Industrial Pavements Design

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ABSTRACT

The objective of this research is to describe a set of specific techniques and procedures for the proper construction of concrete pavements for industrial use, usually referred to as industrial pavements.

In particular, we will define the mechanical and rheological properties of concrete, necessary for the pavements to maintain the functionality for the entire life of the project. These properties are established taking into account the needs during the execution of the project, static and dynamic loads, and the possible conditions of aggression prompted by the environment in which the floor is located. The specifications about the materials for the construction of any surface layer resistant to abrasions must be determined. The materials used in the execution of the contraction joints, insulation joints and construction joints should also be determined.

The reinforcement, in concrete pavements, is generally present in the form of welded mesh, without structural functions. It must absorb the forces generated by movements of thermohygrometric nature. Besides welded mesh, may also be used metallic fibers. Adding fibers to concrete, creates a material with high ductility, capable to endure special stresses (such as accidental stresses caused by falling of metal objects, the strong braking of cars, by the forces of friction in the wheels of the vehicles along the curves, dragging heavy objects etc..) Establishing sufficiently metal fibers allows to increases the flexural strength of the slab. Fibers in the right form, section, length, amount may be added during the mixing of the concrete or they may be added directly to the object. Besides metal fibers, synthetic fibers with different characteristics and compositions can also be used. They have the same function as metal fibers.

Keywords: *industrial pavements, materials, reinforcement, environment.*

1. INTRODUCTION

In Albania, the rules for the design of the industrial pavements do not exist yet. Therefore this study is based on the European literature. There are several factors that must be taken into account during the design of this kind of pavements. We are going to analyze each one of them in this article.

The environmental conditions, which operate on the concrete pavements, should be taken into account for the pavement design, joints dimensions and the slab dimensions. In particular, the environment where the pavement is placed, determines the conditions of physical actions (e.g. freezing, merge) as well as chemical reaction (e.g. the presence of salts, acids etc.). The environment determines the atmospheric conditions, such as temperature, humidity, etc., which affect the slab thickness, joints of control and joints of isolation size.

Reinforcement, in concrete pavements, is generally in the form of welded mesh, without structural functions. It must absorb the forces generated by movements of thermohygrometric nature. Besides welded mesh, may also be used metallic fibers in order to reduce the number of cracks during the shrinkage of concrete in the concrete hardening phase.

The vapor barrier is generally formed in the form of polyethene sheets. It is placed before the execution of the concrete pavement and it is useful to prevent the capillarity of water. The barrier is necessary if the surface of the pavement will be covered with polyurethane. It may reduce the alkaline reactions but it may increase the differential shrinkage.

Precast concrete is prepared in the factories not in the yard. Concrete is mixed in fixed concrete mixers or in automatic concrete mixers. After the transportation to the yard, precast concrete is ready to be placed in the object.

The types of loads which operate on the pavement:

- Static point loads;
- Dynamic point loads produced by the different types of moving vehicles;
- Loads that are distributed on the surface e.g. loads from the different materials;
- Loads that are distributed in a line e.g. loads from the walls, pipes etc...;

The distinction between the types of loads applied on the pavement is based on their contact surface with the pavement. The flexural strength is very important for the pavement design.

Joints assure the continuity of the concrete slab. They must be able to cope with size changes of the concrete slab, ate the same time they ensure stresses transfer that operate on the pavement. There are different types of joints such as construction joints, shrinkage or control joints, expansion joints, isolation joints.

- *Construction joints* lie beyond the section of the pavement (slab). These kinds of joints are executed after pouring concrete in each part of the pavement. They allow horizontal displacements of the parts of the pavement, separated by joints. At the same time they provide shear stresses and flexural stresses transfer.
- *Shrinkage or control joints* are formed by mechanic slab cuts, in order to reduce the dimensions of its resistant section and to stimulate the creation of cracks in concrete. These joints avoid the accidental creation of cracks on the surface of the pavement. They do not avoid shrinkage during the hardening, but they do amortize its effect.
- *Expansion joints* are formed to amortize the effects of pavement dilation while the temperature changes. Usually these joints coincide with execution joints.
- *Isolation joints* are formed to provide independence to the pavement from the nearby structures, such as columns, walls, foundations etc... Control joints are formed by cutting a part of the concrete slab but isolation joints are formed by cutting the whole resistant section. Afterwards it is filled with a deformable material.

The foundation is part of the retaining layer of the basement which is directly in contact with the concrete floor. It may be just a layer of the ground or several layers of compressed gravel. In some cases, the foundation may be a concrete layer or may be formed by a single gravel or ballast layer which helps drainage.

Concrete floor or industrial pavement is usually called a concrete slab which is flattened on the surface. Than is added a layer with high resistance against friction. In order to provide high resistance to the upper layer, is applied a mixture made of water, cement and quartz on the surface of the fresh concrete.

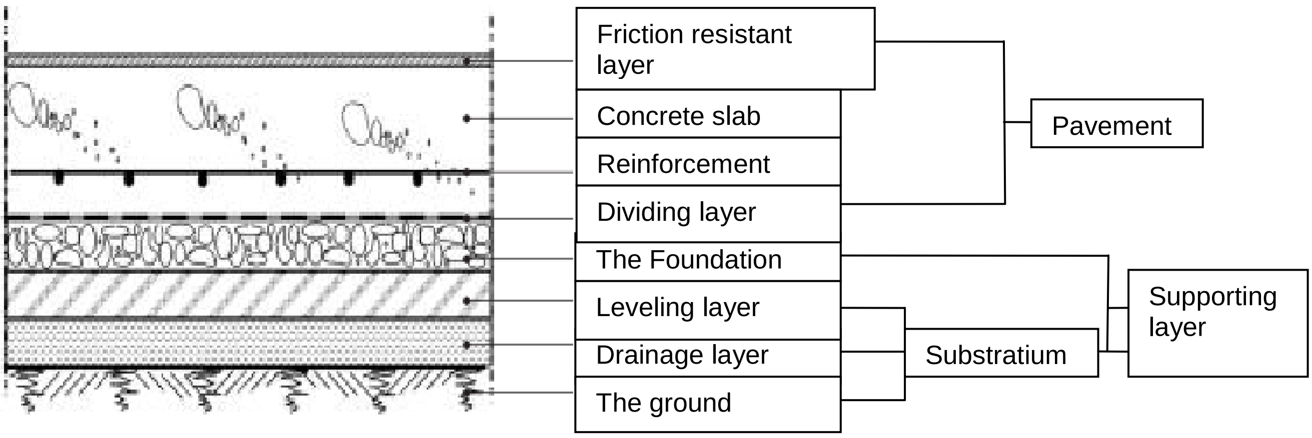
Matureness includes all the precautions including the observation during the process of concrete hardening. The objective of the matureness is to avoid the evaporation of water from the concrete to the outside which may provide cracks and may reduce cement hydration. Consequently it may reduce the mechanical strength of the concrete,

The slippery layer helps to reduce friction during contraction or dilation of the floor. It is made of:

- Sand layer, about 5cm thick.
- Textile synthetic layer
- Polyethylene sheets (vapor barrier)

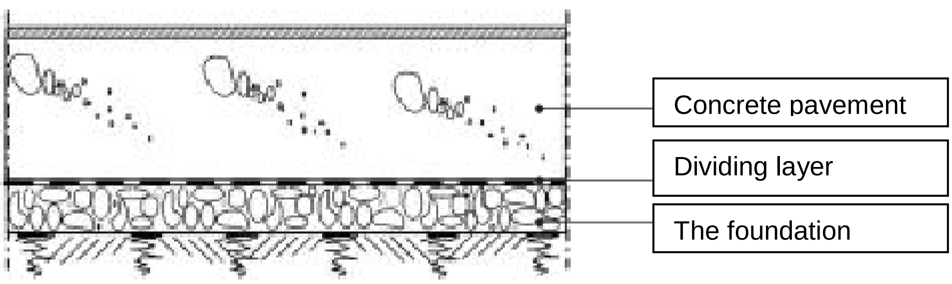
All the layers under the concrete pavement form the supporting layer.

The typical pavement based on the ground

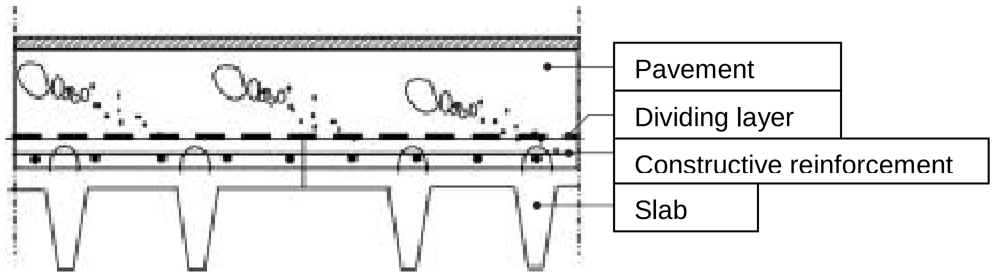


Constructive typologies

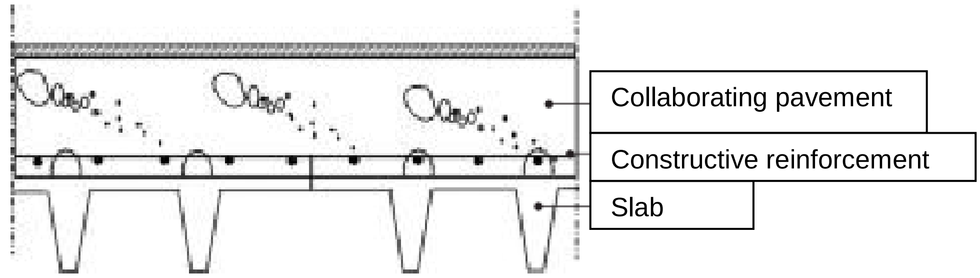
- Pavement based on foundation



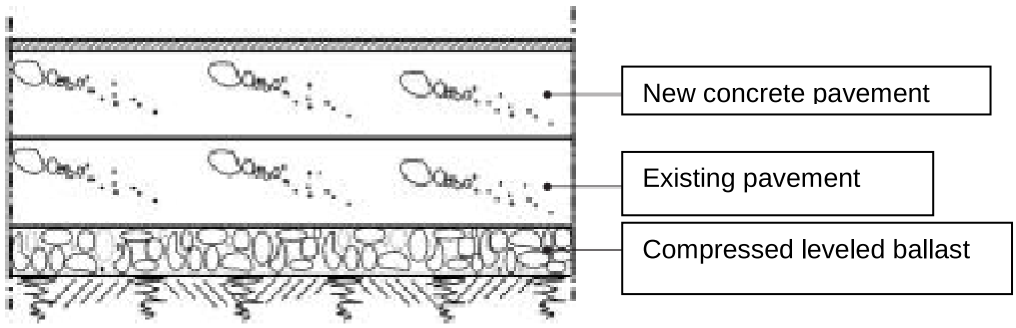
- Pavement based on the slab



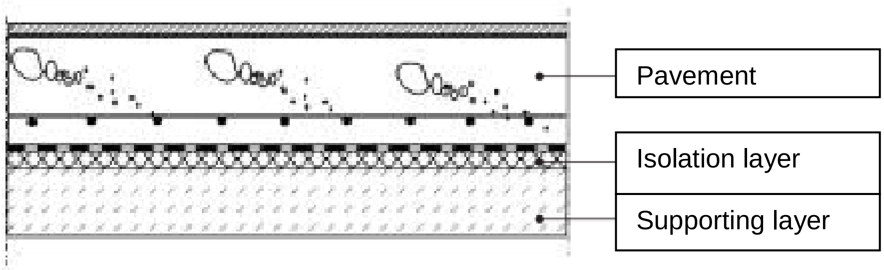
- Pavement collaborating with slab



- Pavement based on an existing pavement



- Pavement based on an isolation layer



2. Calculation methods

In order to calculate the concrete layers of the industrial pavements, the method requires calculating maximal flexural stresses by applying the theory of slabs placed on tensile basement (also called Winkler basement). This kind of basement produces a reaction proportional to cessation. The calculation parameters are:

- k-modulus of subgrade reaction (N/mm^3)
- h-Thickness of the pavement slab (mm)
- R_{ck} - Concrete compressive strength class (N/mm^2)

Forces:

- Uniformly distributed loads, such as machines, deposited materials etc.
- Dynamic loads, e.g. elevators, cranes, vehicles, etc.
- Fixed point loads, e.g. metal shelves, container support, etc.
- Maximal tensile strength (σ) all over must be smaller than concrete tensile strength (f_{ctd}).

$$f_{ctd} = f_{ctk\,0.05} / \gamma_c \tag{1}$$

$\gamma_c = 1.5$

The values of f_{ctk}, depending on the concrete classes, are shown in EC2, e.g. for concrete C25/30 f_{ctk}= 18 daN/cm^2

2.1 Dynamic loads (calculation method)

1) The formula to calculate the maximal tensile strength (σ) caused by a wheel which is in the center of the pavement slab :

$$\sigma = 1.264\ P\ (\log R/b + 0.267) / h^2 \tag{2}$$

P –Load applied on one wheel, (N)
R – Radius of relative stiffness, (mm)

$$R = [E\ h^3 / 12\ (1-\mu)\ k]^{1/4} \tag{3}$$

h – Thickness of the pavement slab, (mm)
E – Young's Modulus of pavement slab, (N/mm^2)
k – Modulus of subgrade reaction, (N/mm^3)
μ – Poisson's Ratio of the pavement slab
b –Correct radius, (mm)

$$b = (1.6\ a^2 + h^2)^{1/2} – 0657\ h \quad \text{if} \quad a<1.724h \tag{4}$$

$$b = a \quad \text{if} \quad a \geq 1.724h$$

a – Radius of contact area, (mm)

$$a=\left(\frac{P}{\text{wheel pressure}\,\pi}\right)^{1/2} \tag{5}$$

2) Calculation of σ^I which is located in the first wheel, caused by the other wheels :

$$\sigma^{I} = f(x/R)\ 6P / h^2 \tag{6}$$

x – Distance between wheels

Depending on the ratio x/R, the value of f(x/R) is determined on the table.

3) The total stress:

$$\sigma_{tot} = \sigma^{I} + \sigma^{II} + \sigma^{III} + \sigma^{IV} + \ldots \tag{7}$$

In order to maintain the floor undestroyed, we must assure that:

$$\sigma_{tot} \le f_{ctd} \tag{8}$$

2.2 Point loads

1) Equation (2) may be used to calculate stresses caused by different point loads such as metal shelves, container support, etc. In this case, we will accept this equation to calculate the radius of contact area:

$$a = (A / \pi)^{1/2} \tag{9}$$

A – The effective surface of point load, (mm^2)

It can also be applied:

2) Equation (6), to calculate stresses from nearby point loads.
3) Equation (7), to calculate total stresses.
4) Equation (8), in order to maintain the floor undestroyed.

2.3 Uniformly distributed loads

We calculate the maximum moment, when the critical width of the floor between two uniformly loaded columns coincides with the critical width. Flexural top and bottom moments:

$$M_{top} = 0.1682\ q / \lambda^2 \tag{10}$$

$$M_{bottom} = 0.1612\ q / \lambda^2 \tag{11}$$

The sign of the moment was not taken into account in Equation (10) and (11)

$$\lambda = (3\ k / Eh^3)^{1/4} \tag{12}$$

3. APPLICATION

In this example we will determine the number of repetitions for a slab that has a certain design thickness. On the slab are applied dynamic loads.

Concrete C20/25, $E=300000\ daN/cm^2$, $f_{ctd}=10\ daN/cm^2$, $h=25$ cm, $k=2\ daN/cm^2$, $\mu=0.2$, $P=3200$ daN, $p=2.6\ daN/cm^2$

Radius of contact area:

$$a = \left(\frac{P}{p\pi}\right)^{1/2} = \left(\frac{3200}{2.6\ \pi}\right)^{1/2} = 19.80 \text{ cm}$$

$$a=19.8 \text{ cm} < 1.724h = 43.125 \text{ cm}$$

Correct radius:

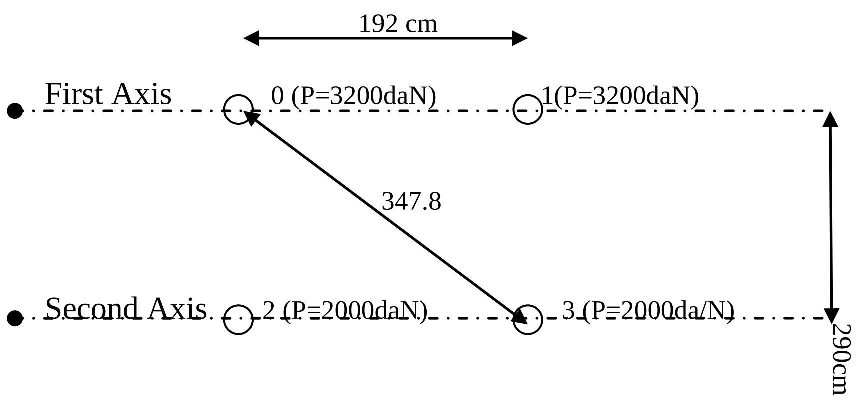
$$b = (1.6a^2+h^2)^{0.5} - 0.657h = (1.6\cdot 19.80^2+25^2)^{0.5} - 0.657\cdot 25 = 18.96 \text{ cm}$$

Radius of relative stiffness:

$$R = \left(\frac{E\cdot h}{12(1-\mu)k}\right)^{1/4} = \left(\frac{300000\cdot 25^3}{12(1-0.2)2}\right)^{1/4} = 125\text{cm}$$

The maximal tensile strength caused by a wheel which is in the center of the pavement slab:

$$\sigma_0 = \frac{1.264\ P\ [\log(R/b) + 0.267]}{h^2} = \frac{1.264\cdot 3200\ [\log(125/18.96)+0.267]}{25^2} = 8.02 \text{ daN/cm}^2$$



Total stress:

$$\sigma = \sigma_0 + \sigma_1 + \sigma_2 + \sigma_3$$

Stresses on the observed wheel, caused by the other wheels:

- On the first wheel is applied P_1=3200 daN, x_1=192cm

$$\sigma_1 = \frac{f(x_1/R)\ 6P}{h^2} = \frac{f(192/125)\ 6\times 3200}{25^2} = \frac{0.0266\cdot 6\times 3200}{25^2} = 0.8171 \text{ daN/cm}^2$$

- On the second wheel is applied P_2=2000 daN, x_2=290cm

$$\sigma_2 = \frac{f(x_2/R)\ 6P}{h^2} = \frac{f(290/125)\ 6\times 2000}{25^2} = \frac{0.0086\cdot 6\times 2000}{25^2} = 0.1651 \text{ daN/cm}^2$$

- On the third wheel is applied P_3=3200 daN, x_3=290cm

$$\sigma_3 = \frac{f(x_3/R)\,6P}{h^2} = \frac{f(347.8/125)\,6\times 2000}{25^2} = \frac{0.0049\cdot 6\times 2000}{25^2} = 0.0094\ \text{daN/cm}^2$$

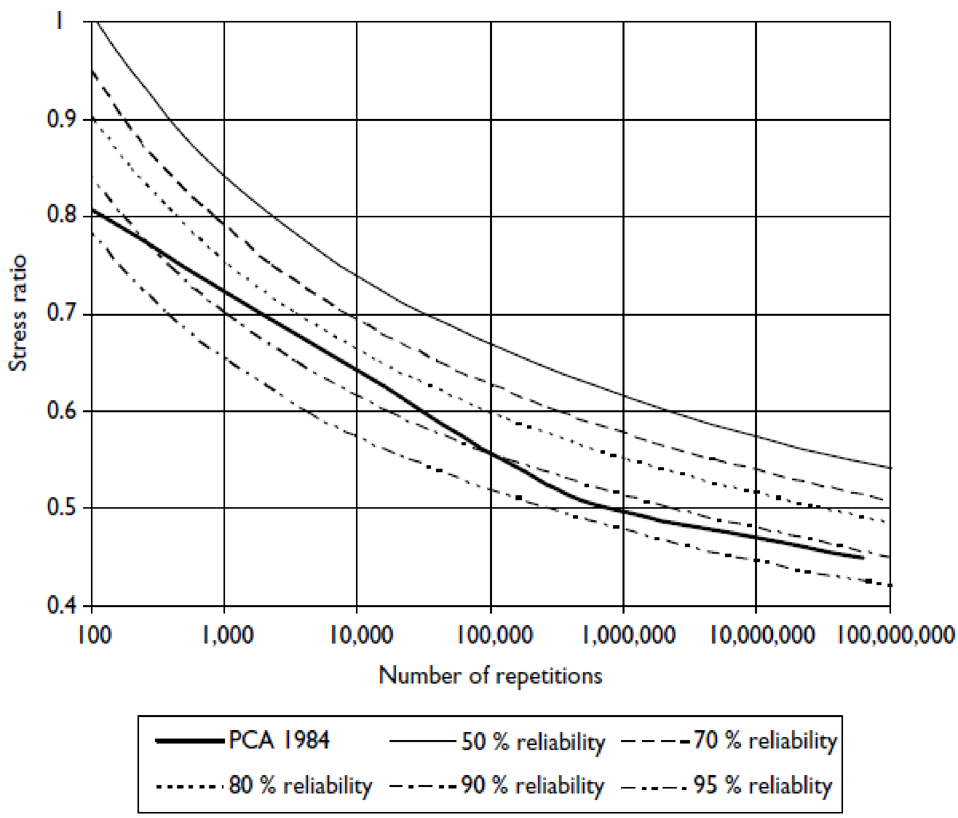
$$\sigma = \sigma_0 + \sigma_1 + \sigma_2 + \sigma_3 = 7.0286 + 0.8171 + 0.1651 + 0.0094 = 8.0202\ \text{daN/cm}^2$$

$$\sigma = 8.0202\ \text{daN/cm}^2 < f_{ctd} = 10\ \text{daN/cm}^2$$

Stress ratio (SR) between traffic-induced stress and the flexural strength of the concrete.

$$SR = \frac{\sigma}{MOR} = \frac{8.0202}{10} = 0.80202$$

MOR-Modulus of subgrade reaction



On this graphic, for SR=0.80202, we obtain the number of repetitions. In this case, this number is 100 repetitions. The result is not profitable, so we will increase the thickness, h=30cm. Following the same steps, for h=30cm, we calculate SR=0.612 and determine the number of repetitions (from the graphic) 77500.

4. CONCLUSION

Through this study we tried to present to the reader an overview of the factors that must be taken into account during the design of industrial pavements. We also presented methods to calculate this kind of pavements for different types of loads.

The analysis was made basing on a certain design thickness of the slab. According to the graphic we calculated the number of repetitions for the certain thickness. For every design thickness, the graphic would help the reader to determine the number of repetitions.

5. REFERENCES

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