NYSDOT Performance Engineered Concrete Mixes
NESMEA
2022

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Materials Engineering Bureau – Field Engineering I Section
Meeting Outline

Share our recent experience with Performance Engineered Mixtures and the opportunities they present toward achieving better performing and more sustainable concrete.
Concrete Mixtures that are engineered to meet or exceed the design requirement, are predictably durable, with increased sustainability. Designed by Contractor/Producer.

- CP Tech Center
Why PEM, why now?

⇒ Our Existing Concrete Specifications (ie: Section 501) “outdated”
- Prescriptive Based Standard Class mixtures (3000 psi)
- Specialty Applications (Design Build / Signature Structures) require higher strength, increased performance that preclude use of standard class mixtures
- Raw material / cost saving opportunities
- Taking better advantage of Contractor/Producer experience/innovation

We need a model that can accommodate better performing & more sustainable mixtures (reduced carbon footprint)
Climate Leadership & Community Protection Act (CLCPA)

Impact on the PCC Materials Arena

- Use of more sustainable mixtures – reduced cement use
- Consideration of recycled/alternate type material use that have consistent properties, when appropriate
- Ensure safety, durability, overall performance
### TABLE 501.3 CONCRETE MIXTURES

<table>
<thead>
<tr>
<th>Concrete Class</th>
<th>T.C.M. Content (lb/ft³)</th>
<th>Sand % Total Agg. (solid volume)</th>
<th>Water/ cementation materials (by weight)</th>
<th>Air Content % Desired (Range)</th>
<th>slump Range (in)</th>
<th>Type of Concrete Aggregate Gradation</th>
<th>Primary Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>606</td>
<td>36.2</td>
<td>0.46</td>
<td>6.5</td>
<td>2 1/2 - 3 1/2</td>
<td>CA 2</td>
<td>general purpose structural</td>
</tr>
<tr>
<td>C</td>
<td>605</td>
<td>35.8</td>
<td>0.44</td>
<td>6.5</td>
<td>1 - 3</td>
<td>CA 2</td>
<td>Pavement, slipform paving, form paving</td>
</tr>
<tr>
<td>D</td>
<td>725</td>
<td>45.8</td>
<td>0.44</td>
<td>7.5</td>
<td>2 1/2 - 3 1/2</td>
<td>CA 1</td>
<td>thin structural applications</td>
</tr>
<tr>
<td>DR</td>
<td>725</td>
<td>45.8</td>
<td>0.40</td>
<td>7.5</td>
<td>3 - 5</td>
<td>CA 1</td>
<td>thin structural applications, overlays</td>
</tr>
<tr>
<td>E</td>
<td>648</td>
<td>35.8</td>
<td>0.44</td>
<td>6.5</td>
<td>3 - 4</td>
<td>CA 2</td>
<td>structural slabs and structural approach slabs</td>
</tr>
<tr>
<td>F</td>
<td>716</td>
<td>34.6</td>
<td>0.38</td>
<td>6.5</td>
<td>2 - 3</td>
<td>CA 2</td>
<td>high early strength for pavement or structural applications</td>
</tr>
<tr>
<td>G</td>
<td>727</td>
<td>45.0</td>
<td>0.45</td>
<td>6.0</td>
<td>6 - 7</td>
<td>CA 2</td>
<td>underwater</td>
</tr>
<tr>
<td>GG</td>
<td>800</td>
<td>45.0</td>
<td>0.43</td>
<td>6.0</td>
<td>6 - 7</td>
<td>CA 1</td>
<td>underwater (special)</td>
</tr>
<tr>
<td>H</td>
<td>675</td>
<td>40.0</td>
<td>0.44</td>
<td>6.5</td>
<td>3 - 4</td>
<td>CA 2</td>
<td>pumping applications</td>
</tr>
<tr>
<td>HF</td>
<td>675</td>
<td>40.0</td>
<td>0.40</td>
<td>6.5</td>
<td>3 - 5</td>
<td>CA 2</td>
<td>pumping, structural slabs, approach slabs, substructures, exposed to chlorides</td>
</tr>
<tr>
<td>I</td>
<td>640</td>
<td>41.0</td>
<td>0.44</td>
<td>6.0</td>
<td>1/2 - 1 1/2</td>
<td>CA 2</td>
<td>slip forming highway median barriers</td>
</tr>
<tr>
<td>J</td>
<td>680</td>
<td>45.8</td>
<td>0.44</td>
<td>6.0</td>
<td>1/2 - 1 1/2</td>
<td>CA 1</td>
<td>slip forming structural median barriers, parapet walls and curbs</td>
</tr>
</tbody>
</table>
Performance criteria specified in lieu of mix proportions

Slump & w/c ratio removed as acceptance criteria

Introduce new performance measures

- Strength, Resistivity and Super Air Meter (SAM)
PCC Performance Criteria

- Higher Compressive Strength (4000 psi)
- Air content
- Durability – Freeze/Thaw, Scaling resistance (Super Air Meter)
- Permeability (Surface Resistivity)
- Optimized Aggregate Gradation
- Maximum Paste Factor
  - Reduced cement use, shrinkage reduction
Newer Performance Criteria - Paste Factor

Traditional Gap Graded Mix – Higher Paste (30%) and Cementitious Content

Optimized Gradation (Well Graded) – Reduced Paste (25-27%) and Cementitious Content
The Contractor shall develop mixtures having a well graded aggregate gradation to minimize the paste content while maintaining workability.

- Optimization Techniques
  - Tarantula Curve
  - Shilstone
  - FHWA Tech Brief – *Blended Aggregates for Concrete Mixture Optimization*
Newer testing tools & methods

- Super Air Meter (AASHTO TP 118)
  - Air void structure assessment of plastic concrete
  - Ability to detect & address issues sooner

- Surface Resistivity Meter (AASHTO T358)
  - Permeability assessment
  - Ability to detect & address issues sooner

Each of our 11 Regions were outfitted with this equipment
National Level Participation

- AASHTO Innovation Initiative (formerly TIG) for Surface Resistivity Test

- Pooled Fund – TPF-5(368) Performance Engineered Mixtures

- Pooled Fund – 1338 Improving Specifications to Resist Frost Damage in Modern Concrete Mixtures
  - Further development and adoption of use of the Super Air Meter (SAM) towards improved assessment of long term pcc durability
Performance Engineered Concrete for Pavements

» Special Specification Item 504.00000011


» Developed in conjunction with the criteria established in AASHTO PP 84 – Standard Practice for Developing Performance Engineered Concrete Pavement Mixtures
501 Pilot Specification

- Special Specification 501.01000001
- Supersedes the requirements of Standard Specification Section 501
- Concrete Mixture design requirements with enhanced performance criteria
- QC Plan requirements to define the production and supply processes
- Acceptance based on Strength/Air Content – Informational testing (SAM & Surface Resistivity)
501 Pilot Specification (cont’d)

**Lump Sum Pay Item** to cover cost of furnishing all materials, equipment and labor necessary to:

- Development of PCC Mixture Designs
- Develop and follow a QC Plan for production and delivery of PCC
- Progress QC activity for all PCC placements

**Pay Factors** – calculated as a shadow program

- Compressive Strength
- Surface Resistivity

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**Compressive Strength**

<table>
<thead>
<tr>
<th>Pay Factor (PF)</th>
<th>Compressive Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>87.5%</td>
<td>≥90.0% and &lt;90.0% of Fc'</td>
</tr>
<tr>
<td>75%</td>
<td>≥85.0% and ≤90.0% of Fc'</td>
</tr>
<tr>
<td>Reject concrete</td>
<td>&lt; 85.0% of Fc'</td>
</tr>
</tbody>
</table>

**Surface Resistivity**

<table>
<thead>
<tr>
<th>Pay Factor (PF)</th>
<th>Surface Resistivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>87.5%</td>
<td>≤1000 Ω-cm²/m²</td>
</tr>
<tr>
<td>75%</td>
<td>&gt;1000 Ω-cm²/m² ≤2000 Ω-cm²/m²</td>
</tr>
<tr>
<td>Reject concrete</td>
<td>&gt;2000 Ω-cm²/m²</td>
</tr>
</tbody>
</table>

*Clay will be tested using a 0.1 m² sample. 
The test will be conducted at 23°C. 
Clay permeability index values will be based on ASTM C1203*

For concrete not meeting strength requirements, but allowed to remain in place, the payment representing the quantity of concrete for a given day / element’s placement shall be reduced as follows:

For concrete not meeting resistivity / permeability requirements, but allowed to remain in place, the payment representing the quantity of concrete for a given day / element’s placement shall be reduced as follows:

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No Concrete pay adjustments will be implemented under this item but shall be calculated as a shadow program for future specifications.
QC/QA key role in a Performance Specification

- **Contractor Required Quality Control Plans for PCC**
  - Contractor/Producers to define QC process for mix proportioning and delivery
  - DOT to audit QC processes and perform all Quality Assurance activity

- **Department responsible for QA**
  - DOT to audit QC processes and perform all Quality Assurance activity
Ongoing PEM projects:

- PEM Special Specification for PCC Pavement Applications
  - (5) projects to date

- Special Provisions for Performance Engineered Concrete Mixtures (SP-9) for Design Build projects
  - (4) projects to date

- 501 Pilot Special Specification - Item 501.01000001
  - (5) complete, (4 +) in progress
Typical PEM placement
Observations from PEM work completed to date

- In general, cement content was reduced by 10-15% (roughly 40-75 lbs/cy depending on standard requirements for the application).
- In most instances where strength requirements exceeded our standard class mix design (3000 psi), PEM mixes were designed without the need for increased cement content.
- Use of limestone blend cements offer further benefit
- Very few loads found to be out of compliance/rejected.
- Little to no cracking
- Some expected “learning curve” for all – *most all of which has been worked out through partnering & collaboration.*
Communication key to success.....

- Meeting with Contractor Producer within 60 days of award (preferably sooner) to discuss specification objectives and begin conversations
- Collaboration with Producer toward PEM mix design and QC plan development
- Trial batching and monitor
  - Partnering with Regional Materials groups
- Once good results obtained, work can commence
Going Forward - Challenges / Opportunities

**Challenges**
- Resistance to Change
- Mix Development – understanding requirements & longer timeframe
- Newer testing techniques – learning curve
- Early age strength gain - sometimes slower
- 56-day age acceptance?

**Opportunities**
- Better Performing, Longer lasting mixtures
- Optimized mix designs are more efficient and cost effective.
- Improved Sustainability with reduced cement use
Performance Engineered Mixes - Project Experience

Adam Miller – NYSDOT
North Eastern States' Materials Engineers Association
Albany, NY – November 1, 2022
PEM 501 Pilot Projects

- 2020: Region 1: 220 ft long, 2 lane, single span bridge.
- 2021: Region 2: 90 ft long, 2 lane, single span bridge.
- 2021: Region 2: 224 ft long, 6 lane, 2 span bridge.
- 2021: Region 9: 45 ft long, 2 lane, single span bridge.
- 2022: Region 3: 250 ft long, 2 lane, 2 span bridge.

Future PEM Projects

- There are currently (4) PEM projects in place for 2023
Mix Design Review Process

Paper Review & Trial Batch

- Material Sources
- Gradations
- Paste Content
- Target Slump
- Target Air
- Super Air Meter (SAM)
- Surface Resistivity
- Compressive Strengths
Mix Design Achievements/Challenges

Super Air Meter (SAM)

- 150+ side by side tests performed between Type B and SAM.
  - Average difference in Air Content was 0.0%
  - 75% of Standard Class SAM tests were less than 0.30
- Designing for SAM <0.20 has very low failing results in field.
  - 160+ tests done in on PEM projects.
  - 93% of all PEM SAM tests were less than 0.30
  - SAM has been used to save loads with low air content in QC plans.
    - If the air content was less than spec but the SAM number tested on the same sample fell between 0.20 - 0.30, we used the concrete.
Mix Design Achievements/Challenges

Surface Resistivity

- NYSDOT tested over 1400 sets of Standard Class HP cylinders that showed an average 28-day age Surface Resistivity of 39 kΩ-cm.
- For PEM projects:
  - 100 + Surface Resistivity tests conducted (28-day age)
    - 34.5kΩ-cm avg
  - In some instances, the 28-day age Surface Resistivity results did not meet 30kΩ-cm requirement, however when carried out to 56 day-age the results typically exceeded the requirement.
Mix Design Achievements/Challenges

Compressive Strength

- Compressive strength increased with the optimized gradation and reduced paste
- Mixes have demonstrated ability to achieve 5000+ psi in 28 days.
  - D264040 – 5500 psi (92% above 4000 psi)
  - D264350 - 5550 psi (96% above 4000 psi)
  - D264561 – 5455 psi (100% above 4000 psi)
  - D264366 - 5760 psi (100% above 4000 psi)
  - D264331 – 7260 psi (100% above 4000 psi)
- NYSDOT Standard Class HP over the last 3 years
  - 5278 psi - 99.5% above 3000 psi
Mix Design Achievements/Challenges

Optimized Gradation

Standard Gap Graded Class HP Mix design – Only looking at few coarse aggregate sieve sizes

Tarantula Curve
Mix Design Achievements/Challenges

Optimized Gradation

Same Mix as before – Looking at all the sieves

Tarantula Curve
Mix Design Achievements/Challenges

Optimized Gradation

PEM Mix Design – R3 Project – Before Optimization

Tarantula Curve
Mix Design Achievements/Challenges

Optimized Gradation

PEM Mix Design – R3 Project

Tarantula Curve
Sustainability Benefit

- Optimized gradations and reduced cement per cubic yard add up to significant reductions on a project level.
  - D264040: 38,850lb or 19.4 ton reduction in cement vs Class HP
  - D264331: 17,064lb or 8.5 ton reduction in cement vs Class HP
  - D264350: 82,860lb or 41.4 ton reduction in cement vs Class HP
  - D264366: 27,300lb or 13.7 ton reduction in cement vs Class HP
  - D264564: 49,440lb or 24.7 ton reduction in cement vs Class HP
- The **108 tons of cement saved** on these projects would produce 432 cy of Class HP or roughly 508 cy.
- These projects reduce CO2 by 194,400 lbs compared to Class HP concrete.
Lessons Learned

- Paste content increased from 25% to 27%.
- Meeting with Contractor/Producer required within 60 days of notice to proceed.
- Mix submittal/test results required 45 day prior to use. Increased from 30 days.
- Specific sieve sizes called out for coarse aggregate gradations.
- Surface Resistivity being considered at 56-day age instead of 28-day age.
- Early loading requirement added into Note 2 under Table 501-03.
- SAM being utilized as a QC tool in the field.
Questions / Discussion

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