FLEXIBLE PAVEMENT DESIGN
WITH WATER-RESISTANT LAYERS
Evolution of Structural Design Approaches

Pre 1950’s Experience

1960’s Development of Empirical Methods

1980’s Initial Mechanistic-Empirical Methods

1990’s NCRHP 1-37A M-E Design

2000’s Implementation of M-E Methods Perpetual Pavements
AASHO Road Test

• 1958 - 1960 near Ottawa, Illinois

• Soil uniform and representative of large portion of US

• 4 large and 2 smaller loops

• Variables included
  ▪ pavement thickness
  ▪ load magnitude
  ▪ environmental effects

• Introduced concept of serviceability (PSI)

• Forms basis of AASHTO Method
1993 AASHTO Design Equation
(Strictly Empirical - Based on AASHO Road Test)

\[
\log W_{18} = Z_R S_0 + 9.36 \log(SN+1) - 0.20 + \frac{\log \left( \frac{\Delta PSI}{4.2 - 1.5} \right)}{1094} + 2.32 \log M_R - 8.07
\]

- Main Inputs
  - Traffic
  - Reliability
  - Variability
  - Performance

Solve the Equation for Target Structural Number \( SN \)

Resilient Modulus of the subgrade soil
1993 AASHTO Structural Design Method

Determine Depths of individual pavement layers...

- Materials
  - Modulus & Structural Coef.
  - Drainage Coefficient

- Outputs
  - Structural Number
  - Computed Depths

\[ SN = a_1D_1 + a_2m_2D_2 + \ldots + a_n m_n D_n \]

...such that sum of all structural numbers \( SN \geq \text{Target} \)
What has changed since AASHO Road Test? & Where is the opportunity to optimize?

With the technological advancement, there are three major improvements since the AASHO Road test:

Better materials / HMA mixing methodology => Higher Moduli
– Effect: Higher Layer Coefficients ($a_1, a_2, a_3...$)

New technologies for Water-Resistant structural layers
– Effect: Higher Drainage Coefficients ($m_2, m_3...$)

Technologies for water-resistant subgrade with higher moduli
– Effect: Higher Resilient Modulus of subgrade ($M_R$)
NCAT Test: AC Modulus @ 68°F is 811K psi
S Coeff @ 811K psi = 0.54 (Extrapolated)

S Coeff recommended by AASHO Test at Elastic Modulus = 450K psi

AASHTO, 1993
1960’s AASHO Road Test recommended structural coefficient of 0.44 for asphalt pavement layers

Better quality materials and mix design methodologies, coupled with new nanotechnology can now improve the resilient moduli of layers.

- Alabama DoT takes LC for asphaltic layers as 0.54
- Washington State DoT assumes 0.50 as LC

Assuming higher values for LC simply means lower depth of layer to hit target SN.

With LC of 0.54, Alabama state saves about 18% on road construction cost.
Drainage Coefficients

Percent time the layer approaches saturation:

\[ P = \frac{(S + R)}{365} \times 100 \]

- \( P \) = \% time saturated
- \( S \) = days of spring thaw
- \( R \) = remaining days with rain if pavement will drain to 85\% in 24 hours, otherwise use days of rain times drainage time in days

With new technology waterproofing, this is not relevant any more.
New nanotechnology ensures waterproofing
Time Saturation < 1%, 95% water removed within 2 Hours
Drainage Coefficient = 1.35 to 1.40

<table>
<thead>
<tr>
<th>Quality</th>
<th>95% Water Removed</th>
<th>% Time Saturated</th>
<th></th>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&lt;1%</td>
<td>1 - 5%</td>
<td>5 - 25%</td>
<td>&gt;25%</td>
<td></td>
</tr>
<tr>
<td>Excellent</td>
<td>2 hours</td>
<td>1.40 – 1.35</td>
<td>1.35 – 1.30</td>
<td>1.30 – 1.20</td>
<td>1.20</td>
<td></td>
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<tr>
<td>Good</td>
<td>1 day</td>
<td>1.35 – 1.25</td>
<td>1.25 – 1.15</td>
<td>1.15 – 1.00</td>
<td>1.00</td>
<td></td>
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<tr>
<td>Fair</td>
<td>1 week</td>
<td>1.25 – 1.15</td>
<td>1.15 – 1.05</td>
<td>1.05 – 0.80</td>
<td>0.80</td>
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<tr>
<td>Poor</td>
<td>1 month</td>
<td>1.15 – 1.05</td>
<td>1.05 – 0.80</td>
<td>0.80 – 0.60</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>Very Poor</td>
<td>Never Drain</td>
<td>1.05 – 0.95</td>
<td>0.95 – 0.75</td>
<td>0.75 – 0.40</td>
<td>0.40</td>
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Effective Modulus of Subgrade

- Definition: an equivalent modulus that would result in the same damage if seasonal modulus values were actually used
- Uses AASHTO relative damage equation

\[ \mu_f = 1.18 \times 10^8 M_R^{-2.32} \]

- Finding \( M_{\text{eff}} \)
  - Find \( u_f \) for each season
  - Determine weighted average \( u_f \)
  - Find \( M_{\text{eff}} \) corresponding to \( u_f \)

New technology ensures dry subgrade \( M_R \) through all seasons.
If subgrade \( M_R = 10K \) psi (based on weighted average \( \mu_f \))
It is safe to take it as 20K psi with new technology
New Tech Highway Design:
With \( LC = 0.54 \), \( DC = 1.2-1.4 \) and Subgrade \( M_R = 20K \) psi

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<tbody>
<tr>
<td></td>
<td>DBM 100 mm WC 60 mm</td>
<td>DBM 60 mm WC 50 mm</td>
<td>DBM 80 mm WC 50 mm</td>
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<tr>
<td>Drainage Coefficient</td>
<td>1</td>
<td>1.2 1.3 1.4</td>
<td>1.2 1.3 1.4</td>
</tr>
<tr>
<td>Structural Number</td>
<td>5.19</td>
<td>5.27 5.62 5.92</td>
<td>5.78 6.17 6.56</td>
</tr>
<tr>
<td>Subgrade Modulus (psi)</td>
<td>10K</td>
<td>20K 20K 20K</td>
<td>20K 20K 20K</td>
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<tr>
<td>Equivalent MSA</td>
<td>40</td>
<td>230 380 574</td>
<td>475 790 1296</td>
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<tr>
<td>Times Improvement</td>
<td>6</td>
<td>10 14</td>
<td>12 20 32</td>
</tr>
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</table>
New Tech Highway Design: Zero Extra Cost

Standard Assumptions for Conventional design
Drainage Coefficient – 1
Subgrade Modulus = 10K psi

> 14 times improvement

New nanotechnology allows
Drainage Coefficient (DC) of 1.4
& Layer Coef of 0.54
$S_N = 5.92$, giving ESAL of 574 MSA
(@ Subgrade modulus = 20K psi)

ESAL : 40 MSA
Serviceability : 4.2 -> 2.0
Std Deviation : 0.44
Reliability : 95%

Reqd Structural Number
$S_N = 5.19$

Design Process with New Tech @ zero extra cost

ESAL : 574 MSA
Serviceability : 4.2 -> 2.0
Std Deviation : 0.44
Reliability : 95%

$S_N : 5.92$
Thank You