Perpetual Pavement Design
An Introduction to the PerRoad Program

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Overview

- Pavement design background
  - Layered elastic theory
- Perpetual pavement design philosophy
  - Sensitivity Study
- Program basics
- Example problems – Design simulations
WHY ARE PERPETUAL PAVEMENTS IMPORTANT?
Perpetual Pavement Award

• Started by the Asphalt Pavement Alliance in 2001.
• Road must be >35 years old.
• No thickness increase >4 inches.
• No overlay interval less than 13 years.
• Nominated by DOT.
Washington State Performance

![Bar chart showing lane miles for different age groups. The x-axis represents age groups (0-10, 11-20, 21-30, 31-40, 41-50, 51-60, 61 or More), and the y-axis represents lane miles (0-1000). The chart compares HMA (Lane Miles) and PCCP (Lane Miles) for each age group.]

- HMA (Lane Miles)
- PCCP (Lane Miles)
Washington State Performance

### Table: Performance Ratings

<table>
<thead>
<tr>
<th>Description</th>
<th>PSR Rating</th>
<th>IRI</th>
<th>NHS Ride Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Good</td>
<td>≥4.0</td>
<td>&lt;1.0 m/km (&lt;60 in/mi)</td>
<td>Acceptable (0-2.7 m/km)</td>
</tr>
<tr>
<td>Good</td>
<td>3.5-3.9</td>
<td>1.0-1.5 m/km (60-94 in/mi)</td>
<td></td>
</tr>
<tr>
<td>Fair</td>
<td>3.1-3.4</td>
<td>1.5-1.9 m/km (95-119 in/mi)</td>
<td></td>
</tr>
<tr>
<td>Mediocre</td>
<td>2.6-3.0</td>
<td>1.9-2.7 m/km (120-170 in/mi)</td>
<td></td>
</tr>
<tr>
<td>Poor</td>
<td>≤2.5</td>
<td>&gt;2.7 m/km (&gt;170 in/mi)</td>
<td>Less than Acceptable (&gt;2.7 m/km)</td>
</tr>
</tbody>
</table>
Material Usage

- HMA, tons:
  - Conv.: 10,000
  - Perp. Pvmnt.: 6,500
  - Save 31%

- RAP, tons:
  - Conv.: 4,000
  - Perp. Pvmnt.: 2,800
  - Save 28%

- Aggregate, tons:
  - Conv.: 10,000
  - Perp. Pvmnt.: 6,400
  - Save 32%

- Binder, tons:
  - Conv.: 400
  - Perp. Pvmnt.: 280
  - Save 28%
Perpetual Pavement versus Conventional Design

![Graph showing HMA Thickness vs Traffic, ESAL]

- AASHTO
- PerRoad
• Asphalt Performance Problems
• Ban Asphalt?

6” Asphalt

6” Stabilized Subgrade

Clayey Subgrade

6” JPCP

6” Stabilized Subgrade

Clayey Subgrade
Goal of Perpetual Pavement Design

• Design the structure such that there are no deep structural distresses
  – Bottom up fatigue cracking
  – Structural rutting

• All distresses can be quickly remedied from surface

• Result in a structure with ‘Perpetual’ or ‘Long Life’
Avoid These!

Structural Rutting

Bottom-Up Fatigue
Surface Distresses Only

Top Down Cracking

Non-Structural Rutting
Pavement Design: Where were we?

- Using 1960s performance equations
- 1950s type of load
- Thin pavement structures (Max. 6” HMA)
- Meaning of structural coefficients
- Limited reliability analysis
- Some movement to M-E
AASHO Road Test Trucks

FIGURE 3 AASHO Road Test truck traffic.
M-E Design Framework

Load Configurations

WESLEA

σ, ε

Transfer Function(s)

Structural Parameters

\[ D = \sum \frac{n_i}{Nf_i} \]

\[ D > 1? \]

\[ D << 1 ? \]

Final Design
How an Elastic Material Behaves.
Dynamic Modulus Test
HMA Modulus Versus Temperature

Modulus, 1000 psi

Temperature, F
Soil Modulus Testing
Effect of Moisture Content

![Graph showing the effect of moisture content on Modulus, ksi. Modulus decreases as moisture content increases.](image-url)
M-E Design Framework

Load Configurations

Structural Parameters

\[ D = \sum \frac{n_i}{Nf_i} \]

Transfer Function(s)

WESLEA

\( \sigma, \varepsilon \)

\( D > 1? \)

\( D << 1? \)

Final Design
M-E Design Framework

Load Configurations

Structural Parameters

WESLEA

\[ D = \sum_{i} \frac{n_i}{Nf_i} \]

\( \sigma, \varepsilon \)

Transfer Function(s)

\( n \)

Final Design

\( D \approx 1 \)？

\( D \ll 1 \)？
Three Layer Systems

Layer 1
HMA
E_1

Layer 2
Granular Base
E_2

Layer 3
Subgrade Soil
E_3

Deflection (\(\delta\))

Tensile Strain (\(\varepsilon_t\))

Compressive Strain (\(\varepsilon_c\))

No bottom boundary, assume soil goes on infinitely.

No horizontal boundary, assume layers extend infinitely.

Tire has a total load \(P\), spread over a circular area with a radius of \(a\), resulting in a contact pressure of \(p\).
M-E Design Framework

Load Configurations

Structural Parameters

WESLEA

Transfer Function(s)

\[ D = \sum \frac{n_i}{Nf_i} \]

Final Design

\( \sigma, \varepsilon \)

\( N_f \)

\( D > 1? \)

\( D << 1? \)
Fatigue Transfer Function

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

- \( E = 200,000 \text{ psi} \) (1,380 MPa)
- \( E = 500,000 \text{ psi} \) (3,450 MPa)
Rutting Transfer Function

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

Vertical Compressive Strain (in./in. \(10^{-6}\))

Load Applications \((N_f)\)
Number of Loads to Failure

Strain, (10^(-6))

Endurance Limit

Normal Range for Fatigue Testing
M-E Design Framework

Load Configurations

Structural Parameters

\[ D = \sum \frac{n_i}{Nf_i} \]

\( \sigma, \varepsilon \)

Transfer Function(s)

Final Design

\( n \)

\( D \leq 1 \)?

\( D \ll 1 \)?
Structural/Performance Analysis

• Initial trial design
  – Initial estimate of layer thickness
  – Required repairs to the existing pavement
  – Pavement materials characterization

• Analyzed by cumulative damage incrementally over time using
  – Structural response
  – Performance models
Perpetual Pavement Design

Log $\varepsilon$

Threshold Strain

Log $N$

No Damage Accumulation
• Sponsored by APA
• Developed at Auburn University / NCAT
• M-E Perpetual Pavement Design and Analysis Tool
# of Layers
- 2
- 3
- 4
- 5

Seasonal Information
- Summer: 26 weeks, Mean Air Temperature, F: 75
- Fall: 8 weeks, Mean Air Temperature, F: 55
- Winter: 12 weeks, Mean Air Temperature, F: 45
- Spring: 6 weeks, Mean Air Temperature, F: 70
- Spring2: 0 weeks
- Current Season: Summer
- Temperature Correction:

Layer 1
- Material Type: AC
- PG Grade: 70
- Min Modulus (psi): 50000
- Modulus (psi): 431091
- Max Modulus (psi): 4000000
- Poisson's Ratio: 0.35
- Min - Max: 0.15 - 0.4
- Thickness (in): 10

Layer 2
- Material Type: Gran Base
- PG Grade: -22
- Min Modulus (psi): 5000
- Modulus (psi): 20000
- Max Modulus (psi): 50000
- Poisson's Ratio: 0.4
- Min - Max: 0.35 - 0.45
- Thickness (in): 12

Layer 3
- Material Type: Soil
- PG Grade: 0.45
- Min Modulus (psi): 3000
- Modulus (psi): 12000
- Max Modulus (psi): 40000
- Poisson's Ratio: 0.45
- Min - Max: 0.2 - 0.5
- Thickness (in): 999

Layer 4
- Material Type: Soil
- PG Grade: 0.45
- Min Modulus (psi): 3000
- Modulus (psi): 12000
- Max Modulus (psi): 40000
- Poisson's Ratio: 0.45
- Min - Max: 0.2 - 0.5
- Thickness (in): 999

Layer 5
- Material Type: Soil
- PG Grade: 0.45
- Min Modulus (psi): 3000
- Modulus (psi): 12000
- Max Modulus (psi): 40000
- Poisson's Ratio: 0.45
- Min - Max: 0.2 - 0.5
- Thickness (in): Infinite

Performance Criteria
- Variability
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Accept Changes
Cancel Changes
<table>
<thead>
<tr>
<th>Position</th>
<th>Criteria</th>
<th>Threshold</th>
<th>Transfer Function</th>
<th>k1</th>
<th>k2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom</td>
<td>Horizontal Strain</td>
<td>-70</td>
<td>microstrain</td>
<td>2.83e-006</td>
<td>3.148</td>
</tr>
</tbody>
</table>

Note: The following sign convention is used...

Negative = Tension
Positive = Compression
Deflection is Positive Downward

Note: The transfer functions are for strain only.
<table>
<thead>
<tr>
<th>Vehicle Classification</th>
<th>% AADTT</th>
<th>Single</th>
<th>Tandem</th>
<th>Tridem</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1.2</td>
<td>1.62</td>
<td>0.39</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>9.4</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>3.3</td>
<td>1.02</td>
<td>0.99</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0.5</td>
<td>1</td>
<td>0.26</td>
<td>0.83</td>
</tr>
<tr>
<td>8</td>
<td>7.4</td>
<td>2.38</td>
<td>0.67</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>68.9</td>
<td>1.13</td>
<td>1.93</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>1.2</td>
<td>1.19</td>
<td>1.09</td>
<td>0.89</td>
</tr>
<tr>
<td>11</td>
<td>6.1</td>
<td>4.29</td>
<td>0.26</td>
<td>0.06</td>
</tr>
<tr>
<td>12</td>
<td>0.8</td>
<td>3.52</td>
<td>1.14</td>
<td>0.06</td>
</tr>
<tr>
<td>13</td>
<td>1.2</td>
<td>2.15</td>
<td>2.13</td>
<td>0.35</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Coming Refinement

• Currently a single fatigue endurance limit is used.
• Results in one-size fits all – overly conservative
• Use FEL Ratio. Use distribution of strains.

\[
\text{Ratio} = \frac{\text{FEL}_n}{\text{FEL}_{lab}}
\]
ROAD MAY BE SUBJECT TO SUDDEN CATASTROPHIC SINKHOLE COLLAPSE
PerRoadXPress

Press F1 to access full help file. Press Shift+F1 to access context-sensitive pop-up help.

Functional Classification: Urban Collector

Two-Way AADT: 1000 (500 to 5000)

%Trucks: 1 (1 to 20)

%Growth: 1 (0 to 3)

Design Trucks: 63482 (Total Trucks in 30 Years)

Design ESALs: 18917 (Total ESALs in 30 Years)

AASHTO Soil Classification: A-1-a

Soil Modulus: 29500 (10,000 to 30,000 psi)

Aggregate Base Thickness: 4 (0 to 10 in.)

HMA Modulus: 800000 (400,000 to 1,000,000 psi)

Calculated HMA in. Design HMA in. Calculated thickness rounded up to nearest 0.25 in.

[calculate button]

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- 5 Presentations on Cracking Tests
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- 5 Presentations on High RAP/RAS
- Implementation of Specifications
- Aging Behavior
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