CHAPTER II
PAVEMENT DESIGN
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1. **Types of road pavements**

A variety of materials may be applied for road pavement construction but generally two types of road pavements are used: asphalt and cement concrete (in the US, traditionally called Portland Cement Concrete - PCC). That difference is with respect to the material in the top layers of pavement.

Asphalt pavement has top layers made of asphalt mixtures (surface, binder and base courses). The bottom layer, sub-base, may be of mineral aggregate unbound or of hydraulically bound mineral aggregate (with cement, lime, fly-ash, etc.). In the first case, the asphalt pavement is called *flexible* (figure 1), in the second – *semi-rigid* (figure 2).

Cement concrete pavement consists of a stiff cement concrete thick slab on top of the sub-structure. The bottom layer is usually made of cement bound mineral aggregate mixture. This type of road structure is called *rigid* (figure 3). Depending on the type of steel reinforcement, three main types of rigid pavement may be listed:

- Jointed plain concrete pavements - JPCP
- Jointed reinforced concrete pavement - JRCP
- Continuously reinforced concrete pavement - CRCP.

A third type of road pavement appeared some years ago – *composite* pavement, which consists of a combination of both materials, asphalt and cement concrete. In most cases the asphalt layer is laid on top of a cement concrete slab. This type of composite may be called *black on white* (figure 4).

Some trials have been executed with the opposite composite pavement laying thin concrete slab on top of asphalt pavement. This type is called *white on black* (figure 5).
2. Modes of deterioration of road pavements

Every road pavement, independently of its type and materials applied, is subjected to certain traffic loads and environmental factors. This results in various modes of deterioration under in-service conditions. Modes of deterioration and the level of susceptibility of the pavement to various deteriorating factors depend on the type of pavement and materials applied.

Generally, one should consider the deterioration of the pavement in one or two modes:

- surface
- structure

In the case of asphalt pavements, the following modes of deterioration are considered:

- surface deterioration
  - decrease in friction (polishing)
  - permanent deformation of asphalt course (usually in the surface course): rutting
  - surface cracking
  - ravelling (stripping)

- structural deterioration
  - permanent deformation of sub-grade
  - fatigue cracking
  - reflective cracking.
In the case of cement concrete pavements the following modes of deterioration may be listed:

- surface deterioration
  - decrease in friction (polishing)
  - surface cracking
  - delamination
  - curling and warping of slabs
  - ravelling of joint sawcuts

- structural deterioration
  - cracking (bottom-up or top-down – JPCP, JRCP)
  - pumping
  - punchout (top-down – CRCP).

It is important to understand this differentiation because of the need for maintenance and to understand properly the term durability of pavement (or pavement life). Surface deterioration is a defect of pavement surface and improvement may consist in maintenance of the surface course only. Structural deterioration is a defect of the whole structure and improvement needs more extensive rehabilitation of pavement.

Source reference(s) for these definitions can be found in "Maintenance techniques for road surfacings, OECD, October 1978, or [6]".

3. Influence of climatic conditions

Changing service conditions on road pavements influence both asphalt and cement concrete pavements.

Warm climates affect asphalt pavements causing an increase in requirements for the use of stiffer binders and mixtures to combat permanent deformations. Rigid pavements subjected to high temperatures during construction are at great risk of early surface drying and "built-in defects" [1].

Environmental factors, such as water, de-icing salt and freeze-thaw cycles influence the performance of both materials, resulting in surface distress of pavement. However it is generally agreed that these factors affect rigid pavements more than asphalt pavements. Under the combination of environmental factors and other factors of chemical origin such as sulphate attack, deleterious alkali-silica (ASR) or alkali-carbonate reactivity (ACR), and delayed ettringite formation (DEF), rigid pavements more often show early, premature distress, after only 3 to 10 years [2]. Water penetrating into pavement structure through cracks or joints (often contaminated with salts and de-icing agents) deteriorates lower layers of the pavement and subsequently the whole structure. This is particularly frequent and more severe in case of cement concrete pavements [3].

4. Influence of traffic loads

It has been universally witnessed in recent years that both traffic volume and loads on roads are increasing. New types of vehicles with a rear triple axle of single wide wheels is beneficial for road users offering a more economically effective transport of goods, but on the other hand it exerts a more aggressive action on the road pavement.

For flexible pavements the influence of traffic loads on pavement deterioration is usually evaluated by transforming real axle loads to standard axle (e.g. 80 or 100 kN). This method enables real traffic to be expressed as a number of standard axles. The background of this method is an assumption that a given number of axle loads N to cause a certain pavement
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deterioration is compared to the number of standard axle loads \( N_{ESAL} \) required to cause the same deterioration. The resulting quotient is called axle factor:

\[
AF = \frac{N_{ESAL}}{N}
\]

The best known AASHTO load equivalency law is based on general relationship:

\[
AF_{r,i} = \left( \frac{R_{r,i}}{R_r} \right)^n
\]

where:

- \( AF_{r,i} \) axle factor based on pavement response \( r \) for axle type \( i \)
- \( R_{r,i} \) amount of pavement response \( r \) to axle loads of defined magnitude and designated as \( i \)
- \( R_r \) amount of pavement response \( r \) to the standard 80 kN single axle load
- \( n \) exponent, usually set to about 4 (for asphalt pavements)

AASHTO Axle Factors are significantly influenced by type of pavement: flexible or rigid [4], especially for tandem and tridem axles (it should be noticed that AASHTO Road Test included single and tandem axles, not tridem axles for which axle loads equivalency was analytically calculated). Comparison of AASHTO axle factors shows that tandem or tridem axles are more dangerous, more aggressive for rigid, cement pavements than for flexible, asphalt pavements. For instance, \( AF \) for a 160 kN tandem axle is 1,36 for asphalt but 2,48 for cement pavement (an 82% increase), \( AF \) for 240 kN tridem axle is 1,66 for asphalt while 4,16 for cement pavement (a 251% increase).

In the case of asphalt pavements, the critical design parameter is the tensile strain level at the bottom of the asphalt layer. Two axles closely spaced contribute in creating tensile and compressive strains which when superimposed produce a lower tensile strain than obtained by the simple addition of two single axle actions. In the case of rigid pavements, the critical parameter is the slab deflection at transverse joint. Two individual or tandem axles contribute in the same way – positively adding action of each other to the total deflection at the joint.

The new French pavement design method [5] based on results of pavement testing on the circular Accelerated Loading Facility at Nantes presents a comprehensive method for calculating aggressivity of traffic (axle or vehicle) loads.

Aggressivity coefficient \( A \) evaluates the fatigue deterioration of road pavement under the load \( P \) of one particular axle in relation to reference axle load \( P_0 \) according to the equation represented by the well known power law:

\[
A = K \left( \frac{P}{P_0} \right)^\alpha
\]

where:

- \( A \) axle aggressivity coefficient
- \( K \) coefficient of axle type: single, tandem, tridem, according to Table 1
- \( P \) axle load
- \( P_0 \) reference (standard) axle load
- \( \alpha \) exponent (index of power), depending on type of pavement according to Table 1.
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Table 1 - Coefficients $\alpha$ and K in dependence to type of pavement and axle configuration

<table>
<thead>
<tr>
<th>Type of pavement</th>
<th>$\alpha$</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Single axle</td>
</tr>
<tr>
<td>Flexible, asphalt</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Semi-rigid</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>Rigid, cement concrete:</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>• slabs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• continuous reinforcement</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

The aggressivity of the vehicle is calculated as the sum of the aggressivity of all axles of the vehicle. The aggressivity of traffic is calculated from:

$$CAM = \frac{1}{NPL} \left[ \sum_{i,j}^3 K_j n_{ij} \left( \frac{P_i}{P_0} \right)^{\alpha} \right]$$

where:

NPL number of vehicles in a design period
K$_j$ aggressivity of vehicles in particular groups, depending on rear axle configuration (single, tandem, tridem)
n$_{ij}$ number of axles of load P$_i$
P$_0$ reference (standard) axle load

A comparison of the aggressivity of axles and different vehicles on asphalt and cement pavements is given in Tables 2 and 3 (reference axle load 100 kN).

Table 2 - Aggressivity coefficients of axles

<table>
<thead>
<tr>
<th>Axle</th>
<th>Axle load, kN</th>
<th>Aggressivity coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Asphalt pavement</td>
</tr>
<tr>
<td>Single</td>
<td>60</td>
<td>0.08</td>
</tr>
<tr>
<td>Single</td>
<td>115</td>
<td>2.01</td>
</tr>
<tr>
<td>Tandem</td>
<td>80</td>
<td>0.25</td>
</tr>
<tr>
<td>Tridem</td>
<td>80</td>
<td>0.35</td>
</tr>
<tr>
<td>Tridem</td>
<td>100</td>
<td>1.10</td>
</tr>
</tbody>
</table>
Table 3 - Aggressivity coefficients of truck vehicles

<table>
<thead>
<tr>
<th>No. of</th>
<th>Total</th>
<th>Load distribution</th>
<th>Vehicle aggressivity coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>axles</td>
<td></td>
<td>Flexible pavement</td>
</tr>
<tr>
<td>1.</td>
<td>Truck</td>
<td>2</td>
<td>120</td>
</tr>
<tr>
<td>2.</td>
<td>Truck</td>
<td>3</td>
<td>200</td>
</tr>
<tr>
<td>3.</td>
<td>Articulated truck</td>
<td>4</td>
<td>290</td>
</tr>
<tr>
<td>4.</td>
<td>Articulated truck</td>
<td>5</td>
<td>300</td>
</tr>
<tr>
<td>5.</td>
<td>Articulated truck (Super Singles)</td>
<td>5</td>
<td>400</td>
</tr>
<tr>
<td>6.</td>
<td>Articulated truck (Super Singles)</td>
<td>5</td>
<td>490</td>
</tr>
<tr>
<td>7.</td>
<td>Articulated truck (Super Singles)</td>
<td>6</td>
<td>440</td>
</tr>
</tbody>
</table>

Special attention should be paid to exponent $\alpha$ in the above equations. Its value reflects the susceptibility of pavement material to increase in traffic load and resulting fatigue damage. For many years its value of 4 was established from the famous AASHTO Road Test conducted in years 1958-1960. For many years the same value of 4 was used in pavement design procedures independently of pavement type, for both flexible and rigid pavements [6].

Research by OECD in various countries provided data for evaluating value of power law exponent for asphalt and cement pavements [6]. In the case of asphalt pavements its value is considered to be 4 or 5 as far as fatigue resistance is concerned and 7 for rutting resistance.

In the case of cement concrete pavements the exponent for fatigue resistance is higher reflecting higher sensitivity of the rigid pavement to increase in traffic loading than flexible pavement. In Spain its value is in the range from 5.5 to 12.6 depending on slab thickness and length as well as climatic conditions (the longer or thicker slab the higher value). In Belgium its value is 14 and in Australia 12 (the same as in France).

5. Pavement design and pavement durability

5.1. Design principles

The structural deterioration of asphalt pavements is caused by traffic loads and is evidenced by both fatigue cracking of the asphalt surface course and the development of structural ruts. Both deterioration modes may be observed in the wheel paths. "Classical" fatigue cracking is induced at the bottom of asphalt layers and propagates to the surface. A "recent" type of fatigue cracking phenomenon has been observed over the last 15 to 20 years, which is a top-down cracking initiated at the top of pavement and propagating down the structure. This is, amongst other factors, caused by high confining and high tensile stresses in the top of the pavement structure.
In the case of asphalt layers, cumulative fatigue damage due to traffic loading causes the elastic stiffness modulus to decrease with the number of load repetitions. Depending on the total asphalt layers, the pavement may work in two modes according to Salam Y.M., Monismith C.L.: Fracture characteristics of asphalt concrete, AAPT, 1972, Vol. 41 and Doan T.H.: Les études de fatigue des enrobés bitumineux au LCPC. Bull. du LCPC, 1977, No. Special V:

- strain controlled
- stress controlled.

Thin asphalt pavements (below 60 mm) work in the strain controlled mode. This means that from the starting point of service life, strains in the bottom of the asphalt layer and in the top of the sub-grade are relatively high. Fatigue deterioration resulting in asphalt layer stiffness decrease will not change the strains considerably but will change the stresses. The asphalt layer is not the major structural component in such a pavement.

Thick asphalt pavements (above 150 mm) work in the stress controlled mode. This means that strains in the bottom of asphalt layer and in the top of sub-grade are relatively low. Fatigue deterioration resulting in asphalt layer stiffness decrease will have a minor effect on change in stresses but will change the strains. Here, the asphalt layer is the major structural component in such a pavement.

The basic principle of rigid cement concrete pavement design is that tensile stresses in the cement concrete slabs are below its flexural strength [Pavement Design and Management Guide. Transportation Association of Canada, Coordinator: Ralph Haas, 1997 or Rigid Pavement Design for Airfields. Elastic Layered Method. Dept. of the Army and the Air Force, Sept. 1988]. It is further assumed that a rigid pavement, because of its rigidity and high modulus of elasticity, tends to distribute the load over a relatively wide area of soil, and thus the structural capacity is supplied by the slab itself [7]. The rigidity of cement concrete slab may, however, lead to a false conclusion that the quality and properties of sub-base and soil sub-grade have no importance for rigid pavement behaviour, which may result in under design of the slab thickness.

Three types of JPCP distresses should be considered in pavement design [8]:

- bottom-up fatigue cracking
- top-down fatigue cracking
- joint faulting.

Both types of cracking (bottom-up or top-down) result from combined action of traffic loads and temperature conditions. Certain loading location – the truck axles near the longitudinal edge of the slab midway between the transverse joints – creates a critical tensile stress at the bottom of the slab. This tensile stress increases when a high positive temperature gradient occurs through the slab. It causes bottom-up cracking of the slab. Another loading location - the truck steering axle near the transverse joint and the drive axle within 3 to 6 meters away and still on the same slab – creates a high tensile stress at the top of the slab between the axles. This stress increases when there is a negative temperature gradient through the slab, a built-in negative gradient from construction, or significant drying shrinkage at the top of the slab. In both cases, repeated loadings of heavy axles result in fatigue damage of the slab.

Another type of distress is joint faulting which is the result of repeated heavy axle loading crossing transverse joints in combination with any of the following conditions:

- less than 80-100 percent load transfer efficiency
• an erodible base, sub-base, shoulder, or sub-grade
• free moisture beneath the slab.

This type of distress quite often results in severe loss of ride quality and early rehabilitation.

It should be underlined that the importance of sub-grade properties for cement concrete as well as asphalt pavements behaviour has been recognized. Significant changes have occurred in the design of cement concrete pavements with respect to the sub-grade properties required [7].

5.2. Design flexibility

From the design principles above, it may be concluded that an asphalt pavement is more flexible in design and applications. It may be designed for all kinds of roads from low to highest traffic loadings with significantly different total thickness of asphalt layers from 5 to above 300 mm. There are no limits from either a pavement design or an asphalt pavement technology point of view. Asphalt pavement is a "tailor-made" type of product.

A rigid pavement is limited by the thickness of the cement concrete slab. High stiffness and high susceptibility to cracking under tensile bending stresses means that it must not be too thin. Thus for low traffic roads, cement concrete pavement will be, by definition, "over designed" in the sense that the pavement design is dominated by the highest expected axle load. The design of a cement concrete pavement is totally different from the design of an asphalt pavement since the designing is not dominated by the highest expected axle load.

Table 4 presents a comparison of typical pavement structures designed for heavy or low traffic according to catalogues of three European countries: France, Germany and Italy. In all cases, sub-grade properties and traffic loadings are the same. This comparison shows that:

• Designed period (traffic) and material characteristics have more significant influence on the thickness of asphalt pavement than cement concrete pavement; it reflects the influence of cement concrete technology and less variability allowed than in case of asphalt pavement;

• When conventional, standard quality asphalt mixtures are applied, asphalt pavement for the highest traffic category is thicker than continuously reinforced cement concrete pavement, but for lower traffic category the pavement thickness for both pavement types is almost the same;

• Application of high quality, innovative high stiffness modulus asphalt mixtures allows for significant decrease of asphalt pavement thickness; such a pavement is even thinner than continuously reinforced concrete pavement designed for 30 years service;

• Asphalt pavements for low traffic roads are roughly twofold thinner than cement concrete pavements;

• In some countries (e.g. France) cement concrete pavements are no longer used for the low traffic roads.
### Table 4 - Comparison of pavement thickness

<table>
<thead>
<tr>
<th>Country</th>
<th>Traffic</th>
<th>Subgrade</th>
<th>Asphalt Structure</th>
<th>Total thickness of asphalt layers, cm</th>
<th>Cement concrete Structure</th>
<th>Total thickness of cement concrete layers, cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>France [8]</td>
<td>TC8₃₀ (&gt;75 mil ESAL130)</td>
<td>PF3</td>
<td>GB2/GB2</td>
<td>46 (8+12+13+13)</td>
<td>BAC/BC2 (CRCP/lean concrete)</td>
<td>38 (20+18)</td>
</tr>
<tr>
<td></td>
<td>TC8₃₀ (&gt;75 mil ESAL130)</td>
<td>PF3</td>
<td>EME2</td>
<td>34 (8+13+13)</td>
<td>BC5g/BC2 (JRCP/lean concrete)</td>
<td>40 (22+18)</td>
</tr>
<tr>
<td></td>
<td>TC5₃₀ (4.5-11.3 mil ESAL130)</td>
<td>PF3</td>
<td>EME2GB2/GB2</td>
<td>31 (8+11+12)</td>
<td>BAC/BC2 (CRCP/lean concrete)</td>
<td>32 (17+15)</td>
</tr>
<tr>
<td></td>
<td>TC5₃₀ (4.5-11.3 mil ESAL130)</td>
<td>PF3</td>
<td>EME2/EME2</td>
<td>21.5 (2.5+9+10)</td>
<td>BC5g/BC2 (JRCP/lean concrete)</td>
<td>34 (19+15)</td>
</tr>
<tr>
<td></td>
<td>TC2₃₀ (&lt;0.2 mil ESAL130)</td>
<td>PF3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Germany [9]</td>
<td>Bauklasse SV (VB&gt;3200)</td>
<td>&gt;120 MPa</td>
<td>A0, 1, 1</td>
<td>34 (4+8+22)</td>
<td>A0, 2, 1 (JRCP/lean concrete)</td>
<td>41 (26+15)</td>
</tr>
<tr>
<td></td>
<td>Bauklasse III (VB=300-900)</td>
<td>&gt;120 MPa</td>
<td>A3, 1, 1</td>
<td>22 (4+4+14)</td>
<td>A3, 2, 1 (JRCP/lean concrete)</td>
<td>37 (22+15)</td>
</tr>
<tr>
<td></td>
<td>Bauklasse VI (VB&lt;10)</td>
<td>&gt;100 MPa</td>
<td>A6, 1, 1</td>
<td>10 (10)</td>
<td>A6, 2, 4.1 (JPCP)</td>
<td>16 (16)</td>
</tr>
<tr>
<td>Italy [10]</td>
<td>45 mil CV</td>
<td>&gt;150 MPa</td>
<td>N. 1F</td>
<td>42 (6+7+29)</td>
<td>N. 1RC (CRCP/lean concrete)</td>
<td>42 (27+15)</td>
</tr>
<tr>
<td></td>
<td>0.4 mil CV</td>
<td>&gt;150 MPa</td>
<td>N. 8F</td>
<td>19 (5+6+8)</td>
<td>N. 8RC (CRCP/lean concrete)</td>
<td>31 (16+15)</td>
</tr>
</tbody>
</table>
Layer bonding plays a crucial role in the pavement design analysis and service life of road pavement, independently of its type. Each layer plays a different role in the pavement structure. The surface course is to provide a safe interaction between wheel and pavement surface, whereas the binder and base course have to transfer traffic load to the sub-grade.

This enables designs which combine layers having significantly different properties, e.g. a thin surface course with relatively soft polymer-bitumen and mineral aggregate of properties specified with regard to skid resistance and a thick base course of high stiffness modulus with hard binder to provide a higher bearing capacity and a longer service life. Both layers may be effectively fully bonded. A hard binder sometimes leads to a shorter fatigue life.

With respect to the above-mentioned, a great advantage of asphalt pavement over cement concrete pavements is the ability to bond a multiple layer structure in one fully bonded body. It has been practically proved that bonding of consecutively laid asphalt layers may be full providing cooperation of layers in the structure.

In the case of cement concrete layers bonding is very difficult and problematic. If there is not a full bonding between the layers there is separation of each layer. The result is that the stiffness of the pavement is lower than expected and furthermore, while the top layer works separately from the bottom slab, it suffers from the premature fatigue deterioration. In the case of Bonded Concrete Overlays (BCO) it has been shown [11] that if full bonding were achieved between the layers, 25% increase in pavement thickness would lead to 95% increase in stiffness. If, however, there was no bonding between the layers, the increase in stiffness would be only 1.6%.

Increase in traffic loadings and the resulting under design of road structure have a less severe effect in the case of asphalt pavements.

Flexible pavements also offer advantage of the ease of maintenance.

On the contrary, under design is more deteriorating in the case of cement concrete pavements. Furthermore, comparing both flexible and rigid structures, it may be considered as a natural trend to under design the more expensive cement concrete pavements which result in shorter life expectancy. This concerns the whole range of road pavements for both low and high traffic volume.

Flexibility in the design of asphalt pavements comes also from the potential of the staged pavement design. Therefore asphalt pavements may be designed to allow future, foreseen increases in traffic. The thickness of the asphalt layer may be fitted to the needs of the pavement design. There are no limitations of technology for either production and laying operations or bonding with the existing layer. In the situation of funding constraints, instead of constructing a thick final structure, the pavement construction may be relatively thin initially and then it may be overlaid in stages, reflecting the traffic increase.

A report prepared by World Road Association (AIPCR/PIARC) [12] has concluded: "There is no known technical limit to the use of asphalt in severe traffic and/or climatic situation".

Asphalt mixes may be used in a variety of applications, in thick or thin road structures. The visco-elastic nature of a bituminous binder with its associated healing effect causes an asphalt pavement to react "forgivingly" for overloading, which means that the asphalt structure will not fail instantly [22, 23].
5.3. Pavement durability

It is often repeated that cement concrete pavements are more durable than asphalt pavements. But as has been already mentioned, one must not confuse durability of the structure with durability of the surface layer.

Durability of road pavement structure is obtained by the proper choice of materials and their properties such as stiffness modulus or strength as well as thickness of pavement layers. Structural durability of road pavement is a function of quality of materials and pavement thickness. Durability of structure is a synonym for pavement life.

Up until recently, it was assumed that asphalt pavements should be designed for 20 years and cement concrete pavement for 30 years.

For asphalt pavements better understanding of materials and structure of road pavements in combination with better tools for calculation of strain-stress modelling and pavement design, allows for optimisation of asphalt pavement thickness and material choice. Thus, the durability of asphalt pavements may be stretched to 30 or 40 years. In fact, many earlier 20 years designed asphalt pavements have already lasted longer than 40 years.

In 1984 the design guide of TRRL [13] advocated a 40-year design life for asphalt pavements by strengthening the pavement after the first 20 years life in-service. The review of the design practice and pavement performance performed in the UK in the late 1990ties showed that: A well constructed flexible pavement that is built above a defined threshold strength has a very long structural life provided that distress, in the form of cracks and ruts appearing at the surface, is detected and remedied before it begins to affect structural integrity of the road. Such a road is referred as a long-life road.

Similarly in the USA, the concept of perpetual asphalt road pavements was "introduced" [14]. This concept has already been used in Europe for many years.

It may be concluded that asphalt pavement life may be extended to a period longer than 20 years. Furthermore, the durability of real asphalt pavement structures may be longer than 20 years without the need for structural rehabilitation, assuming proper surface maintenance takes place.

Cement concrete pavements often show premature defects. In 1995, more than 60% of Illinois interstate cement concrete pavements were overlaid with asphalt and it was expected that by 2000 the rest would be overlaid (excluding recently constructed and reconstructed sections) [15]. A survey and analysis of pavement life in Ontario, Canada [16] concluded with an estimation of cement concrete pavement median service life of 28 years. This result is similar to earlier evaluation of cement concrete pavement life in USA conducted by ERES and ACPA (TRB 1999) based on a survey of 76 road sections. The average pavement life was 34 years with a standard deviation of 5.4 years.

Figure 6 (after [17]) shows the cracking data for cement concrete pavement sections in wet-freeze and wet-non-freeze regions. The actual data show that numerous sections exhibited cracking of up to 50-60% after only 4 million ESALs (80 kN) in wet-freeze regions and after 20 million ESALs in wet-non-freeze regions. This may be translated to, respectively, in wet-freeze regions 5-6 years or in wet-non-freeze regions 20-25 years.
Durability of road pavement surface is a function of the quality of materials in the top layer. The surface of the road pavement is subject to significant action of deterioration under the influence of environmental factors and vehicle wheels. Under this action the surface gradually loses its initial characteristics, usually decreasing ride comfort and, importantly, users' safety. This is mainly because of the decrease in macrotexture and the polishing of aggregates, surface cracking and from surface deformations.

Asphalt pavement maintenance options include resurfacing. This may be performed by using various techniques and materials from surface dressings and microsurfacing to milling and resurfacing or overlaying the surface. Durability of asphalt surface courses depends on climatic and traffic conditions. In Germany, it ranges from 8 to 18 years. In Ontario, Canada, it was evaluated on average for 11 years (range from 4 to 16 years). Median of 10-12 years is usually accepted [16].

In the case of cement concrete pavements, there are also wearing options. On motorways in France after only 5 to 9 years cement concrete pavement is overlaid with thin asphalt wearing course to regain friction characteristics of the pavement. In the USA instead of overlaying with an asphalt layer a method of diamond grinding of cement concrete pavement is promoted by the cement community [18]. A survey [18] of the longevity of this technique showed that with regard to surface texture characteristics it should be repeated every 8 years in freeze regions and every 12 years in non-freeze regions. This technique addresses serviceability problems only and should not be used on pavements showing D-cracking (this is a series of fine cracks parallel to joints, edges or larger structural cracks, they form with the straight line of the joint a shape of D-letter – it is attributed to freeze-thaw cycles) or alkali reactive aggregates. Other problems might be connected with the reduction of pavement thickness. Diamond grinding reduces the thickness of slabs. It is estimated that reduction of slab thickness by 5 mm decreases fatigue life of slab by 30%. It is believed that long-term strength of cement concrete increases in time and is significantly higher than the initial 28 days strength. Several repetitions of grinding may, however, reduce slab thickness by a few centimetres and significantly decrease its fatigue life.
A specific problem is the maintenance of joints in cement concrete pavements. A comprehensive study on joint sealants was performed in SHRP [19]. It showed that, depending on climate and type of material, durability of joint sealing in cement pavements was from 37 to 167 months (results above 82 months were extrapolated). Longer life of joint sealants may be expected in warmer climates. Average durability may be assumed to be 5 years, which is in agreement with maintenance polices in France and Germany [8, 9].

It may be concluded that the durability of surface layer in the case of both types of road pavement, asphalt and cement concrete, is similar and may on average be assumed as roughly 11 years. Structural durability of both types of pavement may be on average similar as well, depending on materials quality and initial pavement design. In both cases it may be 30 or 40 years with surface maintenance every 11 years. In addition to this cement concrete pavements replacement of joint sealing must be foreseen every 5 years.

Comparison of construction and maintenance costs often shows that in the short term as well as in the long term asphalt pavements are less expensive than cement concrete pavements. For instance the study in Maryland [Asphalt Pavement Alliance: www.AsphaltAlliance.com], USA, on US Route 40 (SDR 30000) showed that the speed of rehabilitation of a road which is deteriorated is much higher when it is done with an asphalt overlay than with a cement concrete overlay. In the same time of 12 days, 12500 m² asphalt overlay was laid working on 11 nights only; whereas only 1500 m² cement concrete overlay working full 24 hours a day. The comparison of costs was: cement/asphalt = 2.9/1. On the other hand, analysis of the Whole Life Costing from Ohio [20] or Aargau [21] showed higher costs of cement concrete pavements in a long run. Both cases prove that, under real traffic and climatic conditions durability of rigid pavements and the need for maintenance is similar to that of flexible pavement but the costs of maintenance of asphalt pavement are lower than of cement concrete pavement.

6. Conclusions

- All types of road pavement deteriorate under action of traffic loadings and climatic influence. Surface deterioration is different from structural deterioration. Asphalt pavements are less sensitive than cement concrete pavements to climatic conditions and increases in traffic loadings.

- Asphalt pavements are more versatile and flexible in design – they may be designed for all traffic and climatic conditions. There is no technical limit for asphalt pavement design. This is demonstrated by the large variety of existing and proven solutions. However, a pavement is not just the sum of its (asphalt) layers. An asphalt layer is not just the sum of its ingredients (bitumen, aggregates). The final pavement performance relies on an integrated approach of pavement design, mix design, choice of materials and workmanship. Boundaries and technical limits are continuously improved by better individual materials – e.g. bituminous binders - and even more by an integrated approach of all the design and construction phases.

- Structural durability of asphalt pavement may be designed for specific expectations. In case of heavy traffic roads, initial pavement design period may be up to 40 years with surface maintenance every 10-12 years, on average. Similar durability is observed on real cement concrete pavements with additional replacement of joint sealing every 5 years.
Chapter II – Pavement Design

7. References


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