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Influences of intelligent compaction uniformity on pavement performances of hot mix asphalt

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ABSTRACT

Conventional pavement analysis and design methods are based on the homogeneous or uniform material model such including the multi-layered analysis program and AASHTO design methods. With the Intelligent Compaction (IC) technology on hot mix asphalt (HMA) involved in recent years, the compaction uniformity of material property can be quantified. This paper intends to study the effects of compaction uniformity on pavement performances using the Bomag IC E_{vib} – a measurement of elastic moduli with 100% coverage of the compaction area. The three dimensional (3-D) finite element (FE) model was built to simulate pavement responses with the heterogeneous HMA moduli derived from the field IC measurements. Then the Mechanistic-Empirical Pavement Design Guideline (M-E PDG) models were used to predict HMA performances of rutting and fatigue life. The geostatisical semivariogram model was studied to evaluate the uniformity of predicted performances. Different from conventional pavement analysis and designs, spatial-distributed heterogeneous moduli of the asphalt layer were considered in this work. Results show that spatial uniformity of material moduli affects pavement performances in terms of the distress severity and uniformity. Less uniform material moduli result in higher rutting depths and shorter fatigue lives. For the case study in this paper, the mean and peak values of fatigue lives for the heterogeneous model are 38.2% and 0.1% of those for the uniform model. A pavement section with overall lower material moduli does not necessarily correspond to inferior performances as the effects from uniformity of material property may dominate other factors. Therefore, it is recommended that the uniformity of pavement layer properties that emulate the typically more variable service condition be considered in future pavement designs and performance predictions.

1. Introduction

Uniformity of field compaction has long been considered qualitatively as a factor on pavement performance. A non-uniform compaction results in non-uniform pavement material properties such as moduli. Field compaction uniformity has long been considered an important qualitative characteristic for desired pavement responses and long term performance. However, for the conventional pavement analysis and design method, homogeneous or uniform material properties (including the anisotropy property at different direction) are used for the same pavement layer through spatial distribution. These methods include the currently used multi-layered analysis program, the American Association of State Highway and Transportation Officials (AASHTO) pavement design methods, etc. For the conventional quality control (QC) and quality assurance (QA) method used for field construction, usually the random spot tests for material or structural properties are conducted. For example, the AASHTO's method [1] measures the nuclear gauge (NG) and/or coring densities to check if it reaches the target with a certain percentage (e.g. 80% samples exceed the target of 92% Gmm – the theoretical maximum specific gravity). However, this QC/QA method based on very limited spot number of random tests is unable to evaluate the compaction uniformity. Uniformity measures how uniform or variable the factor is. Meanwhile, some weak spots or zones might be missed using the conventional QC/QA method. It is not until in the past decade that uniformity of field compaction can be quantified with Intelligent Compaction (IC) technologies that can measure levels of compaction for the entire compacted areas. IC technology was initially developed in Europe and Japan and used more than one decade, and introduced to the US in late 2000s [2,3]. Though successfully used for the earthwork and soil compaction, IC as an emerging technology is still immature and involving for the hot mixture asphalt (HMA) [2].

IC uses vibratory rollers equipped with accelerometer-based measurement system, temperature sensors, global position system

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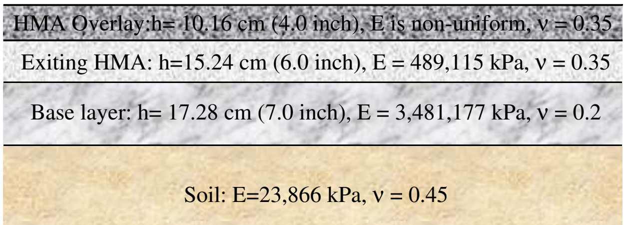

Fig. 1. Pavement structure and material properties (h: depth, E: elastic modulus, ν: Poisson's ratio).

(GPS), and real-time onboard display of measurements [2]. The IC measurement value (ICMV) is an index value relating to the pavement layer stiffness and moduli. From the Federal Highway Administration (FHWA)'s IC demonstration study [4–8], the ICMV exhibits fair linear correlation with layer moduli as back-calculated from the falling or light-weight deflectometer (FWD or LWD). Also, ICMV is usually non-uniform or heterogeneous in field compaction conditions [2]. Non-uniform stiffness in field conditions may result in premature distresses [2,4], or inferior long-term pavement performances. In the FHWA's generic IC specifications [9], IC is considered as a quality control (QC) tool. However, the uniformity is not considered in the QC yet in those specifications. Quantifying the effect of compaction uniformity on the pavement performance remains as a research gap. Alkasawneh et al. [10] studied the influence of vertical heterogeneous property of materials on pavement response. The horizontal heterogeneous property is more common due to non-uniform support and compaction conditions as identified by the IC technology.

The objective of this research is to study the influences of compaction uniformity of hot mixture asphalt on pavement performances such as rutting and fatigue cracking, using the field measured ICMVs. This research may provide rationale and support for including uniformity requirements in future IC specifications. To achieve this goal, following research efforts were performed: (1) IC experiment on the HMA overlay; (2) three-dimensional (3-D) finite element (FE) modeling of pavement responses with the IC measured non-uniform HMA elastic moduli with 100% coverage on the compaction area; (3) mechanistic-empirical (M-E) pavement design guideline (M-E PDG) modeling of pavement performances (rutting and fatigue cracking); and (4) geostatistical study of the

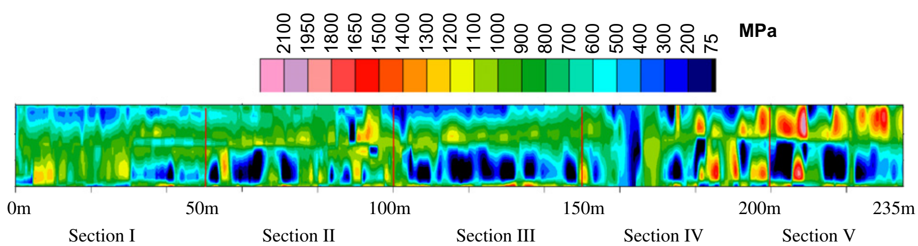

Fig. 2. Kriged HMA elastic moduli E_{vib} for the 235 m compaction lane (total five sections).

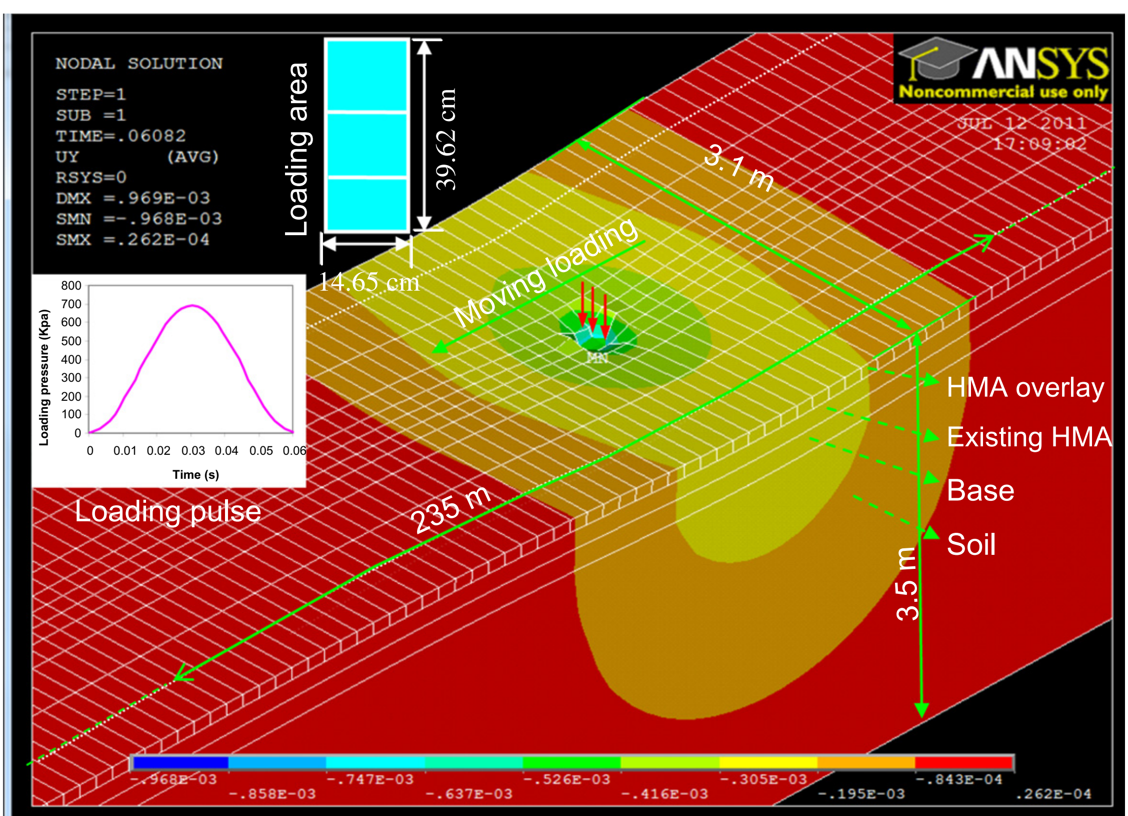

Fig. 3. Finite element model as deformed under loading (max deflection: -9.68×10^{-4} m). Note: the grids of the HMA overlay are volume bodies rather than elements as to possess heterogeneous elastic moduli with ANSYS modeling techniques.