Performance Engineered Concrete Mixtures: Research to Shadow Project to Implementation

North Carolina Concrete Pavement Conference
October 29, 2018
Tara Cavalline, Brett Tempest
Robert (Blake) Biggers, Austin Lukavsky, Ross Newsome, Memoree McEntyre
This PEM thing sounds GREAT!

But where (and how) would we even start?
Each agency will have its own path to implementation

• What does this look like for North Carolina?
• An opportunity to do things better
• Impacts of this effort will be broad-reaching and will impact all stakeholders
• Not a zero-sum game (everybody should benefit!)
Key Considerations

- What performance characteristic(s) do we want to improve?
- How much support from the industry can we expect?
- What are people willing to try?
- If we “put a toe in the water,” what would that look like?
  - Incremental steps...
- “Agency should make the choices that best fit their situation and willingness to share risk” – and reward!
What is PEM concrete for North Carolina?

• Is workable / constructable
• Provides adequate strength
• Provides the desired durability performance
• Achieves other desired special properties or performance requirements
  – Sustainability goals
  – Service life / maintenance goals
  – Addresses construction challenges
    • Pumpable
    • Flowable
    • Temperature issues

• The needed performance for these characteristics varies by application

• PEM initiative challenges state agencies to:
  – Identify the performance characteristics and properties that are desired
  – Specify, measure, and accept based on these
What does Performance-Engineered Concrete need?

**Appropriate material selection/proportioning**
- Appropriate cement contents
- Lower paste contents
- Use of SCMs
  - fly ash
  - portland limestone cement
  - slag
- Stable (non-reactive) aggregates
- Optimized aggregate gradation
- Materials/mixtures that provide:
  - workability/strength
  - reduced permeability
  - reduced cracking/curling
  - freeze-thaw durability

**Tests for enhanced acceptance criteria**
NCDOT’s Initial PEM Steps

• Data collected as part of previous research projects can be leveraged with new, targeted data to support NCDOT’s PEM effort.
• Build on existing knowledge
• Targeted laboratory testing
• Leveraging state-funded research with participation in FHWA Pooled Fund
• Inform data-driven decisions on feasible, justifiable movements towards PEM
# Projects Supporting PEM

<table>
<thead>
<tr>
<th>Previous/ongoing Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field study of bridge deck durability performance</td>
</tr>
<tr>
<td>Concrete inputs for MEPDG pavement design/analysis</td>
</tr>
<tr>
<td>Internal curing of concrete bridge decks</td>
</tr>
<tr>
<td>Technical Assistance Projects – SAM, pavement projects</td>
</tr>
<tr>
<td>Corrosion policy evaluation for coastal bridges</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Research Project 2018-14</th>
</tr>
</thead>
<tbody>
<tr>
<td>data analysis of current/past mixtures</td>
</tr>
<tr>
<td>laboratory evaluation to support identification of resistivity, SAM, performance targets</td>
</tr>
<tr>
<td>develop shadow specifications/PSP</td>
</tr>
<tr>
<td>develop “roadmap” for PEM</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FHWA Implementation Funds</th>
</tr>
</thead>
<tbody>
<tr>
<td>support contractor and NCDOT at current implementation project</td>
</tr>
<tr>
<td>analyze QC/QA data from implementation project</td>
</tr>
<tr>
<td>development of tech transfer documents (resistivity, SAM)</td>
</tr>
<tr>
<td>development and delivery of seminar/workshop for NCDOT division/region personnel</td>
</tr>
</tbody>
</table>
Data Analysis

- Identify trends in materials and proportions, and link to unacceptable, acceptable, and excellent QA/QC test performance
- Link mixture characteristics and QA/QC test results with field performance and observed condition data
What concrete are we placing and how is it doing?

1) Approved mixtures database: 18+ years (33,000+ mixtures)
   • Focus on Class A/AA (structural) and pavement concrete
   • Possibly precast/prestressed

2) Early age test data: strength, air content, slump

3) Asset management databases:
   • Bridge Management System (BMS)
     – 36 years of NBI inspection data, plus some additional
     – 3 years of element-level data
   • Pavement management system (PMS) – 25+ years of condition data
Data Analysis – Goals and Challenges

Key parameters of interest:
• Paste volume and cement content
• Confirm performance improvement from SCMs
• Good actors/bad actors

Findings will:
• Help identify performance/prescriptive measures to include in new PEM specification
• Guide decisions on pilot project(s) for shadow testing or implementation
• Guide development of the laboratory program

This is challenging...
Targeted Laboratory Testing/Evaluation

Goal 1:
Establish performance-related criteria using several rapid, early age QA/QC tests to assess durability currently of interest to NCDOT.

Surface Resistivity, SAM

Goal 2:
Produce additional performance data on concrete containing PLC and fly ash

- better understanding the potential enhanced durability/economy
- provide additional justification for use.
Leveraging data from previous research to support PEM

• Laboratory and field – what do we already know?
Surface Resistivity

• Quick, easy durability measurement on cylinders you’re already making and testing
• Strongly correlates to the rapid chloride permeability test (AASHTO T 277, ASTM C 1202)
• Several states already specify (Louisiana DOTD, NYSDOT, others)
• AASHTO PP 84 suggests use of Formation Factor
  – $F = \frac{\text{resistivity of bulk concrete}}{\text{resistivity of pore solution}}$
  – helps account for pore solution chemistry
  – “Bucket test” – trials ongoing
Rapid Chloride Permeability Test

Surface Resistivity Test

y = 29671x^{-0.86}
R^2 = 0.9423
High quality air void system agreement

Recommended SAM Number

Low quality air void system agreement

Spacing Factor (µm)

OSU Lab Data
FHWA Lab Data
Field Data

SAM Number from T. Ley

ACI 201.2R

From T. Ley

0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80
0 50 100 150 200 250 300 350 400 450 500

OSU Lab Data
FHWA Lab Data
Field Data
PEM Laboratory Program

Differences in:
• Materials
• Exposure conditions
• Construction

Strategic selection of materials/mixture proportions
• Review of approved mixtures/sources
• Representative cement/fly ash sources
• Piedmont coarse aggregate, natural and/or manufactured sand
RP 2018-14 Mixture Matrix

- **w/cm = 0.47**
  - 0% fly ash: 700/0, 650/0, 600/0
  - 20% fly ash: 560/140, 520/130, 480/120
  - 30% fly ash: 420/180

- **w/cm = 0.42**
  - 0% fly ash: 700/0, 650/0, 600/0
  - 20% fly ash: 560/140, 520/130, 480/120
  - 30% fly ash: 420/180

- **w/cm = 0.37**
  - 0% fly ash: 700/0, 650/0, 600/0
  - 20% fly ash: 560/140, 520/130, 480/120
  - 30% fly ash: 420/180

OPC / Fly ash A

PLC / Fly ash A

OPC / Fly ash A
RP 2018-14 Anticipated Research Products

1) Analysis of the characteristics of currently utilized and historically utilized concrete mixtures, along with trends linked to good, acceptable, and poor performance.

2) Test data on typical conventional highway concrete mixtures to support movement towards performance engineered specifications.

- Suggested performance criteria for the targeted technologies surface resistivity, SAM
- Other performance data (strength, shrinkage, freeze-thaw)
- Evaluations of additional PLC and PLC/fly ash concrete blends

3) Guidance on some prescriptive specification measures
- potentially w/cm ratio or paste content
- strength requirements, particularly for SCM mixtures
PEM Implementation Site in North Carolina

- I-85 widening project north of Charlotte – 8 miles in length
- Addition of 4 travel lanes (2 each direction)
- 12-inch thick mainline JPCP
- Two phases

- Contractor-led involvement
- Motivated staff
  - “We know PEM is coming, and we want to get on board.”
  - “We already do some of this QC but want to do more.”
  - “How can we help?”
Implementation site: PEM Tests and QC activities

Mixture design and approval
- Resistivity test results
- SAM test results
- Box test results

Acceptance tests
- NCDOT standard requirements
  - 28-day compressive strength (4,500 psi)
  - Air content (6.0% ± 1.5%)
  - Max slump 1.5 in
- Shadow Tests
  - SAM test results
  - Resistivity test results

VKelly may be utilized on a trial basis
QC/Control Charts

- Air content, slump, unit weight, concrete temperature
  - One test per lot
  - PEM tests
  - SAM – once per day target
  - Resistivity – all cylinders tested for compressive strength
  - Bucket test – performed at UNC Charlotte

- Other control charts may be developed
  - Moisture content of aggregates
  - Fly ash LOI
Current Status

Implementation Site

- Phase 1 paving complete
- Data analysis ongoing
- Phase 2 paving begins April 2019

Surface Resistivity – PEM implementation site Phase 1
Anticipated Research Products from Implementation Project

• “Reality check” for suggested performance criteria for the targeted technologies
  • surface resistivity
  • SAM
  • workability
  • some prescriptive specification measures
    • such as w/cm ratio or paste content

• Better understanding of QC needs/goals/variability

• Provisional specification or project special provisions document in development
PEM Technology Transfer

In development:

• Seminar/workshop tailored to NCDOT regional/divisional personnel
• One-pagers on PEM tests

Coming Spring/Summer 2019:
FHWA Mobile Concrete Trailer
Closing Thoughts

• Movement towards PEM will help us specify and construct the infrastructure we need for the 21st century and beyond.
• Everyone can benefit from PEM
  – “concrete that delivers what is needed”
    • efficiently (cost, environmental impact)
    • reliably
• Balancing risk / reward
• QC is big part of PEM Implementation

Quantifying benefits of PEM implementation is a key goal
  • Benefits to contractor
  • Benefits to agency
How can you get involved?

• Contact me if you are interested in a training session/workshop
• Obtain and use a surface resistivity meter and/or SAM
• Start collecting data
• Share data with us if you are able

Email me!
tcavalline@uncc.edu

Every piece of information helps
Acknowledgements

- Chris Peoples and Brian Hunter
- Brett Tempest
- Steering and Implementation Committees for RP 2011-06, RP 2015-03, RP 2016-06, RP 2018-14, RP 2019-17, and several technical assistance programs
- NCDOT Research Engineers Mustan Kadhibhai, Neil Mastin
- CP Tech Center and PEM Pooled Fund Study Team
- Cecil Jones
- Chris Ange and Fred White, Lane Construction
- Gina Ahlstrom and Mike Praul, FHWA

- Many folks who continue to donated materials
  — a continued THANK YOU!!!

- Wes Maxwell, Research Operations Manager
- Many student research assistants past/present