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Stress estimate in a multi-layer flexible pavement construction

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ABSTRACT

The objective of the paper is providing experts with a procedure for stress estimate in a flexible pavement using tables, diagrams and nomograms. Müller nomograms ensure a reliable estimate of pavement stresses in a multi-layer flexible pavement construction. The paper presents the procedure of the stress estimate in a flexible pavement.

Contents

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Introduction

Theoretical dimensioning of pavement construction is usually done using computer programs like DAMA, Shell method, numerical method and others. In all these methods, pavement is seen as a multi-layered elastic system, where the lower layer (subgrade) is considered as infinite dimension in the vertical direction.

For multilayered pavement which is calculated using one of empirical or semi-empirical method (French method, Aasha method, Lidl method, U.C4.012 or any other) that meets the traffic load, climatic conditions and laboratory characteristics of the built-in material, stresses in individual pavement layers should be checked.

Pavement layers are:

- AB (wearing asphalt-concrete course) = 8 cm,
- BNS (bituminously bound aggregate) = 12 cm,
- CS (cement stabilisation) = 20 cm,
- T_d (subbase course) = 35 cm.

Top layer is bituminously bounded asphalt-concrete and bituminously bounded aggregate, next layer is cement stabilisation and then gravel subbase course.

Calculation of stresses using Muller method

Calculation model of pavement (figure 1) using Müller method, radial tensile stresses are calculated in the asphalt layer and cement-concrete layer and vertical stresses at the level of the subgrade.

Depending on the type of material, the dynamic module can be obtained in the following ways:

With asphalt layers, temperature has a major influence on the dynamic modulus, therefore the dynamic modulus should be tested at various temperatures. Thus obtained dynamic modulus is called complex modulus, and

Dynamic modulus of soil is tested at various humidities.

Dynamic modulus of elasticity for asphalt layers and for the temperature + 20° C varies from 1.000 to 2.000 (MN/m2), and at a temperature of -10° C dynamic modulus is over 10.000 (MN/m2). Adopted values are, in this example, 1.000 for the summer, and 15.000 (MN/m2) for the winter.

The value of the dynamic modulus of soil elasticity, according to Heukel, for certain types of soil varies from 8 to 600 (MN / m2), as shown in tables 1 and 2.

Table 1. Dynamic modulus of elasticity for asphalt layers

Temperature [^{0}C]	E_{din} [MN/m^2]
+40	Less than 1.000
+20	1.000 – 2.000
+10	2.000 – 6.000
0	6.000 – 10.000
-10	Over 10.000

Table 2. Dynamic modulus of soil elasticity according to Heukel

Soil type	E_{din} [MN/m^2]
Peat	8 – 30
Clay	40 – 120
Sand	80 – 180
Sandy-clay	120 - 220
Gravel with clay	210 - 600

In practice, for subbase, dynamic modulus of elasticity is determined by correlation with CBR from relations:

$$E_{din} = 10 * CBR \text{ [MN/m}^2\text{]} \quad (1)$$

Adopted representative value of dynamic modulus for subbase layer is 76%, and for the subgrade 10% of the CBR value for subbase layer. Since the value of CBR = 100% at the subgrade level, dynamic modulus of elasticity varies:

- subbase Edin = 10*100*0,76 = 760 N/m^2, and

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– subgrade Edin = 10*100*0,10 = 100 N/m^2,

As shown in figure of calculation model for pavement.

Multilayer pavement, in which stresses need to be converted, is changed into three layer system (asphalt layer, base layer stabilized with cement and subgrade). A layer of unbound, mechanically stabilized material, thickness of 35 cm, was transformed into a layer of cement stabilization according the following formula:

$$h_2 = h_1 + n^* h_2 \sqrt[3]{\frac{E1(1-v^2)}{E2(1-v^2)}} \tag{2}$$

$$h_2 = 20 + 0,83^*35^* \sqrt[3]{\frac{760(1-0.5^2)}{10000(1-0.5^2)}} = 32,30 \text{ cm}$$

Where n is factor of material type which, for cement stabilization, is 0.83.

Verification of stresses according to Müller's method was carried out for:

– Radius of the contact area r = 15 m,

– Inflation pressure p = 0,7 N/mm^2,

– Maximum wheel load 57.5 kN, i

– Number of repeated loads n = 7.9*10^6.

Model for calculation of pavement using Müller's method, Figure 1, radial tensile stresses in the asphalt layer and cement stabilization are calculated and vertical stresses at the level of the subgrade.

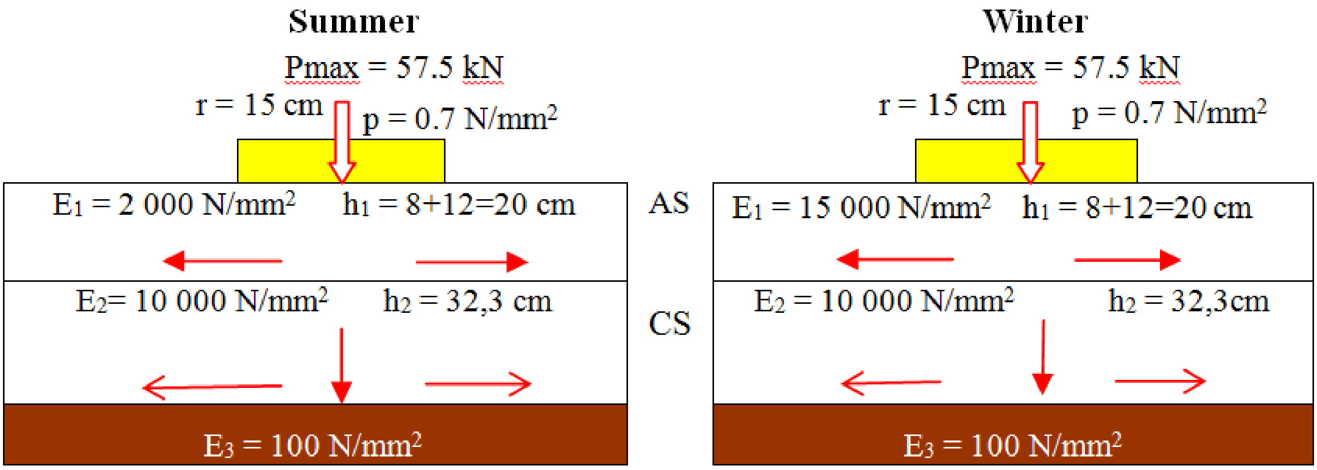

Figure1. Model for calculation of pavement

Adopted representative value of dynamic modulus for subbase layer is 76%, and for the subgrade 10% of the CBR value for subbase layer. For CBR~100, representative values of subbase are:

Subbase - E_{din}=10*100*0.76=760 MN/m^2,

Subgrade - E_{din}=10*100*0.1=100 MN/m^2, and

Cement stabilisation - E_{din} = 10 000 MN/m^2.

For summer period and temperature of 20° C adopted dynamic modulus is E=2 000 MN/m^2, and for winter period and temperature below - 10° C, adopted dynamic modulus is E=15 000 MN/m^2.

Calculation of radial stresses

In order to use Müller's nomograms for calculation of radial tensile stresses on bottom surface of first and second layer, mutual relations in the pavement have to be calculated:

$$k_1 = \frac{E_1}{E_2} \qquad k_2 = \frac{E_2}{E_3} \qquad H = \frac{h_1}{h_2} \qquad A = \frac{r}{h_2}$$

where are

k_1, k_2, - relationship between dynamic elastic modulus, and

H, A - relationship between thickness of layers and radius of the wheel-pavement contact area.

Values k_1 and k_2 for **summer period**: $k_1=\frac{2000}{10000}=0.2$; $k_2=\frac{10000}{100}=100$; $H=\frac{20}{32.3}=0.62$; $A=\frac{15}{32,3}=0.46$

Values k_1 and k_2 for **winter period**: $k_1=\frac{15000}{10000}=1.5$; $k_2=\frac{10000}{100}=100$; $H=\frac{20}{32.3}=0.62$; $A=\frac{15}{32,3}=0.46$

For the calculated values of relationships in the pavement and application of Muller's nomograms, Figures 2, 3 and 4, which are designed for k1 = 2, k1 = 20 and k1 = 200, and according to key given in the diagrams, horizontal tensile stresses σr1/p on the bottom side of the connecting layers are determined. These values are applied to the diagram of a semi-logarithmic scale, and then the points are connected with curved line. The actual value of σr1/p for a real relationship of k1 = E1/E2 is determined from that diagram.

By multiplying the determined value from the semi-logarithmic diagram σr1/p with the value of the contact pressure, the radial tensile stresses on the bottom surface of the first layer σr1 are obtained.

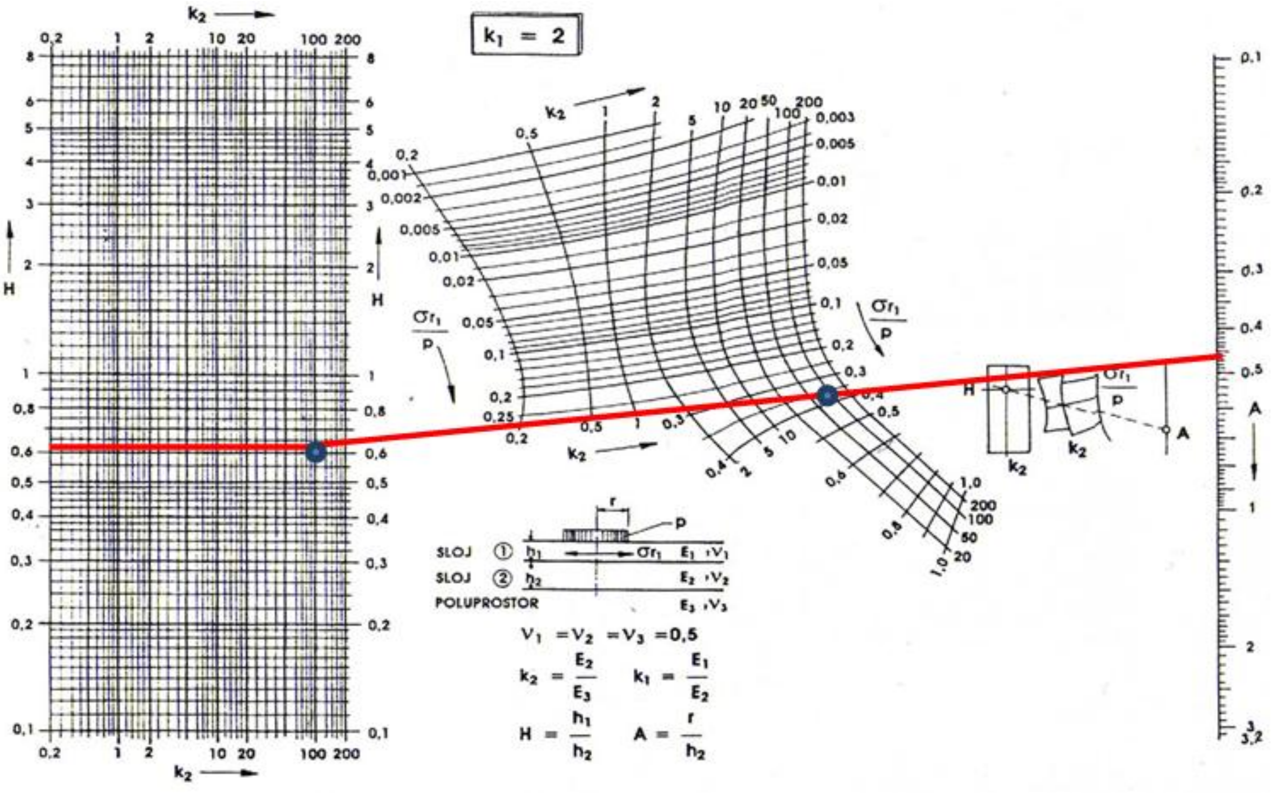

Figure 2. The nomogram for determining the horizontal tensile stress σ_{r1} for k_1=2

For k_1=2 determined value for σ_{r1}/p is 0,35.

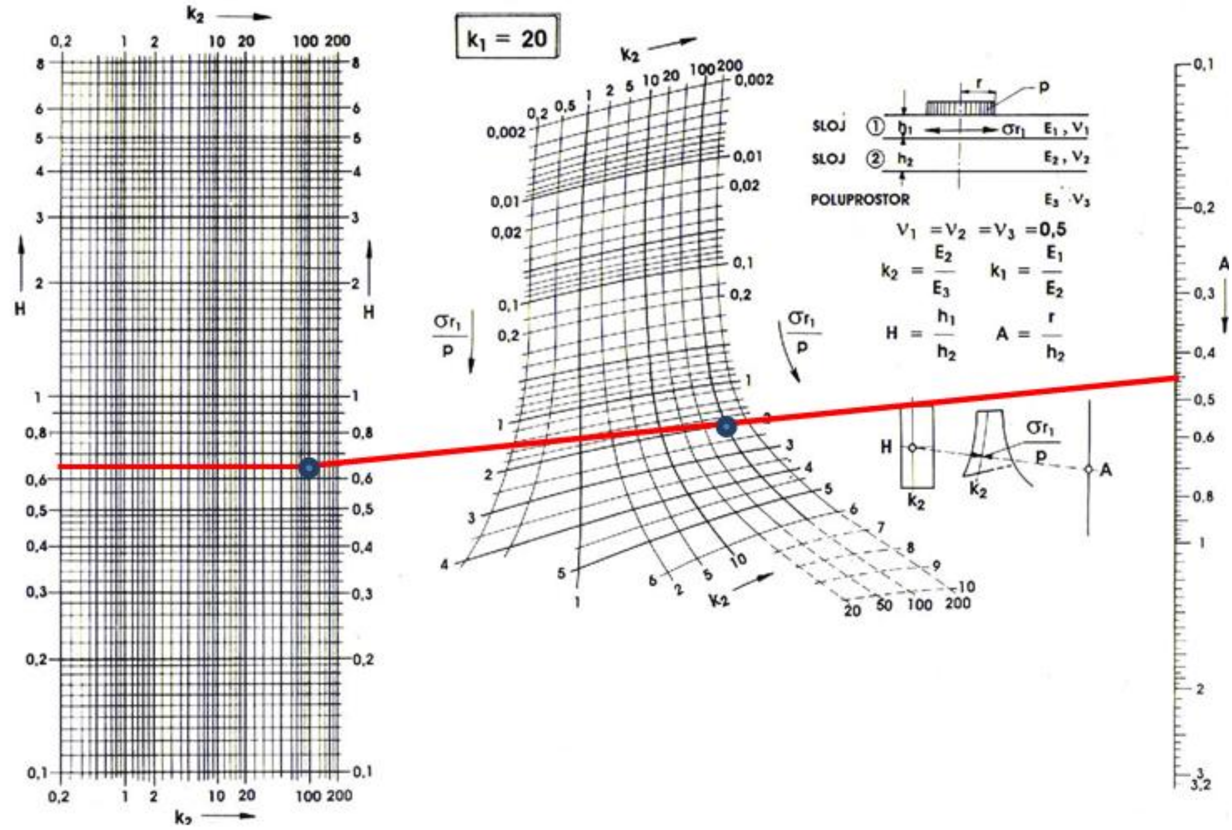

Figure 3. The nomogram for determining the horizontal tensile stress σ_{r1} for k_1=20

For k_1=20 determined value for σ_{r1}/p is 2,2

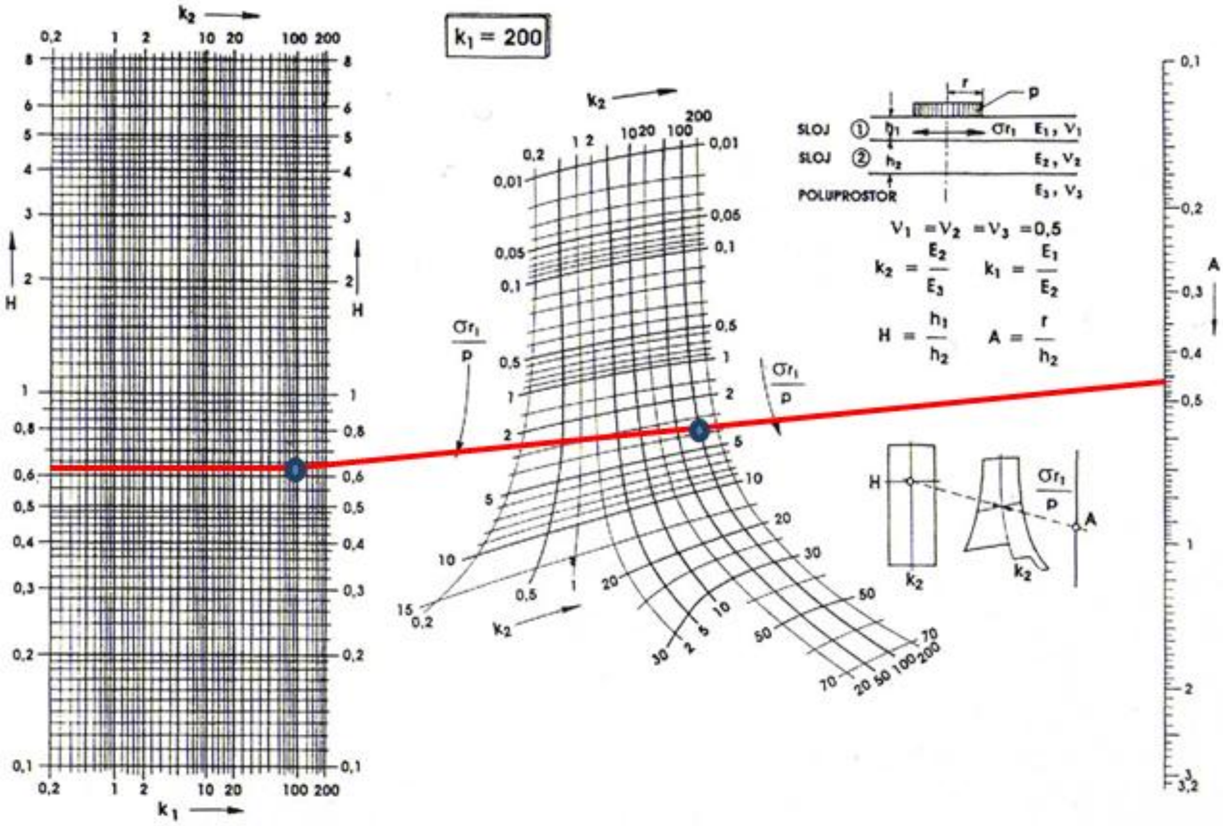

Figure 4. The nomogram for determining the horizontal tensile stress σ_{r1} for k_1=200

For k_1=200 determined value for σ_{r1}/p is 3,9.

Values of horizontal tensile stresses σ_{r1} are:

- for k_1= 2, σ_{r1}/p = 0.35, σ_{r1}=0.35*0.7 = 0.245 MN/m^2,
- for k_1= 20, σ_{r1}/p = 2.20, σ_{r1}=2.20*0.7 = 1.54 MN/m^2, and
- for k_1=200, σ_{r1}/p = 3.90, σ_{r1}=3.90*0.7 = 2.73 MN/m^2.

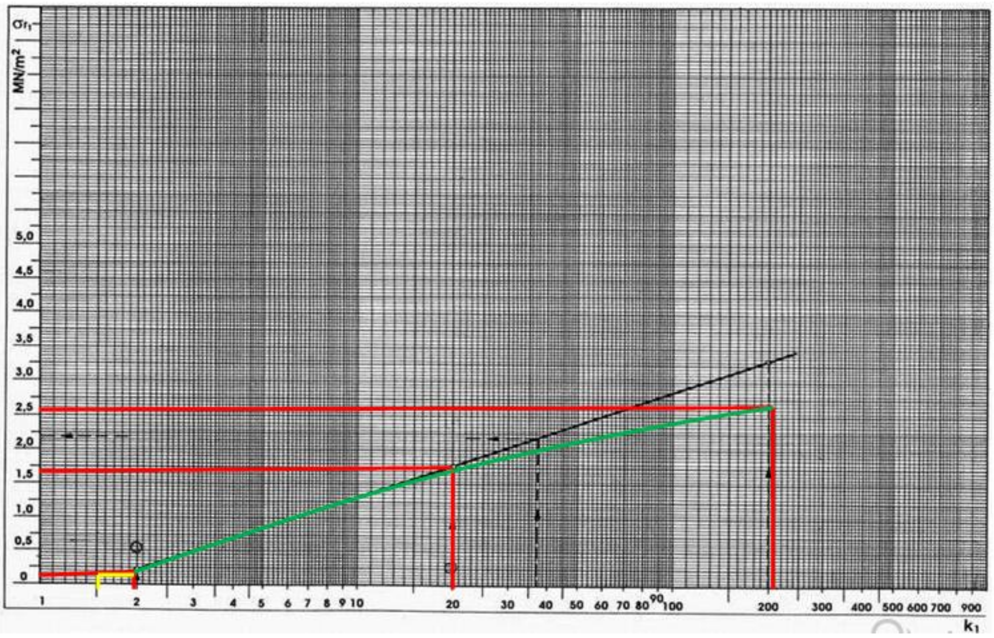

Figure 5. Diagram for determining the horizontal tensile stress σr$_1$ for the actual value of k$_1$

- for k_1 =0.2; since the value is not in diagram 5, the value of k_1=1 is used and therefore σ_{r1}=0,1 MN/m^2, and
- for k_1 =1.5; horizontal tensile stress is σ_{r1}=0.2 MN/m^2.

Value of allowed radial stress is read out from the diagram given in Figure 6.

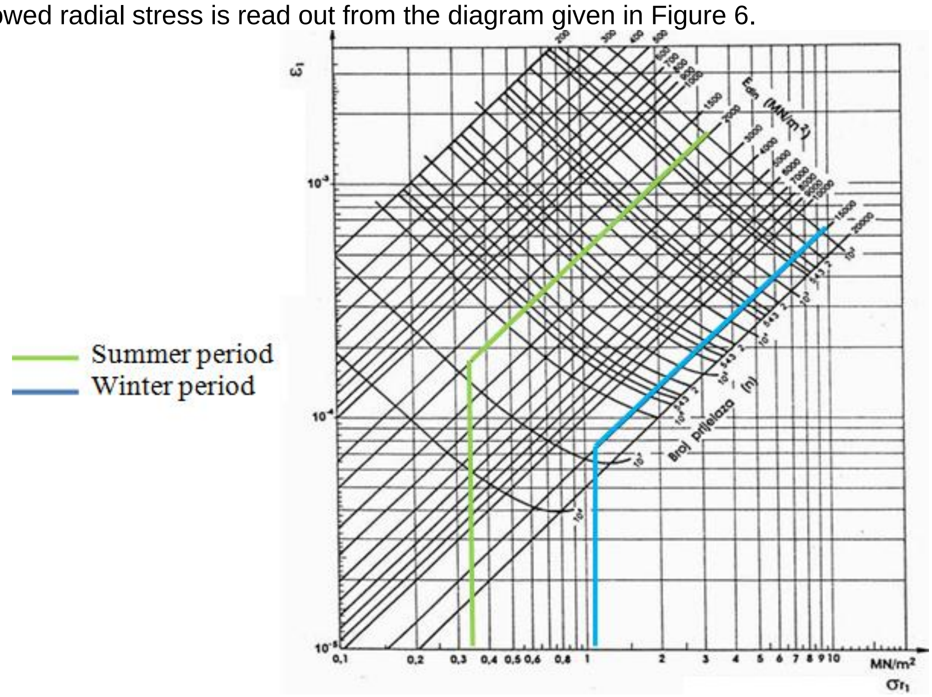

Figure 6. Henkel - Klomp's dependency diagram of dynamic modulus of elasticity of asphalt layer and the number of repeated loads

– for summer period E_{din}=2000, and the number of repeated loads n=7.9*10^6, σ_{rdop} is, σ_{r1dop}=0.35 MN/m^2,

– for winter period E_{din}=15000, and the number of repeated loads n=7.9*10^6, σ_{rdop} is, σ_{r1dop}=1.1 MN/m^2.

σ_{r1dop} for cement stabilisation and traffic load higher than 10^6, allowed stress is 0,5 of static tensile strength of the material. Studies have shown that in these materials static tensile strength in bending is 0.18% of the compressive strength. For the average compressive strength of 5.0 MN/m^2 it is 5*0,18=0,9 MN/m^2.

An engineering principle of comparing the actual stresses or deformations with acceptable deformations in the pavement structure cannot be fully implemented, due to the different climate, hydrological conditions and types of materials in pavement.

Typical conditions can be divided into:

– Spring period; asphalt is rigid, and subgrade is sodden with poor bearing capacity,

– Summer period; asphalt is soft, and subgrade has good bearing capacity,

– Autumn period; asphalt is rigid, and subgrade has good bearing capacity, and

– Winter period; asphalt is very rigid, and the subgrade is frozen.

This leads to changes of modulus of elasticity of material, and thus a change of stresses and deformations.

Calculation of radial stresses on the bottom surface of the cement stabilisation

The following nomogram is used to determine tensile stresses O'_{r2} on the bottom surface of the cement stabilisation for values k_1=0.2, k_1=2 and k_1=20, where the values O'_{r2}/p are read out.

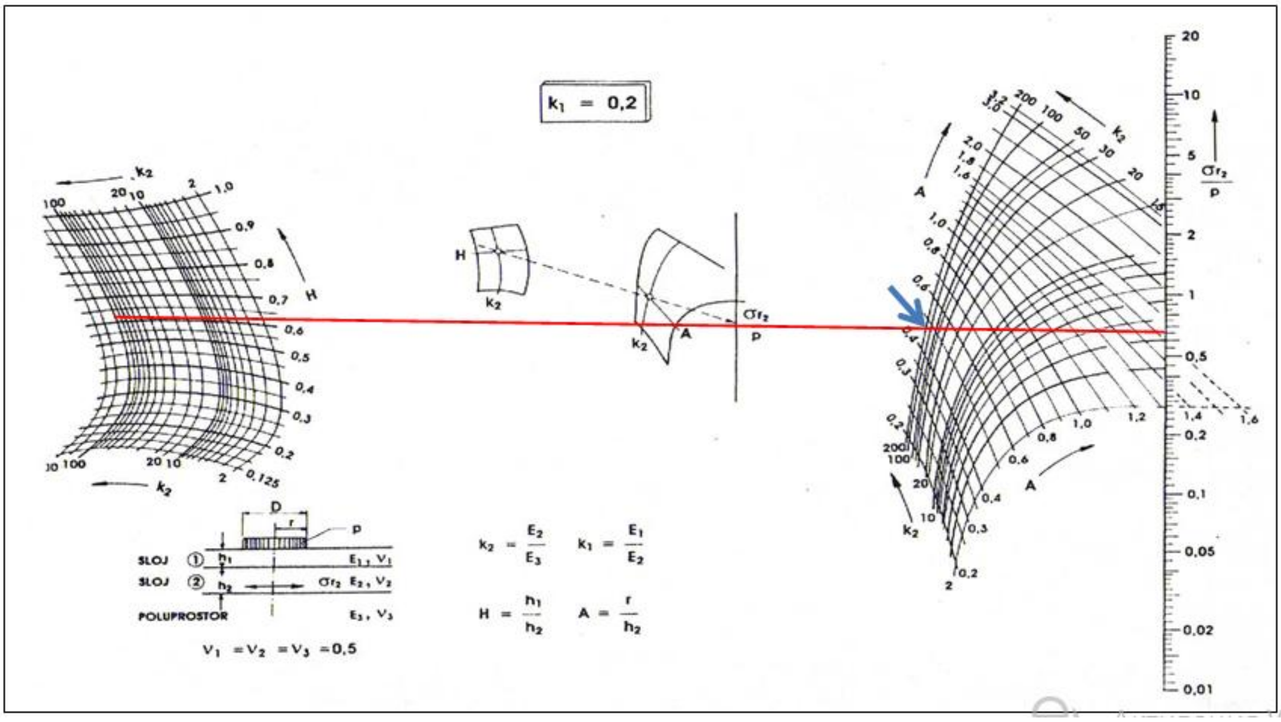

Figure 7. The nomogram for determining the horizontal tensile stress σ_{r1} for k_1=0,2

– for k_1=0.2 determined value for σ_{r1}/p is 0.65.

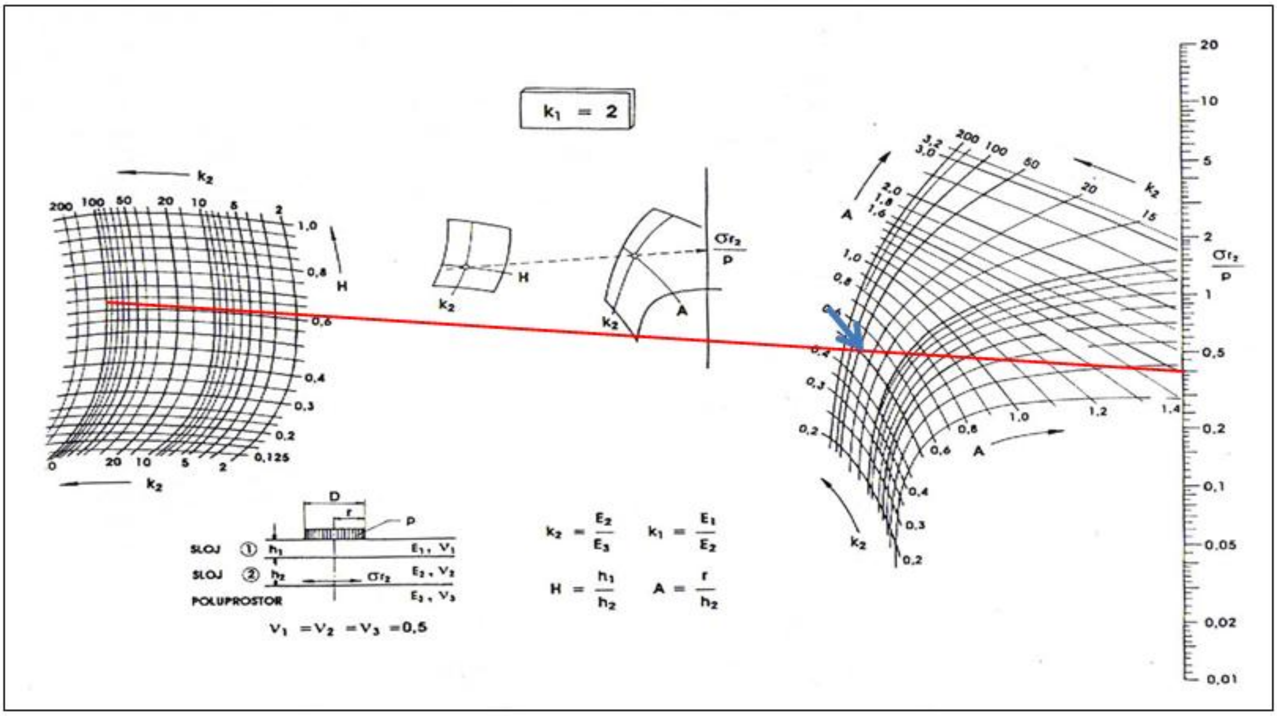

Figure 8. The nomogram for determining the horizontal tensile stress σ_{r1} for k_1=2

– for k_1=2 determined value for σ_{r1}/p is 0.4

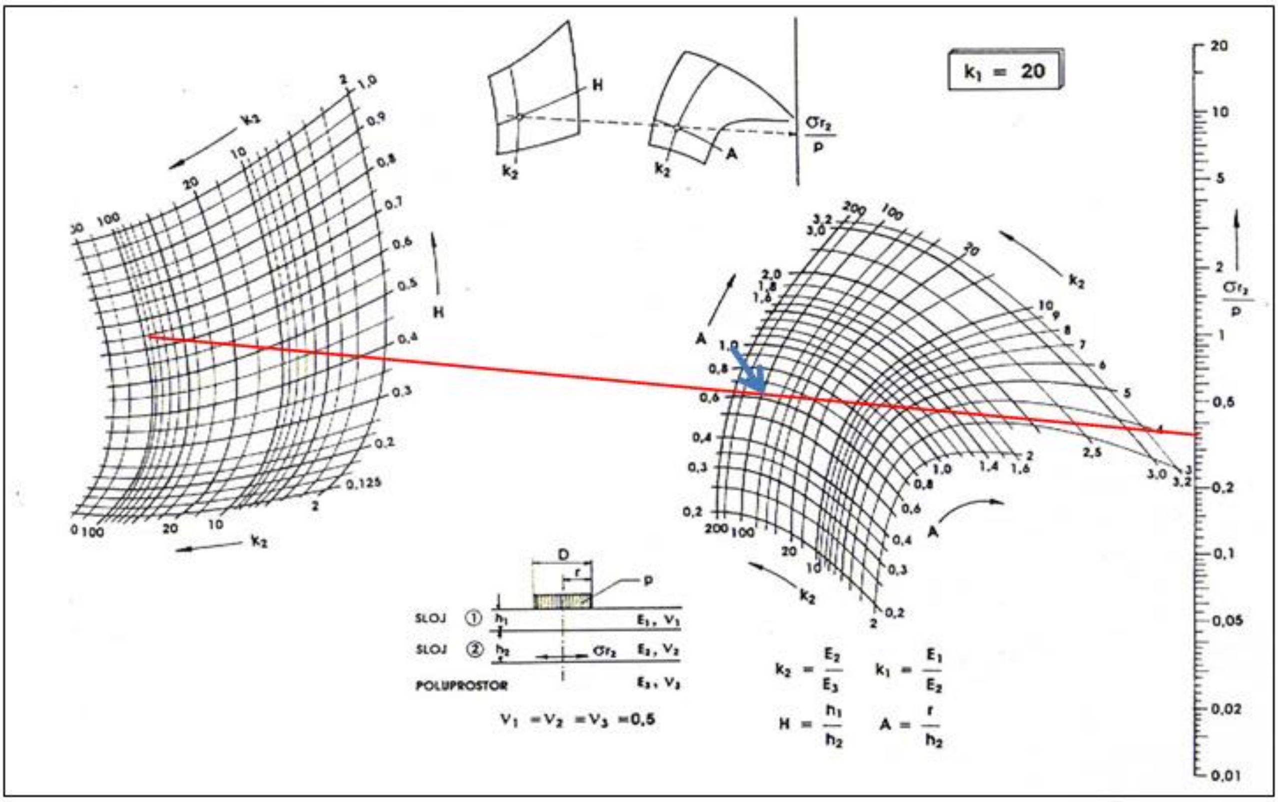

Figure 9. The nomogram for determining the horizontal tensile stress σ_{r1} for k_1=20

– for k_1=20 determined value for σ_{r1}/p is 0.25.

Values of horizontal tensile stresses σ_{r2} are:

- for $k_1 = 0.2$, $\sigma_{r2}/p = 0.65$, $\sigma_{r2} = 0.65*0.7 = 0.45$ MN/m^2,
- for $k_1 = 2$, $\sigma_{r2}/p = 0.40$, $\sigma_{r2} = 0.40*0.7 = 0.28$ MN/m^2,
- for $k_1 = 20$, $\sigma_{r2}/p = 0.25$, $\sigma_{r2} = 0.25*0.7 = 0.175$ MN/m^2.

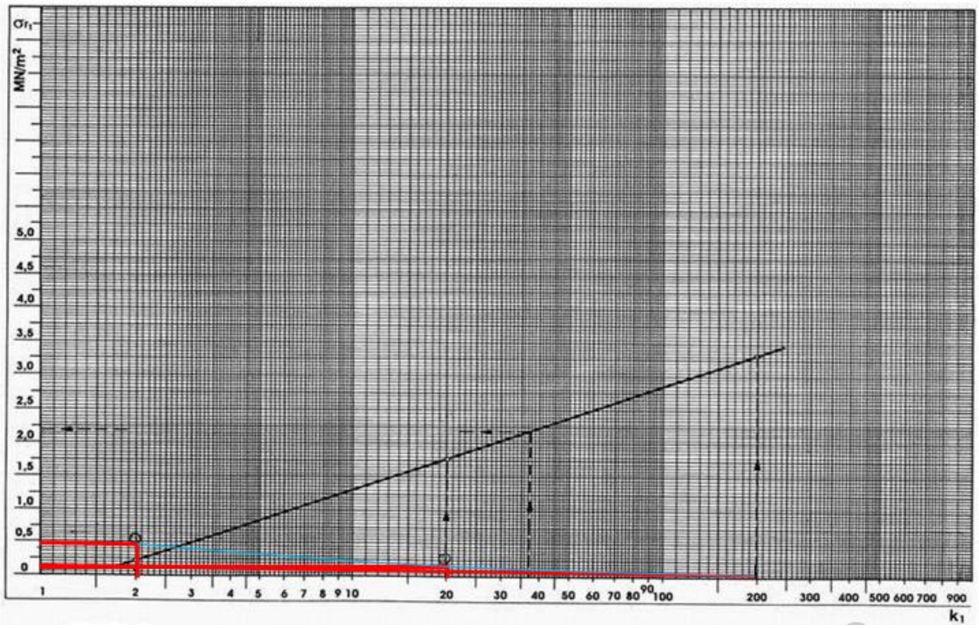

Figure 10. Diagram for determining the horizontal tensile stress σ_{r2} for the actual value of k_1

- for $k_1 = 0.2$ $\sigma_{r2}=0.48$ MN/m^2 (summer period),
- for $k_1 = 1.5$ $\sigma_{r2}=0.2$ MN/m^2 (winter period).

Calculation of vertical stresses at the level of the subgrade

Calculation of vertical stresses at the level of the placenta is carried out in a way that a three-layer pavement is replaced with an equivalent thickness of elastic, homogeneous, isotropic semi-space.

Equivalent thicknesses are calculated using the formula:

- summer period:

$$h_1' = n \cdot h_1 \sqrt[3]{\frac{E_1}{E_3}} = 0,83 \cdot 20 \sqrt[3]{\frac{2000}{100}} = 45 \text{ cm}$$

$$h_2' = n \cdot h_2 \sqrt[3]{\frac{E_2}{E_3}} = 0,83 \cdot 40 \sqrt[3]{\frac{760}{100}} = 154 \text{ cm}$$

- winter period:

$$h_1' = n \cdot h_1 \sqrt[3]{\frac{E_1}{E_3}} = 0,83 \cdot 20 \sqrt[3]{\frac{15000}{100}} = 88 \text{ cm}$$

$$h_2' = n \cdot h_2 \sqrt[3]{\frac{E_2}{E_3}} = 0,83 \cdot 40 \sqrt[3]{\frac{10000}{100}} = 154 \text{ cm}$$

Where n – replacement coefficient for layers; for asphalt layers is 0,83.

Total equivalent thickness expressed in subgrade material is:

$$H = h_1' + h_2'$$

Vertically stress at the level of subgrade is obtained from the diagram in Figure 11.

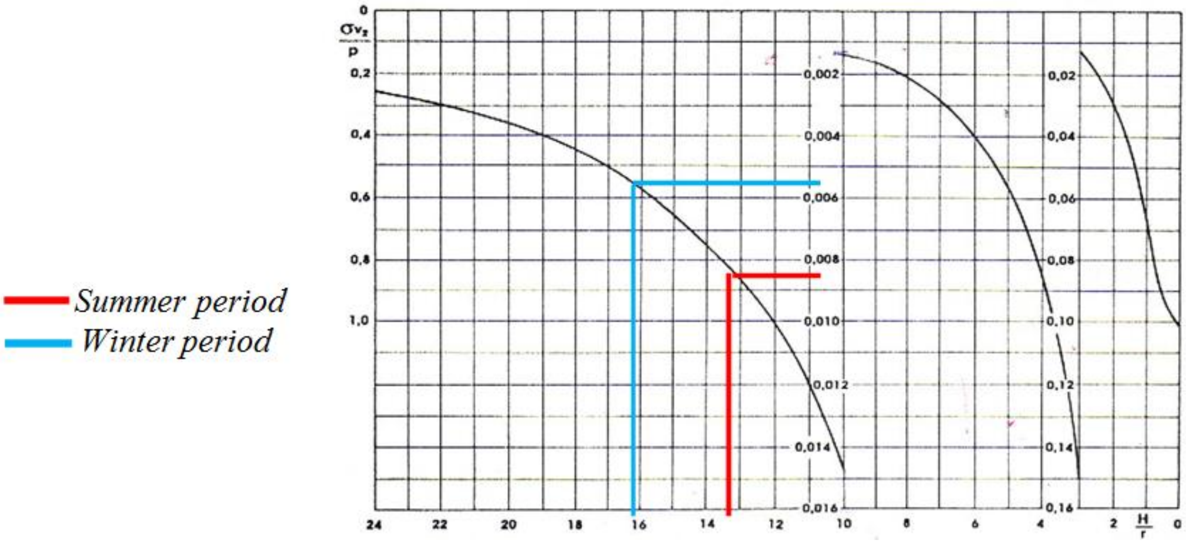

Figure11. Diagram for determining the vertical compressive stresses σ_{v2} according to Odemark

- **Summer period:**

  $h_1' = 45$ cm; $h_2' = 154$ cm; $H = h_1' + h_2' = 199$ cm; $H/r = 13.27$

  $$\frac{\sigma_{v2}}{p} = 0.0085 \Rightarrow \sigma_{v2} = 0.00595 \text{ MN/m}^2$$

- **Winter period:**

  $h_1' = 88$ cm; $h_2' = 154$ cm; $H = h_1' + h_2' = 242$ cm; $H/r = 16.13$

  $$\frac{\sigma_{v2}}{p} = 0.0055 \Rightarrow \sigma_{v2} = 0.000385 \text{ MN/m}^2$$

Conclusion

This research is providing experts with a procedure for stress estimate in a flexible pavement using tables, diagrams and nomograms. Müller nomograms ensure a reliable estimate of pavement stresses in a multi-layer flexible pavement construction.

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Напряжения в многослойном гибком дорожном покрытии

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АННОТАЦИЯ

Целью данного исследования является разработка методики для оценки напряжений в гибкой асфальте с помощью таблиц, диаграмм и номограмм. Номограмма Мюллера обеспечивает надежную оценку напряжений в многослойной гибкой дорожной дорожном тротуарном покрытии. Приведена процедура оценки напряжений в гибком асфальте.

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