Lessons Learned & Success Stories For Long Life Pavements

IOWA STATE UNIVERSITY
Institute for Transportation

National Concrete Pavement Technology Center
Tech Center

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

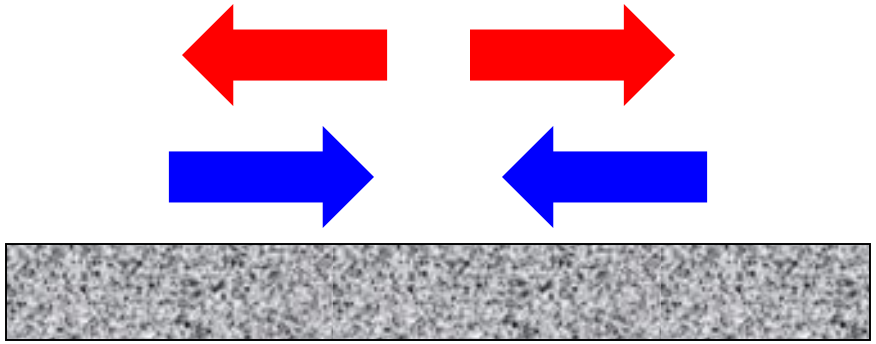
Cracking

Cracking affected by:

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

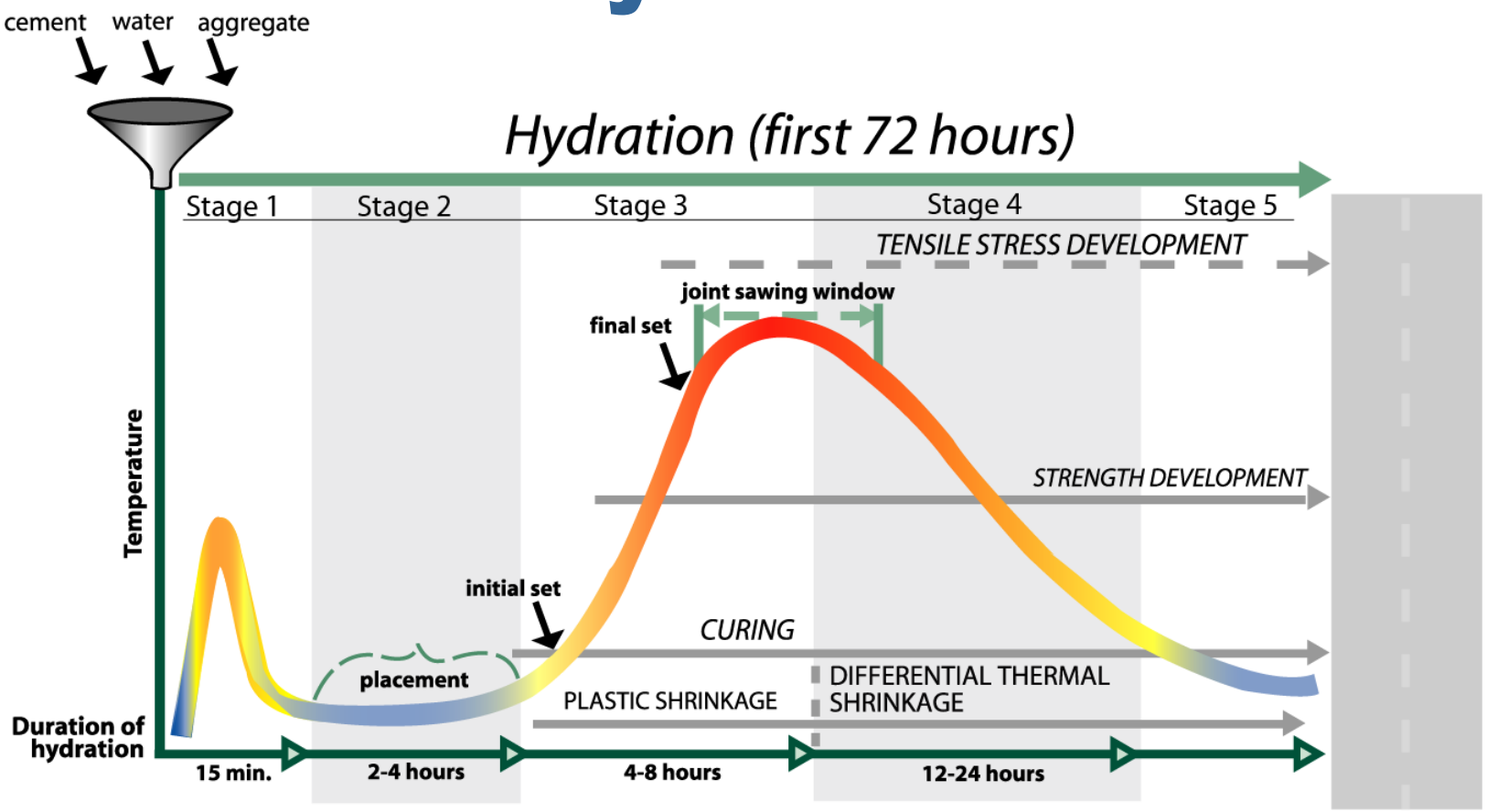
Early-Age Cracking

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



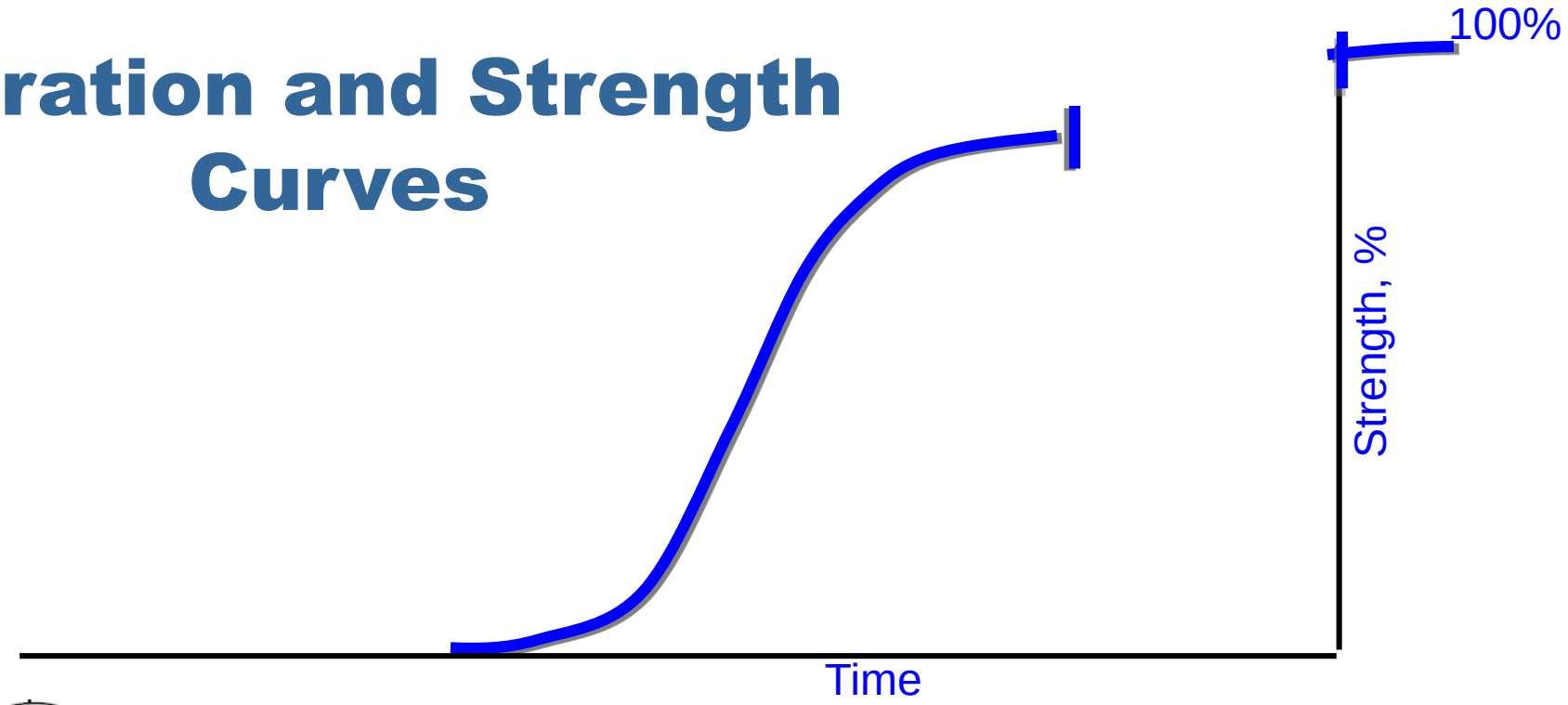
- Concrete expands as **moisture** increases and contracts as **moisture** decreases

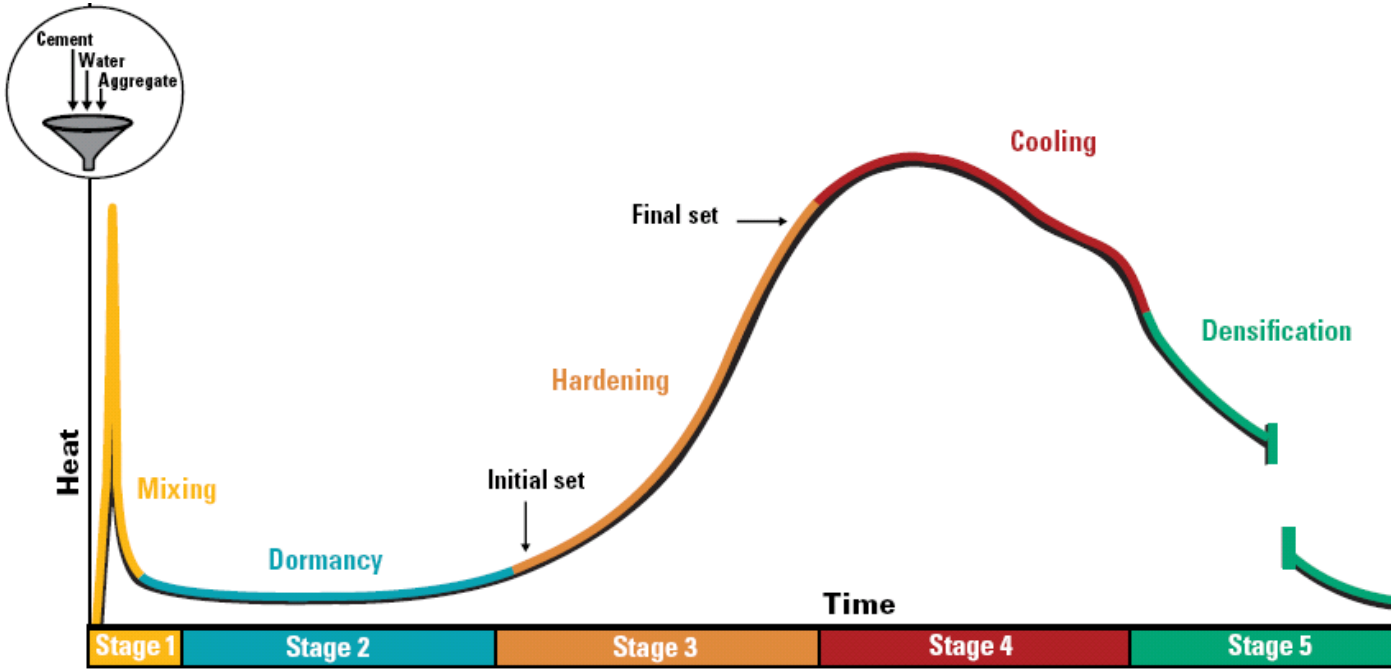
Hydration



Initial Mix	Dormancy	Acceleration	Deceleration	Slow Hydration
(15 minutes)	*(24 hours)*	*(4-8 hours)*	*-24 hours)*	*(Indefinitely)*
High heat followed by rapid cooling	Cool, plastic, workable	Significant heat, less workable, begins to harden	Becomes hard and dense	70 – 75%hydrated after 28 days
	Transport and Place	Begin curing Cut joints	Continue curing	Can continue indefinitely, as long as water can reach un-hydrated particles

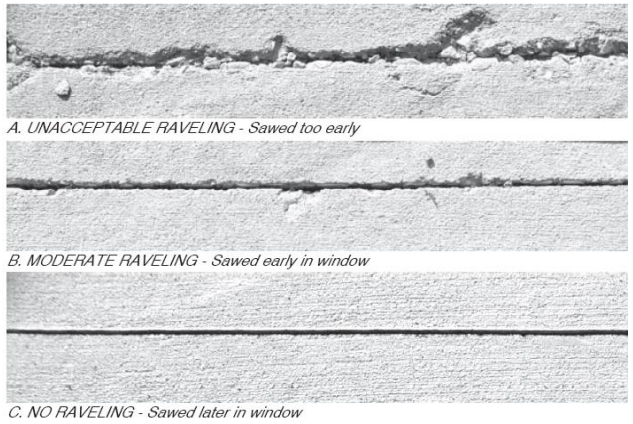
Hydration and Strength Curves





Sawing Window

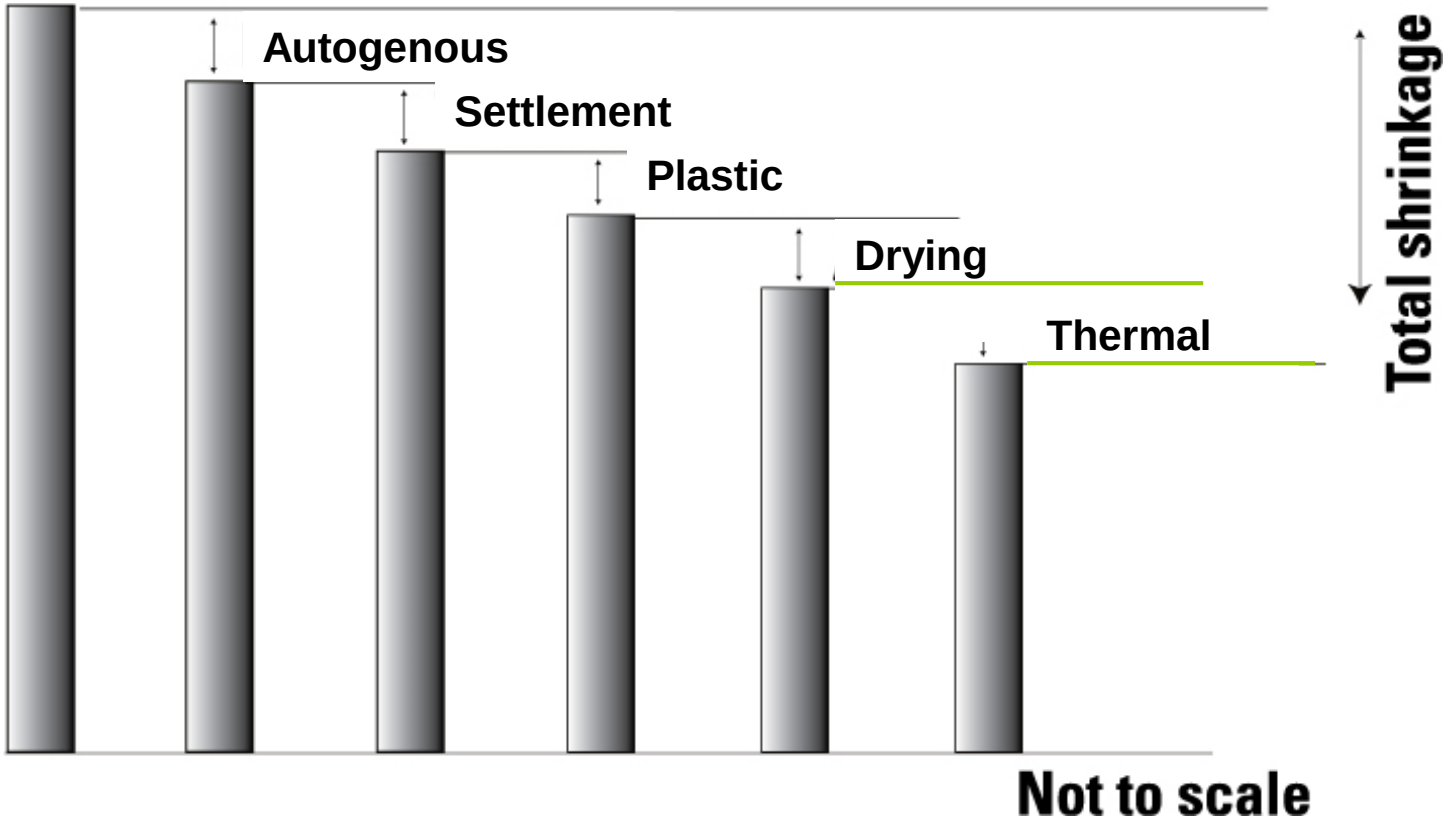
- Weather:
  - Sudden temperature drop or rainshower
  - Sudden temperature rise
  - High winds & low humidity
  - Cool & cloudy
  - Hot & sunny



- 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

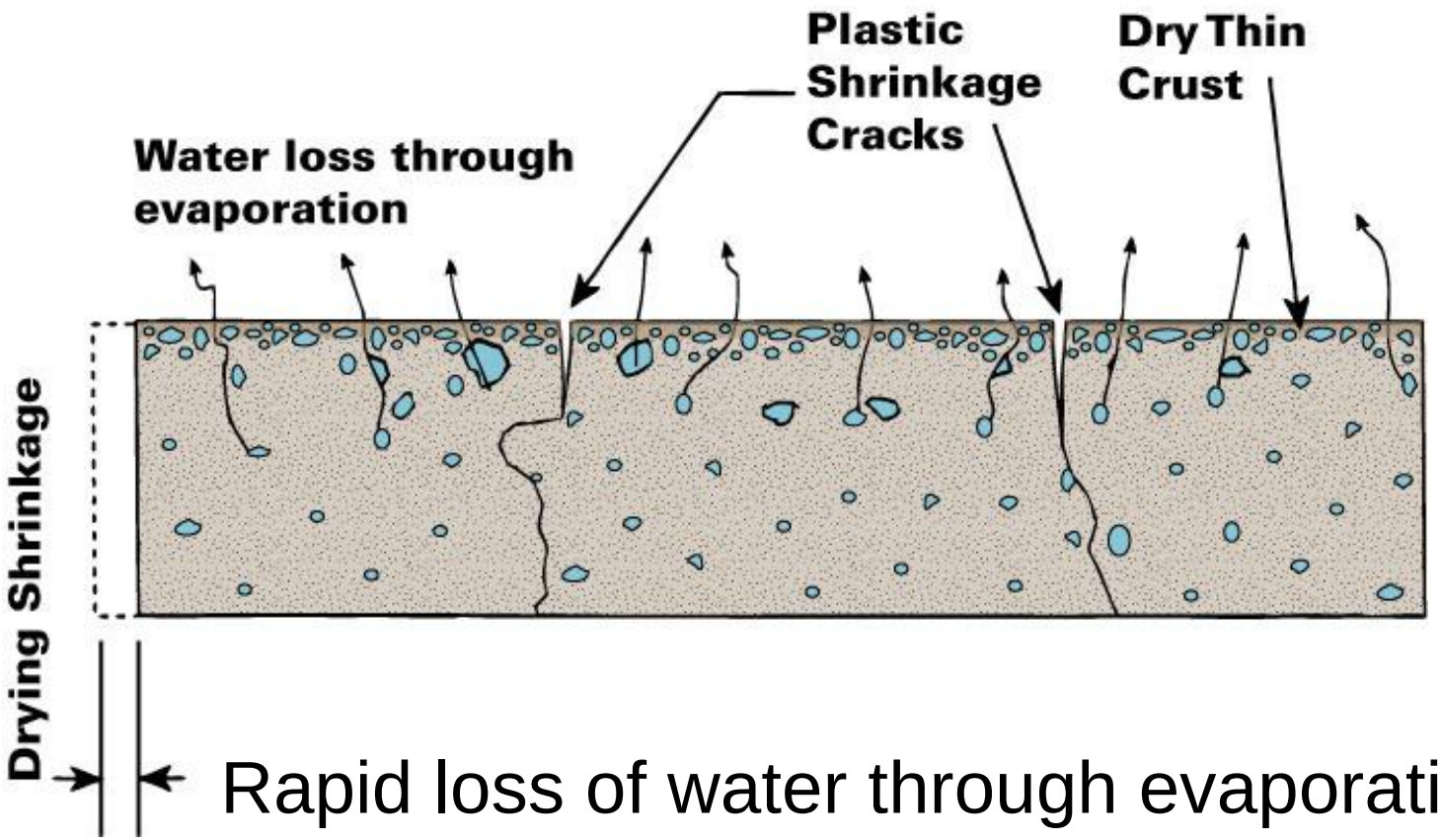
The amount of chemical shrinkage that can be measured in a sample.

- 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

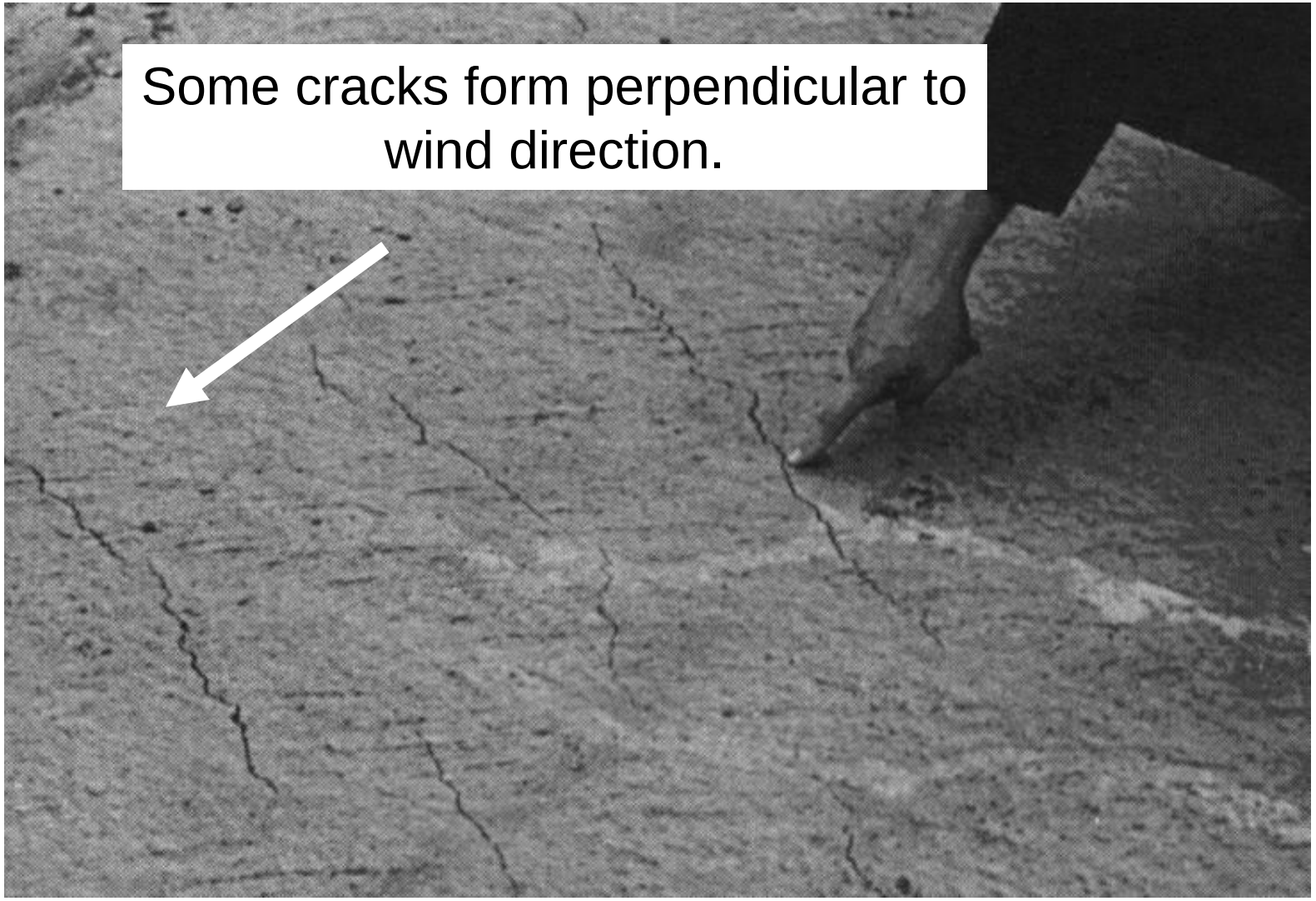
- Bleeding is the development of a layer of water at the top or surface of freshly placed concrete.
- It is caused by sedimentation (settlement) of solid particles (cement and aggregate) and the simultaneous upward migration of water.
- Some bleeding is normal. It should not diminish the quality of properly placed concrete.

Plastic Shrinkage



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



Plastic Shrinkage Cracks

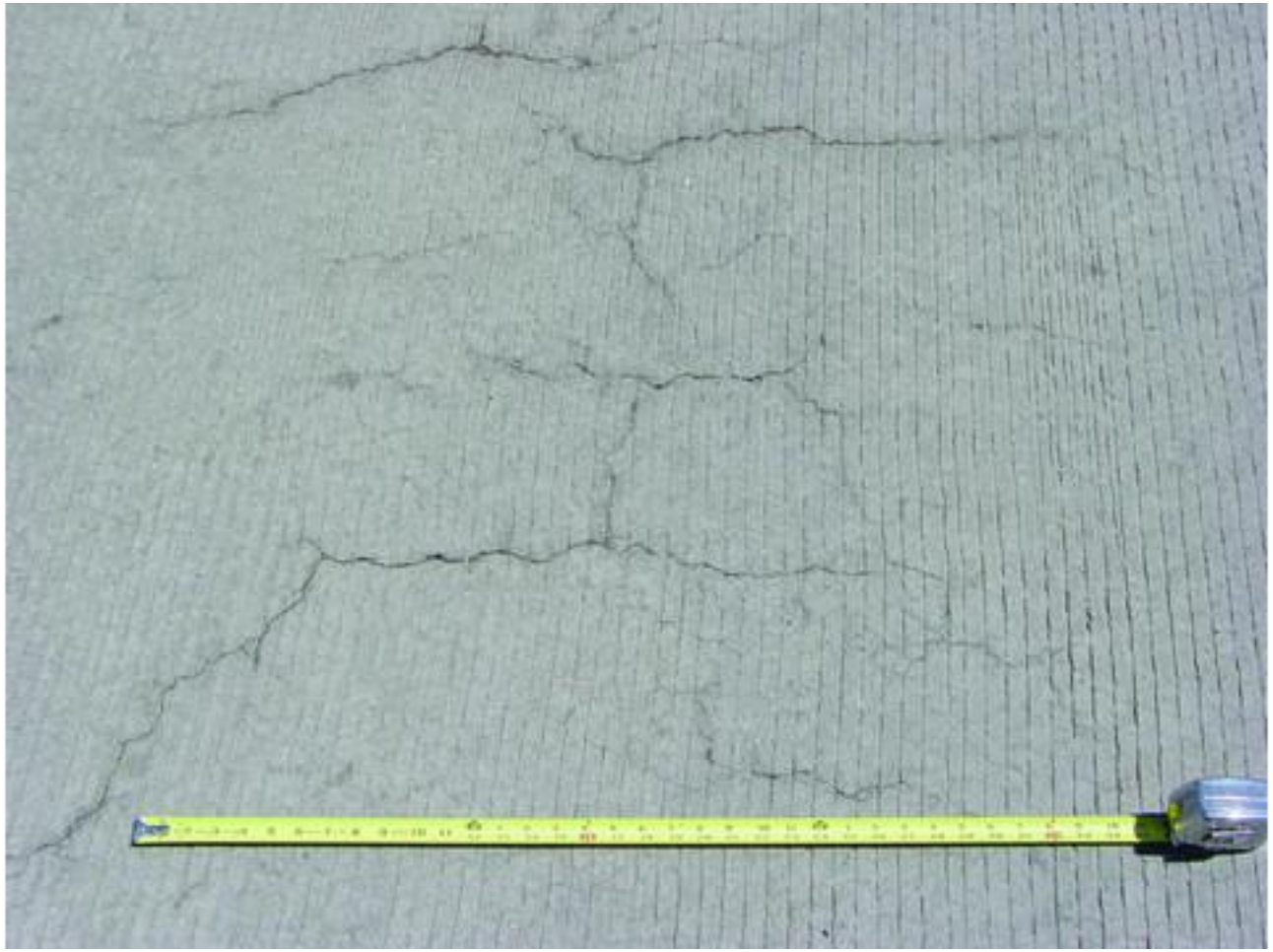
Saw it (correctly)!

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



Wind on Shrinkage

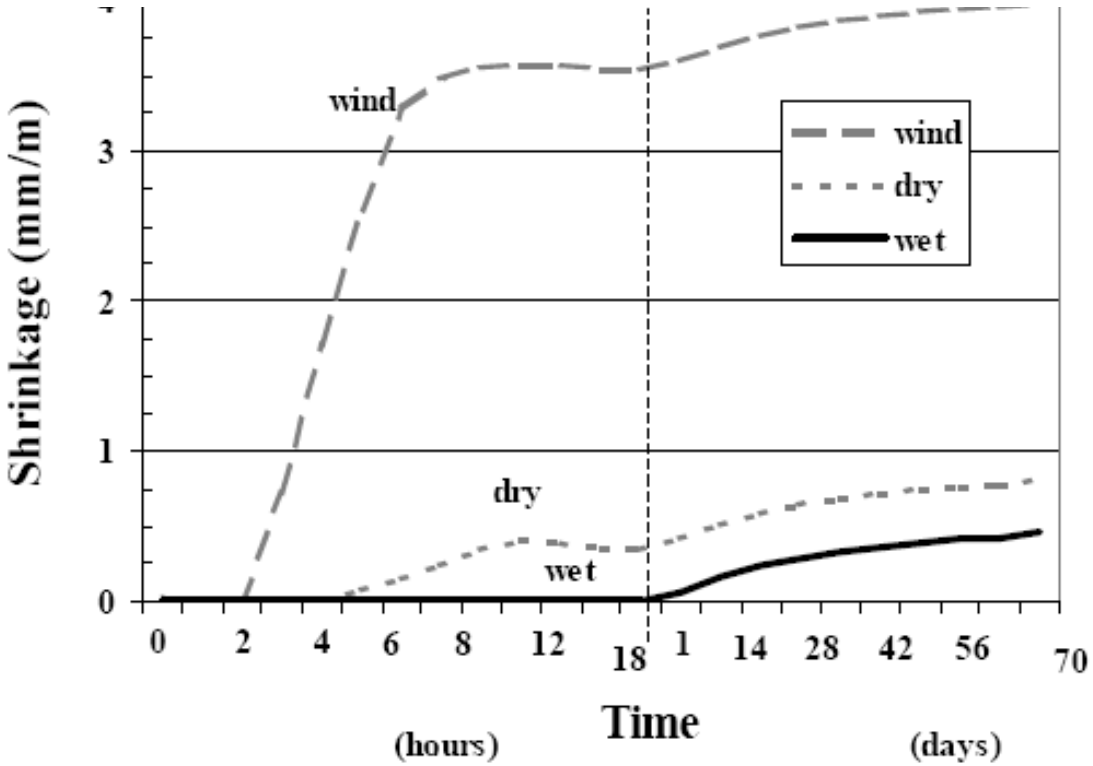
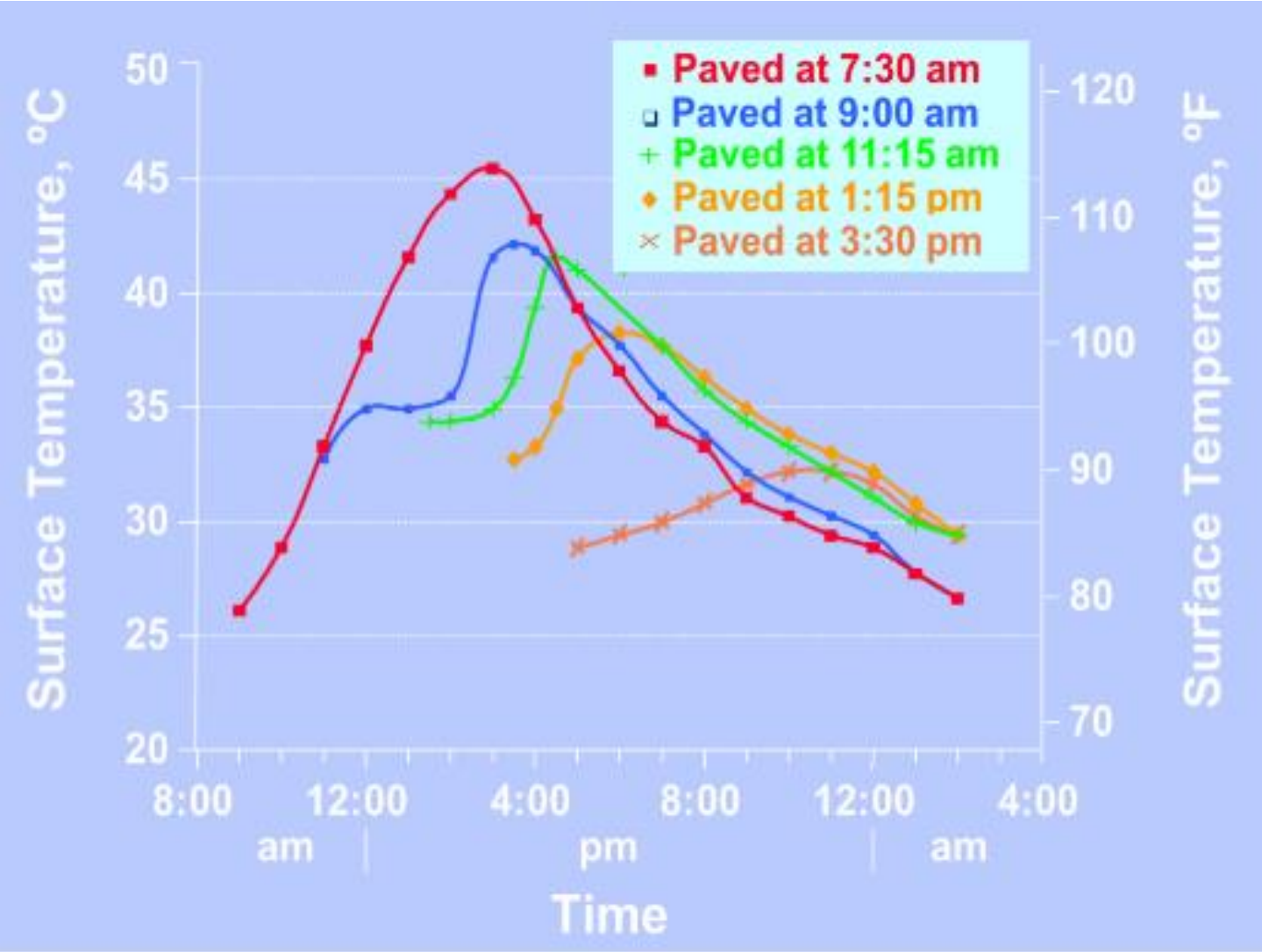


FIGURE 6 Combined early age and long-term shrinkage for three different curing environments (Holt and Leivo, 2000). [1 mm/m = 1,000 µm/m (0.001 in./in.).]

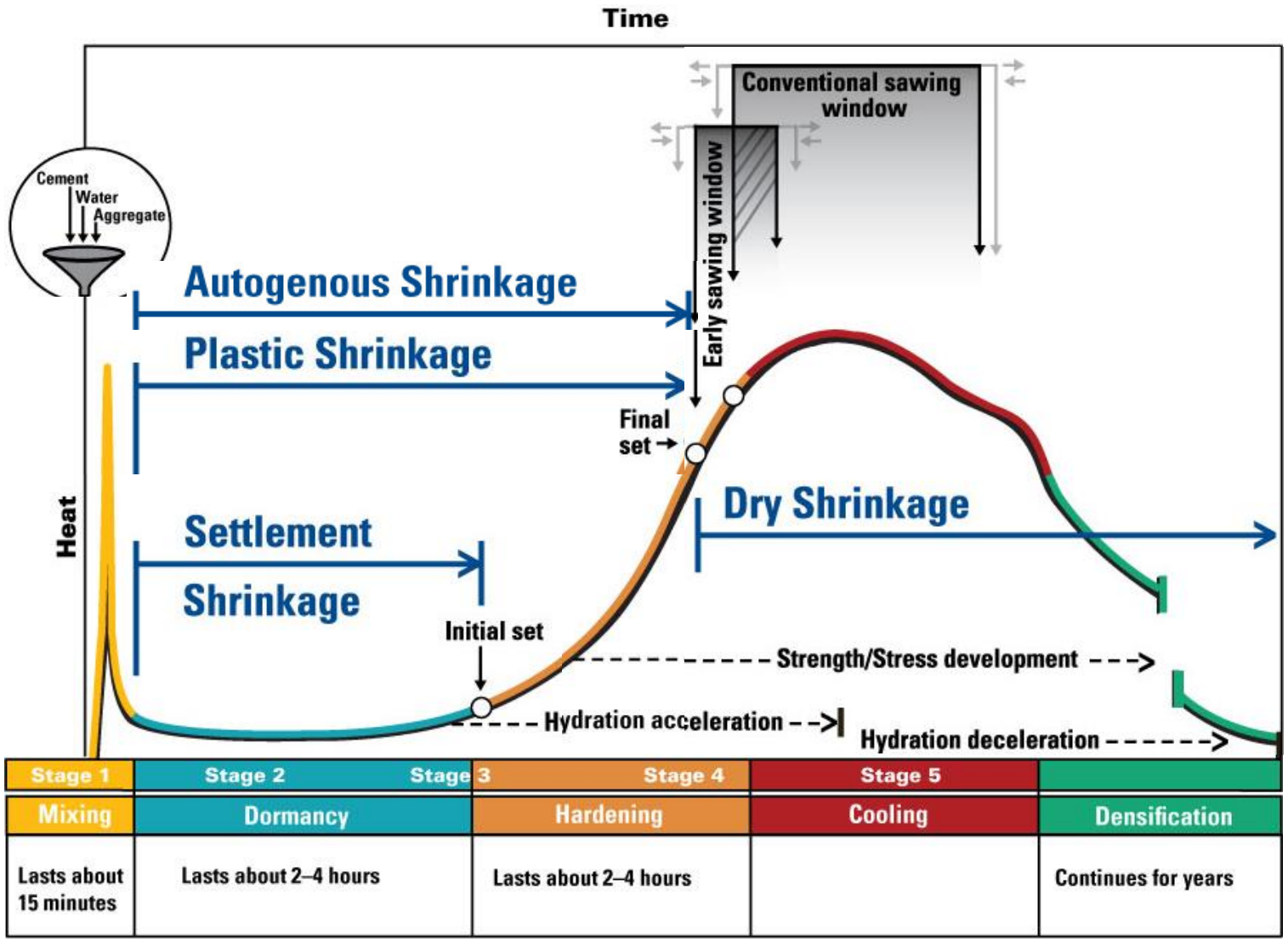
From: Transportation Research Circular E-C107, October, 2006

Thermal Shrinkage

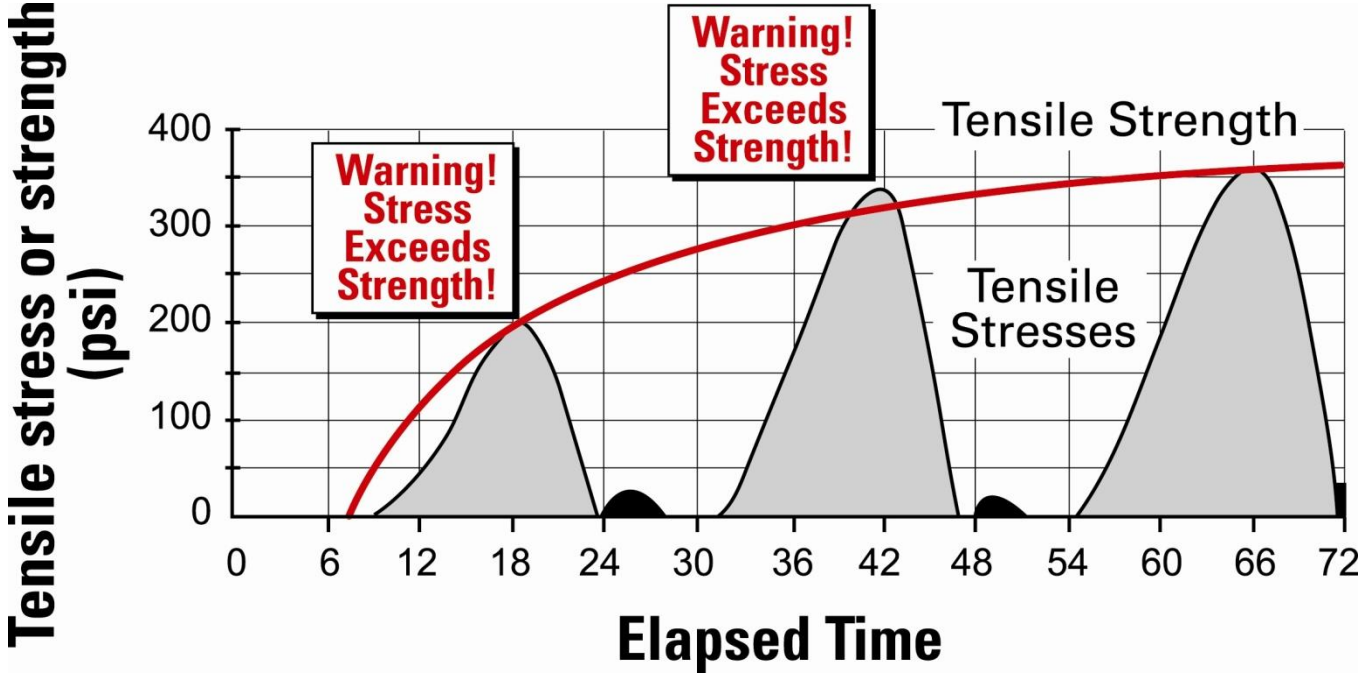


Concrete Shrinkage

Concrete shrinkage mechanisms receive positive benefit from a lower w/c ratio, and lower permeability!



Combined Shrinkage and Curling Stresses



HIPERPAV curve

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

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

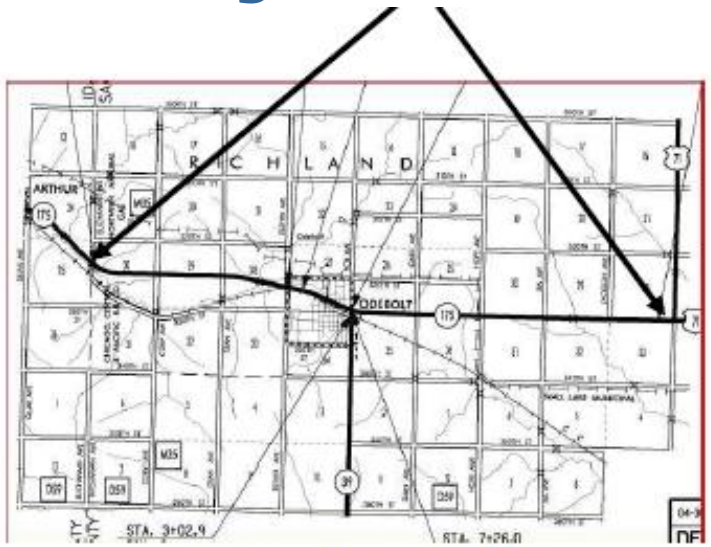
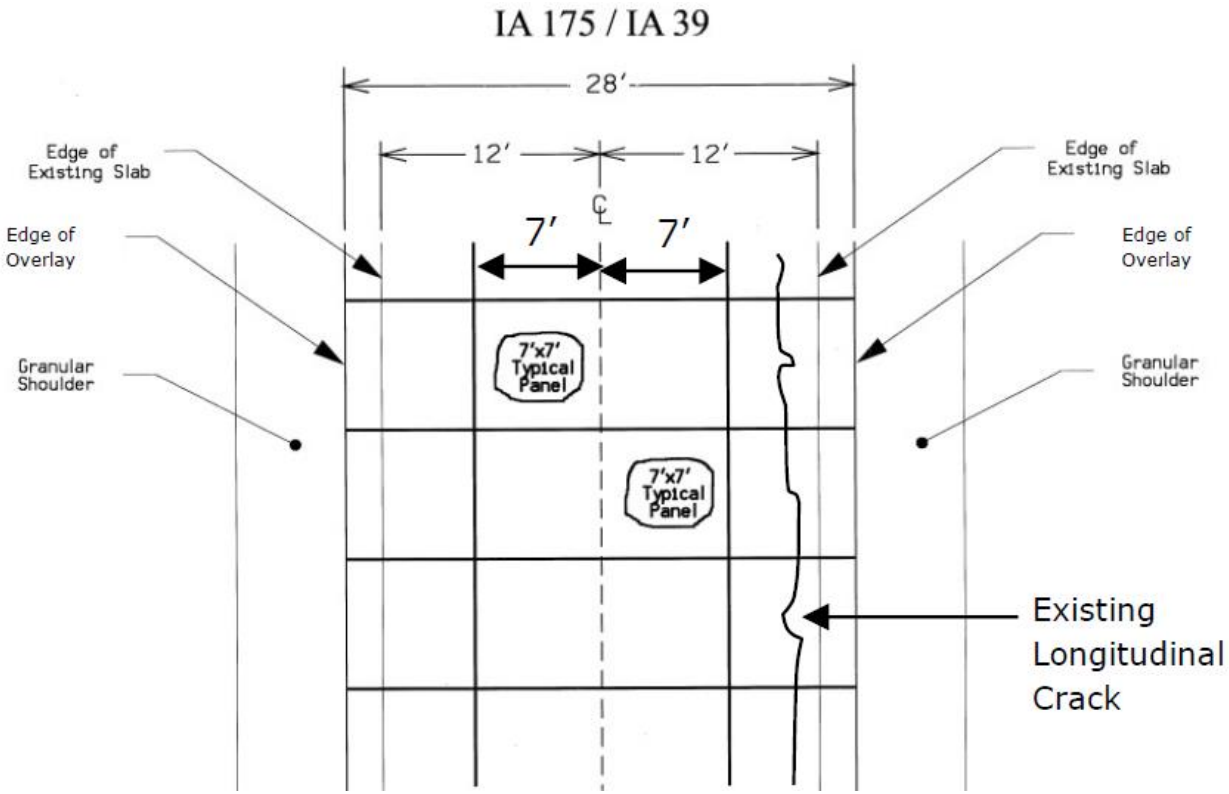
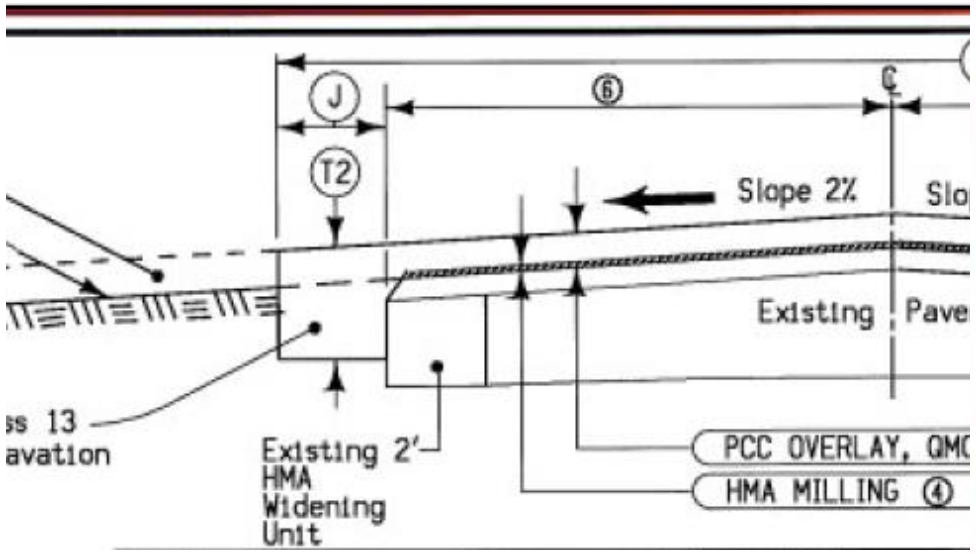


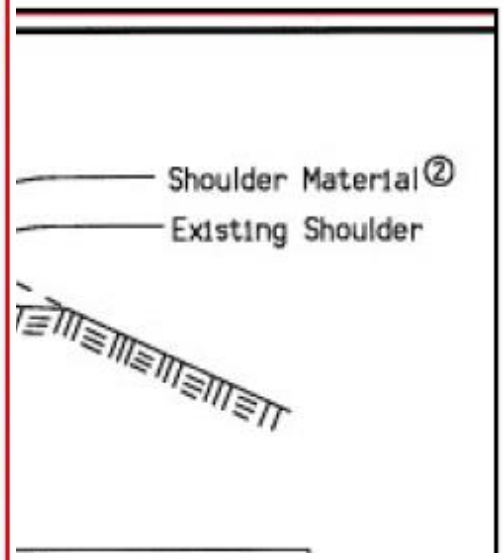
Figure 3-1 Location Map

Concrete Overlays

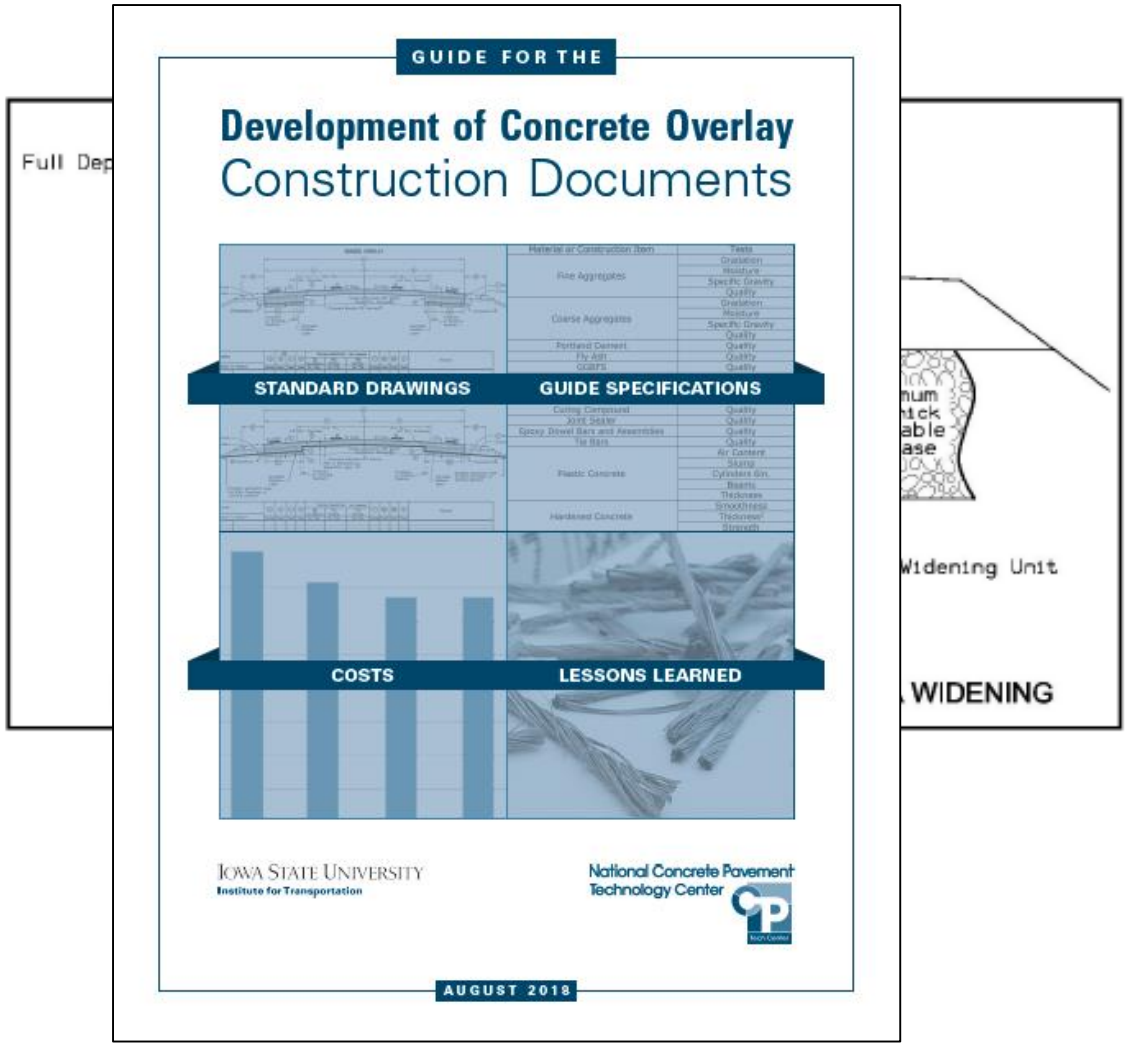


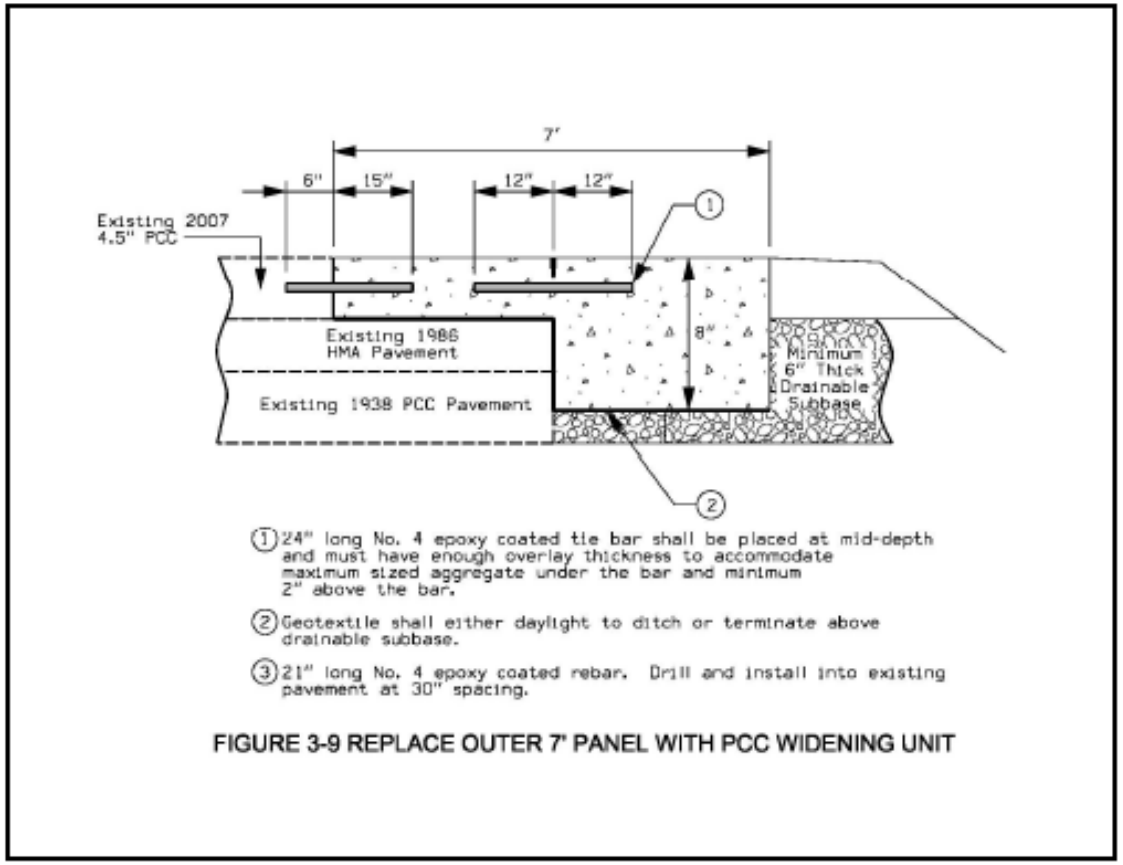
Concrete Overlays





Concrete Overlays

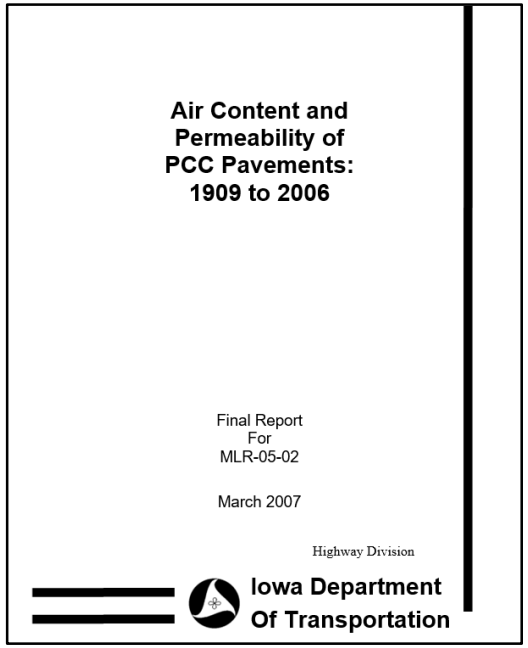




Materials

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

What has Changed?


Air Content and Permeability of PCC Pavements: 1909 to 2006

Final Report For MLR-05-02

March 2007

Highway Division

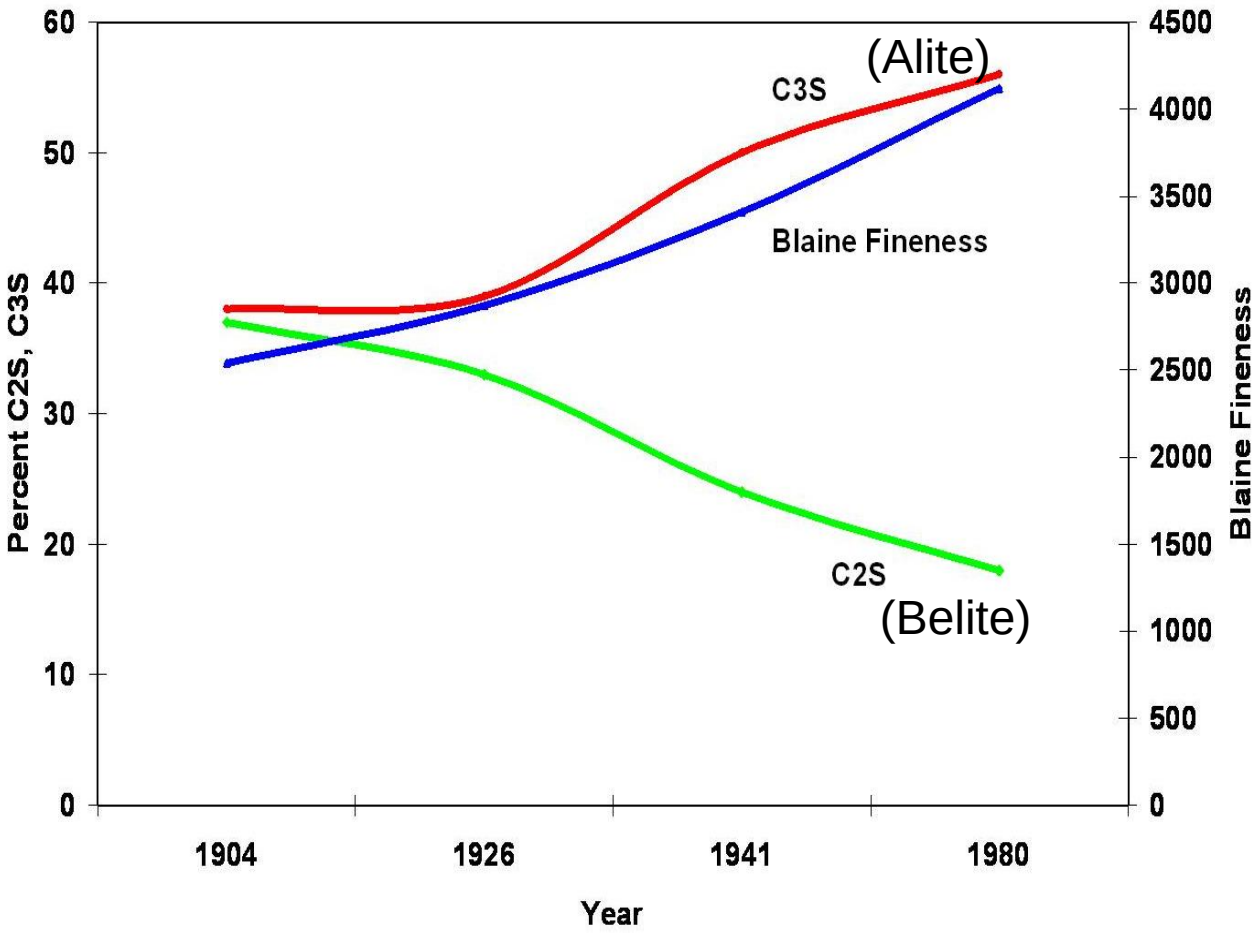
Iowa Department Of Transportation

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

Table 1 - List of Pavements Investigated

County	Year	Location	Fine Agg	Coarse Agg	Cement
Mahaska	1909	Eddyville Cemetery Rd	Eddyville	Eddyville Gravel	n/a
Woodbury	1921	Old 20 E of Sioux City	Correctionville	Correctionville Gravel	Marquette Northwestern
Wapello	1929	Old 63 S of Ottumwa	Ottumwa	Dewey Stone	Marquette Atlas
Monona	1938	IA 175 MP 8.7 to 14.4	Correctionville	Correctionville Gravel	Ash Grove
Pocahontas	1946	IA 15 MP 0 to 5.5	Sacton	Sacton Gravel	Hawkeye
Greene	1955	US 30 MP 94.5 to 99.1	Sprague	Sprague Gravel	Northwestern Penn Dixie
Marshall	1963	US 30 MP 172.2 to 179.9	Clemons	Ferguson Stone	Dewey I Lehigh I
Hamilton	1975	US 20 MP 141.5 to 149.5	Sturtz	Moberly Mine	Marquette Lehigh I
Boone	1980	IA 17 MP 21.6 to 32.7	Christensen	Sturtz Gravel	Northwestern I Penn Dixie I
Story	1992	US 30 MP 151.9 to 156.8	Christensen	Ames Mine	Ash Grove 15% C fly ash
Linn	1997	US 151 MP 33.6 to 36.6	Ivanhoe	Bowser Stone	Holcim IS(35) 10% C fly ash
Jones	2002	US 151	Anamosa	Stone City	Lafarge IS(20) 20% C fly ash
Fremont	2006	IA 2	Oreapolis #8	Weeping Water	Ash Grove IP(25) 20% C fly ash

What has Changed?
Cement Chemistry



Cement chemistry has changed over the years, but we have the same or better results

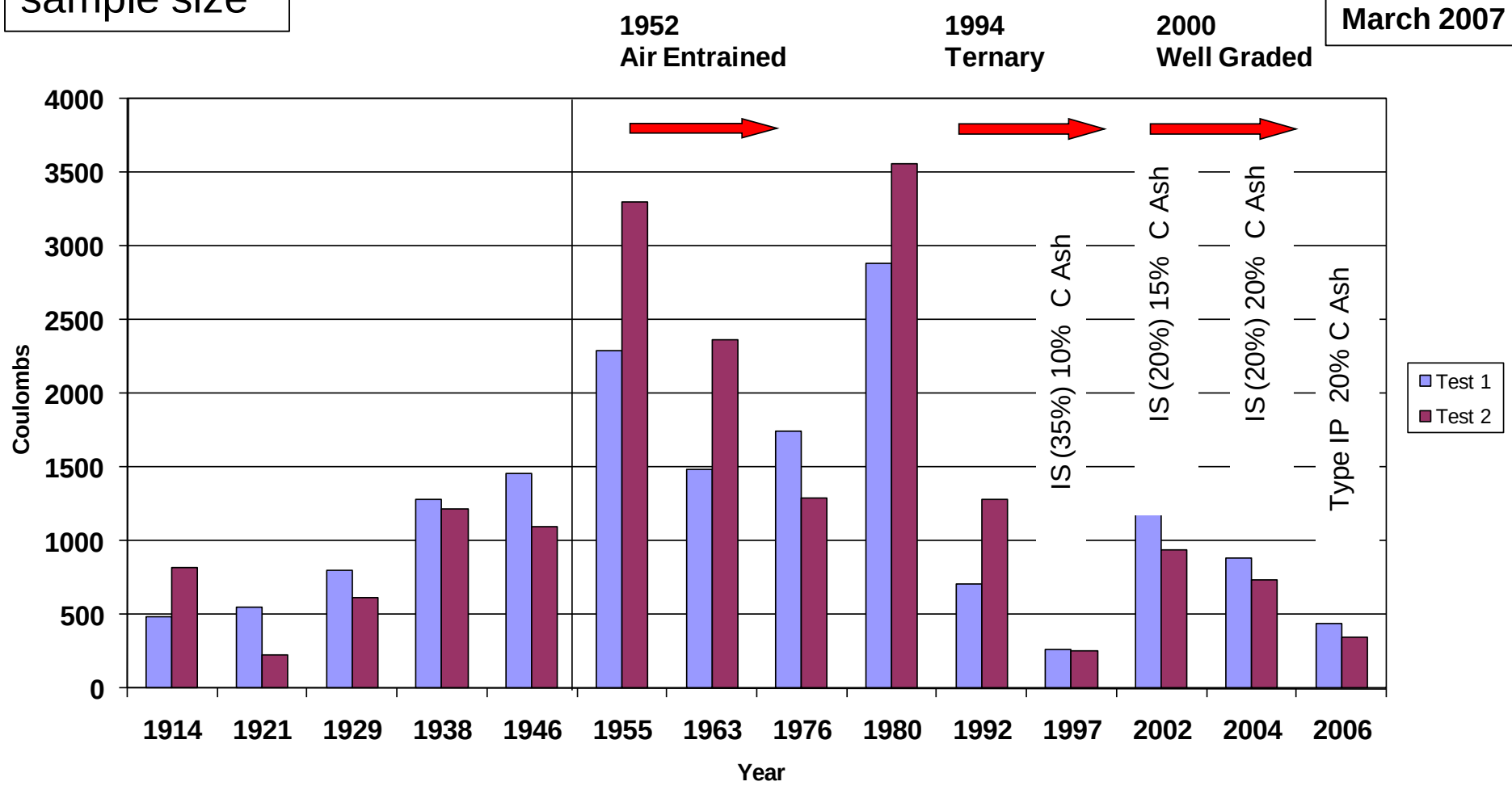
Iowa DOT Report MLR-05-02, March 2007

What has Changed? - Permeability

RCP - **AASHTO T 277**

13 project sample size

Iowa DOT Report MLR-05-02, March 2007

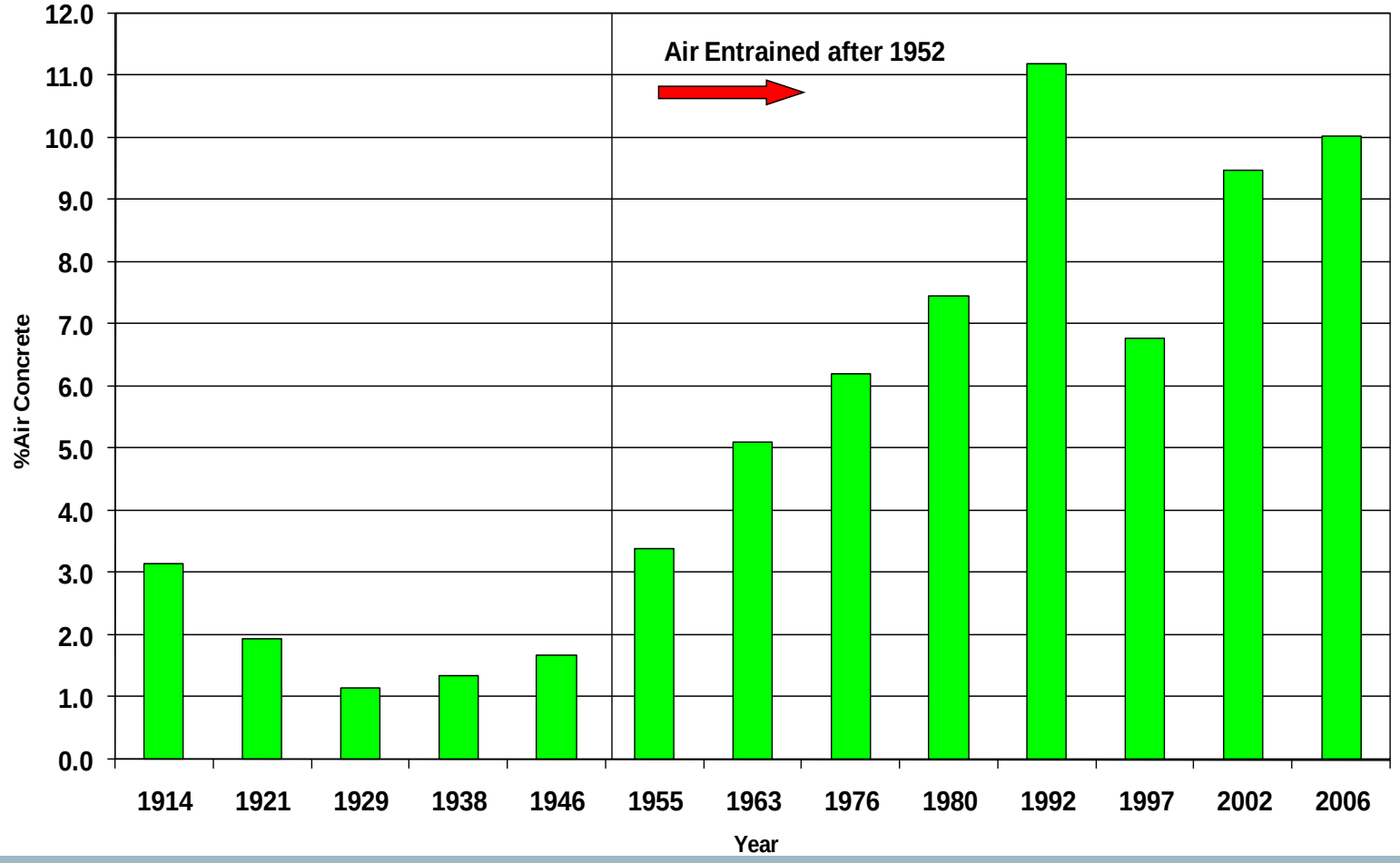


Low permeability is more important than air (based on older pavements)

What has Changed? - Air

13 project sample size

Iowa DOT Report MLR-05-02, March 2007



Results of Iowa DOT (MLR-05-02) Report

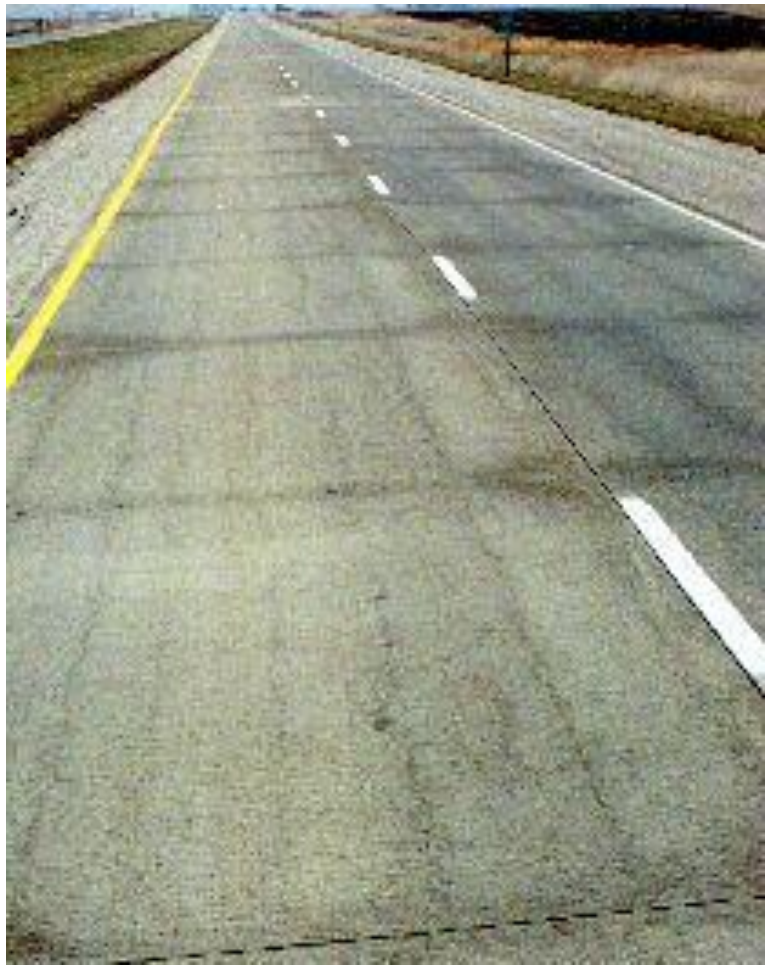
- The air content for projects placed prior to the requirement for air entrainment in 1952 is less than 3%
- Air contents increased as specification limits increased.
- The indicated permeability of older pavements is very low.
- **The permeability of pavements utilizing a Shilstone type gradation and 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%

upper5-6%

lower 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**

Iowa DOT QM-C Mix

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?

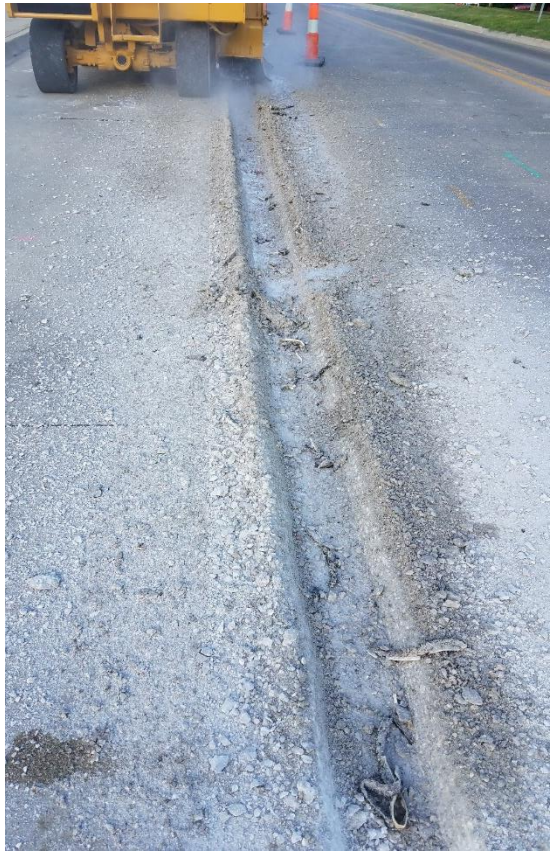
What happened?

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

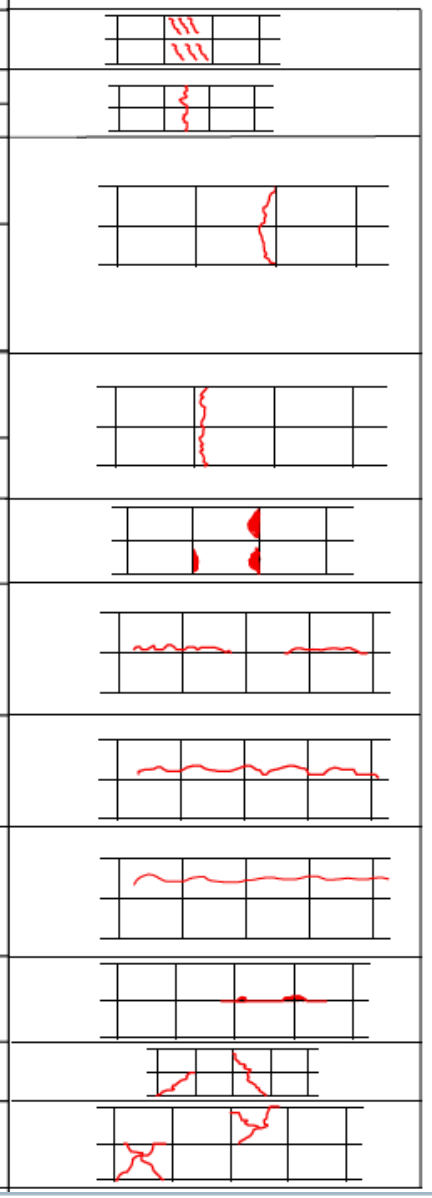
Match Jointing

Diagonal (Random) Cracking

Very poor subgrade

Repairs for PCC Cracking

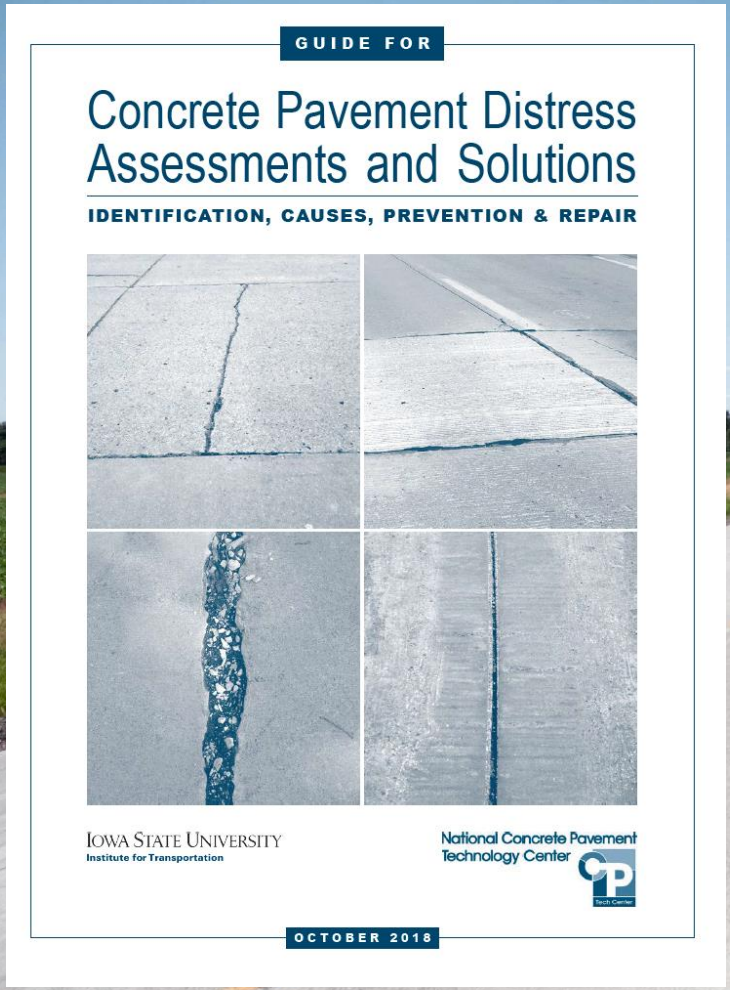
Defect	Orientation	Location	Description	Dowelled/Undowelled Transverse Joints	Recommended Repair
Plastic Shrinkage	Any	Anywhere	Partial-depth and more than 0.007 in. wide	Either	Do nothing
Uncontrolled Crack	Transverse	Mid-Panel	Full-Depth	Undowelled	Saw/route and seal crack
				Dowelled	Full-Depth Repair or LTR[a]
Uncontrolled Crack	Transverse	Crosses or ends at transverse joint	Full-Depth	Undowelled	Saw & seal crack; Epoxy sawed joint if uncracked
				Dowelled	Full-Depth Repair or If crack jumps from sawcut to edge of slab within 3 feet of edge of slab, stop sawcut, saw & seal crack
Uncontrolled Crack	Transverse	Parallel to & within 5 ft. of joint	Full-Depth	Undowelled	Saw and seal crack Seal joint
				Dowelled	Full-Depth repair to replace crack and joint
Spalled sawcut or uncontrolled crack	Transverse	Anywhere	Spalling; more than 3.0 in.wide	Either	Partial-Depth Repair
Uncontrolled Crack	Longitudinal	Relatively parallel to & within 1 ft. of joint; May cross or end at longitudinal joint	Full-Depth	Either	Saw/route & seal the crack or cross-stitch the crack Epoxy sawed joint if uncracked
Uncontrolled Crack	Longitudinal	Relatively parallel to & within wheel path; 1 - 5 ft. from jcint	Full-Depth, hairline, or spalled	Either	Remove and replace panel or cross-stitch crack
Uncontrolled Crack	Longitudinal	Relatively parallel to & further than 5 ft. from a longitudinal joint or edge	Full-Depth	Either	Cross-stitch crack
Spalled sawcut or uncontrolled crack	Longitudinal	Anywhere	Spalled	Either	Partial-Depth Repair
Uncontrolled Crack	Diagonal	Anywhere	Full-Depth	Either	Full-Depth Repair
Uncontrolled Crack	Multiple per panel	Anywhere	Two or more full depth cracks dividing panel into 3 or more pieces	Either	Remove and replace panel

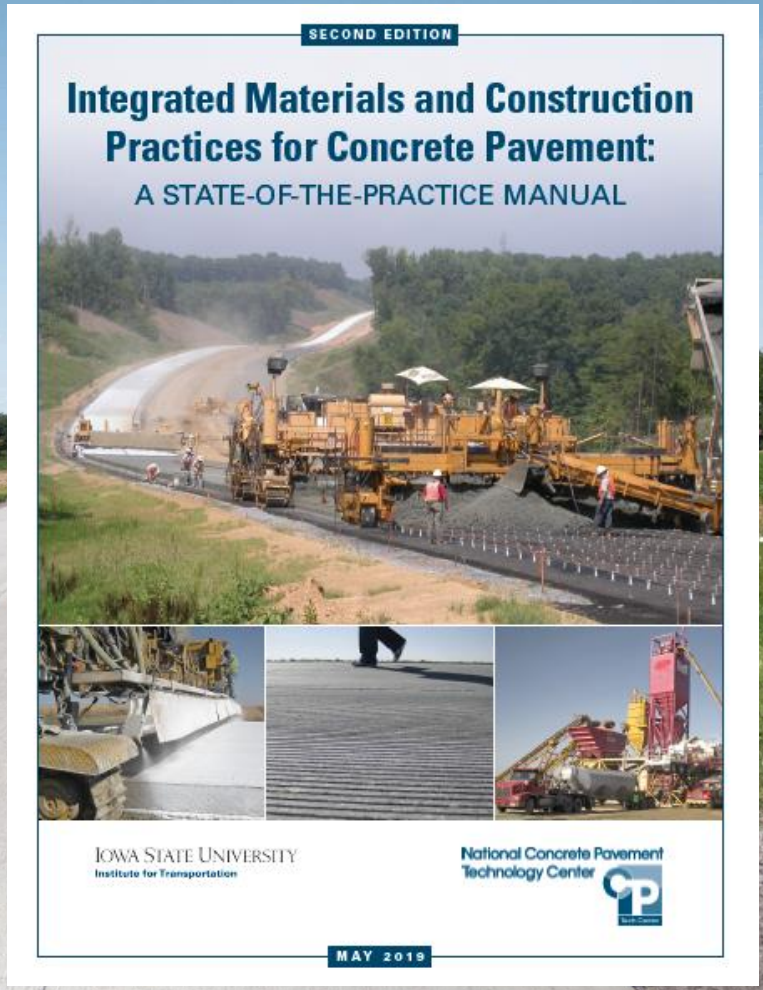


Iowa DOT Construction Manual Appx 9-6

National Concrete Pavement Technology Center

Tech Center





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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

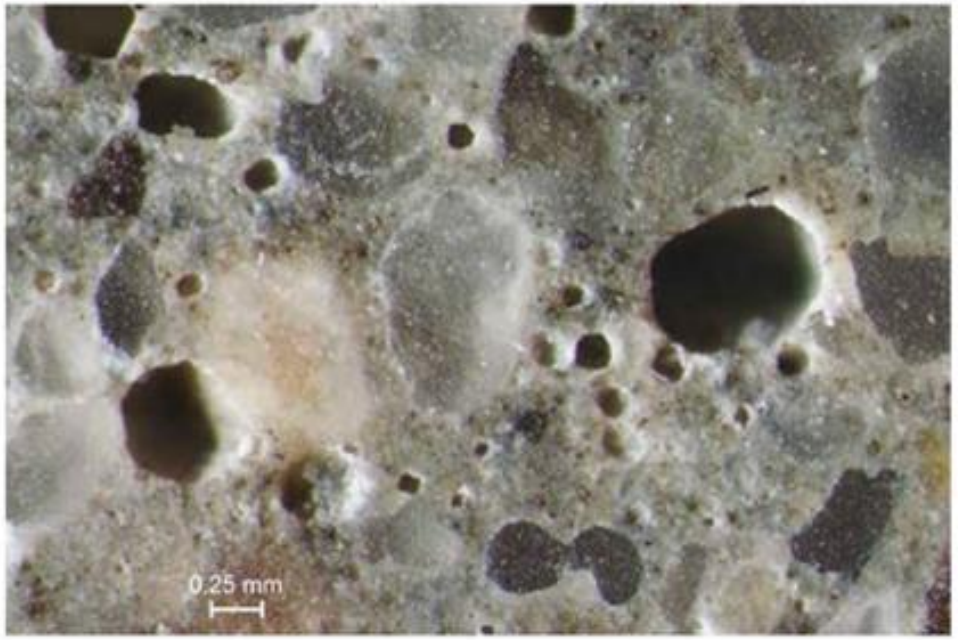


Figure 13a – Adequate Air Entrained System

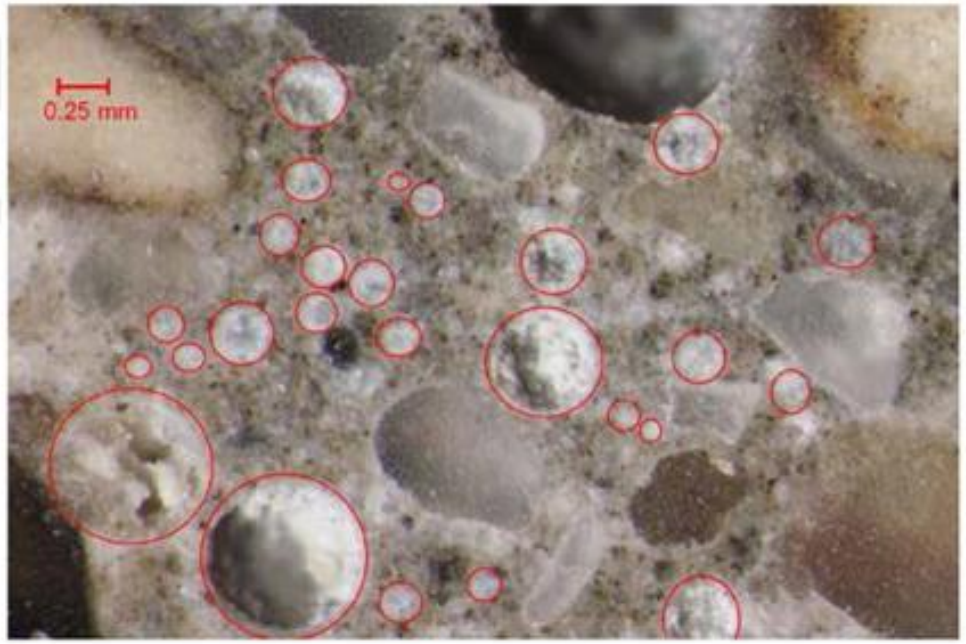


Figure 13b – Air voids Filled with Ettringite

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

Concrete Overlays

Concrete Overlays

Route D-35 near Kansas City

2008 Unbonded Concrete Overlay

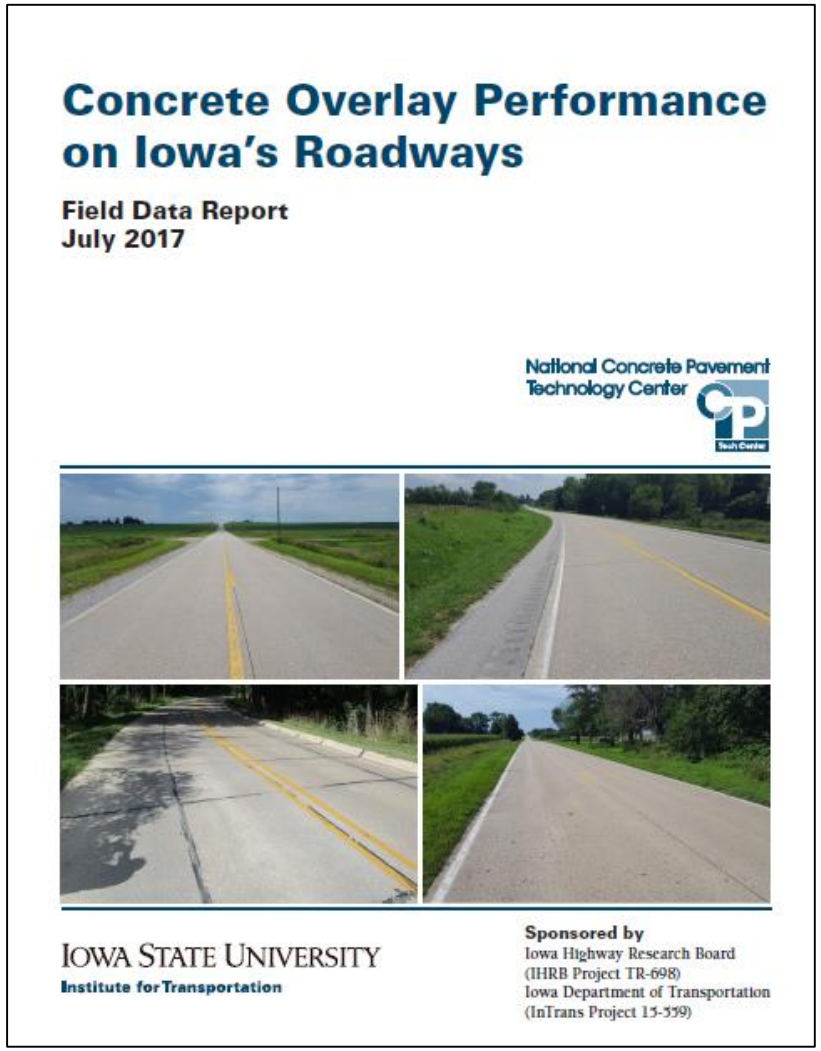
First U.S. project with nonwoven geotextile fabric

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

National Concrete Pavement Technology Center

IOWA STATE UNIVERSITY
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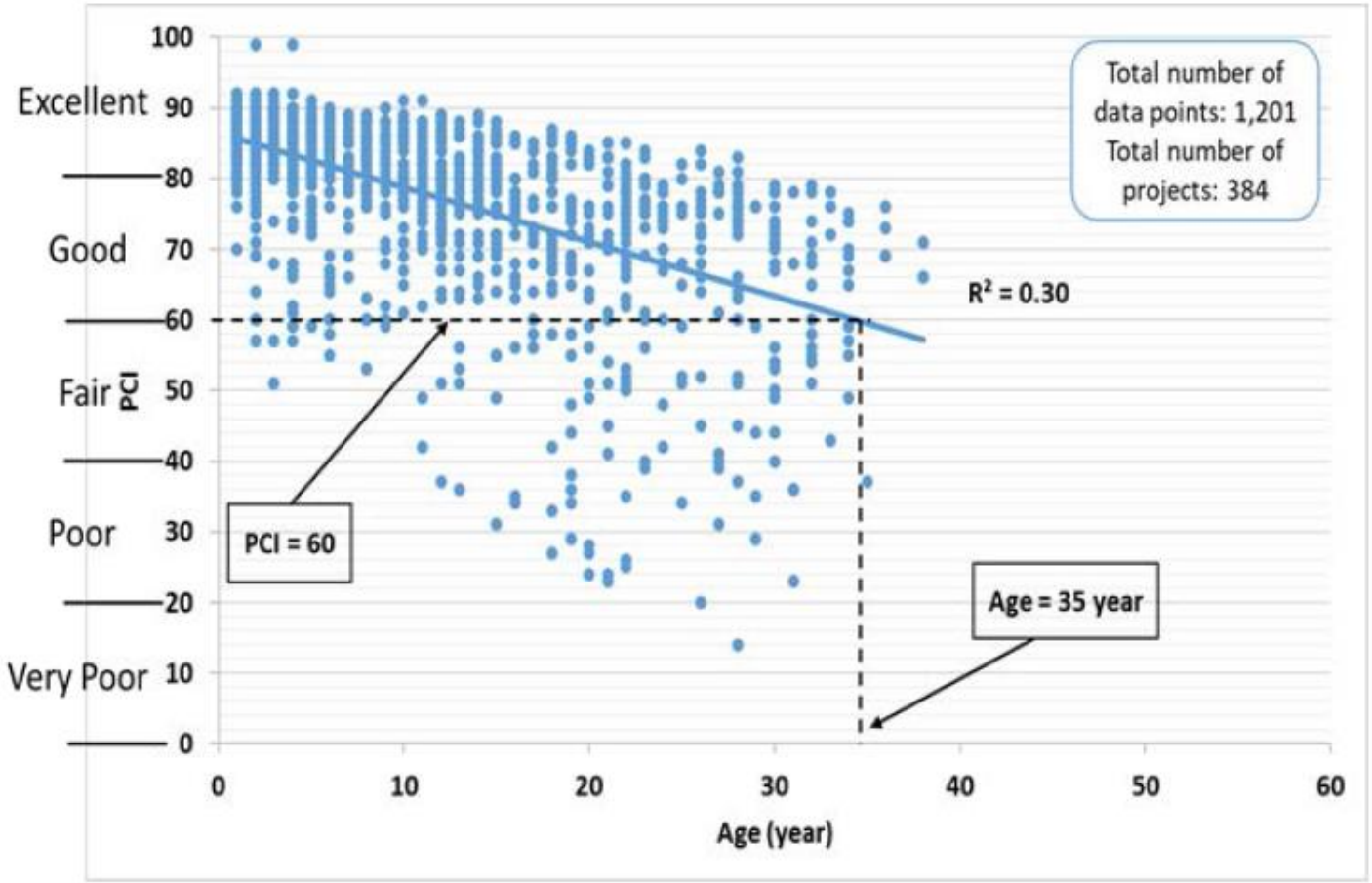
Sponsored by
Iowa Highway Research Board
(IHRB Project TR-698)
Iowa Department of Transportation
(InTrans Project 15-559)



Concrete overlays performing very well

Rehabilitation - Asbury Rd, Dubuque

Credit: Robert Schiesl, City of Dubuque

Rehabilitation - Asbury Rd, Dubuque

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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: INCLUDES: DESIGN, CONSTRUCTION, INSPECTION	$400,791	**$35 / SY**
▪ 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 23rd

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

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

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

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

- $1,000 Per Calendar Day Liquidated Damages
- Any Work Not Completed by June 1st 2012

100-1A
07-15-97

ESTIMATED PROJECT QUANTITIES
(1 DIVISION PROJECT)

Item No.	Item Code	Item	Unit	Total	As Built Qty.
1	2599-9999010	I-680 RECONSTRUCTION	LS	1	

• Pre-Bid Meeting	September 14th
• Began Design	September 15th
• Bid Letting	September 23rd
• Mobilization Into Site	September 24th – 25th
• Pre-Construction Meeting	September 26th
• Begin Pavement Removals	September 26th
• Mainline Subgrade 3D Models	September 30th
• Subgrade Prep Complete (WB I-680)	October 3rd
• I-29 Ramp Geometry & 3D Models	October 4th
• Special Backfill Placement (WB I-680)	October 5th
• 3D Models Complete (I-680 ML & I-29 Ramps)	October 5th
• I-680 WB Pavement Staking	October 7th
• 3D Models Complete (Local Road Ramps)	October 10th
• Begin Paving (I-680 WB)	October 12th
• All 3D Modeling Complete (Incl. Ditches)	October 13th
• I-680 WB Paving Complete (Incl. Ramps)	October 19th
• I-680 EB Paving Complete (Incl. Ramps)	October 25th
• All Paving Completed (Incl. Shoulders)	October 28th
• Ditch Grading Completed	October 30th
• **Open to Traffic (34 days)**	**October 31st**

Tested again in 2019
Some shoulder erosions, no pavement damage

September 19th – EB


October 3rd – EB


October 3rd – WB


October 10th – WB

October 17th – WB

October 24th – WB

Questions:

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