Concrete Pavement
New M-E Design Guide

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PCC Pavement Presentation

- Value of M-E “comprehensive design”
- Control of key distress
- Pavement types and rehab
- Inputs
- Design features
- Reliability
- Calibration
Mechanistic-Empirical Design

Climate

Materials

Response

Structure

Traffic

Damage Accumulation

Time

Damage

Field Distress
Current AASHTO vs. Current Needs

- Wide range of structural and rehabilitation designs
- Limited structural sections
- 50+ million loads
- 1.1 million load reps
- 1 climate/2 years
- All climates over 20-50 years
- 1 set of materials
- New and diverse materials
Biggest Advantage of M-E Design

- “Comprehensive” design procedure: Directly considers key types of structural distress and ride quality.
The Biggest Advantage of M-E Design

- Illustration:
  - Increase PCC strength and expect improved performance?
  - True for simplistic AASHTO Guide!
  - Not necessarily true in the field because $E_c$, shrinkage, and CTE all increase causing higher stresses!
  - Could be increased cracking and faulting!

- Comprehensive design procedure would tell you this, before you build.
Flexible Pavement Layers

**Conventional**
- Asphalt Concrete
- Unbound Base
- Unbound Subbase
- Compacted Subgrade
- Natural Subgrade

**Deep Strength**
- Asphalt Concrete
- Unbound Base
- Compacted Subbase
- Natural Subgrade

**Full-Depth**
- Asphalt Surface
- Asphalt Binder
- Asphalt Base
- Compacted Subgrade
- Natural Subgrade
# Rigid Pavement Layers

(Also Diamond Grinding)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Type</th>
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</thead>
<tbody>
<tr>
<td>Concrete Slab (JPCP, CRCP)</td>
<td></td>
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<tr>
<td>Base Course (agg., asphalt, cement)</td>
<td></td>
</tr>
<tr>
<td>Subbase (unbound, stabilized)</td>
<td></td>
</tr>
<tr>
<td>Compacted Subgrade</td>
<td></td>
</tr>
<tr>
<td>Natural Subgrade</td>
<td></td>
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<tr>
<td>Bedrock</td>
<td></td>
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</tbody>
</table>

- $E_c$
- $E_{\text{base}}$
- $E$ for each layer
Unbonded PCC Overlay Layers

- JPCP or CRCP Overlay
- Separation Layer (HMAC, Other)
- Existing PCC Slab
- Existing Base Course
- Natural Subgrade
- Bedrock
PCC Overlay of Flexible Pavement

- JPCP or CRCP Overlay
- Existing HMAC Layers
- Existing Base Course Layers
- Natural Subgrade
- Bedrock

Layers:
- $E_c$
- $E_{HMAC}$
- $E_{existing~base}$
- $E_{layers}$
Traffic Loadings

- Vehicle volume, growth & classification
- Single, tandem, tridem, quad axle load distributions
- Monthly vehicle distribution
- Hourly load distribution
- Lateral lane distribution
- Tire pressure
- Tractor wheelbase
Axle Load Spectrum (Single Axles)

Percent of axles, %

Axle load

United States
China
1998 Truck Flow
PCC Material Tests

- Elastic Modulus, “E”
  - ASTM C 469

- Flexural Strength, MR, modulus of rupture
  - Third point loading test
  - ASTM C 78

- Concrete coefficient of thermal expansion
  - AASHTO TP60-00
  - Test performed at 10 to 50 deg C

- Concrete shrinkage
  - ASTM C 157
Concrete Thermal Expansion—AASHTO TP60

- Test procedure involves measuring change in length of specimen at different temperatures
- Length change is measured after expansion and contraction cycles

Test Frame

- Baseplate dia = 10"
- Concrete core
- 3 semi-spherical support buttons
- Spring-loaded LVDT

Top View

- Test procedure involves measuring change in length of specimen at different temperatures
- Length change is measured after expansion and contraction cycles
Concrete Coefficient of Thermal Expansion

Age, years

Percent slabs cracked

6.5x10^-6/F
6.0x10^-6/F
5.5x10^-6/F
5.0x10^-6/F

Benefits
Materials/Subgrade Characterization

• HMA Overlays & base course
  - Dynamic modulus (temp., loading speed)
• Cement treated & lean concrete base
  - Elastic modulus
• Unbound aggregate base & soils
  - Resilient modulus (moisture, freezing)
Better Characterization & Selection

• Bring daily, seasonal, and yearly changes in materials into design process
  – Better use of available materials
  – HMA & PCC material mix optimization to minimize distress.
Climate

• Hourly climatic data
  - Temperature
  - Precipitation
  - Wind speed
  - Cloud cover
  - Relative ambient humidity

• Water table level
Components of Curling Stress

\[
\Delta T = \Delta T_{\text{Hourly}} + \Delta T_{\text{Built-in}} + \Delta T_{\text{Shrinkage}}
\]
JPCP Design Features

- Slab thickness
- Slab length (joint spacing)
- Slab width (widened slab)
- Tied PCC shoulder
- Joint load transfer (dowels & interlock)
- Base and subbase layers (bonding)
CRCP Design Features

- Slab thickness
- Reinforcement content
- Slab width (widened slab)
- Tied PCC shoulder
- Base and subbase layers (bonding)
Design Reliability

- Totally different than AASHTO 93
- Not multiplier of traffic loadings as in AASHTO 93
- Based on accuracy of predicting performance
Residuals from Performance Prediction during Calibration

• “Residuals” represent the knowledge that exists of the accuracy of the distress prediction model

• Standard error of estimate

\[ y = 0.9698x \]

\[ R^2 = 0.8445 \]
probability of failure ($\alpha$)

reliability $R = (1-\alpha)$

mean prediction ($R = 50$ percent)

prediction at reliability $R$

$CRK_{avg}$

$CRK_{failure}$

$CRK_0$
AASHTO 93 & Design Guide

I-80 Chicago — Heavy Traffic

Design thickness, in

Reliability, percent

19 million trucks
(30 million ESAL)

AASHTO 93

2002 Design Guide

Benefits
Dowel Diameter Effect on Reliability Level

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

Reliability Level

Dowel Diameter, in

- No dowels
- 1.0 in
- 1.25 in
- 1.375 in
- 1.5 in
National Calibration Models & Local Calibration

- All concrete pavement models successfully calibrated using national LTPP & other data
  - Joint faulting
  - Slab cracking
  - IRI
  - Transverse cracks/Punchouts-CRCP
Calibration database JPCP Cracking

196 LTPP sections
36 RPPR sections
522 total observations
Utah J PCP Case Study

- 10-in J PCP, non-doweled
- PCC w/high thermal coef. expansion
- Lean concrete base
- Tied PCC shoulders
- Random joint spacing of 12, 13, 17, and 18-ft.

Benefits
Utah J PCP Case Study

Inputs obtained and following predicted:

- Joint faulting, in
- Slab cracking, percent slabs
- IRI, in/mile

Benefits
Utah J PCP Case Study — Joint Faulting —

![Graph showing measured and predicted faulting over time.](image-url)

- **Measured faulting from LTPP**
- **Predicted faulting (NCHRP 1-37A)**

The graph illustrates the relationship between age (years) and transverse joint faulting (inches) for a case study involving Utah J PCP. The data points represent measured faulting from LTPP, while the line represents predicted faulting based on NCHRP 1-37A models.
Utah J PCP Case Study
—Fatigue Cracking—

![Graph showing percent slabs cracked vs. age, years. The graph includes a line for predicted cracking (NCHRP 1-37A) and markers for measured cracking from LTPP. The x-axis represents age in years ranging from 0 to 18, while the y-axis represents percent slabs cracked ranging from 0 to 45. The line and markers show an increasing trend in cracking with age.]
Utah J PCP Case Study
—IRI (Ride Quality)—

Measured IRI from LTPP  
Predicted IRI (NCHRP 1-37A)
What If . . . Modified JPCP Design?

- Add 1.25-in diameter dowel bars at transverse joints.
- Use of an aggregate in the PCC with a lower coefficient of thermal expansion.
- Use of 15-ft uniform joint spacing.

Benefits
## Utah J PCP Comparison

<table>
<thead>
<tr>
<th>Distress</th>
<th>Existing Design (4.2 million trks, 17 years)</th>
<th>New Design (65 million trks, 35 years)</th>
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</thead>
<tbody>
<tr>
<td>Slab cracking</td>
<td>26 %</td>
<td>0.7 %</td>
</tr>
<tr>
<td>Joint faulting</td>
<td>0.18-in</td>
<td>0.10-in</td>
</tr>
<tr>
<td>IRI</td>
<td>171-in/mile</td>
<td>139-in/mile</td>
</tr>
</tbody>
</table>
M-E Design Guide Benefits

- Superior engineering tools
- Economic savings
- Improved traveling conditions for public
- Innovative contracting tools
- Improved management of highway network