• Pavement design is an “a priori” process.

The new pavement will be built in the future, on subgrades often not yet exposed or accessible; using materials not yet manufactured from sources not yet identified; by a contractor who submitted the successful "low dollar" bid, employing unidentified personnel and procedures under climatic conditions that are frequently less than ideal.
Historical Overview of Pavement Design
Bates Road Test

- In 1920, Illinois passed a $200 million bond issue to build 9000 miles of paved roads
- To determine the best paving material, they built sections of brick, asphalt, and concrete
- Developed thickness design procedures and chose concrete for the Illinois pavements

Old WWI Army trucks with 9000# wheel loads
1921-23 Pittsburgh Road Test

- Pittsburgh Steel conducted tests in Pittsburgh, CA on plain and reinforced pavements.
- Hoped to prove that reinforced concrete was better.
Additional Road Tests

• Maryland Road Test
  – Set up on existing concrete pavement
  – Set up between truckers and railroad operators to see who was paying their fair share of taxes.

• WASHO Road Test
  – All new asphalt pavements
AASHO Road Test (1958-1960)

- Third Large Scale Road Test
  - Maryland Road Test (1950-51)
    Rigid Pavements Only
  - WASHOO Road Test (1952-54)
    Flexible Pavements only

- Include both Rigid and Flexible Designs

- Include a wide range of axle loads and pavement cross-sections
Purpose of the AASHO Road Test

• Determine relationships between axle loading (type and magnitude) and pavement performance.
  – To explain performance measurements in terms of design factors.
  – To explain capability measurements in terms of design factors.
  – To determine a correlation between the various measurements of performance and capability.
  – Determine equitable cost allocation tables.
AASHO Test Traffic

- Started Nov. 1958
- Ended Dec. 1960
- Loops 3-6:
  - 6 veh/lane
  - 10 veh/lane (Jan '60)
- Operation
  - 18 hr. 40 min.
  - 6 days/wk
- Total Loads
  - 1,114,000 Applications
  - Avg. ESAL - 6.2 million
  - Max ESAL - 10 million (Flex)

Figure 22. Typical test vehicle axle loadings.
Serviceability

- the pavement’s ability to serve the type of traffic (automobiles and trucks) that use the facility
REGULAR MIXED TRAFFIC

Equivalent Number of 18k Single Axle Loads
Perspective

• 1960 – Completion of Road Test Experiment
• 1961-62 Interim Guide for the Design of Rigid and Flexible Pavements
• 1972 Interim Guide for the Design of Pavements
• 1981 Revised Chapter III on Portland Cement Concrete Pavement Design
• 1986 Guide for the Design of Pavement Structures
• 1993 Revised Overlay Design Procedures
• 1998 Supplement to Concrete Design Procedures
1972 AASHTO Design Inputs

• Loadings in ESAL,s
• Initial and Terminal Serviceability  
  (Preset in GA)
• Concrete Flexural Strength  
  (working stress of 450 psi in GA)
• Concrete Modulus of Elasticity
• Support Value, k factor
• Load Transfer Coefficient  
  (Preset in GA)
1962 Rigid Pavement Design Equation (Georgia)

\[
\begin{align*}
\text{Log(ESAL)} & = 7.35 \times \log(D + 1) - 0.06 - \frac{0.1761}{1 + \frac{1.624 \times 10^7}{(D + 1)^{8.46}}} \\
& + (4.22 - 0.32p_t) \times \log \left[ \frac{f'_c}{(215.63 \times J)} \right] \\
& + \left[ \frac{D^{0.75} - 1.132}{D^{0.75} - \frac{18.42}{(E_c / k)^{0.25}}} \right]
\end{align*}
\]

Preset at 3.42

(690) preset
1993 AASHTO Additional Design Inputs

- Drainage Factor
- Reliability Factor
- Overall Deviation
- Edge Support
1993 Rigid Pavement Design Equation

\[ \text{Log}(\text{ESALs}) = Z_R \cdot s_o + 7.35 \cdot \text{Log}(D + 1) - 0.06 + \left(4.22 - 0.32 \cdot p_t\right) \cdot \text{Log} \left[ S'_c \cdot C_d \cdot \left[D^{0.75} - 1.132\right] \right] \]

\[ \text{Change in Serviceability} = \text{Log} \left[ \frac{\Delta \text{PSI}}{4.5 - 1.5} \right] \cdot \left[1 + \frac{1.624 \times 10^7}{(D + 1)^{8.46}}\right] \]

- Standard Normal Deviate
- Overall Standard Deviation
- Depth
- Terminal Serviceability
- Modulus of Rupture
- Drainage Coefficient
- Load Transfer
- Modulus of Elasticity
- Modulus of Subgrade Reaction

- Terminal Serviceability
- Overall Standard Deviation
- Depth
- Standard Normal Deviate
- Load Transfer
- Modulus of Elasticity
- Modulus of Subgrade Reaction

- Log(S'c * Cd * [D^{0.75} - 1.132])
- \[\frac{\Delta \text{PSI}}{4.5 - 1.5}\]
- \[1 + \frac{1.624 \times 10^7}{(D + 1)^{8.46}}\]
DESIGN FEATURES OF CONCRETE PAVEMENTS (Until mid 70’s)

- 9 INCH or 10 INCH THICKNESS
- ERODIBLE BASES
- UNDOWELLED JOINTS
- LONG SLAB LENGHTS (30ft)
- HOT POUR JOINT SEALS
- ASPHALT SHOULDERs
I-475

- OPENED TO TRAFFIC 1966/1967
- 9 INCH THICK PCC
- NO DOWELS, 30 FT JOINT SPACING
- SOIL/ BIT STAB. BASE
- DESIGNED FOR 3.25 MILLION ESAL’S
- CARRIED ±15 MILLION at 1st CPR IN 1980. (± 50 MILLION TOTAL)
I-285
From I-20 to Chamblee-Tucker Road

- Opened to Traffic 1967/1968
- 10 inches Thickness
- No dowels. 30 ft joint spacing
- Inside lane added 1981
- Design Loads 6 million ESAL’s
- CPR in 1981 at 23 million ESAL’s
- Current est. ESAL’s 140 million
PCC PAVEMENT FAULTING PERFORMANCE
Georgia

A - Bituminous Stabilized Base, FI=0.285(T)^0.453
B - Cement Stabilized GAB, FI=0.216(T)^0.459
CONCRETE PAVEMENT DESIGNS (SINCE MID 70’S)

• NON-ERODIBLE BASE
• DOWELLED JOINTS
• SHORTER JOINT SPACING
• TIED CONCRETE SHOULDERS or WIDENED LANE
• EFFECTIVE JOINT SEALS
PCC PAVINGMENT FAULTING PERFORMANCE

Georgia

A - Bituminous Stabilized Base, $FI=0.285(T)^{0.453}$
B - Cement Stabilized GAB, $FI=0.216(T)^{0.459}$
C - Non-erodible Base With Dowels, $FI=0.58(T)^{0.216}$
South from 14th Street in 1953
South from 14th Street in 2004
Is it about “Cheap”?
The question becomes...

What is the optimum design for the expected performance?
Cost - Performance Balance Considerations

- Type of facility
- Design expectations
- Budget constraints
Need for Major Improvement in Pavement Design

1990’s — AASHTO Joint Task Force on Pavements realized technology and theory exist to move to mechanistic design

1996 NCHRP “Workshop on Improved Pavement Design” that included 70 top pavement engineers concluded this could, and should, be accomplished by 2002
Pavement Design Factors

- Climate
- Traffic
- Materials
- Structure

Damage Accumulation

Response

Time
CAUTION

THIS SIGN HAS
SHARP EDGES

DO NOT TOUCH THE EDGES OF THIS SIGN

ALSO, THE BRIDGE IS OUT AHEAD
Effect of Joint Spacing

Percent slab cracking vs Traffic, million ESALs

- 20 ft
- 18 ft
- 17 ft
- 15 ft

Benefits
Sensitivity of JPCP Cracking to Slab Thickness and Joint Spacing

- 8-in slab
- 9-in slab
- 10-in slab
- 11-in slab

19 million trucks (TTC 2 [30 million ESALs])
Wet-freeze climate
8- to 11-in JPCP; 6-in aggregate base

Joint spacing, ft
Percent slabs cracked

- 0 10 20 30 40 50 60 70 80 90 100
- 12 13 14 15 16 17 18 19 20
Concrete Coefficient of Thermal Expansion

- sandstone = 6.1 to 6.7
- gravel = 6.0
- granite = 4.0 to 5.0
- limestone = 3.3 to 4.8
- cement paste = 10.0 to 11.0
Effect of Dowel Diameter on Faulting

- 19 million trucks
- Wet-freeze climate
- 10-in JPCP; 6-in aggregate base
- EROD=4
- AC shoulder
- 15-ft joint spacing

**Graph Details:**
- **X-axis:** Age, months
- **Y-axis:** Faulting, in
- Lines represent different dowel diameters:
  - **No dowels**
  - D = 1 in
  - D = 1.25 in
  - D = 1.375 in
  - D = 1.5 in

**Key Points:**
- The graph shows the increase in faulting over time for different dowel diameters.
- The line for no dowels is significantly lower than the others, indicating less faulting.
- The line for d = 1.5 in is the highest, indicating the greatest faulting.
- The y-axis is labeled in inches, with a range from 0 to 0.3.
Climate and PCC Design

- MEPDG

1735 Total Pages*

38%

659 pages
Dedicated to Drainage
And Climate Effects
Dry Non-Freeze & Wet Freeze Climates

Los Angeles

Nashville
Project I-65 Nashville, TN

- 13-in JPCP
- 4-in Perm. Asphalt
- 4-in Dense Aggregate
- Compacted Subgrade
- Natural Subgrade

Properties:
- CTE, MR, $E_c$
- $E^*$, friction
- Mr, gradation, Atterberg, thermal, & hydraulic properties
## Effect of Climates

<table>
<thead>
<tr>
<th>Climate Parameter</th>
<th>Nashville, TN</th>
<th>Los Angeles, CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Annual Rainfall (in)</td>
<td>49.96 in</td>
<td>14.65 in</td>
</tr>
<tr>
<td>Mean Annual Freezing Index</td>
<td>141 °F-days Below 32 F</td>
<td>0 °F-days below 32 F</td>
</tr>
</tbody>
</table>
## Pavement Life for Thickness

<table>
<thead>
<tr>
<th>Slab Thickness (in)</th>
<th>Location</th>
<th>Age when Joint Faulting &gt; Terminal</th>
<th>Age when Slab Cracking &gt; Terminal</th>
<th>Age when IRI &gt; Terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Nashville</td>
<td>26 years</td>
<td>22 years</td>
<td>30 years</td>
</tr>
<tr>
<td></td>
<td>Los Angeles</td>
<td>&gt; 60 years</td>
<td>28 years</td>
<td>60 years</td>
</tr>
<tr>
<td>13</td>
<td>Nashville</td>
<td>42 years</td>
<td>&gt; 60 years</td>
<td>46 years</td>
</tr>
<tr>
<td></td>
<td>Los Angeles</td>
<td>&gt; 60 years</td>
<td>&gt; 60 years</td>
<td>&gt; 60 years</td>
</tr>
</tbody>
</table>
EXAMPLE PCC PROJECT DESIGN
1981 AASHTO GUIDE (MOD 72 GUIDE)

• 4 lane divided highway
• 20 yr design loadings: 25 million ESAL,s
• Pi = 4.5  Pt=2.5
• Base: 12 inch GAB + 3 inch AC
• K value: 290 psi
• Design Concrete Strength: 600 psi flex
  — (use 450 psi in design equation)
• Design PCC Thickness: 11.7 (use 12 inches)
EXAMPLE PCC PROJECT DESIGN
1993 AASHTO GUIDE

- 4 lane divided highway; non-interstate
- 20 yr design loadings: 25 million ESAL,s
- \( P_i = 4.5 \quad P_t=2.5 \)
- Base: 8 inch GAB ; K value 190 psi
- Drainage factor: 1.2
- Load Transfer factor: 3.2 (dowels, no edge support)
- Reliability: 90%
- Design Concrete Strength: 600 psi flex
- Design PCC Thickness: 10.8 inches
EXAMPLE PCC PROJECT DESIGN
1993 AASHTO GUIDE

• 4 lane divided highway; non-interstate
• 20 yr design loadings: 25 million ESAL,s
• Pi = 4.5  Pt=2.5
• Base: 8 inch GAB ; K value 190 psi
• Drainage factor: 1.2
• Load Transfer factor: 3.2(dowels, no edge support)
• Reliability: 90%
• Design Concrete Strength: 690 psi flex (field strength)

• Design PCC Thickness: 10.1 inches

WHY NOT USE 9 INCHES
This software is for review only and should not be used for design. This software was developed under NCHRP 1-37A and 1-40D. Distribution of this software must be approved by NCHRP.
EXAMPLE PROJECT
9 INCH PCC, 8 INCH GAB, 12FT OSL

Predicted IRI

- IRI
- IRI at specified reliability
- IRI Limit

IRI, in/mile vs. Pavement age, years
EXAMPLE PROJECT
9 INCH PCC, 8 INCH GAB, 12FT OSL
EXAMPLE PROJECT
9 INCH PCC, 8 INCH GAB, 12FT OSL

Predicted Faulting

- Faulting
- Faulting at specified reliability
- Faulting Limit

Pavement age, years
Faulting, in
EXAMPLE PCC PROJECT DESIGN
1993 AASHTO GUIDE

• 4 lane divided highway; non-interstate
• 20 yr design loadings: 25 million ESAL,s
• Pi = 4.5  Pt=2.5
• Base: 8 inch GAB ; K value 190 psi
• Drainage factor: 1.2 ;
• Load Transfer factor: 2.7 (dowels, edge support)
• Reliability: 90%
• Design Concrete Strength: 690 psi flex (field strength)

• Design PCC Thickness: 9.2 inches (use 9 inches)
EXAMPLE PROJECT
9 INCH PCC, 8 INCH GAB, 13FT OSL

Predicted IRI
EXAMPLE PROJECT
9 INCH PCC, 8 INCH GAB, 13FT OSL

Predicted Faulting

Faulting, in
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14

Pavement age, years
0 2 4 6 8 10 12 14 16 18 20 22

Legend:
- Faulting
- Faulting at specified reliability
- Faulting Limit
EXAMPLE PROJECT
9 INCH PCC, 8 INCH GAB, 13FT OSL
Design Guide Implementation Team

\[ y = 0.8166 \ln(x) - 4.5483 \]

\[ R^2 = 0.9721 \]

Traffic (ESALs)

PCC Thickness

AASHTO = MEPDG

Difference in AASHTO vs. MEPDG

Source: Chris Wagner - FHWA
Design Guide Implementation Team

\[ y = 0.7896 \ln(x) - 4.1266 \]

\[ R^2 = 0.9853 \]

\[ \begin{align*}
0 & \quad 2 \quad 4 \quad 6 \quad 8 \\
10 & \quad 12 \quad 14 \quad 16 \quad 18 \quad 20
\end{align*} \]

\[ \begin{align*}
0 & \quad 50,000,000 \quad 100,000,000 \quad 150,000,000 \quad 200,000,000 \quad 250,000,000 \quad 300,000,000
\end{align*} \]

Traffic (ESALs)

Source: Chris Wagner - FHWA
QUESTIONs or COMMENTS

Cost-Effective Concrete Pavement Design for the Desired Performance