Investigation upon Construction Technology, Operation and Maintenance Procedures for Slabs-on-Ground

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Abstract: - Even if concrete is able to provide a highly durable, functional and attractive surface, the concrete quality of slabs-on-ground is often affected by conditions over which the designer and contractor have little control. Some curling and cracking can be expected on every project due to the inherent characteristics of the Portland cement concrete, such as shrinkage. Nevertheless, poor design, inadequate mixture proportions and improper service conditions are key elements responsible for imperfections. By taking these causes into consideration, it is possible to reduce the inadequate results. The paper presents the main causes of imperfections established by an investigation performed at the request of the contractor of a concrete pavement made at the platform of an industrial company, located in the Transylvania Region, Romania.

Key-Words: - industrial slab-on-ground, concrete quality, structural and functional performance, maintenance

1 Background

Concrete is able to provide a highly durable, functional and attractive surface. Concrete pavements for industrial slabs-on-ground can be designed for virtually any service life, from as little as 10 years to 60 years or more. The investigated platform (Figures 1 and 2) is situated in the industrial zone of a Transylvanian city and covers around 200 000 m^2. It was built in 2002 and since then, a considerable amount of maintenance work has been done, especially by replacing the damaged panels.

The investigation was prepared at the request of the contractor of the concrete pavement made at the platform of an industrial company.

Figure 1. The investigated concrete pavement at the platform of an industrial company

Figure 2. The platform covers around 200 000 m^2

2 Research Significance

Concrete pavements are not maintenance free. The quality of concrete in industrial slabs-on-ground is often affected by conditions over which the designer and contractor have little control: some curling and cracking can be expected on every project due to the inherent characteristics of Portland cement concrete, such as shrinkage. But poor design, inadequate mixture proportions and improper service conditions are key responsible for imperfections.

The main causes of imperfections are: cracking of concrete due to plastic shrinkage and restraint to volume changes, curling and warping, early loading and loss of base support, low aggregate durability and frost resistance, excessive cracking caused by poor practices, dusting, scaling and mortar flaking, popouts, blisters and delamination, low wear resistance and joint spalling. By keeping the causes of imperfections in mind, it is possible to reduce the probability of obtaining unsatisfactory results.

Cracking of concrete is a frequent complain. It is mainly caused by the restraint (internal provided by the eventual reinforcement and external given by the continuous base support) to volume change, commonly brought by a combination of factors such as autogenously and drying shrinkage, thermal contraction, curling, settlement of the supporting system and loading. Some cracking can not be prevented, but they can be significantly reduced when the causes are well understood and properly controlled [1]:

a. Plastic shrinkage

Plastic shrinkage cracking is the result of the very rapid loss of moisture at the surface of plastic concrete, caused by a combination of factors like concrete and surroundings temperature, relative humidity and high wind velocity at the surface of concrete. When moisture from the surface of fresh concrete evaporates faster than is replaced by bleed water, the surface of concrete reduces its volume. Thus, within the superficial layer appear cracks with variable length, width and spacing. In time, combined with other phenomena, these shallow cracks may extend to the entire thickness of the element.

b. Restraint to volume changes

Concrete expands and shrinks with changes in moisture and temperature. The overall tendency is to shrink and this can cause cracking (Figure 3). External restraint to global volume change is provided by the subgrade, while internal restraint is generated between parts of the same element that present temperature gradients, moisture migration and embedded reinforcement. When the tensile stresses induced by the restraint to volume reduction exceed the tensile strength of concrete, the element cracks.

Figure 3. Transverse cracks due to restrained shrinkage

Temperature gradients generated by the heat developed during hydration of cement lead to a high temperature of the element. On cooling, the concrete element reduces its volume, while the supports provide an external restraint to it. Thermal contraction can result in strains of 0.14-0.35 ‰, the peak temperatures reaching more than 50 °C. For example, two new pavements using the same materials and mix design are placed on the same day only a few kilometers apart. On the day after placement, one pavement experiences random cracking; the other does not. The difference is: The first pavement was placed early in the morning. Its peak heat of hydration coincided with the hottest part of a summer day, resulting in a peak temperature of 49 °C. The second pavement was placed late in the afternoon. Its peak heat of hydration occurred during the cooler night, resulting in a peak temperature of 32 °C. Because of its higher set temperature and peak temperature, the first pavement experienced significantly more stress during cooling due to thermal contraction.

Drying shrinkage is the result of the loss of moisture from the cement paste constituent, which reduces its volume. The most important factors of influence are the w/c (it should be as low as possible), the dosage and nature of aggregates. Other significant factors may be the admixtures that influence the water content of the fresh concrete mixture. The major progress of this type of shrinkage lasts about 3 years, but continues during the entire lifetime of the structure.

Crazing (map cracking) is a network of fine fissures on the concrete surface that enclose small (12 to 20 mm) and irregular hexagonal areas (Figure 4). Shallow; often only 3 mm deep cracks may occur throughout the panel surface. This type of cracking is caused by restrained drying shrinkage of the surface layer after set (usually apparent the day after placement or by the end of the first week.).

Figure 4. A network of fine fissures on the concrete surface

It is often associated with the following:

- Overfinishing the new surface or finishing while there is bleed water on the surface;
- Mixes with high water-cementitious materials ratios (mixes that are too wet);
- Late or inadequate curing;
- Spraying water on the surface during finishing;
- Sprinkling cement on the surface to dry bleed water.

Some map cracking cannot be seen unless the pavement surface is wet. Visible crazing is somewhat unsightly but generally does not pose a structural problem. However, map cracks do permit water and chemicals to enter the concrete surface, so extensive map cracking may result in long-term durability problems.

c. Curling and warping

Volume change can also cause curling and/or warping.

Curling is caused by differences in temperature between the top and bottom of the slab. During cooler weather (e.g., at night or when a cold front comes through), the top surface of the slab cools more quickly than the bottom of the slab, which is insulated by the soil. The top part of the slab shrinks more quickly than the bottom, causing the slab to curl up at the edges. During hot weather conditions (typically, during the daytime), the top of the slab may be warmer than the bottom, resulting in curling in the opposite direction.

Warping of concrete pavements is caused by differences in moisture content between the top and bottom of the slab. During cool, moist weather (e.g., at night), the bottom of the slab may be drier than the top surface. The bottom of the slab therefore shrinks more quickly than the top, causing the slab edges to warp down. During warm, dry weather conditions (typically, during the daytime), the top of the slab dries and shrinks while the bottom remains moist, resulting in warping in the opposite direction.

Curling and warping actions may offset each other or augment each other. During summer days, for example, curling may be counteracted by warping. During summer nights, however, the curling and warping actions may compound each other. Along the joints, the pavement edges tend to curl upward when the surface of the concrete is drier and cooler than the bottom. Curling and warping are most noticeable at construction joints, but can also occur at cracks and saw-cut joints. At slab corners, the upward curl can be as much as 25 mm, but most slabs that have the curl repaired have edges that have risen 5 to 10 mm from the original plane. At construction joints that have no provision for load transfer, curling generally results in a loss of subbase contact over about 20% of the slab length between joints, twice the amount lost at saw-cut or doweled joints.

d. Early loading and loss of base support

Load is distributed through a concrete slab over a wide area, meaning that the base layer does not have to be particularly strong or stiff. However, at the edges and corners of a slab, there is less area to carry the load, resulting in higher loads and deflections in the base. This indicates that the edges and corners of a slab are particularly sensitive to loading (i.e., susceptible to cracking) before the concrete has gained sufficient strength.

Corner cracks (Figure 5) occur when a pavement carries loads that are heavier than its current strength can support and/or when there is loss of base support. For instance, early loading with heavy construction equipment can cause corner cracking. Furthermore, curled or warped slabs lose base support where the slab lifts away from the grade.

When loads are applied, the pavement will crack in the areas that have reduced support. If the base is not uniform, the slab will similarly lose support where the base is less stable than in the surrounding areas. Repeated loadings may also create voids under slab corners, and when loads are applied the pavement may crack where the support is weakened.

Figure 5. Corner cracks

e. Low aggregate durability and frost resistance

Concrete containing aggregates that are not frost resistant may experience *D-cracking*. Aggregate particles with coarse pore structure may be susceptible to freeze-thaw damage. When these particles become saturated and the water freezes, expanding water trapped in the pores cannot get out. Eventually, the aggregate particles cannot accommodate the pressure from the expanding water; the particles crack and deteriorate. In concretes with appreciable amounts of susceptible aggregate, this freeze-thaw deterioration of the aggregate ultimately results in cracking in the concrete slab, called D-cracking (Figure 6). D-cracking is generally a regional problem caused when locally available, susceptible aggregate is used in concrete. D-cracks are easy to identify. They are closely spaced cracks parallel to transverse and longitudinal joints (where the aggregate is most likely to become saturated). Over time, the cracks multiply outward from the joints toward the center of the pavement slab.

Figure 6. Closely spaced cracks parallel to transverse and longitudinal joints

f. Causes if excessive cracking

While cracking is not strictly a property of concrete, concrete always cracks. A certain amount of early-age, full-depth cracking to relieve tensile stresses is inevitable and normally does not pose a problem. However, the challenge is to control the number and location of these cracks. The excessive cracking is caused by the poor practices given below.

Construction joints spaced too far. Joints are used to limit the frequency and width of random cracks caused by volume changes, and to reduce the magnitude of slab curling. The designer should provide the layout of joints and joint details. If the joint layout is not provided, the designer before proceeding should approve the detailed joint layout and placing sequence. The following factors should be considered when selecting spacing of construction joints:

- Slab thickness;
- Type, amount and location of reinforcement;
- Shrinkage potential of concrete (e.g., cement type, cement content, aggregate size, aggregate quantity, aggregate quality, w/c, type of admixtures, concrete temperature, outside environment);
- Location and type of restraints;
- Layout of equipment pads, trenches etc.;
- Environmental factors (e.g., temperature, wind and humidity);
- Methods and quality of concrete curing.

For plain concrete slabs and slabs without superior reinforcement, joint spacing varies between 24 to 36 times the slab thickness, but not less than 1.5 m. The aspect ratio of slab panels should be between 1.0-1.5 (a ratio of 1 is preferred). L or T shaped panels should be avoided. Plastic or metal inserts are not recommended for constructing or forming a construction joint in any exposed slab surface that will be subjected to wheeled traffic.

Construction joints not deep enough (Figure 7). In order to limit the frequency and width of random cracks caused by volume changes, the joints create planes of weakness where cracks form.

Figure 7. Saw-cut construction joints were not deep enough, so cracking of concrete occurred in the vicinity

Saw-cut joints have a depth of at least 1/4 of the slab depth or 25 mm. For steel fibre reinforced concrete slabs, the saw cut using a conventional saw should be 1/3 of the slab depth.

Construction joints sawn too late: Saw-cutting should be performed before concrete starts to cool, as soon as the concrete surface is firm enough not to be damaged by the blade (the resulting jagged, rough edges are termed raveling), and before development of significant tensile stresses in the concrete and random drying shrinkage cracks occur (Figure 8).

Tipically, saw-cut joints produced using conventional processes are made within 4 h (in hot weather) and 12 h (in cold weather). When saw-cutting of joints is delayed, cracking and subsequent debonding occurs at the bottom of the sawcut (Figure 9).

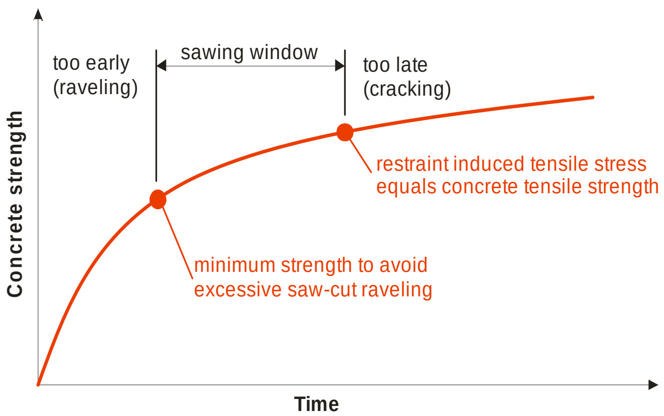


Figure 8. Sawing window showing the duration between minimum strength - when it is recommended to avoid excessive saw-cut (raveling) and the moment when restraint induced tensile stress equals concrete tensile strengths (cracking)

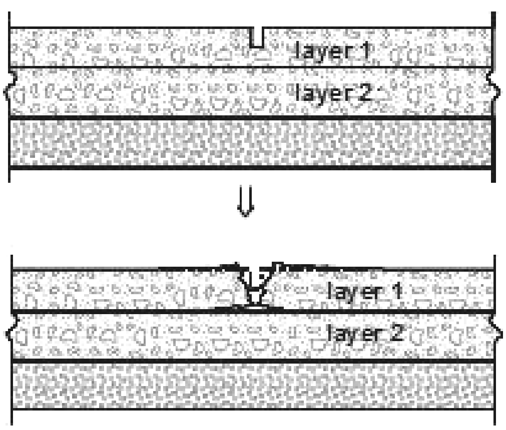


Figure 9. Cracking and subsequent debonding

Improper concrete mixtures: The concrete mix characteristics such as w/c ratio, cement type, aggregate type, admixture types, cement content and mix temperature affect the shrinkage rate of concrete.

Concrete mixes with high cement content and a very low w/c ratio (less than 0.30) are likely to develop significant autogenous shrinkage. Mixes with a too high w/c ratio (more than 0.50) contain an excessive amount of free water, which increases the porosity and results in high drying shrinkage.

- The use of cement that has inherently high shrinkage characteristics can increase overall shrinkage by 25%. Part of the Portland cement can be replaced with blast furnace slag or fly ash, to reduce heat generation from cement hydration;
- Contamination of the aggregate or the use of aggregate that is susceptible to expansion and shrinkage can cause serious shrinkage problems in all concrete mixes. It is important to incorporate the maximum coarse aggregate content possible in order to keep the cement paste portion of the mix to the minimum, while maintaining acceptable workability for ease of placement;
- Concrete mix should not include any admixture with high shrinkage characteristics. The use of accelerators to promote a faster gain in the concrete compressive strength is known to increase shrinkage and slab curling.

Improper curing: Improper curing intensifies differential shrinkage if the surface is allowed to dry too quickly. Adequate curing procedure is required for the mix design in order to meet traffic opening requirements, in association with in place monitoring of the strength gain, and even protocols to deal with adverse environmental changes or conditions.

Curing is applied to the surface and exposed edges of concrete soon after the concrete has been placed and textured. The proper time for applying curing compound to be approximately at initial set, when bleeding is complete. The purpose is to seal the surface that is, to prevent or slow water evaporation from the surface, so that hydration can continue for preferably seven or more days. The most common curing compounds are liquid membrane-forming materials.

Uneven base restraint: Due to its rigid nature, a concrete pavement distributes the pressure from applied loads over a larger area of the supporting material. As a result, deflections are small and pressures on the subgrade are low. Concrete pavements, therefore, do not require especially strong foundation support. More important than a strong foundation is a uniform foundation.

The subgrade should have a uniform condition, with no abrupt changes in the degree of support. That is, there should be no hard or soft spots. Non-uniform support increases localized deflections and causes stress concentrations in the pavement. Localized deflections and concentrated stresses can lead to premature failures, fatigue cracking, faulting, pumping, rutting, and other types of pavement distress.

Providing reasonably uniform support conditions beneath the concrete slab requires controlling three major causes of subgrade nonuniformity:

- *Expansive soils.* Excessive differential shrinkage and swelling of expansive soils can cause non-uniform subgrade support. As a result, concrete pavements may become distorted enough to impair riding quality;
- *Frost action.* Frost action includes the effects of both frost heave and subgrade softening. However, only frost heave is a consideration for concrete pavements. Field experience has shown that subgrade softening, which occurs in the spring, is not a design factor because strong subgrade support is not required under concrete pavements. Concrete pavement reduces pressure on the subgrade layers by distributing applied traffic loads over large areas. Concrete pavements designed for typical subgrade conditions will have ample reserve capacity for the two to three weeks of the spring softening of the subgrade. Frost heave occurs when ice lenses form in the soil, which continue to attract water and expand further. The heaving itself is not a problem for concrete pavements; rather, it is the subsequent thawing and differential settling of the concrete slabs that can lead to roughness and/or cracking;
- *Pumping.* Pumping is the forceful displacement of a mixture of soil and water (i.e., mud) from underneath a concrete pavement during heavy applied loads. Continued, uncontrolled pumping eventually leads to the displacement of enough soil so that uniformity of the subgrade is destroyed, which can result in cracking, faulting, and settling of the concrete pavement.

Poor drainage: Pavement drainage plays an important role in the overall performance of the pavement. The cracks and joints increase the amount of water infiltration into pavement and cause rapid deterioration of performance. Long-term accumulation of water inside the pavement reduces the strength of unbounded granular materials and subgrade soils, and causes pumping of fine materials with subsequent pavement rapid deterioration. When a pavement is saturated with water, heavy vehicle loads cause severe hydraulic shocks leading to pumping, disintegration of cement-treated base and overstressing of the weakened subgrade. Water is also responsible for a large number of non-load related distresses such as D-cracking and accelerated aging.

Other imperfections of concrete slabs-on-ground (Figure 10) are:

- *Dusting, scaling and mortar flaking:*

Dusting is another aspect of weak concrete. Dusting is the result of a thin, weak surface layer, called laitance, which is composed of water, cement and fine particles. However, dusting is more likely to be a problem when it occurs indoor.

Scaling is a physical deterioration mechanism aggravated by the use of deicing salts and freeze-thaw cycles. Salts that are used to melt snow and ice go into solution and penetrate concrete's pore structure, aggravating hydraulic pressures when the solution freezes. In addition, as the water freezes to ice, the salts are concentrated at the freezing site. Unfrozen water migrates toward the site due to osmosis. These osmotic pressures also cause cracking, scaling, and disintegration.

Mortar flaking over coarse-aggregate particles is another form of scaling. Is caused essentially by the same actions that cause regular scaling and often precedes more widespread surface scaling, but its presence is not necessarily an indication of the more extensive scaling.

- *Popouts, blisters and delamination:*

A *popout* is a conical fragment that breaks out of the surface of concrete, leaving a shallow, typically conical, depression. Being caused by mechanical impacts, a fractured aggregate particle may be found at the bottom of the hole. Unless numerous, popouts are considered a cosmetic detraction and do not generally affect the service life of the concrete.

Blisters are bumps that can range from 6 to 100 mm in diameter and approximately 3 mm deep. They appear when bubbles of entrapped air or water rise through the plastic concrete and are trapped under an already sealed, airtight surface. The appearance of blisters during finishing operations leave portions of the top surface vulnerable to delamination once that concrete hardens.

Delaminations are separations in a slab, parallel to and generally near the upper surface. Although the separations can be caused by rebar corrosion or freezing and thawing, on slabs on ground they are caused by a buildup of water and air beneath a dense layer of surface mortar. Because the water and air create a weakened zone, traffic causes the surface layer to break away from the base concrete. Typically the delaminated surface mortar is 3 to 10 mm thick and the affected area from a few square centimeters to more than a hundred square meters. Premature troweling can produce a dense layer of surface mortar by sealing the surface so air and water can not escape, but similar effects can be produced by atmospheric conditions that affect setting and bleeding, because delamination, bleeding and surface setting are interrelated.

Figure 10. Imperfections on the surface of concrete

- *Low wear resistance and joint spalling:*

Abrasion resistance is important for maintaining adequate texture and skid resistance on the concrete pavement surface for proper vehicular control. It is generally related to concrete's compressive strength and to the type of aggregate in the concrete (harder aggregates resist wear better than softer aggregates). Wear is usually minimal with concrete pavements unless vehicles with studs, chains, or metal wheels travel on the pavement, or unless poor aggregates and concrete are used.

Spalled joints are the result of excessive hand finishing or trying to fix the edge slump that occurs when the top edge of a freshly-placed, slipformed concrete pavement sags down after the slab is extruded from behind the pavers. Another cause is the early or heavy traffic, when the concrete can not sustain the local tensile stress concentrations induced by traffic.

3 Design Analysis

As shown in Figure 11, it is important to be mentioned that the pavement condition for industrial slabs-on-ground is a function of time and traffic.

The main objective of a pavement design is to select the pavement's primary features, such as the slab thickness, joint dimensions and the reinforcing system to ensure the load transfer requirements, which will economically meet the needs and conditions of a specific paving project [2]. Thus, 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 significant maintenance costs in future;
- Expensive initial investment with low maintenance costs.

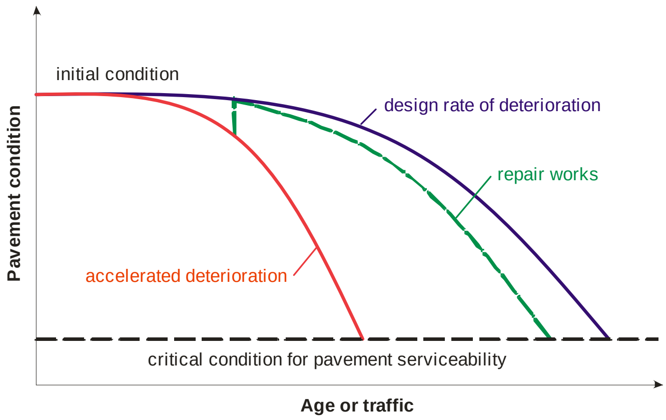


Figure 11. Pavement condition as a function of time and traffic

The aim 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. The desired pavement 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.
- Functional performance refers to the pavement's 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.

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. 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.

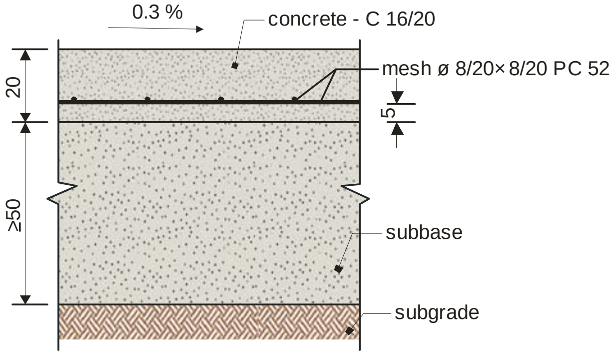


Figure 12. Detail of the pavement

The constructive system of the investigated pavement is an extension of the jointed plain concrete system, 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 12. 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 [3] 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.

4 Materials and Construction Analysis

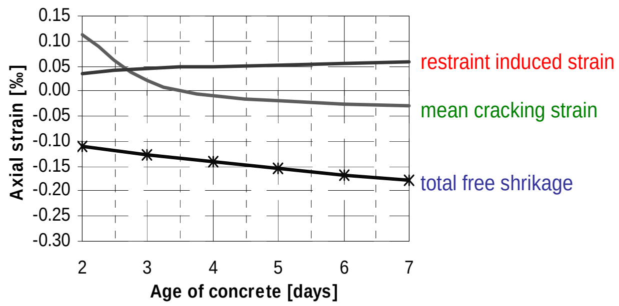
Mix design is fundamental in order to ensure a good quality concrete. The contractor did not specify any reference mix, mentioning that there were several suppliers for the fresh concrete. Visual inspections revealed that the most important factor of distress for the functional performance of the pavement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

During repair works, the contractor replaced plain concrete with steel fibers reinforced concrete (20 kg/m3), 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.

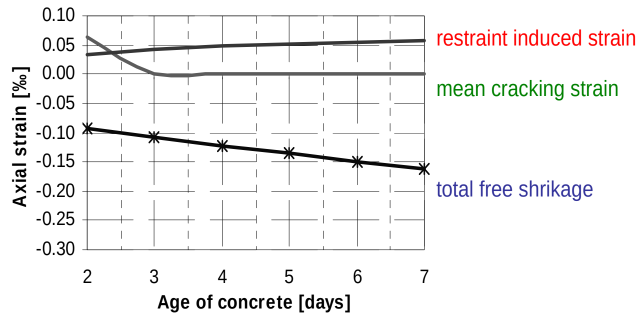
Another important distress factor is scaling and delaminating of concrete. This is obviously caused by the sensitivity of the superficial layer to freeze-thaw cycles, consequence of a high w/c ratio and great permeability (should be mentioned that the small slope is not correlated with the necessary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

Figures 13 and 14 present the short and long term evolution of the shrinkage strain for a typical C16/20 mix, with 350 kg/m3 of cement, and various weather conditions at concrete placing. The evolution is shown both for Portland cement I 32.5 R and composite Portland cement II AS 32.5 R (with slag 6-20 %).

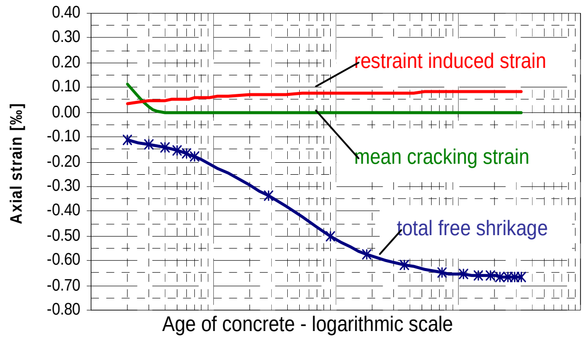


a. cement I 32.5 R, moderate weather



b. cement II A-S 32.5 R, moderate weather

Figure 13. Short term variation of the shrinkage strain for the reference mix C 16/20 in the concrete pavement



cement I 32.5 R, moderate weather

Figure 14. Long term variation of the shrinkage strain for the reference mix C 16/20 in the concrete pavement

The inevitable cracks occurred within the first week from concrete placing. An estimation performed with the procedure proposed by Mircea at all [4] shows that 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 of 0.2 mm.

5 Conclusions and Recommendations

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

The investigation made upon the concrete pavement is pointing out following conclusions [5]:

- 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 maintenance strategy of the pavement was wrong: instead of injecting and sealing the inherent cracks with

openings larger than 0.2 mm, cracks were allowed to evolve, maintenance work consisting in simply replacing the panels reaching an unsatisfactory condition state;

In order to ensure the future performance of the pavement and a reasonable durability, the recommendations are [6]:

- Injection of the cracks with widths more than 0.2 mm at least once per year;
- Replacement of the panels with more than 80 % affected areas with a concrete based on a new mix design. Recommended concrete classes are C 28/35 or C 32/40. Recommended cement is II AS 32.5 R, and maximum water content derived from $w/c \leq 0.42$. Air entraining admixtures to resist freeze-thaw and reduce permeability are also recommended;
- Because the shrinkage potential remains high, in-stead 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;
- In order to avoid a high consumption of reinforcing steel, checking on the need for bottom reinforcement is also recommended.

Studies revealed various methods for pavement treatment prediction [7] as well as diverse classifier used to identifying different type of cracks fast and with high accuracy [8]. Classifying cracks based on visual image is very important. A method for classifying cracks by using multi layer Perceptron (MLP) neural network is proposed by H.T. Shandiz et al [9]. Training data are road images which are taken from road surface in 30 degree, which are first changed to gray scale and then binary images are produced by using proper threshold gray level. The network is trained to perform tasks such as pattern recognition in order to classify each image to longitudinal, transverse etc. Image measurement methods are safe, and can be performed in a short time, and the results are close to those obtained by using the traditional methods [10].

Pavements for industrial slabs-on-ground usually experience many different types of imperfections due to repeated traffic loads, aggressive environmental conditions, construction materials, soil condition of the underline subgrade, and the method of construction. Therefore the early detection and measurement of the extent of defects joined with rapid reactive measures are essential to keep the pavement function at a suitable level.

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