

Analysis of Response of Pavements subjected to Dynamic Loading

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Abstract - The behavior of in-service pavements indicates that the condition of the bonding between pavement layers plays an important role in the performance of the whole pavement structure. Pavement structures comprise of several material layers that have a certain degree of bonding at the interfaces. Inadequate layer bonding can lead to slippage and/or complete separation of the layers, and as a result, distresses such as slippage cracking, delamination, potholes, etc. may appear in the asphalt concrete (AC) layer. Unfortunately, layer interface de-bonding or separation often occurs in AC pavement structures, attributed among other reasons to poor construction practices and/or use of poor bonding materials. Additionally, layer interface de-bonding can occur either between the AC layers or between an AC layer and a base layer. The de-bonding is largely related to poor mix designs, materials, insufficient compaction, and non-application of a tack coat as a bonding material within the AC lifts.

When the coefficient of friction between an AC layer and a rigid base is relatively small, the impact on performance would not be as critical as to when a flexible (aggregate) base is used. Redistribution of stresses and strains in the pavement structure due to poor layer interfacial bonding conditions may thus contribute to premature pavement failures, which is undesired. Using layered linear elastic theory and static linear two-dimensional finite-element model and taking into account different degrees of interfacial bonding conditions between the pavement layers and a horizontal load in addition to the standard vertical load, the layer bonding condition between the asphalt binder course and the base can reduce the pavement life by up to 80%.

Keywords – pavement, asphalt concrete, bonding, finite-element model, viscoelastic model

I. INTRODUCTION

The interface properties depend on the type of materials in contact rather than on the amount of the applied tack coat and/or the interface conditions. The bonding condition between pavement layers plays an important role in the performance of pavement structures. Using materials that require more compaction time will ensure good bond at the interface.

Understanding moisture damage mechanisms in asphalt pavements and evaluating the right combination of materials that are resistant to moisture damage are important. Moisture damage is the loss of strength or stiffness in asphalt mixtures caused by a combination of mechanical loading and moisture. The proper understanding of tire-pavement interaction is important for the accurate analysis of load-induced stresses and strains in the pavement structure. The temperature and the environmental condition also plays an important role in the deterioration of the pavement.

Pavement failure may occur as a result of the environment, repeated traffic loading, deficient construction, and/or poor maintenance strategies. The two main load-associated distresses with flexible pavements are rutting and fatigue cracking. All the above factors cause the pavement failure and decreases the life of the pavement. Hence a detailed investigation has to be done and a model has to be proposed for the mechanical performance of interactive and interface impact on pavement materials.

II. EXPERIMENTAL WORK

Fares Beainy, et.al. (2014) [1] developed Intelligent compaction (IC) of asphalt pavements is an emerging area of research that attempts to extend mechanistic-empirical design principles to the construction of asphalt pavements. These techniques monitor the vibrations of the compactor and vary the roller parameters in real time to ensure adequate and uniform compaction. Although these techniques are in various stages of field demonstration, their performance is still being verified. The lack of established theoretical foundations has limited the widespread acceptance of these techniques. A viscoelastic-plastic (VEP) model is used to simulate the behavior of vibratory

rollers during the compaction of asphalt pavements. The VEP model is shown to be relatively accurate, computationally tractable, and in a form that is conducive to numerical simulation. Comparison of the simulation results with data gathered during construction of asphalt pavements indicate that this model can serve as the basic theoretical foundation for the realization of intelligent compaction of asphalt pavements. Haotian Li and Bin Yu (2014) [2] determined Concrete bridge decks overlaid with asphalt wearing courses often witness early distresses, such as shoving, potholes, raveling, and slippage cracking resulting from poor bonds between the two layers with different modulus. Frequently used laboratory tests, including direct shear test, pull-off test, and torsional shear test, cannot fully represent the critical conditions happening in the fields. In this study, a shear fatigue test under repetitive loads at an angle of 45° was developed. Three tack coat materials, including styrene-butadiene-styrene-modified asphalt, emulsified asphalt, and epoxy resin, were chosen as binding materials to form multilayer deck pavement specimens. Their performances were evaluated through shear fatigue test on a universal test machine. The shear stress and shear displacement of each specimen at failure were first identified, and then four levels of stress were selected to perform the shear fatigue test, based on which a fatigue prediction model was developed.

To approximate the laboratory results to field load scenarios, an adjustment factor, representing the impact of different load combinations on fatigue life, was introduced. The output showed that epoxy resin material has a remarkably superior shear fatigue performance compared with the other two, and the adjustment factor is heavily affected by the load combinations. Dawei Zhang et.al.(2013) [3] conducted Laboratory tests, including splitting tension, three-point bending, and direct shear tests, were conducted on polymer cement mortar (PCM)-concrete composite specimens with various degrees of interface roughness (Ra). The PCM-concrete bond strength, fracture energy, and fracture surface were investigated qualitatively. The failure mode and the condition of the fracture surface significantly affected the interface bond strength and fracture energy. The bond strength and fracture energy were found to increase with increasing interface roughness until the fracture location shifted from the PCM-concrete interface to within either the PCM or the concrete. The interface roughness has a greater influence on the interface fracture energy and the flexural strength than on the tensile and shear strengths. Considering the single mode (Mode I or Mode II) bond and fracture properties, as well as retrofitting costs, a roughness index of approximately $1\text{mm}(0.9\#Ra \#1:1 \text{ mm})$ is proposed as the optimum value of interface roughness, and the corresponding recommended treatment is water-jetting (WJ) to a depth of 2–2.5 mm. Finally, an interfacial tension softening model that takes into account the effects of fracture energy, tensile strength, and failure mode is presented. Srinath R. Iyengar et.al. (2013) [4] also carried out laboratory investigation, aimed at evaluating the potential of polymer binders to stabilize pavement subgrades in Qatar. The conclusions regarding the impact of the polymer stabilizers are based on comparisons with selected physical, chemical, mechanical, and microstructural properties of natural Qatari subgrade soil and soils stabilized with the traditional standard, Portland cement (PC). The results demonstrate that the polymer binders modify the Qatari subgrade soils resulting in more favorable engineering properties:

Debakanta Mishra and Erol Tutumluer (2012) [5] investigated the effects of aggregate type and quality on mechanistic pavement response and rutting performance with implications to over 2.6 million km (1.6 million miles) of unsurfaced roads in the United States. Three aggregate types, crushed limestone, crushed dolomite, and uncrushed gravel, were tested in the laboratory for resilient modulus (MR) and permanent deformation characteristics at different factorial combinations of selected aggregate physical properties. Aggregate properties studied included particle shape and surface texture, type and amount of fines, and moisture and density in relation to required compaction conditions. Stress-dependent material characterization models determined from the laboratory MR tests were used in a nonlinear axisymmetric finite-element analysis program to compute the vertical compressive stress on top of the subgrade as a critical pavement response. The adequacy of the aggregate layer to carry wheel loads and prevent subgrade rutting was evaluated using the concept of the subgrade stress ratio (SSR), defined as the ratio between the vertical stress on top of the subgrade and the subgrade unconfined compressive strength. The laboratory testing and modeling showed that the aggregate physical properties had significant influences on both the modulus and permanent deformation behavior of unbound aggregates. The findings clearly highlighted the importance of considering both the load spreading and rut resistance aspects of the unbound aggregate layer in the design of unsurfaced pavements. The significance of different aggregate properties affecting modulus and permanent deformation model parameters was identified through statistical analyses of variance (ANOVA) conducted on the laboratory test results.

Xiaodi Hu and Lubinda F. Walubita, (2011) [6] worked on the bonding condition between pavement layers plays an important role in the performance of pavement structures. In this research, a three dimensional finite-element (3D-FE) program was used for modeling the mechanistic responses (stresses and strains) in the asphalt concrete (AC) layers by simulating two layer interfacial bonding conditions, namely fully bonded and de-bonded i.e., the layer separated but still considering friction. The 3D-FE modeling incorporated actual measured vertical tire-pavement

contact pressure (TCP) and assumed horizontal TCP, including investigating the effects of vehicle acceleration and deceleration. The results indicated that the layer interfacial bonding condition has a significant effect on some pavement mechanistic responses such as the tensile, compressive, and shear stresses/strains in AC pavement structures. In general, layer interface de-bonding or separation was analytically found to indirectly exacerbate pavement distresses such as slippage cracking, fatigue cracking, shoving, shear deformation, and rutting, which is undesirable.

Elie Y. Hajj et.al.(2010) [7] summarizes the literature review as well as the documented use and performance of airfield pavements that used reclaimed asphalt pavement (RAP) in hot-mix asphalt (HMA). A review of in-service airfield pavements with RAP-containing HMA mixes was conducted as part of this study. Two civilian airports and one military airport were identified as currently using RAP in the HMA surface course. The three airports are Logan International Airport (BOS), Griffin-Spalding County Airport (6A2), and Oceana Naval Air Station (NTU). Furthermore, the impact of RAP on the performance life of HMA airfield pavements on a large hub, small hub, and general aviation was evaluated using actual airport traffic mixes. The performance life analysis used the characteristics and mechanical properties of HMA mixes in the linear elastic airfield pavement design software (LEDFAA) to compare the estimated performance life of HMA pavements with and without RAP materials. The documented research effort has recently been conducted as part of the Airfield Asphalt Pavement Technology Program, Project 05-06.

Laith Tashman et.al.(2008) [8] investigated the influence of several construction practices on the bond strength at the interface between pavement layers. These practices included the surface treatment, curing time, residual application rate, and equipment tracking. Three tests were performed for estimating the bond strength between an existing hot mix asphalt (HMA) and a newly constructed HMA overlay, namely the Florida Dept. of Transportation shear tester, the University of Texas at El Paso pull off test, and the torque bond test. Testing involved a CSS-1 type emulsion as the tack coat. The results from the three tests were statistically analyzed. Generally, milling provided a significantly better bond at the interface between the existing surface and the new overlay. Curing time had a minimal effect on the bond strength. The results indicated that the absence of tack coat did not significantly affect the bond strength at the interface for the milled sections, whereas it severely decreased the strength for the nonmilled sections. The results also showed that increasing the residual rate of tack coat did not generally affect the bond strength at the interface.

Zhanping You,et.al.(2007) [9] has studied the effect of aggregate particle-to-particle interaction through numerical modeling using the discrete element modeling (DEM) approach. The individual material phases (e.g., aggregates and mastic) were modeled with clusters of discrete elements based upon laboratory testing of the individual phases. For a given set of material parameters for each phase, the degree of particle-to-particle contact in an asphalt mixture was found to have a profound influence on overall mixture modulus. A parametric investigation of aggregate modulus revealed that the contribution of aggregate modulus to overall mixture modulus was very significant.

Hassan Ziari, Mohammad Mahdi Khabiri (2007) [10] considered the effects of interface condition on the life of flexible pavements have been determined. The methodology consists of implementing a previously derived interface constitutive model into the Kenlayer program to compute the stresses and strains in typical flexible road structures. The shell transfer functions for fatigue cracking and terminal serviceability were used to estimate the pavement life. The behavior of in-service pavements indicates that the condition of the bonding between pavement layers plays an important role in the road structures performance. Premature failure of road sections due to layer separation, leading to redistribution of stresses and strains in the pavement structure, is often encountered, especially in areas where the vehicles are more likely to apply horizontal forces. In computing the critical stresses and strains, most of the mechanistic design procedures of flexible pavement structures consider that pavement layers are completely bonded or completely unbonded.

Hani Titi (2003) [11] evaluated long-term performance of an alternative flexible pavement design referred to here as stone interlayer pavement. This pavement design was introduced to reduce/defer reflective cracking experienced with soil-cement bases. The stone interlayer pavement consisted of a crushed limestone base on top of a cement-stabilized base. The performance of the stone interlayer pavement was compared to that of the conventional pavement design with a cement-stabilized base. The stone interlayer and conventional pavements were constructed on State Highway LA-97 near Jennings, Louisiana. Both pavements were monitored for 10.2 years after construction. During the evaluation period, pavement distress surveys, testing of roughness and permanent deformation, and evaluation of pavement structural capacity using dynamic nondestructive testing were conducted. Additionally, as a part of the Louisiana Transportation Research Center accelerated pavement testing research program, both pavement designs were tested to failure under the Accelerated Loading Facility in Port Allen, Louisiana. The results of this investigation showed a superior performance of the stone interlayer pavement over the conventional soil cement pavement as tested in the field as well as under accelerated loading.

III. DISCUSSION AND CONCLUSION

The VEP model is found to be relatively accurate, computationally tractable, and in a form that is conducive to numerical simulation. From above study it is observed that a viscoelastic-plastic (VEP) model can be used to simulate the behavior of vibratory rollers during the compaction of asphalt pavements. When the simulation results are compared with the construction data of asphalt pavements indicate that this model can serve as the basic theoretical foundation for the realization of intelligent compaction of asphalt pavements.

Also during the study it is observed that, epoxy resin material has a remarkably superior shear fatigue performance, and the adjustment factor is largely affected by the load combinations. And the layer interfacial bonding condition has a significant effect on some pavement mechanistic responses such as the tensile, compressive, and shear stresses/strains in AC pavement structures. In general, layer interface de-bonding or separation was analytically found to indirectly exacerbate pavement distresses such as slippage cracking, fatigue cracking, shoving, shear deformation, and rutting, which is undesirable.

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