Performance Engineered Concrete Mixtures

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Acknowledgements

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

• Industry Participants/Reviewers
  – Champion States & ACPA Chapter Execs
  – ACPA National
  – PCA
  – NRMCA
AASHTO PP84-17: Standard Practice for Developing Performance Engineered Concrete Pavement Mixtures

- Provisional standard practice that continues to evolve
- Team is now working under a five-year pooled fund study to refine and validate
- The goal is to strengthen the link between specified material properties and performance
PEM - The Path to Implementation

- Improved understanding of concrete performance
  - Structural and durability considerations
- Specify critical properties and test for them
  - Essential to link specified properties to performance
- Obtain mixtures that meet specifications
  - Mixture design
  - Acceptance
Prescriptive Specifications

- Historically used to accommodate a fixed amount of knowledge and a low skilled workforce
  - DOTs specify means and method dictated by experience
  - Each successive generation adds more experience (and specific directions) to the specifications
- Negative: Builds on a 90-year old platform; opportunities to innovate are limited
  - Like driving through the rearview mirror
Performance-Based Specifications

- Take advantage of the knowledge gained from recent research and experience
  - DOTs specify criteria and tests methods linked to desired performance
    - Can form the basis for pay factors
  - Promotes innovative ideas and solutions
- Negative: Knowledge base needs to grow
  - It takes time for everyone to become comfortable
  - Requires greater technical sophistication throughout the workforce
PEM Concept

• Provide a standard practice based on tests linked to performance
  – Tests completed during mixture design or at placement or both
• Allow DOTs to take what they like from the document and make it their own
• DOTs are not expected to give up what they already know is important to them
What is in PP-84?

- Standard practice with test methods and recommended limits
  - There are both prescriptive and performance approaches
  - A commentary is included that gives the technical background behind the tests and limits
- This is a tool to help improve concrete pavement performance
- The document is not designed to be used without modifying for local practice and experience
Thinks of it as a Buffet From Which You Choose What You Like
PEM: Approach to Testing

- Require the things that matter
  - Strength
  - Warping and shrinkage
  - Freeze-thaw resistance
  - Chemical deicer resistance
  - Transport properties
  - Aggregate stability
  - Workability
## Strength

<table>
<thead>
<tr>
<th>Test method</th>
<th>Flexural Strength</th>
<th>Compressive Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>AASHTO T 97</td>
<td>4.1 MPa 600 psi</td>
<td>AASHTO T 22 24 MPa 3500 psi</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Value</th>
<th>Approval?</th>
<th>Acceptance?</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1 MPa</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>600 psi</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>24 MPa</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>3500 psi</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Slide from Tyler Ley
# Axial Drying Shrinkage

<table>
<thead>
<tr>
<th>Test method</th>
<th>Volume of paste</th>
<th>Axial shrinkage 1</th>
<th>Axial shrinkage 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>&lt; 25%</td>
<td>ASTM C157</td>
<td>ASTM C157</td>
</tr>
<tr>
<td>Time</td>
<td></td>
<td>&lt; 420 με</td>
<td>&lt; 360, 420, 480 με</td>
</tr>
<tr>
<td>Approval?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Acceptance?</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Time</td>
<td>28 days</td>
<td>28 days</td>
<td>91 days</td>
</tr>
<tr>
<td>Approval?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Acceptance?</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
ASTM C157

- Cure samples for 28 days in fog room
- Demold and place in drying room (50% RH and 73F)
- Measure their length change over time

Slide from Tyler Ley
<table>
<thead>
<tr>
<th>Test method</th>
<th>Ring Test</th>
<th>Dual Ring</th>
<th>Modeling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>crack free</td>
<td>$\sigma &lt; 60%$ f'r</td>
<td>5, 20, 50% cracking prob</td>
</tr>
<tr>
<td>Time</td>
<td>180 days</td>
<td>7 days</td>
<td></td>
</tr>
<tr>
<td>Approval?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Acceptance?</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Slide from Tyler Ley
Ring Test

Plan View

Steel ring
Strain gauge
Concrete

Store in 73°F and 50% RH

Graph showing strain over time:
- R2_G1
- R2_G3
- R2_G4
- R2_G2

Slide from Tyler Ley
Dual Ring Test

This ring can measure both expansion and contraction.

As the concrete shrinks the ring can measure the strains that occur.

We force a temperature gradient in the concrete and make it crack and compare that to 60% of the split tension capacity after 7 days.

Slide from Tyler Ley
Split Tensile Strength (example)

Residual Capacity
# Freeze Thaw durability

<table>
<thead>
<tr>
<th>Test method</th>
<th>w/cm</th>
<th>Air void volume</th>
<th>Air void system</th>
<th>Time to Critical Saturation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>&lt; 0.45</td>
<td>AASHTO T 152, T196, TP 118</td>
<td>AASHTO TP 118</td>
<td>-</td>
</tr>
<tr>
<td>Approval?</td>
<td>Yes</td>
<td>5 to 8%</td>
<td>≥ 4% Air SAM ≤ 0.20</td>
<td>30 Yrs</td>
</tr>
<tr>
<td>Acceptance?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Slide from Tyler Ley
Admixtures are not the same

Mix A

Mix B

0.40 w/cm

Yes!

No!
The Bucket Test

- Cast concrete and keep sealed for 14 days
- Measure the cylinder mass after demolding
- Place three concrete cylinders in lime water
- Measure their mass at 5 days
- Measure their mass again every 10 days until they are 60 days old
- Oven dry cylinder and take mass
- Vacuum saturate cylinder and take mass
- Calculate the time to critical degree of saturation
Bucket test results (2 months)

ASTM C 666 3.5 month test

Time to Critical Saturation (year)

- SAM <= 0.20 and Air => 4.5%
- SAM > 0.20 or Air < 4.5%

Durability Factor (%)
## Deicer Salts

Are calcium or magnesium chloride deicer salts used?

<table>
<thead>
<tr>
<th>Approach</th>
<th>use SCMs</th>
<th>use sealer</th>
<th>AASHTO T 365</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>&gt; 35%</td>
<td>-</td>
<td>&lt; 0.15g CaOXY/g paste</td>
</tr>
<tr>
<td>Approval?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Acceptance?</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

Slide from Tyler Ley
### Transport Properties

<table>
<thead>
<tr>
<th>Test method</th>
<th>w/cm</th>
<th>RCPT Value</th>
<th>Formation Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>-</td>
<td>AASHTO T 277</td>
<td>AASHTO T 358</td>
</tr>
<tr>
<td></td>
<td>0.45</td>
<td>&lt; 2000</td>
<td>&gt; 500</td>
</tr>
<tr>
<td>Approval?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Acceptance?</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Slide from Tyler Ley
The Formation Factor

• It is a true measurement of how hard it is for solution to move through concrete
  — Reflects volume and connectivity of pores
• Can derive it from RCPT or resistivity test results
  — Must used standardized specimen geometry and condition (temperature and moisture)
  — Must correct for pore solution resistivity
Pore Solution Resistivity

• Three approaches are provided to determine pore solution resistivity
  – Assume a value (this is what we currently do for RCPT)
• Calculate a value based on the cement and SCMs using on-line calculator
  – Based on mill certificates or XRF results
• Squeeze out the pore solution and measure it
Ley lab data 2017

Diffusion Coefficient

Class F ashes

Class C ashes

OPC

Significant variation - This is why we need the formation factor

Resistivity (KΩ cm)

D (x10^{-11}, m^2/sec)
## Aggregate Stability

<table>
<thead>
<tr>
<th>Test method</th>
<th>D Cracking</th>
<th>Alkali Aggregate Reactivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approval?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Acceptance?</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>AASHTO T 161, ASTM C 1646</td>
<td>AASHTO PP 65</td>
<td></td>
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</tbody>
</table>

Slide from Tyler Ley
## Constructability

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Box Test</th>
<th>V-Kelly</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;6.25 mm, &lt; 30%</td>
<td>Yes</td>
<td>15-30 mm per root seconds</td>
</tr>
<tr>
<td>Surf. Void</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approval?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Slide from Tyler Ley
Box Test

- A simple test that examines:
  - Response to vibration
  - Filling ability of the grout (avoid internal voids)
  - Ability of the concrete to hold an edge
Box Test

- Add 9.5” of unconsolidated concrete to the box
- Insert 1” diameter stinger vibrator (8000 vpm) into the center of the box over a three count and then remove over a three count
- The edges of the box are then removed and inspected for honey combing and edge slump
VKelly

• Kelly ball test
  – Developed in the 1950s in US
  – Standardized in California DOT test
  – Comparable to slump test
    • 1.1 to 2.0 times the Kelly ball reading
VKelly

• Measure initial slump (initial penetration)
• Start vibrator for 36 seconds at 8000 vpm
• Record depth every 6 seconds
• Repeat
• Plot on root time
• Calculate slope = VKelly Index

From Peter Taylor
Quality Control

- Tracking how our concrete varies
  - Unit weight
  - Air content/SAM
  - Water content
  - Formation factor
  - Strength
- This is important information that we are ignoring
- AASHTO PP-84 provides guidance for QC
  - Testing targets, frequency, and action limits
  - Guidance will be expanded
This is Just the Beginning

- Best approaches to provide guidance on critical durability issues are provided
- Detailed commentary provides background
- Over time everything will improve:
  - Tests
  - Specification
  - Commentary
  - Implementation
  - People’s attitude
  - Our concrete
New Pooled Fund Study

- PEM Pooled Fund - TPF-5(368)
- Provide technical support to try portions of PEM
  - Introduce PEM to concrete acceptance programs
  - Support PEM with Mobile Concrete Trailer
  - Provide guidance on tests/implementation
  - Develop quality control guidance
  - Incentive Fund Program
  - Develop the next generation of tests to evaluate durability in fresh concrete
Questions?