Lessons Learned & Success Stories
For Long Life Pavements
Overview

• Lessons Learned
  – Background / Early Age Shrinkage
  – Design
  – Materials
  – Construction

• Case Studies
  • Problems
  • Success stories
Early Age Shrinkage-The Basics

1. Fresh concrete shrinks over time
2. Internal stress increase
3. Cracks occur when stresses > strength
4. We can manage frequency and location of cracks
   – Construct proper and timely joints
   – Use good curing practices
Cracking

Cracking affected by:

- Volume changes and restraint
- Curling and warping
- Strength gain during the stages of hydration
- Subgrade support
- Early loading
Early-Age Cracking

- Concrete expands as temperature rises and contracts as temperature falls.

- Concrete expands as moisture increases and contracts as moisture decreases.
Hydration

Hydration (first 72 hours)

- **Initial Mix** (15 minutes)
  - High heat followed by rapid cooling

- **Dormancy** (24 hours)
  - Cool, plastic, workable

- **Acceleration** (4-8 hours)
  - Significant heat, less workable, begins to harden
  - Begin curing
  - Cut joints

- **Deceleration** (-24 hours)
  - Becomes hard and dense
  - Continue curing

- **Slow Hydration** (Indefinitely)
  - 70 – 75% hydrated after 28 days
  - Can continue indefinitely, as long as water can reach un-hydrated particles

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Temperature

- **Curing**
- **Plastic Shrinkage**
- **Differential Thermal Shrinkage**

- **Stage 1**
  - Initial set placement
- **Stage 2**
  - 2-4 hours
- **Stage 3**
  - 4-8 hours
- **Stage 4**
  - 12-24 hours
- **Stage 5**
  - 72 hours

- **Joint Sawing Window**
- **Final Set**

- **Tensile Stress Development**
- **Strength Development**

- **Duration of Hydration**
  - 15 min.
  - 2-4 hours
  - 4-8 hours
  - 12-24 hours

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Cement, water, aggregate
Hydration and Strength Curves

- Strength, %
- Time

Diagram showing stages of hydration and strength:
- Stage 1: Mixing
- Stage 2: Dormancy
- Stage 3: Initial set
- Stage 4: Hardening
- Stage 5: Cooling, Densification
Sawing Window

• Weather:
  – Sudden temperature drop or rainshower
  – Sudden temperature rise
  – High winds & low humidity
  – Cool & cloudy
  – Hot & sunny

• Concrete Mixture:
  – Rapid early strength
  – Retarded set
  – Supplementary cementing materials
Volume Shrinkage

Total shrinkage is the sum of individual shrinkage mechanisms. Minimizing any or all mechanisms will reduce the risk of cracking.
**Autogenous Shrinkage**

The amount of chemical shrinkage that can be measured in a sample.

- Chemical shrinkage is a reduction of volume
- Results from hydration products occupying less space than the original materials
- Typically only significant for W/C less than 0.40
Settlement Shrinkage

- Bleeding is the development of a layer of water at the top or surface of freshly placed concrete.
- It is caused by sedimentation (settlement) of solid particles (cement and aggregate) and the simultaneous upward migration of water.
- Some bleeding is normal. It should not diminish the quality of properly placed concrete.
Rapid loss of water through evaporation causes concrete **on the surface** to shrink. Tension develops, which may cause cracking if concrete strength is exceeded.
Plastic Shrinkage Cracks

Some cracks form perpendicular to wind direction.
Plastic Shrinkage Cracks

Saw it (correctly)!
Cure it (correctly)!
Drying Shrinkage

- Loss of mixing water through hydration and evaporation
  - Overall volume contracts
  - Greater paste content results in greater drying shrinkage and higher tensile stress
  - Low relative humidity of air can affect shrinkage diffusion
Drying Shrinkage
FIGURE 6 Combined early age and long-term shrinkage for three different curing environments (Holt and Leivo, 2000). [1 mm/m = 1,000 μm/m (0.001 in./in.).]
Thermal Shrinkage
Concrete Shrinkage mechanisms receive positive benefit from a lower w/c ratio, and lower permeability!
Combined Shrinkage and Curling Stresses

If the sum of stresses exceeds established strength, cracks can develop.

HIPERPAV curve

www.hiperpav.com
Lessons Learned – Design

Concrete Overlay – Longitudinal Cracking
Concrete Overlays

Existing Conditions:
Iowa DOT Project No.:
STP-175-4(13)—2C-81

Concerns
1. Cracking over widening joint
2. Cracking in inner wheel paths

Pavement History

1938 Pavement
- 7.5" PCC

1986 Pavement
- Existing pavement widened 2’ with asphalt
- 4” HMA overlay

2007 Pavement
- 4 ½” Unbonded PCC overlay
- Milled existing asphalt ½” at centerline and 2% cross slope (existing asphalt served as separation layer)
- Subdrain on one side

2015 Traffic
- 1860 ADT

Figure 3-1 Location Map
Concrete Overlays
Concrete Overlays
Concrete Overlays

FIGURE 3-0 REPLACE OUTER 7" PANEL WITH PCC WIDENING UNIT

124" long No. 4 epoxy coated rebar shall be placed at mid-depth and must have enough overlay thickness to accommodate maximum sized aggregate under the bar and minimum 2" above the bar.

2. Concrete shall either daylight to ditch or terminate above drainable subbase.

3. 211" long No. 4 epoxy coated rebar. Drill and install into existing pavement at 30" spacing.

Existing 1980 HMA Pavement
Existing 1938 PCC Pavement

GUIDE FOR THE
Development of Concrete Overlay Construction Documents

STANDARD DRAWINGS GUIDE SPECIFICATIONS

COSTS LESSONS LEARNED

IOWA STATE UNIVERSITY
Institute for Transportation
National Concrete Pavement
Technology Center
AUGUST 2013
Materials

- Cement Chemistry
- SCM’s
- Air Content
- Chlorides for Snow/Ice Treatment
- Brine Application
What has Changed?

- 13 Pavements
- Constructed from 1909-2006
- Studied Air Content & Permeability

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<th>County</th>
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<td>Stur tz</td>
<td>Moberly Mine</td>
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<td>Christensen</td>
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<td>US 30 MP 151.9 to 156.8</td>
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<td>IA 2</td>
<td>Orea polis #8</td>
<td>Weeping Water</td>
<td>Ash Grove IP(25) 20% C fly ash</td>
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What has Changed? Cement Chemistry

Cement chemistry has changed over the years, but we have the same or better results.
What has Changed? - Permeability

RCP - AASHTO T 277

Iowa DOT Report MLR-05-02, March 2007

13 project sample size

Low permeability is more important than air (based on older pavements)
What has Changed? - Air

Air Content of Pavement Cores

Iowa DOT Report
MLR-05-02, March 2007

13 project sample size
Results of Iowa DOT (MLR-05-02) Report

• The air content for projects placed prior to the requirement for air entrainment in 1952 is less than 3%
• Air contents increased as specification limits increased.
• The indicated permeability of older pavements is very low.
• **The permeability of pavements utilizing a Shilstone type gradation and supplementary cementitious materials, such as slag and fly ash, can reduce indicated permeability to the level of older pavements.**
Materials - Gradation
Pavement Placement Problems
Pavement Placement Problems

- 1991- Distress
  - Vibrator trails
  - Joint spalling
- Visible in 3 – 5 yrs
- Strength vs other properties?
Excessive Vibration

- Aggregate segregation
- High mortar area
- Low Air <3%
- Poor Spacing
  Factors >0.35 mm

- Upper 2-3%
- Lower 5-6%
- Upper 5-6%
- Lower 6-8%
QMC Mix

• 1997 pilot project (1)
  – 28 day compressive strength >4500 psi

• 1998 cooperative projects (5)

• 1999 projects (7)
  – 28 day third point flexural >600 psi

• 2000 projects & later
  – Shilstone gradation -coarseness and workability factors for project
QMC Development

- Partnership with contractors expedited changes
- Placement impacts long term durability
- Well graded aggregates (*intermediate coarse aggregates*) improve placement characteristics
- Gradation, aggregate shape and texture affect paste content (*well-graded reduces paste demand*)
- Supplementary cementitious materials and well graded aggregates reduces permeability
Durability Mixes – Iowa DOT QMC

- Quality Management Concrete (QMC) mix
  - Iowa DOT DS-15038
  - Well-graded aggregate combination (IM 532)
  - 44-48% coarse, 10-15% intermediate, and 38-42% fine aggregate.
  - Basic w/cm ratio is 0.40
  - Max. w/cm ratio is 0.42
  - Min. absolute volume of cementitious is 10.6%
Construction
What happened?
What happened?
Construction – Partial Depth Repairs

Restore the Joint

- Better results with compressive relief material
- Saw to full depth of patch only if board cannot provide complete separation of patch material on both sides of joint (Iowa DOT)
- SUDAS requires board
Construction – Partial Depth Repairs

Critical Items:
- Remove loose material
- Prepare surface
- Grout
- Restore the joint
Construction – Partial Depth Repairs

US 20 – Waterloo, Iowa
Partial-Depth Repairs
Construction – Partial Depth Repairs

US 59 - Denison

- Partial-Depth Repairs
- Full-Depth Repairs
- Dowel Bar Retrofit
- Diamond Grinding
Longitudinal Cracking

Saw too late or not deep enough
Transverse Cracking

Sawed too late
Match Jointing
Diagonal (Random) Cracking

Very poor subgrade
<table>
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<tr>
<th>Defect</th>
<th>Orientation</th>
<th>Location</th>
<th>Description</th>
<th>Dowelled/Undowelled Transverse Joints</th>
<th>Recommended Repair</th>
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<td>Plastic Shrinkage</td>
<td>Any</td>
<td>Anywhere</td>
<td>Partial-depth and more than 0.007 in. wide</td>
<td>Either</td>
<td>Do nothing</td>
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<td>Uncontrolled Crack</td>
<td>Transverse</td>
<td>Mid-Panel</td>
<td>Full-Depth</td>
<td>Undowelled</td>
<td>Sew &amp; seal crack; Epoxy sawed joint if uncracked</td>
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<td>Dowelled</td>
<td>Full-Depth Repair or LTR²</td>
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<td>Transverse</td>
<td>Crosses or ends of transverse joints</td>
<td>Full-Depth</td>
<td>Undowelled</td>
<td>Sew &amp; seal crack; Epoxy sawed joint if uncracked</td>
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<td>Full-Depth Repair or LTR²</td>
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<td>Transverse</td>
<td>Parallel to &amp; within 3 ft. of joint</td>
<td>Full-Depth</td>
<td>Undowelled</td>
<td>Sew and seal crack; Seal joint</td>
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<td>Dowelled</td>
<td>Full-Depth repair to replace crack and joint</td>
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<td>Spalled sawcut or uncontrolled crack</td>
<td>Transverse</td>
<td>Anywhere</td>
<td>Spalling; more than 3.0 in wide</td>
<td>Either</td>
<td>Partial-Depth Repair</td>
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<td>Uncontrolled Crack</td>
<td>Longitudinal</td>
<td>Relatively parallel to &amp; within 1 ft. of joint</td>
<td>Full-Depth</td>
<td>Either</td>
<td>Saw &amp; seal the crack or cross-stitch the crack Epoxy sawed joint if uncracked</td>
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<td>Uncontrolled Crack</td>
<td>Longitudinal</td>
<td>Relatively parallel to &amp; within wheel path; 1 - 5 ft. from joint</td>
<td>Full-Depth, hairline, or spalled</td>
<td>Either</td>
<td>Remove and replace panel or cross-stitch crack</td>
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<td>Relatively parallel to &amp; further than 5 ft. from a longitudinal joint or edge</td>
<td>Full-Depth</td>
<td>Either</td>
<td>Cross-stitch crack</td>
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<td>Partial-Depth Repair</td>
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<td>Multiple per panel</td>
<td>Anywhere</td>
<td>Two or more full-depth cracks dividing panel into 2 or more pieces</td>
<td>Either</td>
<td>Remove and replace panel</td>
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Case Study: Existing Condition

Joint deterioration
Case Study: Existing Condition
Case Study: Core sample (2014)
Case Study: Cause of distress

Causes:

• Subsurface moisture and saturation
• Development of ettringite in air voids.
• Deficient air void system because of ettringite
• Aggregate durability (25 years of freeze-thaw)

Result:

• D-Cracking
Case Study: Cause of distress

Figure 13a – Adequate Air Entrained System

Figure 13b – Air voids Filled with Ettringite
Case Study: Recommendation

- C-SUD mix / QMC mix (w/c 0.40-0.42)
- Use SCMs
- Drainable subbase and subdrain
- Use quality aggregate
Success Stories
Concrete Overlays
Concrete Overlays

Pre-overlay repairs

Consist of bituminous, cementitious, or other materials meeting approval.
Concrete Overlays

Placing Fabric

Securing Fabric
Concrete Overlays

Placing and Finishing Surface
Concrete Overlays

Route D-35 near Kansas City

2008 Unbonded Concrete Overlay

First U.S. project with nonwoven geotextile fabric

5” min, 6’ panels

9300 AADT (5% trucks)

10 years old and performing very well
Concrete Overlays

Concrete Overlay Performance on Iowa’s Roadways
Field Data Report
July 2017

Concrete overlays performing very well
Rehabilitation - Asbury Rd, Dubuque

Credit: Robert Schiesl, City of Dubuque
Rehabilitation - Asbury Rd, Dubuque

COMPLETED PROJECT - DETAILS

- PROJECT COMPLETION: 29 WORKING DAYS
  45 DAY CONTRACT
- FINAL CONSTRUCTION COST: $354,822 $31 / SY
- TOTAL PROJECT COST: $400,791 $35 / SY
  INCLUDES: DESIGN, CONSTRUCTION, INSPECTION
- DOWEL BARS INSTALLED: 3,300
- FULL DEPTH PATCHES, PCC: 350 SY
- DIAMOND GRINDING: 11,600 SY
- TRAFFIC CONTROL: $37,000

Credit: Robert Schiesl, City of Dubuque
I-680 Reconstruction

Flooding from June – September, 2011

Total Project Length 3.42 miles
  • 2.63 Miles of Mainline I-680 Reconstruction
  • 0.79 Miles of Interchange Ramp Reconstruction

Project Quantities (Approximate)
  • 368,000 CY Cut  23,000 CY Fill
  • 140,900 TON Special Backfill
  • 46,100 CY Modified Subbase
  • 95,400 SY 11” PCC Pavement
  • 46,500 SY 7” PCC Shoulders
Incentive / Disincentive:

- $80,000 per Calendar Day Bonus
- Opening I-680 to Two Lane, Two Way Traffic by December 23\textsuperscript{rd}

- $2,000 per Calendar Day Additional Bonus
- Opening all Four Lanes of Traffic by December 23\textsuperscript{rd}

- $2,000,000 “No Excuses” Bonus
- Entire Project Completed by November 20\textsuperscript{th}

- $82,000 per Calendar Day Disincentive
- Not having Two Lane, Two Way Traffic after December 23\textsuperscript{rd}

- $2,000 per Calendar Day Disincentive
- All Four Lanes Not Open to Traffic after December 23\textsuperscript{rd}

- $1,000 Per Calendar Day Liquidated Damages
- Any Work Not Completed by June 1\textsuperscript{st} 2012
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- Pre-Bid Meeting
- Began Design
- Bid Letting
- Mobilization Into Site
- Pre-Construction Meeting
- Begin Pavement Removals
- Mainline Subgrade 3D Models
- Subgrade Prep Complete (WB I-680)
- I-29 Ramp Geometry & 3D Models
- Special Backfill Placement (WB I-680)
- 3D Models Complete (I-680 ML & I-29 Ramps)
- I-680 WB Pavement Staking
- 3D Models Complete (Local Road Ramps)
- Begin Paving (I-680 WB)
- All 3D Modeling Complete (Incl. Ditches)
- I-680 WB Paving Complete (Incl. Ramps)
- I-680 EB Paving Complete (Incl. Ramps)
- All Paving Completed (Incl. Shoulders)
- Ditch Grading Completed
- Open to Traffic (34 days)

- September 14th
- September 15th
- September 23rd
- September 24th – 25th
- September 26th
- September 26th
- September 30th
- October 3rd
- October 4th
- October 5th
- October 5th
- October 7th
- October 10th
- October 12th
- October 13th
- October 19th
- October 25th
- October 28th
- October 30th
- October 31st

Tested again in 2019
Some shoulder erosions, no pavement damage
September 19th – EB
October 3rd – EB
October 10th – WB
October 17th – WB
October 24th – WB
Questions:

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515-964-2020