AASHTO Flexible Design Procedure

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Topic 7 – AASHTO Flexible Pavement Design

1. Development

American Association of State Highway and Transportation Officials
http://www.aashto.org/

1.1 AASHO Road Test

• Late 50’s road test in Illinois
• Objective was to determine the
• Provided data for the design criteria

1.2 Performance Measurements

Establishment of performance criteria is critical

Functional ⇐ AASHTO Vs AI ⇒ Structural
1.2 Performance Measurements (cont)

- AASHO Road Test performance based on user assessment:
  - Difficult to quantify (Highly variable)
  - 0-1 – V. Poor
  - 1-2 – Poor
  - 2-3 – Fair
  - 3-4 – Good
  - 4-5 – V. Good

A panel of experts drove around in standard vehicles and gave a rating for the pavement.

- Measurable characteristics (performance indicators):
  - Visible
  - Surface friction
  - Roughness

1.3 AASHTO Performance Relations

Establish correlation between user assessment (ride experience) and performance indicators (measurable characteristics)

**Present Serviceability Index (PSI)**

\[
PSI = A_0 + A_1 F_1 + A_2 F_2 + A_3 F_3
\]

- \( A_0 \ldots A_3 \) = Regression Coefficients
- \( F_1 \) = Measure of roughness
- \( F_2 \) = Measure of rutting
- \( F_3 \) = Measure of cracking

How does the true (user) performance correlate to the measured performance?

Calculated the regression coefficients for the PSI equation.
1.3 AASHTO Design Equations

1.3.1 Performance Requirements & Design Life

AASHTO performance requirement =

• PSI scale: 1 (V. Poor) → 5 (V. Good)

Terminal PSI (known) → Pvt is no longer functional

What are the three factors affecting performance (ΔPSI)?
1.3.3 Definition of Structural Number

<table>
<thead>
<tr>
<th>Layer</th>
<th>Value</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>$D_1$</td>
<td>$a_1$</td>
</tr>
<tr>
<td>BASE</td>
<td>$D_2$</td>
<td>$a_2$</td>
</tr>
<tr>
<td>SUB-BASE</td>
<td>$D_3$</td>
<td>$a_3$</td>
</tr>
</tbody>
</table>

Structural Coefficient ($a$):

$$a = f(n, c)$$

Basic Procedure:
- Determine the traffic (ESAL)
- Calculate the
- Select the performance level (N)
- Solve for the required

1.3.4 Design Notes

i. Different combination of materials & thicknesses may result in the same SN

ii. Your job as a designer is to select the most economical combination, using available materials and considering the following:

- 
- 
- 

iii. AASHTO assumes that pavement structural layers will not be overstressed:

- Must check that
Topic 7 – AASHTO Flexible Pavement Design

2. Design Inputs
2.1 General Design Variables

- Design Life
- Material Properties
- Traffic
- Reliability
  - Degree of certainty that the pavement will last the design period
  - Uncertainty in:
    - 
    - 
    - 

2.2 AASHTO Reliability Factor ($F_R$)

Adjust traffic for reliability:

$$W_{18} = w_{18} \times F_R$$

Where:

- $W_{18}$ = 
- $w_{18}$ = 

Steps:
1. Define functional class (Interstate/Local)
2. Select reliability level ($R$) – Table 11.14
3. Select a standard deviation ($S_0$)
   - Flexible:
     - No traffic variation: $S_0 = 0.35$
     - With traffic variation: $S_0 = 0.45$
   - Rigid:
     - No traffic variation: $S_0 = 0.25$
     - With traffic variation: $S_0 = 0.35$
2.3 Performance Criteria

Design for serviceability change:
- $\Delta \text{PSI} = \text{PSI}_0 - \text{PSI}_t$
  - $\text{PSI}_0 = \text{...}$
  - $\text{PSI}_t = \text{...}$

2.4 Material Properties

2.4.1 Effective Subgrade Resilient Modulus

- Obtain $M_R$ values
- Separate year into time intervals
- Compute the
  \[ u_f = 1.18 \times 10^8 \times M_R^{-2.32} \]
2.4.1 Effective Subgrade Resilient Modulus (cont)

![Map of United States with regions and characteristics](image)

<table>
<thead>
<tr>
<th>Region</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Wet, no freeze</td>
</tr>
<tr>
<td>II</td>
<td>Wet, freeze - thaw cycling</td>
</tr>
<tr>
<td>III</td>
<td>Wet, hard freeze, spring thaw</td>
</tr>
<tr>
<td>IV</td>
<td>Dry, no freeze</td>
</tr>
<tr>
<td>V</td>
<td>Dry, freeze - thaw cycling</td>
</tr>
<tr>
<td>VI</td>
<td>Dry, hard freeze, spring thaw</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>U.S. Climatic Region</th>
<th>Very Poor</th>
<th>Poor</th>
<th>Fair</th>
<th>Good</th>
<th>Very Good</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>2,800*</td>
<td>3,700</td>
<td>5,000</td>
<td>6,800</td>
<td>9,500</td>
</tr>
<tr>
<td>II</td>
<td>2,700</td>
<td>3,400</td>
<td>4,500</td>
<td>5,500</td>
<td>7,300</td>
</tr>
<tr>
<td>III</td>
<td>2,700</td>
<td>3,000</td>
<td>4,000</td>
<td>4,400</td>
<td>5,700</td>
</tr>
<tr>
<td>IV</td>
<td>3,200</td>
<td>4,100</td>
<td>5,600</td>
<td>7,900</td>
<td>11,700</td>
</tr>
<tr>
<td>V</td>
<td>3,100</td>
<td>3,700</td>
<td>5,000</td>
<td>6,000</td>
<td>8,200</td>
</tr>
<tr>
<td>VI</td>
<td>2,800</td>
<td>3,100</td>
<td>4,100</td>
<td>4,500</td>
<td>5,700</td>
</tr>
</tbody>
</table>

*Effective Resilient Modulus in psi
2.4.2 Pavement Structural Layers

- Layer coefficient $a_i$; relative quality as a structural unit:
  - 2" of material with $a=0.2$ provides

- Initially layer coefficients were derived from AASHO road test results; have subsequently been related to resilient modulus

Hot-Mix Asphalt

- AASHTO does not require test to determine HMA modulus; usually assume $a_{HMA}=0.44$

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2.4.2 Pavement Structural Layers (cont)

Untreated and Stabilized Bases

- Can estimate the base layer coefficient from Figure 7.15 for:
  - Untreated base
  - Bituminous-treated base
  - Cement-treated base
- For untreated base can also use the following (instead of interpolating from the figure):
  - 

Granular Sub-bases

- Can estimate the sub-base layer coefficient from Figure 7.16
- Can also use the following (instead of interpolating from the figure):
  - 

2.5 Drainage

- AASHTO guide provides means to adjust layer coefficients depending
- Define quality of drainage of each layer based upon:
  - 
  - 
- Determine drainage modifying factor (m) from Table 11.20
  \[ SN_i = a_i \times D_i \times m \]

<table>
<thead>
<tr>
<th>Quality of drainage</th>
<th>Water removed within</th>
<th>Percentage of time pavement structure is exposed to moisture levels approaching saturation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>2 hours</td>
<td>Less than 1% [1.40-1.35] 1.35-1.30 1.30-1.20 1.20</td>
</tr>
<tr>
<td>Good</td>
<td>1 day</td>
<td>1.35-1.25 1.25-1.15 1.15-1.00 1.00</td>
</tr>
<tr>
<td>Fair</td>
<td>1 week</td>
<td>1.25-1.15 1.15-1.05 1.00-0.80 0.80</td>
</tr>
<tr>
<td>Poor</td>
<td>1 month</td>
<td>1.15-1.05 1.05-0.80 0.80-0.60 0.60</td>
</tr>
<tr>
<td>Very poor</td>
<td>Never drain</td>
<td>1.05-0.95 0.95-0.75 0.75-0.40 0.40</td>
</tr>
</tbody>
</table>

*Source: After AASHTO (1986).*

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2.6 Computation of Required Pavement Thickness

2.6.1 Basic Approach

- Determine the required SN for design traffic
- Identify trial designs that meet required SN

2.6.2 Nomograph to Solve for SN
2.6 Computation of Required Pavement Thickness (cont)

2.6.3 Solving the Equation

\[ \log(W_{18}) = (Z_R \cdot S_0) + 9.36 \cdot \log(SN + 1) - 0.2 + \frac{\log(\frac{\text{PSI}}{4.2 - 1.5})}{1094} + 2.32 \cdot \log(M_R) - 8.07 \]

- Declare the known variables – \(W_{18}, Z_R, S_0, \text{PSI}, M_R\)
- Give an initial estimate for the SN
- Allow the equation solver (Matlab, Maple, Mathcad, Excel, etc.) to iterate for the solution

2.6.4 Pavement Structural Layers

- \(SN = a_1D_1 + a_2D_2m_2 + \ldots\)
- **No Unique Solution!** Many

- Optimize the design; consider the following:
  - Design constraints – drainage, minimum thickness, available materials
  - Construction constraints – minimum layer thickness
  - Economics

2.6.5 Layered Design Analysis

- Nomograph determines the SN required to protect the subgrade
- However, each structural layer must be protected against overstressing
- Procedure developed using the AASHTO design nomograph
  - Determine the SN required to protect each layer
First we need to protect the subgrade; use the nomograph to get SN needed to provide adequate protection

BUT,

Only top (AC) layer

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**2.6.6 General Procedure**

1. Using $E_2$ as the $M_r$ value, determine from Figure 11.25 the structural number $SN_1$ required to protect the base and compute the thickness of layer 1 by
   
   $$ D_1 = \frac{SN_1}{a_1} $$

2. Using $E_3$ as the $M_r$ value, determine from Figure 11.25 the structural number $SN_2$ required to protect the subbase and compute the thickness of layer 2 by
   
   $$ D_2 \geq \frac{SN_2 - a_2 D_1^*}{a_2 m_2} $$

3. Based on the roadbed soil resilient modulus $M_{Ref}$, determine from Figure 11.25 the total structural number $SN_3$ required and compute the thickness of layer 3 by
   
   $$ D_3 \geq \frac{SN_3 - a_3 D_2^* - a_3 D_3^* m_3}{a_3 m_3^2} $$
2.7 Other Thickness Considerations

2.7.1 AASHTO Suggested Minimums

<table>
<thead>
<tr>
<th>ESAL</th>
<th>Asphalt Concrete</th>
<th>Aggregate Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50,000</td>
<td>1”</td>
<td>4”</td>
</tr>
<tr>
<td>50,000 – 150,000</td>
<td>2”</td>
<td>4”</td>
</tr>
<tr>
<td>150,000 – 500,000</td>
<td>2.5”</td>
<td>4”</td>
</tr>
<tr>
<td>500,000 – 2,000,000</td>
<td>3”</td>
<td>6”</td>
</tr>
<tr>
<td>2,000,000 – 7,000,000</td>
<td>3.5”</td>
<td>6”</td>
</tr>
<tr>
<td>&gt; 7,000,000</td>
<td>4”</td>
<td>6”</td>
</tr>
</tbody>
</table>

2.7.1 Construction / Stability
Layer must be thick enough to act as a unit:
- Thickness > 2* (Maximum Aggregate Size)

2.8 Cost Considerations

- Consider:
  - Different combination of materials
  - Cost of materials
  - Cost of excavation (cut areas)
- Express cost as a unit contribution to SN

<table>
<thead>
<tr>
<th>Material</th>
<th>$/sq.yd.-in</th>
<th>a_i</th>
<th>m_i</th>
<th>$/unit SN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crushed Stone</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pit-Run Gravel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphalt Concrete</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Maximize crushed stone thickness – minimize AC thickness
  - Can also stabilize base to use less HMA
- Use gravel only for fill or frost