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International Journal of Pavement Research and Technology 10 (2017) 203–218

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Alternatives for calibration of dynamic modulus prediction models of asphalt concrete containing RAP

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Received 21 June 2016; received in revised form 16 November 2016; accepted 20 November 2016
Available online 1 December 2016

Abstract

Dynamic modulus is a measure of stiffness of an asphalt concrete (AC) mix when subjected to cyclic sinusoidal compressive stresses. In the Mechanistic-Empirical Pavement Design Guide (MEPDG) and its software Pavement ME, dynamic modulus (E^*) is an essential parameter for the prediction of asphalt pavement distresses such as rutting and fatigue cracking. Several empirical models have been developed to estimate the E^* from AC mix properties to compliment laboratory measured E^* values. Two models developed under NCHRP 1-37A and NCHRP 1-40D projects have been integrated into the MEPDG program. The models estimate E^* values when Level 2 and Level 3 inputs for AC mixes are used. This paper presents the evaluation of uncalibrated E^* values obtained from NCHRP 1-37A and NCHRP 1-40D and compares the results to two calibrated techniques; an exponential fit of uncalibrated model outputs, and updated model coefficients using nonlinear multiple regression. In total, 51 specimens from 17 types of AC mixes containing 0–50% RAP were prepared and tested in the laboratory. E^* was determined in the laboratory and compared to estimated values based on calibrated and uncalibrated models. The results showed that uncalibrated NCHRP 1-37A produced lower error in predicting E^* than uncalibrated NCHRP 1-40D. Both calibration techniques enhanced the accuracy of the models, however nonlinear multiple regression showed the best potential for predicting E^*. Calibrated models showed improvement in prediction of E^* for all RAP mixes for Level 3 inputs, although high RAP mixes showed the least improvement among the other RAP mixes.

Keywords: Dynamic modulus; Local calibration; Nonlinear multiple regression; MEPDG; Exponential fit

1. Introduction

In the Mechanistic-Empirical Pavement Design Guide (MEPDG) and its software Pavement ME, the dynamic modulus (E^*) of an asphalt concrete (AC) mix is a required input for design and performance prediction. Based upon the quality and quantity of available data for each material property, there are three levels of input options in MEPDG [1]. Level 1 input option generally requires site specific material properties data which are obtained through laboratory or field testing. These data have the highest level of reliability and are expected to provide the optimum design and analysis. For Level 1 inputs, the dynamic modulus is measured in the laboratory in accordance with the AASHTO T342 test method [2]. The test is typically conducted at five different temperatures and six different frequencies. Level 2 inputs have an intermediate level of reliability. The input data are generally obtained through limited laboratory or field testing or estimated from correlations with other measured properties. Level 3 inputs have

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Peer review under responsibility of Chinese Society of Pavement Engineering.

http://dx.doi.org/10.1016/j.ijprt.2016.11.005
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the lowest level of reliability since typical agency data or software default inputs are used [3].

Although Level 1 inputs for the AC mix provide more reliable results than Level 2 and Level 3 inputs, the comprehensive laboratory testing required to obtain Level 1 inputs is time consuming and expensive. When Level 1 inputs for the AC mix cannot be obtained, the dynamic modulus can be estimated from correlations with other properties of the AC mix [1]. The NCHRP 1-37A and NCHRP 1-40D models have been incorporated into the MEPDG program to estimate E^* when Level 2 and Level 3 inputs for asphalt mix and asphalt binder are used in the design and analysis of pavement structures.

2. Dynamic modulus predictive models

There are several empirical models available to predict E^*. In this paper, NCHRP 1-37A and NCHRP 1-40D models were used to predict E^* and compared with measured laboratory E^*.

2.1. NCHRP 1-37A model

This model estimates E^* in Level 2 and Level 3. A total of 2750 data points from asphalt mixes containing unmodified and modified asphalt binders were used in developing the coefficients of the NCHRP 1-37A model. This model assumes a sigmoid function of inputs for the AC mix. It is constructed based upon asphalt binder viscosity and asphalt mix volumetric properties [1]. Eq. (1) shows the NCHRP 1-37A model.

$$\mathrm{Log}_{10}E^* = -1.249937 + 0.02923\rho 200 - 0.001767(\rho_{200})^2 - 0.002841\rho_4 - 0.058097V_a - 0.802208\frac{V_{beff}}{V_{beff}+V_a} + \frac{3.871977 - 0.0021\rho_4 + 0.003958\rho_{38} - 0.000017(\rho_{38})^2 + 0.00547\rho_{34}}{1+e^{(-0.603313-0.313351(\log f)-0.393532(\log\eta))}} \quad (1)$$

where E^* = dynamic modulus of the mix, 10^5 psi, η = bitumen (asphalt binder) viscosity, 10^6 Poise; f = loading frequency, Hz.; V_a = air voids content, %; V_{beff} = effective bitumen content,% by volume; ρ_{34} = cumulative % retained on the 3/4 in. (19 mm) sieve; ρ_{38} = cumulative % retained on the 3/8 in. (9.5 mm) sieve; ρ_4 = cumulative % retained on the #4 sieve; ρ_{200} = % passing the #200 sieve.

2.2. NCHRP 1-40D model

In 2006, a new model was developed based on 7400 data points from 346 mixtures to predict the E^* of asphalt mixtures. This model is a sigmoid function of volumetric properties, aggregate gradation similar to NCHRP 1-37A model, however, complex shear modulus (G^*) and phase angle (δ) of asphalt binder were used to characterize the asphalt binder instead of asphalt binder viscosity [4,5]. In 2006, this model was revised under NCHRP 1-40D project to be implemented in MEPDG program.

In this paper, the E^* model, presented in final report of NCHRP 1-40D and shown in Eq. (2) [4,5], is used in the comparisons to locally calibrated values. El-Badawy et al. [6] reported that NCHRP 1-40D model was revised in 2007, shortly after it was first released. The revised model, Eq. (3), is the one being implemented in MEPDG software since version 0.9 to date.

$$\mathrm{Log}_{10}E^* = -0.349 + 0.754(|G_b^*|^{-0.0052})^*\left(6.65 - 0.032\rho_{200} + 0.0027(\rho_{200})^2 + 0.011\rho_4 - 0.0001(\rho_4)^2 + 0.006\rho_{38} - 0.00014(\rho_{38})^2 - 0.08V_a - 1.06\left(\frac{V_{beff}}{V_{beff}+V_a}\right)\right) + \frac{2.558 + 0.032Va + 0.713\left(\frac{V_{beff}}{V_{beff}+V_a}\right) + 0.0124\rho_{38} - 0.0001(\rho_{38})^2 - 0.0098\rho_{34}}{1+e^{\left(-0.7814-0.5785\left(\log\left(|G_b^*|\right)\right)+0.8834(\log(\delta_b))\right)}} \quad (2)$$