NCHRP Project 9-57

Laboratory Tests to Assess Cracking Resistance of Asphalt Mixtures

Sponsored by
National Cooperative Highway Research Program

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The Need

• Volumetric Mix Design – Does it make sense when our materials have changed so much?

• Balanced Mix Design
  – Max. set by AC for 98% density
  – Max. AC set by rutting test (must be less than 98% density)
  – Min. AC set by cracking test
  – Optimum is between max. AC and min. AC
Types of Cracking

- Thermal
- Reflection
- Bottom-Up Fatigue
- Top-Down Fatigue
Outline

• Project Objectives/Tasks
• Workshop and Products
• Workshop Outcomes
• Experimental Designs
  – Ruggedness
  – Interlaboratory Study
• Validation Experimental Designs/Potential Sections
  – Thermal
  – Reflection
  – Top-Down
  – Bottom-Up
• Summary
Cracking Tests Workshop

• Goals
  – Select cracking tests for 4 cracking types
  – Identify potential field/APT test sections

• What we prepared for the workshop:
  – Interim report
  – Cracking test webinars
  – Cracking test booklet
  – 9 cracking test videos
## Workshop Outcomes

<table>
<thead>
<tr>
<th>Items</th>
<th>Thermal Cracking</th>
<th>Reflection Cracking</th>
<th>Bottom-up Fatigue Cracking</th>
<th>Top-down Fatigue Cracking</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Selected cracking tests</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. DCT</td>
<td></td>
<td>1. OT</td>
<td>1. BBF</td>
<td>1. SCB at intermediate temp.</td>
</tr>
<tr>
<td>2. SCB-IL</td>
<td></td>
<td>2. SCB at intermediate temp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. SCB at low temp.</td>
<td></td>
<td>3. BBF</td>
<td></td>
<td>2. IDT-UF</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key factors for designing field experimental test sections</th>
<th>1. Climate (temperature, moisture, solar radiation); 2. Traffic; 3. Pavement structure and subgrade; 4. Asphalt mixtures; 5. Existing pavement conditions for reflection cracking.</th>
</tr>
</thead>
</table>

| Potential field test sections | 1. LTPP; 2. SPS10; 3. MnRoad; 4. NCAT Test Track; 5. Test sections under NCHRP 9-55, 9-58, and 9-59. |
Selected Cracking Tests

• Disc Compact Tension (DCT)
• Semi-Circular Bending (SCB)
  – University of Minnesota – Low Temperature
  – Louisiana Transp. Research Center – Intermed. Temp
  – University of Illinois – Intermed. Temp
• Overlay Tester (OT)
• Indirect Tension Test (IDT)
• Bending Beam Fatigue (BBF)
Laboratory Evaluation

• Review Existing Information and Studies
  – SCB ILS - ASTM
  – Asphalt Institute
  – NCAT
  – MnDOT

• Available Test Equipment
• Ruggedness Testing
• Precision and Bias
Ruggedness Testing

- Purpose: Identify factors that influence test results and determine how closely they must be controlled.
- Sensitivity test on variables instead of materials.
- Example: SCB
  - Specimen thickness
  - Loading rate
  - Test temperature
  - Notch depth
  - Air voids
Interlaboratory Study

• Purpose: Determine repeatability and reproducibility of test method.
  – Repeatability – single operator
  – Reproducibility – multiple laboratories

• Test familiarization is important

• Test specimens from one laboratory
  – Virgin DGA with 19 mm NMAS
  – Virgin DGA with 9.5 mm NMAS
  – DGA with high binder replacement
Field Validation
Experimental Design

• Objective:
  – Validate Cracking Tests
  – Not Study Cracking Mechanisms

• Want to make sure cracking test differentiates mixes that will crack from those that will not.

• D-optimal Design
  – Full or even partial factorials not practical
  – D-opt: computer generated design that selects the best subset of factor-level combinations
  – Considers important effects with smaller number of observations
Field Validation
Experimental Design

• Consider Factors
  – Pavement Structure
  – Climate
  – Traffic
  – Mix Types
  – Binders

• Existing Facilities vs. New Sections
Field Validation

• Present Schedule
• Cost Estimate
• Material Quantities
• Provide Forensic Plan
Forensic Plan

- Is cracking present?
  - Yes: Perform visual inspection of site
    - Obtain:
      - As-builts for layer thicknesses
      - Mixture designs
      - QC/QA data
      - Material sources
  - No: Do not consider for forensic testing
- Is construction data available?
  - Yes: Perform GPR to determine layer thickness and if any voids or water are present
  - No: Perform visual inspection of site
- Could sub-layers be a primary contributor to cracking?
  - Yes: Perform FWD and other testing to determine strength of layers
  - No: Perform necessary field testing to identify cracking origin and mechanisms.
- Acquire field samples (cores) for lab testing
  - Can exact and/or similar raw materials be acquired?
    - Yes: Acquire materials and run appropriate lab testing to correspond with cracking type. Evaluate field correlation.
    - No: Summarize and report findings
Thermal Cracking

• Climate
  – Cold, few F-T cycles
  – Diurnal cycling

• Mix Types
  – DGA with spec binder
  – DGA Low PG-1 grade
  – SMA

• Pavement Structure
  – Thick: > 6 inches
  – Thin: ≤ 6 inches

• Traffic
  – High: > 300k ESAL/yr
  – Low: < 300k ESAL/yr
## Thermal Cracking D-opt.

<table>
<thead>
<tr>
<th>Test section</th>
<th>Climate</th>
<th>Mixture</th>
<th>Structure</th>
<th>Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cold</td>
<td>DGA_Regular PG</td>
<td>Thick AC</td>
<td>High</td>
</tr>
<tr>
<td>2</td>
<td>Cold</td>
<td>SMA</td>
<td>Thin AC</td>
<td>High</td>
</tr>
<tr>
<td>3</td>
<td>Cold</td>
<td>DGA_PG-Lower</td>
<td>Thin AC</td>
<td>Low</td>
</tr>
<tr>
<td>4</td>
<td>Diurnal cycling regions</td>
<td>DGA_PG-Lower</td>
<td>Thick AC</td>
<td>High</td>
</tr>
<tr>
<td>5</td>
<td>Diurnal cycling regions</td>
<td>SMA</td>
<td>Thick AC</td>
<td>Low</td>
</tr>
<tr>
<td>6</td>
<td>Diurnal cycling regions</td>
<td>DGA_Regular PG</td>
<td>Thin AC</td>
<td>Low</td>
</tr>
</tbody>
</table>
Thermal Cracking

Thermal Cracking
Cold climate

Thermal Cracking
Dry, hot climate
Reflection Cracking

- Climate
  - Steady state warm
  - Diurnal temp cycling

- Existing Structure
  - Cracked AC/Gran Base
  - Cracked AC/CTB
  - JPCP with poor LTE
  - JPCP with good LTE

- Mix Type
  - DGA
  - Performance Mix (SMA, A-R, etc.)
  - Crack resistant (Strata, Texas CAM, etc.)

- Overlay Thickness
  - Thin: <2 in.
  - Thick: 2-6 in.

- Traffic: High (>300k ESAL/yr)
## Reflection Cracking D-opt.

<table>
<thead>
<tr>
<th>Test section</th>
<th>Climate</th>
<th>Existing pavement type</th>
<th>Mixture</th>
<th>Overlay thickness</th>
<th>Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Steady state</td>
<td>Cracked AC/Granular base</td>
<td>DGA</td>
<td>≤ 50 mm (2 inches)</td>
<td>&gt; 300,000 ESAL/year</td>
</tr>
<tr>
<td>2</td>
<td>Steady state</td>
<td>Cracked AC/CTB base</td>
<td>Special crack resistant mix</td>
<td>≤ 50 mm (2 inches)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Steady state</td>
<td>JPCP with low LTE</td>
<td>Performance mix</td>
<td>≤ 50 mm (2 inches)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Steady state</td>
<td>JPCP with high LTE</td>
<td>Special crack resistant mix</td>
<td>50–150 mm (2–6 inches)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Temperature cycling</td>
<td>Cracked AC/Granular base</td>
<td>Special crack resistant mix</td>
<td>≤ 50 mm (2 inches)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Temperature cycling</td>
<td>Cracked AC/CTB base</td>
<td>Performance mix</td>
<td>50–150 mm (2–6 inches)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Temperature cycling</td>
<td>JPCP with low LTE</td>
<td>DGA</td>
<td>50–150 mm (2–6 inches)</td>
<td></td>
</tr>
</tbody>
</table>
Temperature Cycling for Refl. Cracking
Bottom-up Fatigue

- **Climate**
  - High temp/moist cycling
  - All other

- **Traffic**
  - High: >300k ESAL
  - Low: ≤300k ESAL

- **Mix Type**
  - V. good resistance
  - Good resistance
  - Medium resistance
  - Poor resistance

- **Pavement Structure (AC < 6 in)**
  - AC/gran
  - AC/CTB

- **Subgrade**
  - Good
  - Poor
# Bottom-up Fatigue

<table>
<thead>
<tr>
<th>Test section</th>
<th>Climate</th>
<th>Traffic</th>
<th>Mixture</th>
<th>Pavement structure</th>
<th>Subgrade</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>All others</td>
<td>High</td>
<td>Very good cracking resistance mix</td>
<td>AC/CTB base</td>
<td>Poor</td>
</tr>
<tr>
<td>2</td>
<td>High temperature/moisture cycling regions</td>
<td>High</td>
<td>Good cracking resistance mix</td>
<td>AC/granular base</td>
<td>Poor</td>
</tr>
<tr>
<td>3</td>
<td>All others</td>
<td>High</td>
<td>Medium cracking resistance mix</td>
<td>AC/granular base</td>
<td>Good</td>
</tr>
<tr>
<td>4</td>
<td>High temperature/moisture cycling regions</td>
<td>High</td>
<td>Poor cracking resistance mix</td>
<td>AC/CTB base</td>
<td>Good</td>
</tr>
<tr>
<td>5</td>
<td>Low</td>
<td>Low</td>
<td>Very good cracking resistance mix</td>
<td>AC/granular base</td>
<td>Good</td>
</tr>
<tr>
<td>6</td>
<td>All others</td>
<td>Low</td>
<td>Good cracking resistant mix</td>
<td>AC/CTB base</td>
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<td>Low</td>
<td>Medium cracking resistance mix</td>
<td>AC/CTB base</td>
<td>Poor</td>
</tr>
<tr>
<td>8</td>
<td>All others</td>
<td>Low</td>
<td>Poor cracking resistance mix</td>
<td>AC/granular base</td>
<td>Poor</td>
</tr>
</tbody>
</table>
Bottom-up Fatigue

Bottom-up cracking in high temperature region

Bottom-up fatigue cracking in moisture cycling region
Top-down Cracking

- **Climate**
  - Hard freeze, low solar
  - Hard freeze, high solar
  - No freeze, low solar
  - No freeze, high solar

- **Mix Type**
  - DGA coarse, high AV
  - DGA coarse, low AV
  - DGA fine, high AV
  - DGA fine, low AV

- **Traffic**
  - High (>300k ESAL/yr) fast
  - Low (<300k ESAL/yr) slow
  - High (>300k ESAL/yr) slow

- **Pavement:** ≥6 in.
# Top-down Cracking D-opt

<table>
<thead>
<tr>
<th>Test section</th>
<th>Climate</th>
<th>Traffic</th>
<th>Mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hard Freeze, High Solar</td>
<td>Low volume, low speed</td>
<td>DGA fine, high AV</td>
</tr>
<tr>
<td>2</td>
<td>Hard Freeze, High Solar</td>
<td>High volume, low speed</td>
<td>DGA coarse, high AV</td>
</tr>
<tr>
<td>3</td>
<td>Hard Freeze, Low Solar</td>
<td>High volume, high speed</td>
<td>DGA fine, low AV</td>
</tr>
<tr>
<td>4</td>
<td>Hard Freeze, Low Solar</td>
<td>High volume, low speed</td>
<td>DGA fine, high AV</td>
</tr>
<tr>
<td>5</td>
<td>No Freeze, High Solar</td>
<td>High volume, high speed</td>
<td>DGA coarse, low AV</td>
</tr>
<tr>
<td>6</td>
<td>No Freeze, High Solar</td>
<td>Low volume, low speed</td>
<td>DGA coarse, high AV</td>
</tr>
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<td>No Freeze, High Solar</td>
<td>High volume, low speed</td>
<td>DGA fine, low AV</td>
</tr>
<tr>
<td>8</td>
<td>No Freeze, Low Solar</td>
<td>High volume, high speed</td>
<td>DGA fine, high AV</td>
</tr>
<tr>
<td>9</td>
<td>No Freeze, Low Solar</td>
<td>Low volume, low speed</td>
<td>DGA coarse, low AV</td>
</tr>
</tbody>
</table>
### Available Facilities and Characteristics

<table>
<thead>
<tr>
<th>Items</th>
<th>APT</th>
<th>Full-scale test tracks</th>
<th>Full-scale Test Roads</th>
<th>In-service Pavements</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Examples</strong></td>
<td>FHWA-ALF, Louisiana-LAF, CalTrans-HVS, Florida-HVS, Illinois-ATLAS, TxDOT-APT</td>
<td>WesTrack NCAT test track</td>
<td>MnRoad</td>
<td>LTPP-GPS/SPS sections and state DOT sections NCHRP Sections</td>
</tr>
<tr>
<td><strong>Traffic load</strong></td>
<td>Known traffic; well controlled traffic; often overloaded</td>
<td>Known traffic; WesTrack: 4 units of tractor/trailer – triple combinations NCAT Track: four fully loaded trucks</td>
<td>Known traffic; Real traffic</td>
<td>Unknown traffic (most of time); Real traffic; many SPS sections equipped with WIMs</td>
</tr>
<tr>
<td><strong>Traffic speed</strong></td>
<td>Slow; around 5-12 mph</td>
<td>Around 40-45 mph</td>
<td>Real traffic and real speed (around 60 mph)</td>
<td>Real traffic and real speed (around 60 mph)</td>
</tr>
<tr>
<td><strong>Test period</strong></td>
<td>Several months</td>
<td>one-three years</td>
<td>4 years</td>
<td>Several years to more than 15 years</td>
</tr>
<tr>
<td><strong>Environment</strong></td>
<td>Temperature is often controlled</td>
<td>Natural weather</td>
<td>Natural weather</td>
<td>Natural weather</td>
</tr>
<tr>
<td><strong>Aging effect</strong></td>
<td>Artificial aging can be considered, but not natural aging</td>
<td>Impact of short-term aging on performance is considered.</td>
<td>Impact of short/medium-term aging is considered</td>
<td>Impact of long-term aging is addressed</td>
</tr>
</tbody>
</table>
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