Design of flexible pavement layers

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ABSTRACT: Several research projects realised by the Chair of Pavement Engineering at the Dresden University of Technology aim at the development of an analytical design method to predict the stress and strain behaviour of a pavement or to calculate the remaining life cycle of the pavement structure. The developed dimensioning model is based on the fundamental idea of freely choosing any possible construction (flexible pavement). Furthermore, the dimensioning model aims at the optimisation of the pavement construction considering traffic loading and weather-induced factors. Using different materials, the particular thickness of each layer is optimised on the basis of failure hypotheses.

KEY WORDS: Design, asphalt, layers, stresses ,strains

1. INTRODUCTION

Several research projects realised by the Chair of Pavement Engineering at the Dresden University of Technology aim at the development of an analytical design method comprising a multitude of factors effecting the pavement condition. The stress and strain behaviour of a pavement can be predicted or the remaining life cycle of the pavement structure is calculated by means of such a method. These advantages are especially important regarding warranty claims.

The developed dimensioning model is based on the fundamental idea of freely choosing any possible construction (flexible pavement). In this way, a particular pavement structure can be set depending on layer thickness and layer material.

Furthermore, the dimensioning model aims at the optimisation of the pavement construction considering traffic loading and weather-induced factors. Using different materials, the particular thickness of each layer is optimised on the basis of failure hypotheses. The described approach is illustrated by a calculation comparing various constructions and examining separately cracking and rutting as the two main reasons for material failure.

On the basis of the calculation example relevant influence parameters (layer thickness, resilient modulus of unbound base layers, material composition) are determined and the general feasibility of the method is shown. The calculation results exhibit a suitable first approximation considering all simplifications made during the approach. In the first place, the results are used for a qualitative evaluation of the described parameters.

2. FACTORS EFFECTING PAVEMENT CONSTRUCTIONS

The designing method regards three different factors. The factors are

- Traffic loading
- Climatic conditions
- Material data and layer positioning

2.1 Traffic loading

Traffic loading is one of the factors, which must be predicted. The developed dimensioning model is very customisable regarding different aspects of traffic loading. The axle load cycles are divided into ten categories of loads. According to current definitions, each load category covers the range of two tons. The number of load categories can be selected to fit the needs of each single project.

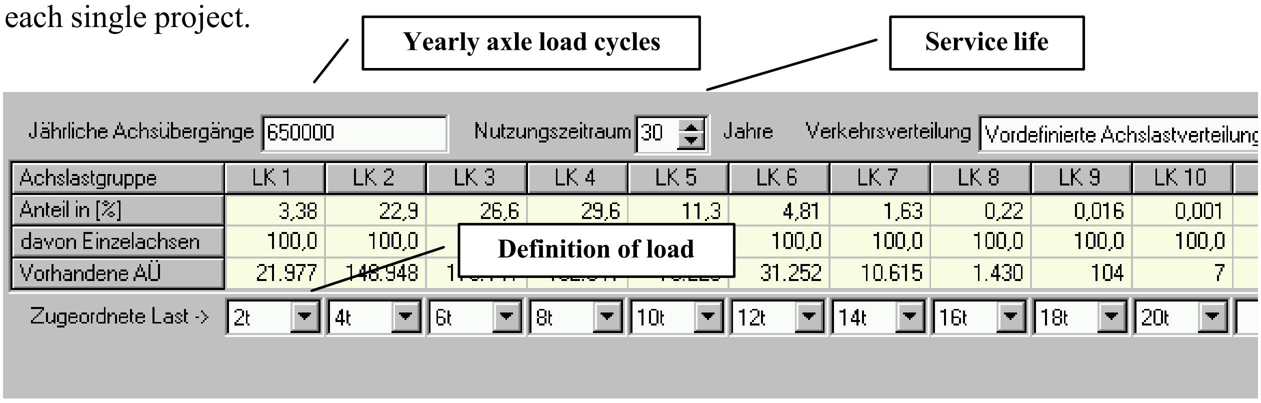

Figure 1: Example of traffic loading data

A typical load configuration can be assigned to each load category describing the positioning of the loads and each value.

With the described information, the load of each axle-load-cycle can be determined and the resulting stresses and strains can be calculated regarding the effects of the exact load value. Only with this way of determining the stresses and strains, the estimation of any kind of rutting or sensitivity for rutting is possible.

The determination of equivalent single axle loads is not necessary anymore. This prevents any inaccuracies caused by the use of the fourth power law.

2.2 Climatic conditions

Constructions with asphalt layers are sensitive regarding the temperature. Asphalt is a thermo viscous material. The material stiffness will change according to the temperature. At temperatures below +20°C cracking is the main failure criteria. Below +2,5°C additional thermo induced stresses increase the risk of cracking. If the temperature rises above +35°C the decreasing stiffness pushes the risk of permanent deformation (rutting) to the foreground.

To consider the climatic conditions 13 temperature curves inside the asphalt layers based on 13 surface temperatures [see Figure 2] are determined. The number of curves can be adapted to the actual climatic conditions. With this method, the temperature at any depth inside the construction can be ascertained.

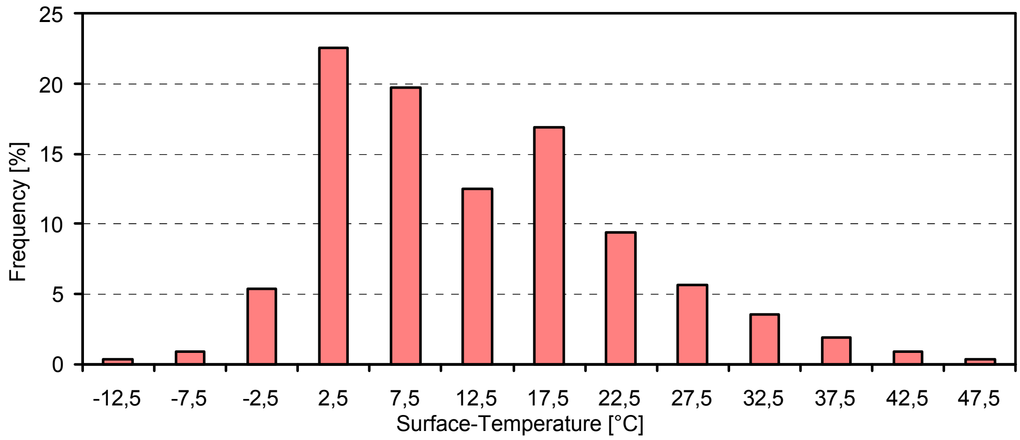

Figure 2: Example of surface temperatures specific for the northern part of Germany

In addition to the surface temperatures the frequency of the specified surface temperature has to be provided. The combination of this frequency and the number of load cycles per year indicates the number of load cycles per year for each surface temperature.

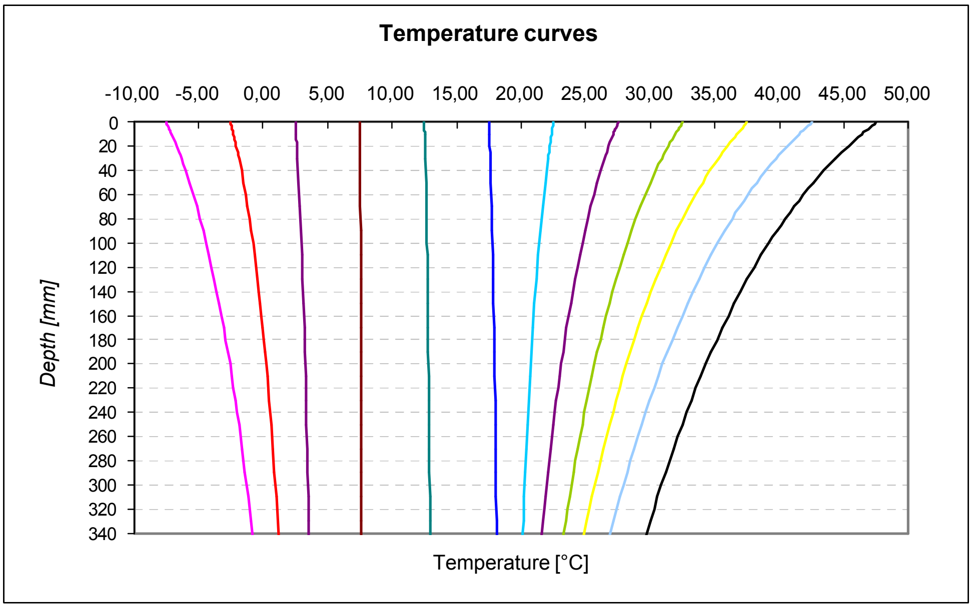

Figure 3: Temperatures curves

2.3 Characteristic properties of materials

The material properties needed to calculate stresses and strains are determined using the method of FRANCKEN and VERSTRAETEN. This method is able to predict the Young's modulus of asphalt materials on the basis of mixture data. The important parameters are binder content, bitumen density, bulk density, maximum density and the needle penetration. In combination with the actual temperature the exact Young's modulus of the specific asphalt layer can be calculated.

Fatigue cracking

A fatigue law can be assigned to each set of material parameters. If no other fatigue law is selected the HEUKELOM fatigue law is used. According to HEUKELOM the maximum number of tolerable axle load cycles was determined by following equation:

$$N = 10^{\frac{2{,}633\,(\lg E+1)}{(g \cdot 10 s)^5}} \qquad (1)$$

With:

N	[-]	number of tolerable load cycles
E	[MN/m²]	Young's modulus of the concerning asphalt layer
s	[MN/m²]	tensile stress at the bottom of the asphalt
g	[-]	safety factor (crack resistance)

The fatigue law is an important part to determine the allowable load cycles.

Permanent deformation

The determination of the critical stress level for materials can only be done by appropriate tests. Tri axial tests or indirect tensile tests. Figure 4 shows the results of one material tested at different stress levels.

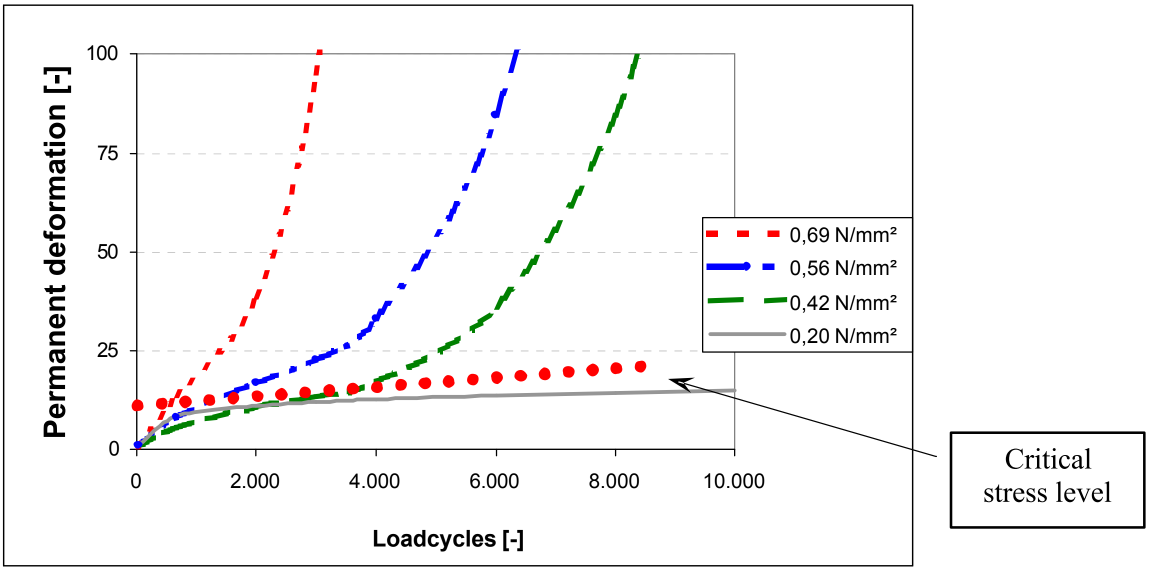

Figure 4: Example for the critical stress level

If the level of stress is too high, the material fails instantly [Figure 4. red line]. By reducing the stress, the number of load cycles until failure rises. For small values of stress, the permanent deformation will stay on a certain level after the post compaction period. The maximum allowable stress level can be determined by selecting the stress level without increasing deformation after the post compaction period [Figure 4; line with dots]. To prevent permanent deformation the occurring deviator-stress must not exceed this level.

3. DESIGNING PROCESS

3.1 Composition of layers

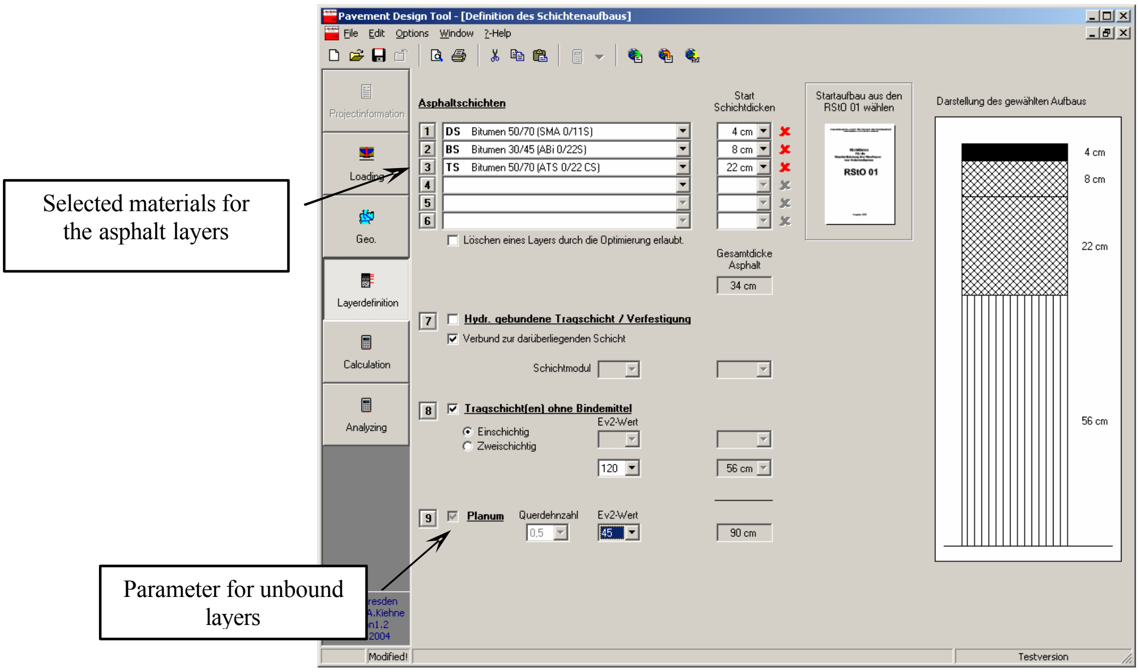

Figure 5: Composition of layers

By selecting a material for one of the six possible asphalt layers, the pavement construction can be defined step by step. All parameters needed for the calculation are determined by this selection. Only the thickness has to be adjusted to complete the design of the asphalt layers.

The number of unbound granular layers, the thickness and the bearing capacity for each unbound layer must be specified. The last step is to select the bearing capacity for the underground.

This selection is the basis to build the model for the calculation. The asphalt layers will be divided into sub layers with 1 cm thickness each and linear elastic behaviour will be assumed (μ = 0,35). The Young's modulus is calculated regarding the temperature of the sub layer. The modulus for each unbound layer was calculated according to the evaluation of the plate-bearing test.

The material parameters for the model are determined separately for each temperature curve.

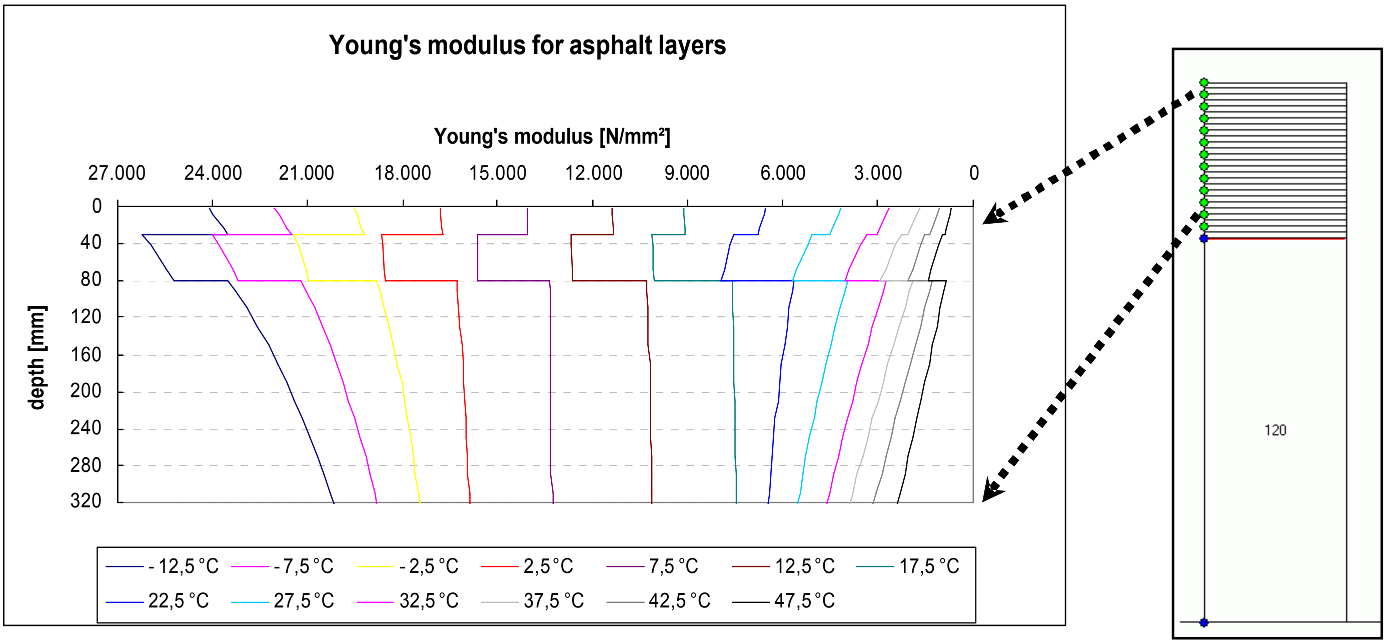

Figure 6: Young's modulus for asphalt layers

3.2 Calculations

Asphalt Layers

Stresses and strains within the layers are calculated separately for each load category and for each temperature gradient.

The calculation will be done in two steps. The first is to calculate all temperature states in combination with all selected load categories. These combinations can reach the number of 130 or more depending on the number of load categories and the number of surface temperatures. Because of the short calculation time of a calculation according to the multi layer (course) theory, this first step is executed with this calculation method.

The second step is performed using the finite element method to examine for example critical temperature states by using material specific calculation models. This part of the analysis needs more time to be calculated.

In case of complete adhesion of the asphalt layers the highest values for the tensile stresses occur on the bottom of the asphalt base.

For each result the number of tolerable axle load cycles are determined and compared with the existing load cycles of the according load category. The results are accumulated by the hypothesis of MINER.

Accumulated damage:

$$\frac{N_a}{N_{Ba}} + \frac{N_b}{N_{Bb}} + \frac{N_c}{N_{Bc}} + \ldots \frac{N_z}{N_{Bz}} \leq 1 \qquad (2)$$

With:

$N_{a\,(b,\,c,\,\ldots)}$	[-]	number of existing load cycles in state a (b, c, …)
$N_{Ba\,(Bb,\,Bc,\ldots)}$	[-]	number of tolerable load cycles in state a (b, c, …)

If the sum of the MINER-Term is equal to 1 the fatigue cracking of the asphalt layers starts. Figure 7 shows the progress of the sum of MINER for the service life that was supposed to be 30 years. The MINER value of 1 is equal to the 100 percent of figure 7. This pavement construction will start cracking after 21.5 years of service. Intensive maintenance must be expected.

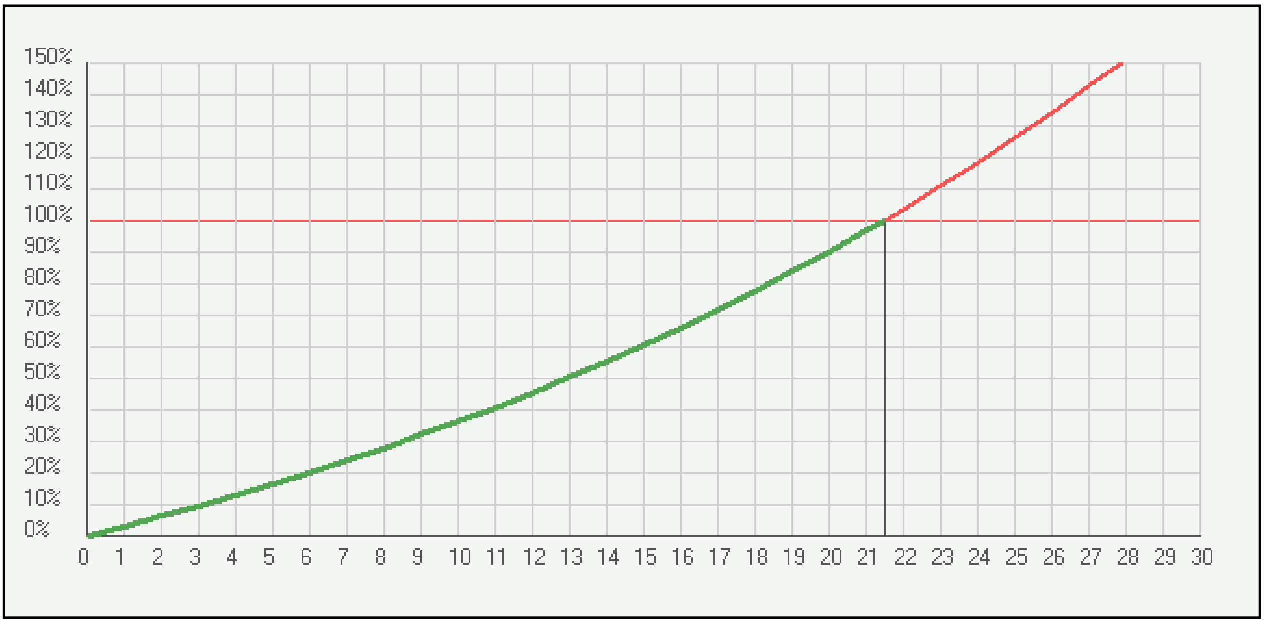

Figure 7: Example for cracking within the service life (after approximately 21.5 years)

Unbound layers

The unbound layers were treated the same way as the asphalt layers. The number of allowable load cycles was determined by using equation 3. If the number of the existing axle load cycles is lower than the tolerable load cycles, permanent deformations in the unbound layers are almost impossible.

$$N_B = 10^{\frac{1}{0,7}\left(\frac{0,00875 \cdot E_{v2}}{g \cdot \sigma_Z} - 1\right)} \qquad (3)$$

with:

N_B	[-]	number of tolerable load cycles
E_{V2}	[MN/m²]	stiffness of the sub-base/sub grade, measured with the plate bearing test
σ_Z	[MN/m²]	vertical (compressive) stress on the top of the unbound layers
g	[-]	safety factor

The safety of standard pavement constructions, which were used in Germany so far, against permanent deformation of the unbound layers, is about three times higher than the safety of the asphalt layers. A failure of the unbound layers is improbable.

4. EXAMPLE

Basis data for the construction
- Traffic loading of 525.000 axle load cycles per year from 2 tons to 20 tons.
- Climatic conditions as shown in Figure 2 and 3

Two different pavement constructions have to be compared to select the best variation.

Construction A:

4 cm surface course
    SMA 0/11 S Bitumen B 50/70
8 cm binder course
    ABi 0/16 S Bitumen B 30/45
16 cm asphalt base
    ATS 0/22 CS Bitumen B 50/70
62 cm unbound granular material

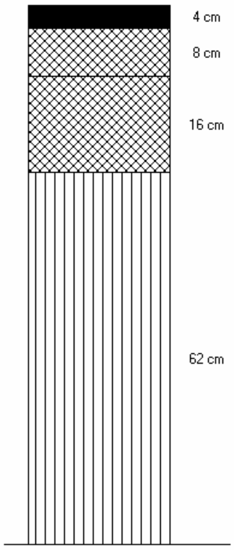

Figure 8: Construction A

Construction B:

4 cm surface course
    SMA 0/11 S Bitumen B 50/70
4 cm binder course
    ABi 0/16 S Bitumen B 30/45
20 cm asphalt base
    ATS 0/22 CS Bitumen B 50/70
62 cm unbound granular material

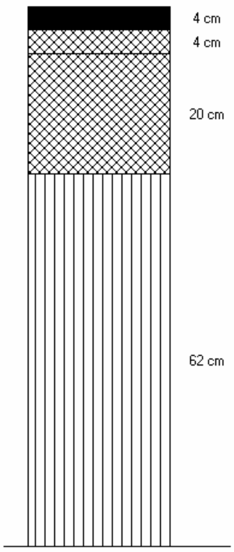

Figure 9: Construction B

Calculation results

Fatigue cracking

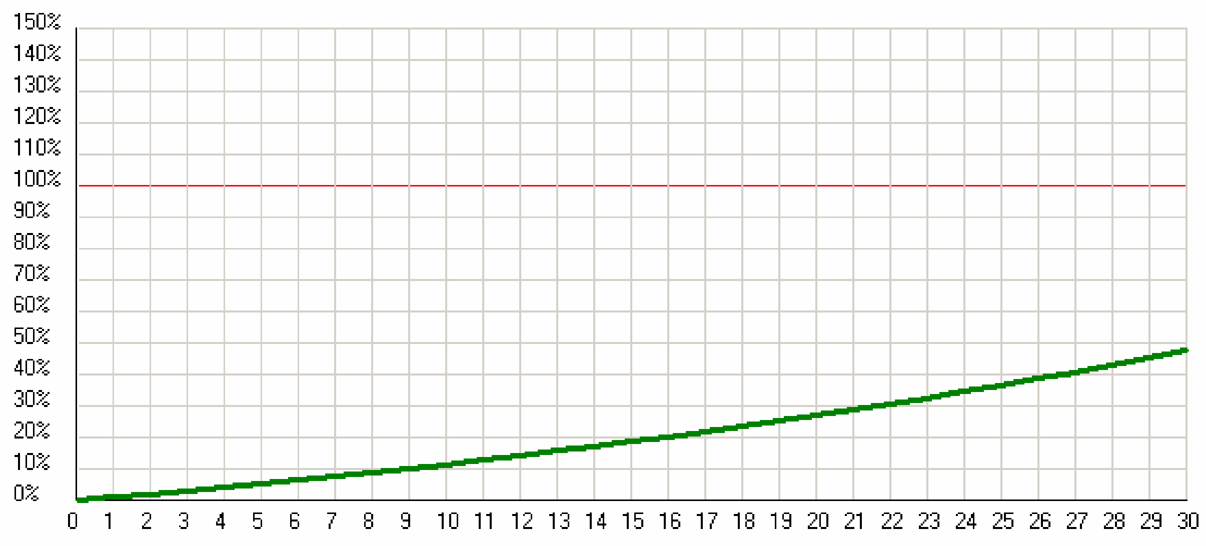

Figure 10: Progress of cracking within the service life

Both constructions show the same MINER value of 0,48 (equivalent to 48 %). This result indicates both constructions to be equal and both constructions are capable to overcome the service life of 30 years.

Permanent deformation

Focusing on the permanent deformation differences can be discovered. The value for the critical stress is higher in construction A (0.869 N/mm²) than in construction B (0.515 N/mm²). The conclusion of this fact is that the risk of rutting is much higher if construction A is selected.

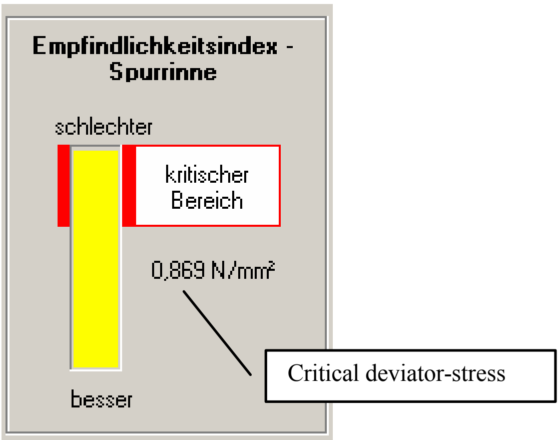

Figure 11: Critical stress value for construction A

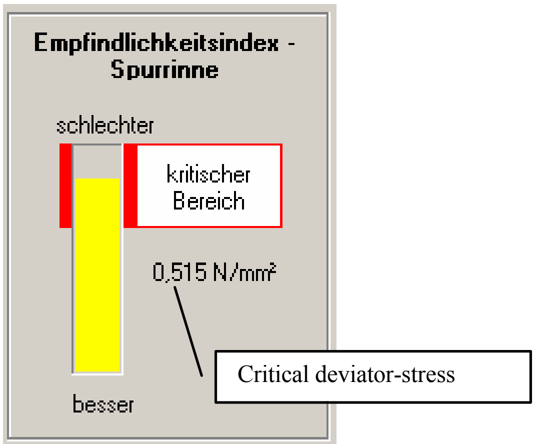

Figure 12: Critical stress value for construction B

5. SUMMARY

With the developed method, the calculation of safety levels of flexible pavement layers (asphalt and unbound layers) is possible. Different road constructions with different layer thickness, layer stiffness and mixture composition can be evaluated and compared (in this case cracking and permanent deformations). The method is capable to check the possibility of alternative constructions with the same safety level against failure.

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