The Performance of Colored Concrete Pavement in Minnesota

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Minnesota Department of Transportation

Office of Materials and Road Research
“Streetscaping”
Delineation
Problem?

6 years old
LRRB Investigation 929

Investigation and Assessment of Colored Concrete Pavement

- Principal Investigator(s):
  - Tom Burnham – MnDOT
  - Ally Akkari – (formerly MnDOT)

- Subcontractor – American Engineering Testing, Inc.
  - Gerard Moulzolf
    - Willy Morrison
    - Larry Sutter (Michigan Tech Univ)
Scope of Study

- Determine project locations
- Perform field evaluation and collect samples
- Laboratory testing and evaluation
- Data analysis and interpretation
- Identify repair and rehabilitation techniques
- Final report with findings and recommendations
Site visits

- Visited 29 of 45 sites listed in 2012 database
- 19 of 29 sites had some type of visible distress
  - Joint deterioration
  - Cracking
  - Severe distress
  - Surface abrasion
  - Edge chipping
  - Smooth surface
- Many sites too new to assess performance
Good Performer: Sauk Rapids (2007)
Good Performer: Detroit Lakes (2011)
Good Performer: Minneapolis (2010)
Good Performers: Roseville (2001)
Joint Deterioration

13 years old  
6 years old  
14 years old

25 years old

13 years old
Cracking
Severe Distress

13 years old

1 year old

13 years old

11 years old
Edge chipping

6 years old

1 year old
Smooth Surface
### Potential Causes for Distress

#### Construction practices

<table>
<thead>
<tr>
<th>Cause</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hand placement</td>
<td>Inadequate consolidation, high porosity</td>
</tr>
<tr>
<td>Over-finishing surface</td>
<td>Excess paste near surface, scaling</td>
</tr>
<tr>
<td>Lack of proper curing</td>
<td>Shrinkage cracking, high early temps</td>
</tr>
<tr>
<td>Infill construction</td>
<td>Raised edges, chipping</td>
</tr>
</tbody>
</table>
Construction practices
Potential Causes for Distress

- Materials related reduction in durability

<table>
<thead>
<tr>
<th>Cause</th>
<th>Effect</th>
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<tbody>
<tr>
<td>Low air content</td>
<td>Reduced freeze/thaw resistance</td>
</tr>
<tr>
<td>Secondary ettringite growth</td>
<td>Reduced freeze/thaw resistance, microcracking</td>
</tr>
<tr>
<td>High porosity (high w/cm)</td>
<td>Increased saturation, ingress of deicing chemicals</td>
</tr>
<tr>
<td>Lack of proper curing</td>
<td>Shrinkage cracks, inadequate hydration</td>
</tr>
<tr>
<td>Pigment properties</td>
<td>Poor paste-to-aggregate bond</td>
</tr>
<tr>
<td>Pigment incompatibilities</td>
<td>Chemical attack of paste and/or aggregates</td>
</tr>
</tbody>
</table>
Full-depth macro and microcracking
Aggregate and Paste Dissolution

Green = Iron    Blue = Magnesium

SEM
# Potential Causes for Distress

- **Chemical attack**

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Carbonation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deicers</td>
<td>Excessive periods of saturation (reactions with aggregates, paste, pigments?)</td>
</tr>
<tr>
<td>ASR</td>
<td>Cracking and expansion of slabs</td>
</tr>
</tbody>
</table>
Alkali Silica Reaction
(Occurring in aggregates not normally reactive in Minnesota)
Potential Causes for Distress

- **Project Design**

<table>
<thead>
<tr>
<th>Cause</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slow drainage</td>
<td>Saturation of concrete, increased susceptibility to freeze/thaw damage</td>
</tr>
<tr>
<td>Loss of joint sealant</td>
<td>Saturation of concrete, increased susceptibility to freeze/thaw damage</td>
</tr>
<tr>
<td>Thermal incompatibility</td>
<td>Cracking</td>
</tr>
<tr>
<td>Connection to neighboring slabs</td>
<td>Edge chipping, faulted joints</td>
</tr>
</tbody>
</table>
Thermal Incompatibility
Infilling Issues
Summary of Petrographic Analysis Results

- Micro-cracking through the depth of joints
- A poor bond between paste and aggregate
- High water-to-cementitious ratios (up to 0.50) = High porosity
- Initially adequate hardened air content system
  - Systems now have reduced freeze/thaw resistance
- Surprising presence of ASR in typically sound aggregates used for concrete in Minnesota
- Chemical alteration of paste and aggregates
Summary of SEM Investigation

- Magnesium chloride solutions are permeating the concrete, likely as a result of deicer exposure
- Appears to be strong evidence of paste dissolution
- There appears to be an affinity for iron by magnesium ions
## Freeze/Thaw Durability

<table>
<thead>
<tr>
<th>Lab Mix, SSD (pcy) (1)</th>
<th>Mix #1-Control- No pigment - 0.43 w/cm</th>
<th>Mix #3-Pigment 4% - 0.43 w/cm</th>
<th>Mix #3-Pigment 4% - 0.40 w/cm</th>
<th>Mix #4-Pigment 6% - 0.43 w/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lafarge Davenport (lbs)</td>
<td>592</td>
<td>592</td>
<td>592</td>
<td>592</td>
</tr>
<tr>
<td>Portage Fly Ash (lbs)</td>
<td>104</td>
<td>104</td>
<td>104</td>
<td>104</td>
</tr>
<tr>
<td>Lakeville +3/4&quot;, Coarse Aggregate. (lbs)</td>
<td>742</td>
<td>742</td>
<td>757</td>
<td>742</td>
</tr>
<tr>
<td>Lakeville -3/4&quot;, Coarse Aggregate. (lbs)</td>
<td>823</td>
<td>823</td>
<td>839</td>
<td>823</td>
</tr>
<tr>
<td>Lakeville -1/2&quot;, Coarse Aggregate. (lbs)</td>
<td>274</td>
<td>274</td>
<td>280</td>
<td>274</td>
</tr>
<tr>
<td>Lakeville Fine Aggregate (lbs)</td>
<td>966</td>
<td>966</td>
<td>985</td>
<td>966</td>
</tr>
<tr>
<td>Water (lbs)</td>
<td>299.0</td>
<td>299.0</td>
<td>278.4</td>
<td>299.0</td>
</tr>
<tr>
<td>Vinsol Resin, Air Entrainer (oz/cwt)</td>
<td>0.8</td>
<td>0.8</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>Pigment, % by weight of cementitious</td>
<td>---</td>
<td>4.0</td>
<td>4.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Water to Cementitious Ratio</td>
<td>0.43</td>
<td>0.43</td>
<td>0.40</td>
<td>0.43</td>
</tr>
</tbody>
</table>

### Fresh Properties

<table>
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<tr>
<th></th>
<th>Mix #1-Control- No pigment - 0.43 w/cm</th>
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<th>Mix #3-Pigment 4% - 0.40 w/cm</th>
<th>Mix #4-Pigment 6% - 0.43 w/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit Weight, pcf</td>
<td>144.0</td>
<td>145.2</td>
<td>144.8</td>
<td>146.0</td>
</tr>
<tr>
<td>Slump (in)</td>
<td>4.00</td>
<td>4.00</td>
<td>3.25</td>
<td>3.75</td>
</tr>
<tr>
<td>Air Content (%)</td>
<td>7.0</td>
<td>6.2</td>
<td>6.8</td>
<td>6.0</td>
</tr>
</tbody>
</table>

### Average (2) ASTM C666, Rapid Freezing and Thawing, Proc. A, Relative dynamic modulus, %

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<th>Mix #4-Pigment 6% - 0.43 w/cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 Cycles</td>
<td>94</td>
<td>89</td>
<td>97</td>
<td>92</td>
</tr>
</tbody>
</table>

### Notes:

1. Mix design provided by MnDOT. Mix identified as "Mix 3A21 HEF" July 2000. Mix adjusted for higher water to cementitious requirements of this study.
2. Average of three 3x3x11-1/4-in beams.
ASTM C1567 Test Results for Fine Aggregate, % Expansion

- Mix #1-Control-0.43 w/cm
- Mix #2-0.43 w/cm; Pigment 4%
- Mix #3-0.40 w/cm; Pigment 4%
- Mix #4-0.43 w/cm; Pigment 6%

Time, days:
- 4 days
- 7 days
- 11 days
- 14 days
- 21 days
- 28 days

% Expansion:
- 0.000
- 0.050
- 0.100
- 0.150
- 0.200
- 0.250
- 0.300
- 0.350

ASR Testing
Overall Findings of Study

- Early distress has and continues to occur in colored concrete pavements throughout Minnesota
- Current placement practices are not the primary cause for the distress (secondary cause?)
- The primary cause for early joint deterioration is the high porosity of the mixes
- Deicing chemicals may be accelerating the distresses
- Designers must consider thermal compatibility with surrounding areas
- Chemical attack and ASR has been identified in both field samples and lab produced mixes
Recommendations

- Reduce the porosity of colored concrete mixes
  - Specify w/cm ratio < 0.43 (lower = better)
  - Increase consolidation during placement
- If possible, limit the application of magnesium-based deicers on colored concrete
- Investigate whether ASR mitigation possible with higher % of flyash and/or slag
- Construct adequate texture
- Consider alternative ways to produce colored concrete (other than full-depth color)
Questions?