Minnesota’s Improved Aggregate/Concrete Specifications for Enhanced Durability

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North Carolina Concrete Pavement Conference
October 28, 2014
WHAT DRIVES CONCRETE PAVEMENT PERFORMANCE?

- Durability
  - Materials
  - Workmanship
- Smoothness
  - What the travelling public cares about
In 1995, MnDOT decided to move away from strength to a low w/c ratio specification for acceptance to achieve more durable and longer lasting pavements.

Pilot projects with different variables tried:
- Bought Water Reducer for Contractor
- Statistically based aggregate quality spec
- Well-Graded Aggregate Variations
- Use of incentives
- Use of 1 ½” coarse aggregate
Minnesota’s Concrete Paving Spec

- 3 Principal factors that guide the current spec:
  - Mix durability
  - Curing Practices
  - Incentives/disincentives
- W/C Ratio (Max $3.00/cy)
- Well-Graded Aggregate (Max $2.00/cy)
- Coarse Aggregate Quality (Max $2.00/cy)
- Smoothness (Max $890/0.1 mile segment)
Concrete Strength

- Historically
  - Strength achieved in 7 days
  - HE mixes achieved strength in 3 days

- W/C specs
  - Achieve strength in $\approx 3$ days
  - HE mixes can be designed to easily achieve opening times in 24 hours.

- Strength is not a specification but a side effect of low w/c is:
  - Pre w/c spec core strength average $\approx 4500$ psi
  - Post w/c spec core strength average $> 6000$ psi
GOALS OF WATER/CEMENTITIOUS INCENTIVES

- Make concrete more durable by reducing permeability and thus make it more freeze–thaw resistant and less susceptible to aggregate deteriorations.
- Reduce w/c by taking out water, not by increasing cementitious content.
"The single parameter that has the largest influence on durability is the w/c ratio."
~ Sidney Mindess and J. Francis Young

"Chemical Admixtures for Concrete" 2nd Edition by M.R. Rixom and N.P. Mailvaganam
## W/C Ratio and Cementitious Content

<table>
<thead>
<tr>
<th>Year</th>
<th>Max. w/c ratio</th>
<th>Minimum Cement</th>
<th>Minimum Cementitious</th>
<th>Maximum Cementitious</th>
<th>% Fly Ash Allowed</th>
<th>% Slag Allowed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-1996</td>
<td>0.46</td>
<td>450</td>
<td>530</td>
<td>850</td>
<td>15</td>
<td>35</td>
</tr>
<tr>
<td>1996</td>
<td>0.42</td>
<td>450</td>
<td>530</td>
<td>600</td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td>2000</td>
<td>0.40</td>
<td>450/420</td>
<td>530</td>
<td>600</td>
<td>25/30**</td>
<td>35</td>
</tr>
<tr>
<td>2002</td>
<td>0.40</td>
<td>400/385*</td>
<td>530</td>
<td>600</td>
<td>30**</td>
<td>35</td>
</tr>
<tr>
<td>2015</td>
<td>0.40/0.42</td>
<td>400</td>
<td>530</td>
<td>615</td>
<td>33</td>
<td>35</td>
</tr>
</tbody>
</table>

Total Alkalis (Na2Oe) in Cement 0.6%

Total Alkalis (Na2Oe) in Concrete based upon cement content 3.0 lbs/yd³
Advantages of w/c ratio

- Immediate results
- Eliminate testing variables related to strength
- Assured quality & performance
- Increased strengths
Determination of w/c ratio incentive

- Based on the Contractor’s batch ticket as verified by Agency testing
- Agency does moisture testing
- The Agency uses the actual water and cementitious contents from an average of 10 batch tickets
- Agency testing to verify water content is performed according to AASHTO TP23–93 “Standard Test Method for Water Content of Freshly Mixed Concrete Using Microwave Oven Drying”
Possible Sources of Error in Water Content

- Batch Ticket vs. Microwave Oven Test
  - Water meter calibration
  - Testing errors
- Sampling & testing procedures
- Equipment

*Used as a verification tool ~ not for acceptance*
# Implementation of w/c ratio

<table>
<thead>
<tr>
<th>Year</th>
<th>Maximum w/c ratio</th>
<th>Minimum w/c ratio for incentive</th>
<th>Target Air Content (+/− 1.5%)</th>
<th>Admixtures Allowed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre−1996</td>
<td>0.46</td>
<td>NA</td>
<td>5.5%</td>
<td>None Allowed</td>
</tr>
<tr>
<td>1996</td>
<td>0.40</td>
<td>0.35</td>
<td>6.5%</td>
<td>Type A Water Reducers</td>
</tr>
<tr>
<td>2000</td>
<td>0.40</td>
<td>0.35</td>
<td>7.0%</td>
<td>Type A and Type A Mid Range Water Reducers</td>
</tr>
<tr>
<td>2010</td>
<td>0.40</td>
<td>0.35</td>
<td>7.0%</td>
<td>Viscosity Modifying Admixtures (VMA) and Hydration Stabilizers</td>
</tr>
<tr>
<td>2011</td>
<td>0.40</td>
<td>0.37</td>
<td>7.0%</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>0.40/0.42</td>
<td>0.37/0.39</td>
<td>7.0% (+2/−1%)</td>
<td></td>
</tr>
</tbody>
</table>
2015 Fly Ash and Cement Issues

- What happened this year?
  - Flooding (Mississippi River)
  - Railroads prioritizing cargo with oil/frac sand
    - Delivery is unreliable (unless hauling unit trains (100+ cars)
    - The railroads are controlling supply to MN
    - Delivering coal to power plant is not consistent either
  - Aging infrastructure of cement plants
  - Regulatory Issues ~ Conversion to natural gas
Fly Ash and Cement Issues

- Why did MnDOT have to react?
  - Current Specifications push toward higher quality fly ash (Class F)
  - One failure using ternary – left it a prohibited option
  - We had it good while it lasted!!!
Current MnDOT Certified Sources
Current Efforts

- Review AASHTO PP65 – Determining the Reactivity of Concrete Aggregate and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction
- Reviewed over 3400 tests ranging from 1999 – 2014
- ASTM C1260 and ASTM C1567 MnDOT Modified (14 day expansion)
Current Efforts

- Allow Ternary Concrete (Up to 40% SCM)
- Reduce minimum SCM based upon ability to mitigate (less conservative – but more economical???)
- This change may ease the pain – but transportation and regulatory issues will continue to be a battle.
## Proposed Paving Spec Changes for ASR Mitigation

### Table 2301-3
Fine Aggregate ASR Mitigation Requirements

<table>
<thead>
<tr>
<th>14-day Fine Aggregate Unmitigated Expansion Limits (worst case)</th>
<th>Class F Fly Ash</th>
<th>Class C Fly Ash</th>
<th>Slag</th>
<th>Slag/Class F Fly Ash</th>
<th>Slag/Class C Fly Ash</th>
<th>IS(20)/Class F Fly Ash</th>
<th>IS(20)/Class C Fly Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 0.150</td>
<td></td>
<td></td>
<td></td>
<td>No mitigation required</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 0.150 – 0.200</td>
<td>Minimum 20%</td>
<td>Minimum 20%</td>
<td>35%</td>
<td>20% Slag with a minimum of 15% Class F fly ash</td>
<td>20% Slag and 20% Class C fly ash</td>
<td>Type IS(20) with a minimum of 15% Class F</td>
<td>Type IS(20) with a minimum of 15% Class C</td>
</tr>
<tr>
<td>&gt; 0.200 – 0.300</td>
<td>Minimum 20%</td>
<td>Minimum 30%</td>
<td>35%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 0.300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>The Department will reject the fine aggregate</td>
<td></td>
</tr>
</tbody>
</table>
## W/C Ratio Payment Incentive/Disincentives Per Cubic Yard

<table>
<thead>
<tr>
<th>QI Value</th>
<th>Pre–2011 $/Cubic Yard</th>
<th>2011–2014t $/Cubic Yard</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.35 or less</td>
<td>4.00</td>
<td>–</td>
</tr>
<tr>
<td>0.36</td>
<td>3.00</td>
<td>–</td>
</tr>
<tr>
<td>0.37</td>
<td>2.00</td>
<td>3.00</td>
</tr>
<tr>
<td>0.38</td>
<td>1.25</td>
<td>1.75</td>
</tr>
<tr>
<td>0.39</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>0.40</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>0.41</td>
<td>-0.50</td>
<td>-0.50</td>
</tr>
<tr>
<td>0.42</td>
<td>-1.25</td>
<td>-1.75</td>
</tr>
<tr>
<td>0.43</td>
<td>-2.00</td>
<td>-3.00</td>
</tr>
<tr>
<td>0.44</td>
<td>-3.00</td>
<td>As determined by the Concrete Engineer</td>
</tr>
<tr>
<td>0.45+</td>
<td>As determined by the Concrete Engineer</td>
<td>–</td>
</tr>
</tbody>
</table>
## 2015 W/C Ratio Incentive/Disincentives

<table>
<thead>
<tr>
<th>W/C Ratio Test Result</th>
<th>Payment incentive/disincentive per cu. yd</th>
<th>W/C Ratio Test Result</th>
<th>Payment incentive/disincentive per cu. yd</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤ 0.37</td>
<td>+$3.00</td>
<td>≤ 0.39</td>
<td>+$3.00</td>
</tr>
<tr>
<td>0.38</td>
<td>+$1.75</td>
<td>0.40</td>
<td>+$1.75</td>
</tr>
<tr>
<td>0.39</td>
<td>+$0.50</td>
<td>0.41</td>
<td>+$0.50</td>
</tr>
<tr>
<td>0.40</td>
<td>$0.00</td>
<td>0.42</td>
<td>$0.00</td>
</tr>
<tr>
<td>0.41</td>
<td>−$0.50</td>
<td>0.43</td>
<td>−$0.50</td>
</tr>
<tr>
<td>0.42</td>
<td>−$1.75</td>
<td>0.44</td>
<td>−$1.75</td>
</tr>
<tr>
<td>≥ 0.43</td>
<td>Determined by the Concrete Engineer</td>
<td>≥ 0.45</td>
<td>Determined by the Concrete Engineer</td>
</tr>
</tbody>
</table>

When using fly ash

When using slag/ternary

Determined by the Concrete Engineer
Enforcement is key!

- Do not place concrete mix not meeting the 0.40 water/cement ratio requirement when using fly ash and 0.42 when using slag/ternary in the work.
- Water added to the surface of the concrete without the approval of the Engineer, is not eligible for w/c ratio or ride incentives
GOALS OF AGGREGATE QUALITY INCENTIVES

- Reduce life cycle costs by increasing pavement life by enhancing aggregate durability
## COARSE AGGREGATE QUALITY

<table>
<thead>
<tr>
<th>Year</th>
<th>Class A – Granites, Gneiss, Quartzites</th>
<th>Class B – Carbonates, Dolostones</th>
<th>Class C – Natural Gravels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997 – present</td>
<td>$1.00/cu. yd</td>
<td>$1.00/cu. yd</td>
<td>$1.00/cu. yd</td>
</tr>
<tr>
<td>2000 HPC Spec Only</td>
<td>$1.90/cu. yd</td>
<td>$1.90/cu. yd</td>
<td>$1.90/cu. yd</td>
</tr>
</tbody>
</table>

*Only pay on the 2 largest fractions of coarse aggregate*

- **Class A – Automatic incentive**
- **Class B – Lower % Absorption in aggregate (1.75% Max)** ~Ave 1.40% or less
- **Class C – Reduced % carbonate in aggregate (30% Max)** ~Ave 20.0% or less
GOALS OF WELL-GRADED AGGREGATE INCENTIVE

- Promotes lower water demand, leading to lower w/c ratios and therefore reduces permeability
- Reduces segregation
- Promotes ease of placement (workability and finishability)
- Reduces paste content therefore reduces risk of shrinkage cracks
MnDOT Gradation Requirements

- Require 2 Fractions of coarse aggregate
  - $\frac{3}{4}"+$ and $\frac{3}{4}"-$
  - 4 aggregate bins typical
  - Seen as many as 6 aggregates
- Provide a Job Mix Formula (JMF) ~ composite gradation of all aggregates
INCENTIVES FOR WELL-GRADED AGGREGATE

- Incentive paid on Contractor’s gradation results
- Gradations run by Contractor and verified by Agency with split samples
- Based on the average of 4 gradations per day
Well-graded aggregate

Optional Gradation Incentive Specification
(Stay in the Area Between Lines)

Coarseness Factor Chart

Tarantula Bounds Comparison
## Well-graded Aggregate

<table>
<thead>
<tr>
<th>Year</th>
<th>Optional 8 – 18% Retained</th>
<th>Optional 7 – 18% Retained</th>
<th>Required HPC 8 – 18% Retained</th>
<th>Alternate Bid 6 – 18% Retained</th>
<th>Workability and Coarseness Factor – ZONE II–A</th>
<th>Tarantula Curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>$0.50</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>1998</td>
<td>$2.00</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>2000</td>
<td>$2.00</td>
<td>$0.50</td>
<td>−$5.00</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>2010</td>
<td>$2.00</td>
<td>$0.50</td>
<td>NA**</td>
<td>−$2.00</td>
<td>$2.00</td>
<td>NA</td>
</tr>
<tr>
<td>2015</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>$2.00</td>
</tr>
</tbody>
</table>

**ELIMINATED HPC PAVING SPECIFICATIONS
Shilstone Workability/Coarseness
% of Fines over Time (Tarantula)
Tarantula Bounds Comparison

1996–1998

2014
Importance of Concrete Curing

- Critical for low w/c ratio concrete
- Probably the most ignored process of concrete paving
- Mn/DOT Specs require blanket cure or membrane cure
- Membrane cure requires poly-alpha-methyl styrene (AMS)
  - 5 to 10 TIMES (not %) less water loss at 1 and 3 days according to MnDOT lab tests
Concrete Curing

- Pre–1999
  - Water Based Curing Compound
- 1999 – present
  - Poly–alpha methyl styrene (AMS)
- 2005 – present
  - Apply homogeneously to provide a uniform solid white opaque coverage on all exposed concrete surfaces (equal to a white sheet of typing paper).
Equal to a white sheet of typing paper
Other efforts to ensure quality

- Vibration Monitoring Requirements for Slipform Paving Applications
- Testing before and after paver to determine the air loss due to consolidation
  - Establishment of Air Loss Correction Factor (ACF) ~ Max 5.0%
- Dowel Bar Alignment Testing
- Contractor Quality Control testing that counts
Dowel Bar Alignment Specs

- Contractor required to provide and use MIT–T2
- Quality Control Plan for anchoring and checking baskets
- Enforcement is the most critical aspect of this specification
- If a spall occurs during construction – do not do a partial depth repair.
- MnDOT has 4 available for use
MIT–T2 Spec

- User Manual available on Concrete Unit website
- Agency and Contractor personnel shall mutually use this non-destructive testing device several times a day during concrete pavement construction.
- Does not relieve the Contractor of the requirement to properly place the concrete reinforcement and dowel bars as shown in the plans
QC Plan for Anchoring Baskets

- At least 7 days prior to paving, the Contractor is required to submit a QC plan for anchoring baskets
  1. Proposed type and number of fasteners
  2. Proposed installation equipment
  3. Dowel basket assembly anchoring plan (i.e. Anchored all basket assemblies prior to concrete placement, one lane at a time, anchor all basket assemblies during the concrete placement operation, etc.)
  4. Action plan if mis-aligned baskets are identified during concrete pavement placement

- The Engineer will suspend paving operations if the Contractor fails to comply with their Quality Control Plan.
Anchoring Dowel Baskets

- Before the beginning of concrete pavement placement and each day prior to beginning paving, demonstrate the fastening method to the Engineer for approval.
- Consider dedicating a person to making sure baskets were anchored and/or use the MIT–Scan T2
### MIT–Scan T2 Contractor Hardened Concrete Testing Rates

<table>
<thead>
<tr>
<th></th>
<th>On First Day</th>
<th>If First Day Acceptable</th>
<th>If First Day Not Acceptable</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transverse Joints</strong></td>
<td>7 per 1000 ft (Random)</td>
<td>4 per 1000 ft (Random)</td>
<td>Increase rate</td>
</tr>
<tr>
<td><strong>Longitudinal Joints</strong></td>
<td>75 ft per 1000 ft</td>
<td>75 per 3000 ft</td>
<td>Increase Rate</td>
</tr>
</tbody>
</table>

Contact the Concrete Engineer for recommendations if alignment tolerances are not met.
Minimum Plastic Concrete Testing Rates

- Utilize a walk bridge that spans the width of the pavement.
- After locating both the upstream and downstream limits of the dowel bar basket, ensure the proposed saw cut is centered on the dowel bars (± 3 inches) and that the dowels remain anchored parallel to the roadway centerline.
- After locating both ends of the tie bar, ensure the proposed saw cut is centered on the tie bar (± 5 inches).
Discussion of Incentives

To Be Continued…
Thank You

Questions?