Minnesota DOT Path from Prescription to Performance
How do we implement?

Maria Masten, PE
MnDOT Concrete Engineer

Research Pays Off
September 20, 2016
WHAT DRIVES CONCRETE PAVEMENT PERFORMANCE?

- Durability
  - Materials
  - Workmanship

- Smoothness
  - What the travelling public cares about
MnDOT’s Path

- Prescriptive...
- Thinking outside the prescriptive box...
- Performance...
Prescriptive....

- Pavements from the early 80’s were showing premature deterioration
Thinking Outside the Prescriptive Box....

- In 1995, MnDOT moved away from strength to low w/c ratio specification for acceptance
- 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 Paving Specifications

<table>
<thead>
<tr>
<th>Pre 1995</th>
<th>Post 1995</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical w/c ratio – 0.46</td>
<td>w/c ratio ≤ 0.40</td>
</tr>
<tr>
<td>Min Cement – 450 lb</td>
<td>Min Cement – 400 lb</td>
</tr>
<tr>
<td>Min Cementitious – 530 lb</td>
<td>Min Cementitious – 530 lb</td>
</tr>
<tr>
<td>15% fly ash allowed</td>
<td>Max Cementitious – 600 lb</td>
</tr>
<tr>
<td>No admixtures allowed</td>
<td>30% max fly ash allowed</td>
</tr>
<tr>
<td>Air Content – 5.5% ± 1.5%</td>
<td>Admixtures allowed</td>
</tr>
<tr>
<td></td>
<td>Air Content – 7.0% ± 1.5% (≥ 5.0 behind paver)</td>
</tr>
</tbody>
</table>
What About 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:
  - Pre w/c spec core strength average $\approx 4500$ psi
  - Post w/c spec core strength average $> 6000$ psi
Minnesota’s Concrete Paving Spec

- 3 Principal factors that guide the current spec:
  - Mix durability
  - Incentives/disincentives
    - Max w/c Ratio
    - Coarse Aggregate Quality
    - Well-Graded Aggregate Optional Incentive
  - Curing Practices
W/C Ratio Specifications

- Immediate results
  - How? – we cook concrete in the microwave
  - Pay off batch tickets as verified by microwave test
- Eliminate testing variables related to strength
- Assured quality & performance
- Increased strengths
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.
Optional Well-graded aggregate Incentive

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

![Graph showing percentage retained vs sieve size for different gradation specifications.]

Tarantula Bounds Comparison

![Graph showing workability factor vs coarseness factor, with a workability box indicated.]

Coarseness Factor Chart

![Diagram with workability box and gradation specifications.]

Percent Retained (%) vs Sieve Number

![Graph showing percent retained vs sieve number for different gradation specifications.]

---

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

Workability Factor

Coarseness Factor

Sieve Number

Percent Retained (%)
How Did The Transition Go?

- Water reducers
- Cement
- Fly ash
- Sand
- Aggregate gradation
- Recycled aggregates
- Finishing
- Curing
- Ride

It’s a “system”
How Do We Get Contractor Buy In To These Ideas?

- Reward excellence
- Reward innovation
- Encourage new ideas
- Allow for mistakes and failure
How Did We Work Through The Changes And Get Contractor Buy In?

- Communication!!!
  - Contractors need to know what the objectives are
  - Contractors need to know what has worked and what hasn’t
  - Contractors need to be given leeway/opportunity to learn
- Shared risk
- More carrot than stick
Did MnDOT Spec Changes make a difference?
Ongoing Investigation of Benefits of the MnDOT w/c Specification

- Pre–1996 (19 projects)
- 1996 & After (15 projects)
Lower Permeability
- Concrete holds less water
- Fights the ingress of deicers
- Lower critical saturation level
- Can’t transport as much water
How Are We Doing?

- Contractors believe in and buy into the incentive system.
  - Contractors Will Reduce Their Bids Partially To Account For Some Of The Expected Incentive To Assure Being The Low Bidder
- After 17+ years little signs of deterioration
- All noticeable defects appear to be construction related
- Smoothness has improved
- Durability has improved
Performance Engineered Mixes Expert Task Group

- FHWA Initiative – motivated by MAP–21 legislation that focuses on performance
- MnDOT currently involved in ETG
- Implementation needs Champion States:
  - Indiana, Iowa, Michigan, Minnesota, Nebraska, South Dakota, Wisconsin, Illinois Tollway, Manitoba
  - Paving Industry Representatives participate on the Champion State phone calls
- Step 1 – AASHTO Provisional Specification for Performance Engineered Concrete Mixes
Where do Performance Engineered Mixes fit into MnDOT’s plans?

- Entered a data gathering mode on concrete paving projects through consultant testing (AET)
  - SAM testing
  - Box testing
  - Vkelly ball testing
  - Aggregate Voids Testing
  - Resistivity (AET and MnDOT)
  - Formation Factor (MnDOT)
Super Air Meter (SAM)

- AASHTO Provisional Standard TP 118
  - Modified version of typical pressure meter (ASTM C231)
  - Two sequential pressurizations of the concrete, the difference between the pressure steps calculates the SAM Number, which is correlated with the average spacing between air voids in the concrete mixture.

Photo courtesy of Dr. Tyler Ley, OSU
Super Air Meter (SAM)

Slide courtesy of Dr. Tyler Ley, OSU

SAM limit 0.20 – 68% agreement
SAM limit 0.25 – 79% agreement
MnDOT SAM Data

Slide courtesy of Dr. Tyler Ley, OSU
The Box Test

- A simple test that examines:
  - Response to vibration
  - Filling ability of the grout
  - Ability of the slip formed concrete to hold a sharp edge (cohesiveness)

- The Slump test can not tell us this!

- Slide courtesy of Dr. Tyler Ley, OSU
Box Test

- In most cases, the box test has proven out very workable concrete mixes
Surface Resistivity

- Measurement used as indicator of durability
- Excellent Tool – however flaws do exist
- Concrete Materials Lab, Concrete Research, Concrete Unit and AET have worked together to build up a database of information for future spec development
We can relate obtain the F Factor from resistivity and relate it to depth of chloride penetration.

From Weiss et al. 2016c
Formation Factor

- MnDOT is performing XRF testing on cementitious samples from 2016 paving projects
- Entering mix design and chemistry data into the pore solution calculator to see what today’s mixes predict
- Intend to test cores from each project for surface resistivity
Taking the remaining cores from the w/c investigation (~17 years of service)
Shipping to Oregon State University for them to grind up the concrete and determine the chemistry of the original materials that can correlate to current field performance
Some closing thoughts...

- Change can be hard for some
- Balancing risk and reward can be a challenge for both the Contractor and Agency
- Further development of performance mix designs will evolve...the exciting thing is technology is getting to the point where we will have tools that can give us better indications of the long term quality of the concrete...
Thank You

Questions?