Interlayer Bond Evaluation in the Flexible Pavement Structures Using a Nondestructive Testing Method

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Abstract

The paper proposes a new approach to the bond condition evaluation of flexible pavement structural courses using a nondestructive testing method. It provides numerical modeling results of the effect of the bond loss between flexible pavement components on the form of acceleration frequency-response characteristics on the pavement surface under impulse loading. It has been determined that providing a full bond between all components of the flexible pavement structure, there is one distinct frequency peak magnitude on the acceleration frequency-response characteristics. With the interlayer bond loss between the asphalt concrete layers and the pavement base course on the acceleration frequency-response characteristics of the flexible pavement surface, recorded at 0.75-1.25 m from the loading point there are two frequency peak magnitudes within 0-350 Hz and 350-500 Hz. With the interlayer bond loss between all components of the flexible pavement structure on the acceleration frequency-response characteristics recorded at 0.25 – 2.5 m, there is a number of frequency peak magnitudes located in the frequency domains of 0-200; 200 – 350, 350 – 500 Hz. The adequacy of the numerical modeling results is proved by good coherence between the forms of acceleration frequency-response characteristics measured with the use of the analytical model of the dynamic strain – stress condition and frequency-response characteristics recorded on the flexible pavement surface in different operation field conditions. There have been determined opportunities for the development of the proposed approach which are related to the improvement of the methods and techniques of the pavement evaluation in the frequency domain under dynamic loading.

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1. Introduction

The major challenge of all highway engineers over the world is premature deterioration of road pavement caused by both dynamic impact of heavy traffic and negative effect of climatic factors. This problem is solved by performing rehabilitation activities which include major repair works and reconstruction. However, it is essential to make rehabilitation “targeted”, i.e. focused on the removal of the destruction source. It can be achieved by improving the information content of the flexible pavement evaluation methods conducted as part of highway test operation system. The scientific basis for pavement analysis should be modern concepts of allied sciences, primarily, deformable solid mechanics and geophysics.


In recent years much attention to the development of nondestructive testing methods on flexible pavements has been given at Rostov school of mechanics and flexible pavements directed by Prof. E.V. Uglova. Particularly, the papers (Lobov, 2004; Uglova et al, 2009; Iliopolov et al, 2002) propose new experimental approaches for flexible pavement evaluation methods through dynamic loading wave field spectrum analysis in the pavement structures [10 - 12]. Abroad this method has been adopted and is being rapidly developed primarily by American scientists, such as Nazaryan S, Gugunski V (Nazaryan, 1992; Nazaryan and Yuan, 2002; Nazaryan, 2010) and others [13 - 15]. Particularly, their papers develop and specify the SASW method (spectrum analysis of surface waves), adapted from geophysics for evaluation of asphalt concrete courses and certain components of road pavements.

The development potential of this method is directly related to the problems of flexible pavement structural deflections connected with the bond loss between their layers due to deterioration on the boundaries of asphalt concrete courses and loosening of noncoherent base courses. This problem is the focus of the present paper.

2. Methodology

To determine major concepts and criteria for flexible pavement design evaluation Rostov State University of Civil Engineering have developed the analytical model of dynamic stress-strain condition of multilayer half space based on the current concepts of the theory of elasticity and viscous elasticity [12]. The contact conditions between the layers as well as between the half-space and overlying layer can be taken as both rigid and homogeneous conditions of the sliding contact on one or more boundaries. At infinity there are radiation conditions in the form of the limiting absorption principle. For the systems “road design – subgrade”, characterized by a higher strength of the surface layers, application of the given principle is equivalent to the principle of Sommersfield’s radiation which takes as a solution only the waves going from their source to infinity.

Using this model we have conducted a numerical simulation to study the effect of different bond conditions on the interlayer boundaries of flexible pavements on the form of acceleration frequency-response characteristics on the surface pavement. The informative value of acceleration frequency-response characteristics for flexible pavement evaluation has been proved in operation. [10]

The numerical experiment focuses on the following cases:
- Rigid interlayer bond between all components of the pavement structure;
- Interlayer bond loss between asphalt concrete slab and the base course of the pavement structure;
- Total bond loss between all components of the flexible pavement structure.

Bond conditions between pavement elements in case of the bond loss were recorded as:

\[ U_z^{(j)}(R,Z_j) = U_z^{(j+1)}(R,Z_j); \quad \sigma_z^{(j)}(R,Z_j) = \sigma_z^{(j+1)}(R,Z_j) \]  
\[ \tau_{kl}^{(j)}(R,Z_j) = \tau_{kl}^{(j+1)}(R,Z_j) = 0; \]  

(1)
These equations determine the equity of vertical displacements ($U_z$) and normal stress ($\sigma_z$), as well as absence of shear stress ($\tau_{xz}$) on the boundaries of abutting layers of the pavement structure. The results of the numerical modelling of the acceleration frequency-response characteristics depending on the interlayer bond conditions are given in Figure 1.

Fig. 1. Effect of the bond conditions between the pavement courses on the form of recorded acceleration frequency-response characteristics (y-axis-acceleration values, m/s; x-axis-frequency, Hz)
The performed numerical simulation allows for the following conclusions:

With the total interlayer bond on the acceleration frequency response characteristics of the flexible pavement surface there is one distinct frequency peak magnitude;

With the interlayer bond loss between the asphalt concrete layers and the pavement base course on the acceleration frequency response characteristics of the flexible pavement surface, recorded at 0.75-1.25 m from the loading point there are two frequency peak magnitudes within 0-350 Hz and 350-500 Hz;

With the interlayer bond loss between all components of the flexible pavement structure on the acceleration frequency response characteristics, recorded at 0.25 – 2.5 m there is a number of frequency peak magnitudes located in the frequency domains of 0-200; 200 – 350, 350 – 500 Hz

3. Results

To confirm the adequacy of the simulation results we performed experimental recording of the acceleration frequency-response characteristics of the pavement surface on the operating road sections and compared them to the analytical module results. To conduct experimental recording of dynamic strain on the flexible pavement surface we used a vibration measuring device VIK-1, designed at Rostov State University of Civil Engineering (Figure 2a).

This vibration measuring device includes: 1- portable impulse loading device, 2- multichannel vibratory device, 3- a set of accelerometer transducers to record acceleration values on the flexible pavement surface. Employment of this vibration measuring system is due to the short contact time between the plate of the portable impulse loading device and the pavement surface reaching 0.003 sec (Figure 2b).

Under the impulse load to the pavement surface acceleration frequency-response characteristics are measured in the points of location of accelerometer transducers. Recorded signal processing is conducted on the basis of Fourier transformation constructing acceleration frequency-response characteristics on the pavement surface. The operating road sections, where measurements were made, considerably vary in traffic operating condition. So, Section № 1 is characterized by a perfect operating condition and has no failures. Section № 2 has transverse and longitudinal cracking. Section № 3 has a cracking pattern, wheel tracking and settlements.

The comparison results of experimental and recorded acceleration frequency-response characteristics are given in Figure 3. Analyzing the given figure we can make a conclusion about a good coherence between the forms of acceleration frequency-response characteristics recorded on the sections with different interlayer bond conditions, which proves the adequacy of the results obtained during numerical simulation.
4. Discussion

The results of the field measurements (Figure 3) confirmed by the numerical simulation results allow to suggest a possibility of monitoring bond loss on the boundaries of flexible pavement courses using nondestructive testing method. A number of local peak magnitudes occur, in our opinion, due to unbalance between different structural components of the flexible pavement under dynamic loading. From a practical perspective the suggested approach can be effective for providing technical evaluation of rehabilitation activities, particularly, when deciding on a partial or full depth replacement of the existing asphalt concrete layers, or when evaluating expediency of the complete removal of the flexible pavement.

![Figure 3. Comparison of experimental and recorded acceleration frequency response characteristics on the pavement surface (y-axis- acceleration values, m/s; x-axis- frequency, Hz). The upper row – experimental acceleration frequency response characteristics on the pavement surface, the bottom row – recorded frequency response characteristics on the pavement surface.](image)

5. Conclusion

1) The research proposes a new approach to evaluation of the interlayer bond between structural components of the flexible pavement.

2) The mechanical and mathematical simulation determines the effect of the interlayer bond of a pavement on the form of the acceleration frequency- response characteristics on the flexible pavement surface:
   - With the full interlayer bond on the acceleration frequency response characteristics of the flexible pavement surface there is one distinct frequency peak magnitude.
   - With the interlayer bond loss between the asphalt concrete layers and the pavement base course on the acceleration frequency- response characteristics of the flexible pavement surface, recorded at 0.75-1.25 m from the loading point there are two frequency peak magnitudes within 0-350 Hz and 350-500 Hz;
   - With the interlayer bond loss between all components of the flexible pavement structure on the acceleration frequency- response characteristics, recorded at 0.25 – 2.5 m there is a number of frequency peak magnitudes located in the frequency domains of 0-200; 200 – 350, 350 – 500 Hz

3) The major potential for application of this method is attributed to the improvement of the methods and techniques for analyzing the pavement structure in the frequency domain. So, it appears to be a relevant objective to determine trends of the form of the acceleration frequency-response characteristics recorded at different distances from the loading point, from the elasticity modulus of certain pavement courses. It should also be noted that in this paper while evaluating the effect of the conditions of the interlayer bond on the acceleration frequency- response characteristics we applied a simplified approach, since the contact conditions on the boundaries of the layers were accepted to be ‘smooth’. Certainly, in the field operation conditions the interlayer bond conditions will take ‘intermediate’ values. On this basis, a promising way of improving the proposed approach is to provide the
possibility of determining the intermediate interlayer bond conditions in the road pavement structure at the operation stage. However, in conclusion it has to be said that in our opinion it is the frequency-response characteristics registered in the pavement structure under the dynamic loading that are the most informative, and can be employed to evaluate the road pavement condition at the operation stage, as well as while developing and calibration of the mechanical and mathematical models of road structures.

References