Performance Engineered Mixtures – The Key to Predictable Long-Life Pavement Performance

Virginia Concrete Conference
Richmond, Virginia
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Cecil L. Jones, PE
Diversified Engineering Services, Inc.
PEM - The Path to Implementation

- What is PEM?
- Why is it needed?
- Who has been involved?
- What has been accomplished to date?
- PEM Specification Basics
- Future Plans
What is PEM?

- A program to:
  - Understand what makes concrete last
  - Specify the critical properties and test for them
  - Prepare the mixtures to meet those specifications
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 practices.
- Allow innovation.
- Increase sustainability in our mixture designs.
**PEM - The Path to Implementation**

**Current specifications typically:**

- Do not measure critical engineering parameters.
  - Historically we commonly specify air, slump, and strength, local aggregate requirements.
- Changes in source materials is difficult.
- Mixes are often over cemented.
- Are often built around previous failures – thereby introducing unintended consequences.
VDOT Concrete Pavement Specifications

- Section 217 Table II-17
  - Minimum Compressive Strength
  - Laboratory Permeability
  - Minimum Cementitious Content
  - Max w/c ratio
  - Slump & Air

- Mix Design Options
  - Prescriptive Method following ACI 211
  - Trial Batch Method
  - Documented Field Experience Method
PEM - Goal

Require the things that matter

- Transport properties (everywhere)
- Aggregate stability (everywhere)
- Strength (everywhere)
- Cold weather resistance (cold locations)
- Shrinkage (dry locations)
- Workability (everywhere)
The Vision:

Concrete Mixtures that are **engineered** to meet or exceed the design requirement, are predictably durable, with increased sustainability.

Keys:

- Design and field control of mixtures around engineering properties related to performance.
- Development of practical specifications.
- Incorporating this knowledge into an implementation system (Design, Mat’ls, Construction, Maintenance).
- Is validated and refined by performance monitoring.
30 DOTs, FHWA, Illinois Tollway, Manitoba

TTCC Pooled Fund States
NCC Reno meeting April 2015.

- The NCC decided to organize champion states to work with FHWA & leading national researchers to evaluate new testing technologies & develop a PEM framework.
PEM Champion States

+Manitoba, FHWA MCT & Illinois Tollway
PEM - The Path to Implementation

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

Industry Participants/Reviewers
- Champion States & ACPA Chapter Execs
- ACPA National
- PCA
- NRMCA
PEM - The Path to Implementation

What has been accomplished:

- New testing technologies that measure properties related to critical engineering properties have been integrated into a specification framework.
- Ongoing evaluation of new test methods.
- TPF established to assist DOTs with implementation. Solicitation # 1439
- AASHTO voted to approve the standard.
Provisional AASHTO Standard Practice for Developing Performance Engineered Concrete Pavement Mixtures & Commentary AASHTO PP 84-17

Will be published in April 2017
PEM - The Path to Implementation

- PEM Mixture Design Parameters (Test the things that matter)
  - Strength
  - Cracking tendency (dimensional stability)
  - Freeze-Thaw durability
  - Resistance to Fluid Transport
  - Aggregate stability
  - Workability*

- Performance and prescriptive options for each, except strength
Test Methods Included

- Workability
  - VKelly
  - Box
- SAM
- Resistivity / Formation Factor
- Transport and Pore Structure
- Oxychloride Formation
- Dual Ring Cracking Test
PEM - The Path to Implementation

Specification Framework

- Measure properties at the right time
  - Prequalification
  - Process control
  - Acceptance
Specification Basics

- “Menu” specification
- Not an off the shelf drop in
- Select from what you want to satisfy the needs you have
- Intended to work for SHAs and local agencies
- Intended to respect organizational traditions while offering performance options
### Specification Basics

<table>
<thead>
<tr>
<th>Section</th>
<th>Property</th>
<th>Specified Test</th>
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<th>Mixture Qualification</th>
<th>Acceptance</th>
<th>Selection Details</th>
<th>Special Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3 Concrete Strength</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.4 Reducing Unwanted Slab Warping and Cracking Due to Shrinkage (If Cracking is a Concern)</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>6.5 Durability of Hydrated Cement Paste for Freeze-Thaw Durability</td>
<td></td>
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</tr>
<tr>
<td>6.6 Transport Properties</td>
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</tr>
<tr>
<td>6.7 Aggregate Stability</td>
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<tr>
<td>6.8 Workability</td>
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</table>
## Specification Basics - Strength

### Section 6.3

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>6.3.1</td>
<td>Flexural Strength</td>
<td>AASHTO T 97</td>
<td>4.1 MPa</td>
<td>600 psi</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>6.3.2</td>
<td>Compressive Strength</td>
<td>AASHTO T 22</td>
<td>24 MPa</td>
<td>3500 psi</td>
<td>Yes</td>
<td>Yes</td>
<td>Choose either or both</td>
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*Note: Choose either or both.*
# Specification Basics – Warping and Cracking

## Section 6.4

<table>
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<th>Property</th>
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<th>Special Notes</th>
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</thead>
<tbody>
<tr>
<td>6.4.1.1</td>
<td>Volume of Paste</td>
<td>25%</td>
<td>Yes</td>
<td>No</td>
<td></td>
<td></td>
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<tr>
<td>6.4.1.2</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>Curing Conditions</td>
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<tr>
<td>6.4.2.1</td>
<td>Unrestrained Volume Change</td>
<td>ASTM C157</td>
<td>360, 420, 480 με</td>
<td>at 91 days</td>
<td>Yes</td>
<td>No</td>
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<tr>
<td>6.4.2.2</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></td>
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<tr>
<td>6.4.2.3</td>
<td>Restrained Shrinkage</td>
<td>AASHTO TP XXX</td>
<td>σ &lt; 60% f’r</td>
<td>at 7 days</td>
<td>Yes</td>
<td>No</td>
<td>Dual ring test is currently under consideration as an AASHTO Provisional Test Method</td>
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<tr>
<td>6.4.2.4</td>
<td>Probability of Cracking</td>
<td>Appendix X1</td>
<td>5, 20, 50%</td>
<td>as specified</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Commentary</td>
<td>Quality control check</td>
<td>~</td>
<td>~</td>
<td>~</td>
<td>No</td>
<td>Yes</td>
<td>Variation controlled with mixture proportion observation or F Factor and Porosity Measures</td>
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# Specification Basics – Paste Durability

## Section 6.5

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<tbody>
<tr>
<td>6.5.1.1</td>
<td>Water to Cementitious Ratio</td>
<td>~</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>
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<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>
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<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 Years</td>
<td>Yes</td>
<td>No</td>
<td>Note 1 Note 2</td>
<td>Variation controlled with mixture proportion observation or F Factor and Porosity Measures</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>AASHTO M 224</td>
<td>~</td>
<td>Topical Treatment</td>
<td>Yes</td>
<td>Yes</td>
<td>Are calcium or magnesium chloride used, use specified sealers</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>Choose one</td>
<td>Are calcium or magnesium chloride used</td>
</tr>
</tbody>
</table>
### 6.6 Transport Properties

<table>
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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>6.6.1.1</td>
<td>Water to Cementitious Ratio</td>
<td>~</td>
<td>≤ 0.45 or ≤ 0.50</td>
<td>~</td>
<td>Yes</td>
<td>Yes</td>
<td>The required maximum water to cementitious ratio is selected based on freeze-thaw conditions.</td>
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<tr>
<td>6.6.1.2</td>
<td>Formation Factor</td>
<td>Table 1</td>
<td>≥ 500 or ≥ 1000</td>
<td>~</td>
<td>Yes</td>
<td>Yes</td>
<td>Based on freeze-thaw conditions. Other criteria could be selected</td>
</tr>
<tr>
<td>6.6.2.1</td>
<td>Ionic Penetration, F Factor</td>
<td>Appendix X2</td>
<td>25 mm at 30 year</td>
<td>Yes, F through ρ</td>
<td>~</td>
<td>Choose Only One</td>
<td>Determined using guidance provided in Appendix X2.</td>
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</table>
## Section 6.7

<table>
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<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>
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</table>

### 6.7 Aggregate Stability

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<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>
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</table>
# Specification Basics – Workability

## Section 6.8

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>6.8.1</td>
<td>Box Test</td>
<td>Appendix X3</td>
<td>&lt;6.25 mm, &lt; 30% Surf. Void</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.8.2</td>
<td>Modified V-Kelly Test</td>
<td>Appendix X4</td>
<td>15-30 mm per root seconds</td>
<td>No</td>
<td></td>
<td></td>
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</tbody>
</table>
Specification Basics

- Specification describes process and choices
- Includes acceptance requirements
- Includes quality control provisions
  - Contractor submits quality management plan
  - Some minimum requirements listed
Specification Basics

- Appendices for new and emerging test methods
  - Cracking and volume change
  - Formation factor and pore solution resistivity
  - Box test
  - V-Kelly test
  - Transport and pore structure
  - Commentary
Specification Basics

- Commentary (60 pages)
  - Detailed discussion of each section
  - References for more detailed background
Road Map to the Future of Performance

➢ Pooled fund to provide technical support for performance approach to concrete
  • FHWA
  • States
  • Industry

➢ Follow-up FHWA initiatives
  • Introduce PEM and a performance approach to concrete acceptance programs
  • Support PEM with Concrete Pavement Trailer
  • Provide additional guidance on tests/implementation
  • Develop quality control guidance
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
  - Strength
- Provides guidance for QC
  - Testing targets, frequency, and action
  - Guidance will expand on this
PEM - The Path to Implementation

TPF Work Tasks

- Implementing what we know: Education, Training & Technical Support
- Performance Monitoring and Specification Refinement
- Measuring and Relating Early Age Concrete Properties to Performance
PEM - The Path to Implementation

TPF Elements

- Phase 1 with the Scope described
  - 5 years (2017-2021)
  - $3 million
  - Ready to support work by January 1, 2017

- Phase 2 (to support performance monitoring)
  - 5 years (2022-2026)
  - $ TBD
Proposed Funding

- Total of $3 million over 5 years
  - FHWA - $200,000/ year = $1m
  - DOTs – 14 @ $15,000/ year = $1.05m
    - Currently (6): Iowa, Ohio, Pennsylvania, South Dakota, Wisconsin, New York
  - Industry - $200,000/ year = $1m
A Coordinated Approach to Implementation

Performance Engineered Mixes

- FHWA
- Agencies
- Industry
- Academia
PEM Goal: A Provisional Specification

- Follow-up FHWA initiatives
  - Introduce PEM and a performance approach to concrete acceptance programs (including QC)
  - Support PEM with Concrete Pavement Trailer and workshop
  - Provide additional guidance on tests/implementation
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.

- Mobile Concrete Trailer
- Video clips
- QA Toolkit
- QC framework
- Implementation Workshops
Thank You!

www.cptechcenter.org