JERSEY DOT'S

"Turning Problems into Solutions"

Tech Brief

Dynamic Modulus of Hot Mix Asphalt

FHWA-NJ-2009-011 February 2010

SO, HERE'S THE PROBLEM…

- The dynamic modulus, E*, is a fundamental property of asphalt mixtures that describes the asphalt mixture's stiffness at different temperatures and loading speeds.
- The dynamic modulus, E*, is one of the prime required inputs for the Mechanistic Empirical Pavement Design Guide (MEPDG), as well as an effective means of evaluating the general performance of asphalt mixtures.
- For some state agencies that do not have the equipment to conduct the dynamic modulus test, the use of a dynamic modulus database or prediction equations has been recommended as a substitute to measured values. Unfortunately, this causes additional issues, especially with the New Jersey Department of Transportation (NJDOT).
    - First, NJDOT does not have a dynamic modulus mixture database to use in the MEPDG.
    - Second, a number of predictive/empirical equations that have been developed and evaluated to predict the dynamic modulus show conflicting conclusions by a number of various researchers as to which method is better.
- Another issue with the dynamic modulus is that the test procedure is supposed to be applicable to most servo-hydraulic equipment, as long as the test apparatus and test conditions follow those of the specifications (AASHTO TP62) (Figure1). However, to date there has been no attempt to determine the general precision of the test method.
- Therefore, it is imperative for NJDOT to evaluate the general precision of the test procedure if they plan on specifying its use for material input of the MEPDG. Also, if equipment/testing laboratories are not locally available or funding does not allow for the purchase of equipment or testing services, it would be highly beneficial for NJDOT to have an E* material database or confidence in one of the E* predictive equations.

Figure 1 – Different Testing Machines Used to Measure the Dynamic Modulus of Hot Mix Asphalt

AND, HERE'S OUR SOLUTION

- Develop a round robin testing program to evaluate the general precision of the dynamic modulus test;
- If needed, revise the dynamic modulus test procedure to improve the test procedure's precision;
- Develop a database of asphalt mixtures for New Jersey from plant produced asphalt mixtures;
- Compare the different dynamic modulus prediction equations to the measured values of the New Jersey database.

HERE'S WHAT WE CAME UP WITH…

We set out with a round robin testing program that included Rutgers University, as well as six other laboratories;

- Advanced Asphalt Technologies (AAT), Sterling, VA.;
- Burns, Cooley, Dennis, Inc. (BCD), Jackson, MS.;
- National Center for Asphalt Technology (NCAT) at Auburn University, AL;
- North Central Superpave Center at Purdue University (Purdue), IN;
- Texas Transportation Institute (TTI) at Texas A&M University, TX; and
- Pavement Research Institute of Southeastern Massachusetts at the University of Massachusetts (UMass) Dartmouth, MA.

The Round Robin testing program was designed to test two different Superpave-designed HMA mixtures; 9.5mm and 25mm nominal maximum aggregate size (NMAS). Each laboratory was asked to conduct the latest version of AASHTO TP62 on three specimens of each mixture designation (total of six test samples) and to report all results in accordance with AASHTO TP62-07. The collected test data were then evaluated in a precision statement environment, where ASTM E691 was used to evaluate the variability of the test procedure. The test results and statistically analysis indicated;

- Not all laboratories were capable of testing HMA mixtures at the 14^{o}F test temperature in AASHTO TP62-07. Since the MEPDG currently requires the 14^{o}F test temperature for the generation of the master stiffness curve, a procedure such as the reduced testing procedure recommended by Bonaquist and Christensen (2006) would be required.
- The variability of the dynamic modulus (E*) was greatest at the low testing temperatures with over 50% of the variance being associated with the laboratory itself. Since some labs are currently not capable of testing at 14^{o}F and those that did showed the highest level of variance, the elimination of this test temperature should be considered.
- The variability of phase angle (ϕ) was greatest at the low and high testing temperatures. This may have been due to non-linearity or micro-strain values falling outside of the recommended range of 50 to 150 micro-strains.
- The proportion of variance associated with multiple laboratories was significantly larger for non-SPT devices than for SPT devices. Therefore, laboratories considering the future purchase of dynamic modulus test equipment may want to consider procuring a test machine capable of adhering to the specifications of the SPT units. However, it should be noted that only one manufacturer's SPT machine was involved in the study. This may have attributed to the better precision of the test data.
- A Precision Statement was generated for AASHTO TP62-07 utilizing the test data for all laboratories at all test temperatures and loading frequencies. The Precision Statement indicated that:
  - For Single Operator:
    - Dynamic Modulus: 1S% = 13.03; D2S% = 36.47
    - Phase Angle: 1S% = 6.76; D2S% = 18.93
  - Multi-Laboratory:
    - Dynamic Modulus: 1S% = 26.89; D2S% = 75.3
    - Phase Angle: 1S% = 19.46; D2S% = 54.49
- Additional Precision Statements were generated for other testing scenarios, including an abridged test procedure that eliminated the low and high test temperatures and also by separating the SPT and Non-SPT devices. The results indicated that the use of the SPT devices with the elimination of the low and high test temperatures produced the best precision characteristics.

Once a modified test procedure was recommended, the development of the dynamic modulus database for NJDOT began. A total of twenty-one (21) different asphalt mixtures were collected during the 2008 paving season and tested to develop the dynamic modulus database. The dynamic modulus database was eventually presented to NJDOT during a workshop that was used to instruct NJDOT pavement designers how to incorporate the database in the MEPDG.

The dynamic modulus database was also utilized to evaluate two different dynamic modulus predictive equations; 1) Hirsch Model and 2) Witczak Predictive Equation. These are the two most commonly used dynamic modulus prediction equations utilized by the pavement design industry. The test results indicated that the Witczak Prediction Equation provided a slightly more accurate prediction equation (Percent Difference = 10.5%) than the Hirsch Model (Percent Difference = 12.6%).

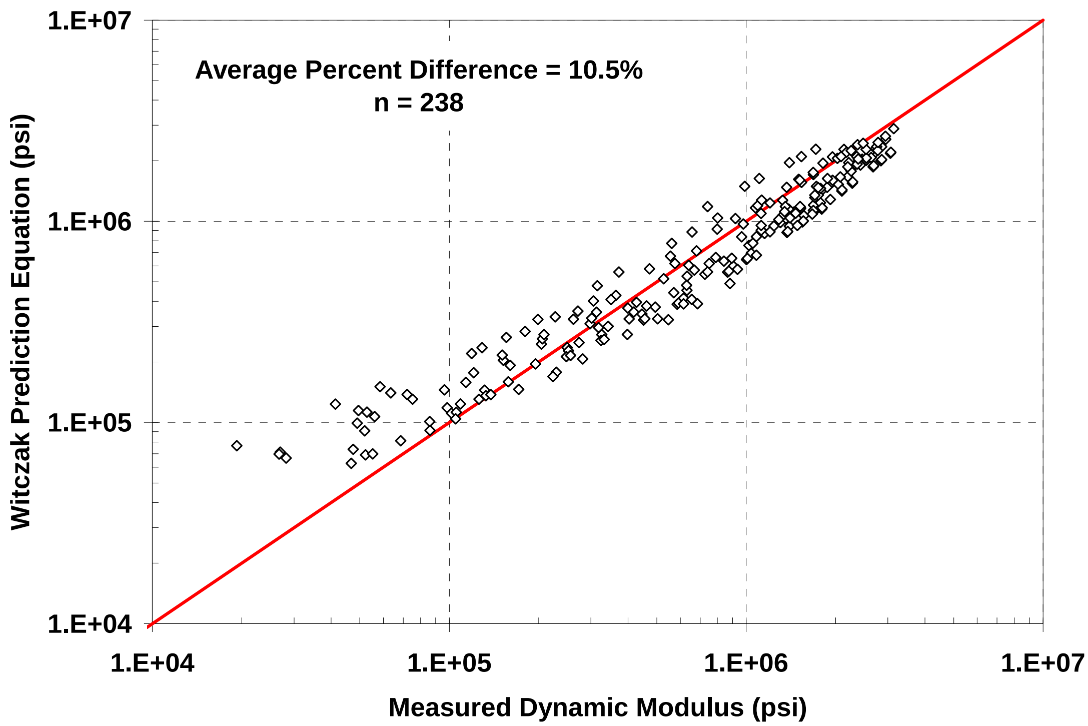

Figure 2 – Witczak Prediction Equation Predictions – All Data

However, the comparison of the prediction equation results did indicate that the Witczak Prediction Equation was more accurate at the intermediate and low temperatures while the Hirsch model was not as biased with respect to temperature.

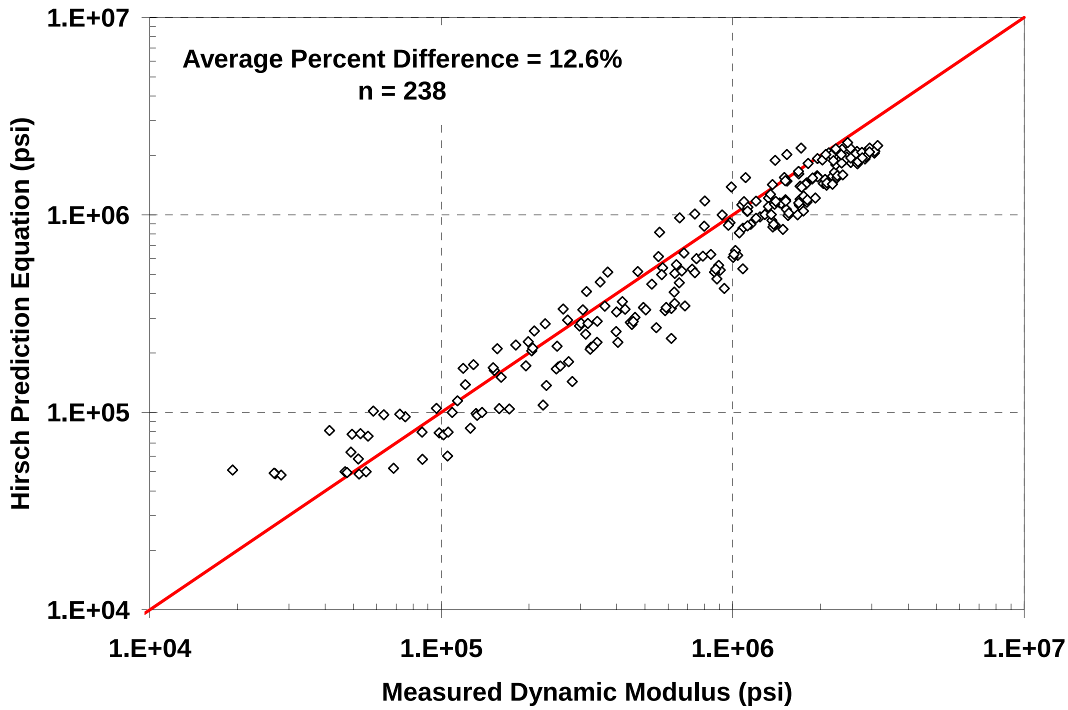

Figure 3 – Hirsch Model Predictions – All Data

The dynamic modulus database also provided the opportunity to evaluate how the dynamic modulus relates to measured permanent deformation (rutting) and fatigue cracking tests. Flow Number testing, in accordance with AASHTO TP79*, Determining the Dynamic Modulus and Flow Number for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)* was conducted on each specimen previously tested for dynamic modulus. Additional test specimens of the identical asphalt mixture were also tested for fatigue cracking resistance in the Overlay Tester (Figure 4) in accordance with TXDOT Tex-248-F, *Test Procedure for the Overlay Test.*

The research showed that relatively good correlations were found between the dynamic modulus and the permanent deformation and fatigue cracking properties of the asphalt mixtures. Overall, the Flow Number and Dynamic Modulus properties had an average correlation coefficient (R^2) of 0.68, when eliminating the 0.01 Hz dynamic modulus test results. Using the correlations developed for each loading frequency, recommended dynamic modulus “bands” were generated for different ESAL levels, shown as Table 1.

For the fatigue cracking potential, an average correlation coefficient (R^2) of 0.78 was found between the Dynamic Modulus and Overlay Tester results. Using the correlations developed, dynamic modulus “bands” were generated and shown in Table 2. The performance bands recommend maximum dynamic modulus values for generally “good” fatigue resistance of asphalt mixtures, as well as required fatigue performance for placement over PCC/composite pavements (i.e. – mixtures like Reflective Crack Relief Interlayers, Rich Bottom Layer, High Performance Thin Overlays) as indicated by field comparisons at TxDOT.

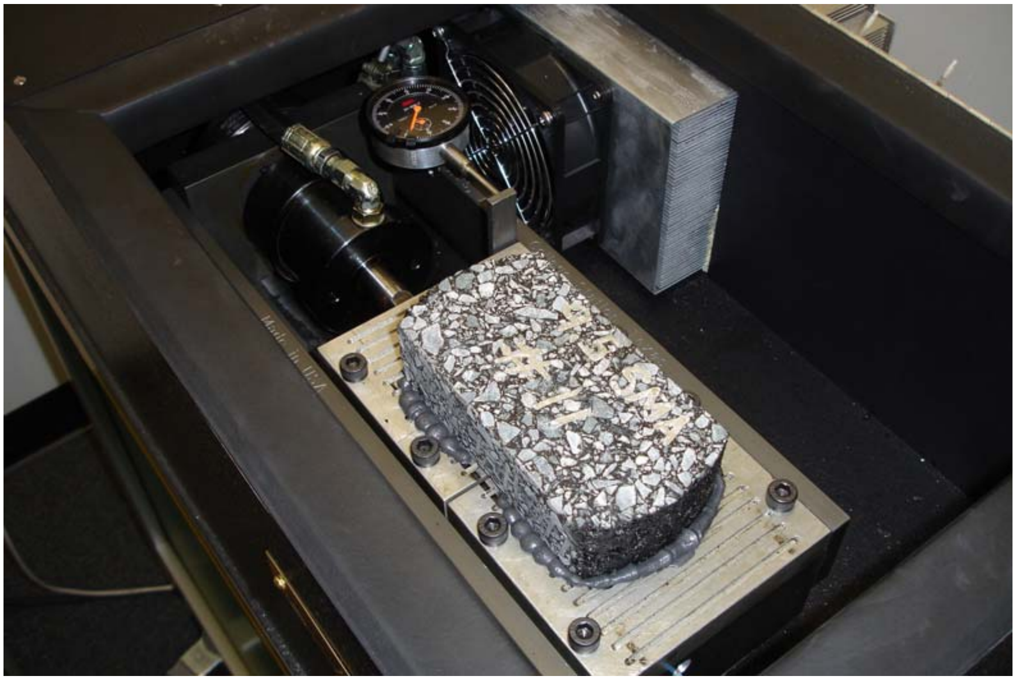

Figure 4 – Picture of the Overlay Tester (Chamber Door Open)

Table 1 – Minimum Required Dynamic Modulus to Limit Rutting Potential of Asphalt Mixtures

Frequency (Hz) at 45C	**Minimum E* (ksi) to Obtain Flow Number at 54C**		
	> 30M ESAL's	**< 30M to > 10M ESAL's**	**< 10M ESAL's**
25	338	274	205
10	238	187	133
5	182	140	94
1	95	69	41
0.5	70	50	28
0.1	38	26	13

Table 2 – Dynamic Modulus Performance Bands for Limiting Fatigue Cracking Potential

Frequency (Hz) at 20C	**Maximum E* (ksi) to Obtain Overlay Cycles**			
	750	**300**	**200**	**100**
25	729	969	1100	1364
10	583	791	907	1145
5	485	670	774	989
1	300	432	509	673
0.5	243	355	422	563
0.1	136	209	254	352

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A final report is available online at
http://www.state.nj.us/transportation/refdata/research/

If you would like a copy of the full report, please FAX the NJDOT, Bureau of Research, Technology Transfer Group at (609) 530-3722 or send an e-mail to Research.Bureau@dot.state.nj.us and ask for:

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