Comparative evaluation of the performance of different asphalt concrete road pavements on reinforced concrete road structures

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Abstract. Comparative design of structures allows at an early stage of project development to assess their behavior and predict service life. Approximate numerical methods, for example, the finite element method, are widely introduced to simulate the operation of pavements on road structures. The variety of modern asphalt concrete poses the problem of finding the most effective design solutions based on the results of comparing the performance indicators of road pavements. The article presents the results of modeling by the finite element method of the work of road pavements, consisting of a two-layer asphalt-concrete package, on a reinforced concrete slab of bridge. Various options for combinations of asphalt concrete are considered. The well-known American method of the Asphalt Institute was used as a methodological basis. For the criterion of the limiting state, the indicator of accumulated fatigue cracks in the amount of 10% of the wheelpath area is taken. Preliminary recommendations are given on the field of application of the considered road pavements on reinforced concrete bridges in the conditions of the Syrian Arab Republic.

1. Introduction

The traditional methods of designing pavements on highways, based on solving the problem of a multilayer system "pavement (surface, base, sub-base) on subgrade", cannot be applied to the design of pavements of a bridge deck. In global practical experience, most often, road pavements of bridges are assigned without calculation, taking into account the accumulated experience based on the results of monitoring the condition and statistics on the actual service life of pavements under various operating conditions. However, in case of a lack of statistical material, effective designs of road pavements can be proposed based on modeling their operation in specified modes.

Asphalt pavements on bridge deck are much thinner than pavement on subgrade. Its thickness is about 8-12 cm. because of the different stiffness of stresses and strains, they must be considered separately for both concrete and orthopedic surfaces.

The most common types of damage and defects to pavements on bridge structures are cracks, rutting, corrosion, various forms of permanent deformations, and potholes. Corrosion of the surface course is damage that is largely due to the Corrosion and grinding resistance of coarse aggregate(crushed stone). Shear defects (formation of waves, corrugation, transverse unevenness, patches) can be minimized with the correct designation and determination of the binder grade for asphalt concrete and it's ratio.
Potholes are a "neglected" defect that usually occurs with inadequate current maintenance of the bridge deck.

Therefore, predicting the growth of fatigue cracks in asphalt concrete layers will be most indicative for assessing the serviceability by the strength of road pavements of bridges. It is appropriate and expedient to perform such express-forecasting of resistance to the impact of multiple traffic loads of road pavements using computer modeling using the finite element method [1, 8].

2. Method of investigation

The fatigue life of an asphalt pavement may be defined as the magnitude of traffic, expressed as the number of equivalent standard axles (ESAs) (single axle, dual wheels carrying 80 kN load ) that it can withstand before distress in terms of cracking of a certain percentage of the wheelpath area is observed. The tolerable cracking level may vary depending on design traffic loading but generally ranges from 10 to 45%.

The fatigue life of pavements is determined based on the state of stresses and strains of the structure and material properties obtained from laboratory and experimental results. The most common methods for calculating fatigue life are the Asphalt Institute method, the AASHTO 2004 method, the Shell method, the University of Nottingham method and the Center for Road Research and transport in Belgium method. The listed methods have certain similarities. However, the most widely used method is the Asphalt Institute. The Asphalt Institute model (Asphalt Institute 1981) is also based on strain and stiffness but also takes into account the influence of effective binder volume ($V_b$) and air voids ($V_a$) on fatigue life [7, 11, 12].

The Asphalt Institute model is given by the following equation [14]:

$$N_f = 18.4 \times C \times (6.167 \times 10^{-5} \times \varepsilon_{ha}^{-3.291} \times |E|^{-0.054})$$

(1)

where

- $N_f$ – Number of repetitions to fatigue cracking;
- $\varepsilon_{ha}$ – Tensile strain at the bottom of the asphalt layers;
- $E$ – Stiffness modulus of the material, MPa;
- $C$ – Adjustment coefficient.

$$C = 10^M$$

(2)

$$M = 4.84 \times [V_b/(V_b + V_a) - 0.69]$$

(3)

where

- $V_b$ – Effective binder content (%);
- $V_a$ – Air voids (%).

Modern pavement designs on bridge decks must include at least two layers of asphalt concrete. At the same time, various types of asphalt concrete are used, in both the upper and lower layers. Since the upper layer is designed to be as a wearing course, it is rarely constructed and laid with a thickness of more than 5 cm, often limited to only 4 cm thick. The lower layer of the pavement, which is responsible for the overall structural stability, is assigned, as a base course, with a thickness of at least 4 cm.

As part of a numerical experiment, the simulation of the operation of six different road pavements was performed, consisting of various combinations of varieties of asphalt concrete, arranged on reinforced concrete slabs of bridge deck. For all the options under consideration, the thickness of the upper coating layer was taken equal to 4 cm, and the lower coating layer 4 cm (Figure 1).

In (Figure 1), the following abbreviations and acronyms are adopted: Dense AC rous asphalt concrete.
based on bitumen grade 60/90; SMA PBB 60 - Stone-mastic asphalt concrete based on polymer-bitumen binder PBB 60; Mastic AC - Mastic asphalt concrete based on bitumen-rubber composite binder BRCB [3, 5, 6, 10, 16].

The properties and design characteristics of asphalt concrete strongly depend on their temperature. Under real operating conditions, the temperature of asphalt concrete changes significantly. Taking this condition into account greatly increases the complexity of the experiment.

Taking into account that for the conditions of the Syrian Arab Republic the average annual temperature is about 15 ... 25 °C, it was decided to set the design characteristics of asphalt concrete corresponding to a temperature of 20 °C.

**Figure 1.** The typical layouts pavement layers on the bridge decks.

The table 1. shows the physical-mechanical properties of the asphalt concrete of the investigated and studied pavements [2, 9, 13, 15].

**Table 1.** Physical-mechanical properties of the asphalt concrete, adopted for experimental modelling.

| Asphalt concrete type | Elastic modulus (E) at a temperature of +20 °C, MPa | Poisson's ratio | $V_b$ (%) | $V_a$ (%) |
|-----------------------|-----------------------------------------------|----------------|------------|------------|
| Dense AC              | 1800                                           | 0.35           | 5.5        | 4.0        |
| Porous AC             | 1200                                           | 0.35           | 4.0        | 6.0        |
| SMA PBB 60            | 2600                                           | 0.35           | 6.5        | 3.0        |
| Mastic AC             | 2900                                           | 0.35           | 7.0        | 2.0        |
3. Research results

Finite Element Simulation (FEM) was performed using EverStressFE software. The deformations that occur in the layers of road pavements on reinforced concrete bridges were calculated.

The thickness of the reinforced concrete slab is taken to be 20 cm, and the calculated wheel load was 40 KN, the contact pressure of the wheel on the coating was 690 kPa (Figure 2).

![Figure 2. Interface of the wheel load design parameters input window.](image)

On the basis of computer finite element method (FEM) calculations and review of the literature the strains which occur in the different bridge pavements placed on reinforced concrete bridges decks were shown (Figure 3).

The performance of pavements is often assessed and judged by the number of applications of the design load before the beginning of the limit state according to the criterion under consideration [4].

Depending on the selected pavement structure, the discrepancy in performance according on the criterion of fatigue cracking was quite important. Thus, the variance of designs No. 2 and No. 3 exceeded 5.5 times (Figure 4).

The results obtained showed that the best performance according to the criterion of fatigue cracking is possessed by pavements with a top layer of (SMA) stone-mastic asphalt concrete on a polymer-bitumen binder, so these design solutions can be recommended for bridges on roads with the highest traffic density.

On bridges located on roads with a load corresponding to III and IV categories, we can recommend the more economical option No. 1. In the case of a low-traffic local road network, the design of option No. 2 can be applied. Such recommendations can be taken as a basis for the development of catalogs of typical road pavements on reinforced concrete bridges.
Figure 3. Graphical results of the performance of asphalt bridge pavements from a numerical experiment.
4. Conclusion
To evaluate the performance of two-layer asphalt bridge pavements on a rigid reinforced concrete base, the finite element method was applied. The Asphalt Institute algorithm developed by American specialists was used. It has been established that pavements with layers of (SMA) stone-mastic asphalt concrete on polymer-bitumen binder have the highest performance, expressed in the number of applications of the design load, according to the criterion of fatigue cracking. The results obtained will contribute to the development of standard design solutions for bridge structures in the Syrian Arab Republic. In the absence of a clear and reliable design method for designing paving layers over bridges. The method studied is considered the basis for a comprehensive study to develop a method for designing asphalt pavement layers over bridges.

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