Moving to Performance Specifications for Concrete

Michael F. Praul, P.E.
Senior Concrete Engineer
FHWA Office of Asset Management, Pavements, and Construction
Performance Specifications

- **Performance** specifications are different from **Prescriptive** specifications.

- **Performance** specifications communicate the desired characteristics of the material or product.

- **Prescriptive** specifications communicate how the material or product is to be formulated and constructed.
Why Move to a Performance Approach?

- **MAP-21**
  - Greater Federal emphasis on performance
  - Linking investments to outcomes

- **Demographics in “Our World”**

- **Public agency and industry desire**
  - It’s a natural evolution
  - Improved durability and mix design
  - Sustainability

- **Completed research and new tests**

U.S. Department of Transportation
Federal Highway Administration
How Things Change!

Concrete

- **Slump Cone**: 1922, ASTM C143
- **Pressure Meter**: 1949, ASTM C231
- **Rapid Chloride Permeability Test**: 1981, FHWA/PCA

Cars

- **1920**
- **1940**
- **1960**
- **1980**
- **2000**

U.S. Department of Transportation
Federal Highway Administration
Performance in Mix Design

- 1:2:3 in 1920s
- 1:2:3¼ in 1940s with max 6 gal water/bag
  - 350 minimum flexural strength at 28 days
- Slump, air, strength, minimum cement, gradations, .....
Performance Engineered Mixture (PEM) Development

The Team
- Dr. Peter Taylor, Director, CP Tech Center
- Dr. Jason Weiss, Oregon State University
- Dr. Tyler Ley, Oklahoma State University
- Dr. Tom VanDam, NCE
- Mike Praul, FHWA
- Cecil Jones, Diversified Engineering
- Tom Cackler, CP Tech Center

Industry Participants/Reviewers
- Champion States & ACPA Chapter Execs
- ACPA National
- PCA
- NRMCA
Quality in the Concrete Paving Process

PEM Concept

- Understand what makes concrete last and what failure mechanisms do we see
- Specify the critical properties and test for them
- Prepare the mixtures to meet those specifications
- Starting point for a performance-driven QA specification and acceptance program for states and other owner agencies
Why are PEM specifications needed?

- Pavements have not always performed as designed.

- Premature pavement distress has become more severe with changes in cements, SCMs, and winter maintenance (de-icing) practices.

- Allow/encourage innovation.

- Increase sustainability in our mixture designs.
PEM: A Better Specification

Require the things that matter

- Strength (everywhere)
- Shrinkage (dry locations)
- Cold weather resistance (cold locations)
- Transport properties/permeability (everywhere)
- Aggregate stability (everywhere)
- Workability (everywhere)
## Concrete Strength (6.3)

<table>
<thead>
<tr>
<th>Section</th>
<th>Property</th>
<th>Specified Test</th>
<th>Specified Value</th>
<th>Mixture Qualification</th>
<th>Acceptance</th>
<th>Selection Details</th>
<th>Special Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3.1</td>
<td>Flexural Strength</td>
<td>AASHTO T 97</td>
<td>600 psi</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td>Choose either or both</td>
</tr>
<tr>
<td>6.3.2</td>
<td>Compressive Strength</td>
<td>AASHTO T22</td>
<td>3500 psi</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Reducing Unwanted Cracking Due to Shrinkage (6.4)

<table>
<thead>
<tr>
<th>Section</th>
<th>Property</th>
<th>Specified Test</th>
<th>Specified Value</th>
<th>Mixture Qualification</th>
<th>Acceptance</th>
<th>Selection Details</th>
<th>Special Notes</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.4</td>
<td>Volume of Paste</td>
<td></td>
<td>25%</td>
<td></td>
<td>Yes</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.4.1.1</td>
<td>Unrestrained Volume Change</td>
<td>ASTM C157</td>
<td>420 µε</td>
<td>at 28 day</td>
<td>Yes</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.4.1.2</td>
<td>Unrestrained Volume Change</td>
<td></td>
<td>360, 420, 480 µε</td>
<td>at 91 days</td>
<td>Yes</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.4.2.1</td>
<td>Restrained Shrinkage</td>
<td>AASHTO T 334</td>
<td>crack free</td>
<td>at 180 days</td>
<td>Yes</td>
<td>No</td>
<td>Choose only one</td>
<td></td>
</tr>
<tr>
<td>6.4.2.2</td>
<td>Restrained Shrinkage</td>
<td>AASHTO T ???</td>
<td>σ &lt; 60% f'c</td>
<td>at 7 days</td>
<td>Yes</td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.4.2.3</td>
<td>Probability of Cracking</td>
<td>~</td>
<td>5, 20, 50%</td>
<td>as specified</td>
<td>Yes</td>
<td>No</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Hardened Cement Paste Freeze-Thaw Durability (6.5)

<table>
<thead>
<tr>
<th>Section</th>
<th>Property</th>
<th>Specified Test</th>
<th>Specified Value</th>
<th>MQ</th>
<th>AC</th>
<th>Selection Details</th>
<th>Special Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.5.1.1</td>
<td>Water to Cement Ratio</td>
<td>AASHTO T 318</td>
<td>0.45</td>
<td>~</td>
<td>Yes</td>
<td>Yes</td>
<td>Choose Either 6.5.1.1 or 6.5.2.1</td>
</tr>
<tr>
<td>6.5.1.2</td>
<td>Fresh Air Content</td>
<td>AASHTO T 152, T196, TP 118</td>
<td>5 to 8</td>
<td>%</td>
<td>Yes</td>
<td>Yes</td>
<td>Choose only one</td>
</tr>
<tr>
<td>6.5.1.3</td>
<td>Fresh Air Content/SAM</td>
<td>AASHTO T 152, T196, TP 118</td>
<td>≥ 4% Air; SAM ≤ 0.2</td>
<td>%, psi</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>6.5.2.1</td>
<td>Time of Critical Saturation</td>
<td>&quot;Bucket Test&quot; Specification</td>
<td>30</td>
<td>Years</td>
<td>Yes</td>
<td>No</td>
<td>Note 1</td>
</tr>
<tr>
<td>6.5.3.1</td>
<td>Deicing Salt Damage</td>
<td>~</td>
<td>35%</td>
<td>SCM</td>
<td>Yes</td>
<td>Yes</td>
<td>Are calcium or magnesium chloride used</td>
</tr>
<tr>
<td>6.5.3.2</td>
<td>Deicing Salt Damage</td>
<td>~</td>
<td>~</td>
<td>~</td>
<td>Yes</td>
<td>Yes</td>
<td>Choose one</td>
</tr>
<tr>
<td>6.5.4.1</td>
<td>Calcium Oxychloride Limit</td>
<td>Test sent to AASHTO</td>
<td>&lt; 0.15g CaOXY/g paste</td>
<td>Yes</td>
<td>No</td>
<td></td>
<td>Are calcium or magnesium chloride used</td>
</tr>
</tbody>
</table>
# Transport Properties/Permeability (6.6)

<table>
<thead>
<tr>
<th>Section</th>
<th>Property</th>
<th>Specified Test</th>
<th>Specified Value</th>
<th>Mixture Qualification</th>
<th>Acceptance</th>
<th>Selection Details</th>
<th>Special Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.6</td>
<td>Transport Properties</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.6.1.1</td>
<td>Water to Cement Ratio</td>
<td>AASHTO T 318</td>
<td>0.45</td>
<td>~</td>
<td>Yes</td>
<td>Yes</td>
<td>Other criteria could be selected</td>
</tr>
<tr>
<td>6.6.1.2</td>
<td>RCPT Value</td>
<td>AASHTO T 277</td>
<td>2000</td>
<td>~</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>6.6.1.3</td>
<td>Formation Factor/Resistivity</td>
<td>AASHTO xx</td>
<td>500</td>
<td>~</td>
<td>Yes</td>
<td>through $\rho$</td>
<td>* Note this is currently based on saturated curing and an adjustment is needed to match with AASHTO Spec</td>
</tr>
<tr>
<td>6.6.2.1</td>
<td>Ionic Penetration, F Factor</td>
<td>AASHTO xx</td>
<td>25 mm at 30 year</td>
<td>Yes, F</td>
<td>through $\rho$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Aggregate Stability (6.7)

<table>
<thead>
<tr>
<th>Section</th>
<th>Property</th>
<th>Specified Test</th>
<th>Specified Value</th>
<th>Mixture Qualification</th>
<th>Acceptance</th>
<th>Selection Details</th>
<th>Special Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.7.1</td>
<td>D Cracking</td>
<td>AASHTO T 161, ASTM C 1646</td>
<td>~</td>
<td>~</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>6.7.2</td>
<td>Alkali Aggregate Reactivity</td>
<td>AASHTO PP 65</td>
<td>~</td>
<td>~</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>
### Workability (6.8)

<table>
<thead>
<tr>
<th>Section</th>
<th>Property</th>
<th>Specified Test</th>
<th>Specified Value</th>
<th>Mixture Qualification</th>
<th>Acceptance</th>
<th>Selection Details</th>
<th>Special Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.8 Workability</td>
<td>6.8.1</td>
<td>Box Test</td>
<td>~</td>
<td>&lt;6.25 mm, &lt;30% Surf. Void</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.8.2</td>
<td>Modified V-Kelly Test</td>
<td>~</td>
<td>15-30 mm per root seconds</td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Quality Assurance Defined
23 CFR 637

- Agency Acceptance
- Contractor Quality Control
  - Qualified (certified) Personnel
  - Qualified Laboratories
  - Independent Assurance
  - Dispute Resolution for Test Results

State processes, independent of material
Quality Control

- PEM acknowledges the key role of QC in a performance specification
- Requires an approved QC Plan
- Requires QC testing and control charts
  - Unit weight
  - Air content/SAM
  - Water content
  - Formation Factor (via resistivity)
  - Strength
- QC
  - Testing targets, frequency, and action limits
  - Guidance will expand on this
Quality Control

- Uses **real time** feedback

- A good Contractor QC system:
  - Doesn’t just echo Agency requirements
  - Implements QC procedures as standard practice
  - Isn’t just paperwork...**it’s a mindset**
Quality in the Concrete Paving Process
Long-Term Implementation of PEM

- Demonstration through shadow specification
  - IN, IA, MI, MN, ND, SD, WI, IL Tollway, Manitoba (ACPA chapters participating)

- Establish “enhanced” ETG
- Guidance on specification, tests, and quality control
- Fill in research gaps
- Build on PEM to establish a model concrete acceptance program
Quality in the Concrete Paving Process

PEM Champion States

+Manitoba, FHWA MCT & Illinois Tollway
A Coordinated Approach to Implementation

Performance Engineered Mixes

- FHWA
- Agencies
- Industry
- Academia
Quality in the Concrete Paving Process

Road Map to the Future of Performance

- Pooled fund solicitation to support PEM refinement and implementation: 5 years
  - FHWA ($200,000/yr)
  - States (14 states, $15,000 each/yr)
  - Industry ($200,000/yr)

- Follow-up FHWA initiatives
  - Concrete Pavement Performance System (CPPS)
  - Support PEM with Concrete Pavement Trailer
  - Support PEM and a performance approach to concrete QA programs...training, training, training
Concrete Pavement Performance System

Coordinated effort to provide guidance and tools to states and industry to advance concrete Quality Assurance programs in the direction of performance.

- QA Toolkit
  - Videos
  - Testing guidance
- QC framework
- Implementation Workshops
- Mobile Concrete Trailer
FHWA Working Group

- Mike Praul, Office of Asset Management, Pavements, and Construction
- Gina Ahlstrom, Office of Asset Management, Pavements, and Construction
- Katherine Petros, TFHRC
- Richard Duval, TFHRC
- Ahmad Ardani, TFHRC
- Dennis Dvorak, RC
- Bob Conway, RC
CPPS Testing Videos and Guidance

- YouTube style 5-10 minute videos of PEM and other tests
- Will include narrative and be appropriate for technician training
- Mobile Concrete Trailer will participate
- “One pagers” (possible app)
  - Describe the test, what it measures and why
  - Incorporating the test into acceptance or QC programs
  - Suggested frequency
  - Data analysis (PWL, single test pass/fail, control charting)
CPPS Tests

- Super Air Meter
- Unit weight
- Strength
- Surface Resistivity
- MIT Scan
- MIT Scan T2
- Maturity
- Microwave water content
- Box Test
- V-Kelly
- Formation factor
- Coefficient of thermal expansion
- Calorimetry
CPPS Quality Control

- Change state mindset that QC is not their business
- Gordon Smith example
- Provide guidance on developing state specification language on:
  - Equipment inspection
  - Construction inspection
  - Testing guide (very similar to guidance for the acceptance program but slanted to industry)
    - Appropriate QC tests
    - Frequency
    - Control charts and usage
PEM/CPPS Implementation Workshops

- FHWA is being called on by states and industry to provide training
- PEM and CPPS workshop
- Timing for development of workshop dependent on PEM and CPPS progress and implementation
- Conceptual phase
Other “One pagers” Related to Performance

- Largely based on MCT results
- Lowering Cement Content is nearly ready for distribution
- 2\textsuperscript{nd} will be on Optimized Gradation (including spreadsheet tool)
- Looking for suggestions
FHWA Mobile Concrete Trailer

**Mission**

- Technology Transfer to SHA’s
  - Field demos on active projects
  - Equipment loan
  - Training of staff
  - Conferences and workshops
FHWA Mobile Concrete Trailer

- Nondestructive/In-situ Tests
- Sustainability
- AASHTOWare Pavement ME Design
- Performance Related Specifications
- Quality Assurance
- Performance Engineered Mixture

U.S. Department of Transportation
Federal Highway Administration
Additional Benefits / Outcomes

- Evaluate new technologies / equipment
  - On actual field projects / geographical regions
  - Under *practical* working conditions
  - Feedback to researchers
  - Lowers the technology refinement time
Thank You

- For more information:
  michael.praul@dot.gov
  (207) 512-4917