IOP Conf. Series: Materials Science and Engineering **356** (2018) 012026 doi:10.1088/1757-899X/356/1/012026

Assessment of technical condition of concrete pavement by the example of district road

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Abstract. The article presents the comprehensive assessment of concrete pavement condition. Analyses included the district road located in the swietokrzyskie province, used for 11 years. Comparative analyses were conducted twice. The first analysis was carried out after 9 years of pavement operation, in 2015. In order to assess the extent of pavement degradation, the tests were repeated in 2017. Within the scope of field research, the traffic intensity within the analysed road section was determined. Visual assessment of pavement condition was conducted, according to the guidelines included in SOSN-B. Visual assessment can be extended by ground-penetrating radar measurements which allow to provide comprehensive assessment of the occurred structure changes within its entire thickness and length. The assessment included also performance parameters, i.e. pavement regularity, surface roughness and texture. Extension of test results by the assessment of changes in internal structure of concrete composite and structure observations by means of Scanning Electron Microscope allow for the assessment of parameters of internal structure of hardened concrete. Supplementing the observations of internal structure by means of computed tomography scan provides comprehensive information of possible discontinuities and composite structure. According to the analysis of the obtained results, conclusions concerning the analysed pavement condition were reached. It was determined that the pavement is distinguished by high performance parameters, its condition is good and it does not require any repairs. Maintenance treatment was suggested in order to extend the period of proper operation of the analysed pavement.

1. The purpose of technical condition assessment of concrete pavements

Taking into consideration safe operation of concrete pavements, diagnostics of pavement structure performance is of crucial importance. Diagnostics of concrete pavements refers to the set of methods and procedures aimed at the assessment of technical condition of the analyzed structures. The diagnostics refers to the anticipation of the pavement changes occurring as a result of external loads and weather conditions and anticipating the period of failure-free pavement performance. Assessment criteria of the approved concrete pavement diagnostics system are the following: load bearing capacity, evenness and coarseness requirements. Due to the traffic safety, the performance criterion referring to pavement evenness and coarseness, along with surface macro texture is of particular significance.

So far, less attention has been paid to structural factors caused by operating conditions concerning the assessment of pavements. In this regard, properties of working surfaces of pavement slabs appear to be particularly significant. The condition of these slabs can be of tribologic and non-tribologic wear and tear nature. Wear of pavement is the damage of its surface consisting in the gradual reduction of surface layer subject to vehicle traffic or chemical reactions, for example: this type of wear is also the result of such phenomena as: corrosion, cracking, material fatigue. The process of tribologic wear refers to all materials occurring naturally and in technology. Intensity of this phenomenon depends on surface layer resistance, type of interaction and its intensity. Within the area particularly exposed to pavement wear, abrasion and slowly increasing flaking occurred within immediate environment, caused by previous structural defects of surface layer, i.e. so called spalling may occur – Figure 1.

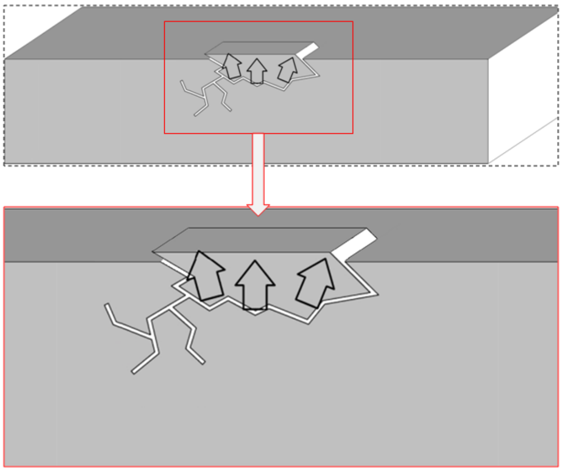

Figure 1. Diagram of spalling destruction of surface layer of concrete pavement.

2. The purpose and scope of the research

The purpose of the research was to assess technical condition of pavement made of cement concrete. The subject of the analysis was the district single-carriageway used for 9 and 11 years. Field research was conducted in spring 2 years apart and was aimed at disclosing the progressive pavement degradation process. Within the area of the entire pavement of the length of 5000m and the width of 5m, within each traffic lane, the research cross-sections located every 50m were determined, where the research was conducted each time. For the purposes of analyses, the entire research section was divided into five uniform sections.

Arrangement was defined and the most frequently occurring damages within the analysed pavement were determined, with reference to the reasons for their occurrence. The area of analyses in this case included the entire road surface within transversal cross-section and profile section. The analysis included the classification of the occurring damages, according to [12]. The following symbols of damages were determined: PL for longitudinal and diagonal cracks, PT for transversal cracks, BS – for broken slab, WU – for defective sealing, UN – for corner damage, WS – crack chipping, UP- surface damages. The occurred damages within the analysed section were defined as portions.

Global assessment of technical condition included assessment criteria of pavement operating condition, due to the traffic safety. The assumed technical and operation parameters in case of concrete pavements each time include the assessment of cracks condition (N_j), occurrence of ruts (K_j), the assessment of pavement condition (Sp_j) and defining anti-skid properties (S_j). The assessment of the pavements was determined on the basis of the global factor according to [11], in compliance with (1).

$$G = 100 - [\, W_N \cdot N_j + W_K \cdot K_j + W_{Sp} \cdot Sp_j + W_S \cdot S_j \,] \tag{1}$$

In formula (1) the following symbols W_N, W_K, W_{Sp}, W_S indicate the weight of the assumed parameters, the sum amounts to 1. While N_j, K_j, Sp_j, S_j indicate crack rate, ruts, pavement condition factor, anti-skid properties – determined in accordance with [12, 13, 14, 15]. Due to the weight value variations, which can be dependent on the assumed strategy of road maintenance, the following assumptions were made for the article purposes:

a) priority of improvement of pavement structural condition (which assumed that $N_j + Sp_j$ are 70%)
b) priority of improvement of traffic safety condition (which assumed that $N_j + K_j + S_j$ are 70%).

Within the scope of current assessment of technical condition of the analyzed pavement, the following indicators, according to [4] were determined: Z_B – pavement damage indicator according to (2), D – pavement performance indicator (3) and N – repair indicator (4).

$$Z_B = \frac{1}{A}\left[\, 1.8\, U_1 \,+\, 1.22\, U_2 \,+\, U_3 + \, U_4 + \, U_5 \,\right] \quad (2)$$

$$D = Z - \, Z_p - \, N \quad (3)$$

$$N = \frac{R}{A} \cdot 100 \quad (4)$$

The following symbols were approved in formulas (2), (3) and (4): U_1 – surface of cracks, corners and entire slabs subsidence [m^2]; U_2 – surface of cracking and edge chipping [m^2]; U_3 – flaking off surface [m^2]; U_4 – multiple cracks surface [m^2]; U_5 – deep damage surface [m^2]; A – slab surface [m^2]; R – repaired surface [m^2]; Z – damage indicator in 2017; Z_p – damage indicator in 2015.

Anti-skid pavement properties, identified with the value of friction coefficient, is the ability to generate friction force between the pavement and wheels of vehicles during adverse weather conditions. During field studies, the roughness factor was determined in case of each test section in left tyre track on each of traffic lanes in six measuring points, according to [15].

In case of individual measuring points, the average of 5 measurements was assumed as the value. Tests were conducted by means of Portable Skid Resistance Tester in accordance with test procedure, subject to [10]. Reliable rut depth was determined, according to [14] in case of each section of right tyre track. According to the research, the rut was defined as permanent deformation of cross-section of pavement which occurred along the road within the area of wheels impact. For research purposes, the method of 2-metre-patch and wedge was used. Cracks condition in case of the analysed pavement was determined, according to the guidelines of [12].

Pavement operation influences the change of performance parameters, among others macro texture and friction coefficient [5, 6]. Due to the fact of relatively long pavement operation period and the possibility of uncovering of grit grains through mortar, surface layer texture was defined. It is the parameter which also influences the extent of pavement coarseness. It was defined in three points in case of each traffic lane within test sections. The texture was defined by means of Sand Patch Method, according to the guidelines. [8].

Based on the non-destructive method, the condition of cement concrete in pavement structure was defined. Ground-penetrating radar method allowed to recognize invisible changes in concrete structure, such as: dampness, detailed information concerning expansion gaps, loosening between contact layer and base course or the change of layer thickness and delamination. Research was conducted in line with the direction of the moving vehicles in three profiles on each traffic lane. Measurement profiles were located 50 cm from the road edge. Each measurement sequence included the length of the analysed pavement, together with expansion gaps located between the slabs. The extent of identification of deep structure depends on the antenna frequency [2], therefore in order to obtain more accurate information about structure layers, two antennas of diversified frequency were used (1.20 GHz and 500 MHz).

Using sclerometer method – rebound hammer allowed to define the compressive strength of concrete by means of non-destructive method based on the assessment of surface hardness. In the course of field study, in order to determine the strength, the rebound hammer type Digi Schmidt 2N was used. Measurements were conducted within the area of the selected road, according to the guidelines of PN-EN 12504-2:2002 [7]. In order to define average compressive strength using sclerometer method, in case of the discussed pavement, 5 measurement points were found along 4 test sections, on each traffic lane. In case of each point, 10 indications were made and then average value of rebound number per compressive strength, assuming conversion curve was determined.

Standard tests which determine concrete parameters of pavements should be extended by observations of internal structure of hardened cement concrete. Particular attention should be paid to the surface layer because within this particular area, the destructive influence of environmental conditions, intensified by operational load may increase the occurrence of surface damage. Changes which occur within cement matrix significantly influence mechanical parameters of concrete [1]. These parameters, with reference to pavement concrete, are the basic factors which determine its durability. In accordance with the scientific literature [1, 3], in case of hardened concrete, the hardened cement slurry can be distinguished (also referred to as cement matrix), grains of coarse and fine aggregate (mainly of diversified mineral composition and diversified shapes and sizes), air voids, pores, cracks and various types of reinforcement. Preliminary observations were carried out, which allowed to distinguish individual components. Microscope analysis of concrete sample was conducted by means of Scanning Electron Microscope of Quanta 3D FEG Dual Beam type. Using concrete samples, preparations, subject to SEM observations were made, surface of which was of more than 100 mm2 each time. Using computed tomography allow obtaining layered images of the tested cement concrete sample. By means of tomography method, we can measure precisely individual elements of internal concrete structure in all directions and identify spatially possible defects or discontinuities. [3] Exemplary micro photographs obtained in case of samples collected from the cement pavement were presented on figure 2. In case of concrete, numerous micro cracks were observed. In case of cement matrix, these cracks were distinguished by average aperture of 8 μm. Cracks of interface between aggregate grains and cement matrix occurred mostly within the whole grains area and their maximum aperture was up to 5 μm. One of the most significant elements of internal structure of cement composite, which is considered as structure concrete service life determinant, is porosity characteristics. Diversity concrete porosity has also been observed. The air pores diameters in case of this concrete were dependend of cross section.

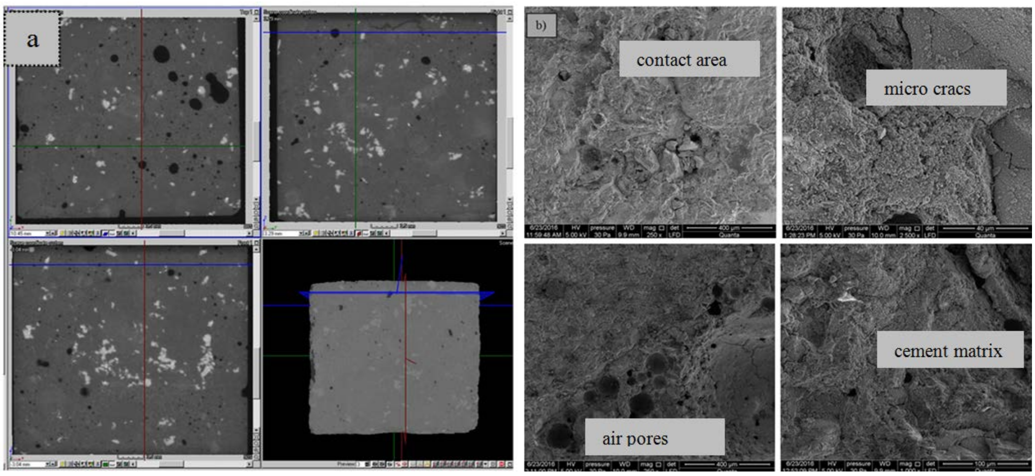

Figure 2. Exemplary images of cement concrete samples together with analysed cross-sections a) using computed tomography method (depth slice, blue and red lines depth section, surface view) b) scaning electron microscopy method (contact area, micro cracs, air pores, cement matrix).

3. Results and discussion

According to the visual assessment of pavement condition, the significant influence of operation on the change of the occurred damage quantity was proved. In case of tests conducted within the first measurement period, in total, 41 damages were classified, out of which the prevailing majority were defective sealing expansion gaps - Figure 3. Subsequent two years of operation contributed to the progressive pavement degradation and the number of the detected damages increased up to 108. Similarly, during the previous period, damages of expansion gaps filling prevailed. Widths of the occurred longitudinal and crosswise gaps ranged from 8 to 11mm.

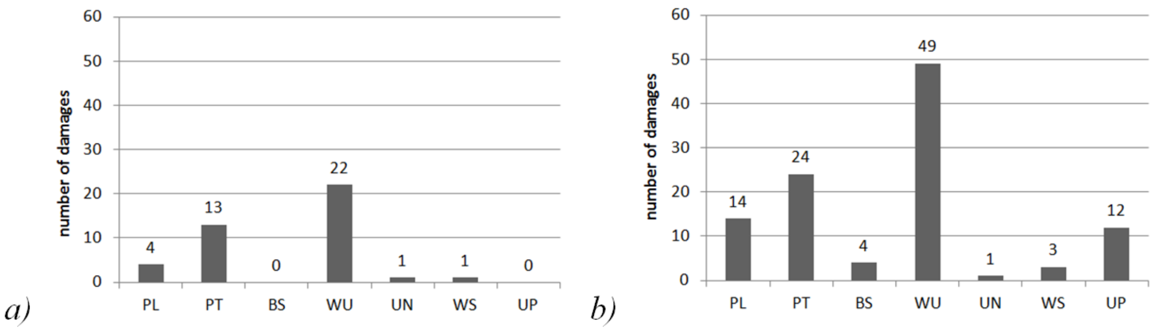

Figure 3. Qantitative specification of the occurred damages within the analysed pavement in 2015 (a) and 2017 (b).

It should be noted that single crosswise, longitudinal and diagonal cracks occurred within the analysed section. All damages of this type, both in case of the first and the second analysed period, were of minor damage potential, according to [11]. In case of analyses conducted in 2017, additionally surface damages in the form of flaking and local defects and 4 broken slabs were found. Predominant amount of defective expansion gaps filling proves omission of proper pavement maintenance. Within the analysed section, the absence of filling and local extrusion of poured sealant were found. Gap filling, in most cases has lost its initial properties and loosened from slab edges, mixture hardened and numerous cracks occurred.

Calculated global pavement condition factor in case of this road reached high values, which proves good pavement condition. The conducted analyses proved that there is no predominant parameter. None of technical and operational parameters was qualified to C or D class, which proves the warning or critical technical condition of the pavement - table 1.

Table 1. Assessment of the analysed pavement for uniform sections, assuming the priority of improvement of pavement structural condition (a) and the improvement of traffic safety condition (b).

Year	W_N priority		N_j	W_K priority		K_j	W_{Sp} priority		Sp_j	W_S priority		S_j	G priority	
	a	b		a	b		a	b		a	b		a	b
2015	0,4	0,2	0,98	0,3	0,2	2,15	0,2	0,2	0,99	0,1	0,4	0,73	98,7	98,9
2017	0,4	0,2	0,96	0,3	0,2	3,85	0,2	0,2	0,97	0,1	0,4	0,68	98,2	98,6

Calculated indicators of the current assessment of pavement technical condition, in case of the analyzed section reached the values corresponding to very good performance condition in 2015 and 2017 - table 2.

Table 2. Determined indicators of the current technical assessment together with the requirements for very good condition (wym).

Year	Z	Z_{wym}	S	S_{wym}	R	R_{wym}	D	D_{wym}	N	N_{wym}
	%									
2015	4	< 10	0.30	< 0.57	0.09	< 1.0	0.04	< 1.0	0	< 1.0
2017	8	< 10	0.42	< 0.57	0.12	< 1.0	0.04	< 1.0	0	< 1.0

According to the conducted research concerning friction coefficient of pavement (Figure 4a), it was proved that the extended period of operation influences the reduction of the tested characteristic. However, the entire research section, independent of test date, proves satisfactory coarseness -Figure 4b.

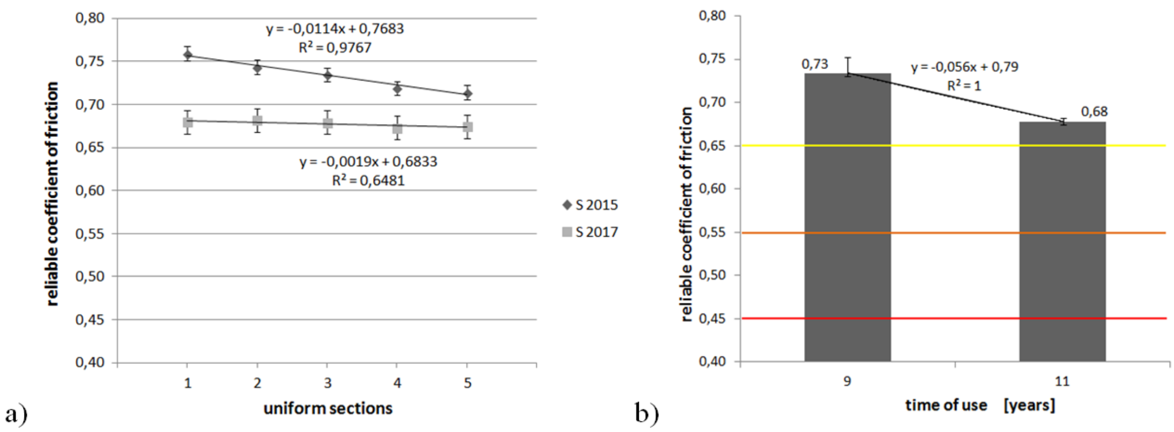

Figure 4. Average value of reliable friction coefficient for the uniform section (a) and for the entire analysed pavement section (b) (R^2 - correlation measure).

According to the determined reliable pavement rut depth it was proved that the extended period of operation influences the increase of the tested characteristic. However, the entire research section, independent of the test date, proves good condition - Figure 5.

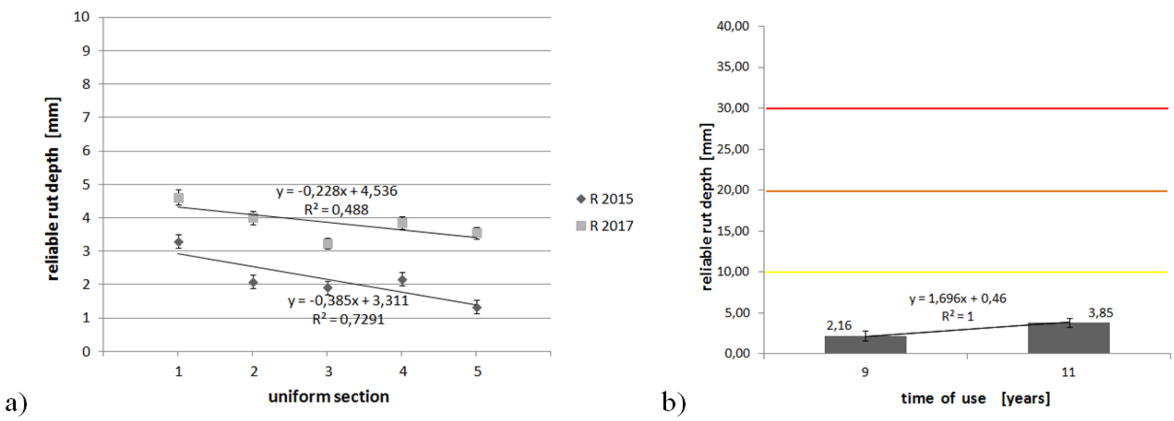

Figure 5. Average reliable rut depth for the uniform section (a) and for the entire analysed pavement section (b) (R^2 - correlation measure).

According to the conducted tests of pavement macro texture, it was proved that the extended period of operation does not significantly influence the tested characteristic. The entire test section, independent of the test date, proves average value of macro texture depth within the reliable scope – Figure 6.

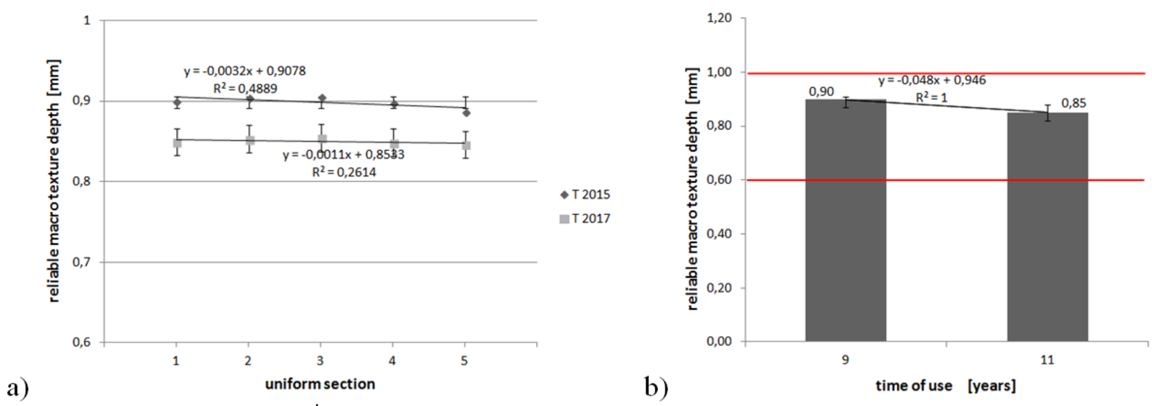

Figure 6. Average value of reliable depth of macro texture in case of uniform section (a) and entire analysed pavement section (b) (R^2 - correlation measure).

In accordance with the obtained sclerometer test results, it was proved that performance parameters of the analysed pavement have not deteriorated for two years - Figure 7.

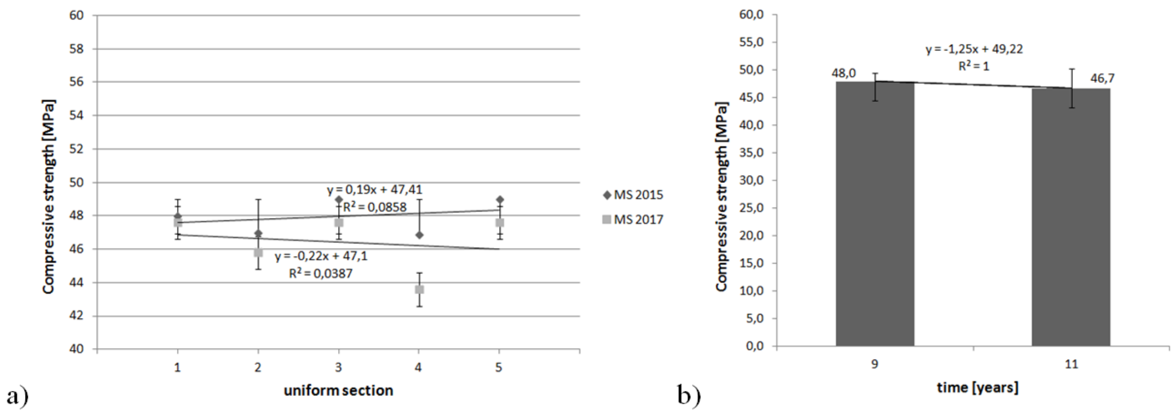

Figure 7. Average value of compressive strength - sclerometer test results - a) for uniform section (1-5), b) for the entire analysed pavement section in 2015 and 2017 (R^2 - correlation measure).

Based on the ground-penetrating radar reading, local relaxation of the structure was proved within the analysed section. The aforementioned loosening was found within sections located directly under the damaged expansion gaps (c). As a result of continuity disruption or absence of mixture filling the expansion gaps, in favourable conditions, due to migration of water and humidity deep into the pavement, degradation process of the structure progresses. Exemplary excerpts of echograms registered on the analysed road has been included in Figure 8. Within the analysed area, it was possible to determine cement concrete thickness, both in case of pavement surfacing (a) and base course (b). According to the obtained data, possible damages of structural layers of pavement were also determined. Within the entire analysed section damages within the area of layer interface (voids and delamination) (d) and damages within the area of individual layers (cracks and gaps) were identified (e).

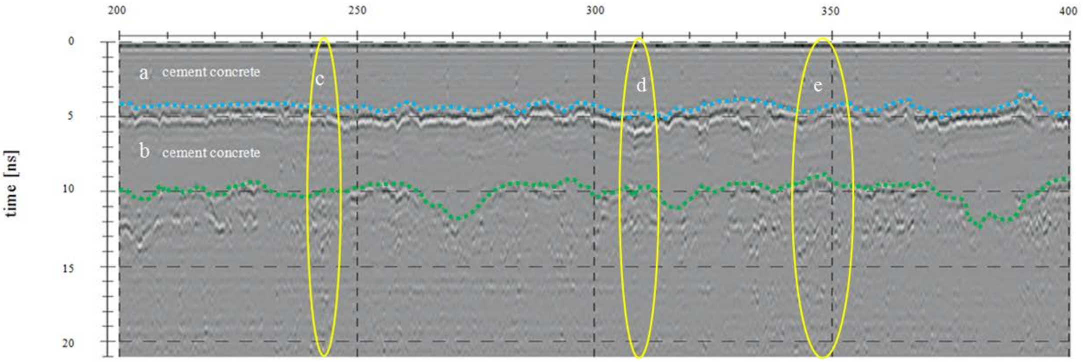

Figure 8. Exemplary echogram registered on the analysed pavement, KM 0+200 - KM 0+400.

4. Assessment of the influence of pavement operating time on the change of pavement parameters

The global pavement condition determined according to SOSN [11] and the determined indicators of the current technical assessment [4] prove very good pavement condition, which does not require any repairs. However, due to the fact that expansion gaps are the weakest element of concrete pavements and damages occurring within this area most often contribute to degradation of surface condition and the occurrence of damages within this section, the maintenance of expansion gaps filling is recommended in case of the entire analysed pavement. The occurred damages of this pavement element are the consequence of improper maintenance policy. Durability of the applied pourable sealant is maximum 5 years and it should be replaced by the new one afterwards. In the vicinity of the damaged gaps, there are rare corner damages which result from the insufficient slab support within this area. The change of slab support within corner area may be the consequence of water filtrated through untight expansion gaps filling. Damages of pourable sealant and local discontinuity thereof contribute to loosening of the structure and material washed-out and corrosion. With reference to thereof, in case of the analysed pavement, it is recommended to perform maintenance procedures concerning the replacement of the pourable sealant. Such solution will prevent the structure from damage progress.

Cracks of minor harmfulness occurring on the surface within the current period of time, do not require any repair procedures. It is recommended to apply surface treatment in the form of soaking components. However, it should be emphasised that constant monitoring of the condition of these cracks is necessary, as well as all the aspects which influence pavement technical condition. Delamination of concrete observed on the pavement surface prevailed within areas of the increased unevenness, where rainwater can cumulate during favourable weather conditions. The occurred damages did not exceed 3mm and were classified as shallow and did not require any repairing actions. However, reduction of surface destruction process is recommended. For this purpose, soaking components can be used, which will reduce surface water penetration deep into the structure through concrete sealing and reducing its absorbability.

Pavement, due to its texture parameters and roughness, does not require application of procedures which will increase this parameter in the current condition. According to the analyses of the obtained results - Figure 9 significant correlation between the examined characteristics was proved. The significance increases together with the extension of performance period. In case of the pavement after 9 years of operation, the correlation coefficient of the examined characteristics remains within the average level, while after the next 2 years of operation, it reaches the high level.

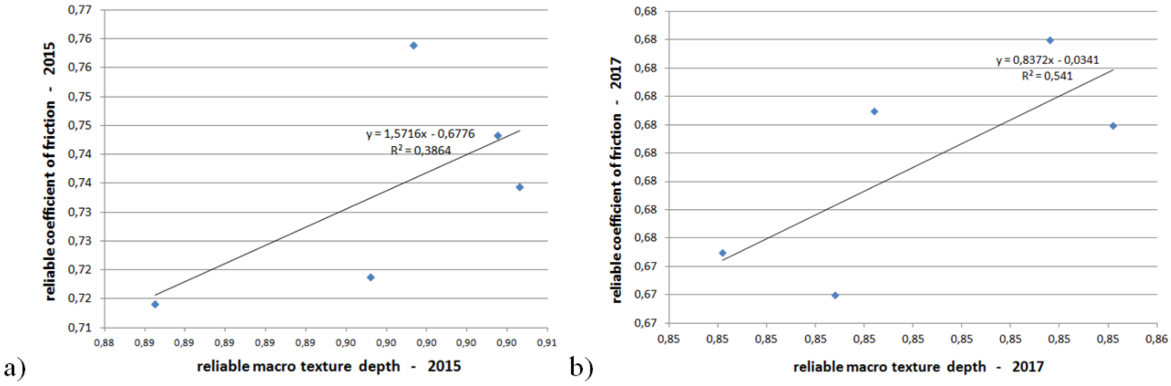

Figure 9. Correlation of pavement roughness and texture in 2015 (a) and 2017 (b).

Pavement evenness is good and it is not necessary to introduce any procedures aimed at the increase of this parameter during the current period of time.

5. Conclusions

According to the conducted research, the following conclusions were reached:

- The analysed pavement made of cement concrete is resistant to the occurrence of permanent deformations in the form of ruts, independent of operating time and weather conditions, within the analysed area and the applied load;
- The presented quantitative analysis has not proved significant damages and the global assessment of pavement condition proves good condition thereof;
- The pavement is distinguished by high performance parameters, which is referred to comfort and most of all, operation safety;
- Based on the ground-penetrating radar reading, local loosening of structure was proved within the analysed section. Which for the current situation not cause the significant threat to pavement durability.
- Advantages of concrete pavement meet users expectations, however due to the nature of expansion gaps, for proper structure operation it is recommended to clean local filler gaps and then filled in with pourable sealant.
- It is also necessary to analyse wear of the upper surface of concrete road in tribologic aspect. To justify thereof, pavement condition with respect to the change of its roughness, in the course of its operation should draw the attention, i.e. classic issue of friction occurring between vehicles moving on the pavement during slowing down.

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[12] Application guidelines of „Concrete Pavement Condition Assessment System", SOSN-B. Attachment 1: Concrete Pavement Condition Assessment System.
[13] Application guidelines of „Concrete Pavement Condition Assessment System", SOSN-B. Attachment 2: Catalogue of typical concrete pavement damages for the purposes of continuous quantity survey of damage using visual method, according to Concrete Pavement Condition Assessment System.
[14] Application guidelines of „Concrete Pavement Condition Assessment System", SOSN-B. Attachment C: Principles of measurement and assessment of bituminous pavement ruts condition, according to Pavement Condition Assessment System SOSN.
[15] Application guidelines of „Concrete Pavement Condition Assessment System", SOSN-B. Attachment D: Principles of measurement of assessment of anti-skid properties of bituminous pavements, according to Pavement Condition Assessment System SOSN.