Pavement Design

- A highway pavement is a structure consisting of superimposed layers of processed materials above the natural soil subgrade. The primary function of a pavement is to distribute applied vehicle loads to the subgrade in the environment which it operates. It should do so minimizing distress and at an acceptable ride quality for its design life.

- A highway pavement should also be maintainable, minimize impact on users and businesses while maximizing accessibility, be safe or have an acceptable skid resistance, and minimize environmental and aesthetic impacts including noise pollution and light reflectance. All of these additional requirements should be met in the environment which it operates.
Pavement Design

- Placing an efficient, economical and effective pavement requires at least three important steps:
  - Accurate Assessment of Existing Conditions
    - Subgrade Support, Drainage, Environmental Conditions
    - Current Traffic and Future Traffic (Future Development)
    - Availability and Suitability of Materials (Specifications)
  - Selection of Proper Mix Type(s) & Materials (Construction)
  - Pavement Design - Layer and Thickness
    - Method verified academically
    - Method correlated/calibrated locally
Prior to 1962 designs were “locally” calibrated and highly subjective

- Post WWI Truck Traffic and ADT Tripled (1919-1929)
- Post WWII Truck Traffic and ADT Doubled Again (1945-1955)
- Rapid transportation expansion - Rapid transport expansion
- 1942 ushered in almost universal 18,000 lb. axle limits on "low pressure" pneumatic tires with 32,000 lb. tandem limits - war time recommendations became the standard — heavier axle loads on “softer” tires with tandem transports

AASHO in 1955 initiated a "Road Test" via the HRB (TRB) to construct, instrument and develop a road test resulting in engineered pavement design criteria

- The 1962 AASHO Road Test was modeled on a completed road test initiated by WASHO from 1952-1954 in southern Idaho
The AASHO Road Test was built, constructed, analyzed and deliverables developed (AASHO Design Guide) in 1962

- Constructed on a “green field” portion of the under construction Interstate 80 between Ottawa and LaSalle, IL, about 80 miles SW of Chicago
- 34-inch avg. rainfall, 25-in. avg. snow, 76 deg. avg. mean summer, 27 deg. avg. mean winter temperatures; multiple freeze-thaw w/ avg. frost depth 28-in.
- Glacial subgrade (a-6/a-7-6) 1-2 ft. depth soils on substratum of a-7-6 soils another 2 ft. thickness interspersed with sand/gravel lens
- Special Embankment (3-ft.) MDC of A-6 (Groups 9-13); PI~11 to 15; LL~27 to 32; 80%-85% -#200
- ONE climate zone, ONE subgrade, LIMITED variables, construction methods and vehicles representative of the 1950’s.
- Cost was approximately $127 million (ND’s share was $122,085!)
AASHO Road Test 1956-1960

Near Ottawa, Illinois

Road test determined relationship between axle load and road damage

\[
\frac{W_x}{W_{18}} = \left[ \frac{L_{18} + L_{2x}}{L_x + L_{2x}} \right]^{4.79} \left[ \frac{10^{G/\beta_x}}{10^{G/\beta_{18}}} \right] \left[ L_{2x} \right]^{4.33}
\]
Pavement Response to Load
Strain at the Bottom of HMA
Pavement Deflection
Relationship of Load to Damage

- Deflection $d$ is proportional to axle group weight $W$
  \[ d \propto W \]

- Damage $D$ is proportional to $4^{th}$ power of deflection $d$
  \[ D \propto d^4 \]
  or \[ D \propto W^4 \]
4th Power Damage Relationship

Damage versus Axle Load

Damage (ESALS) vs. Single Axle Weight (kips)
Thickness Design Methods

- AASHTO Thickness Design
  - Used by most state DOTs
  - Based on structural number concept
- AASHTO MEP Design Guide
  - Future design method closing on ratification
  - Based on mechanistic design principles
- Asphalt Institute
  - SW-2
  - For pavements on highways, airports, HWL
Pavement Design

- Basic AASHTO 93/98 Pavement Design Guide
  - Determine the desired Terminal Serviceability ($p_t$)
  - Convert traffic volumes to number of Equivalent 18-kip Single Axle Loads (ESAL)
  - Determine the Structural Number ($SN$)
  - Determine Layer Coefficients ($a_i$)
  - Determine Moisture damage coefficients ($M_i$)
  - Determine Reliability and Standard Deviate ($S_0$, $Z_R$)
  - Solve layer thickness equations for individual layer thickness
\[
\log_{10}(W_{18}) = 9.36 \times \log_{10}(SV + 1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta P_{SI}}{4.2 - 1.5}\right)}{0.40 + \log_{10}(M_{d, x})} + 2.32 \times \log_{10}(M_{d, x}) - 8.07
\]

where:

- \( W_{18} \) = predicted number of 80 kN (18,000 lb.) ESALs
- \( Z_R \) = standard normal deviate
- \( S_0 \) = combined standard error of the traffic prediction and performance prediction
- \( S_N \) = Structural Number (an index that is indicative of the total pavement thickness required)
  
  \[ S_N = \sum a_i D_i + a_2 D_2 m_2 + a_3 D_3 m_3 + \ldots \]
  
  \( a_i \) = ith layer coefficient
  \( D_i \) = ith layer thickness (inches)
  \( m_i \) = ith layer drainage coefficient
- \( \Delta P_{SI} \) = difference between the initial design serviceability index, \( p_0 \), and the design terminal serviceability index, \( p_t \)
- \( M_R \) = subgrade resilient modulus (in psi)
Pavement Design
Serviceability

- Based on Present Serviceability Rating (PSR) of original AASHO Road Test
- Subjective rating by individual/panel
  - Initial/Post Construction
  - Through the life of pavement and effects of distress
- $0 < \text{PSR} < 5$
- $\text{PSR} < 2.5$ Poor or Unacceptable
- AASHTO 93 modified to Present Serviceability Index (PSI)
  - Correlated to physical measurements
  - Attempt to include distress factors as well as ride quality
  - Still empirical
Pavement Design
Serviceability

Figure 1: Concept of pavement performance using Present Serviceability Index (PSI). (Hveem and Carmany, 1948[2])
Pavement Design
Structural Number Concept

- Total structural number based on
  - number of equivalent loads over design period
  - subgrade support

- Structural number coefficients based on
  - Materials Type
  - Materials Condition
    - May be reduced for existing pavements with distress

\[ SN = a_1D_1 + a_2D_2M_2 + a_3D_3M_3 \]

where:
- \( a_1, a_2, a_3 \) = structural-layer coefficients of the wearing surface, base, and subbase layers, respectively,
- \( D_1, D_2, D_3 \) = thickness of the wearing surface, base, and subbase layers in inches, respectively, and
- \( M_2, M_3 \) = drainage coefficients for the base and subbase, respectively.
Pavement Design
Structural Number Concept

4"

9"

16"
Pavement Design
Structural Number Concept
Pavement Design
Structural Number Concept

4"

9"

16"

.44

.14

.11

= 1.76

= 1.26

= 1.76

= 4.78
Pavement Design

Structural Number Concept

- The structural coefficient of a layer represents the relative strength of materials built into that layer.

<table>
<thead>
<tr>
<th>Asphalt Concrete Structural Coefficients (αj)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Items 424, 442, 443, 446, 448, 826, 857, 859, 874 – AC Surface</td>
<td>0.43</td>
</tr>
<tr>
<td>Items 442, 443, 446, 448, 826, 857 – AC Intermed.</td>
<td>0.43</td>
</tr>
<tr>
<td>Items 301, 302 AC Base Course.</td>
<td>0.36</td>
</tr>
<tr>
<td>Item 304 – Aggregate Base</td>
<td>0.14</td>
</tr>
<tr>
<td>Item 320 – Rubblized Concrete</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Ohio DOT Structural Coefficients (Example Only)
Pavement Design Reliability

“The reliability of the pavement design-performance process is the probability that a pavement section designed using the process will perform satisfactorily over the traffic and environmental conditions for the design period.” (AASHTO, 1993[1])

AASHTO 93 Utilizes the Reliability concept to account for design uncertainty. Reliability consists of two parts:

1. $Z_R$ or **Standard Normal Deviate**: Desired probability of exceedance or a “miss”. 5% $Z_R$ = 95% Reliability

2. $S_O$ or **Combined Standard Error**: Error in Traffic Prediction and/or Performance Prediction


Pavement Design Reliability

Table 1. Suggested Levels of Reliability for Various Functional Classifications (from AASHTO, 1993[11])

<table>
<thead>
<tr>
<th>Functional Classification</th>
<th>Recommended Level of Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Urban</td>
</tr>
<tr>
<td>Interstate and Other Freeways</td>
<td>85 – 99.9</td>
</tr>
<tr>
<td>Principal Arterials</td>
<td>80 – 99</td>
</tr>
<tr>
<td>Collectors</td>
<td>80 – 95</td>
</tr>
<tr>
<td>Local</td>
<td>50 – 80</td>
</tr>
</tbody>
</table>

Typical values of So used are 0.40 to 0.50 for flexible pavements and 0.35 to 0.40 for rigid pavements.
Pavement Design
Use AASHTO 93 Wisely -

- Considerations AASHO Road Test - Significant Limitations
  - Specific & Limited Materials, Specific Environment
  - AASHO Road Test was a 2-year test....results projected for 20-year design life
  - All loading was identical and timely for 1955...no mixed loading, no radial tires

- When you utilize AASHTO 93, you have slept with AASHO Road Test
  - Extrapolating other subgrade support values to far different soils
  - Assuming the loading in AASHO road test can be extrapolated with 18k ESAL
  - Assuming similar environmental effects
Areas of Special Interest

- Structural Coefficients
  - The NDDOT has 50+ years of calibration on NDDOT mixes and performance on the SHS
  - New Materials?

- Subgrade Support
  - Resilient Modulus ($M_r$) and Historical Significance with R-Value/CBR
  - Seasonal Impacts or “It’s hard to describe -30 deg. F. unless you’ve been there”

- Moisture & Drainage
  - A lower $M_i$ with AASHTO 93 = More Thickness....not necessarily More Strength
  - The NDDOT has 50+ years of performance (pavement management system), soil data and experience with ND’s varied soils

- Traffic
  - Accurate traffic data collection and classification a must
  - The $S_0$ has proven to be highly variable on historical studies (e.g. Alabama/NCAT, et. al.)

Pavement Design
Use AASHTO 93 Wisely -
Pavement Design

Use AASHTO 93 *Wisely* - Case in Point

Spring Load Restrictions: Moisture in base and subgrade freezes and thaws top-down, causing moisture to be drawn upward and trapped during spring thaw.

- **Summer**: Moist unfrozen
- **Fall**: Moist freezing
- **Winter**: Fully frozen
- **Spring**: Thawing weak
Pavement Design
PaveXpress - A Design Tool

- Functional
- AASHTO 93/98 Design Tool for Flexible & Rigid Pavements
- A scoping tool
- A “go to” for Pavement Resources
Introduction
Welcome to PaveXpress, a scoping tool to help you create simplified pavement designs while taking into account key engineering inputs.

Resources
PaveXpress includes access to resources such as design guides from state DOTs and industry associations so you can build formal designs from its simple recommendations.

Get Started
Click on the button below to launch the PaveXpress Scoping Tool and start creating your own designs, with options for both flexible and rigid pavement construction.
Pavement Design
PaveXpress - A Design Tool

Resources
The following resources accompany the PaveXpress Simplified Pavement Design Tool

- State DOTs
- State Asphalt Pavement Associations
- Parking Lot Design Guides
### Project Information

<table>
<thead>
<tr>
<th>Location, Roadway Classification and Pavement Type</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Project Name</strong></td>
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<tr>
<td><strong>Project Description</strong></td>
</tr>
<tr>
<td><strong>Estimated Completion Year</strong></td>
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<table>
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<td><strong>State</strong></td>
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<tr>
<td><strong>Pavement Type</strong></td>
</tr>
</tbody>
</table>
DAPA Annual Meeting

Traffic Data

- **Method of Determining ESALs:**
  - Using AADT
  - Design ESALs

- **Completion Year Traffic (vehicles):** 43,800
- **Load Equivalency Factor:** 0.1181
- **Completion Year ESALs:** 52,000
- **Design Period:** 30 Years
- **ESAL Growth Rate:** 2%

**Total Design ESALs (W1):** 2,936,000
### DAPA Annual Meeting

<table>
<thead>
<tr>
<th>Project Information</th>
<th>1</th>
<th>Location, Roadway Classification and Pavement Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Parameters</td>
<td>2</td>
<td>Specific Design Variables</td>
</tr>
<tr>
<td>Traffic Data</td>
<td>3</td>
<td>Traffic and Loading Data</td>
</tr>
<tr>
<td>Pavement Structure</td>
<td>4</td>
<td>Pavement Layer(s) Information</td>
</tr>
<tr>
<td>Pavement Sub-Structure</td>
<td>5</td>
<td>Base, Sub-Base and Subgrade</td>
</tr>
</tbody>
</table>

#### Pavement Structure (Flexible) (Asphalt)

- **Use Multiple Lifts:** No
- **Layer Coefficient (a):** 0.44
- **Drainage Coefficient (m):** 1
- **Minimum Thickness:** 2 in

![Asphalt Layer Diagram]
### DAPA Annual Meeting

#### Project Information
- Location, Roadway Classification and Pavement Type

#### Design Parameters
- Specific Design Variables

#### Traffic Data
- Traffic and Loading Data

#### Pavement Structure
- Pavement Layers Information

#### Pavement Sub-Structure
- Base, Sub-Base and Subgrade

#### Calculated Design

---

### Base Layers

<table>
<thead>
<tr>
<th>Layer Type</th>
<th>Layer Coef.</th>
<th>Drainage Coef.</th>
<th>Thickness</th>
<th>Resilient Mod</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate Base</td>
<td>0.115</td>
<td>1</td>
<td>6 in.</td>
<td>30000</td>
<td></td>
</tr>
<tr>
<td>Aggregate Subbase</td>
<td>0.065</td>
<td>1</td>
<td>2 in.</td>
<td>12000</td>
<td></td>
</tr>
</tbody>
</table>

---

### Subgrade

- Resilient Modulus (M_r): 15000 psi

- **Calculate VR**

---

**Asphalt Layer**

**Base Layers**

**Subgrade**
DAPA Annual Meeting

1 Project Information
   Location, Roadway Classification and Pavement Type

2 Design Parameters
   Specific Design Variables

3 Traffic Data
   Traffic and Loading Data

4 Pavement Structure
   Pavement Layer Information

5 Pavement Sub-Structure
   Base, Sub-Base and Subgrade

Calculated Design

Scoped Design

Required minimum design SN: 3.30

Layer Thicknesses (in)

- Surface: 6.00
- Aggregate Base: 8.60
- Aggregate Subbase: 3.00

Total SN: 3.76

Design Notes

Resources

Dakota Asphalt Pavement Association
<table>
<thead>
<tr>
<th>Name</th>
<th>Created</th>
<th>Last Update</th>
<th>Actions</th>
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<tr>
<td>DAPA Annual Meeting</td>
<td>Jan 07 2015</td>
<td>Mar 30 2015</td>
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About

The PaveXpress Scoping Tool is a simplified pavement design tool to help engineers and pavement decision-makers analyze pavement structures and create technically sound structural designs. Some of the tool's key features:

- Accessible via web and mobile
- Free, no cost to use
- Based on AASHTO pavement design equations
- User-friendly
- Share, save, and print project designs
- Interactive help and resource links

The PaveXpress Scoping Tool was developed by Pavia Systems, with generous sponsorship from the National Asphalt Pavement Association (http://www.asphaltpavement.org), the Asphalt Pavement Alliance (http://www.asphaltroads.org), and a consortium of state asphalt pavement associations.
Pavement Design

- PaveXpress soon to be available seamlessly on revamped DAPA web page
- Adding other Pavement Resources to DAPA web page
  - Parking Lot Model Designs
  - Mixture and Binder Selection Guides
  - Bike Path and Pedestrian Path Recommendations
  - Asphalt Contracting Do’s and Don’ts
  - Quantity Take-off Tools
  - Compaction/PaveCool Tools
  - Expanded Bid Letting Announcements
  - Project Profiles and New Technology White Papers
  - Other Pavement and Instructional Resources

Expected Roll Out May 1, 2015
Pavement Design

Questions???

Thank you!