Investigations regarding the degradation state of a Romanian country road

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Abstract. This study is aimed to identify and to describe some of the most common types of pavement degradations that may develop on some Romanian county roads. According to the road safety management system, The County Direction of Road and Bridge Administration has the responsibility to ensure the traffic conditions, by preventing or repairing any degradation that may have adverse effects on the ride’s safety and comfort. The most common types of degradations that can be identified on the Romanian county roads are: block cracks, longitudinal / transverse cracks, joint stepping, rocking, joint sealant defects and local declines. The process of interventions for restoring the road safety condition is continuous and span through the entire lifecycle of the structure (planning, design, build, operate, maintain and decommission). In order to illustrate the degradation state and to identify the most appropriate type of intervention required to restore the road safety condition, a case study is presented. The latter consists in a county road located in the Northern part of Romania (Suceava County), designated with the route number DJ 177A. The viability of the road was evaluated based on visual inspections and laboratory testing of its component materials. Based on the experimentally results several intervention works were suggested.

1. Introduction

The performance of road pavements degradation with the impact of the traffic volume and the effect of the environmental climate, in case of heavy traffic and severe environmental conditions, the road structure is usually designed as a concrete pavement, also referred as rigid pavement. This type of road structure is considered a long-lasting solution, since it possesses several advantages when compared to regular bituminous pavement [1, 2]. For example, the concrete pavements are suitable for road traffic with large point loads and they also withstand diesel spillage and other aggressive materials [3]. Moreover, the rigid pavements are suitable for cases where sub-grade strength is low and the road is exposed to high temperature. However, due to the evaporation and the hydration processes, the humidity of the concrete cannot be maintained in a close range. This phenomenon causes a negative pressure in the capillary pores and thus, produces drying shrinkage and cracks inside the concrete element [4].

According to the Romanian National Norm CD 155-2001 [5] the assessment of the concrete pavement performances is performed based on the value of the degradation evaluation index. The latter accounts for various degradations, including block cracks, longitudinal and transverse cracks, joint stepping, rocking, surface spelling and raveling. These degradations are, usually, caused by the gradually
accumulated damage of the pavement constituent materials, under the combined action of traffic load, humidity, light and temperature, in a significant period of time [6-10].

In order to illustrate the degradation state and to identify the most appropriate type of intervention required to restore the road safety condition, a case study is presented. The latter consists in a county road located in the Northern part of Romania (Suceava County), designated with the route number DJ 177A. The road starts from the Frasin town, near the bridge over the Suha River and connects two major roads of national interest DN 17 and DN 17B. It should be also noted that the DJ 177A connects the towns of Frasin and Broșteni (where the headquarters of several wood processing companies are located) and crosses the settlements of Frasin, Doroteia, Stulpicani, Ostra, Tarnița, Holda, cumulating a total length of 43.615 km. Thus, this road serves as the main route for the transportation of significant wood and timber cargos, between local producers and retailers. The geometry of the road consists in a 6 m carriageway (two driving lanes of 3 m width) bordered by two ballast shoulders, each having a width of 1 m. The degradation evaluation index was assessed by both visual inspections and laboratory testing of the pavement materials, including uniaxial compression test, indirect tensile test and static modulus of elasticity evaluation.

2. Pavement degradation index

In most of the cases, the evaluation index of concrete pavement serviceability for maintenance focus on the features related to driving safety, such as: the bearing capacity, the deflection state, the surface condition, the riding quality and comfort, the joints condition, and the skidding resistance [11, 12]. These six aspects of concrete pavement performance can be easily evaluated with automatic test equipment, such as deflectometers and bearing plates. However, the results provided by these devices represent the strength of the entire pavement structure and cannot be limited to the structural layers of interest. Therefore, the exact bearing capability of each individual course can be determined only through laboratory tests, performed on the pavement materials. In this manner, the evaluation index of the concrete pavement can be properly determined, by quantifying the contribution of each component of the structure.

2.1. Identification of the homogeneous sections for site investigation

According to the Romanian Norm AND 547-2013, the homogeneous sections for site investigations are determined by taking into account the following parameters: the traffic characteristics, the type of the road structure, the hydrologic type, the geometry of the transverse profile and the level of degradation (defined empirically by the grading good, medium or bad). The site evaluation sector located between km 0 + 000 and km 2 + 520 was selected to determine the evaluation index of the surface course of the county road DJ 177A. According to the design documentation, the road structure is homogeneous throughout the entire site investigation sector.

2.2. Degradation state of the site investigation sector

The evaluation of the degradation state of the concrete pavement was performed according to the provisions given in the Romanian Norm AND 547/2013. The concrete pavement of the county road DJ 177A consists in a thin-plate structure exposed to the external environment for 54 years. Due to various traffic loads and severe environmental conditions, several types of degradation were developed. The most relevant degradations that were identified during the visual inspection stage are described in the following.

2.2.1. Joint sealant degradation. This degradation consists in cracks that are developed in the seal material, creating a break path for external materials and substances to penetrate into the joints. The joint degradations do not disturb the road traffic, but favor the occurrence and development of several failure mechanisms. This is due to the atmospheric water, which can seep through the joints into the lower road courses and into the foundation ground. The joint sealant degradation of the county road DJ 177A is illustrated in figure 1.
2.2.2. Longitudinal cracks. This type of concrete pavement degradation consists in a large crack (over 3 cm), located at the longitudinal joints level. Similar to the joint sealant degradation, the longitudinal cracks can lead to water infiltrations in the lower structural courses. The longitudinal cracks developed on the county road DJ 177A are illustrated in figure 2.

![Figure 1. Joint sealant degradation on the county road DJ 177A.](image1)

![Figure 2. Longitudinal cracks developed on the county road DJ 177A.](image2)

2.2.3. Slab settlement/joint stepping degradation. The slab settlement degradation is characterized by the development of a level variation between the boundaries of two adjacent slabs. A concrete pavement is considered to have an unacceptable settlement when the differences between the longitudinal or the transverse levels among two neighbour slabs is greater than 5 mm. The slab settlement degradation occurred on the county road DJ 177A is illustrated in figure 3.

![Figure 3. Slab settlement/joint stepping developed on the county road DJ 177A.](image3)

2.2.4. Surface spalling/Ruptures. Usually, these degradations consist in a break down or a disintegration of the slab surface at edges, joints and corners. The surface spalling degradation can also be developed as a continuous path of cracks with variable depth that can even reach the thickness of the surface course. The ruptures occur either on small surfaces, or extended ones, along the entire length of the transverse joints. The surface ruptures developed on the county road DJ 177A are illustrated in figure 4.

![Figure 4. Surface spalling developed on the county road DJ 177A.](image4)

2.2.5. Transverse cracks. This degradation consists in a crack that develops transversely across the pavement/slab. Depending on the opening level, the cracks can be classified as active or passive. Active cracks are considered to have openings which increase or decrease with more than 0.5 mm at a daily variation of the concrete temperature above 10 °C.
The passive cracks are considered those whose openings remain almost constant as the concrete temperature varies. The transverse cracks that were identified on the county road DJ 177A are illustrated in figure 5.

2.2.6. **Longitudinal cracks.** This degradation consists in an unconnected crack that develops longitudinally along the pavement/slab. Typically, it occurs due to the settlement of the foundation layers, or due to the transverse contractions of the concrete slabs (triggered by uneven load bearing capacity throughout the carriageway width). The longitudinal cracks that were identified on the county road DJ 177A are illustrated in figure 6.

![Figure 5. Transverse cracks identified on the county road DJ 177A.](image1)
![Figure 6. Longitudinal cracks identified on the county road DJ 177A.](image2)

2.2.7. **Corner cracks.** This degradation consists in several diagonally arranged cracks, in a right-angled triangle pattern, whose hypotenuse connects a joint or a transverse crack with a longitudinal joint or a slab edge. These degradations can occur frequently on both sides of two adjacent slabs. The corner cracks that were identified on the county road DJ 177A are illustrated in figure 7.

2.2.8. **Potholes.** The potholes that develop in concrete pavements are characterized by a roundly shaped cavity, having depths greater than 3 cm. Generally, the potholes develop in heterogeneous segregated concrete pavements, by gradually material removal due to repeated traffic. The potholes that were identified on the county road DJ 177A are illustrated in figure 8.
2.3. Evaluation of the pavement degradation index
The pavement degradations were grouped by representative types, and then evaluated according to the provisions given in the Romanian Norm CD 155/2001. The surface degradation state is characterized by the pavement degradation index (ID=14.7), calculated with the following equation.

\[
ID = \frac{NDS}{S_{NS}} \cdot \frac{ID}{ID_{max}}
\]

\[
NDS = D1 + 0.5 \cdot D2 + (0.5 \cdot D3 \cdot N) \cdot S^{-1} + 0.3 \cdot D4
\]

where \(N\) = the number of slabs on a lane = 4 pcs.; \(S\) = the sector surface measured on a lane = 90 m²; \(D1\) = the number of slabs damaged by settlements = 1 pcs.; \(D2\) = the number of slabs damaged by filled potholes and crocodile cracks = 2 pcs.; \(D3\) = the area of the surface damaged by longitudinal, transverse and corner cracks = 52.2 m²; \(D4\) = the area of the surface damaged by ravelling = 0.

\[
NDS = 1 + 0.5 \cdot 2 + (0.5 \cdot 52.2 \cdot 4) \cdot 90^{-1} + 0.3 \cdot 0
\]

\[
NDS = 3.16 \text{ pcs.} \sim 3 \text{ pcs}
\]

2.4. The surface degradation rating criteria
The surface degradation rating criteria is established based on the pavement degradation index (ID), as presented in table 1 (CD 155-2001) [5]. As it can be observed, for the value of the pavement degradation index (ID) of 14.7, the surface degradation is considered to be “bad”. According to the Romanian Norm CD 155-2001, Appendix 7, mandatory maintenance works are required, generally consisting in laying either minimum two bituminous layers, or an equivalent concrete layer.

| Surface Degradation Rating | ID Value |
|----------------------------|----------|
| BAD                        | > 13     |
| MEDIUM                     | 7.5...13.0|
| GOOD                       | 5.0...7.5|
3. Uniaxial compression test
The uniaxial compression test is a well-established testing practice, which enables the evaluation of the compressive strength of various pavement materials [13].
Also, through repeated uniaxial compressive tests, the static modulus of elasticity can be determined. For this work, 8 cylindrical core specimens (4 for compressive tests and 4 for elasticity modulus evaluation) were extracted from the existing concrete course of the county road DJ 177A [14, 15]. The compressive tests were performed using a universal testing machine, Zwick Roell 1000 kN. The force-displacement variations are graphically depicted in figures 9-12. The ultimate compressive strength and the corresponding moduli of elasticity are listed in table 2.

| No. | h (cm) | Φ (cm) | Test type          | $F_{\text{max}}$ (kN) | $E_c$ (MPa) | $f_c$ (MPa) |
|-----|--------|--------|-------------------|------------------------|-------------|-------------|
| 1   | 19.20  | 9.10   | Compressive strength | 183.60                 | -           | 28.23       |
| 2   | 19.50  | 9.40   | Compressive strength | 250.00                 | -           | 36.02       |
| 3   | 18.50  | 9.30   | Compressive strength | 282.60                 | -           | 41.60       |
| 4   | 18.80  | 9.30   | Compressive strength | 211.60                 | -           | 31.15       |
| 5   | 19.90  | 9.40   | Modulus of elasticity | -                     | 33543.5     | -           |
| 6   | 20.20  | 9.30   | Modulus of elasticity | -                     | 28394.8     | -           |
| 7   | 19.80  | 9.30   | Modulus of elasticity | -                     | 43209.4     | -           |
| 8   | 19.20  | 9.30   | Modulus of elasticity | -                     | 35493.4     | -           |

Table 2. Compressive strengths and elasticity moduli.

Figure 9. Core sample 1. Force-displacement variation.
4. **Indirect tensile test**

The indirect tensile test is a commonly used test, performed to support the pavement design and to evaluate the courses tensile characteristics. Moreover, the indirect tensile strength is often used to
evaluate the fatigue stress at the bottom of the continuous courses. Most importantly, the cores extracted from existing concrete pavements, even those consisting in relatively thin layers, can be tested directly in the laboratory, by applying this test method. For this work, 4 cylindrical core specimens were extracted from the existing concrete course of the county road DJ 177A [16]. The indirect tensile tests were performed using a universal testing machine, Zwick Roell 1000 kN. The ultimate tensile forces and the ultimate tensile strengths are listed in table 3.

Table 3. Ultimate tensile forces and strengths.

| No. | h (cm) | Φ (cm) | Test type     | F_max (kN) | E_c (MPa) | f_st (MPa) |
|-----|-------|-------|---------------|------------|-----------|------------|
| 1   | 17.50 | 9.30  | Tensile strength | 72.00      | -         | 2.82       |
| 2   | 17.80 | 9.40  | Tensile strength | 82.40      | -         | 3.14       |
| 3   | 17.30 | 9.30  | Tensile strength | 95.00      | -         | 3.76       |
| 4   | 15.00 | 9.30  | Tensile strength | 91.20      | -         | 4.16       |

5. Conclusions
This work presents various investigations, performed both on site and on laboratory tests aiming to evaluate the state of a county road. Based on the visual inspection findings, it can be concluded that the road was inadequately exploited and the maintenance works that were conducted during the service life period were unsatisfactory. The degradations that were identified on the road surface cover a large spectrum of defects, which can negatively influence the ride comfort and the road safety conditions. Since the road administration did not perform the proper type of intervention works (only some asphalt laying on isolated surfaces), the required works to remedy the degradations are complex and expensive. The possible solutions consist in laying either minimum two bituminous layers, or an equivalent concrete layer. The pronounced variations of the elasticity moduli, of the compressive and tensile strengths indicates that the traffic was not consistent, most likely fluctuating between periods with heavy and light volumes. Also, the scattering of results indicates that the maintenance works were executed on isolated portions of the concrete pavement. If the maintenance works would have been executed on time and on the entire road surface, the mechanical characteristics of the course constituent materials would have ranged in a considerable narrow interval.

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