Types of Pavement Issues: Why and Prevention

2013 Municipal Streets Seminar
November 13, 2013

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How and Why Do We Keep Shooting Ourselves in the Foot?

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Long Lasting Concrete Pavement

Design

Carries the Design Traffic

Plant

Fresh Properties

Results

QC

Harden Properties (Durability)

QA

Placement

Construction

QC

ESAL => 18k
This wagon => 73k !!

1300 bushels on 1 axel !!
What are the Challenges to Achieve Durability Pavements

Hardened Properties (Durability)

- Permeability
  - W/C Ratio
  - Gradation
  - Curing

- Crack Resistance
  - Shrinkage
    - Temperature
    - Moisture

- Frost Resistance
  - Air Void System
  - Salt Scaling
  - Pop Out

- Sulfate Resistance
  - Minimize Sulfate
  - Water

- Material Reaalted Resistance
  - ASR
  - D-Cracking

What's not on that list? Strength!
Permeability

- Keep stuff out
  - Water
  - Chlorides
    - Deicing salts
  - Sulfates
- Mix design
- How to measure it
Basic Mix Proportioning

- **Paste** (cement + water)
  - 9 - 15% Cement
  - 15 - 16% Water

- **Mortar** (paste + fine aggregate)
  - 25 - 35% Fine aggregate

- **Concrete** (mortar + coarse aggregate)
  - 30 - 45% Coarse aggregate
Optimized Combined Gradation

- What will it do for me?
  - Improved workability
  - Reduce segregation potential
  - Reduced cementitious content for equal strength

Less paste=> Less permeable
- Normally reduce cost
Gradation

Gap Graded

Well Graded
**Water/Cement Ratio**

- Weight of water divided by weight of cementitious (cement, fly ash, GGBFS)
- Direct relationship permeability

\[ \frac{W}{C_m} = \]
Permeability

- Controlled by $W/C_m$
How SCM’s Work

Cement

Calcium Silicates + Water → CSH + CH

Calcium Silicate Hydrate + Calcium Hydroxide

Secondary Reaction

Fly Ash / Slag

Supplemental Cementitious Material + Water + CH → CSH

Begins after the cement reaction
Ternary Mix Design - Lab Study

Permeability AASHTO T277 - Virginia Cure Method

$w/c = 0.426$

<table>
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<tr>
<th>Coulombs</th>
<th>100% Cement</th>
<th>15% C Ash</th>
<th>30% C Ash</th>
<th>20% GGBFS 25% Ash</th>
<th>35% GGBFS 15% Ash</th>
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<tr>
<td></td>
<td>&gt;4000</td>
<td>High</td>
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<tr>
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<td>2000-4000</td>
<td>Moderate</td>
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<td>Low</td>
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<td>&lt;100</td>
<td>Negligible</td>
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</table>

$w/c = 0.426$

Binary (% SCM)

Ternary (% SCM)
Curing

- Hydration continues as long as water is present
Permeability

- The ease with which fluids can penetrate concrete
- Minimize durability damage by
  - Minimize paste volume
  - Use low W/Cm
  - Use SCMs
  - Curing
  - Minimize cracking
Factors Affecting Early-Age Cracking

- Volume shrinkage
- Strength
- Curling/warping
- Early loading
(a) Cracks generally do not develop in concrete that is free to shrink.

(b) Slabs on the ground are restrained by the subbase, creating tensile stresses that result in cracks.
Volume Shrinkage

Total shrinkage is the sum of individual shrinkage mechanisms. Minimizing any or all mechanisms will reduce the risk of cracking.
Primary Factors of Early-Age Cracking

- Concrete expands as temperature rises and contracts as temperature falls

- Concrete expands as moisture increases and contracts as moisture decreases
Optimized Combined Gradation

- What will it do for me?
  - Reduced cementitious content for equal strength
    - Less water => Less cement => Less shrinkage, Less heat
  - Less potential for cracking
Drying Shrinkage

- Loss of mixing water through hydration and evaporation
  - Overall volume contracts
  - Greater paste content $\Rightarrow$ greater drying shrinkage $\Rightarrow$ higher tensile stress
  - Low relative humidity of air can affect shrinkage diffusion-curing is critical!
Five Stages of Hydration

Stage 1: Mixing
Stage 2: Dormancy
Stage 3: Hardening
Stage 4: Cooling
Stage 5: Densification
Software tool for assessing cracking risk
SCM Effect

Secondary Reaction

Cement Water Aggregate

Heat

Time

Conventional sawing window

Early sawing window

Less Horsepower

Reduce peak temperature

Initial set

Final set

Strength/Stress development

Hydration acceleration

Hydration deceleration

Stage 1

Stage 2

Stage 3

Stage 4

Stage 5

Mixing

Dormancy

Hardening

Cooling

Densification

Lasts about 15 minutes

Lasts about 2–4 hours

Lasts about 2–4 hours

Continues for years
Factors Affecting Thermal Properties

- Cement fineness
- Amount of Pozzolans
  - Class F fly ash heat of hydration
    - Typically 50 percent of cement
  - Class C fly ash heat of hydration
    - Typically 70 to 90 percent of that of cement
- Pozzolans are a secondary reaction
  - Reduce the maximum temperature
Factors Affecting Thermal Properties

- Aggregate types
  - Account for about 60 to 75 percent of concrete by volume
  - Coefficient of Thermal Expansion (CTE) of aggregates dominates CTE of concrete
Restraint

**External Restraint:**  A bonding or friction between a slab and the base or an abrupt change in the slabs cross-section.

**Internal Restraint:**  The outer concrete shrinks or expands and the core does not.
Curling and Warping

- Variations in contraction and expansion cause differential, non-uniform movements

Curling => Change in Temperatures
Warping => Change in Moisture

- These movements, especially when restrained, can cause cracking
Curling and Warping of Slabs

Temperature curling
Moisture warping

Hot days (curling counteracts warping)

Temperature curling
Moisture warping

Cool nights (curling compounds warping)
Plastic Shrinkage

Rapid loss of water through evaporation causes concrete on the surface to shrink. If shrinkage is restrained, tension develops, which may cause cracking.
Plastic Shrinkage Cracks

Some cracks form perpendicular to wind direction.
Cracking

- Minimize durability damage by
  - Minimize paste volume
  - Use low w/cm
  - Use SCMs
  - Curing
  - Minimize cracking
Early Joint Deterioration

- A new problem
  - Not D-cracking
  - Not freeze/thaw damage
Early Joint Deterioration

- Deterioration stops at the edge of the traveled lane
Incremental Cracking
The Symptoms

- Not typical freezing and thawing
  - No thin flakes
The Symptoms

- The aggregate is polished
Interfacial Zone
**Saturation**

- **Tunneling** – water trapped in saw-cut
Purdue Work

- Damage depends on degree of saturation

![Relative Dynamic Modulus (N=6)](image)

- 12% Paste Air
- 31% Paste Air

Li et al. to be Submitted
Saturation

- Bottom-Up Moisture
An Example

- No sealant-joints dry first
- If they don't drain, salts collect
The Mixture

- 5% minimum behind the paver
- 0.40 max w/cm
- Use appropriate SCMs
Integrated Materials and Construction Practices for Concrete Pavement:
A State-of-the-Practice Manual

FHWA Publication No. HIF-07-004

U.S. Department of Transportation
Federal Highway Administration

Integrated Materials and Construction Practices for Concrete Pavement:
A State-of-the-Practice Manual

December 2006

Summary of Preventable Early-Age Cracks:
Corner Breaks

Time of Occurrence
Corner breaks can occur after wet, hot, pavement is opened to the public. However, corner breaks can continue to form for years, even as the pavement has matured due to still settling, moisture, frost heaving, expansive soils, or excessive cutting and loading.

Description
- Cuts in concrete at the corner intersections and longitudinal joint at approximately a 45-degree angle (Figure 7-3-22)
- Taper 1/2 in. to 1 in. long, half the slab width on each side
- Full depth

Cause
Corner cracks occur when a concrete corner is loaded under load that is less than the amount required for corner cracking support, either when there is lack of base support. For instance, early loading with heavy construction thickness can cause corner cracking.

Furthermore, cured or unsecured slab base support, where the slab is exposed to live loads, can lead to the same that have reduced support.

If the base is not uniform, the slab will similarly lose support when the base is less stable than in the middle, leading to corner cracking.

Properly cured concrete will develop adequate strength, and when loads are applied for pavement use, no pavement may exist where the support is reduced.

Effect
Corner cracks usually represent minor failures.

Prevention
To prevent corner cracking, consider the following measures:
- Make sure the base is uniformly stable over time.
- Keep contractors and users off the pavement as long as possible.
- Properly cure the concrete as long as possible to help prevent or reduce cracking and delamination.

Repair
Corner cracks generally require full-depth repair of the slab and pavement stabilization of the base.
Rocky asks:
Any Questions?

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