ALTERNATIVE HMA CHARACTERIZATION FOR M-E PAVEMENT REHABILITATION DESIGN

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Outline

- Objective
- Background  (Data Input Level for Rehabilitation Design)
- Approach
  - Field tests  (Previous Study) + Laboratory Tests
- Results
- Findings and Conclusions
- Other Related Efforts
Acknowledgments

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Project Objective

- Determine the in-place HMA layer modulus for Mechanistic-Empirical Pavement Rehabilitation Design
- Verify the MEPDG proposed method for determining the field damaged HMA master curve
- Recommend how to improve it if found not applicable for VA pavements
Background: *Data Input Level 1*

- **FWD DATA**
  - Measure deflection
  - Backcalculate combined HMA modulus ($E_i$)

- **FIELD CORING**
  - Volumetric properties

- **UNDAMAGED MASTER CURVE**

$$\log E^* = 3.750063 + 0.02932\rho_{200} - 0.001767(\rho_{200})^2 - 0.058097V_a - 0.802208\left(\frac{V_{beff}}{V_{beff} + V_a}\right)$$

$$+ \frac{3.871977 - 0.0021\rho_4 + 0.003958\rho_{38} - 0.000017(\rho_{38})^2 + 0.005470\rho_{34}}{1 + e^{-0.603313 - 0.313351\log(f) - 0.393532\log(\eta)}}$$

$$\log\left|E^*\right| = \delta + \frac{\alpha}{1 + e^{\beta - \gamma \log f_r}}$$
Data Input Level 1 (Cont.)

- ESTIMATE DAMAGE, dj:
  \[ d_j = 1 - \frac{E_i}{E^*} \]

- DETERMINE \( \alpha' \)
  \[ \alpha' = (1 - d_j) \cdot \alpha \]

- COMPUTE FIELD DAMAGED MODULUS
  \[ \log |E^*| = \delta + \frac{\alpha'}{1 + e^{\beta - \gamma \log f_r}} \]
Data Input Level 2

FIELD CORING
- Volumetric Properties

UNDAMAGED MASTER CURVE

\[
\log E^* = 3.750063 + 0.02932 \rho_{200} - 0.001767 (\rho_{200})^2 - 0.058097 V_a - 0.802208 \left( \frac{V_{\text{beff}}}{V_{\text{beff}} + V_a} \right) \\
+ \frac{3.871977 - 0.0021 \rho_4 + 0.003958 \rho_{38} - 0.000017 (\rho_{38})^2 + 0.005470 \rho_{34}}{1 + e^{-0.603313 - 0.313351 \log(f) - 0.393532 \log(\eta)}} \\
\log |E^*| = \delta + \frac{\alpha}{1 + e^{\beta - \gamma \log f_r}}
\]
LABORATORY RESILIENT MODULUS, Mr

ESTIMATE DAMAGE, dj:

\[ d_j = 1 - \frac{M_r}{E^*} \]

DETERMINE \( a' \)

\[ \alpha' = (1 - d_j) \alpha \]

COMPUTE FIELD DAMAGED MODULUS

\[ \log |E^*| = \delta + \frac{\alpha'}{1 + e^{\beta - \gamma \log f_r}} \]
TYPICAL MIX PROPERTIES

UNDAMAGED MASTER CURVE

\[
\log E^* = 3.750063 + 0.02932\rho_{200} - 0.001767(\rho_{200})^2 - 0.058097V_a - 0.802208\left(\frac{V_{beff}}{V_{beff} + V_a}\right)
\]

\[
+ \frac{3.871977 - 0.0021\rho_4 + 0.003958\rho_{38} - 0.000017(\rho_{38})^2 + 0.005470\rho_{34}}{1 + e^{-0.603313 - 0.313351\log(f) - 0.393532\log(\eta)}}
\]

\[
\log|E^*| = \delta + \frac{\alpha}{1 + e^{\beta - \gamma \log f_r}}
\]
DISTRESS/CONDITION SURVEY

- Pavement Rating: Excellent, Good, Fair, Poor, Very Poor

Data Input Level 3 (Cont.)

ESTIMATE DAMAGE, $d_j$:

<table>
<thead>
<tr>
<th>Category</th>
<th>Damage ($d_j$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>0.00 – 0.20</td>
</tr>
<tr>
<td>Good</td>
<td>0.20 – 0.40</td>
</tr>
<tr>
<td>Fair</td>
<td>0.40 – 0.80</td>
</tr>
<tr>
<td>Poor</td>
<td>0.80 - 1.20</td>
</tr>
<tr>
<td>Very Poor</td>
<td>&gt; 1.2</td>
</tr>
</tbody>
</table>
Data Input Level 3 (Cont.)

¬ DETERMINE $a'$

$$\alpha' = (1 - d_j) \cdot \alpha$$

¬ COMPUTE FIELD DAMAGED MODULUS

$$\log |E^*| = \delta + \frac{\alpha'}{1 + e^{\beta - \gamma \log f_r}}$$
**APPROACH**

- From previous study (different sites in VA)
  - FWD Testing → Backcalculated Moduli
  - Distress/Condition Survey
  - Coring + Laboratory Testing
    - Volumetric Analysis and Mr
- Calculate Estimated Undamaged $E^*$
- Calculate Damaged $E^*$ for three input levels
- Measure $E^*$ in the lab
- Compare
Selected Sites

- Flexible Pavements
- Composite Pavements

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## Selected Sites (Cont.)

<table>
<thead>
<tr>
<th>Site</th>
<th>County</th>
<th>Route</th>
<th>Direction</th>
<th>Milepost</th>
<th>Pavement Type</th>
<th>Pav. Age/ Surf.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Amherst</td>
<td>US-29</td>
<td>South</td>
<td>7.80-7.30</td>
<td>Flexible</td>
<td>34 / 11</td>
</tr>
<tr>
<td>3</td>
<td>Louisa</td>
<td>I-64</td>
<td>West</td>
<td>9.91-9.41</td>
<td>Flexible</td>
<td>34 / 9</td>
</tr>
<tr>
<td>6</td>
<td>York</td>
<td>I-64</td>
<td>West</td>
<td>2.62-2.12</td>
<td>Flexible</td>
<td>25 / 7</td>
</tr>
<tr>
<td>12</td>
<td>Greensville</td>
<td>I-295</td>
<td>North</td>
<td>5.50-6.00</td>
<td>Comp. JPCP (rehab)</td>
<td>14 / 6</td>
</tr>
<tr>
<td>14</td>
<td>Russell</td>
<td>I-19</td>
<td>North</td>
<td>8.68-9.18</td>
<td>Flexible</td>
<td>6 / 6</td>
</tr>
<tr>
<td>15</td>
<td>Rockbridge</td>
<td>I-81</td>
<td>South</td>
<td>22.92-22.42</td>
<td>Flexible</td>
<td>37 / 17</td>
</tr>
<tr>
<td>16</td>
<td>Frederick</td>
<td>I-81</td>
<td>North</td>
<td>21.31-21.87</td>
<td>Flexible</td>
<td>39 / 13</td>
</tr>
<tr>
<td>17</td>
<td>Washington</td>
<td>I-81</td>
<td>South</td>
<td>12.50-12.00</td>
<td>Flexible</td>
<td>42 / 11</td>
</tr>
<tr>
<td>18</td>
<td>Washington</td>
<td>I-81</td>
<td>South</td>
<td>1.50-1.00</td>
<td>Flexible</td>
<td>5 / 3</td>
</tr>
</tbody>
</table>
Field Data Collection
FWD Testing

- Test pattern dependent on pavement structure

- Basin Testing
  - 4 load levels and 3 drops per load level
  - 50 foot intervals in OWP (AC surface)
FWD Analysis: Flexible Site 16

- SM + BM
- Aggregate Base Type I + Select Material Type I
- Subgrade
- SM (lab)
- BM (lab)

SITE 16 – Flexible

Resilient Modulus (MPa)

Distance (m)

Subgrade
Fill w/compacted clay & gravel, damp clay w/silt

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Coring and Boring

- Retrieve pavement materials samples for laboratory testing
- Number of tests varied based on pavement type
- Controlling factor was amount of lane closure time
Distress Survey

VT Digital Camera System

Transversal Crack

Longitudinal Crack
## Pavement Condition

<table>
<thead>
<tr>
<th>Site</th>
<th>NDR</th>
<th>LDR</th>
<th>CCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>74.5</td>
<td>96.7</td>
<td>75</td>
</tr>
<tr>
<td>3</td>
<td>68.6</td>
<td>95.8</td>
<td>69</td>
</tr>
<tr>
<td>6</td>
<td>80.5</td>
<td>96.3</td>
<td>81</td>
</tr>
<tr>
<td>12</td>
<td>97.2</td>
<td>95.8</td>
<td>96</td>
</tr>
<tr>
<td>14</td>
<td>99.9</td>
<td>99.9</td>
<td>100</td>
</tr>
<tr>
<td>15</td>
<td>92.3</td>
<td>89.7</td>
<td>90</td>
</tr>
<tr>
<td>16</td>
<td>91.6</td>
<td>99.8</td>
<td>92</td>
</tr>
<tr>
<td>17</td>
<td>92</td>
<td>94.2</td>
<td>92</td>
</tr>
<tr>
<td>18</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
Other Measurements…

Profile
(Smoothness/Rutting)

Friction

GPR Testing
Laboratory Tests

- Specimen preparation
  - Core 6” cores to 4”
  - Cut the ends

- Dynamic Modulus
  - 5 Temperatures: 10°F, 40°F, 70°F, 100°F, 130°F
  - 6 Frequencies: 0.1Hz, 0.5Hz, 1Hz, 5Hz, 10Hz, 25Hz
**Dynamic Modulus**

\[
|E^*| = \frac{\sigma_0}{\varepsilon_0} \quad E^* = E' + iE'' \quad E^* = |E^*|(\cos \phi + i\sin \phi)
\]

\[
\phi \text{ (degrees)} = \frac{\text{time lag}}{\text{Period}} \times 360
\]
SITE 01
Results: Site 01 (Core S01C4)

- Volumetric Analysis
  - Ignition
  - Gradation

- Undamaged E*
  - Witczak equation
Estimated Undamaged Master Curve

\[ T_{\text{ref}} = 70^\circ \text{F} \]

\[ \log |E^*| = 2.868 + \frac{3.860}{1 + e^{1 - 0.314 \log f_r}} \]

\[ \alpha = 3.86 \]
Data Input Level 1

- **Backcalculated Modulus:**
  - \( E \text{ (avg.)} = 462 \text{ksi}, \text{Avg. Temp.} = 74.2^\circ \text{F} \)

- **Undamaged E* @ 5Hz, 74.2^\circ \text{F} = 672 \text{ksi}**

\[
d_j = 1 - \frac{462}{672} = 0.31
\]

\[
\alpha' = 0.69 \times 3.86 = 2.66
\]
Resilient Modulus

- Mr (Wearing Surface) = 746ksi
- Mr (Base) = 433ksi

\[ M_{rc} = \left( \frac{h_1^{3/2}M_{rWS} + h_2^{3/2}M_{rBM}}{h_1 + h_2} \right)^3 \]

- Undamaged E* @ 1.6Hz, 77°F = 468ksi

\[ d_j = 1 - \frac{569}{468} = -0.22 \]

\[ \alpha' = 1.22 \times 3.86 = 4.71 \]
Data Input Level 2

- NDR = 74.5 LDR = 96.7 CCI = 75
- Rating = Good

\[ d_j = 0.3 \]

\[ \alpha' = 0.7 \times 3.86 = 2.7 \]
Too High?
SITE 03
SITE 06

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Very Low Backcalculated HMA Modulus
Findings

- Volumetric properties from the same site were different from core to core, which resulted in different measured dynamic modulus.

- Sigmoidal function provides a very good fit to the dynamic modulus master curve.
Findings (Cont.)

- Laboratory-measured resilient modulus test does not give a good indication of the combined behavior of thick HMA layers

- Using the average values for the backcalculated FWD may not provide the best estimates for the damage factor
The Witczak prediction equation gives reasonable values for the dynamic modulus

- Same order of magnitude as the measured ones
- In most cases: $0.3 < \frac{E_{predicted}}{E_{measured}} < 1.8$
The use of level 3 data on previously overlaid pavements may be misleading because the surface condition does not reflect the overall condition of the entire HMA layer.
CONCLUSIONS

Level 2, as currently used in the proposed M-E Pavement Design Guide, provides unreasonable values for the damaged dynamic modulus master curves

Linked to the method used to measure the Resilient Modulus?
CONCLUSIONS

- Level 1 data is necessary to obtain reliable estimates of the properties of the existing HMA layers.

  ✔ FWD testing appears to be the only reliable procedure that can measure the overall condition of the entire HMA layer
RECOMMENDATIONS

- VDOT should not use level 2 type of input for rehabilitation when the proposed ME guide is implemented.

- Perform sensitivity analysis on the effect of the existing HMA layer dynamic modulus values on the overlay design.
Related Projects

- Catalog of HMA properties for MEPDG
  - 3 surface, 4 intermediate & 4 base mixes
  - Dynamic Modulus
  - Creep
  - Resilient Modulus
  - IDT

- Distress Model Calibration (pending approval)

- ...
Questions?