Integrated Materials and Construction Practices for Concrete Pavement

2nd Edition

Iowa State University
Institute for Transportation

National Concrete Pavement Technology Center
Purpose

A resource to:

• Bridge the gap between research and practice
• Encourage good practices
• Provide practitioners with tools to design, build, and maintain concrete pavements
• Help practitioners improve communication between practice areas
Learning objectives

• Understand concrete pavements as integrated systems
• Appreciate that constructing a concrete pavement project is a process involving interrelated practices
• Implement technologies to optimize performance
• Recognize and avoid factors leading to premature distress
• Access how-to and troubleshooting information
Anyone interested in optimizing concrete performance

- Engineers
- Quality control (QC) personnel
- Specifiers
- Contractors
- Materials and equipment suppliers
- Technicians
- Construction supervisors
- Tradespeople
What’s New

This edition is an update:

- Sustainability
- MEPDG
- PEM
- RTS

Authors

- Peter Taylor
- Tom Van Dam
- Larry Sutter
- Gary Fick

Review by

- TAC
- Previous authors
Overview

• 10 Chapters
  • Sustainability
  • Design
  • Materials and Mixtures
  • Construction
  • Quality
  • Troubleshooting
Chapter 2 Basics of Concrete Pavement Sustainability

- What is Pavement Sustainability?
- Concrete Pavement Design
- Materials
- Construction
What is Sustainability?

A sustainable pavement is one that achieves its specific engineering goals, while:

- It meets basic human needs
- Uses resources effectively
- Preserves/ restores surrounding ecosystems
Strategies for Design

• Longevity
  • Reduced user impact
  • Durable mixtures
  • Increased Thickness
  • CRCP for heavy traffic

• Local and Recycled Materials
  • Use less fuel to haul it in
  • Avoid throwing away the old pavement
Sustainability and Materials

• Recycled, Coproduct, and Waste Materials
• Cementitious Materials and Concrete Mixtures
  • Portland Cement
  • Supplementary Cementitious Materials
  • Blended Cements
• Aggregate Materials
• Concrete Mixture Proportioning and Production
• Other Concrete Mixtures and Emerging Technologies
What About Operations?

- At least 80% of the energy and emissions associated with pavements is incurred during use
  - Fuel efficiency
    - Traffic flow
    - Rolling resistance
  - Albedo
    - Heat island
    - Lighting costs
  - Noise
Which is more “sustainable”?
Chapter 3 Basics of Concrete Pavement Design

- Integrated Pavement Design
- Pavement Types
- What Do We Want?
- What Factors Do We Have to Accommodate?
- Getting What We Want
- Constructability Issues
- Concrete Overlays
It’s Not Just Thickness

Jointed Plain
It’s Not Just Thickness

Continuously reinforced
What Do We Want?

- Service life
  - Structural models assume that materials will not fail
  - How long should it last?
- Performance:
  - Structural
  - Functional
What Do We Want?

• Structural – is it broken?
What Do We Want?

- Functional – do I want to drive on it?
Chapter 4 Fundamentals of Materials Used for Concrete Pavements

• Cementitious Materials
• Aggregates
• Water
• Chemical Admixtures
• Dowel Bars, Tiebars, and Reinforcement
• Curing Compounds
• References
What do we have to work with

- **9-15% Cement**
- **15-15% Water**
- **25-35% Fine aggregate**
- **30-45% Coarse aggregate**

**Paste** (cement + water)

**Mortar** (paste + fine aggregate)

**Concrete** (mortar + coarse aggregate)
Aggregates

• Aggregates comprise ~70% of the volume of a concrete mix.

• Aggregate properties can have an influence on concrete properties:
  • Durability
  • Workability
  • Strength
  • Dimensional changes
Cementitious Materials

**Hydraulic cement** – reacts with water, creates CH

- Portland Cement
- Slag Cement
- Class C Fly Ash
- Class F Fly Ash
- Silica Fume

**Pozzolan** – reacts with cement and water, consumes CH

Not to scale
Cement is Changing

### Chemical Composition

- **C3S**
- **C2S**
- **C3A**

### Fineness

- Blaine m²/kg

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23
Supplementary Cementitious Materials

- Fly ash
- Slag
- Natural pozzolan
- Silica fume

“We deal with the negatives to get a positive”
Effects of Extra Water on Concrete

- Increases workability
- Lowers strength
- Increases drying shrinkage
- Increases permeability and reduces durability
Chemical Admixtures

- Air entraining admixtures (AEA)
- Water reducers
- Set modifying admixtures

Don’t use to fix a bad mixture, use to Enhance!
Contents

• Chapter 5 Hydration
  • Stages of Hydration: Overview
  • Portland Cement
  • Supplementary Cementitious Materials
  • Impact of Hydration
  • Stages of Hydration: Details
Five Stages of Hydration

1. Mixing
2. Dormancy
3. Hardening
4. Cooling
5. Densification
Effects of SCMs

- Delayed final set.
- Reduced heat peak.
- Extended heat generation.
- Increased long-term strength.
- Reduced permeability.
Contents

• Chapter 6 Critical Properties of Concrete
  • Introduction
  • Fresh Properties
  • Mechanical Properties
  • Durability Related Properties
Fresh Properties

- Uniformity
- Workability
- Segregation
- Bleeding
- Setting
- Temperature effects
Mechanical Properties

- Strength
- Stiffness
- Shrinkage
- Polishing
- Cracking
Early-Age Cracking

- Factors
  - Concrete moves (temperature and moisture gradients)
  - Movement + Restraint → Load
  - Loads + Stiffness → Stress
  - Stress > Strength = Cracks
Early Age Cracking

Discuss
Early Age Cracking

Discuss
Durability Properties

Ability of the concrete to survive the environment to which it is exposed:

• Transport
• Cold weather
• Sulfates
• AAR
Transport

The ease with which fluids can penetrate concrete

- Significance
  - All durability damage is governed by permeability

- Factors
  - w/cm
  - SCM type and dose
  - Hydration
  - Cracking
Cold Weather

Two mechanisms:
• Saturated freeze thaw
• Oxychloride formation
Alkali-Silica Reaction

- Water + alkali hydroxide + reactive silicate aggregate $\rightarrow$ alkali silicates
- Alkali silicates + water $\rightarrow$ gel + expansion

- Silicates from aggregates
- Alkalis from cement (Na and K)
D-Cracking

- Certain calcareous aggregates absorb water
- Pore size prevents water leaving the system
- Freezing causes damage
Contents

• Chapter 7 Mixture Design and Proportioning
  • Introduction
  • Sequence of Development
  • Aggregate Grading Optimization
  • Calculating Mixture Proportions
  • Adjusting Properties

“The beast of interesting proportions”
Design

• Choosing what you need
  • Workability, setting time
  • Durability, strength, cracking risk
Proportioning
How do we proportion to achieve design goals?

<table>
<thead>
<tr>
<th></th>
<th>Workability</th>
<th>Transport</th>
<th>Strength</th>
<th>Cold weather</th>
<th>Shrinkage</th>
<th>Aggregate stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type, gradation</td>
<td>✔️ ✔️</td>
<td>-</td>
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</tr>
<tr>
<td>Paste quality</td>
<td></td>
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</tr>
<tr>
<td>Air, w/cm, SCM type and dose</td>
<td>✔️</td>
<td>✔️ ✔️</td>
<td>✔️ ✔️</td>
<td>✔️ ✔️</td>
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<td>✔️</td>
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<tr>
<td>Paste quantity</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Vp/Vv</td>
<td>✔️</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>✔️ ✔️</td>
</tr>
</tbody>
</table>
Step 1 Paste Quality

- Binder type
  - Cement type
  - SCM type and dosage
- w/cm
  - ~0.38-0.42
- Air void system
  - <0.2 SAM
  - <0.008 in. spacing factor
  - >5% in place
  - Stable
Step 2 Aggregate system

• Tarantula Curve

Greater than 15% on the sum of #8, #16 and #30
24-34% of fine sand (#30-200)
Step 3 Paste Content

Paste should be approximately 1.5x - 2x of voids
Support system should be stable and uniform with decent drainage
Contents

• Chapter 9 Quality and Testing
  • Quality Assurance
  • Monitoring the Mixture
  • Monitoring Construction Activities
  • Test Methods

“Delivering what is expected”
Defining Quality

• Simple Definition (Philip Crosby)
  • Quality: “Conformance to requirements”
  • Quality is defined by our customers

• QA = “Making sure the quality of a product is what it should be”
Why Should I Care

• Money!
  • Penalties vs Incentives
Why Should I Care

• Better working environment
  • Project partners are qualified
  • Contractor knows how the Agency will accept/pay for the product
  • QC Plans remove some of the daily stress
• Product you paid for
Trick Question

How do the following people affect quality?
- Designer/Specifier
- Agency Inspector
- QC Technician
- Loader Operator at the concrete plant
- Truck Driver
- Paver Operator
- Concrete Finisher
- Texture/Cure Machine Operator
Core Elements of an Agency QA Program

Quality Assurance

Quality Control

Agency Acceptance
The Goal...

Long-lasting pavement

Acceptance

QC

Construction Activities

QC data should be invisible to the Acceptance process
How Do We Evaluate the Mixture?

- Measure everything during prequalification
  - Constructible (Workable)
  - Dimensionally stable
    - Aggregates
    - Shrinkage
  - Impermeable (Transport properties)
  - Cold weather resistant
  - Freeze thaw
  - Salt attack
  - Strong (enough)

<table>
<thead>
<tr>
<th>Concrete property</th>
<th>Test description</th>
<th>Test method</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Workability</td>
<td>Aggregate gradation</td>
<td>ASTM C 136 / AASHTO T 27</td>
<td>Use the individual gradations and proportions to calculate the combined gradation.</td>
</tr>
<tr>
<td></td>
<td>Combed gradation</td>
<td>Tarantula curve</td>
<td>Adjust combined gradation to achieve optimum workability.</td>
</tr>
<tr>
<td></td>
<td>Paste content</td>
<td>Batch mix</td>
<td>Adjust paste content to find optimum paste needed while still workable and confirm that total is below maximum permitted for shrinkage.</td>
</tr>
<tr>
<td></td>
<td>V-kelly or box</td>
<td>TF 129 / PP 84 X2</td>
<td>Confirm that the mixture responds well to vibration.</td>
</tr>
<tr>
<td></td>
<td>slump at 0, 5, 10, 15, 20, 25, &amp; 30 minutes</td>
<td>ASTM C 143 / AASHTO T 119</td>
<td>Look for excessive slump loss due to incompatibilities. This is more likely at elevated temperatures. Determine approximate WRA dosage.</td>
</tr>
<tr>
<td></td>
<td>Segregation</td>
<td>-</td>
<td>Look for signs of segregation in the slump samples.</td>
</tr>
<tr>
<td></td>
<td>Air void system</td>
<td>Foam drainage</td>
<td>Assess stability of the air void system for the cementitious / admixture combination proposed.</td>
</tr>
<tr>
<td></td>
<td>Air content</td>
<td>ASTM C 231 / AASHTO T 152, T 196</td>
<td>Determine approximate AEA dosage.</td>
</tr>
<tr>
<td></td>
<td>SAM</td>
<td>AASHTO PP 118</td>
<td>= 0.5 target.</td>
</tr>
<tr>
<td></td>
<td>Mortar content</td>
<td>ASTM C 457</td>
<td>Calibrate SAM limits.</td>
</tr>
<tr>
<td></td>
<td>Unit weight</td>
<td>ASTM C 119 / AASHTO T 12</td>
<td>Provides information on the coarse aggregate content – maximum is ~ 10%.</td>
</tr>
<tr>
<td>Strength development</td>
<td>Compressive or flexural strengths</td>
<td>ASTM C 39 / AASHTO T 72 &amp; ASTM C 78 / AASHTO T 97 at 1, 3, 7, 28 &amp; 56 days</td>
<td>Calibrate strength gain for early age QC. Calibrate flexural with compressive strengths.</td>
</tr>
<tr>
<td></td>
<td>Maturity</td>
<td>ASTM C 1074</td>
<td>Calibrate the mixture so maturity can be used in the field to determine opening times.</td>
</tr>
<tr>
<td>Transport</td>
<td>Electroactivity / F factor</td>
<td>-</td>
<td>Determine development of F factor over time.</td>
</tr>
<tr>
<td></td>
<td>Sorption</td>
<td>ASTM C 1585</td>
<td>Determine time to critical saturation.</td>
</tr>
<tr>
<td></td>
<td>w/cm</td>
<td>Microwave</td>
<td>Calibrate microwave test with batch data.</td>
</tr>
<tr>
<td>Other</td>
<td>Hydration</td>
<td>Semi-adiabatic calorimetry</td>
<td>Determine hydration rates of mixture.</td>
</tr>
</tbody>
</table>
Quality Control

- QC should include
  - Unit weight
  - Calorimetry
  - Maturity
  - Strength development
  - Air void stability
- And a response…
- Risk management

1. Get lab mix accepted
2. Ensure we are getting that mix
Contents

• Chapter 10 Troubleshooting and Prevention
  • Overview
  • Before the Concrete Has Set
  • After the Concrete Has Set
  • In the First Days after Placing
  • Some Time after Construction
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