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Numerical analysis of an influence of the interlayers' contact on the fatigue strength of flexible pavements

flexible pavements, interlayer contact,
FEM, mechanistic design method

Abstract

Numerical simulations of flexible pavement (KR4 category) were carried out in the paper. The special attention was put on modelling of a friction behaviour between structural layers. Three types of models were prepared: no possibility of slide, contact with a friction factor 0,65, contact with a friction factor 0,8. In the models in which the slip was made possible the fatigue strength was one order of magnitude smaller then in a traditional model used in mechanistic design method.

ANALIZA NUMERYCZNA WPŁYWU SCZEPNOŚCI MIĘDZYWARSTWOWEJ NA WYTRZYMAŁOŚĆ ZMĘCZENIOWĄ NAWIERZCHNI PODATNYCH

Streszczenie

W pracy zbadano wpływ modelowania poślizgu pomiędzy warstwami nawierzchni podatnej kategorii KR4 na wyniki projektowania mechanistycznego. Wykonano analizę numeryczną za pomocą komercyjnego programu Abaqus. Modelowano trzy przypadki konstrukcji nawierzchni drogowej: brak możliwości poślizgu, kontakt ze współczynnikiem tarcia 0,65 oraz kontakt ze współczynnikiem tarcia 0,8. Następnie obliczono trwałość zmęczeniową zgodnie z procedurą projektowania mechanistycznego nawierzchni podatnych. W przypadku modeli, w których możliwy był przesuw między warstwami z betonu asfaltowego trwałość zmęczeniowa była o rząd wielkości mniejsza od tradycyjnego modelu wykorzystywanego przy projektowaniu mechanistycznym.

1. INTRODUCTION

Research shows that interlayers' contact have a significant impact on the fatigue strength of a pavement and thus on the number of loads until the first signs of the pavement's destruction. In the paper [1] there was an experimental segment of a pavement prepared on which several levels of bond (tackiness) were simulated. The stiffness moduli were calculated on the basis of the FWD's (Falling Weight Deflectometer) deflections. Authors observed that the moduli changed through the entire experimental section of the road. In the section where the slide between the asphalt concrete layers was made possible (no bond), the elastic modulus significantly decreased. This decreased value of the modulus is connected only with the possibility of slip between layers. Thus, this modulus shouldn't be used when it comes to calculate strains for the fatigue strength criteria. The lack of bond between layers should be taken into account in the FEM software used for strains calculations. In the paper [1] it is shown that when decreased stiffness modulus is used for strains calculations with the layers completely tied (no contact) the fatigue strength is lower than in the case when real modulus was taken and the lack of bond between layers was taken into considerations. It reveals that awareness of the level of bond between layers is crucial in the process of pavement design.

The purpose of this paper is the numerical (FEM) analysis of a flexible pavement considering the possibility of the slip between structural layers followed by the calculations of the fatigue strengths. The results will be compared to the standard model used in mechanistic design method of pavements.

2. FATIGUE CRITERIA

The mechanistic design method of pavements, generally, is to determine the fatigue strength of a structure on the basis of the analysis of stress and strain state. The pavement is modelled as a multilayer half space as it is shown in Fig 1. Most often the material is modelled as linear elastic so that a pavement's layer is characterized by three values (its thickness, elastic modulus and Poisson's ratio).

The fatigue strength (fatigue life) of a pavement structure is a limiting value of a traffic loading expressed by the number of so called equivalent axis (100 kN or 115 kN) per lane and per twenty-four hours.

The fatigue strength of a pavement's structure, according to mechanistic procedure, is calculated using purely empirical formulas called fatigue criteria. There are a lot of these criteria as the formulas have been obtained by various companies

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and scientific facilities from around the world. In this paper the criteria according to Asphalt Institute will be described because these criteria are used most frequently in Poland.

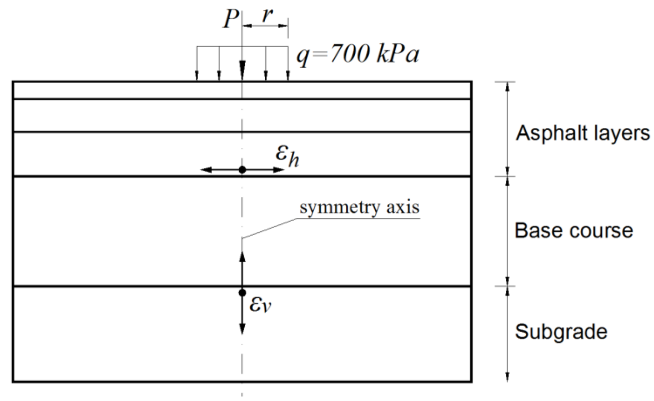

Fig.1. FEM model used in mechanistic design method; $r = \sqrt{\frac{P}{q\,\pi}}$

2.1 The criteria of Asphalt Institute

According to mechanistic designing method there are two fatigue criteria [10]:
- asphalt concrete layers' fracturing criterion,
- permanent deformations' criterion.

The criterion of asphalt concrete layers' fracturing is expressed by the formula:

$$N_f^{asp} = 18{,}4 \cdot 10^M \cdot \left(6{,}167 \cdot 10^{-5} \cdot \varepsilon_h^{-3{,}291} \cdot |E|^{-0{,}854}\right) \tag{1}$$

$$M = 4{,}84\left(\frac{V_b}{V_a + V_b} - 0{,}69\right) \tag{2}$$

where: ε_h – horizontal tension strain at the bottom of the lowest asphalt layer (see Fig. 1)
$|E|$ – stiffness modulus of the asphalt aggregate mixture [MPa],
V_b – content of asphalt in the mixture by volume [%],
V_a – content of free spaces in the mixture by volume [%].

Permanent deformations' criterion is given by the formula:

$$N_f^{fou} = \left(\frac{k}{\varepsilon_v}\right)^{\frac{1}{m}} \tag{3}$$

where: $k = 1{,}05 \cdot 10^{-2}$; $m = 0{,}233$ – material parameters
ε_v – vertical tension strain at the top of the foundation layer (see Fig. 1)

The vertical and horizontal strains are obtained based on the finite element method analysis of an elastic half space. The stiffness modulus $|E|$ in the formula (1) will be understood as a real elastic modulus if the layer's material is modelled as a linear elastic. If the material is modelled as viscoelastic the value $|E|$ is an absolute value of the complex modulus (dynamic modulus).

During the designing process the lowest fatigue strength is taken as the final one. The pavement category is finally determined on the basis of the fatigue strength.

3. MODEL PROPERTIES AND FE RESULTS

All of the pavement's structural layers were modelled as linear elastic. The calculations was carried out for three cases:
- no contact,
- contact with the friction factor: $\mu_T = 0{,}65$,
- contact with the friction factor: $\mu_T = 0{,}80$.

In every case the fatigue strength was calculated and the results were compared to each other. The commercial program Abaqus was used for the analysis (Abaqus/Standard: Static/General solver).

A typical structure of a flexible pavement (KR4 category) was chosen for the analysis (Fig. 2). As the problem is axisymmetric, only half of the structure was modelled on a width of 2 metres. The foundation layer was assumed to be

2 metres high. The axisymmetric 8-node finite elements were selected for the analysis (CAX8). The boundary conditions are shown in Figure 3.

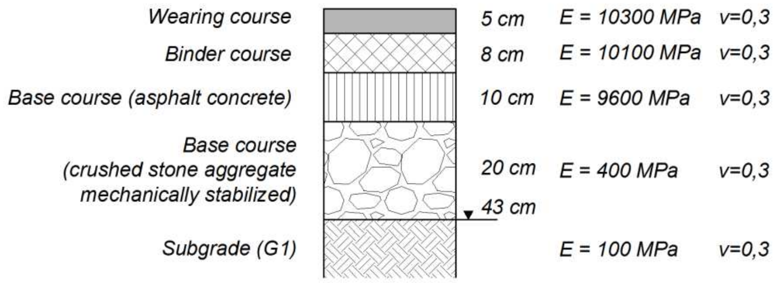

Fig.2. KR4 category flexible pavement structure with material properties

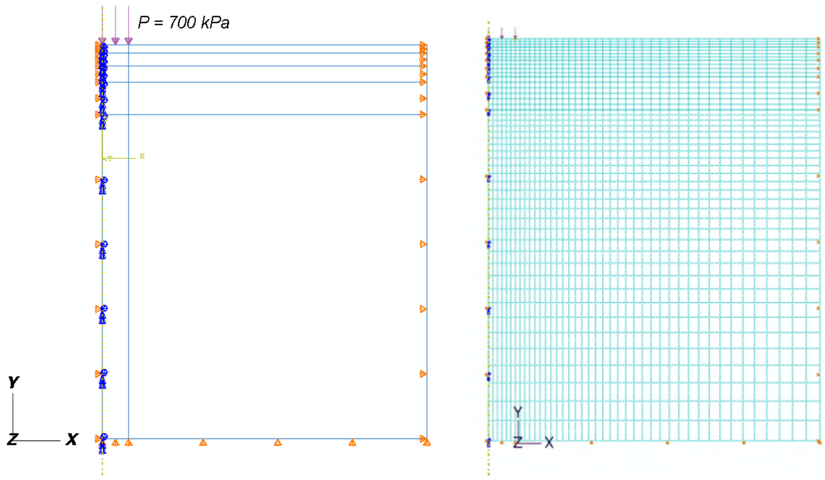

Fig.3. Boundary conditions and mesh

A standard Coulomb friction model (penalty formulation) was used in Abaqus to describe frictional contact behaviour. In this model, two contacting surfaces can carry shear stresses up to a certain magnitude across their interface before they start sliding relative to one another. The Coulomb friction model defines this critical shear stress, τ_{crit}, at which sliding of the surfaces starts as a fraction of the contact pressure, p, between the surfaces ($\tau_{crit} = \mu p$) [2]. The fraction, μ, is known as the coefficient of friction. The model assumes that μ is the same in all directions (isotropic friction). For three-dimensional simulation Abaqus calculates an "equivalent shear stress" $\bar{\tau} = \sqrt{\tau_1^2 + \tau_2^2}$ [2]. The interaction between layers was stabilized at the start of the simulation using the procedure described in [2] (34.3.5 Adjusting initial surface positions and specifying initial clearances in Abaqus/Standard contact pairs). It was also assumed that structural layers cannot separate after achieving contact.

Table 1 shows calculated fatigue strengths in all three cases of the analysis. These values were obtained using the formulas (1) and (3) and the strains results from Abaqus. In the figures 4, 5 and 6 there are also shown the contour plots of strains in the analysed structure. The contour plots reveal that, when the slip is possible, pavement structure behave like partially independent system of plates.

Tab. 1. Calculated fatigue strengths

	No contact	Friction; $\mu_T = 0{,}65$	Friction; $\mu_T = 0{,}80$
N_f [equivalent axis/24h/lane]	562	39	42
Category	KR4	KR2	KR2
Location	Base course	Base course	Base course

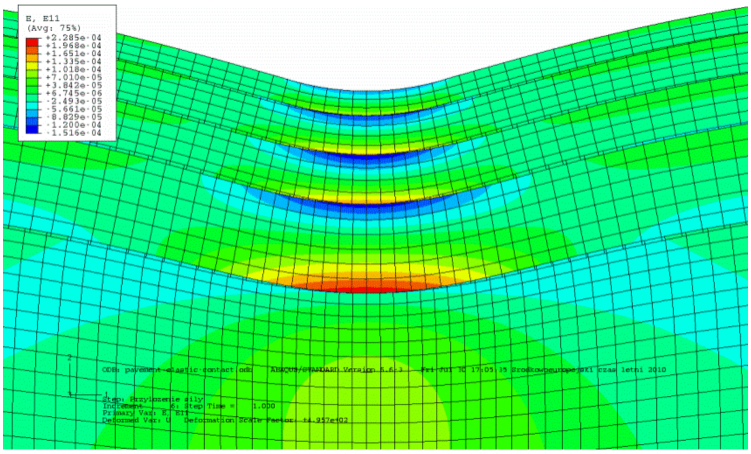

Fig.4. Horizontal strains ε_{11}. Contact with the friction factor equal to 0,65

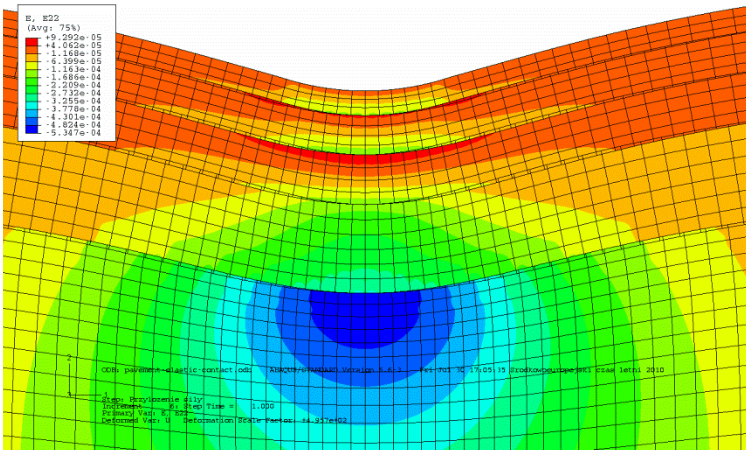

Fig.5. Vertical strains ε_{22}. Contact with the friction factor equal to 0,65

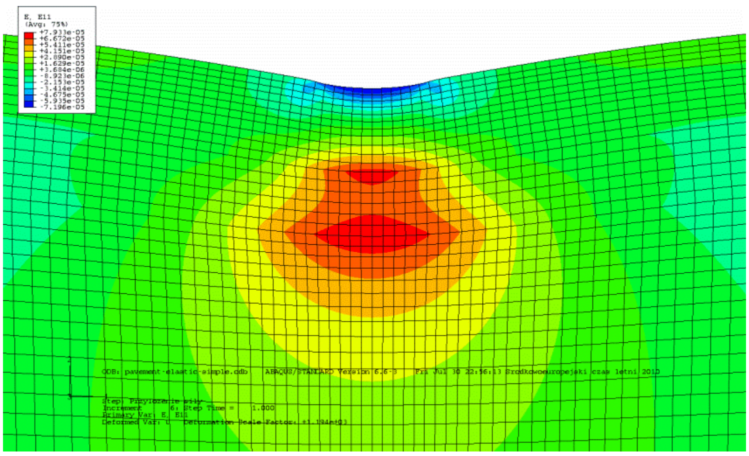

Fig.6. Horizontal strains ε_{11}. No contact (classic mechanistic model).

4. CONCLUSION

The analysis carried out demonstrates that, when the slip between the pavement's layers is considered, the fatigue strength significantly decreases. This conclusion is consistent with the experimental tests. In all three cases, the limiting (smallest) value of the fatigue strength occurred in the base course. However, when contact was considered, this value was one order of magnitude lower than in a traditional way of modelling.

Taking into consideration the possibility of slide between structural layers, using different friction factors leads to almost the same results. Therefore, in this type of structure and with such loads, only the existence of slide behaviour has an impact.

The analysis prepared reveals how important it is to carry out appropriate actions during the construction of the pavement to prevent the slip between layers.

5. REFERENCES

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