Pavement Design Basics

Darlene Goehl, P.E.
Texas A&M Transportation Institute

2018 Transportation Short Course
October 16, 2018
Overview

- History of Pavement Design
  3-6
- Rigid Pavement Design
  7-10
- Flexible Pavement Design
  11-14
- Pavement and Material Evaluation
  15-32
- Pavement Design Report
  33-34
History

- TxDOT established 100+ years ago
- Pavement design largely concerned with protecting the subgrade until the end of WWII
- Initiation of highway road tests following WWII
- AASHO develops relationship between repetitive axle loads and pavement damage/serviceability
- AASHO Empirical design is developed based on Road Test; formalized in early 1970’s.
History

• TxDOT initializes research into developing own empirical flexible design system early 1970s into 1980s.
• FPS-19 introduced early 1990s using material moduli and elastic layer theory
• AASHTO ME design released 2006
• TxME development continues . . .
**Pavement**

- **Pavement Structure.** Combination of surface course and base course placed on a subgrade to support the traffic load and distribute it to the roadbed.

- The primary structural difference between a rigid and flexible pavement is the manner in which each type of pavement distributes traffic loads over the subgrade.
Rigid vs. Flexible Pavement

- A rigid pavement has a very high stiffness and distributes loads over a relatively wide area of subgrade –
  - a major portion of the structural capacity is contributed by the slab itself.
- Flexible pavement’s load carrying capacity is dependent on the layers.
  - load-distributing characteristics of the layered system is critical
Overview of Rigid Pavement Thickness Design

• TxCRCP-ME Design Program for CRCP Developed under department research project 0-5832, “Develop Mechanistic/Empirical Design for CRCP.
  – Uses Punchouts as main distress

• AASHTO Rigid Pavement Design Procedure for CPCD
  – The 1993 AASHTO Guide for Design of Pavement Structures

![Construction site image]
Overview of Rigid Pavement Subbase Design

• Base layer combinations for concrete slab support (CRCP or CPCD):
  – 4 in. of hot-mix asphalt (HMA) or asphalt treated base (ATB), or
  – a minimum 1 in. hot-mix asphalt bond breaker over 6 in. of a cement treated base

These are non-erodible subbases. TxDOT chose this strategy instead of requiring subbase drainage designs.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Usual Input</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Life (years)</td>
<td>30</td>
<td></td>
<td>May lower depending on Roadway.</td>
</tr>
<tr>
<td>Punchouts per Mile</td>
<td>10</td>
<td></td>
<td>TxCRCP-ME program will evaluate depth entered to determine if it is adequate, however this may be a trial and error process to determine the minimum thickness required.</td>
</tr>
<tr>
<td>Thickness of Concrete</td>
<td>7&quot; to 15&quot;</td>
<td>Estimated depth</td>
<td></td>
</tr>
<tr>
<td>Number of Lanes</td>
<td>in One Direction</td>
<td></td>
<td>Refer to Typical section</td>
</tr>
<tr>
<td>Design Traffic</td>
<td>One-Way total 18-kip ESALs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Classification of Subgrade</td>
<td>GW, GP, SW, SP, GM, SM, GC, SC, ML, OL, MH, CL, CH, OH</td>
<td>Determine from subgrade testing</td>
<td>Refer to Unified Soil Classification System</td>
</tr>
<tr>
<td>Base Layer Requirements</td>
<td>Asphalt treated base (ATB), hot mix (HMA) or cement treated base (CTB)</td>
<td>Select most cost effective base layer</td>
<td></td>
</tr>
<tr>
<td>Modulus of Base Layer (ksi)</td>
<td>100-700</td>
<td>HMA or ATB use 400</td>
<td>CTB use 500</td>
</tr>
<tr>
<td>Parameter</td>
<td>Range</td>
<td>Usual Input</td>
<td>Comments</td>
</tr>
<tr>
<td>-----------------------------------------------------</td>
<td>----------------</td>
<td>-------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Design Life (years)</td>
<td></td>
<td>30</td>
<td>AASHTO equation can be used with trial and error process to determine depth or depending on equation calculator program may be able to calculate thickness needed.</td>
</tr>
<tr>
<td>Thickness of Concrete</td>
<td>7” to 15”</td>
<td>Estimated depth</td>
<td></td>
</tr>
<tr>
<td>28-day Conc. Modulus of Rupture, psi (MOR)</td>
<td>620 - 680</td>
<td>620</td>
<td></td>
</tr>
<tr>
<td>Reliability, %</td>
<td>90% - 95%</td>
<td>90% or 95%</td>
<td>Use 90% when &lt;= 5 M ESALs Use 95% when &gt; 5 M ESALs</td>
</tr>
<tr>
<td>Overall Standard Deviation</td>
<td>0.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load Transfer Coefficient (J)</td>
<td>2.5 – 2.9</td>
<td>2.9</td>
<td>JCP with tied concrete shoulder</td>
</tr>
<tr>
<td>28-day Concrete Elastic Modulus, psi</td>
<td>5,000,000</td>
<td>Initial: 4.5</td>
<td></td>
</tr>
<tr>
<td>Serviceability Indices</td>
<td></td>
<td>Terminal: 2.5</td>
<td></td>
</tr>
<tr>
<td>Design Traffic</td>
<td>One-Way 18-kip ESALs</td>
<td></td>
<td>Can apply lane distribution factor (LDF) when total lanes are &gt;4 lanes. For 6 lanes, LDF=0.7, &gt;=8 lanes, LDF=0.6</td>
</tr>
<tr>
<td>Effective Modulus of Subgrade Reaction, psi (k)</td>
<td>300 - 800</td>
<td>300</td>
<td>Assuming 4” of ACP or 6” of CTB + 1” ACP</td>
</tr>
<tr>
<td>Drainage Coefficient</td>
<td></td>
<td></td>
<td>Select Drainage Coefficient based on annual rainfall.</td>
</tr>
<tr>
<td>Annual Rainfall (in.)</td>
<td>58-50</td>
<td>0.91-0.95</td>
<td></td>
</tr>
<tr>
<td></td>
<td>48-40</td>
<td>0.96-1.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>38-30</td>
<td>1.01-1.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>28-20</td>
<td>1.06-1.10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18-8</td>
<td>1.11-1.16</td>
<td></td>
</tr>
</tbody>
</table>
Overview of Texas Flexible Pavement Design Process

- **FWD Data**
- **Design Info**
- **MODULUS**
- **FPS 21**
  - **Texas Triaxial Check** (Overloads on thin)
  - **Mechanistic Check** (Rutting and Cracking)

Diagram:
- **HMA**
- **Base**
- **Subgrade**
  - $h_1$
  - $h_2$
Flexible Pavement Loading and Response

- **Deflection under Load**
- **Stress Load/Area (σ)**
- **Strain Deformation (ε)**

**Diagram:**
- **Surface** \( E_1, v_1 \)
- **Base** \( E_2, v_2 \)
- **Subgrade** \( E_3, v_3 \)

- **Total Load** \( P \)
- **Radius** \( r \)

- **Original Surface** \( W_1 \)
- **Deflected Surface** \( W_2 \)

- **12”**

**Equations:**
- **Tension**
- **Compression**
Service Histories of Several Trial Designs

Serviceability Index, SI

Min. acceptable SI

Required analysis period or design life

Performance period

Trial B

Trial A

Trial A1

Trial A2

TA

Td
Failure & Serviceability

• Structural
  – Material fails to point can no longer function to distribute loading.
  – May require complete rehabilitation

• Functional
  – Loss of Ride
  – Loss of Friction
  – May only require repair of riding surface

• Serviceability
  – Can be correlated to pavement roughness
    • Initial should be a good smooth ride
    • Final will be rough ride
Available Pavement Evaluation Tools

- **FWD** structural strength, including subgrade
- **GPR** thickness variability; identify major problem areas; sampling locations
- **DCP** in-site strengths of lower layers
- **TPAD** structural strength of concrete pavement, weak subgrades, poor load transfer
- **LiDAR** ditch depth; horizontal and longitudinal slopes; drainage evaluations
GPR data
TPAD DATA

Deflections
Sensors 1 and 2
Falling Weight Deflectometer - FWD
Stress Distribution and Deflections Under FWD Loading
Raw Deflection Data Indices

Indices:
- $W_1 \rightarrow \text{Overall} \, \text{Pavement Stiffness}$
- $W_1 - W_2 (\text{SCI}) \rightarrow \text{Top 8”}$
- $W_2 - W_3 (\text{BCI}) \rightarrow 8” \text{ to 16”}$
- $W_7 \rightarrow \text{Subgrade} \, \text{> 48”}$

Normalized to 9 kip Drop Load
Interpreting Relative Deflection Bowl Shape

A  Good Base/Good Subgrade
B  Bad Base/Good Subgrade
C  Good Base/Bad Subgrade
Subgrade Evaluation

  - USDA soil information webpage
- Sample and Test Subgrade

- 0-6 in Sandy clay  PI 6  M 10.2%
- 6-18 in Brown clay  PI 32  M 25.8%
- 18-30 in Tan clay  PI 52  M 32.3%
Site Coring validating defects - additional testing
Subgrade and Existing Pavement Layers

- **FPS**
  - Priority should be to use the project-specific backcalculated subgrade modulus.
  - Defaults by county are available in the FPS design program.
  - Typical Design Modulus range is 8-20 ksi.
  - Typical Poisson’s Ratio range is 0.35-0.45
    - Wetter or more highly plastic materials warrant higher Poisson ratios.
  - New location construction
    - deflection testing on an adjacent highway, or
    - intersecting highways can provide data for backcalculation.
    - Alternatively, elastic modulus correlations to field or laboratory derived CBR or the program default may be used.
## Stabilized Subgrade

<table>
<thead>
<tr>
<th>Material Type</th>
<th>2014 Spec</th>
<th>Design Modulus</th>
<th>Poisson’s Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime or Cement Treated Subgrade</td>
<td>Item 260, 275</td>
<td>30 - 45 ksi</td>
<td>0.30</td>
</tr>
<tr>
<td>Emulsified Asphalt Treatment (Subgrade)</td>
<td>Item 314, various special specs</td>
<td>15 - 25 ksi</td>
<td>0.35</td>
</tr>
<tr>
<td>Material Type</td>
<td>2014 Spec</td>
<td>Design Modulus</td>
<td>Poisson’s Ratio</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>----------------------------</td>
<td>-------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Asphalt Treatment (base)</td>
<td>Item 292</td>
<td>250 - 400 ksi</td>
<td>0.35</td>
</tr>
<tr>
<td>Emulsified Asphalt Treatment (Base)</td>
<td>Item 314, various OTU special specs</td>
<td>50 - 250 ksi</td>
<td>0.35</td>
</tr>
<tr>
<td>Flexible Base</td>
<td>Item 247</td>
<td>If historic data not available, modulus shall be no greater than 3-4 times the subgrade modulus or use FPS default, whichever is lower. Typical range 40-70 ksi.</td>
<td>0.35</td>
</tr>
<tr>
<td>Lime Treated Base</td>
<td>Item 260, 263</td>
<td>60 - 75 ksi</td>
<td>0.30 - 0.35</td>
</tr>
<tr>
<td>Cement Treated Base</td>
<td>Item 275, 276</td>
<td>80 - 150 ksi</td>
<td>0.25 - 0.30</td>
</tr>
<tr>
<td>Fly Ash or Lime-Fly Ash Treated Base</td>
<td>Item 265</td>
<td>60 - 75 ksi</td>
<td>0.30</td>
</tr>
<tr>
<td>Material Description</td>
<td>Modulus Value</td>
<td>Poison’s Ratio</td>
<td>Cohesiometer Value for MT check</td>
</tr>
<tr>
<td>----------------------------------------------------------</td>
<td>----------------------------------------------------</td>
<td>----------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td><strong>Existing Material</strong> (not reworked, including Subgrade)</td>
<td>500 ksi or Back-calculated from FWD data,</td>
<td>0.35</td>
<td>na</td>
</tr>
<tr>
<td><strong>Existing Pavement</strong> – Scarified, Reshaped and Compacted</td>
<td>~3 times the subgrade modulus</td>
<td>0.35</td>
<td>na</td>
</tr>
<tr>
<td><strong>Stabilize Blend of Existing Pavement &amp; Subgrade</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mostly granular base (75% or more base)</td>
<td>100 ksi</td>
<td>0.3</td>
<td>800</td>
</tr>
<tr>
<td>blend subgrade &amp; base (50% to 75% base)</td>
<td>65 ksi</td>
<td>0.3</td>
<td>650</td>
</tr>
<tr>
<td>mostly subgrade (&lt;50% base)</td>
<td>35 ksi</td>
<td>0.35</td>
<td>300</td>
</tr>
<tr>
<td><strong>New Flexible Base over Stabilized Subbase</strong> (mostly granular base)</td>
<td>70 ksi</td>
<td>0.35</td>
<td>na</td>
</tr>
<tr>
<td>1st 6” lift of new flexible base (when multiple lifts are required)</td>
<td>~3 times the subgrade modulus, but not &gt; Districts default modulus value (40-70 ksi)</td>
<td>0.35</td>
<td>na</td>
</tr>
</tbody>
</table>
Sampling Projects for FDR or CIR

- HMA Sections > 2 ins
  Keep HMA and Base Samples Separate
TxDOT new Small Sample Mix Design procedure

“Traditional” vs “Small” Sample Sizes

- Traditional sample sizes
  - 110 pounds per design
- Small samples
  - 15 pounds per design
- Oftentimes 4 to 8 different mixtures under consideration
- Complete lab design in 5 working days
<table>
<thead>
<tr>
<th>Material Type</th>
<th>2014 Spec</th>
<th>Design Modulus</th>
<th>Poisson’s Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seal Coat (nonstructural layer)</td>
<td>Item 316</td>
<td>200 - 250 ksi</td>
<td>0.35</td>
</tr>
<tr>
<td>Limestone Rock Asphalt Pavement</td>
<td>Item 330</td>
<td>200 - 350 ksi</td>
<td>0.35</td>
</tr>
<tr>
<td>Hot-Mix Cold-Laid ACP</td>
<td>Item 334</td>
<td>300 - 400 ksi</td>
<td>0.35</td>
</tr>
<tr>
<td>Dense-Graded Hot-Mix Asphalt</td>
<td>Item 340, 341</td>
<td>Combined HMA thickness:</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≤ 4 in. use 500 ksi</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 4.0 in. use 650 ksi</td>
<td></td>
</tr>
<tr>
<td>Permeable Friction Course</td>
<td>Item 342</td>
<td>300 ksi</td>
<td>0.35</td>
</tr>
<tr>
<td>Superpave Mixtures</td>
<td>Item 344</td>
<td>Combined HMA thickness:</td>
<td>0.35</td>
</tr>
<tr>
<td></td>
<td></td>
<td>≤ 4.0 in. use 650 ksi</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 in. &lt; T ≤ 6 in. use 750 ksi</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; 6.0 in. use 850 ksi</td>
<td></td>
</tr>
<tr>
<td>Stone-Matrix Asphalt</td>
<td>Item 346</td>
<td>Same as Item 344</td>
<td>0.35</td>
</tr>
</tbody>
</table>
**THIN MIXES**

- 30% Cost savings over traditional mixes - lifts of 1 inch or less
- Must pass Rutting (HWTT) and Cracking (OT) performance tests
- Min 6% PG 76-22  SAC A Rock, 100% passing 3/8”  NO RAP or RAS
Pavement Design Report – Supporting Documentation

• Background Material
  – As-Built PS&E
  – SiteManager Construction Records
  – Maintenance History
  – PMIS data
  – 4 year Plan scope of work
  – Traffic Data
  – Previous Pavement Design Reports

• Drainage analysis
• Design exceptions and approvals
• Document Assumptions
• Existing Material testing Reports
• Core Report
• Life-cycle cost analysis
• PG binder selection criteria
• Surface Aggregate Selection Form 2088

• Traffic Data
• Results of NDT to characterize the existing structural condition
  – Falling Weight Deflectometer (FWD)
    • MODULUS, including the backcalculation summary
  – TPAD
  – Ground Penetrating Radar (GPR)

• Soils Report
  – Material Description: Tex 141-E, 142-E
  – PI: Tex 104-6-E
  – Sulfate Content: Tex-145-E, Tex-146-E
  – Organic Content, Tex-148-E
  – PVR: Tex-124-E

• Material Designs
  – Treatment: Tex 120-E, 121-E, 127-E, 122-E

• Design Program Inputs and Results
  – FPS 21 summary,
    • modified Texas Triaxial check,
    • mechanistic checks,
    • stress analysis, etc.,
  – Alternate pavement design
    • AASHTO (DARWin® 3.1) design summary for CPCD rigid pavements.
    • TxCRCP-ME Design summary for CRCP rigid pavements.
• Clearly define the pavement layers
  – Description, thickness, and materials with estimate rates (if applicable)
    • Note: An underseal, Prime Coat, etc. will not be modelled in the design software. It needs to be shown on the summary and proposed typical section, don’t assume the designer knows that it is needed.
  – Controlling specification item for each layer

• Proposed Typical Section
  – Changes within the limits of the project (more than one typical section)
    • Frontage Roads vs. Mainlanes
    • Cross overs and intersections
    • Widening details
    • Stage Construction and detours.
    • Undercut areas or Soil mitigation areas (include details for replacement or treated materials)
    • Include special details such as widening, hot mix tapers, stage construction details

• Summary Cost Analysis
  – Comparison of alternates considered
  – Life cycle cost analysis
Questions