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Road and Rail Infrastructure II

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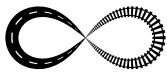
PRINCIPLES OF ROAD MAINTENANCE
BASED ON PERFORMANCE CRITERIA

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Abstract

Evaluation of technical condition based on performance criteria during service life of a road becomes extremely necessary in terms of cost efficiency in maintenance strategies in the road administration. Using existing technical regulations by combined analysis of the technical condition evaluation in the sense that it is desired a parametric quantification of degradation occurring by traffic loads and variations in environmental conditions, practically define the actual performance level of the road at the time field investigation.
This paper aims to present an assessment scheme of intervention to measures performance criteria based maintenance, which, moreover, has been regulated in Romania too.

Keywords: asphalt mixture, cracking, fatigue, permeability

1 The general framework of the paper

One of the criteria for assessing the performance of wearing courses quality is the waterproof characteristics of asphalt layer. The road structure behaviour is based on this property, throughout the life cycle, because the presence of the water in lower layers of a road structure leads to degradation of their physical and mechanical characteristics. A bigger influence of water, inside of a road structure, happens when the water contains elements from de–icing solutions used during winter time to fight against glazed frost. In these circumstances, knowing the state of road wearing course waterproof layer is extremely important to take necessary preventive measures, so that it be restored and preserved throughout the period of the road operation. This paper aims to propose a simple qualitative method for indirect identification of waterproof state of wearing course, by the degree of road surface cracking. Thus, the next steps of analysis are listed below:
· laboratory analysis to identify road permeability layer in asphalt mixture design stage;
· identification of the permeability of asphalt layer wearing course;
· determination of the performance quality index.
Of those listed above, it can be seen that asphalt wearing course that cracked, is the one without proper maintenance and can deteriorate further because of the humidity influence. Structural damage of a road depends on the aggressiveness of external factors, one of them being the humidity excess.
Severity of degradation depends on the cracking level, which allows infiltration of large amounts of meteoric water in the road structure. It works differently onto the structural composition of each layer according to the road material used in manufacturing and technical condition of the road depending on the time of analysis. Knowing the rate of cracking and the severity, assessed by Romanian Norm 540, it is possible to predict the degradation process by the procedure presented below.

Quantifying the carriageway surface induced cracks for the qualitative assessment in terms of excess moisture, is necessary so we can determine a remedial action for prevention of the development of structural damage to roads phenomenon.

2 The influence of structural porosity on wearing course

2.1 Wearing course permeability to water infiltration

Infiltrated water in the road structure has considerable influence on its durability. A cracked pavement, so permeable, acts adversely to the phenomenon of freeze–thaw action that adversely affects the mechanical strength of the overall road structure.
Existing in structure's road layers of micro–and macro–pores, capillaries, caves, micro–and macro–cracks are structural defects that reduce quality of each layer both in terms of meteoric water permeability and the terms of mechanical strength.
Water permeability is determined by road layer porosity and the distribution, size and type of pores and cracks. Theoretically, the water permeability can be assessed by the coefficient of permeability (к) given by Darcy:

$$K = \frac{Q \cdot h}{A \cdot t \cdot \Delta a} [m/s] \tag{1}$$

where: Q = water quantity [cm³] drained in time t [s]; A = sample's transversal area [m²]; h = thickness of the sample [m]; Δa = collapse pressure of the liquid column in the sample (meters of water column). Practically, the impermeability rate of the road surface layer is conducted by standard methods and depends on the depth of penetration of conventional water under certain pressure, in a certain time.

2.2 Asphalt mixture cracking

Asphalt cracking causes are multiple and depend primarily on the structural characteristics of road materials. The causes are: cracking because of aging, reflective cracking, fatigue cracking, fatigue from a wrong mixture design and other causes.
The presence of various phases of an asphalt mixture, from the elastic behaviour in the early phase of service life and the passing to an elasto–plastic and the plastic behaviour, precede rupture, leading to various stages of cracking from micro cracks to bigger cracks.
This development of the cracking process involves various stages of wearing course permeability, which allows gradual degradation of an entire road structure, thus the appearance of defects in lower layers (base and subbase).
Knowing the evolution of this process and proposing solutions to prevent the extension of road structure degradation is important to recognize the permeability properties of asphalt wearing course. Thus, the permeability quality at of a wearing course is a priority for improving the quality of road surface.

3 Laboratory analysis for permeability identification at mixture design stage

The starting point is given by Darcy's permeability law, which points out the permeability coefficient. In roads sector, this principle is applied by a well known test. Thus, the permeability of a road structure is measured in situ by an apparatus called 'permeability–meter', which consists of a tube under pressure applied on a road surface, sealed at the bottom. The water flow rate, both in situ and in laboratory conditions on plate type samples of asphalt mixtures, can be measured by this apparatus (Figure 1).

The water flow rate can be determined using the Darcy law and can be assimilated to a permeability coefficient. But in this formula the road surface is not pointed out. This parameter is extremely important because it must be in correlation with the cracking degree.
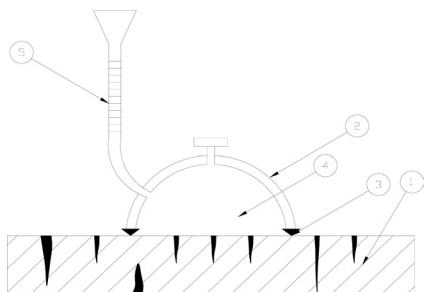

Figure 1 The permeability meter with its components: (1) Cracked wearing course, (2) Liquid measuring container, (3) Mastic sealer bead, (4) Measuring liquid (5) Graduated tube for measuring the gradient of liquid infiltration.

In this case a notion of permeability coefficient with the notion of permeability coefficient on cracked surface must be extended; κs and it will have the following meaning:

$$K_S = K / S \left[m^{-1} s^{-1} \right] \tag{2}$$

So the Darcy law will have the following shape:

$$K_S = \frac{Q \cdot h}{S \cdot A \cdot t \cdot \Delta a} \left[m^{-1} s^{-1} \right] \tag{3}$$

where: Q = water quantity [m³], drained in time t [s]; S = plain surface based on a cracked surface [m²]; A = sample's transversal area [m²]; h = thickness of the sample [m]; Δa = collapse pressure of the liquid column in the sample.

After the initial permeability coefficient kS1 is determined, then the cracked sample is controlled and the permeability coefficient on a cracked surface is determined.. In laboratory we can induce multiple stages of study to highlight the variation of permeability function of length and crack opening (Figure 2).
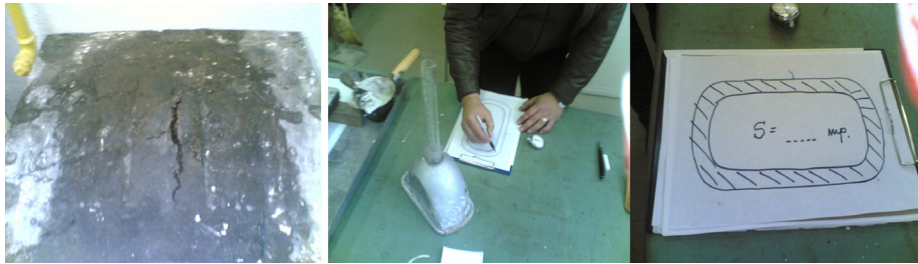
Figure 2 Photos during work

If we take into consideration a measuring device with recipient which has a contact surface with the carriageway surface of a square shape with L side (Figure 2), then the formula proposed for κ_s can be:

$$K_S = \frac{Q \cdot h}{L^2 \cdot L \cdot h \cdot t \cdot \Delta a} = \frac{Q}{L^3 \cdot t \cdot \Delta a}; \quad K_S = \frac{Q}{L^3 \cdot t \cdot \Delta a}\left[m^{-1}s^{-1}\right] \tag{4}$$

By indirect measurements κ_s depending on the cracking degree of the measured surface can be determined.

$$K_S = g_S \cdot g_F \tag{5}$$

where: K_S = permeability coefficient on investigated surface; g_S = severity grade of the cracked surface; g_F = cracking grade of the cracked surface.
These parameters are interdependent. κ_s can be determined by measurements performed in laboratory on reduced scale models. Depending on the cracking grade (g_F) the severity grade of the cracked surface can be determined. For material types used in road pavements κ_s are identified and observed according to the (g_F) and (g_S) and a grid of values can be determined for these two parameters.

4 Permeability identification of a wearing course in use

Subsequently measurements on experimental sectors can be made, with the aim being that depending on the coefficients (g_F) and (g_S) determined by the field visual measurements to assess κ_s as a quality parameter of the wearing course surface.
Quantitative determination of a cracked surface permeability through the permeability coefficient k_s, requires knowledge of a range of embedded parameters, as follows:

$$k_s = \frac{Q \cdot h \cdot d \cdot l}{S \cdot A \cdot t \cdot \Delta a} \text{ (mm.water column/s)} \tag{6}$$

where: Q = amount of water infiltrated; h = wearing course thickness; t = the measurement time; S = plane surface affected by crack; A = total surface of measurement; Δa = the pressure fall of the fluid column in the graduated tube Δa=35 cm; d = average crack opening; l = crack length.
When road pavement is not cracked, permeability coefficient $k_S^{(1)}$ is given by structural permeability (water infiltrated through the structural voids). When the pavement is cracked, permeability coefficient $k_S^{(2)}$ is given by the structural permeability cumulated with water infiltration through the crack. From here one can calculate the cracked surface permeability index (I_F) by reference to cracked surface:

$$I_F = \frac{k_S^{(2)} - k_S^{(1)}}{k_S^{(1)}} \cdot 100 [\%]$$

<div align="right">(7)</div>

4.1 Field permeability measurement conducting

In this way an area with a developed cracking system is analyzed by comparison with one adjacent carriageway surface which is not cracked. The reduced scale device (Fig. 3a) designed for laboratory testing which has useful area of 187.2 cm², will be extended as surface to the value of 6400 cm² (Fig. 3b). By expanding the measured surface by 37 times we aim to highlight the cracked surface, respectively identifying the cracking grade (g_F).

Thus, we first need to choose the measurement area for the representative cracked surface from the carriageway.
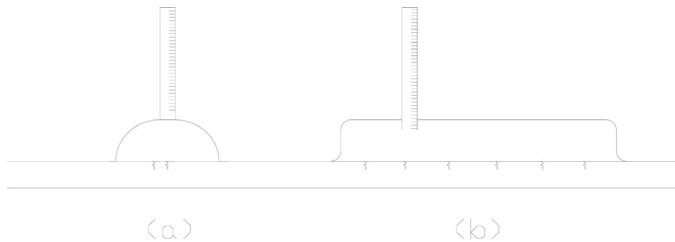

Figure 3   Laboratory (a) and field (b) measurement devices

To highlight the field measurement procedure of the permeability index (I_F), stages of investigation are presented successively through photographic images:
· laboratory measurement device compared to that intended for field measurements, according to the drawing shown in Fig. 3;
· measurement area delimitation (Figure 4, first photo);
· the mounting of the field device (Figure 4, second photo);
· selection of the measured surface I for comparison with the permeability of an uncracked surface II;
· measurement of crack affected area (S1) in relation to total uncracked area (s).

Figure 4   Surface marking; Sealing material application; Field device

After these operations what follows is the device laying on chosen 'footprint' and the performance of measurement of carriageway surface permeability (Figure 4). In figure 4 (third photo) an image with device vat and the graduated tube mounting is presented, as well as the reservoir and graduated tube filling to measure the infiltration time of a predetermined volume of water in the road surface.

4.2 Permeability field measurements results interpretation

Determine the area affected by cracks (S = total area covered by the measuring device of the field carriageway surface permeability, S_1 = area affected by cracks in the surface s), Figure 5. In this sense, one can interpret the permeability index of the cracked surface (I_F), using the relationship between permeability coefficient (k_s), cracking grade of the cracked surface (g_F) and the severity grade of the cracked surface (g_s), as follows:

$$I_F = g_s \cdot g_F \cdot \frac{k_s^{(2)} - k_s^{(1)}}{k_s^{(1)}} \tag{8}$$

where: $k_s^{(1)}$ = uncracked surface permeability coefficient; $k_s^{(2)}$ = cracked surface permeability coefficient. The cracking grade (g_F) is determined on analyzed surface as ratio of area actually affected by cracks and the total area analyzed (0.8 x 0.8 mp). The severity grade (g_s) of the cracking is determined according to the Standard AND 540 depending on the three stages.
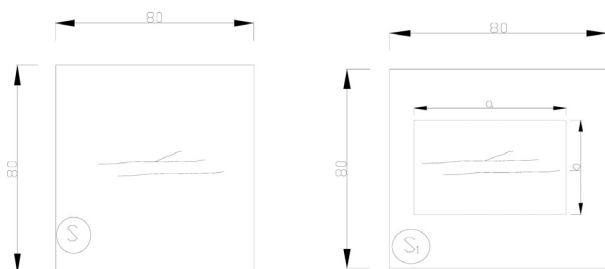

Figure 5   Cracked surface

Table 1   Severity grade

Severity grade	LOW	MODERATE	HIGH
Coefficient from AND 540	0.4	0.7	1.0

Coefficients were taken from the block cracking degradation type, considering the measuring area of device (0.8 x 0.8 mp). After the assessment, conditions to quantify the carriageway surface quality determined in laboratory, initially on the same type of road material, have changed, depending on effective permeability index (on field):

· $I_F \leq 0.2$ microcracked surface
          VERY GOOD impermeability
· $0.2 < I_F \leq 0.7$ cracked surface
          ACCEPTABLE impermeability
· $I_F > 0.7$ HARD−cracked surface
          BAD impermeability

In this situation the remedial measures of carriageway surface impermeability quality can be evaluated qualitatively as follows (Table 2):

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Table 2   Maintenance operations depending on the impermeability grade

For VERY GOOD impermeability – be kept under observation

For ACCEPTABLE impermeability – surface colmation

For BAD impermeability – be executed
ultrathin layers to seal the surface

5   Research conclusions

At the procedural analysis level, the research of stated problem has revealed a qualitative methodology for the permeability evaluation of a wearing course, by means of a performance coefficient which represents the ratio between the permeability of the un–cracked surface versus the cracked one.

With this methodology, laboratory tests were performed on plates manufactured in the laboratory. From the results interpreted it can be observed that the evolution of permeability coefficient after a similar mathematical relationship with Darcy law varies proportionally with the water flow infiltrated in cracked layer. It has been observed that the permeability index (I_p) increases with the growth of cracked surface.

Management systems require accurate data to support conclusions where and when to invest in maintenance, rehabilitation and road construction. In Romania, at this moment, the technical state analysis of the roads in service uses similar procedures as the U.S.A. program SHRP, which requires an assessment of technical condition indices on homogeneous road sectors, by observing the evolution of degradation state during exploitation of the road.

The permeability measuring method for road wearing course is in its research phase in Romania, whose technical regulations now condition only skid resistance and roughness as quality imposed to carriageway surface, thus minimizing the importance of wearing course impermeability.

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