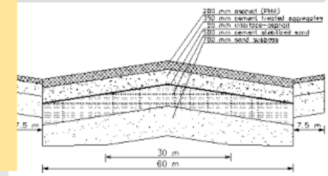
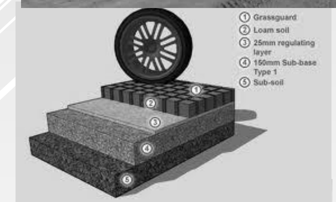
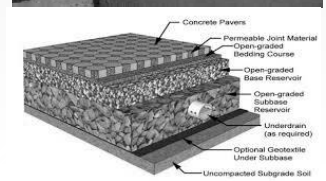
LECTURE 13:
Special design considerations







13.1 Introduction

Pavements don't have an infinite width and pavements with a cement treated base are vulnerable for reflection of the shrinkage cracks in the cement treated base through the asphalt top layer. In this chapter attention will be paid to how these two specific factors can be taken into account in pavement design.

13.2 Edge effect

If the pavement is rather narrow, traffic loads come very close to the pavement edge and it will be obvious that in such cases the stresses and strains in the pavement layers and the subgrade will be higher than in case the load is at some distance of the pavement edge (figure 115).

Figure 115: Edge loading conditions.

The procedure presented in [37] for the assessment of the edge effects is shown hereafter. First of all the distance to the edge of the pavement is determined using:

$$b_{edge} = (b_{traffic\ lane} - 2.50) / 2 - b_{lateral\ wander}$$

Where:
b_{edge} = distance to the pavement edge [m],
$b_{lateral\ wander}$ = as determined by means of figure 86.

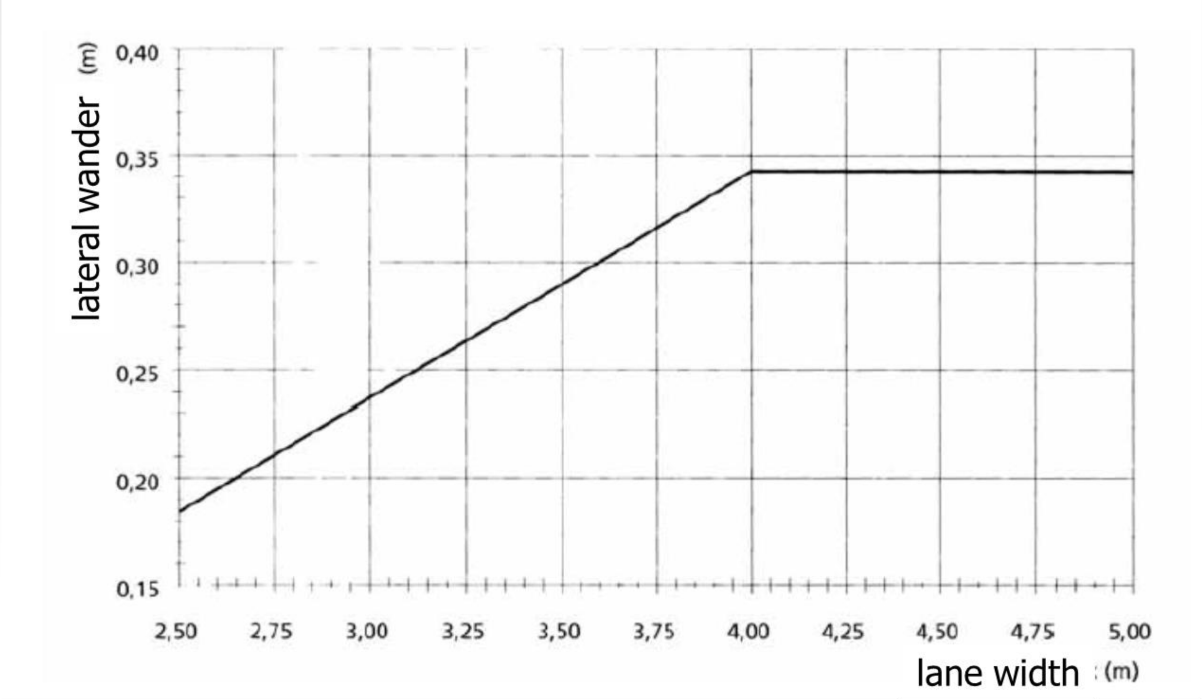


Figure 86: Lateral wander in relation to lane width.

Next we determine the radius of relative stiffness following:

$$L_k = \{E_1 h_1{}^3 (1 - v_4{}^2) / 6\, E_4 (1 - v_1{}^2)\}^{0.33}$$

Where:
L_k = radius of relative stiffness [mm],
E_1 = stiffness modulus of the asphalt layer [MPa],
E_4 = stiffness modulus of the subgrade [MPa],
v_1 = Poisson's ratio of the asphalt mixture,
v_4 = Poisson's ratio of the subgrade

Figure 116 shows the multiplication factor that has to be applied on the tensile strain at the bottom of the asphalt layer. Figure 117 shows the correction factor that has to be applied on the vertical stress at the top of the base layer. One should be cautious in using figure 117 because of the fact that lack of lateral support (figure 115 shows that in that case there is hardly any lateral support!) can have a very negative influence on the stiffness of the base and subbase. This effect is not taken into account in developing figure 117.

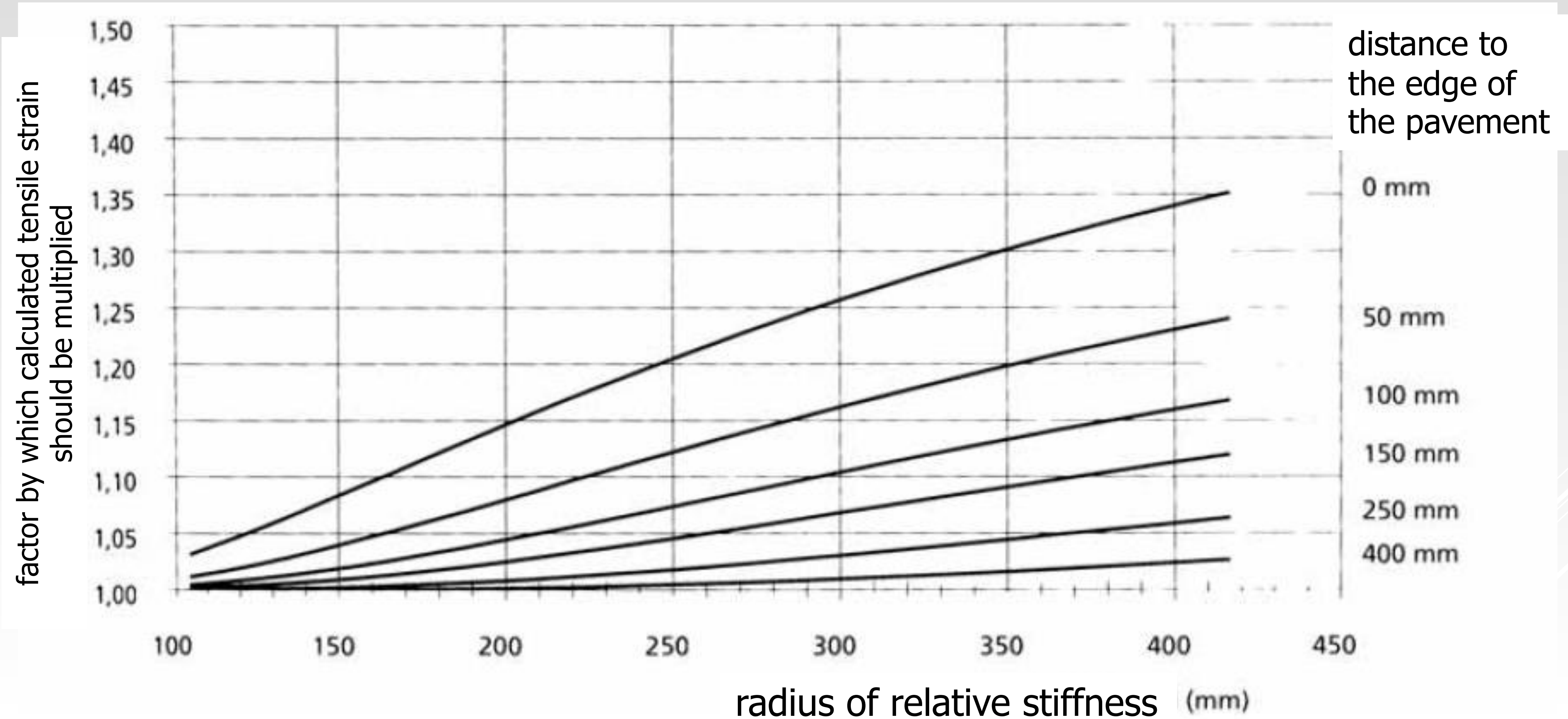


Figure 116: Edge effect on the tensile strain at the bottom of the asphalt layer.

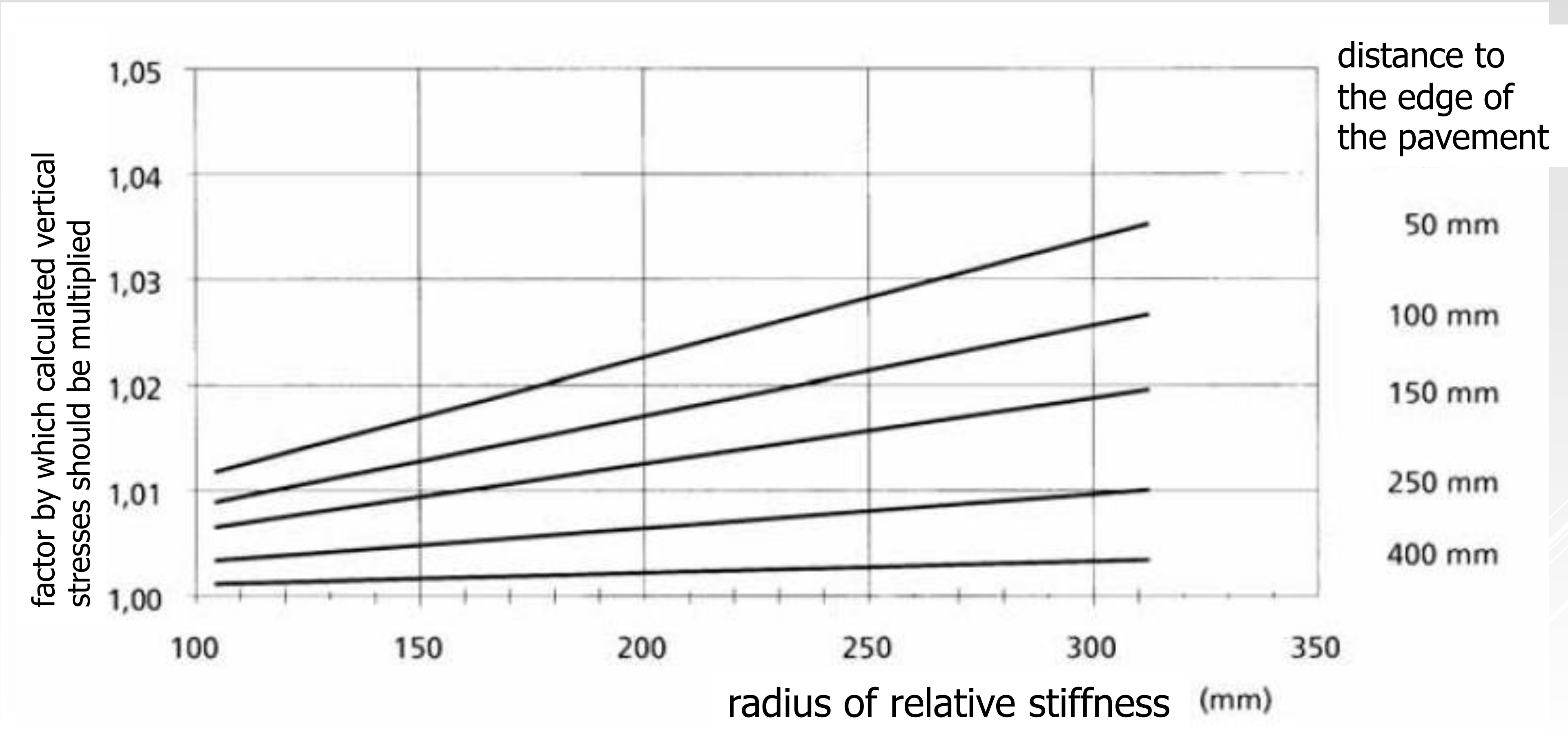


Figure 117: Edge effect on the vertical stress at the top of the base.

13.3 Reflective cracking

Reflective cracking cannot be analyzed by means of linear elastic multi layer theory. The finite element method needs to be used in order to be able to model the effects of discontinuities like cracks. Furthermore principles of fracture mechanics need to be used in order to be able to analyze the rate at which the crack will propagate through the asphalt layer. In principle there are two mechanisms that are responsible for the crack propagation being temperature effects and traffic loads. Both effects are schematically represented in figures 118, 119 and 120.

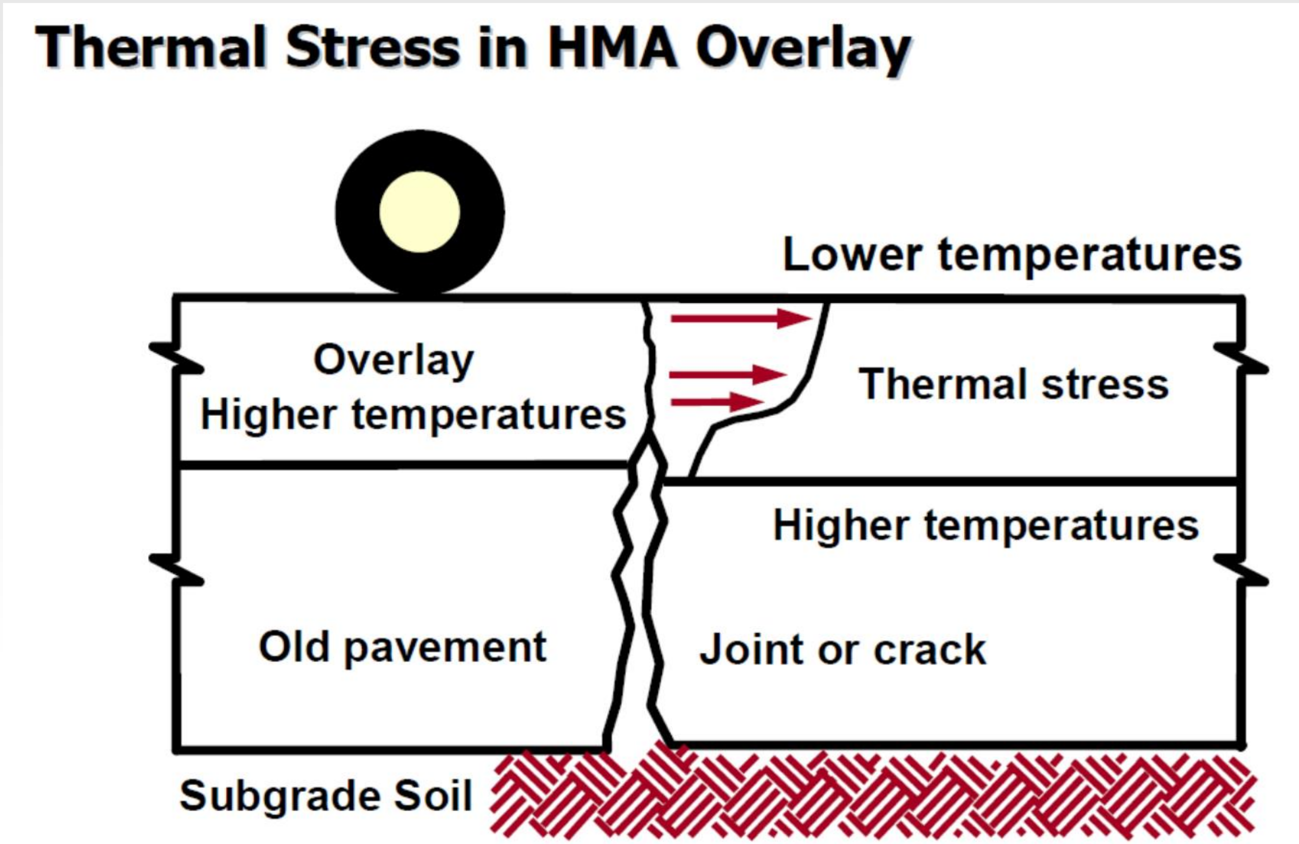


Figure 118: Crack reflection because of shrinkage of the base.

Thermal Stress in HMA Overlay

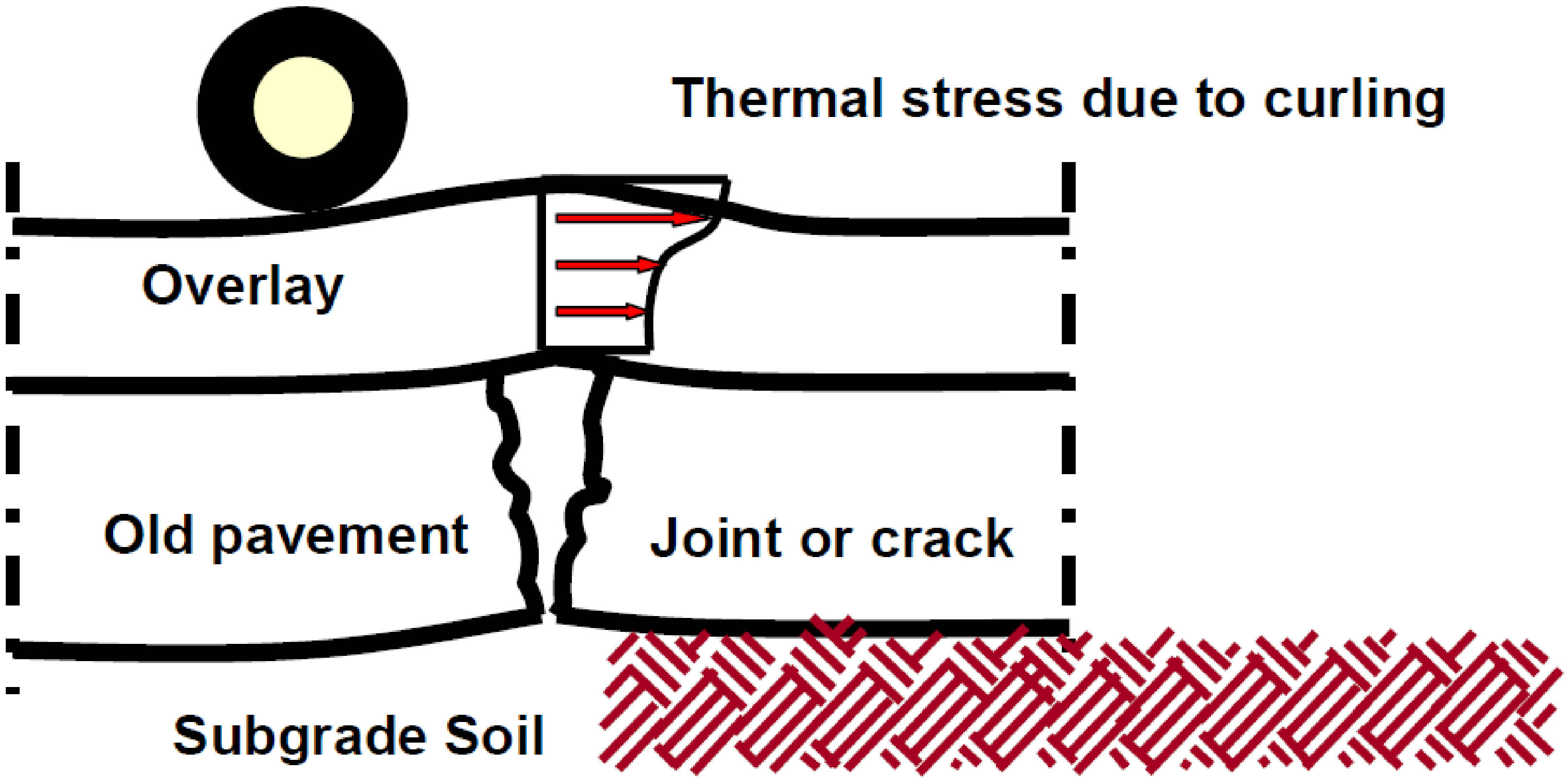


Figure 119: Crack reflection due to curling of the cement treated base.

Shearing and Bending in HMA Overlay

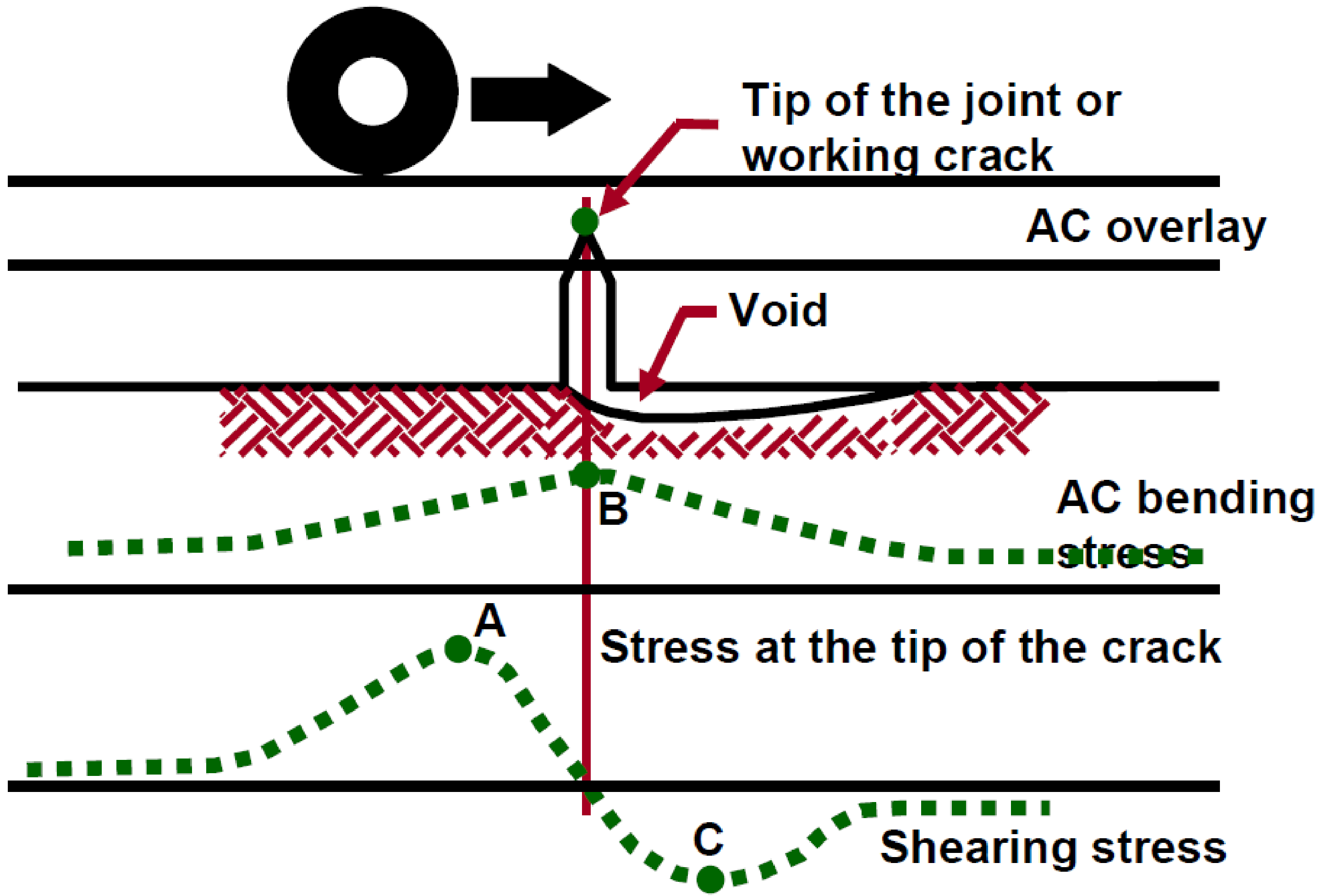


Figure 120: Crack reflection due to traffic loads.

The effect of the mechanisms shown in figures 118 and 119 can be greatly reduced if the cement treated base is pre-cracked by sawing shrinkage joints in the base every 5 – 7 m just like in concrete pavements. What remains to be analyzed is the effect of traffic loads.

Before one is going in detailed finite element analyses, it might be wise to analyze the crack reflection due to traffic loads first of all with a simplified procedure. Such a simplified procedure is presented hereafter.

A general applicable simple design system has been developed by Lytton [55]; this method is based on the propagation of cracks in fully supported beams. In the text hereafter the equations given in [55] will be given. This is followed by an explanation of how this method can be used for analyzing crack reflection in pavements.

Let us consider the two loading conditions as shown in figure 121.

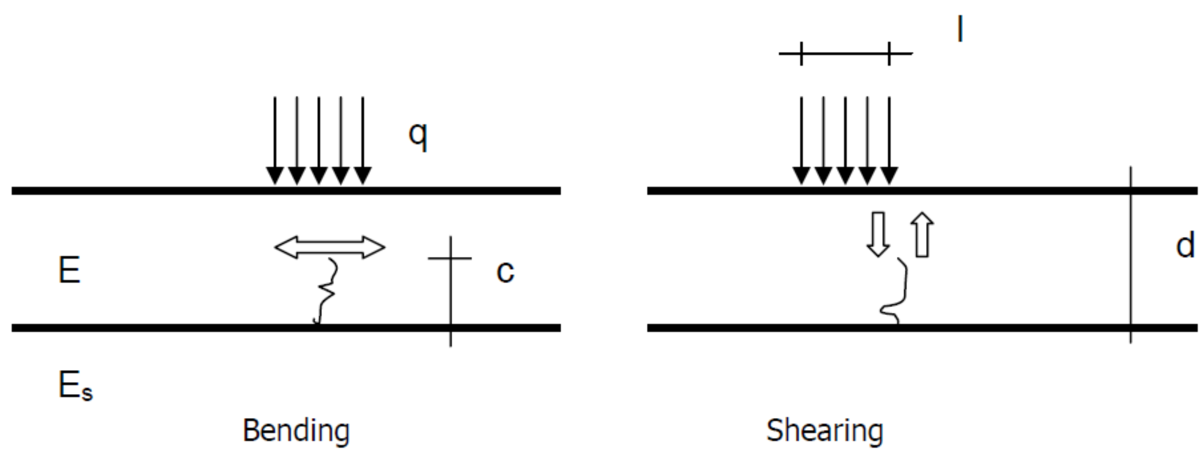


Figure 121: Crack propagation in a fully supported beam as a result of bending and shearing.

The stress intensity factors at the tip of the crack due to bending and shearing can be calculated in the following way.

$K_{bending} = k_b . q . e^{-\beta/2} . \sin(\beta . l / 2) / \beta^2 d^{1.5}$

$K_{shearing} = k_s . q [1 + e^{-\beta l} . [\sin(\beta . l) - \cos(\beta . l) / 4 \beta \sqrt{} d$

$\beta = (E_s / E)^{0.33} / 0.55 d$

Where:
k_b = dimensionless stress intensity factor due to bending,
k_s = dimensionless stress intensity factor due to shearing,
q = contact pressure [MPa],
l = width of loading strip [mm],
c = length of the crack [mm],
d = thickness of the beam [mm],
E = modulus of the beam [MPa],
E_s = modulus of the supporting layer [MPa].

Figure 122 shows how the dimensionless stress intensity factors change in relation to the ratio c / d. As one will observe, the stress intensity factor due to shearing increases with increasing crack length. This is logical because with increasing crack length, the area that has to transfer the load decreases so the stresses in that area increase.

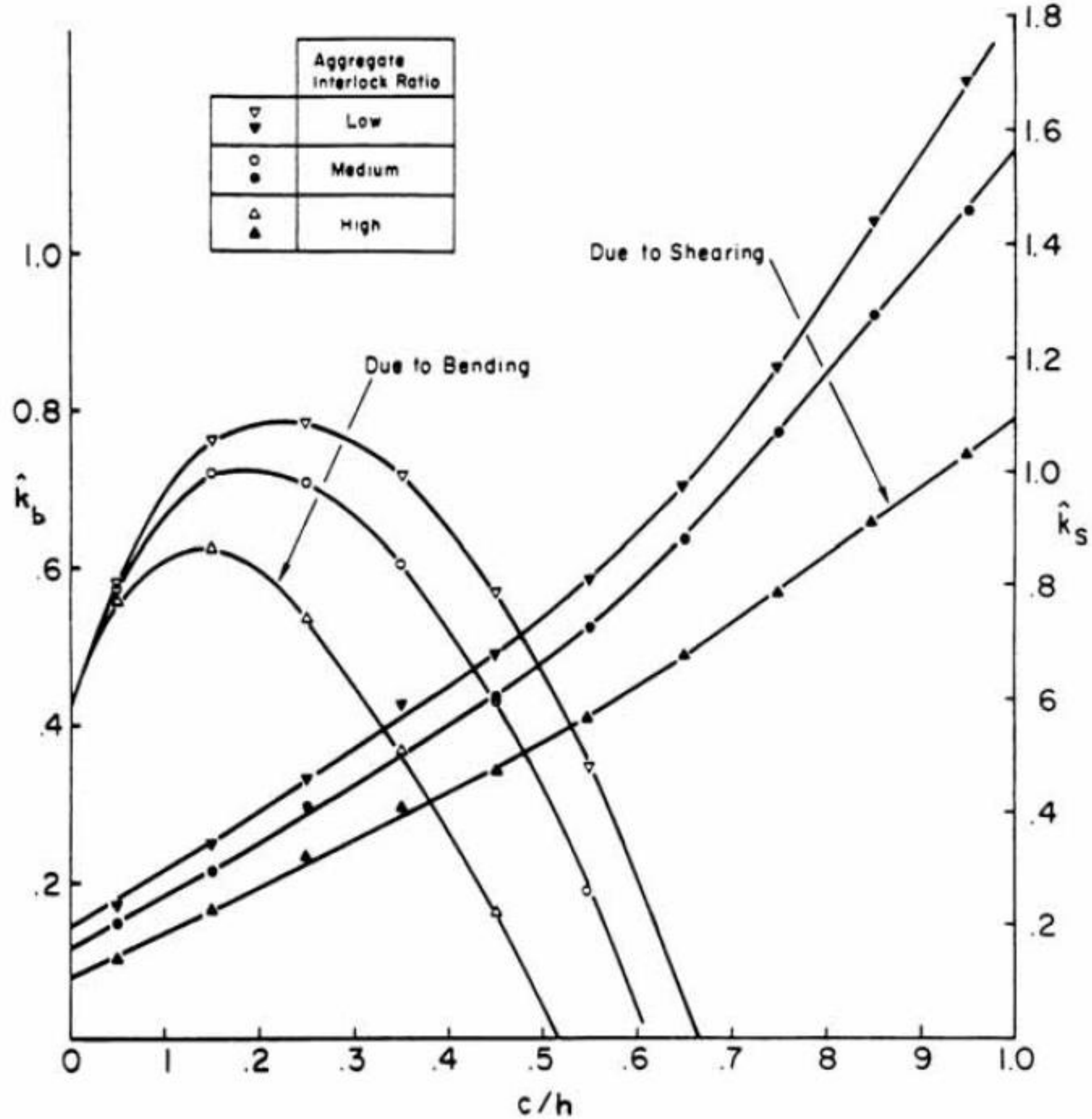
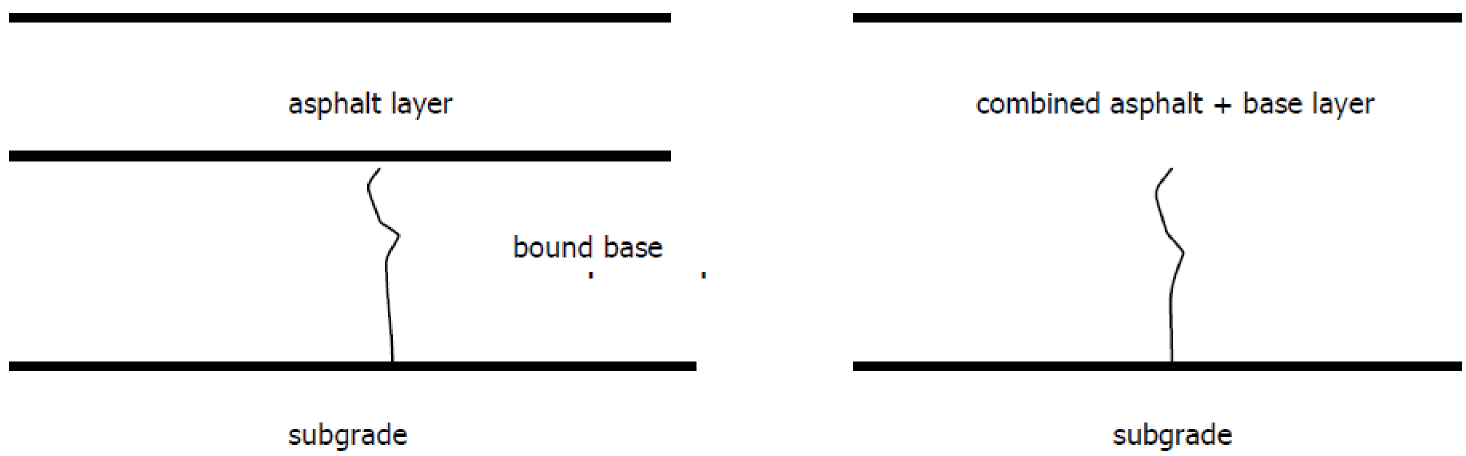


Figure 122: Relationship between c / d and the dimensionless stress intensity factors.

Figure 122 however also shows that the stress intensity factor due to bending increases first with increasing crack length but then decreases to a value of zero. This is because of the fact that the crack reaches the neutral axis of the pavement at a given moment and penetrates the zone where horizontal compressive stresses are acting. Then the cracks stops to grow since the driving force has disappeared.

The question now of course is how this beam approach can be used for the design of overlays on cracked pavements. The first step how to schematize a cracked pavement is shown in figure 123.



c = $h_{bound\ base}$
d = $h_{bound\ base} + h_{existing\ asphalt}$
E_s = $E_{subgrade}$
E = combined modulus of asphalt layer and bound base

Figure 123: Schematization of structures with a cracked base.

The question now is how to arrive to the combined modulus values of the asphalt layer and the cement treated base. This is done using Nijboer's equation.

$$E = E_b \,.\, \{[b^4 + 4\, b^3 n + 6\, b^2 n + 4\, b\, n + n^2] \,/\, [(b + n)\,.\,(b + 1)^3]\}$$

Where:
E = combined modulus of asphalt layer and cement treated base,
E_b = modulus of the cement treated base,
b = thickness of cement treated base / thickness asphalt layer,
n = modulus of asphalt layer / modulus of cement treated base.

The procedure is illustrated by means of an example.

Example:
Assume a given pavement that consists of a 100 mm thick asphalt layer on a 300 mm thick base which in turn is placed on a subgrade. The modulus of the asphalt layer is 6000 MPa. The base has a stiffness modulus of 3000 MPa and the subgrade a modulus of 100 MPa.

This means that: $b = 3$ and $n = 2$

First of all the E value of the combined asphalt – base layer was calculated using the above mentioned equation; this resulted in E = 4059 MPa.

Assume the contact pressure is 0.7 MPa and the width of the loaded strip equals 300 mm.
The value of β was calculated to be $\beta = 1.339 * 10^{-3}$.

Given the fact that the c / d ratio equals 300 / 400 = 0.75, $k_s = 1$ if we assume medium load transfer.
Given all this information we calculate $K_s = 4.22$ N / mm$^{1.5}$.

Please note that the product βl in sin (βl) and cos (βl) is in radians!

Since K_s is known, the crack propagation rate can be calculated using:

$$dc / dN = A\, K_s^{\,n}$$

Where:
dc/dN = increase in crack length per load cycle,
A, n = material constants,
n = slope of the fatigue relation,

$\log A = -2.890 - 0.308\, n - 0.739\, n^{0.273 \log S_{mix}}$ (see [34] for details),

S_{mix} = stiffness modulus of the asphalt mixture [MPa].

The number of load repetitions that is needed for the crack to reflect through the asphalt layer is calculated.
$N = \int_c^d h_{asphalt} / K_s(c)\, dc$

Where:
$K_s(c)$ = stress intensity factor due to shear as a function of the crack length c.

The question now is to what extent beam theory is representative for real pavement problems. This is of course not the case and some shift factors resulting in similar stress conditions in the beam as in the real pavement are therefore necessary. The easiest way to do this is to compare the stresses at the bottom of the beam with the stresses that would occur at the bottom of the top layer (combined layer asphalt + bound base with modulus E) in the two layer system when calculated with a program like BISAR. Most probably the stresses at the bottom of the beam are higher than the stresses at the bottom of the layer. The correction factor that is needed to fit the stresses at the bottom of the beam to the stresses at the bottom of the layer can also be used as correction factor for the stress intensity factors.