Fatigue Resistant Asphalt Base

- Minimize Tensile Strain with Pavement Thickness
- Thicker Asphalt Pavement = **Lower Strain**
- Strain Below Fatigue Limit = **Indefinite Life**

![Diagram showing Compressive Strain, MicroStrain, Tensile Strain, and Fatigue Life with a range of 60 - 70.](image-url)
Mechanistic Performance Criteria

Under ESAL

Limit Bending to $< 65 \mu \varepsilon$
(Monismith, Von Quintus, Nunn, Thompson)

Limit Vertical Compression to $< 200 \mu \varepsilon$
(Monismith, Nunn)
### $$$ Comparison for Pa DOT

#### PRICES

<table>
<thead>
<tr>
<th>Material</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA Base</td>
<td>$29.00/ton</td>
</tr>
<tr>
<td>HMA Rich Bottom</td>
<td>29.90/ton  (+1/2% AC @ $180/ton)</td>
</tr>
<tr>
<td>HMA PG 64-22</td>
<td>36.36/ton</td>
</tr>
<tr>
<td>HMA PG 76-22</td>
<td>42.00/ton</td>
</tr>
<tr>
<td>Scratch Course</td>
<td>34.00/ton</td>
</tr>
<tr>
<td>Seal Coat Shoulder</td>
<td>0.85/sy</td>
</tr>
<tr>
<td>Mill 2-inches</td>
<td>0.80/sy</td>
</tr>
<tr>
<td>Deep Patching</td>
<td>81.00/sy</td>
</tr>
</tbody>
</table>

**Notes:**
- 4-inches of Rich Bottom is an additional $0.20/sy
- 2-inches of PG 76-22 Wearing is an additional $0.62/sy
### Perpetual Pavement vs DOT AASHTO

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Initial</th>
<th>LCC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>14.5-inch Pavement Section</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PP 15/15 vs DOT 10/10</td>
<td>+ 3.1 %</td>
<td>- 8.1 %</td>
</tr>
<tr>
<td>PP 15/12 vs DOT 15/10</td>
<td></td>
<td>- 2.4 %</td>
</tr>
<tr>
<td><strong>16-inch Pavement Section</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PP 15/15 vs DOT 10/10</td>
<td>+ 1.9 %</td>
<td>- 7.5 %</td>
</tr>
<tr>
<td>PP 15/12 vs DOT 15/10</td>
<td></td>
<td>- 2.3 %</td>
</tr>
</tbody>
</table>

*Sign reflects perpetual pavement advantage (-) or disadvantage (+)*
# Comparison of Alternates

<table>
<thead>
<tr>
<th>Alternate</th>
<th>X-section</th>
<th>AC</th>
<th>Comp</th>
<th>$/SY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 standard</td>
<td>2,3,10,4,8</td>
<td>74</td>
<td>498</td>
<td>36.52</td>
</tr>
<tr>
<td>subgrade</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 standard</td>
<td>2,3,10,4,12</td>
<td>58</td>
<td>225</td>
<td>33.80</td>
</tr>
<tr>
<td>3 pp PG76</td>
<td>2,7,3,4,8</td>
<td>62</td>
<td>130</td>
<td>33.06</td>
</tr>
<tr>
<td>4 pp PG76</td>
<td>2,8,4,4,12</td>
<td>70</td>
<td>188</td>
<td>40.80</td>
</tr>
<tr>
<td>subgrade</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 pp PG70</td>
<td>2,8,4,4,12</td>
<td>50</td>
<td>105</td>
<td>36.19</td>
</tr>
</tbody>
</table>

HMA, Rich Bottom, ATPB, Subbase
Perpetual Pavement Design Software

Under development by Dr. David Timm at NCAT for the Asphalt Pavement Alliance
M-E Design Framework

Load Configurations

Structural Parameters

\[ D = \sum \frac{n_i}{N_{f_i}} \]

\( n \)

\( \sigma, \varepsilon \)

Transfer Function(s)

\( N_f \)

D>1?

D<<1?

Final Design
Key Software Components

• Based on fully functional M-E design software
• Layered elastic analysis
• Incorporates
  – Seasonal effects
  – Thickness variability
  – Material property variability
  – Load Spectra or ESALs
  – Deterministic and Probabilistic analyses
  – Conventional M-E design and Perpetual Pavement Design
Structural Inputs
Up to 5 Layers
Seasonal Properties
Material Type
Stiffness
Poisson
Thickness
Variability
Perpetual Pavement
Failure Criteria
Asphalt Modulus vs. Temperature

AC - Temperature Relationship (F1 for Help)

\[ E_{AC} = Q_1 \times e^{\left( \frac{(T+Q_2)^2}{Q_3} \right)} \]

Q1  16693.4
Q2  26.2
Q3  -1459.7

Note: Changing these coefficients will update ALL of the asphalt concrete seasonal moduli, according to temperature.
Perpetual Pavement Failure Criteria

- Designer selects location(s) in layer
- Type of criteria (stress, strain, deflection)
- Threshold value

![Layer Failure Criteria Window](image)
Fatigue Cracking and $N_{fatigue}$

\[
\log N_f = 15.947 - 3.291 \log \left( \frac{\varepsilon_t}{10^{-6}} \right) - 0.854 \log \left( \frac{E}{10^3} \right)
\]

- $E = 200,000$ psi ($1,380$ MPa)
- $E = 500,000$ psi ($3,450$ MPa)
Vertical Compressive Strain (in./in.)

\[ N = 1.077 \times 10^{18} \left( \frac{10^{-6}}{\varepsilon_v} \right)^{4.4843} \]

Total Pavement Rut Depth and \( N_{rutting} \)
Transfer Functions

Fatigue

\[ N_F = K_1 \left( \frac{10^6}{\varepsilon_t} \right)^{K_2} \]

- \( K_1 = 2.83 \times 10^{-6} \)
- \( K_2 = 3.20596 \)

Rutting

\[ N_R = K_3 \left( \frac{1}{\varepsilon_v} \right)^{K_4} \]

- \( K_3 = 5.5 \times 10^15 \)
- \( K_4 = 3.929 \)
Load Spectra

- Consider weight distributions of singles, tandems, tridem and steer axles separately

![Loading Conditions (F1 for Help)](image)

- Expected Number of Axles in Given Weight Classes:

<table>
<thead>
<tr>
<th>Weight Class</th>
<th>0-2</th>
<th>14-16</th>
<th>0</th>
<th>28-30</th>
<th>0</th>
<th>42-44</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-4</td>
<td>0</td>
<td>16-18</td>
<td>0</td>
<td>30-32</td>
<td>0</td>
<td>44-46</td>
<td>0</td>
</tr>
<tr>
<td>4-6</td>
<td>0</td>
<td>18-20</td>
<td>0</td>
<td>32-34</td>
<td>0</td>
<td>46-48</td>
<td>0</td>
</tr>
<tr>
<td>6-8</td>
<td>0</td>
<td>20-22</td>
<td>0</td>
<td>34-36</td>
<td>0</td>
<td>48-50</td>
<td>0</td>
</tr>
<tr>
<td>8-10</td>
<td>0</td>
<td>22-24</td>
<td>0</td>
<td>36-38</td>
<td>0</td>
<td>50-52</td>
<td>0</td>
</tr>
<tr>
<td>10-12</td>
<td>0</td>
<td>24-26</td>
<td>0</td>
<td>38-40</td>
<td>0</td>
<td>52-54</td>
<td>0</td>
</tr>
<tr>
<td>12-14</td>
<td>0</td>
<td>26-28</td>
<td>0</td>
<td>40-42</td>
<td>0</td>
<td>54+</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: Weight expressed in kips.
ESAL Approximation

Expected Number of Equivalent Single Axle Loads, ESALs

1000000

OK

Cancel
Analysis

• Deterministic:
  – Program considers possible combinations of material properties and loadings
  – Calculates pavement responses
  – Determines if thresholds are exceeded (i.e., non-perpetual)

• Probabilistic:
  – Program uses Monte Carlo simulation to model input distributions
    • Load, Materials, thickness
  – A distribution of pavement response is determined
  – Reliability = probability that response(s) below threshold
Monte Carlo Simulation

Input Distributions

WESLEA

Output Distribution
Characteristic Distribution

Extreme-Value Type I

\[ F(n) = e^{-e^{(\alpha(n-\mu)}} \]

\[ R = 1 - F(n) \]
Program Output

Output & Design Studio (F1 for Help)

Damage Analysis - Using Nominal Values
- Fatigue Damage: 0.69
- Rutting Damage: 0.44

Reliability Analysis
- Fatigue Reliability: 73%
- Rutting Reliability: 78%

Cost Analysis

Thickness Design Studio
- Number of Pavement Layers: 3
- Type of Design: ESAL, New Construction

Layer 1 | Layer 2 | Layer 3 | Layer 4 | Layer 5
--- | --- | --- | --- | ---
Material: AC | GB | Soil | Soil | Soil
Thickness, in.: 6 | 18 | 999 | 999 | Infinite

Disclaimer | Export Data | Leave Studio
Miner’s Hypothesis

• Provides the ability to sum damage for a specific distress type

• $D = \sum \frac{n_i}{N_i} \leq 1.0$

  where $n_i = \text{actual number of loads during condition } i$

  $N_i = \text{allowable number of loads during condition } i$