QMC - PEM Test Data Comparison

Iowa Concrete Paving Conference
February 7th, 2020
Des Moines, IA
Todd Hanson, PE Concrete Materials Engineer
Introduction

- Brief History of QMC
- Lessons Learned
- PEM Shadow Project
- QMC vs PEM
- Future
Pavement Placement Issues

• Mid ‘80s to mid ‘90s seemed to get a couple projects a year with workability issues
• Some related to mix & some related to incompatibility
• Since QMC rarely
Direct Relationship To Placement Problems & Long Term Durability

US 169 Webster Co. 2007
Development of QMC Specification

- 1997 First (QMC) project awarded
- Technical Partnering Meetings
- Incentive – Compressive Strength
- A- Mix
QMC History - Strength

- 1998 to 1999 projects -12 projects
  - 28 day third point flexural
    - >600 psi (avg - 1 stdev)
QMC History - Strength

- Multiple Mix Designs
- Fred Carlson Lab
  - 11 mixes for Mason City bypass
QMC History - Strength

- Minimal mix improvement
- Couple projects with significant disincentive
- Issues with long haul distance with soft aggregate
- Changes to QMC Needed

Average 28 Day MOR-TPL vs Average w/c Ratio
IM-80-1(236)-13-78

<table>
<thead>
<tr>
<th>Date</th>
<th>MOR-TPL</th>
<th>w/c ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>13-Aug-99</td>
<td>0.42</td>
<td>0.42</td>
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<tr>
<td>18-Aug-99</td>
<td>0.43</td>
<td>0.43</td>
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<tr>
<td>23-Aug-99</td>
<td>0.44</td>
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<td>28-Aug-99</td>
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<td>0.45</td>
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<tr>
<td>02-Sep-99</td>
<td>0.43</td>
<td>0.43</td>
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<td>07-Sep-99</td>
<td>0.42</td>
<td>0.42</td>
</tr>
<tr>
<td>12-Sep-99</td>
<td>0.41</td>
<td>0.41</td>
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</table>
Do we make better concrete because we test beams?

Or, do we make better beams?

Not a strong correlation of strength to durability
Optimized Gradation in Slipform Rail Experience

- 1999 near Rudd
- Reduced Cement 709 to 603 lbs/cy
- 1st Use of Shilstone Gradation
- Left car running, in case it went south
- But, Placement improved dramatically
Optimized Mix Design for Pavements

Based on Coarseness - Workability Factor Chart

- Improved Placement Characteristics
- Response to vibrator
- Reduced Shrinkage
- Allows for Quality Control
CONCRETE MIX ANALYSIS
INTERPRETING THE COARSENESS FACTOR CHART

The Coarseness Factor Chart was developed by James Shilstone in 1974 following research for the U. S. Army Corps of Engineers for construction in Saudi Arabia. The findings were reported in CONCRETE INTERNATIONAL, June 1990 in a paper titled "Concrete Mixture Optimization" (p. 33). Since introduction, the chart has been extensively used as a means to evaluate the characteristics of concrete mixtures.

The purpose is to address the combined aggregate grading. When aggregates are mixed in concrete, it is the combined grading that affects performance on the job. Strength is seldom the problem. The problems are related to placement, finishing, and durability. While the concrete industry normally classifies aggregates as coarse or fine, the research reflected the need for three size groupings - coarse, intermediate, and fine.

The Coarseness Factor (x-axis) on the chart is the percent of all material retained on the No. 8 sieve that is also retained on the 3/8 sieve. The y-axis is the percent of aggregate passing the No. 8 sieve adjusted for cementitious materials content. The x plotted on the chart reflects the effect of cement content on the effective amount of fine sand. When a "-" is plotted, no adjustment was necessary. The diagonal bar reflects the approximate optimum combined aggregate grading when using rounded gravel or cubically crushed stone and natural sand.

Much has been learned regarding use of this chart. Following is a summary of interpretations derived from many years of experience evaluating thousands of mixtures:

ZONE I: Coarse, gap-graded tends to segregate; ZONE II: Well graded 1-1/2" and 1"; ZONE III: 3/4" and finer; ZONE IV: Sticky - "The Courthouse"; ZONE V: Rocky 0" - Optimum but excellent control required; "1" - Excellent but caution; "2" - Excellent paving and slip form; "3" - High quality slab; "4" - Good general; "5" - Varies to materials and construction needs. Same general trends for Zone III.

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QMC Gradation Incentive 2000-2004

1 Workability Factor VS Coarseness Factor for Combined Aggregate

<table>
<thead>
<tr>
<th>Gradation Zone</th>
<th>Pay Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Box A, Zone 1, 2, &amp; 3</td>
<td>1.03</td>
</tr>
<tr>
<td>Box B, Zone 4</td>
<td>1.02</td>
</tr>
<tr>
<td>Box B, Zone 5</td>
<td>1.00</td>
</tr>
<tr>
<td>Box C</td>
<td>0.98</td>
</tr>
</tbody>
</table>

- III
- IV
- V
- I
QMC Gradation Incentive 2004-2007

1 Workability Factor VS Coarseness Factor for Combined Aggregate

Conversations with Jim Shiltsone
QMC Gradation Incentive 2007-2015

1 Workability Factor VS Coarseness Factor for Combined Aggregate

Assumptions: 564 lbs cement per cubic yard, 1 inch Aggregate, and Slipformed

<table>
<thead>
<tr>
<th>Grade</th>
<th>Workability Factor</th>
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<tr>
<td>II-A</td>
<td>103%</td>
</tr>
<tr>
<td>II-B</td>
<td>102%</td>
</tr>
<tr>
<td>II-C</td>
<td>101%</td>
</tr>
<tr>
<td>II-D</td>
<td>100%</td>
</tr>
<tr>
<td>IV</td>
<td>98%</td>
</tr>
<tr>
<td>I</td>
<td>95%</td>
</tr>
</tbody>
</table>
QMC Gradation 2016 to 2019

1 Workability Factor VS Coarseness Factor for Combined Aggregate

Assumptions: 564 lbs cement per cubic yard, 1 inch Aggregate, and Slipformed

<table>
<thead>
<tr>
<th>Gradation Zone (Materials I.M. 532)</th>
<th>Pay Factor</th>
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<tbody>
<tr>
<td>II</td>
<td>1.00</td>
</tr>
<tr>
<td>IV</td>
<td>0.98</td>
</tr>
<tr>
<td>I</td>
<td>0.95</td>
</tr>
</tbody>
</table>

Lab mix design not required.
QMC Effect of Aggregate Shape

Intermediate Aggregates
QMC – Aggregate Shape

- US 75 Woodbury Co. 2000
- Quartzite CA & IA
  - 45.5% CA/ 19.5% IA/ 35% FA
- Coarse on Shilstone Chart
- Results
  - finishing difficulties
  - edge tear
  - slow production rates
QMC – Aggregate Shape

- US 75 Woodbury 2001
- Quartzite CA & IA
  - 53.5% CA/ 9.5% IA/ 37% FA
- Better Intermediate aggregate shape
- Results
  - better finishability
  - no edge tear
  - normal production rates
Intermediate Aggregate Research

- MLR-2000-03
  - Class 2, 3, 3I pea gravel
  - F/T test salt soaked
  - Minimal difference
- Allow pea gravel up to 15% lower durability class
- Improved Workability
QMC - Aggregate Shape

• IA 60 Sioux County 2005
• Quartzite CA & Pea Gravel IA
  – 42.5% CA/ 14.5% IA/ 43% FA
• Results
  – Excellent finishability
  – Excellent smoothness
QMC - Aggregate Shape

- Quartzite CA Stockpile
- Pea Gravel IA Stockpile
QMC – Aggregate Shape

• US 20 Woodbury County 2016
• Gravel CA & Pea Gravel IA
  – 48% CA/ 10% IA/ 42% FA
• Key results
  – Excellent finishability
  – normal production rates
  – Edge tended to dip at baskets
Too workable or Too much paste ??
QMC Lessons Learned Summary

- Partnership with contractors expedited changes
- Placement impacts durability
- Excessive handling with soft aggregates affect strength
- Well graded aggregates improve placement
- Aggregate shape and texture affect placement
- Slag and fly ash reduce permeability
How does QMC mix compare with PEM?
PEM – Critical Parameters

- Cold weather resistance (cold locations)
  - SAM Air Meter, LTDSC- Salt Resistance
- Transport properties/permeability (everywhere)
  - Resistivity/Formation Factor
- Aggregate stability (everywhere)
  - ASR/D-Cracking
- Workability (everywhere)
  - Box Test/V-Kelly
- Strength (everywhere)
  - Flexural or Compressive
- Shrinkage (dry locations)
  - Ring Test
PEM Pooled Fund Research Project

- Shadow projects
- Investigate ruggedness of test methods
- Develop specification limits
- Collect data for modelling
- Contractor QC Testing
- FHWA Mobile Concrete Trailer
Iowa PEM Shadow Project

- US 20 Woodbury Co. 2018
- Comprehensive QC Plan
  - Control Charts
  - Air PWL
  - SAM Test
  - Box Test
  - Resistivity/Formation Factor
  - Calcium Oxy Chloride Potential
  - Trial batch mix design reduced cement
Super Air Meter (SAM)

- Test at 14.5, 30 & 45 psi
  - Release and repeat
- Air content & SAM number
- SAM number correlates to spacing factor => F/T Test
- Mix Design SAM # <0.20
- Field SAM # <0.30 & Air>6%
Workability

• Slump Test
  – Uniformity Test tells nothing about response to vibration

• Box Test and V-Kelly
  – Response to Vibration

• Factors in Workability
  – Aggregate Gradation
  – Paste Content
  – Admixtures
Workability - Box Test

- Fill box to 9.5 inches
- Insert vibrator 12,500 vpms
  - 3 seconds to bottom
  - 3 seconds out
- Edges of box are removed and inspected
- PEM Limits <30% Voids or Rating of 2 or less
Combined Aggregate Gradation

Average Project Workability Factor VS Coarseness Factor

Coarseness Factor (percent)

Workability (percent)

III

IV

II

I

V

Boundary Line
Combined Aggregate Gradation

Tarantula Curve Combined Aggregate Gradation, % Retained
Transport Properties - Resistivity

- Cast Two Cylinders
- Place in bucket with (Ca, Na, K) hydroxide solution
- Test Resistivity at 3, 7, 28, 56 and 91 days
Transport Properties – Formation Factor

US 20 Test Results w 20% fly ash

- Resistivity Low Range
  - 18-20 k-ohm-cm
- Formation Factor Moderate to Low range - 957

<table>
<thead>
<tr>
<th>ASTM C1202 Classification</th>
<th>Charge Passed (Coulombs)</th>
<th>Resistivity (kΩ · cm)$^a$</th>
<th>Formation Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>&gt;4,000</td>
<td>&lt;5.2</td>
<td>520</td>
</tr>
<tr>
<td>Moderate</td>
<td>2,000–4,000</td>
<td>5.2–10.4</td>
<td>520–1,040</td>
</tr>
<tr>
<td>Low</td>
<td>1,000–2,000</td>
<td>10.4–20.8</td>
<td>1,040–2,080</td>
</tr>
<tr>
<td>Very low</td>
<td>100–1,000</td>
<td>20.8–207</td>
<td>2,080–20,700</td>
</tr>
<tr>
<td>Negligible</td>
<td>&lt;100</td>
<td>&gt;207</td>
<td>20,700</td>
</tr>
</tbody>
</table>

$^a$ Calculated using first principles.
Calcium Oxychloride Potential

• Salts can cause chemical attack
  – Reaction between Ca(OH)$_2$ and CaCl$_2$ or MgCl$_2$
  – Expands $\sim$30% and forms above 32F

• Low temperature differential scanning calorimetry (LT-DSC)

• Reduce potential with use of SCM’s
Calcium Oxychloride Potential

- Limit the CaOXY to less than 0.15 (g/100g)
- 20% Class C fly ash replacement met the limit
- More slag / fly ash replacement further reduces potential
Dr. Taylor estimated cement content based on dry rodded unit weight of combined aggregate.
PEM Mix Design

• Some concerns lowering cement content of standard A mix for shoulder
  – Used QMC proportions
• Performed trial batch
  – Box Test
• Placement went very well
PEM Mix Design

Box Test Ranking

Paving Date

0 1 2 3 4
Box Test Rank
## 2019 PEM Data

### 2019 PROJECT AVERAGES

<table>
<thead>
<tr>
<th>Location</th>
<th>SAM #</th>
<th>BOX #</th>
<th>W/C</th>
<th>Resistivity</th>
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<tbody>
<tr>
<td>Polk I35</td>
<td>0.23</td>
<td>1.2</td>
<td>0.39</td>
<td>11.89</td>
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<tr>
<td>Harrison I29</td>
<td>0.22</td>
<td>1.1</td>
<td>0.40</td>
<td>15.67</td>
</tr>
<tr>
<td>Black Hawk US 20</td>
<td>0.18</td>
<td>1.4</td>
<td>0.40</td>
<td>7.15*</td>
</tr>
<tr>
<td>Plymouth US 75</td>
<td>0.20</td>
<td>1.3</td>
<td>0.40</td>
<td>12.64</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>0.21</td>
<td>1.25</td>
<td>0.40</td>
<td>11.84</td>
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</tbody>
</table>

* Aggregates with high absorption affect results
Table 3—Specification Worksheet

<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>
</tr>
</thead>
<tbody>
<tr>
<td>6.3 Concrete Strength</td>
<td>Flexural Strength</td>
<td>T 97</td>
<td>4.1 MPa</td>
<td>Yes</td>
<td>Yes</td>
<td>Choose either or both</td>
</tr>
<tr>
<td></td>
<td>Compressive Strength</td>
<td>T 22</td>
<td>24 MPa</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

6.4 Reducing Unwanted Slab Warping and Cracking Due to Shrinkage (if cracking is a concern)

<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>
</tr>
</thead>
<tbody>
<tr>
<td>6.4.1.1</td>
<td>Volume of Paste</td>
<td></td>
<td>25%</td>
<td>Yes</td>
<td>No</td>
<td>Choose only one</td>
</tr>
<tr>
<td>6.4.1.2</td>
<td>Unrestrained Volume Change</td>
<td>ASTM C157</td>
<td>420 µe</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>6.4.1.3</td>
<td>Unrestrained Volume Change</td>
<td>ASTM C157</td>
<td>390, 420, 480 µe</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>6.4.2.2</td>
<td>Restricted Shrinkage</td>
<td>T 334</td>
<td>Crack free</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>6.4.2.3</td>
<td>Restricted Shrinkage</td>
<td>TF XXX</td>
<td>≤ 60% /f′</td>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>6.4.2.4</td>
<td>Probability of Cracking</td>
<td>Appendix X1</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>
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</tbody>
</table>

6.5 Durability of Hydrated Cement Paste for Freeze–Thaw Durability

<table>
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<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>
</tr>
</thead>
<tbody>
<tr>
<td>6.5.1.1</td>
<td>Water to Cementitious Ratio</td>
<td></td>
<td>0.45</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>6.5.1.2</td>
<td>Fresh Air Content</td>
<td>T 152, T 196, TP 118</td>
<td>5 to 8</td>
<td>%</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>6.5.1.3</td>
<td>Fresh Air Content/SAM</td>
<td>T 152, T 196, TP 118</td>
<td>24% air, ≤0.2</td>
<td>%, psi</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>6.5.2.1</td>
<td>Time of Critical Saturation</td>
<td>“Bucket Test” Specification</td>
<td>30 yr</td>
<td>No</td>
<td></td>
<td></td>
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<tr>
<td>6.5.3.1</td>
<td>Deicing Salt Damage</td>
<td></td>
<td>35%</td>
<td>Yes</td>
<td>Yes</td>
<td>Choose only one</td>
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<tr>
<td>6.5.3.2</td>
<td>Deicing Salt Damage</td>
<td>M 224</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>6.5.4.1</td>
<td>Calcium Oxide Chloride Limit</td>
<td>Test sent to AASHTO</td>
<td>≤0.15 g CaO/CXV/g paste</td>
<td>Yes</td>
<td>No</td>
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6.6 Transport Properties

<table>
<thead>
<tr>
<th>Section</th>
<th>Property</th>
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<th>Specified Value</th>
<th>Mixture Qualification</th>
<th>Acceptance</th>
<th>Selection Details</th>
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<tbody>
<tr>
<td>6.6.1.1</td>
<td>Water to Cementitious Ratio</td>
<td></td>
<td>≤0.45 or ≤0.50</td>
<td>Yes</td>
<td>Yes</td>
<td>Choose only one</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>Yes</td>
<td>Yes</td>
<td></td>
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<tr>
<td>6.6.2.1</td>
<td>Ionic Penetration, F Factor</td>
<td>Appendix X2</td>
<td>25 mm at 30 yr</td>
<td>Yes, F</td>
<td>Through ρ</td>
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6.7 Aggregate Stability

<table>
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<th>Section</th>
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<th>Specified Value</th>
<th>Mixture Qualification</th>
<th>Acceptance</th>
<th>Selection Details</th>
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<tbody>
<tr>
<td>6.7.1</td>
<td>D Cracking</td>
<td>T 161, ASTM C1646</td>
<td></td>
<td>Yes</td>
<td>No</td>
<td></td>
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<tr>
<td>6.7.2</td>
<td>Alkali Aggregate Reactivity</td>
<td>R 80</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
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6.8 Workability

<table>
<thead>
<tr>
<th>Section</th>
<th>Property</th>
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<th>Specified Value</th>
<th>Mixture Qualification</th>
<th>Acceptance</th>
<th>Selection Details</th>
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</thead>
<tbody>
<tr>
<td>6.8.1</td>
<td>Box Test</td>
<td>Appendix X3</td>
<td>≤0.25 mm, ≤30%</td>
<td>surface void</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>6.8.2</td>
<td>Modified V/Kelly Test</td>
<td>Appendix X4</td>
<td>15–30 mm/root s</td>
<td>No</td>
<td></td>
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</table>

Notes:
STRENGTH

Iowa DOT Current Practices QMC
- Average 635 PSI Flexural
- Average 5800 PSI Compressive Class C
## SHRINKAGE - CRACKING

### Iowa DOT Current Practices QMC
- Volume of Paste = 24.3%

| 6.4.1.1 | Volume of Paste | — | ≤ 25% | | Yes | No | Choose only one
<table>
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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 days</td>
<td>Yes</td>
<td>No</td>
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<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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<td>6.4.2.2</td>
<td>Restrained Shrinkage</td>
<td>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>T 363</td>
<td>σ(Re) &lt; 60% f'</td>
<td>At 7 days</td>
<td>Yes</td>
<td>No</td>
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<td>6.4.2.4</td>
<td>Probability of Cracking</td>
<td>Appendix X1</td>
<td>As specified</td>
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<td>Yes</td>
<td>No</td>
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<td>Commentary</td>
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**FREEZE-THAW DURABILITY**

<table>
<thead>
<tr>
<th>6.5.1.1</th>
<th>Water to Cementitious Ratio</th>
<th>0.45</th>
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<th>Yes</th>
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<tbody>
<tr>
<td>6.5.1.2</td>
<td>Fresh Air Content</td>
<td>T 152, T 196, TP 118</td>
<td>5 to 8</td>
<td>%</td>
</tr>
<tr>
<td>6.5.1.3</td>
<td>Fresh Air Content/SAM</td>
<td>T 152, T 196, TP 118</td>
<td>≥4 to 8% air, ≤0.2 psi</td>
<td>%</td>
</tr>
<tr>
<td>6.5.2.1</td>
<td>Time of Critical Saturation</td>
<td>ASTM C1585</td>
<td>30 year</td>
<td>Yes</td>
</tr>
<tr>
<td>6.5.3.1</td>
<td>Deicing Salt Damage</td>
<td>—</td>
<td>35%</td>
<td>SCM</td>
</tr>
<tr>
<td>6.5.3.2</td>
<td>Deicing Salt Damage</td>
<td>M 224</td>
<td>—</td>
<td>Topical treatment</td>
</tr>
<tr>
<td>6.5.4.1</td>
<td>Calcium Oxycarbide Limit</td>
<td>T 365</td>
<td>&lt;0.15 g CaOXY/g paste</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Iowa DOT Current Practices QMC**
- w/c Ratio = 0.42 max.
- Air Content 6 to 10%
  - SAM Results all below 0.30
- Calcium Oxycarbide Limit = 0.15 g/100g
TRANSPORT PROPERTIES

Iowa DOT Current Practices QMC
• w/c Ratio = 0.42 max.
• Formation Factor ~1000 w 20% C ash
• Lower when using blended cements and fly ash
### AGGREGATE STABILITY

<table>
<thead>
<tr>
<th>6.7.1</th>
<th>D Cracking</th>
<th>T 161, ASTM C666</th>
<th>—</th>
<th>—</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.7.2</td>
<td>Alkali Aggregate Reactivity</td>
<td>R 80</td>
<td>—</td>
<td>—</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

Iowa DOT Current Practices QMC
- Aggregates – Iowa DOT Methods
WORKABILITY

Iowa DOT Current Practices QMC

- Workability Typically Good
- Combined Aggregate Grading for 20 years
Where are we going?

- Iowa QMC Mixes compare close with PEM
- Use PEM testing to validate QMC Mixes at Reduced Cement Content
  - 0.099 Abs Vol Cement – (1st Iteration)
    - 524 lbs/cy Type I/II
    - 517 lbs/cy Type IS(20)
    - 499 lbs/cy Type IP(25)
  - Trial Mix Design - SAM Air Test and Box Test
  - QC Testing - SAM Meter 1/day, Box Test – 1/wk
- Eventually, modify QMC DS
What can you do?

• Gathering data on SAM testing, workability, resistivity, etc.
• Get a SAM Meter and practice using
  – Purchase
  – FHWA or ICPA equipment loan
• Box Test – Build box
  – Vibrator requirements
• Try lower cement mix on shoulders

V-Kelly Workability

[Graph showing V-Kelly Workability with different data points]
Questions?

For More Information
https://cptechcenter.org/performance-engineered-mixtures-pem/