Utilization of the Mechanistic-Empirical Pavement Design Guide in Moisture Susceptibility Prediction

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ABSTRACT

Moisture susceptibility of asphalt pavements is considered a major problem that shortens pavement service life. Moisture susceptibility is most commonly tested using the modified Lottman test. The shift towards mechanistic design calls for the utilization of a more fundamental test to evaluate moisture damage. It has been recommended to use the dynamic modulus test for moisture damage evaluation. The dynamic modulus results can be used as an input for the Mechanistic-Empirical Pavement Design Guide (MEPDG).

This research used field-procured/laboratory-compacted mixtures from the State of Iowa. The mixes had varying levels of moisture susceptibility. Two sets of samples were tested for dynamic modulus. The first set was a control set, while the second was moisture conditioned. The MEPDG was utilized to predict the pavement response. The simulation results showed that the MEPDG is a good tool to predict the effect of moisture on the major pavement distresses. The results also showed a difference between the various mixes in the amount of distress levels associated with their moisture susceptibility.

Key words: hot mix asphalt—MEPDG—moisture susceptibility—pavement distresses
INTRODUCTION

Pavements are subjected to different stresses during their design lives. A properly designed pavement will perform adequately during its design life, and the distresses will not exceed the allowable limits. A good design is one that provides the expected performance with appropriate economic considerations. One of the factors that leads to premature failure of pavements is moisture sensitivity. The presence of water in pavements can be detrimental if combined with other factors such as freeze-thaw cycling. Many factors can affect the moisture sensitivity of a mix and can be divided into three main categories. The first category is the material properties, which include the physical and chemical properties of the asphalt and the aggregates. The second category is the mixture properties, which include asphalt content, film thickness, and the permeability of the mixture (interconnectivity of the air voids). The third category is the external factors; these factors include construction, traffic, and environmental factors (Santucci 2002). The American Association of State Highway and Transportation Officials (AASHTO) Mechanistic-Empirical Pavement Design Guide (MEPDG) enables a designer to simulate many of these factors, but it does not include the effect of moisture on mixture properties. The objective of this paper is to investigate the effect of moisture on three different asphalt-concrete mixes by testing the material properties for each of them with and without moisture conditioning and by simulating the results using the MEPDG.

BACKGROUND

Moisture damage has been a major concern to asphalt technologists for many years. Researchers have been searching for a test that differentiates between good- and bad-performing asphalt-concrete mixtures from stripping potential since the 1920s (Solaimanian et al. 2003). Since the 1920s, it has been known that the problem relates to the loss of adhesion between asphalt and aggregate and the loss of cohesion within asphalt. The challenge has been to find a test that identifies moisture susceptible mixes (Solaimanian et al. 2003). The standard test used to identify the moisture susceptibility of asphalt mixtures is the modified Lottman test (AASHTO T 283). Although AASHTO T 283 has been used for several years as the standard test for moisture sensitivity, it assists in minimizing the problem, and it does not appear to be a very accurate indicator of stripping (Brown et al. 2001). One test that has the potential to replace indirect tensile-strength testing contained within AASHTO T 283 is the dynamic modulus test. This test has been around for a long period of time, but its use started to become more common when the Federal Highway Administration (FHWA) developed a request for proposals for a research project to develop a simple performance test in 1996 (McGhee 1999). This test can characterize the performance of asphalt mixtures to be used in a particular pavement layer based upon fundamental engineering properties in conjunction with the established volumetric-testing procedures. Various tests were employed, analyzed, and correlated with performance data from test-track facilities that could be used as the Superpave Simple Performance Test (SPT). Witczak et al. (2002) has shown that dynamic modulus and flow number have promising correlations with field performance (Witczak et al. 2002). The dynamic modulus test is commonly used with the MEPDG. The MEPDG is a design guide developed after the proposal made in 1996 by the AASHTO Joint Task Force in Pavements. The MEPDG includes computational software that provides a prediction of pavement performance taking into consideration traffic, climate, and pavement structure; special consideration of loading with multiple tires and axles; and an approach for evaluating design variability and reliability (NCHRP 2004).

The use of the dynamic modulus test for moisture susceptibility evaluation was recommended by the National Cooperative Highway Research Program (NCHRP) Report 589 (Solaimanian et. al 2007). The researchers also suggested that the results of the dynamic modulus could be simulated using the MEPDG (Solaimanian et al. 2007).
EXPERIMENTAL PROGRAM

Loose field mix was procured from three projects in the state of Iowa. The three mixes are labeled Rose, 235S (2005 construction season), and 235I (2006 construction season). The loose field mixes were compacted with a Superpave Gyratory Compactor, using a 100 mm diameter mold compacted to a 150 mm height. A total of 10 samples were compacted for each project. The samples were divided into two groups, each containing five samples with equal average air voids. One group was tested dry and used as the control group, while the other group was moisture conditioned. The testing procedure for dynamic modulus testing was derived from the NCHRP Report 513 “Simple Performance Tester for Superpave Mix Design” (Bonaquist et. al 2003). Four linear variable displacement transducers were mounted on the sides of the specimen with a gauge length of 100 mm. The sample was then axially loaded under a strain-controlled test at 80 microstrains. The test setup is shown in Figure 1. The conditioning of the specimens followed the procedure outlined in AASHTO T 283, with one freeze-thaw cycle. A total of nine test frequencies were run at two test temperatures for inclusion in MEPDG simulations. The concept of time-temperature superposition was used to develop a master curve for each mix. The master curve was used to calculate the dynamic modulus at other temperature-frequency combinations to satisfy the MEPDG input requirements.

MOISTURE SUSCEPTIBILITY TESTING

Table 1 summarizes the dynamic modulus results for the three mixes for both the conditioned and unconditioned groups. The ratios of dynamic modulus of moisture-conditioned samples to unconditioned samples (E* ratio) are presented in Table 2. It can be seen from the results that the best performer was 235S, followed by 235I, and the worst performer was Rose. It is also evident that the E* ratio values increase with the increase of frequency and decrease with the increase of temperature.

MEPDG SIMULATION

The MEPDG was used to investigate the difference between the two projects for both control and moisture conditioned samples. The cross section shown in Figure 2 was used as a typical cross section to evaluate the difference in pavement performance. All the inputs were maintained constant in all the designs, except those of the top layer. To be able to capture the effect of the moisture conditioning on the pavement performance, a level 1 design was used for the top asphalt-concrete layer. The results from the dynamic modulus tests for the two sample groups were used together with the results from the volumetric
analysis of the specimens and the properties of the asphalt binder used. Level 3 design was used for all the other layers. The location of the project was assumed to be Des Moines, Iowa, and a traffic spectrum was used that gives a traffic level equivalent to 10,000,000 equivalent single axle loads (ESALs).

### Table 1. Dynamic modulus test results

<table>
<thead>
<tr>
<th>Project</th>
<th>Conditioning</th>
<th>Temperature (°C)</th>
<th>E* (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.1 1 5 10 15 25</td>
<td></td>
</tr>
<tr>
<td>Rose</td>
<td>Control</td>
<td>4 3.30 10.33 13.07 14.96 15.65 16.34 16.39</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moisture</td>
<td>21 2.77 5.09 6.83 7.60 8.13 8.86 8.86</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moisture</td>
<td>21 1.81 3.40 5.22 6.07 6.62 7.40</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moisture</td>
<td>21 1.20 2.24 3.70 4.38 4.81 5.34</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2. Dynamic modulus ratios

<table>
<thead>
<tr>
<th>Conditioning</th>
<th>Temperature (°C)</th>
<th>E* (Ratio)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1 1 5 10 15 25</td>
<td></td>
</tr>
<tr>
<td>Rose</td>
<td>4 0.79 0.84 0.89 0.88 0.89 0.94</td>
<td></td>
</tr>
<tr>
<td></td>
<td>21 0.69 0.75 0.82 0.84 0.84 0.85</td>
<td></td>
</tr>
<tr>
<td>235S</td>
<td>4 1.09 1.12 1.13 1.14 1.13 1.15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>21 1.11 1.21 1.19 1.19 1.20 1.21</td>
<td></td>
</tr>
<tr>
<td>235I</td>
<td>4 0.84 0.84 0.87 0.88 0.88 0.90</td>
<td></td>
</tr>
<tr>
<td></td>
<td>21 0.83 0.86 0.89 0.90 0.90 0.90</td>
<td></td>
</tr>
</tbody>
</table>
Figure 3 through Figure 7 present the results from the MEPDG simulations. The results of the analysis show the difference between the three asphalt concrete mixes. In the case of the Rose design, which is expected to be a moisture-susceptible mix using the E* ratio results, all distresses increased significantly. In the case of the 235I, there is also an increase in the predicted distresses, but the increase is lower than the predicted for Rose. For 235S, because of the E* ratio that is higher than one, there was a slight decrease in the predicted distresses. Although the Rose mix is ranked as the most moisture-susceptible mix and is predicted to have a higher increase in distresses with moisture conditioning, its overall performance is good and is better than 235I mix. This emphasizes the role of the MEPDG evaluation in quantifying the damage caused by moisture.
Figure 3. Permanent deformation in the AC layer

Figure 4. Permanent deformation in total pavement structure
Figure 5. Alligator cracking

Figure 6. International Roughness Index (IRI)
CONCLUSIONS

This paper has presented the possibility of using the MEPDG in simulating the difference of performance of asphalt pavement when moisture is present. This, in part, allows for the evaluation of this environmental effect in the MEPDG. This approach evaluates only the major distresses simulated in the design guide. Moisture damage can cause other problems in the pavement, such as raveling and stripping, and this needs to be further investigated. This paper presents the approach, and further validation is needed by simulating more test sections and comparing the results to field performance.

Based on the results of the experimental work and the output of the MEPDG simulations for the three sections investigated, the following can be concluded:

- Rose asphalt-concrete mixture is expected to be a more moisture-susceptible concrete mixture based upon the E* ratio.
- For all the mixes, E* ratios are directly proportional to the loading frequency and inversely proportional to the test temperature.
- Combining the dynamic modulus testing with the MEPDG offers a tool to predict the effect of moisture damage on pavement performance. Further calibration of the design guide equations might be needed based on the field validation of the results.
- The MEPDG results showed a clear distinction between the mixes, but further evaluation of other mixes and comparison with field data is needed.
- E* ratio for all frequencies shows only whether the mix is moisture susceptible or not. Utilizing the dynamic modulus test results in the MEPDG shows the effect of moisture damage on pavement performance from a pavement distress prospective. This can be a good approach in judging whether the increase in distresses due to moisture susceptibility will exceed the allowed design limits or may increase within the user-prescribed design limits.
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REFERENCES