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Fatigue life of asphalt pavements on bridge decks

Piotr Pokorski[a]*, Piotr Radziszewski[a], Michał Sarnowski[a]

[a]*Warsaw University of Technology,The Faculty of Civil Engineering, Al. Armii Ludowej 16, 00-637 Warsaw, Poland*

Abstract

Pavement is one of the basic elements of a bridge structure. In Europe and Poland pavements for engineering objects are made in the asphalt technology. Requirements for ensuring the sustainability of the entire object also refer to pavement. Fatigue life is one of the parameter that must be satisfy but there is no requirements connected with it. It is directly related to the stresses and strains which occur in the pavement. Based on a state of art and using calculation results of software with finite element method (FEM) the strains in characteristic points of the bridge pavement were presented. Strains in pavements on the soil, concrete and steel deck were compared. One of the classic and one of the modern criteria for fatigue life were described. Calculation models for fatigue life of asphalt pavement does not classify separately bridge pavements. A typical technology and materials used in the bridge deck pavements were presented. Fatigue life of asphalt bridge pavements were estimated. The analysis of the results and evaluation of the adequacy of fatigue life models were made.

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Keywords: life; bridge pavement; asphalt mix

1. Introduction

Bridge pavement works in a very specific load conditions. It is subjected to loads of traffic vehicles and climatic factors. On the pavement act horizontal and vertical forces, low and high temperatures, water and de-icing salts. Aggressiveness load in the case of bridge decks is much higher than the pavement on soil. Wheel loading vehicle

* Corresponding author. Tel.: +48 22 234 64 61
E-mail address: p.pokorski@il.pw.edu.pl

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causes, as in outside pavement of the object, stress and strain compressive and tensile loads. They can cause permanent deformation, and fatigue cracking of asphalt layers. Stress and strain in bridge pavement are bigger than on the soil, therefore there is greater risk of damages. Stress and strain in the bridge pavement depend on the type of the deck. Other values are the maximum strain in the surface on the object with a concrete and orthotropic steel decks [1,2,3,4].

2. Fatigue life prediction models

Determining the fatigue life based on the state of stresses and strains of the structure, material properties obtained from laboratory and experimental design called mechanistic methods. There are two criteria of destruction: the criterion of cracking of asphalt layers and the criterion of permanent deformation. The most common methods for calculating fatigue life are Asphalt Institute method, Shell method , University of Nottingham method and the Centre for Road and Transport Research in Belgium method. Methodology were developed in the 80s. 20th century [1, 5, 6].

The criterion of fatigue cracking of asphalt layers is usually defined according to the formula [1, 5, 6]:

$$N_f = a\left(\frac{1}{\varepsilon_f}\right)^m \quad (1)$$

where:

N_f – number of repetitions to fatigue cracking,

ε_f – tensile strain at the critical location,

a, m – laboratory regression coefficients.

In the method of the Institute of Asphalt (IA) criterion of fatigue cracks takes the form:

$$N_f = 18{,}4C(6{,}167 \cdot 10^{-5} \cdot \varepsilon_{ha}^{-3{,}291} \cdot |E|^{-0{,}854}) \quad (2)$$

where:

N_f – number of repetitions to fatigue cracking,

ε_{ha} – tensile strain at the bottom of the asphalt layers, m/m,

$|E|$ – stiffness modulus of the material, Pa,

C – laboratory to field adjustment factor.

$$C = 10^M \quad (3)$$

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

where:

V_a – air voids (%),

V_b – effective binder content (%).

Nowadays, the most commonly used methods is the AASHTO 2004 criterion and the French criterion. Method AASHTO 2004 has been calibrated on the basis of the test results a large amount of experimental sections located in different climatic conditions [5].

The revised AASHTO 2004 model can then be written as shown in the following equation [5, 6]:

$$N_f = 7{,}3557(10^{-6})\,C\,k_1'\left(\frac{1}{\varepsilon_t}\right)^{3{,}9492}\left(\frac{1}{E}\right)^{1{,}281} \tag{5}$$

where:

N_f – number of repetitions to fatigue cracking,

k_1' – function of the asphalt concrete layer thickness, m

ε_t – tensile strain at the bottom of the asphalt layers, m/m,

E – stiffness modulus of the material, Pa,

C – laboratory to field adjustment factor.

$$C = 10^M \tag{6}$$

$$M = 4{,}84\left(\frac{V_b}{V_b + V_a} - 0{,}69\right) \tag{7}$$

where:

V_a – air voids (%),

V_b – effective binder content (%).

For the alligator fatigue (bottom up) cracking the “k_1” parameter is given by the following equation:

$$k_1' = \frac{1}{0{,}000398 + \dfrac{0{,}003602}{1 + e^{(11{,}02 - 1{,}374 \cdot h_{ac})}}} \tag{8}$$

For the alligator fatigue (bottom up) cracking the “k_1” parameter is given by the following equation:

$$k_1' = \frac{1}{0{,}01 + \dfrac{12}{1 + e^{(15{,}676 - 1{,}1097 \cdot h_{ac})}}} \tag{9}$$

h_{ac} – total thickness of the asphalt concrete layers, cm.

3. Asphalt pavement layer systems on bridge decks

In Europe bridge asphalt pavements are paved on the insulations (waterproofing). Asphalt pavement on the bridges consists of a protective layer and wearing course. These layers are usually made of mastic asphalt MA, asphalt concrete AC and stone mastic asphalt SMA. Due to the specific conditions of the load on a bridge decks, asphalt mixes with a high content of mastic and closed structure are preferred. There are a mixture of mastic asphalt MA and SMA for the protective layer and asphalt concrete, SMA for wearing course [4,7]. Figure 1 shows the typical layouts pavement layers on the bridge decks.

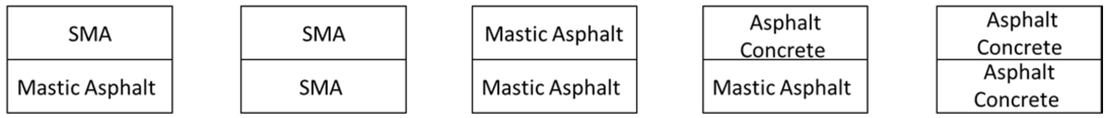

Fig. 1. Types of asphalt layer system on bridge deck

4. Stresses and strains in asphalt pavements

On the basis of computer finite element method (FEM) calculations and review of the literature the strains which occur in the pavement on the soil and in the bridge pavement placed on different types of decks were shown. The thickness of the asphalt layers on soil is approx. 10-30 cm. In a typical pavement structures on soil the bottom of the asphalt layers have horizontal tensile strain. Values are in the range of 60-150 microstrains. Adopted for the calculation of the construction of the pavement on the soil and the distribution of horizontal stains at different depths are shown in figure 2. The calculations were made in the BISAR 3.0 software. Extreme values of the horizontal tensile strains of asphalt are on the bottom of asphalt layer. For the adopted layout ε_{xx}= 90 microstrians.

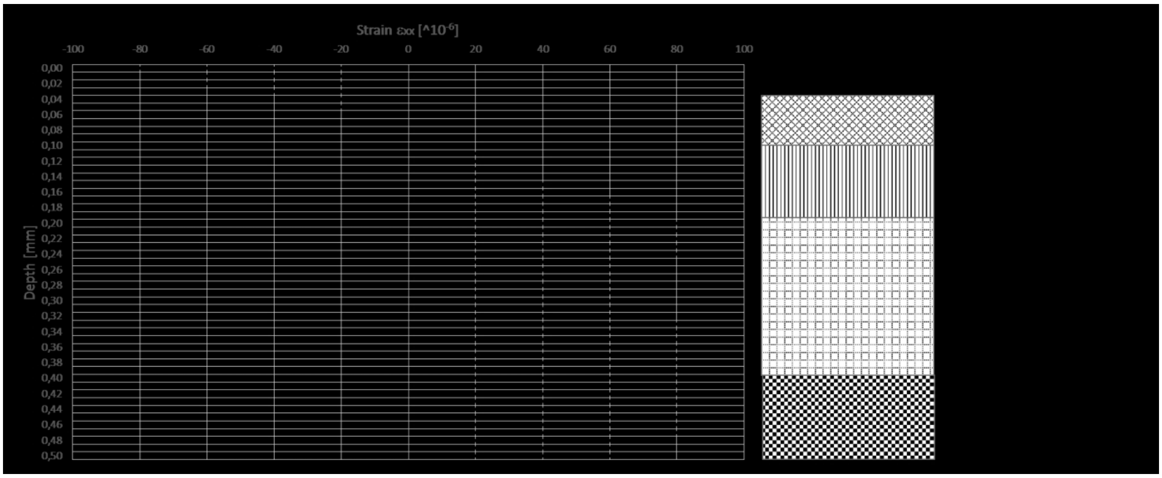

Fig. 2 Horizontal strain in asphalt pavement on the soil

Asphalt pavement on bridge decks are much thinner than pavement on soil. Their thickness is approximately 8-12 cm. Due to the different stiffness of stresses and strains should be considered separately for concrete and orthotropic decks.

Concrete bridge decks have a high stiffness. At the bottom of the asphalt layers there are not large tensile strain. Construction of the pavement on the concrete bridge deck and the distribution of horizontal stains at different depths are shown in Figure 3. At the bottom of the asphalt layers horizontal tensile strain is equal to εxx=16 microstrains. The calculations were made using the Finite Element Program Bisar 3.0.

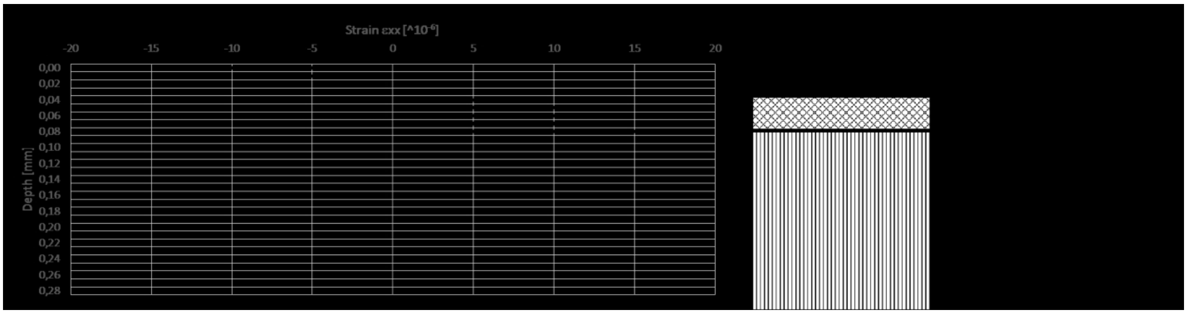

Fig. 3 Horizontal strain in asphalt pavement on the concrete bridge deck

Figure 4 shows a graph of strains on the bottom layers of asphalt as a function of time of a moving vehicle model on concrete bridge deck created with MES software at the Warsaw University of Technology [4]. In this model, the maximum tensile strain is equal to εxx = 11, maximum compressive strain is equal to εxx = -109.

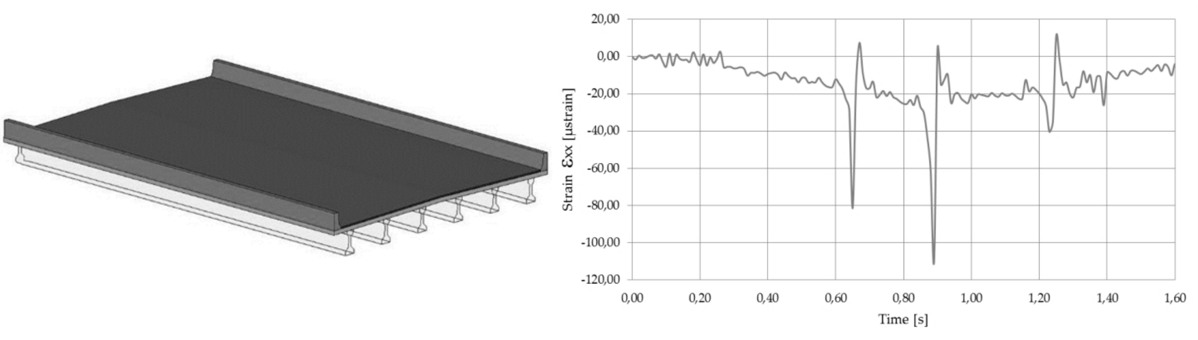

Fig. 4. FEM model of concrete bridge and strain εxx distribution at the bottom surface of the MA layer in the direction of the truck movement for the pavement located on the bridge [4]

FEM model of concrete platform developed in Italy received little different volume of maximum horizontal strain in the pavement [8]. Table 1 shows the maximum horizontal stresses and strains in the pavement depending on the stiffness modulus of the asphalt mixture. For the stiffness E = 6000 MPa the horizontal tensile strain εxx=76 microstrains.

Table 1. Stresses and strain in FEM of concrete bridge deck pavement [8]

E^* [MPa]	σxx [MPa]	σyy [MPa]	εxx [μstrain]	εyy [μstrain]
4 500	0,452	0,607	102	157
6 000	0,462	0,625	76	119
10 000	0,490	0,635	48	35

Orthotropic steel decks work in a complex way. In order to determine the stresses and strains of the deck and the pavement it is necessary to apply a FEM model [9,10,11]. Figure 4 shows an example of FEM modeling of bridge structure, made in the framework of the European research program. Figure 5 presents the horizontal strain which occur at the bottom surface of the asphalt layers located on the orthotropic steel decks. Maximum tensile strain is equal to εxx=250 microstrains, while the compressive is equal to εxx=-600 microstrains.

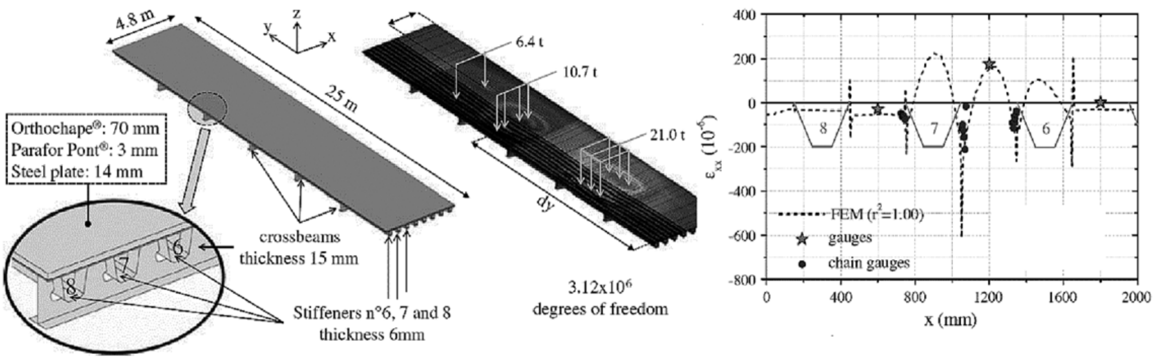

Fig. 5 FEM model of steel orthotropic deck and strain εxx distribution at the bottom surface of the MA layer in the direction of the truck movement for the pavement located on the bridge [9]

5. Analysis of the results

Fatigue life was assessed on the basis of IA method and AASHTO 2004 method. It depends on the strains that occur at the bottom of asphalt layers and the modulus of asphalt mixtures. For the calculation of the fatigue life of pavement design was adopted with the use of mastic asphalt in the protective layer (E = 6000 MPa, Va = 0.5%, Vb = 19%). The results are given in table 2 in millions of axis.

Table 2. Fatigue life of bridge pavement

Strain [microstains]	5	10	20	100	150	200	250	300
Fatigue Life N [mln]:								
IA method	>1 000 000	462 058	47 207	236	62	24	12	6
Aashto 2014 method	>1 000 000	>1 000 000	>1 000 000	>1 000 000	523	168	69	34

For strains that occur in the pavement on concrete deck, due to the low values of tensile strain horizontal estimated fatigue life of both methods accepted very high values. In Figure 6 shows the results of fatigue life using various methods adopted for horizontal strains in the range of 150-300 microstrains. Estimated fatigue life by the method AASHTO 2014 is much higher than by Asphalt Institute formulas. For strain equal to 150 microstrains received high results of fatigue life. For extreme strains occurring in the orthotropic steel deck (approx. 250 microstrains) fatigue life for the AI method is equal to f N = 12 million and for the AASHTO methods is equal to N = 34 million. In Poland, the heavy traffic on the soil required fatigue life between 2 - 52 million and for very heavy traffic minimum 52 million.

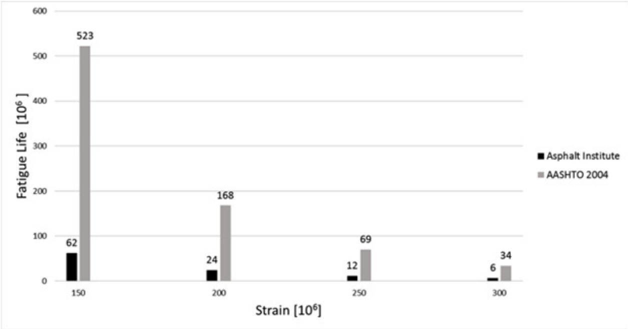

Fig 6. Fatigue life of asphalt bridge pavement

6. Conclusions

Bridge pavements should have high durability. Fatigue life of asphalt pavements depends on the horizontal strains at the bottom of asphalt layers. Deformations of the bridge pavement depend on the type of the bridge deck. On the concrete bridge decks stresses and strains take these values do not exceed those of the pavement on the soil. On the orthotropic steel decks strain values are high and exceed those that occur on the soil. The calculation results confirm that on the concrete decks should not be a problem with ensuring resistance to fatigue cracking. In order to determine the strain in the pavement on orthotropic steel deck the FEM model of the actual object is required, and calibrate. The results of the fatigue life calculated using both AI and AASHTO 2004 for large strain on the orthotropic steel decks show that for this type of objects may be a problem to provide resistance of fatigue cracking. There is no separate criteria for evaluating the fatigue life of the asphalt pavement on bridges. The above analysis can serve as an introduction to the discussion on ensuring the fatigue life of pavement on bridges. Raising the fatigue life of asphalt bridge pavement can be obtained through the use of modern technological solutions and materials.

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