: due to increase in speed of vehicles and decrease in evenness of a pavement, the dynamic load of wheels and its impact on RPC increase significantly; due to an increase in surface roughness of a pavement, strains in a pavement may develop etc. In calculations applied in practice, all these parameters are summarised by an equivalent load of vehicle wheels, calculated on the basis of strains that result in RPC. Methodology for calculating RPC loads is described in instructions VSN 46-83 and VSN 42-87 [1, 3].

In order to evaluate the impact of loads appearing on a pavement due to wheels in service life of asphalt layers, first of all the link between RPC elastic deflection or relative deformation and strains in its layers resulting from incurved pavement is determined, as well by strains in ground of a roadbed due to such load are determined. Analysis of methods for constructing a road pavement [1, 3] indicates that it is possible to determine the impact of loads, that appear on a pavement due to vehicle wheels, on service life of a flexible road pavement, if the link between the number of cyclic loads N, which the sample of asphalt concrete or asphalt resists before deterioration, and amplitude of strains σ that appear in a sample or relative deformation ε. The link between $N_{(\sigma)}$ and σ or $N_{(\varepsilon)}$ and ε is determined by means of laboratory test by controlling amplitude of strains σ or relative deformation ε [25]; ($N_{(\sigma)}$ is the number of cyclic loads, which the sample of asphalt concrete or asphalt resists before deteriorating due to amplitude of strains σ appearing in it, $N_{(\varepsilon)}$ is the number of cyclic loads, which the sample of asphalt concrete or asphalt resists before deteriorating due to relative deformation ε appearing in it).

In Russia flexible RPC have been designed by means of DORNII method [1] for many years, according to which the most important RPC strength criterion is allowed elastic deflection. For road pavements that meet this condition an obligatory resistance of non-binding material layers to shearing strain, obligatory resistance of solid layers to binding tension, obligatory resistance of pavement to cold and reliable drain of RPC base layers away from roadbed should also be ensured.

When calculating the obligatory enforcement of RPC according to VSN 46-83 [1], the worsening of its solid layer characteristics is predicted in poor detail; decrease in strength of material of pavement layers due to fatigue failures is not evaluated, thus it is difficult to avoid early deterioration of RPC or at least to reduce the scale of its spreading.

The aim of this study is to suggest rational and timely measures to extend real service life of RPC by means of objective strength criteria for evaluating the state of flexible RPC.

2. Experimental and theoretical studies on the state of a road pavement and its construction

In order to determine the characteristics of RPC (ie the elasticity modulus E, deterioration extent D, strength and remaining resource of strength on the basis of values of strength coefficient K_{st}), we have carried out our experiments on district road No 121 (Anykščiai–Troškūnai–Panevėžys) in Lithuania. The experiments have been performed in spring and summer 2003–2005. Their aim was to suggest rational measures for repair of road pavement and its construction. Eighteen RPC sample sections (each of 100 m length), characterised by a varied deterioration level (extreme, average, slight deterioration) of the pavement, were selected on the above-mentioned road. The sections were selected in such a way as they were equal in their projected RPC and traffic intensity on them.

The deterioration extent of pavement *D* was measured on all lengths of selected sections. When measuring and applying the classification provided in study [10], seven types of failures were identified as well as the state of RPC was evaluated. After an analysis of experimental results the elastic deflection of RPC was measured on the selected 18 sections similar in type of failures and area. Measurements were carried out in spring in compliance with VSN 46-83 [1] instructions. Aiming to determine in what way the strength of RPC declines in relation to its deterioration extent *D* which is calculated according to methodology in study [8], measurements were taken on sections without failures as well. Elastic deflection was measured by means of the Benkelmann beam, vehicles with rear axle load of group A of 100 kN (MAZ-5551) were used as the load on RPC. All the data were registered in a register indicating the object name, its length, number and stakes of the section, RPC, information concerning the year, when the road was constructed and repaired, date and time of measurements performed, air conditions, air and pavement surface temperature, width of carriageway, height of embankment, type of failures in a pavement as well as experimental data.

Elasticity modulus *E* (MPa) and strength coefficient K_{st} of a road construction on the basis of measured values of elastic deflection *l* were calculated by means of equations [26]:

$$E = \frac{pD_p\left(1-\nu^2\right)}{l}, \text{ in MPa}; \tag{1}$$

$$K_{st} = \frac{E_f}{E_r}, \tag{2}$$

here: *p* – air pressure in a tyre when contacting the pavement (including measured and calculated values of $p = Q/(2S)$ in kg/cm^2; *Q* – rear axle load in kN; D_p – diameter of projected modified wheel track in cm, ν – Poisson coefficient, in this case we used $\nu = 0{,}3$; *l* – RPC elastic deflection in mm. E_f and E_r – factual and required elasticity modules (E_f is calculated by means of equation (1) – $E_f = E$, E_r is determined by evaluating traffic intensity of projected vehicles at the end of perspective period *T* = 20 by means of methodology in study [20].

Since during the measurements the temperature of asphalt concrete layer could differ from its temperature at a projected period (+10 °C), we recalculated the RPC elasticity modulus *E* (see Eq 1), according to a widely applied formula, and the result is E_p [27]:

$$E_p \approx KE - \Delta E_{gr} + \frac{0{,}27}{D_p}\left(h_1\Delta E_1 + h_2\Delta E_2 + h_3\Delta E_3\right), \text{ MPa}, \tag{3}$$

here: *K* – coefficient, determined when making measurements in autumn, $K = 0{,}90$; E_p – elasticity modulus of RPC at a projected period in MPa; *E* – elasticity modulus of RPC, calculated on the basis of results obtained when measuring vertical elastic deflection of RPC in MPa; ΔE_{gr} – correction to RPC elasticity modulus taking into account the ground moisture content in MPa; ΔE_1, ΔE_2, ΔE_3 – corrections taking into account differences in values of elasticity modules of asphalt concrete layers during measurement periods and values of these modules at projected periods in MPa; h_1, h_2, h_3 – thickness of asphalt concrete layers in RPC in cm.

At the first stage deflections were measured in selected sections, the RPC of which was not damaged. The measurements were carried out on 20 evenly located (in length) spots on the right roadway. At the second stage deflections were measured in sections with typical RPC failures, in 5 to 7 spots of every typical failure. All the measurement results were registered. Having measured RPC elastic deflections in the selected sections, failures in road pavement were identified in great detail. By means of methodology presented in study [8] the extent of its deterioration *D* was determined.

During the experiment in 198 sections ($\sum n = 198$) on road No 121 (Anykščiai–Troškūnai–Panevėžys) elastic deflection of RPC was measured (in 18 sections, 11 measurements in each of them) and RPC elasticity modulus *E*, strength coefficient $K_{st} = E/E_r$ (E_r – obligatory RPC elasticity modulus) and extent of pavement deterioration *D* (Table 1, Figs 1, 2) were determined. The quantity of sections to be examined and measurement results for each section were chosen in such a way as in sections with a different extent of deterioration (when values of parameter of deterioration extent *D* are 5–8 %, *D* = 8–16 % and *D* > 16 %), the number of individual results *n* of measured elastic deflection *l* and elasticity module *E* and strength coefficient K_{st} was equal to $n \geq 30$. This will enable to make an objective comparison between average values of RPC strength characteristics *E* and K_{st} in RPC sections characterised by a different extent of deterioration due to a sufficient quantity of statistical results (Table 1).

Our previous studies [8–10] prove that when values of RPC deterioration extent *D* = 5–8 %, aiming to stop a road pavement deterioration, it is necessary to perform speedy minor repair works that include the repair of pavement failures: deteriorated parts (potholes, hulls, shellings) of a pavement are fixed by means of asphalt concrete patches; cracks in a pavement are fixed by means of bitu-

Table 1. Quality parameters of road pavement and its construction, in which measurements were performed

Quality parameter of RPC	Values of quality parameter			
	Compulsory value	Average values, when the extent of pavement and its construction deterioration is *D*, and a need for repair works		
		D = 5–8 %, minor repair of pavement is necessary, n = 38	D = 8–16 %, preventive (average) repair of pavement is necessary, n = 65	D > 16 %, major repair of RPC is necessary, n = 95
Elasticity modulus E in MPa	218	208	179	174
Strength coefficient K_{st}	1,00	0,95	0,82	0,80

men mastic (or other), displacements, waves, vehicle tracks; other failures of a pavement are mill cut and patched with asphalt concrete. When D = 8–16 %, pavement needs average repair which includes renewal of a pavement by adding ('Remix+' method) or not adding ('Remix-' method) new materials; in other words, it is advisable to renew and even the pavement (to increase its evenness). When D > 16 %, it is necessary to perform major repair works on RPC including strengthening the RPC by constructing a new upper asphalt concrete or a concrete layer. The thickness of asphalt concrete layer for strengthening RPC is determined by calculating first of all the required (rational) strength coefficient of reinforced RPC. Preliminary values of coefficient K_{st}: $K_{st} = 1{,}5-1{,}6$ (for motorways), $K_{st} = 1{,}4-1{,}6$ (for 1st category roads), $K_{st} = 1{,}3-1{,}4$ (for 2nd category roads), $K_{st} = 1{,}2-1{,}3$ (for 3rd category roads), $K_{st} = 1{,}1-1{,}2$ (for 4th category roads) and $K_{st} = 1{,}05-1{,}1$ (for 5th category roads with asphalt pavement). Results in Table 1 indicate that when the extent of RPC deterioration is D > 16 % and when strength coefficient is $K_{st} \le 0{,}80$, major repair works are necessary. When D = 8–16 % and $K_{st} \le 0{,}82$, preventive (average) repair works are necessary. When D = 5–8 % and $K_{st} \le 0{,}95$, minor repair of pavement is necessary. The results presented comply with the results of previously performed tests [16], which justify the reliability of the tests.

The results indicate (Figs 1, 2) that there have been significant changes in average values of RPC elastic deflection l and elasticity modulus E in separate sections of road in question, and there have been changes in values of average square deviations σ_l and σ_E and respectively.

The results of our study indicate (Table 1) that 48 % of examined road sections need major repair of RPC, 33 % of sections need average repair of asphalt pavement and 19 % need a minor repair (Fig 3).

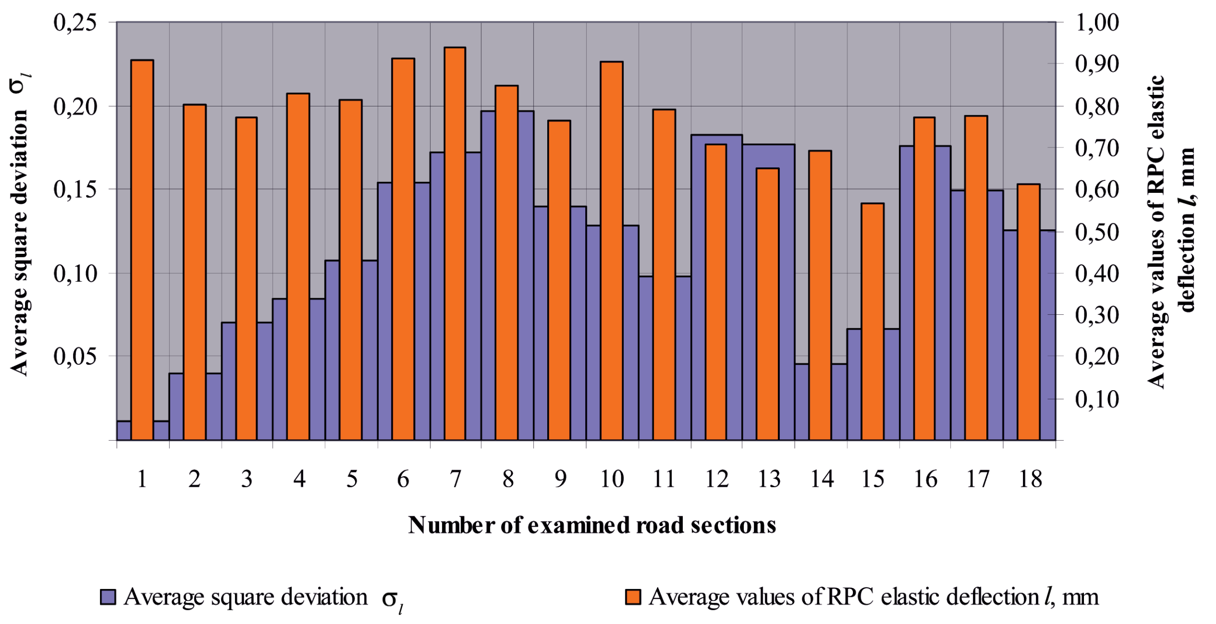

Fig 1. Diagram of average values of RPC elastic deflection l and its average square deviation σ_l values on road Anykščiai–Troškūnai–Panevėžys sections

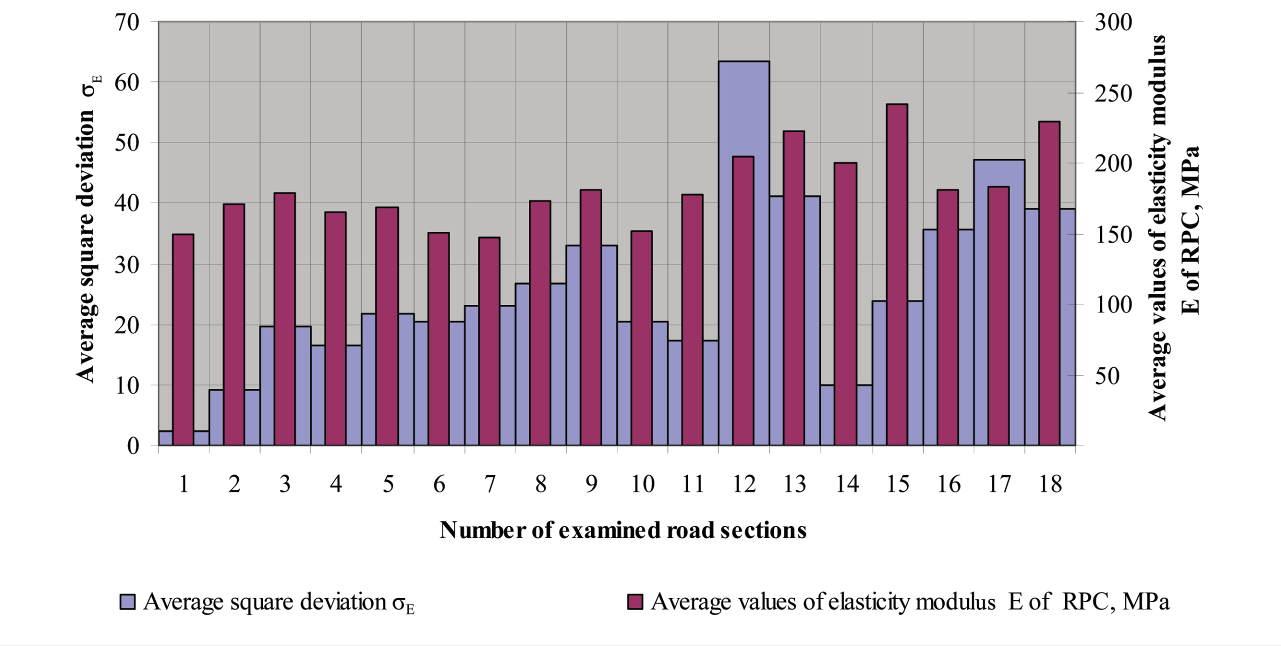

Fig 2. Diagram of average values of RPC elasticity modulus *E* and its average square deviation σ_E values on road Anykščiai–Troškūnai–Panevėžys sections

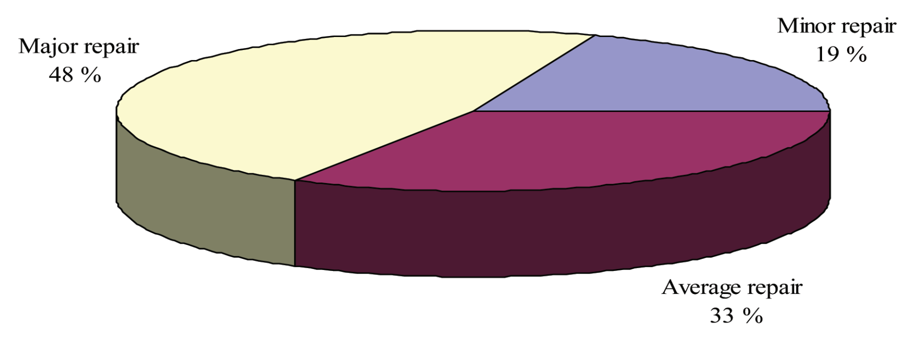

Fig 3. Data illustrating the necessity of repair of pavement and construction of examined road sections, type of repair work and its extent taking account of state of road pavement and its construction expressed by the extent of the deterioration *D*

3. Conclusions

1. Having performed theoretical and experimental test on the state of RPC we have proved that being aware of RPC and asphalt pavement deterioration extent parameter *D*, RPC elasticity modulus *E* and its strength coefficient K_{st}, it is possible to reach an objective evaluation of RPC state, to determine the necessity of repair works on road pavement and its construction, type of repair as well as volume of repair works.

2. When performing minor repair work on a pavement, RPC strength during the initial stage of its service declines less, but when time approaches for preventive (average) repair works to be performed (when macrofailure occurs) it declines significantly faster: at the first stage the values of RPC strength coefficient K_{st} decline by 5 % on average, while at the second stage they decline by approx 13–15 %.

3. The methodology for prognosis of repairs on a road pavement and its construction that we offer will help perform repair works in time and to economise on funds allocated for repair works as well as to extend the real service life of a road pavement.

4. In order to make a rational use of the strength of materials in RPC layers, we advise to perform a simplified type of major repair by constructing a thin (1,5–3,0 cm) upper layer of RPC asphalt pavement to reinforce RPC.

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