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Design, Materials and Construction Analysis of a Concrete Pavement

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Summary

The paper presents the performance analysis of a concrete pavement, conclusions of the investigation and recommendations made for ensuring its durability. The main causes of imperfections were established by an investigation performed at the request of the contractor of a concrete pavement made at the platform of an industrial company. The platform covers around 200 000 m^2, and was built in 2002. Since than, numerous maintenance works were done, especially by replacing the damaged panels. The purpose of the investigation was to identify the causes that led to an unacceptable performance of the concrete pavement claimed by the owner, and to recommend measures in order to ensure the future normal service of the pavement.

KEYWORDS: concrete quality, structural and functional performance, maintenance

1. INTRODUCTION

Concrete pavements can be designed for virtually any service life, from as little as 10 years to 60 years or more. The primary factors in the design life are the materials quality and slab thickness. However, pavement concrete mixtures with enhanced strength and durability characteristics should be combined with a performant conception and structural design to ensure long service periods.

The platform situated in the industrial zone of a Transylvanian city covers around 200 000 m^2, and was built in 2002 (Figure 1). Since than, numerous maintenance works were done, especially by replacing the damaged panels.

Concrete is able to provide a highly durable, serviceable and attractive surface, but the quality of concrete pavements is often affected by conditions over which the designer and contractor have little control.

By keeping the causes of the imperfections in mind, it is possible to reduce the probability of unsatisfactory results.

ISSN 1582-3024

Figure 1. The investigated concrete pavement

Contractors are not necessarily responsible for all imperfections. Poor design, unsatisfactory mixture proportions and improper service conditions are also implied. Some curling and cracking can be expected on every project due to the inherent characteristics of Portland cement concrete such as shrinkage.

2. DESIGN ANALYSIS

Various levels and frequencies of constructability reviews can be conducted, depending on the purpose and complexity of the project. Briefly, the problem is related to the whole life cycle analysis, so the decision has to be taken by choosing between the following two possibilities:

- Initial low cost pavement with important maintenance costs;

- Expensive initial investment with low maintenance costs.

The main objective of pavement design is to select pavement primary features, such as slab thickness, joint dimensions and reinforcing system to ensure the load transfer requirements, which will economically meet the needs and conditions of a specific paving project.

The goal of all pavement design methods is to provide a pavement that performs well. That means, to provide a serviceable pavement over the design period for the given traffic and environmental loadings.

A pavement desired performance is generally described in terms of structural performance and functional performance:

- Structural performance is the ability of the pavement to support current and future traffic loadings and to withstand environmental influences.

The structural performance of concrete pavements is influenced by many factors, including design, materials, and construction. The most influential design-related variables for structural performance at a given level of traffic are slab thickness, reinforcement, concrete strength and support conditions. The most prevalent type of structural distress is load-related cracking, which may appear as corner cracks, transverse cracks, or longitudinal cracks.

- Functional performance refers to the pavement ability to provide users a comfortable ride for a specified range of speed.

Most often, functional performance is thought to consist of ride quality and surface friction, although other factors such as noise and geometrics may also come into play. Functional distress is generally represented by a degradation of a pavement driving surface that reduces ride quality.

Both structural and functional distresses are considered in assessing overall pavement performance or condition. Even well-designed and well-constructed pavements tend to degrade at an expected rate of deterioration as a function of the imposed loads and/or time. Poorly designed pavements (even if they are well-constructed) will likely experience accelerated deterioration. Regarding to the above presented aspects, the analysis of the investigated pavement will be made as following.

There are three basic types of pavement construction. Each of these design types can provide long-lasting pavements that meet or exceed specific project requirements.

- Jointed plain concrete pavements: Because of their cost-effectiveness and reliability, the vast majority of concrete pavements constructed today are of this type. They do not contain reinforcement, and have the transverse joints generally spaced less than 6.5 m apart. They may contain dowel bars across the transverse joints to transfer traffic loads across slabs and also may contain tie bars across longitudinal joints to promote aggregate interlock between slabs.

- Jointed reinforced concrete pavements: This type of pavement contains both joints and reinforcement (e.g., welded wire fabric, deformed steel bars). The joint spacings are longer (typically about 9 to 12 m), and the dowel bars and tie bars are used at all transverse and longitudinal joints, respectively.

The reinforcement, distributed throughout the slab, composes about 0.15 to 0.25 percent of the cross-sectional area and is designed to hold tightly together any transverse cracks that could develop in the slab.

It is difficult to ensure that the joints are cut where the reinforcement has been discontinued.

- Continuously reinforced concrete pavements: They do not have any transverse joints, but they contain a significant amount of longitudinal reinforcement, typically 0.6 to 0.8 percent of the cross-sectional area. Transverse reinforcement is also often used. The high content of reinforcement influences the development of transverse cracks within an acceptable spacing (about 0.9 to 2.5 m apart) and serves to hold cracks tightly together. Some agencies use CRCP designs for high-traffic urban routes, because of their suitability for high-traffic loads.

The constructive system of the investigated pavement is an extension of the jointed plain concrete system (Figure 2), a bottom reinforcing mesh being introduced in order to sustain tensile stresses induced by heavy traffic. No information about the analytical design and durability design were received. A cross-section of the pavement under investigation, declared by the contractor and verified on site, is shown in Figure 3. Joints are placed correctly, delimiting panels with 1:1 aspect ratio (4.0×4.0 m and 5.0×5.0 m). Saw cut joints are 7 cm deep.

The pavement is framed by EN 206 provisions in the exposure class XF3 in relation with freeze-thaw attack (description of environment: high water saturation, without de-icing agents). Thus, related to the performance of the pavement, following remarks are necessary:

- The very small slope of 0.3% (e.g., recommended slopes are 2-3%, but not less than 1%), which leads to a very poor surface drainage. Pavements are exposed to severe humid environment conditions, and poor drainage amplifies the severity of the service conditions, accelerating aging of concrete and degradation of the pavement system;

- For the exposure class XF3, EN 1992 recommends the concrete class C 30/37 to ensure the proper durability. In the design, the concrete class C 16/20 was adopted, which presume less shrinkage but a lower permeability and more sensitivity to freeze-thaw cycles. According to the contractor, the choice of a lower class was taken in relation with the constructive solution, considering as target minimum shrinkage (and consequent lack of specific reinforcement – see paragraph below) since the strength is sufficient;

- The lack of top reinforcement suggests that the solution was adopted for a low initial investment. Concrete can not sustain tensile stresses and cracking of concrete pavement is inevitable. Thus, the system has no reinforcement which should keep within the acceptable limit (less than 0.2 mm) the crack widths, and visual inspection emphasized that this represents the major distress. Unsymmetrical disposed reinforcement also provides a higher restraint at the bottom of the slabs, giving support through the induced parasite tensile stresses to the occurrence and development of the cracks.

The consequence of this conception is that the pavement needs more often repair works by injecting and sealing the cracks in order to maintain its performance;

- The lack of dowels presumes a regular stiffness of the subbase and subgrade, with low softening sensitivity. The subbase level is below the minimum freezing depth (-0.80 m) in that area. Nevertheless, visual inspections revealed that practically there are no problems with the subbase and subgrade softening and frost heave. The satisfactory compacting of the subbase and subgrade is confirmed.

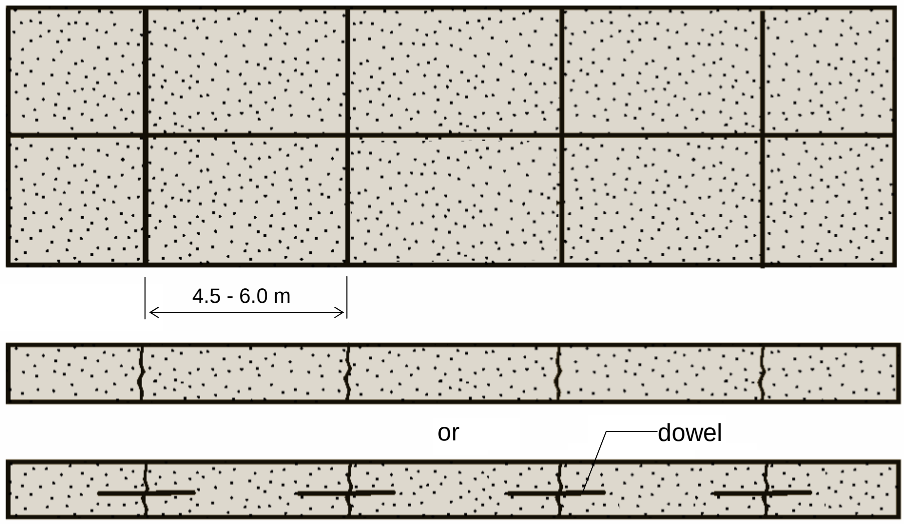

Figure 2. Jointed plain concrete pavement

ISSN 1582-3024

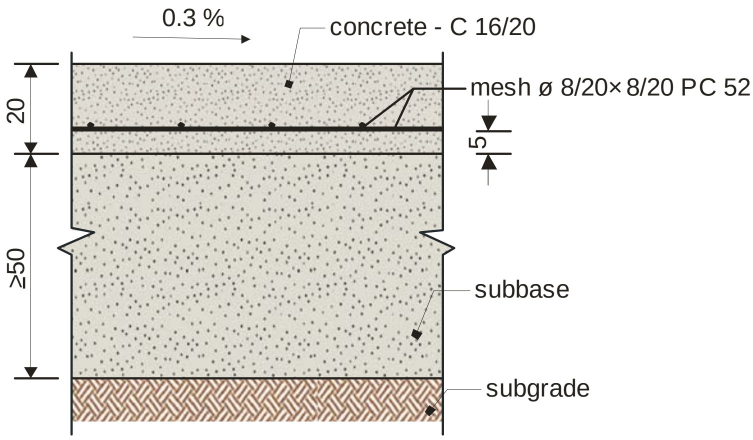

Figure 3. Detail of the pavement

3. MATERIALS AND CONSTRUCTION ANALYSIS

If compressive strength is enough to sustain the mechanical actions, and the structural performance was ensured at the time of the investigation, problems refer to the rest of the properties that influence the global performance of the pavement.

Mix design is fundamental in order to ensure a good quality concrete. The contractor did not specify any reference mix, mentioning that there were several suppliers for the fresh concrete. Visual inspections revealed that the most important factor of distress for the functional performance of the pavement is excessive cracking.

Studies revealed the short and long term evolution of the shrinkage strain for a typical C 16/20 mix, with 350 kg/m^3 of cement, and various weather conditions at concrete placing, both for Portland cement I 32.5 R and composite Portland cement II AS 32.5 R (with slag 6-20 %).

Peak temperatures are reached at 12-16 hours age of concrete, and the maximum temperature change and associated axial strains caused by volume contraction are shown in Table1.

Table 1. Reference temperature changes and volume contraction at the C 16/20 pavement

Weather conditions	Cement type	Maximum effective temperature change [ºC]	ε_v [‰]
cold	I 32.5 R	12.5	-0.125
moderate	I 32.5 R	9.6	-0.096
hot	I 32.5 R	11.2	-0.112
cold	II A-S 32.5 R	10.0	-0.100
moderate	II A-S 32.5 R	7.7	-0.077
hot	II A-S 32.5 R	9.0	-0.090

The inevitable cracks occur within the first week from concrete placing. Analysis crack widths reach about 0.4 mm in the case of cement I 32.5 R, and about 0.26 mm in the case of cement II A-S 32.5 R, both more than the allowable limit 0.2 mm. Considering the results of the analysis and the observations of visual inspections, appears obvious that the concrete mix contains cement type I 32.5 R and has a high w/c ratio, with greater shrinkage potential.

During repair works, the contractor replaced plain concrete with steel fibers reinforced concrete (20 kg/m^3), in order to reduce cracking. Because steel fibers are dispersed on the entire volume of the slab, this quantity is not enough to reduce significant the crack widths, its effect being a global increase of the ductility of concrete, property that practically has no significance for the analyzed problem.

Tests on core samples reveal that in some areas, concrete compressive strength is beyond the one prescribed by the design.

It should be noticed that due to the uncertain age of the tested concrete, this problem could be justified also by accelerated aging of concrete. However, supplementary analyses are necessary in order to determine if some of the cracks that are currently justified by early or heavy traffic, are caused practically to the insufficient strength of concrete.

Concerning the construction, it should be mentioned that visual inspections revealed a careful made construction process. No major imperfections can be justified by poor construction practice, even if it was performed and maintained in various weather conditions.

Another important distress factor is scaling and delaminating of concrete. This is obviously caused by the sensitivity of the superficial layer to freeze-thaw cycles, consequence of a high w/c ratio and great permeability (should be mentioned that the small slope is not correlated with the necessary properties).

Due to the severe exposure conditions, besides mechanical strength, other properties of the hardened concrete are critical and have to be considered:

- Permeability: concrete with permeability classes P8 (200 mm water penetration at 28 days under a pressure of 8 bars) or P 12 (300 mm water penetration at 28 days under a pressure of 12 bars) is commonly used in pavements;

- Gelivity (freeze-thaw resistance): concrete with freeze-thaw resistance from 100 cycles, up to 200 cycles are preferred for long term durability.

4. CONCLUSIONS AND RECOMMENDATIONS

The investigation made upon the concrete pavement is pointing out following conclusions:

At the time of investigation, the structural performance of the pavement was good;

Functional performance presents two important distress factors:

- Excessive cracking, due to restrained shrinkage of concrete and early and/or heavy traffic;

- Low freeze-thaw resistance, causing scalling and delamination of the superficial layers;

The degradation mechanisms related to the above mentioned distress factors are:

- Excessive cracking of concrete allows easily water to penetrate inside concrete. Low temperatures during winter transform the water in ice, which enlarge the initial volume and exerts pressure upon the surrounding concrete.

Thus, microcracks are developed and in short periods of time initial cracks present much larger openings. This aspect affects the functional performance, and in time also reduces the structural performance beyond the acceptable limit.

- High permeability allows water to penetrate the concrete, resulting in scalling and occurrence of new cracks that grow further following the above mechanism; high w/c ratio also led to significant delamination;

In order to ensure the future performance of the pavement and a reasonable durability, the recommendations are:

- Injection of the cracks with widths more than 0.2 mm at least once per year;

- Replacement of the panels with affected areas more than 80 % with a concrete based on a new mix design. Recommended concrete classes are C 25/30 or C 30/37. Recommended cement is II AS 32.5 R, and maximum water content derived from w/c $\leq$ 0.42. Air entraining admixtures to reduce porosity are also recommended;

- Because the shrinkage potential remains high, instead of injecting and sealing the excessive cracks, reinforcing of the superficial layer (at least 0.2 % reinforcing ratio) with a two-directional mesh is recommended.

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