NATIONAL ACADEMIES Sciences Engineering Medicine

TRB TRANSPORTATION RESEARCH BOARD

TRB Webinar: Innovations in Concrete Bridge Deck Design, Construction, and Materials

March 28, 2025

12:00 – 1:30 PM

PDH Certification Information

1.5 Professional Development Hours (PDH) – see follow-up email

You must attend the entire webinar.

Questions? Contact Andie Pitchford at TRBwebinar@nas.edu

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net. A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP.

ENGINEERING RCEP REGISTERED CONTINUING EDUCATION PROGRAM

Purpose Statement

This webinar will explore innovative practices being implemented across the U.S. to enhance bridge deck durability and serviceability. Presenters will discuss strategies to mitigate concrete deck deterioration caused by steel reinforcement corrosion, and share insights on materials, design techniques, and construction methods that improve longevity.

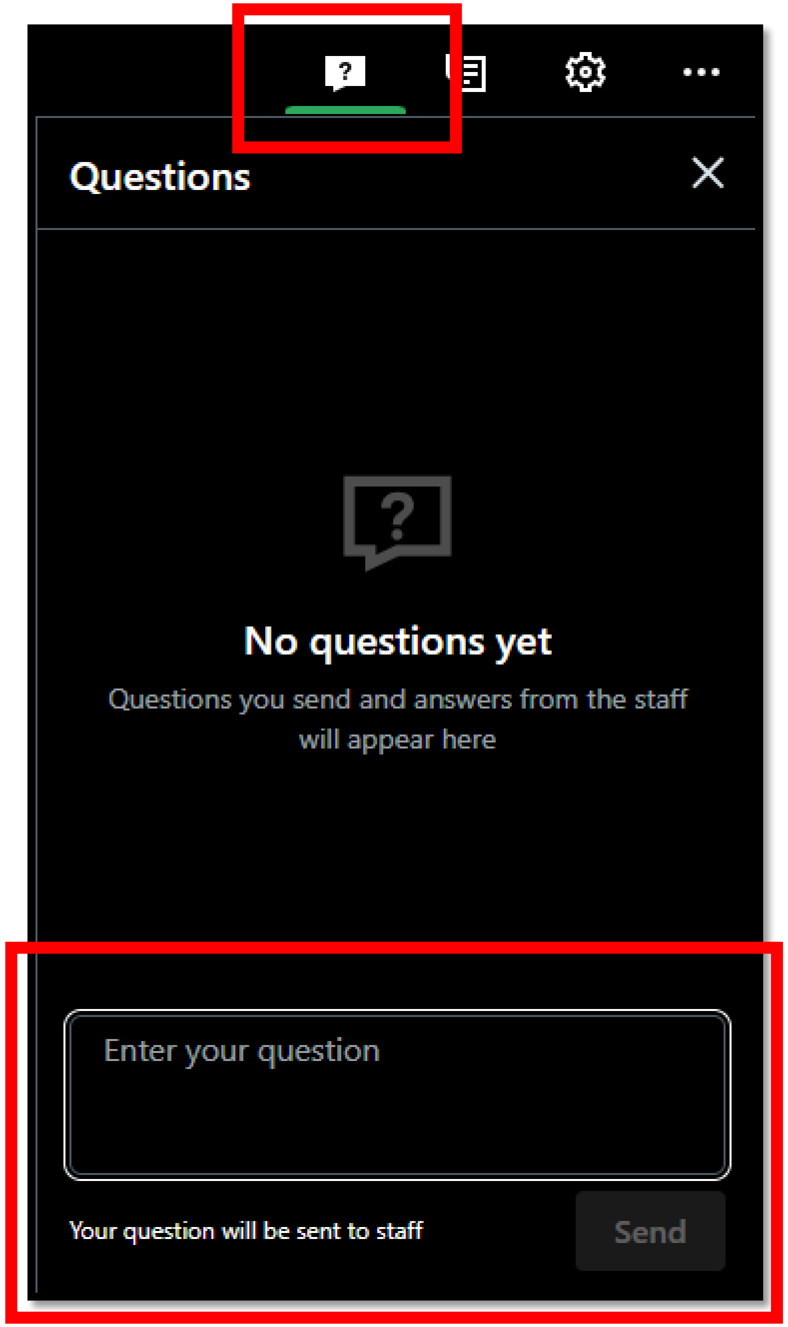
Learning Objectives

At the end of this webinar, you will be able to:

- Identify lessons learned from construction of bridge deck projects that utilize innovative materials and strategies
- Consider future approaches to design bridge decks to provide better durability and service life
- Use readily available technologies to control drying shrinkage to eliminate or greatly reduce bridge deck cracks

Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



Today's presenters

Pinar Okumus
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KU THE UNIVERSITY OF KANSAS



NCHRP Project 20-68, Scan 22-01
Innovations in Concrete Bridge Deck Design, Construction, and Materials

Transportation Research Board Webinar

March 28, 2025

Presenters

Donn Digamon, PE
State Bridge Engineer
Georgia DOT
Scan Team Chair
Moderator

Pinar Okumus, PhD
Associate Professor
University at Buffalo
Scan Subject Matter Expert
Presenter

David Darwin, PhD, PE
Professor
The University of Kansas

Presenter

Craig Knapp, PE
Senior Bridge Engineer
California DOT

Presenter

Pinar Okumus, PhD
Associate Professor
Scan Subject Matter Expert
University at Buffalo

Overview and Findings NCHRP Scan 22-01

NCHRP Domestic Scan Program

NCHRP Domestic Scan 20-68:

- Facilitate information sharing and technology exchange among transportation agencies
- Accelerate the rate of advances in practice
- Identify actionable items of common interest
- Info at: https://domesticscan.org/

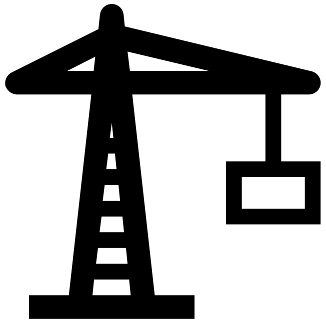
NCHRP Scan 22-01

- Identify innovations in the Design, Construction and Materials for Concrete Bridge Decks

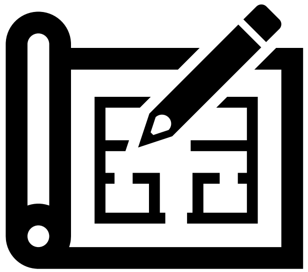
Scan Motivation

Need for innovation in:

Materials



Construction



Design

to improve service life.

Scan Team Members

Donn Digamon,
Georgia DOT, Team Chair

Bijan Khaleghi (retired),
Washington State DOT

Hannah Cheng,
New Jersey DOT

Trey Carroll,
North Carolina DOT

Terry B. Koon,
South Carolina DOT

Edward Lutgen,
Minnesota DOT

Cheryl Hersh Simmons,
Utah DOT

Don Nguyen-Tan,
California DOT

Pete White,
Indiana DOT

Kevin R Pruski,
Texas DOT

Scott M. Walls,
Delaware DOT

Rick Liptak,
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Harry L. White 2nd,
New York State DOT

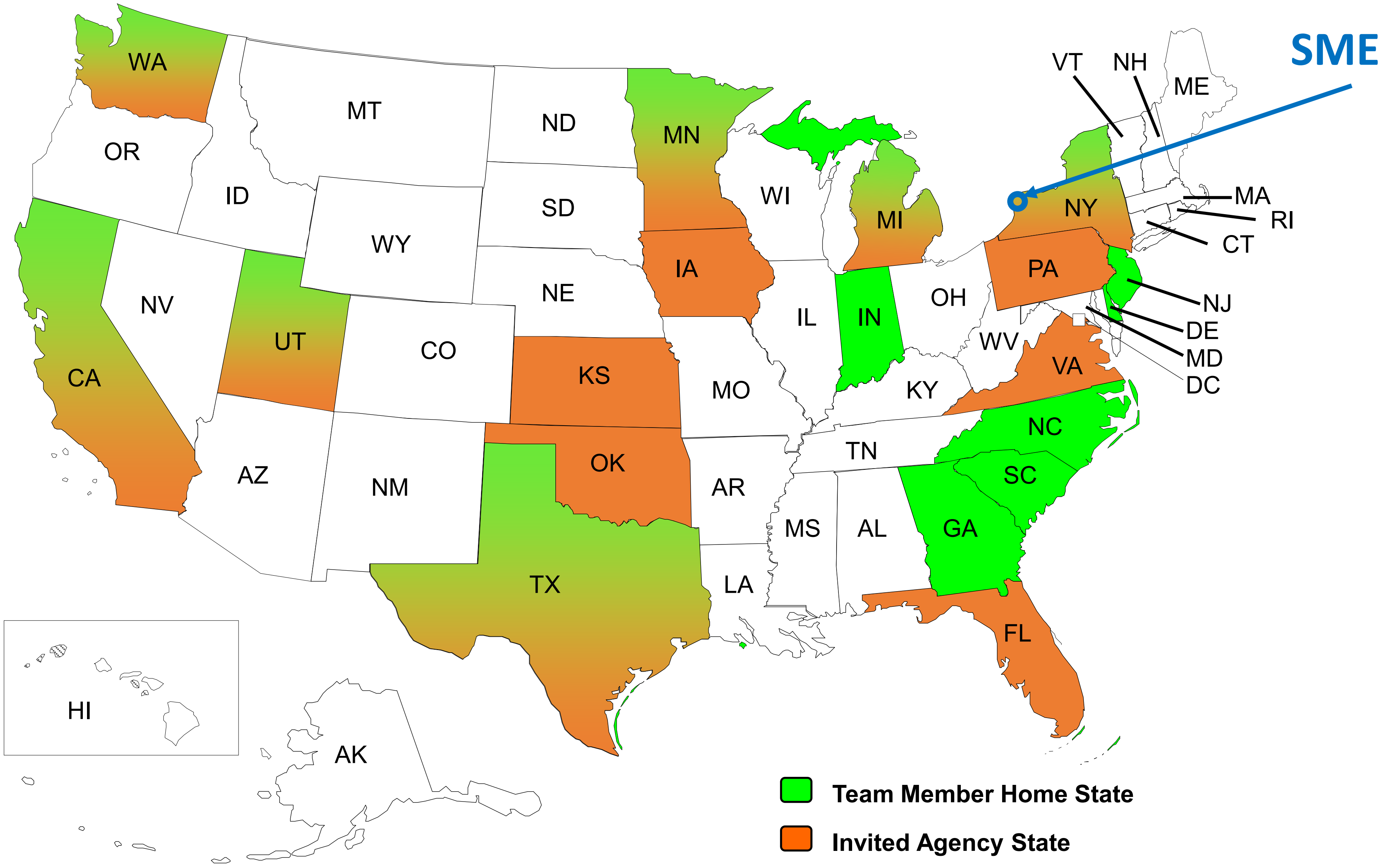
Linh Warren,
FHWA

Pinar Okumus,
University at Buffalo, The State University of New York, Subject Matter Expert

Scan Management

Harry Capers and Melissa Jiang,
Arora and Associates, P.C.

Team Member and Invited Agency States



For More Information

Report Contents

Concrete Mixes, Placement, Protection

- Concrete Mixes
  - Paste Content
  - Performance-Based Mixes
  - Limiting Shrinkage
  - Supplementary Cementitious Materials
  - Test Methods for Concrete
- Placement
- Curing
  - External Curing
  - Internal Curing
- Surface Protection

QA/QC, Workforce Knowledge and Continuity

- Construction Quality Assurance/Control
- Workforce Knowledge
- Knowledge Continuity

Fiber Reinforced Concretes

- Mixes with Fiber
- Ultra High-Performance Concrete
  - Link Slabs
  - Precast Concrete Deck Panel Joints
  - Decks with Optimized Geometry
  - Overlays
  - Non-proprietary mixes
- Engineered Cementitious Composites

Corrosion Resistant Reinforcement

- Fiber Reinforced Polymers
- Galvanized Reinforcing Bars
- Stainless steel
- Stainless Steel Clad Bar
- ASTM A1035 Steel

Prefabrication

- Partial-Depth Decks
- Full-Depth Decks
- Decked Precast Girders
- Proprietary systems

Design and Detailing Practices

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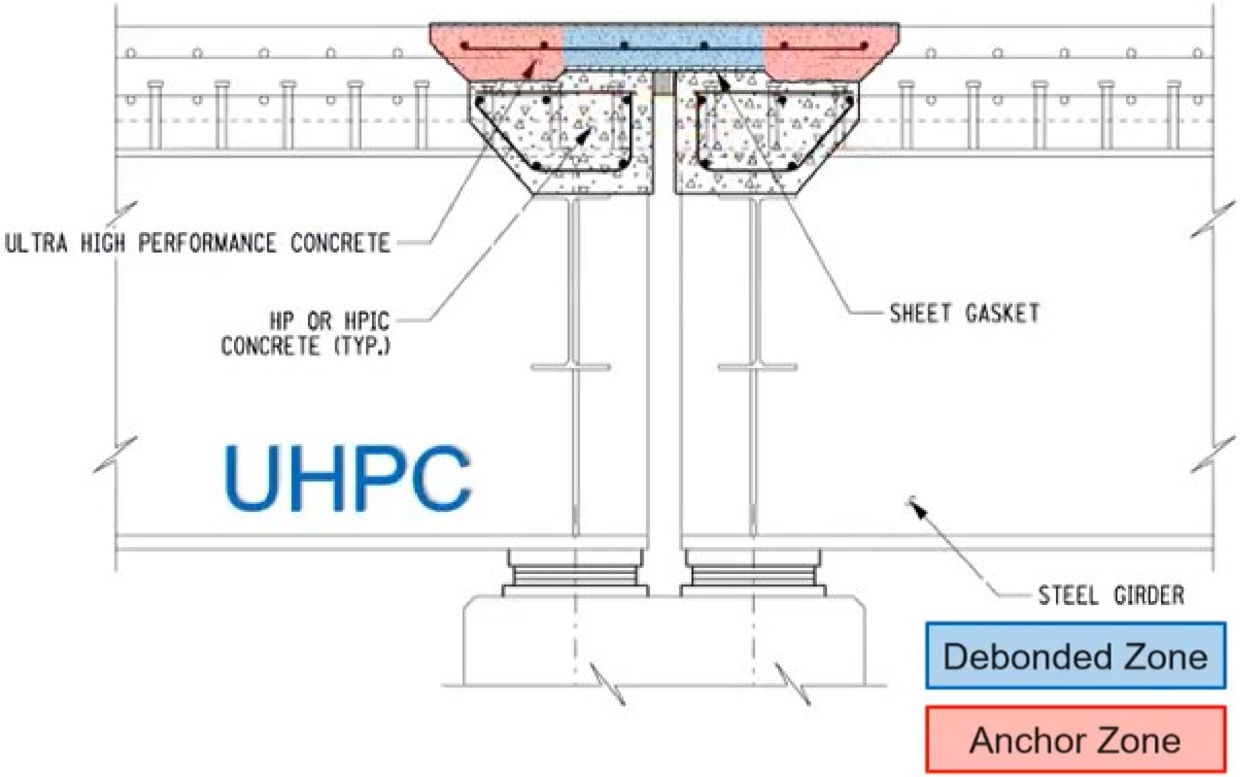
Design and Detailing Practices

Ultra High Performance Concrete (UHPC)

- A fiber reinforced concrete with a specific performance objective
- Tensile strain hardening
- Typically steel fibers
- High compressive strength (>17 ksi or >22 ksi)
- High binder ratio
- High packing density, low permeability

UHPC Link Slabs

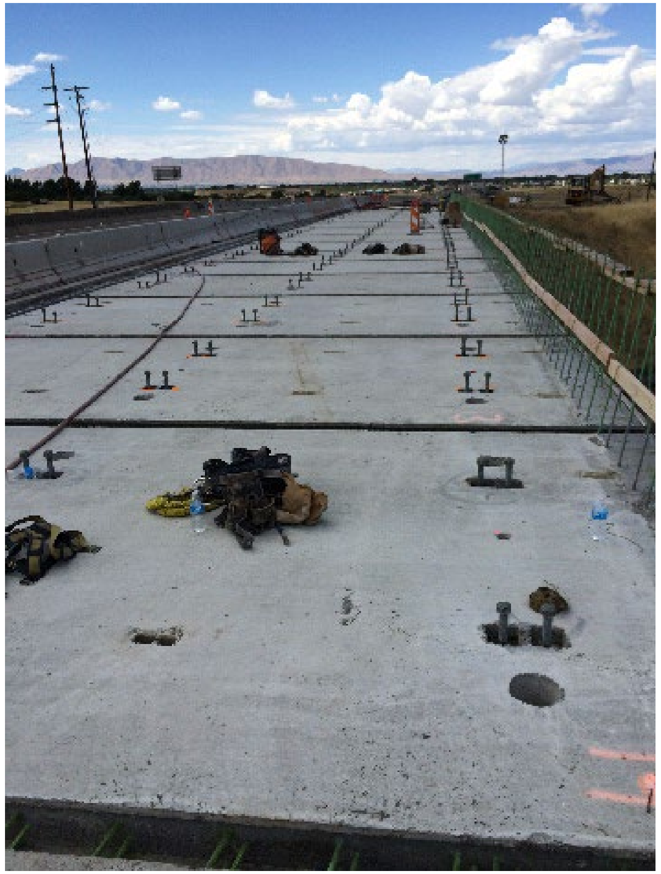
- Used to eliminate expansion joints
- UHPC allows much smaller link slab lengths and thickness than concrete

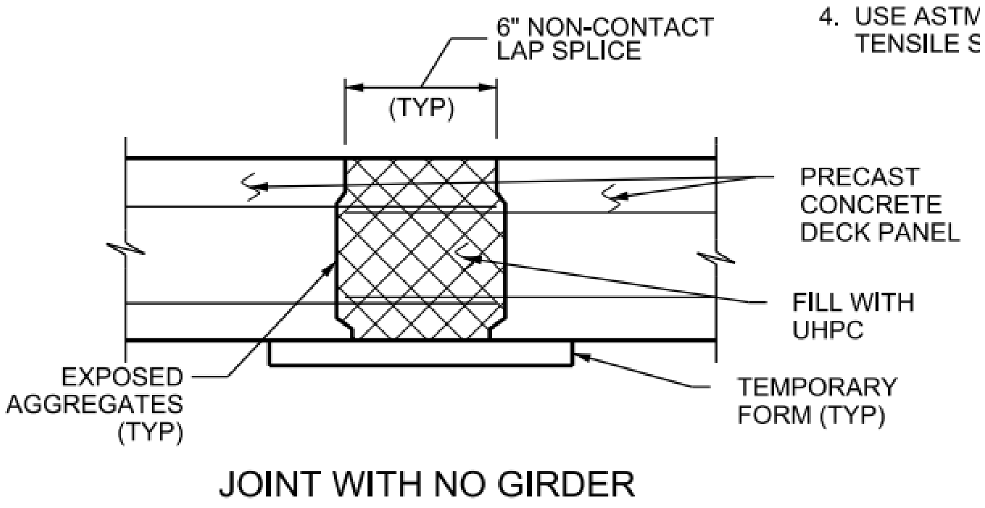


UHPC link slab from New York

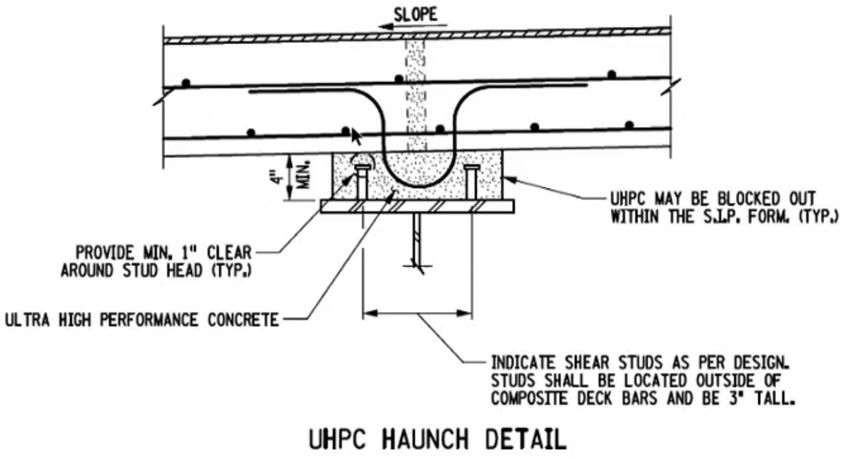
UHPC Deck Panel Joints

- UHPC joints can provide equivalent performance to joint post-tensioning.





UHPC deck joint from Utah

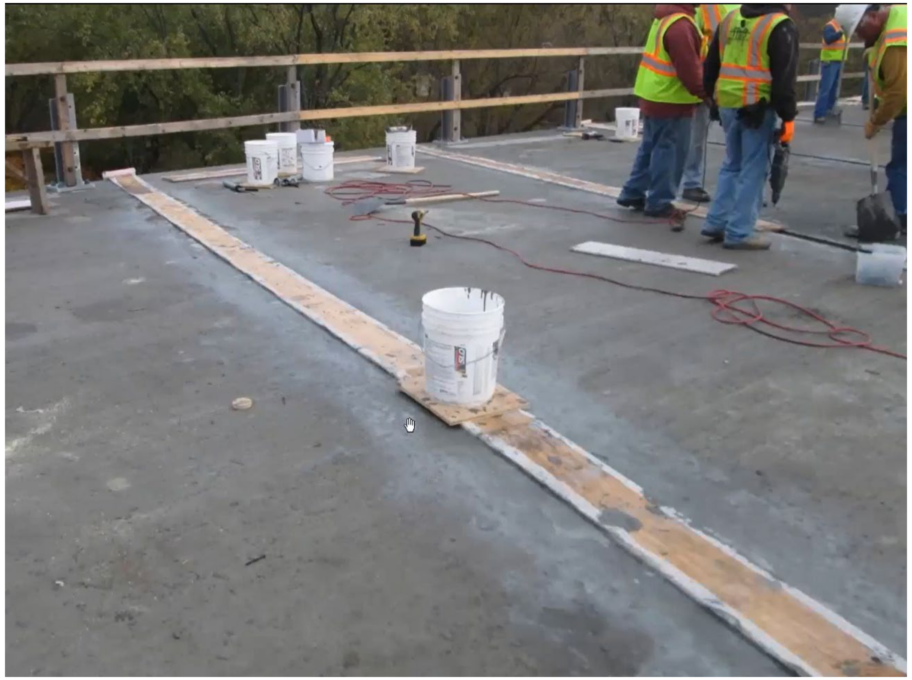


UHPC girder-deck joint from New York

UHPC Deck Panel Joints

For successful applications:

- Seal forms against leakage
- Maintain hydraulic pressure over joints as UHPC tends to settle
- Limit flow length to prevent fibers aligning in the flow direction
- Roughen concrete surfaces
- Bring surfaces to saturated surface dry before placing UHPC
- Require supplier to be on site



Sealing of forms from New York

Non-proprietary UHPC mixes

- Proprietary mixes can be costly (although they come with support)
- States and Universities are developing their own mixes.
- E.g.,

Ingredient	Cement	Sand	Masonry Sand	Silica Fume	Water
Volume Ratio (for 1.0 ft^3)	0.425	0.226	0.200	0.060	0.089
Proportion (lb/yd^3)	1500	790	710	210	320

Iowa DOT

w/c	Portland Cement Type I	GGBFS	Silica Fume	HRWR	Silica Sand (Fine)	Silica Sand (Coarse)	Steel Fiber, 0.5 in
0.22	0.5	0.5	0.25	3%	0.30	1.21	2.0 % by volume

Michigan DOT

Constituent	lb/yd^3
Cement	1522
Silica fume	114
Fly ash	158
Sand	1706
Water	326
HRWR	36.6
Steel fiber	200
w/cm	0.181

Texas DOT

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Design and Detailing Practices

Fiber Reinforced Polymer (FRP) Rebar

- Glass FRP rebar is the most common with vinylester or epoxy resin.
- Differences with metallic reinforcement:
  - Does not corrode
  - Light weight: facilitates construction, but may float during pour
  - Does not yield
  - Design is often controlled by crack control requirements
  - Deck replacement or widening may not be possible because rebar gets damaged
  - Can be used with metallic reinforcement
  - Cannot be field bent
  - Mostly proprietary products
- Florida DOT used FRP rebar since 1980's.

Glass FRP bars in a deck from Kansas

Galvanized Rebar

- Rebar with a metallurgically bonded zinc layer
- Two types:
  - Hot-dip or batch galvanizing (ASTM A767)
  - Continuous galvanizing (ASTM A1094)
- Better bond to concrete than epoxy coated rebar
- Minnesota, Texas, Pennsylvania, Utah, Washington (from the scan) provide galvanized rebar as an alternative to epoxy rebar

Galvanized rebar in Washington

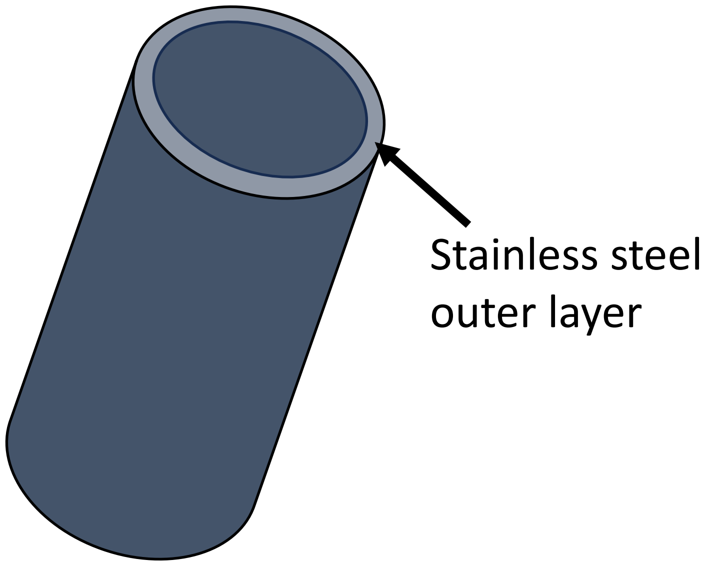
Stainless Steel Rebar

- Level of corrosion protection depends on the composition of the alloy. i.e., not all stainless steel is the same.
- X-ray fluorescence can be used to verify alloy composition
- Virginia DOT reports:
  - An additional cost of 5% of the entire bridge cost.
  - Cost may be smaller than a future overlay.
  - Used when longer service life is needed.
  - Cost is sensitive to alloy cost that vary over time.

X-ray fluorescence by Virginia DOT

Stainless Steel Clad Rebar

- Thin stainless steel outer layer metallurgically bonded to carbon steel
- Cheaper than pure stainless steel
- Ends need protection
- Limited availability in the US (produced in the UK)
- Used in Michigan and Virginia but only on few projects



ASTM A1035 Steel

- Low-carbon, chromium alloy steel
- Alloy type
  - CS
  - CM
  - CL

  Higher corrosion resistance (higher price)
- 100 ksi or 120 ksi yield strength
- Michigan DOT reports:
  - $2.03-$3.00/lb (for CS) vs $1.50-$1.98/lb for epoxy coated bars in 2021
- Most states use CS to be conservative

Utah DOT

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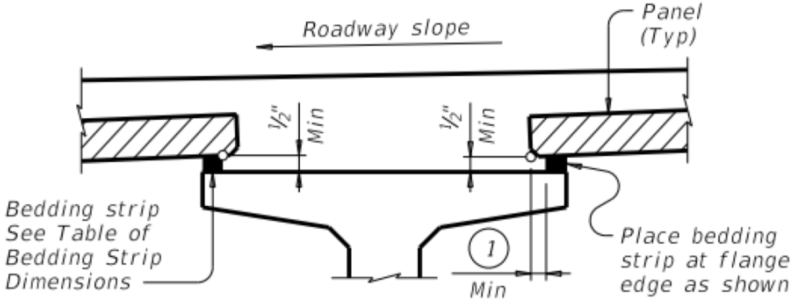
Design and Detailing Practices

Partial-Depth Precast Decks

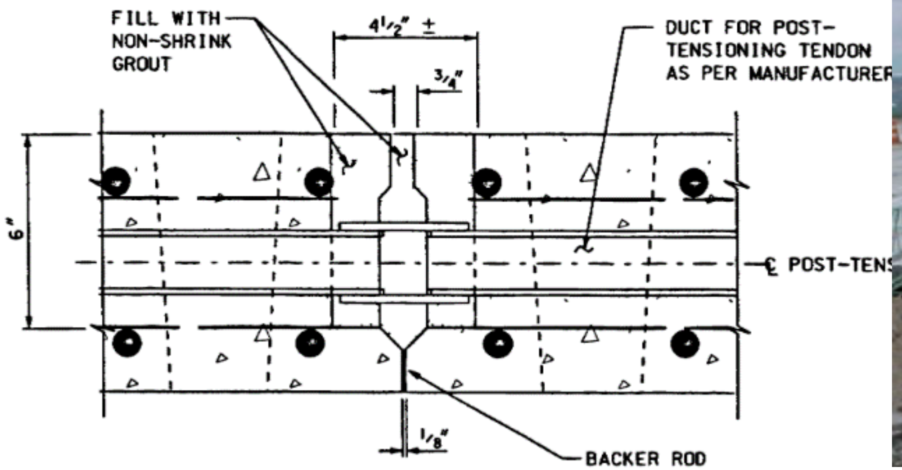
- Thin (~half deck thickness) pretensioned panels that are ~ 8ft long
- Serve as stay-in-place forms made composite with the cast-in-place topping
- Standard practice in Texas, others report reflective cracking.
- Keys to success:
  - Provide bedding strips to support panels over girders so that well-consolidated concrete can form permanent support.
  - Pre-wet panels to achieve saturated surface dry condition.



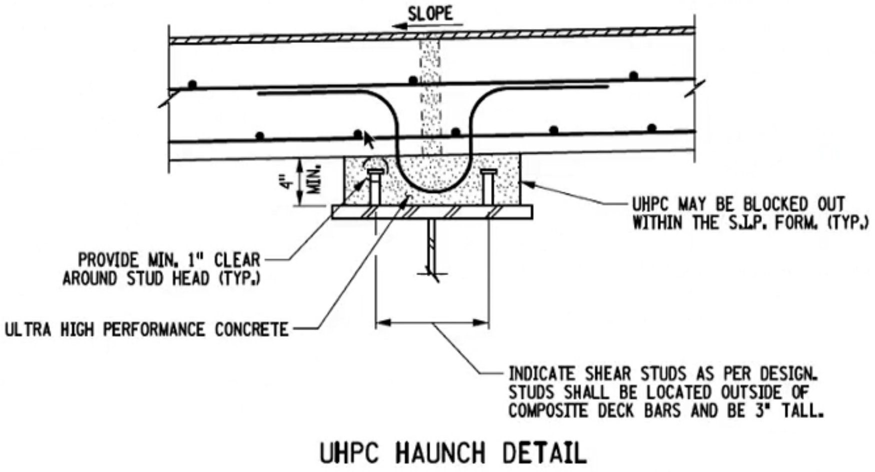
Texas DOT

Full-Depth Precast Decks

- Benefits for rapid construction and for areas far from concrete suppliers
- Likely costly for bridges with complex geometries
- Joint details and materials are critical for performance
- Utah experience:
  - Either post-tensioned or UHPC joints perform well.
  - Wider, normal concrete joints had transverse cracking.



Utah DOT



Hidden UHPC joint detail of New York DOT

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Design and Detailing Practices

Construction Quality

- Preparation is key:
  - On-site or off-site test pours for each new mix
  - Pre-deck pour meetings
  - Construction checklists
  - Training field crew and inspectors
  - Slump and cylinder sampling on-site
  - Frequent sampling and testing of alternative rebars…

Pre-Pour-Planning the Placement: It is required that a pre-pour meeting with the Contractor be scheduled to specifically discuss:

- ☐ Time of starting of pour -- Anticipated weather conditions?
- ☐ Anticipated rate of delivery of concrete?
- ☐ How much material will be needed? At what rate? Haul time from plant?
- ☐ Discuss pouring sequence concerns. Admixtures, dosage rates?

Example checklist from Minnesota

Test pour by Washington

Knowledge Continuity

- Need to keep track of innovative projects through:
  - Innovation specific databases/inventories (e.g., Utah)
  - Websites (e.g., Florida)
  - Agency defined elements for inspection (e.g., Minnesota)
  - Inspection reports
  - Research studies
  - Internal committees
  - Surveys
  - Lessons learned reports
- Innovations require iterations, which require continuity of knowledge.

Select Scan Recommendations

1. Develop documentation strategies.
2. Invest in training and certification.
3. Provide opportunities to predict potential issues with new practices.
4. Invest in research to refine life cycle and deterioration models.
5. Integrate design, materials, inspection and construction perspectives. AND… allow sufficient time for planning.
6. Develop acceptance guidelines for fibers, lightweight aggregate, shrinkage reducing admixtures.
7. Support research to generate field and lab data on corrosion performance of deck materials.

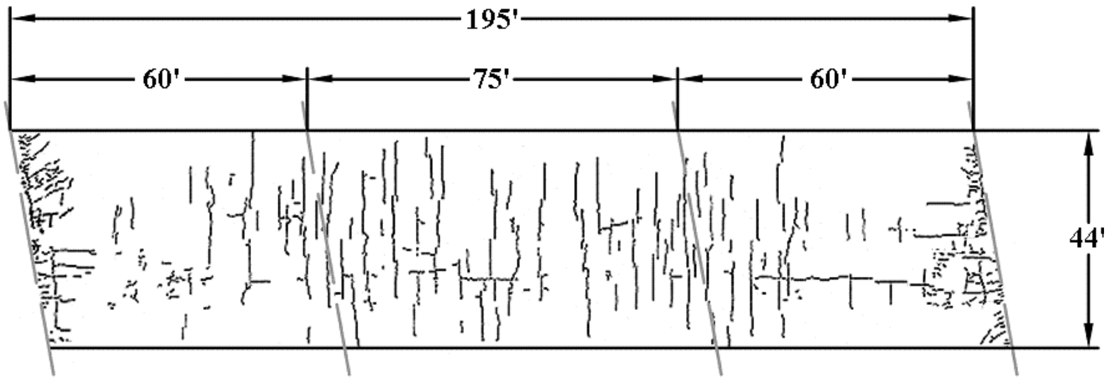
Low-Cracking High-Performance Concrete

David Darwin
University of Kansas

March 29, 2025

Outline – Bridge decks

- Scope
- Findings
- Early Specifications
- Field Experience
- Technologies
- Summary



Bottom Line(s)

- Bridge decks do best with minimal cracking
  - Low paste content (< 27% by volume)
  - Good consolidation*
  - Minimal finishing*
  - Early and thorough curing*
  - Don’t use overlays in new construction

- *Many contractors don’t know how to do this

Scope of Work

Beginning in 1993

First surveys established principal factors controlling cracking

Starting in 2005

Constructed 25 bridge decks under Low Cracking High-Performance Concrete (LC-HPC) specifications (17 in Kansas)

Scope of Work

Beginning in 2013

Large-scale project to evaluate multiple crack-reduction technologies in lab and field, including crack surveys in Indiana, Kansas, Minnesota, and Virginia

Scope of Work

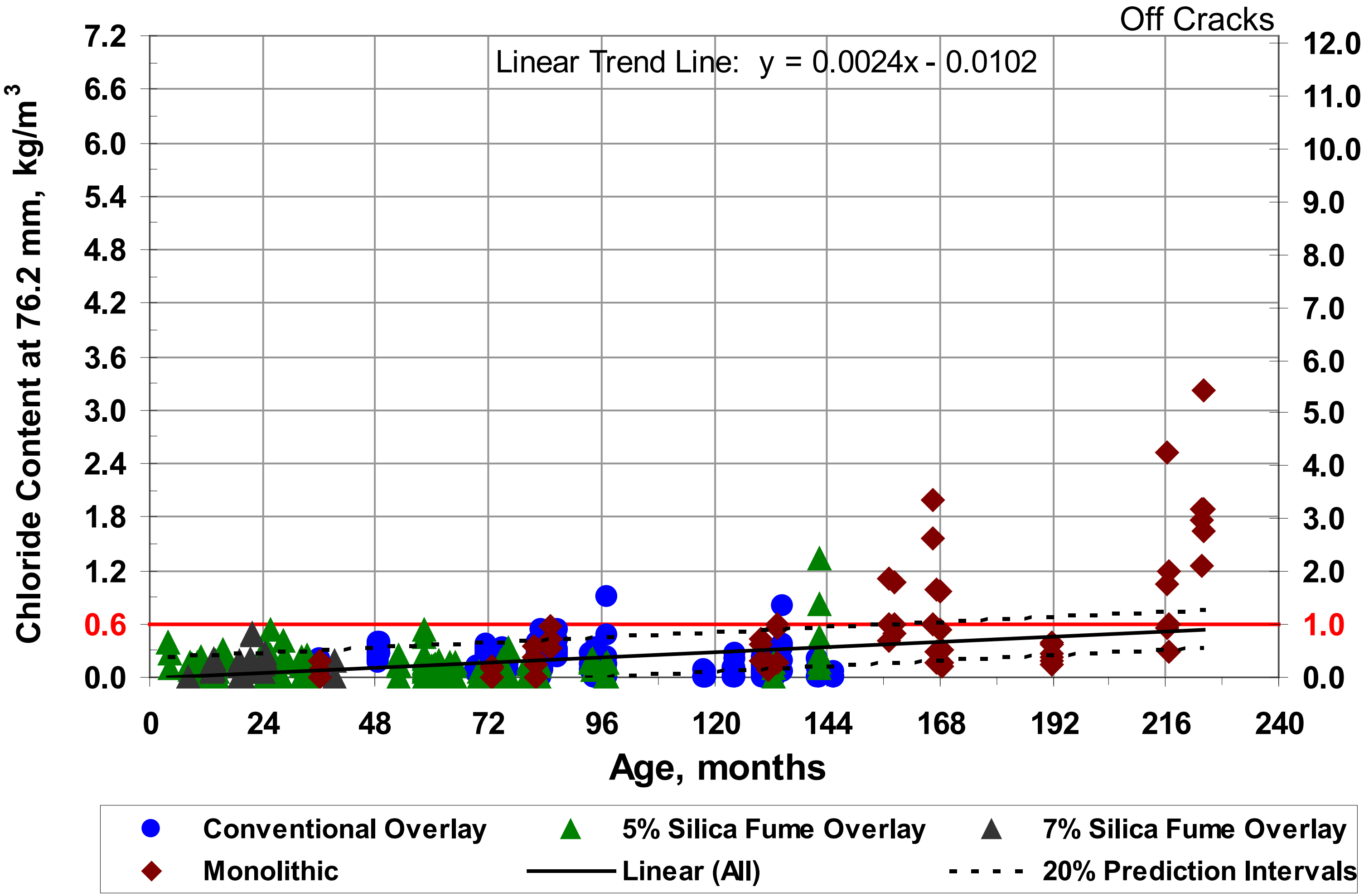
Beginning in 2016

Working with KDOT and MnDOT on construction of 12 bridge decks with internal curing combined with slag and silica fume as partial replacements for portland cement

- Over 600 bridge deck crack surveys using standardized methods (150+ decks)

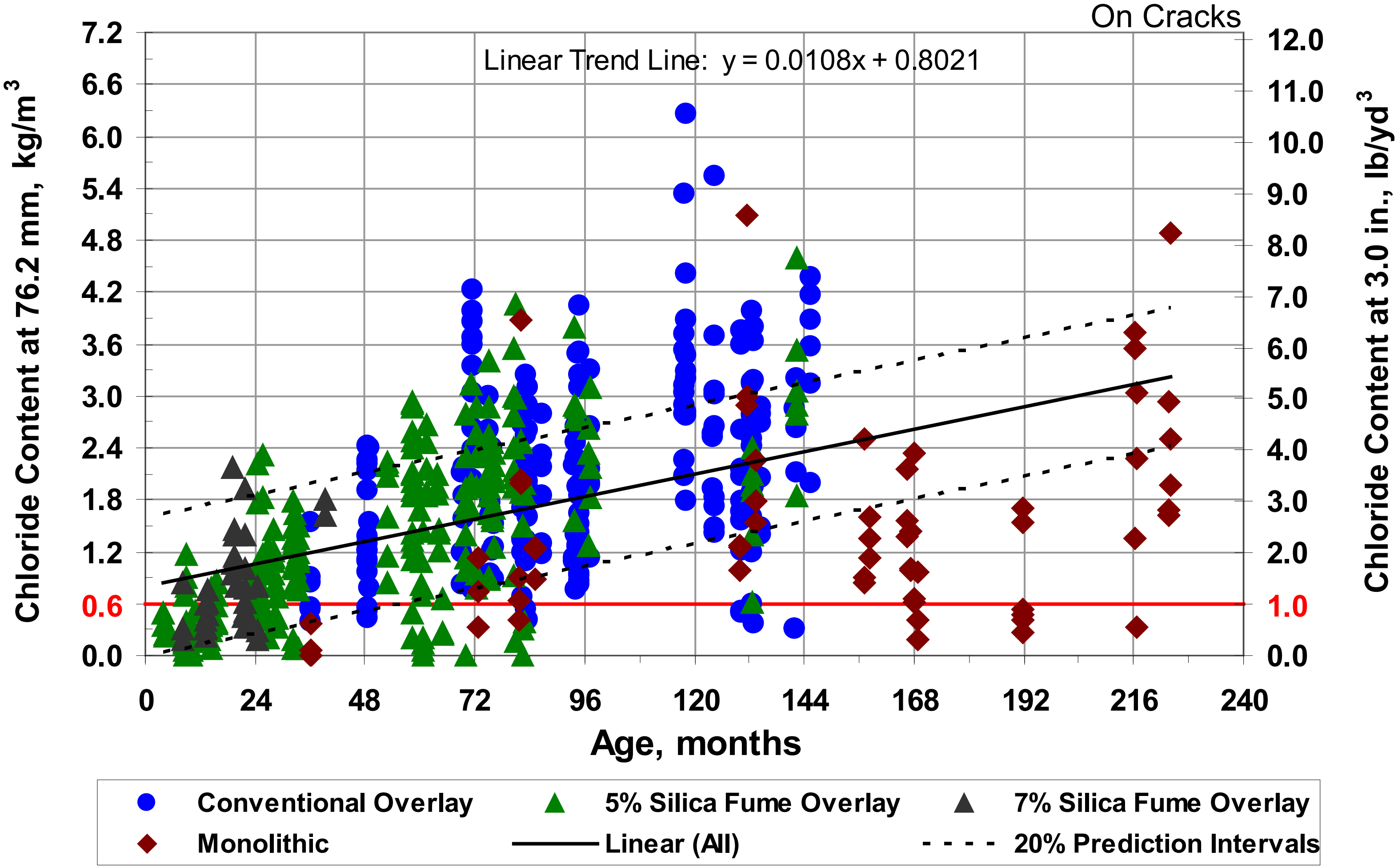
Findings

Why is crack control important?



(3 in.) Off cracks

Why is crack control important?

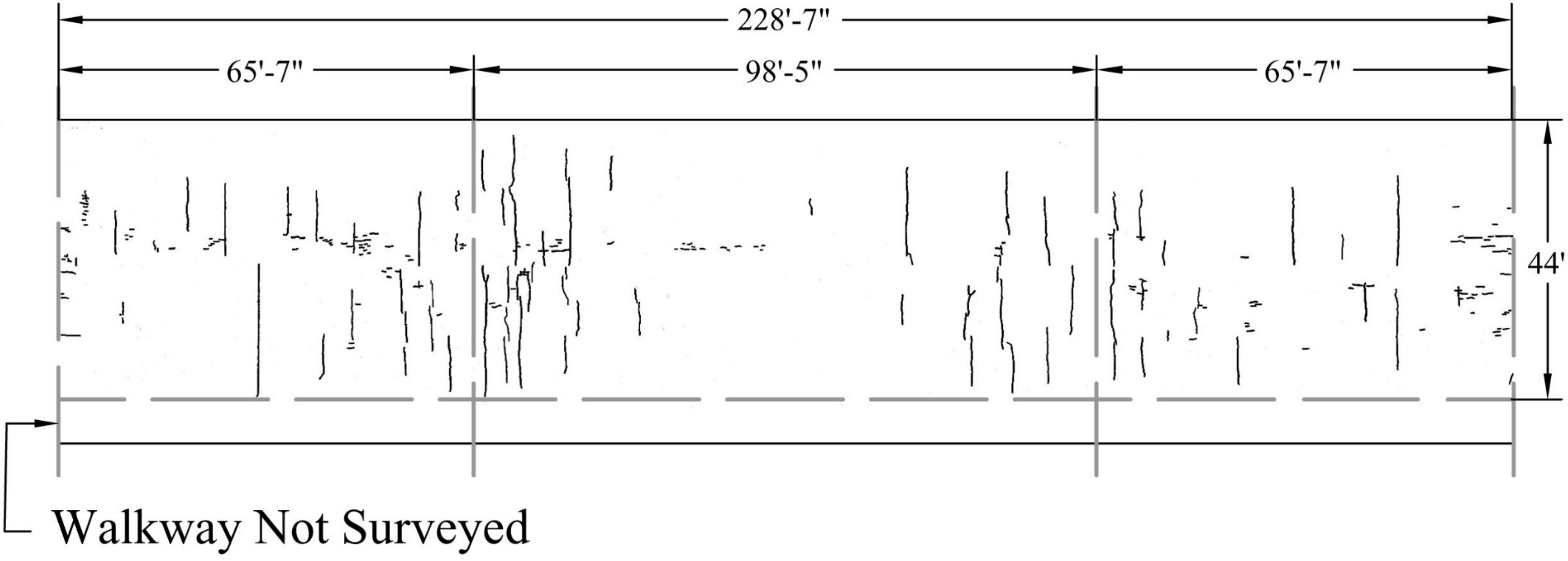


(3 in.) On cracks

What’s not a major concern

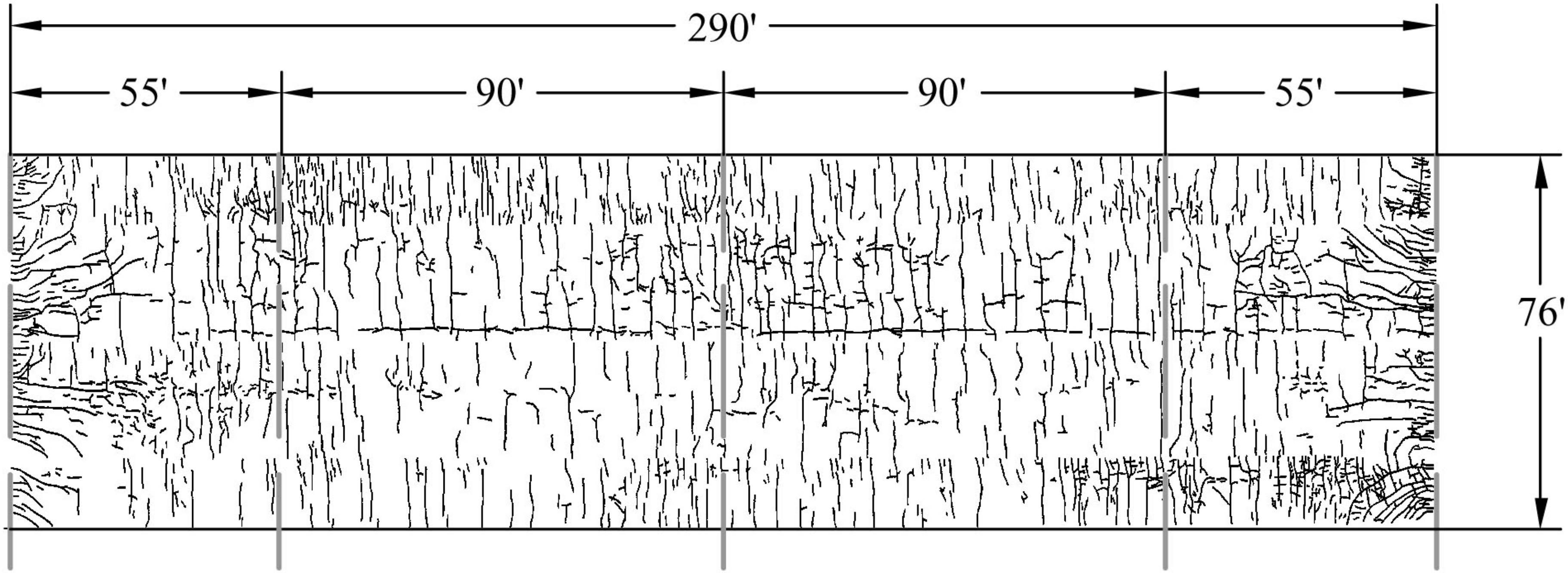
- Moment region and load-induced stresses in the deck

Moment region



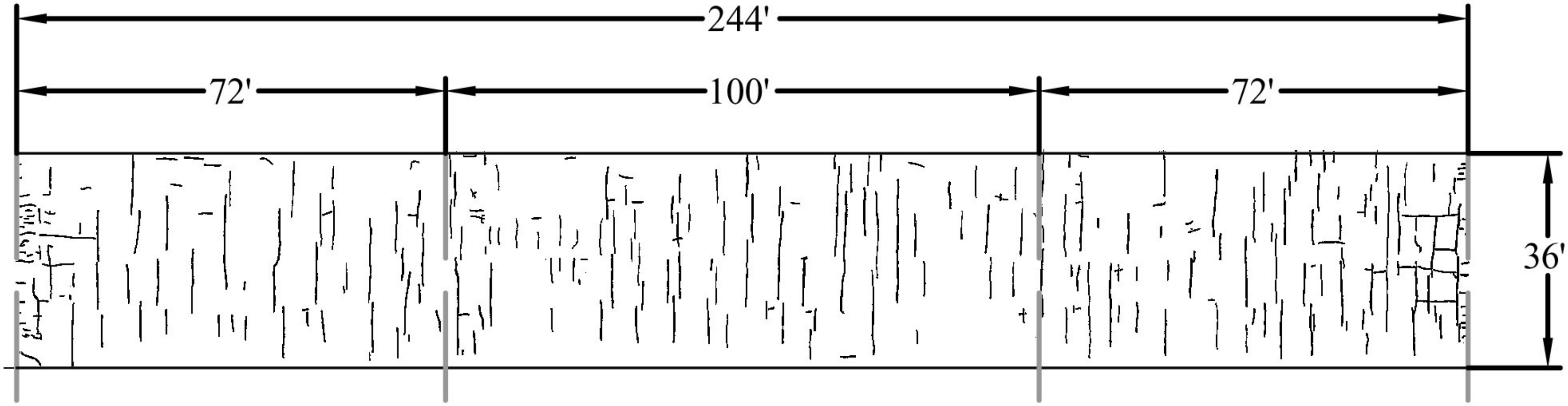
7% Silica Fume Overlay

Moment region



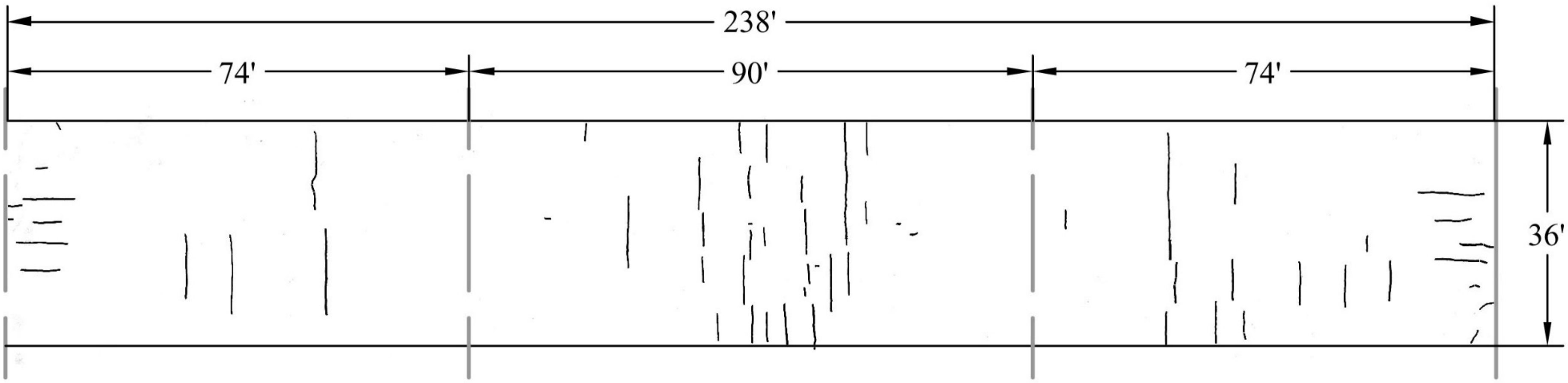
Conventional Overlay

Moment region



Monolithic

Moment region



Monolithic

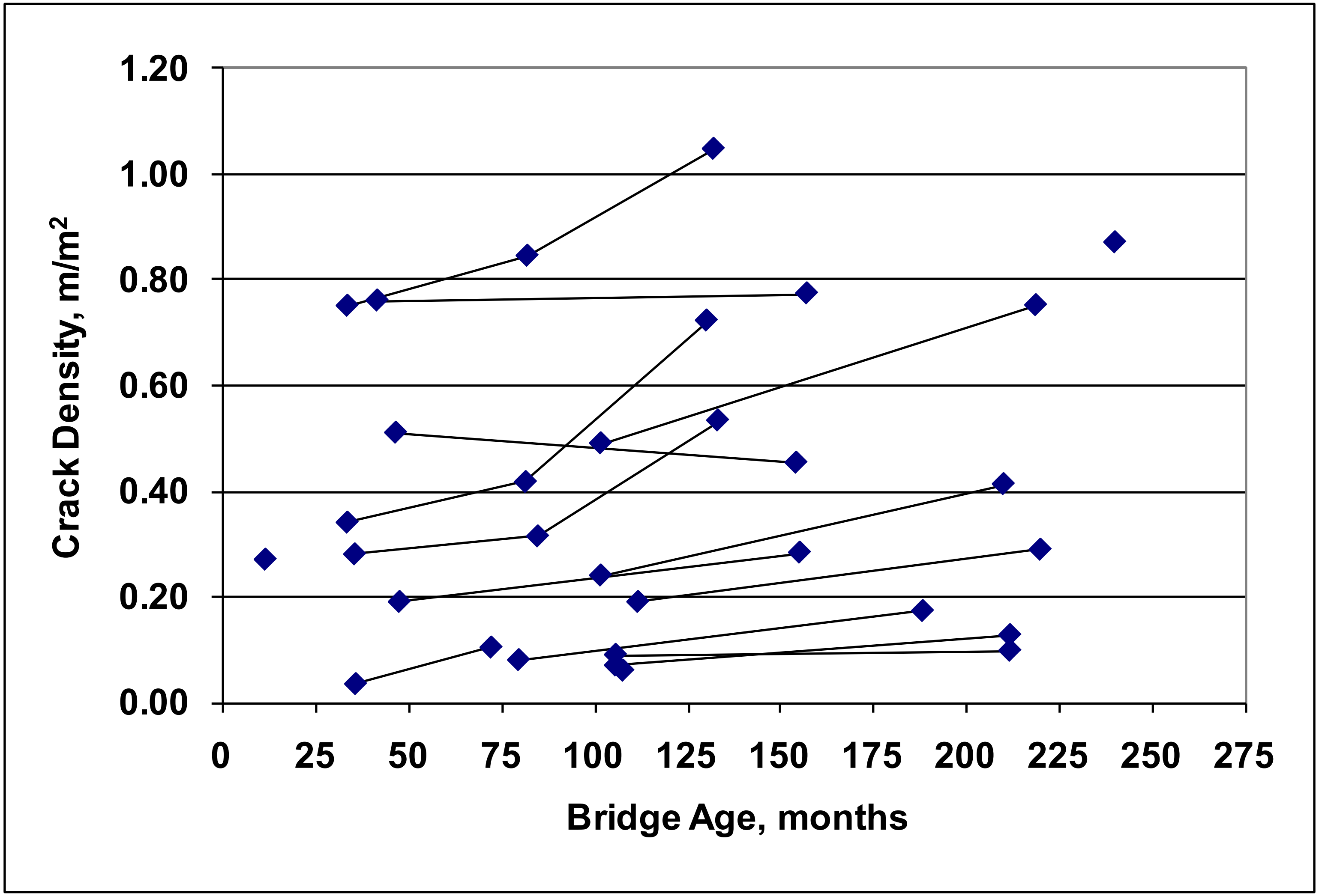
Factors

- Age
- Bridge Deck Type
- Material Effects
- Site Conditions – Temperature Range
- Consolidation, Finishing, and Curing

Factors

- Age – cracking increases with age
  - Cracking at 3 years predicts long-term performance
- Bridge Deck Type
  - Decks with overlays crack much more than monolithic decks

Age

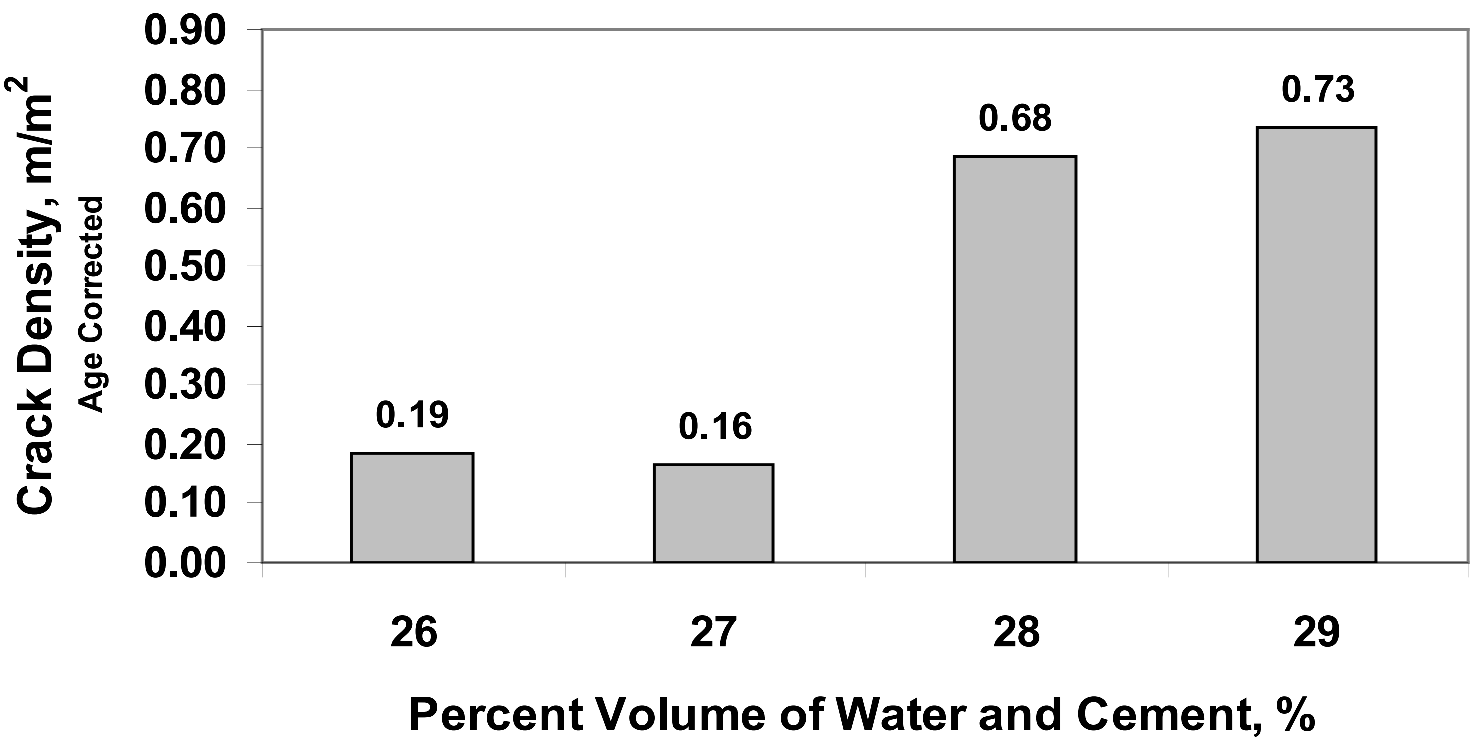


Monolithic

Material Effects:

- Cracking increases with
  - Increased volume of cement paste
  - Increased slump
  - Increased compressive strength
  - Decreased air content

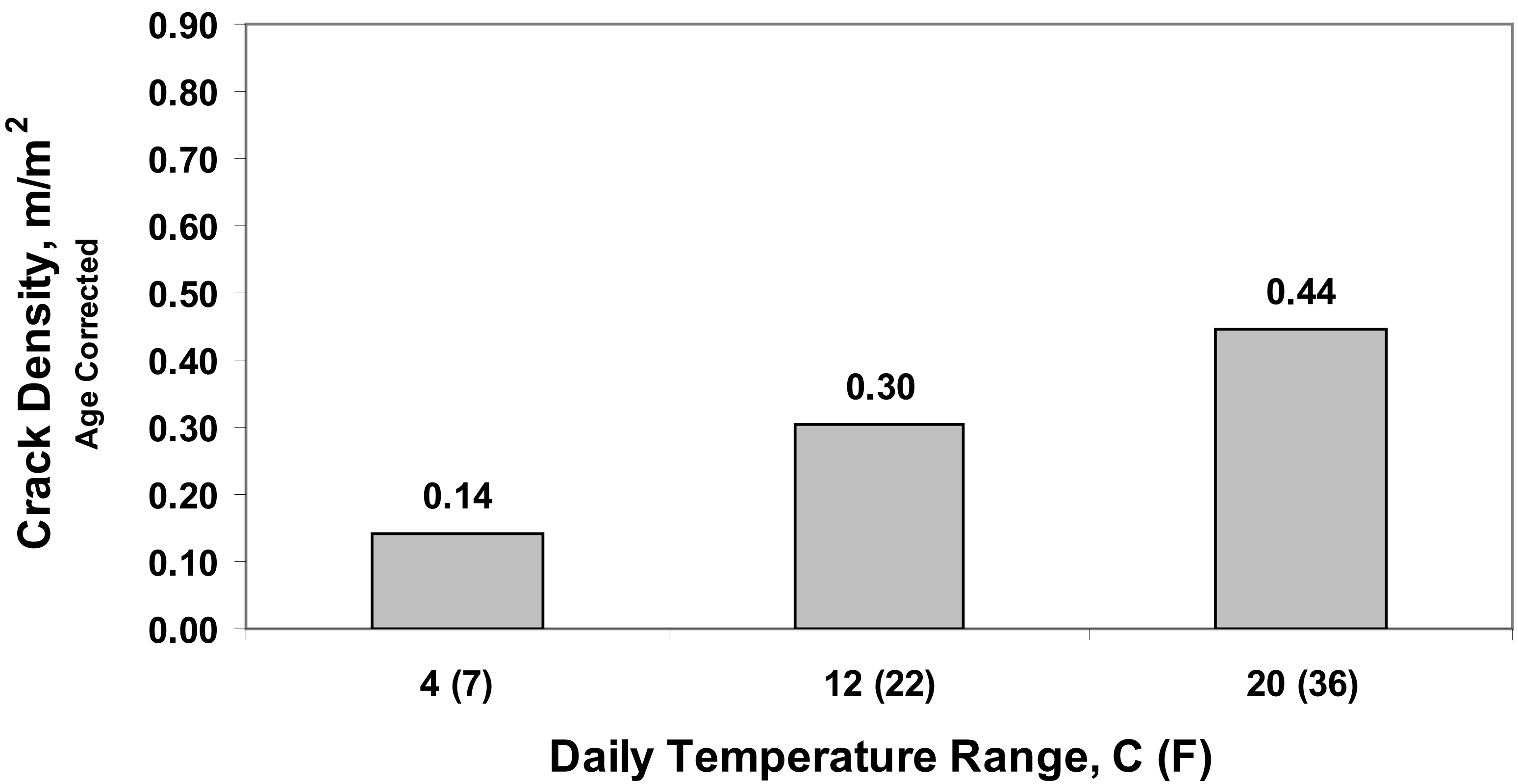
Paste Content



Number of Placements	(8)	(16)	(4)	(5)
Number of Surveys	(16)	(31)	(8)	(11)

Monolithic

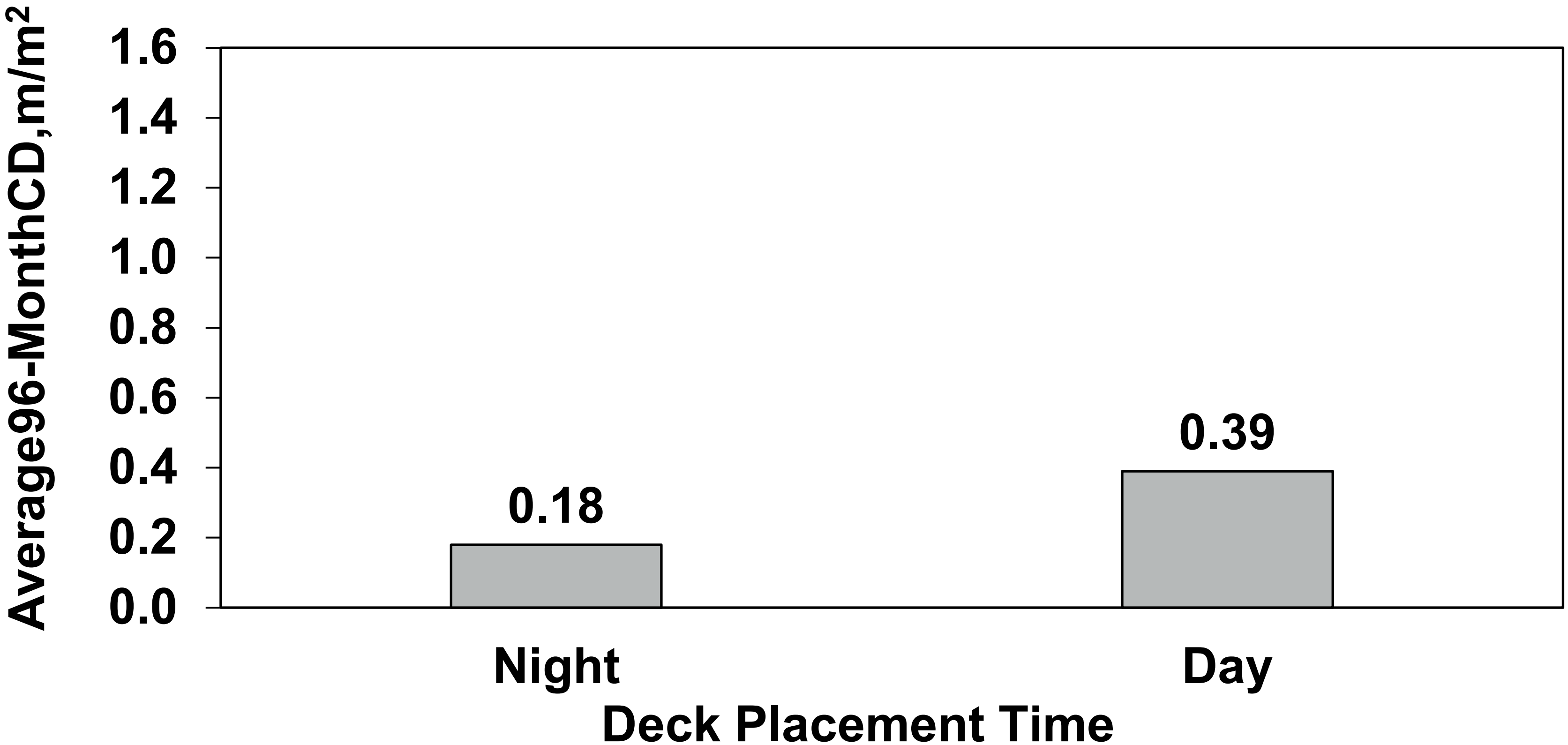
Temperature Range – Day of Construction



	4 (7)	12 (22)	20 (36)
Number of Placements	(2)	(20)	(10)
Number of Surveys	(4)	(42)	(19)

Monolithic

Casting at night



Number of Placements	**(8)**	**(5)**
Start Time Range	**(1:30 am-7:30 am)**	**(5:30 am-11:00 am)**
Finished Time Range	**(6:00 am-11:10 am)**	**(12:30 pm-9:30 pm)**

Monolithic

Overall Approach (2005)

Work to reduce plastic, settlement, thermal and drying shrinkage cracking

Low cement & water contents

Low slump

Moderate, not high, strength

Control concrete temperature

Good consolidation

Minimum finishing

Early start and extended curing

Consolidation Requirements

Vertically mounted internal gang vibrators

Concrete Finishing

General Rule:

Less is More

- Pan or burlap drag
- Bullfloating
- No finishing aids!
- If you have excess bleed water: Don't touch the concrete!

Curing

- Presoaked burlap
- Timely placement
- Constantly wet
  - Spray hoses
  - Soaker hoses
  - 14 days

Curing

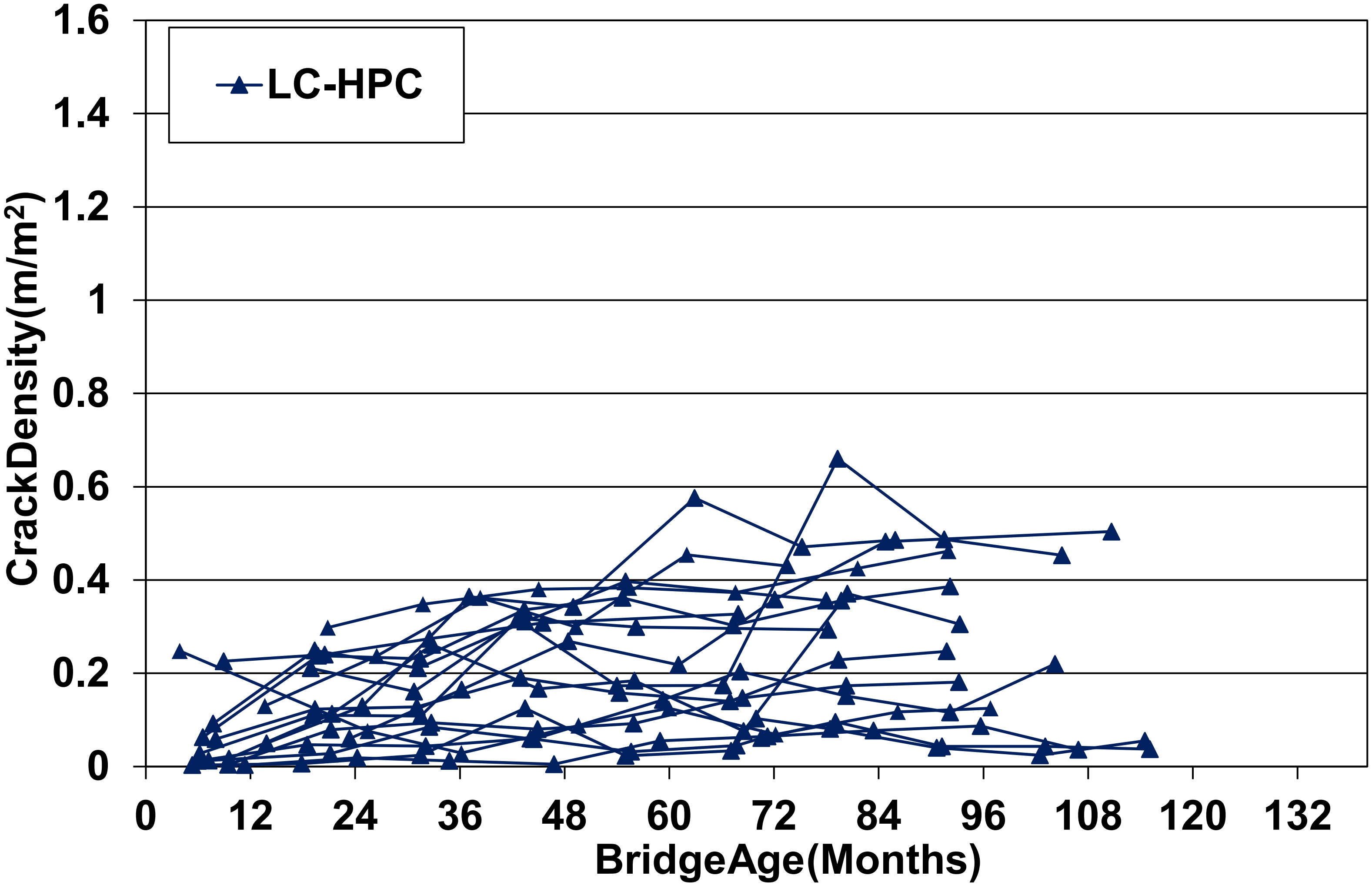
- 14 days wet cure with burlap, soaker hoses, and plastic
- Followed by curing compound to slow the rate of evaporation

Deck surface

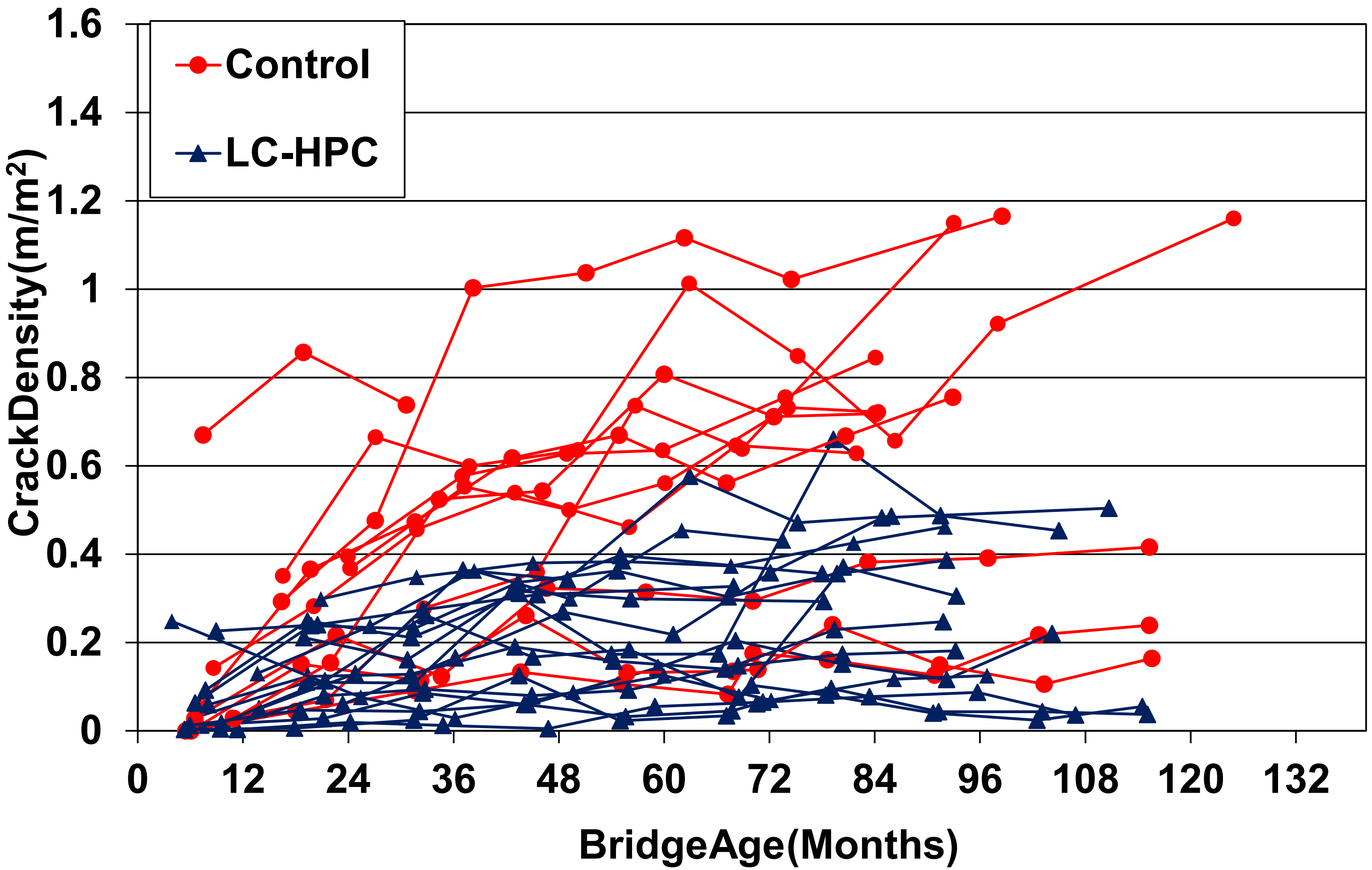
- Grinding and grooving is better than tining
  - Tining disrupts the concrete and displaces the coarse aggregate
  - Delays curing
  - Can lead to scaling damage

Field Observations

LC-HPC Performance



LC-HPC Performance



Most important factors?

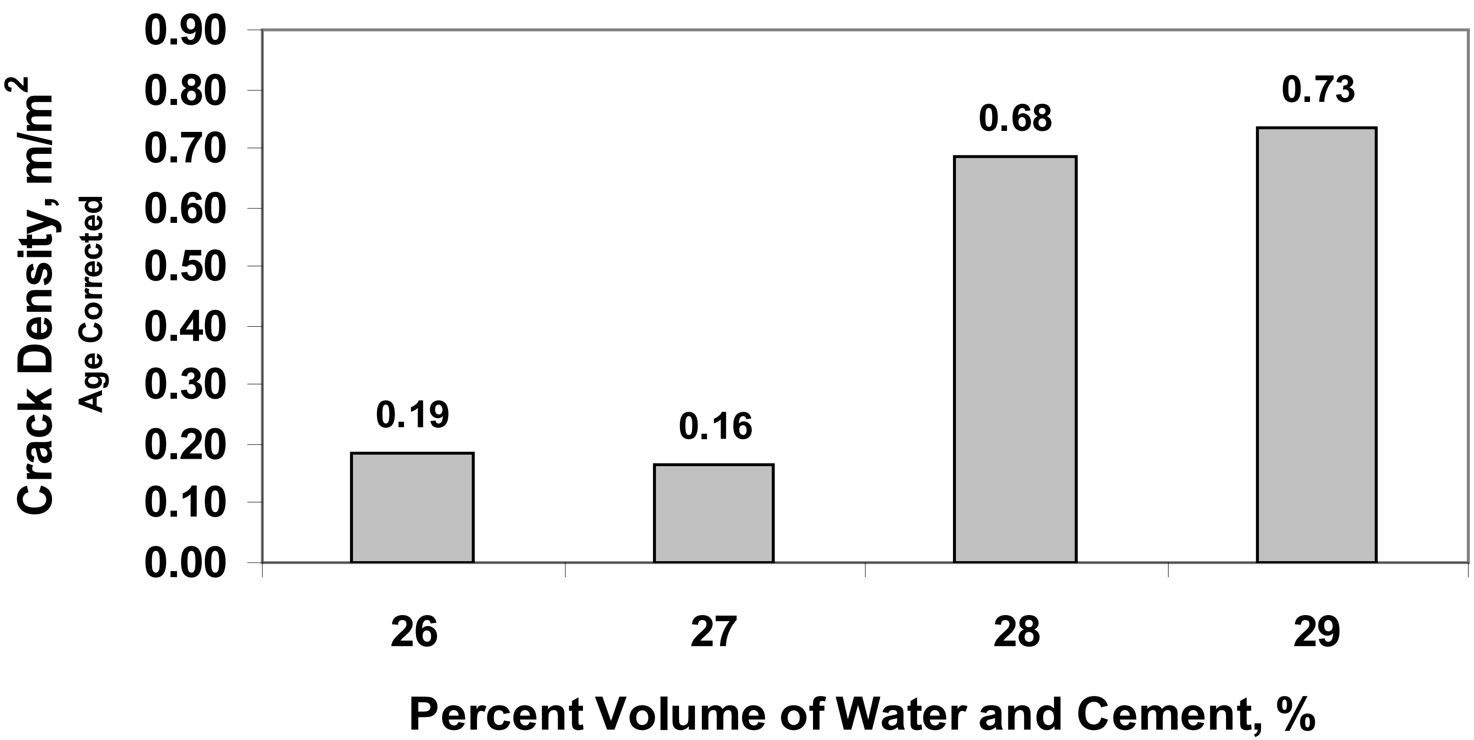
Most important factors?

- Paste Content
- Temperature range on the date of construction

Model Including Paste Content, Temp Range, Concrete Strength, Slump, and Air Content

Factor	Slope Coefficient	*p*
Paste Content	0.237	3×10^{-8}
Temp Range	0.009	0.015
Concrete Strength	0.060	0.110
Slump	0.103	0.103
Air Content	– 0.024	0.494

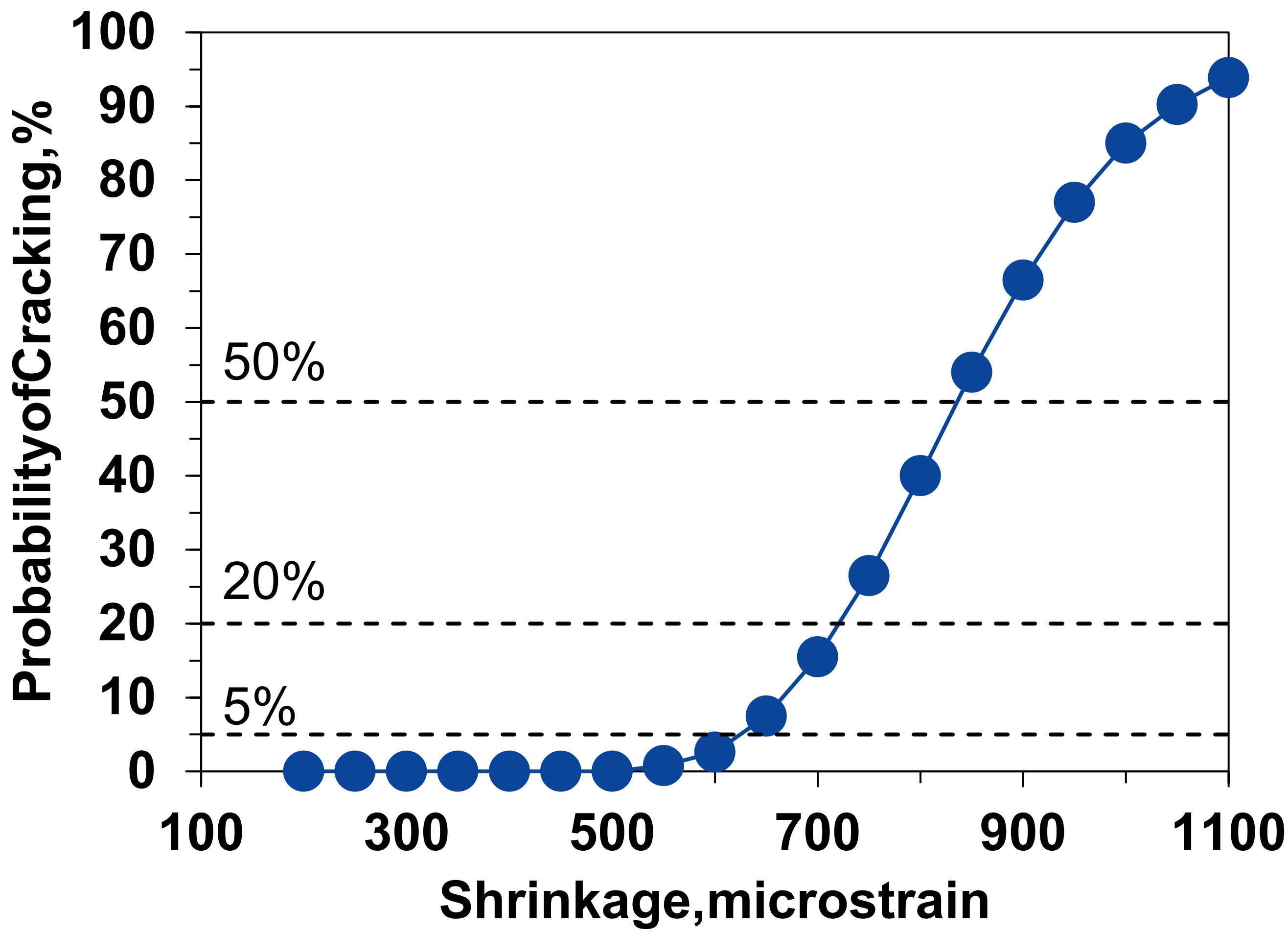
Paste Content



	26	27	28	29
Number of Placements	(8)	(16)	(4)	(5)
Number of Surveys	(16)	(31)	(8)	(11)

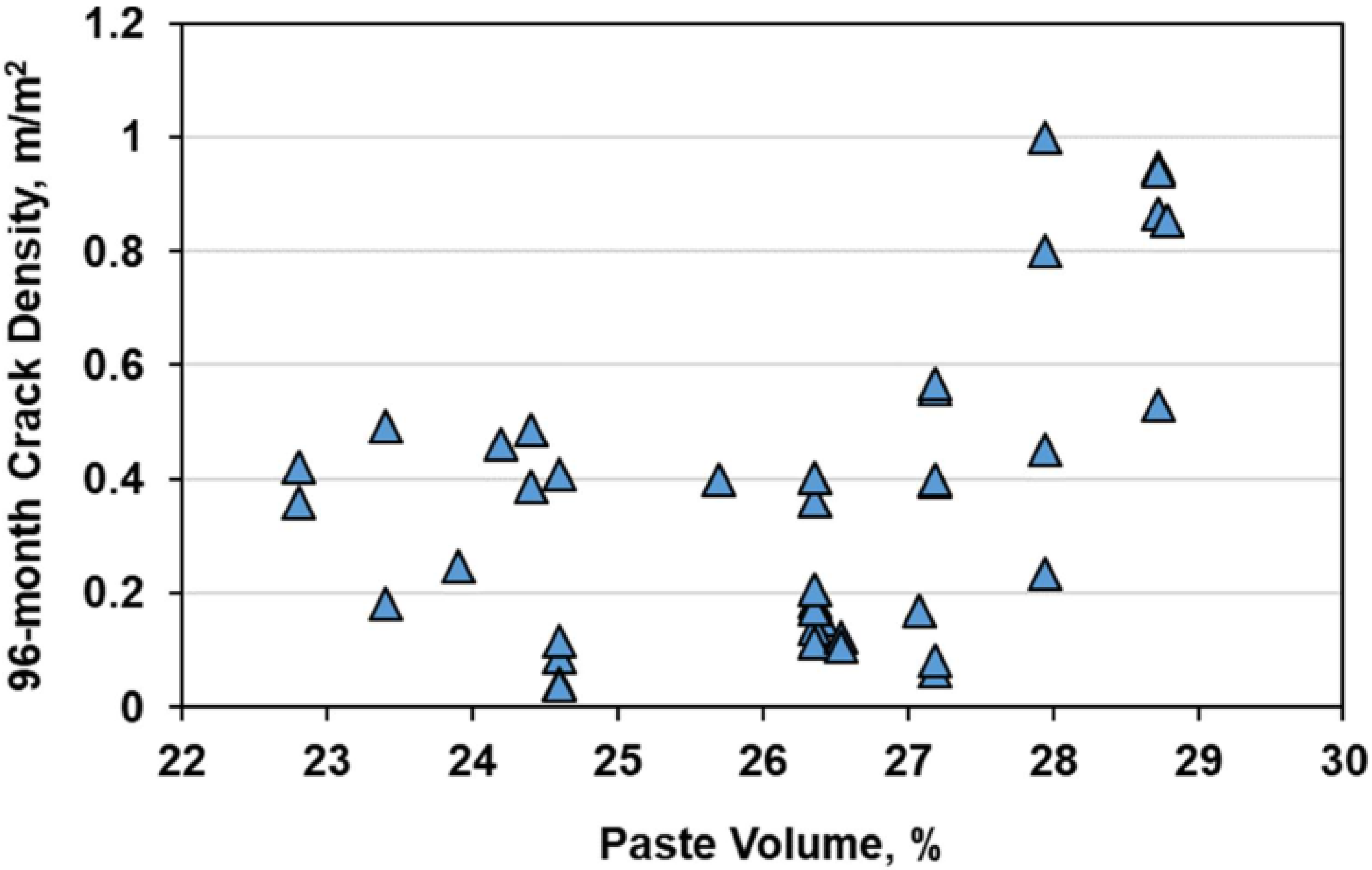
Monolithic

Probability of Cracking

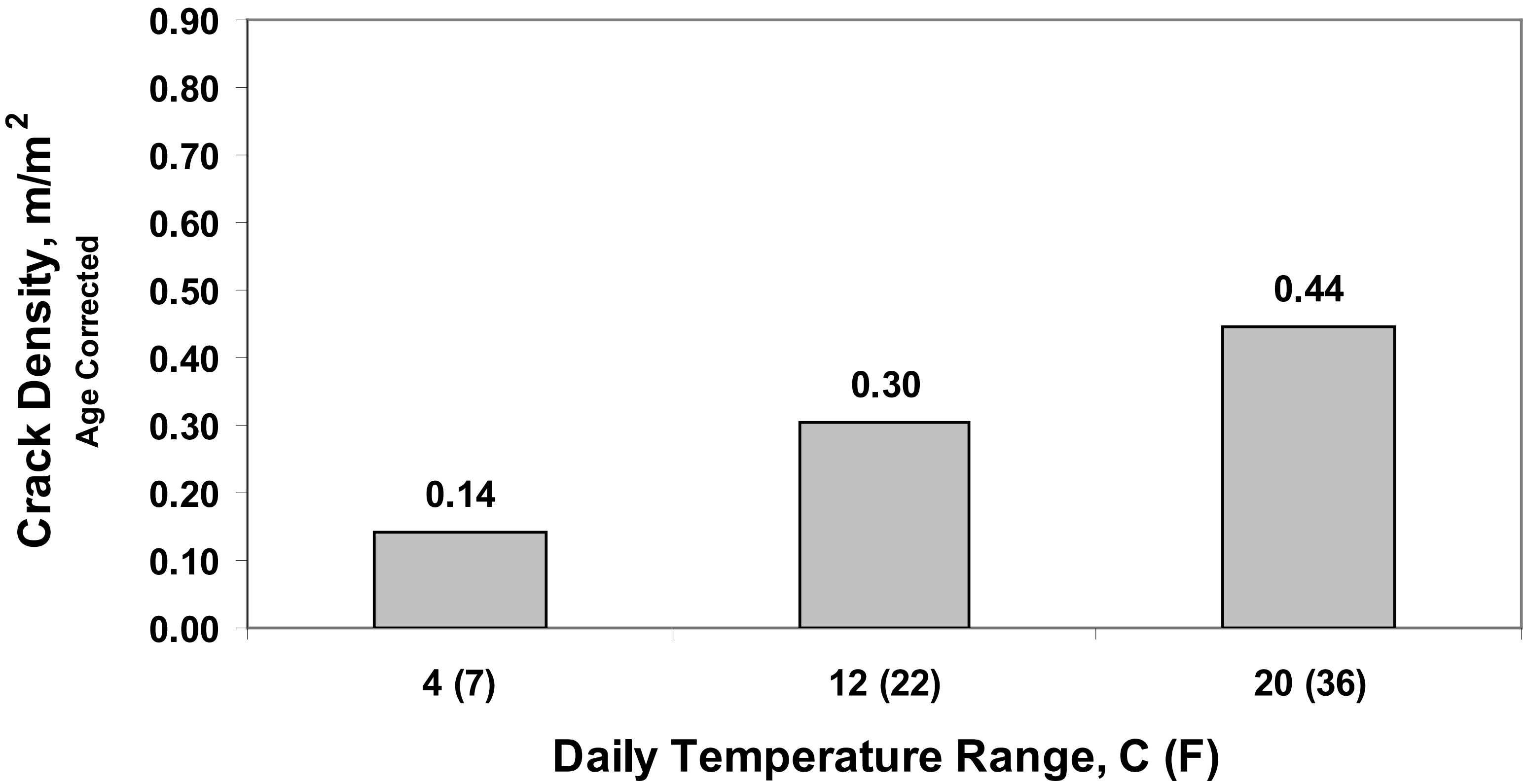


Adapted from Radlińska, A. and Weiss, J., (2011). “Toward the Development of a Performance-Related Specification for Concrete Shrinkage,” Journal of Materials in Civil Engineering, Vol. 24, No. 1, pp. 64-71.

Bridge Deck Cracking



Temperature Range – Day of Construction



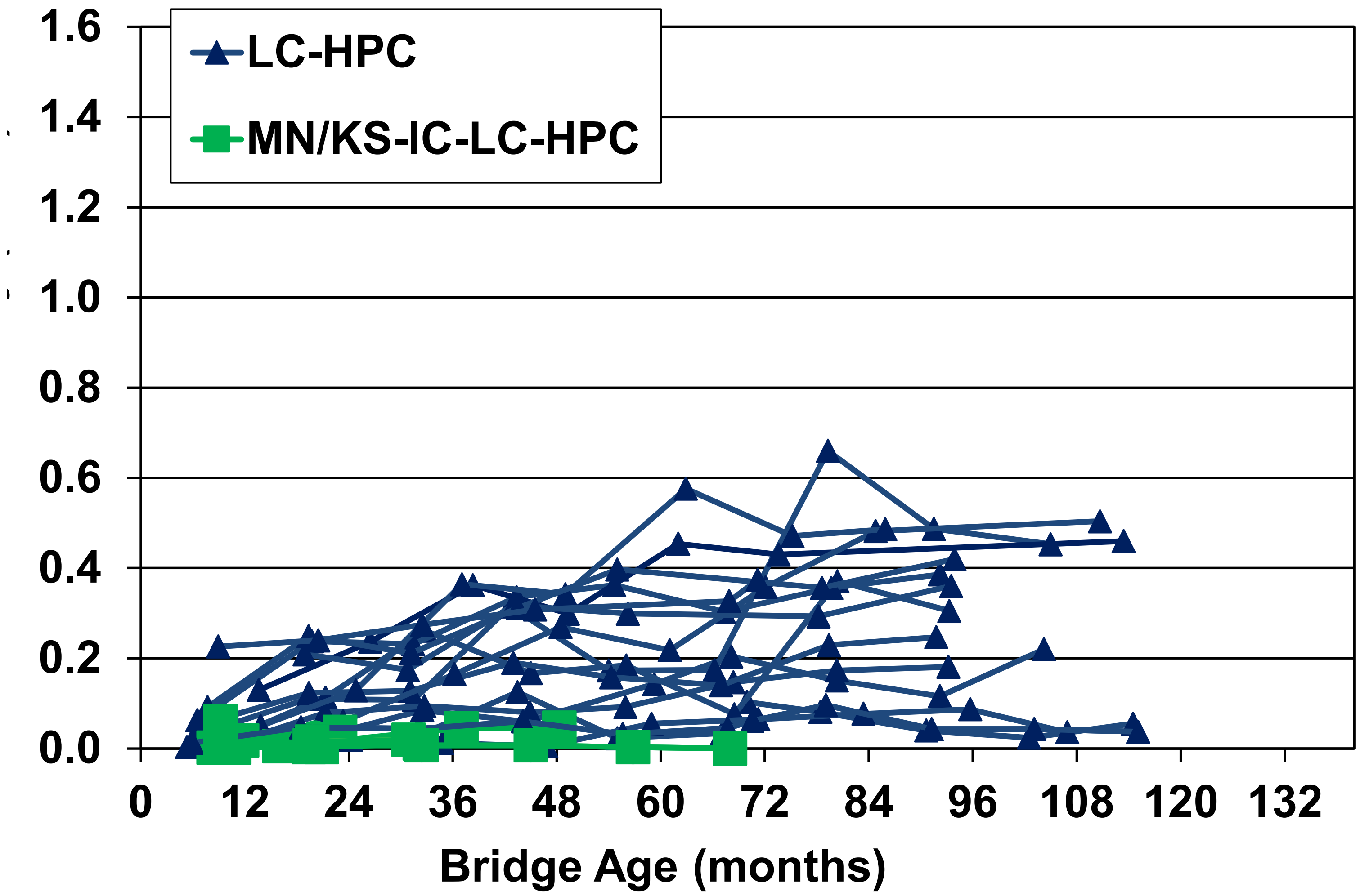
	4 (7)	12 (22)	20 (36)
Number of Placements	(2)	(20)	(10)
Number of Surveys	(4)	(42)	(19)

Monolithic

Other Technologies

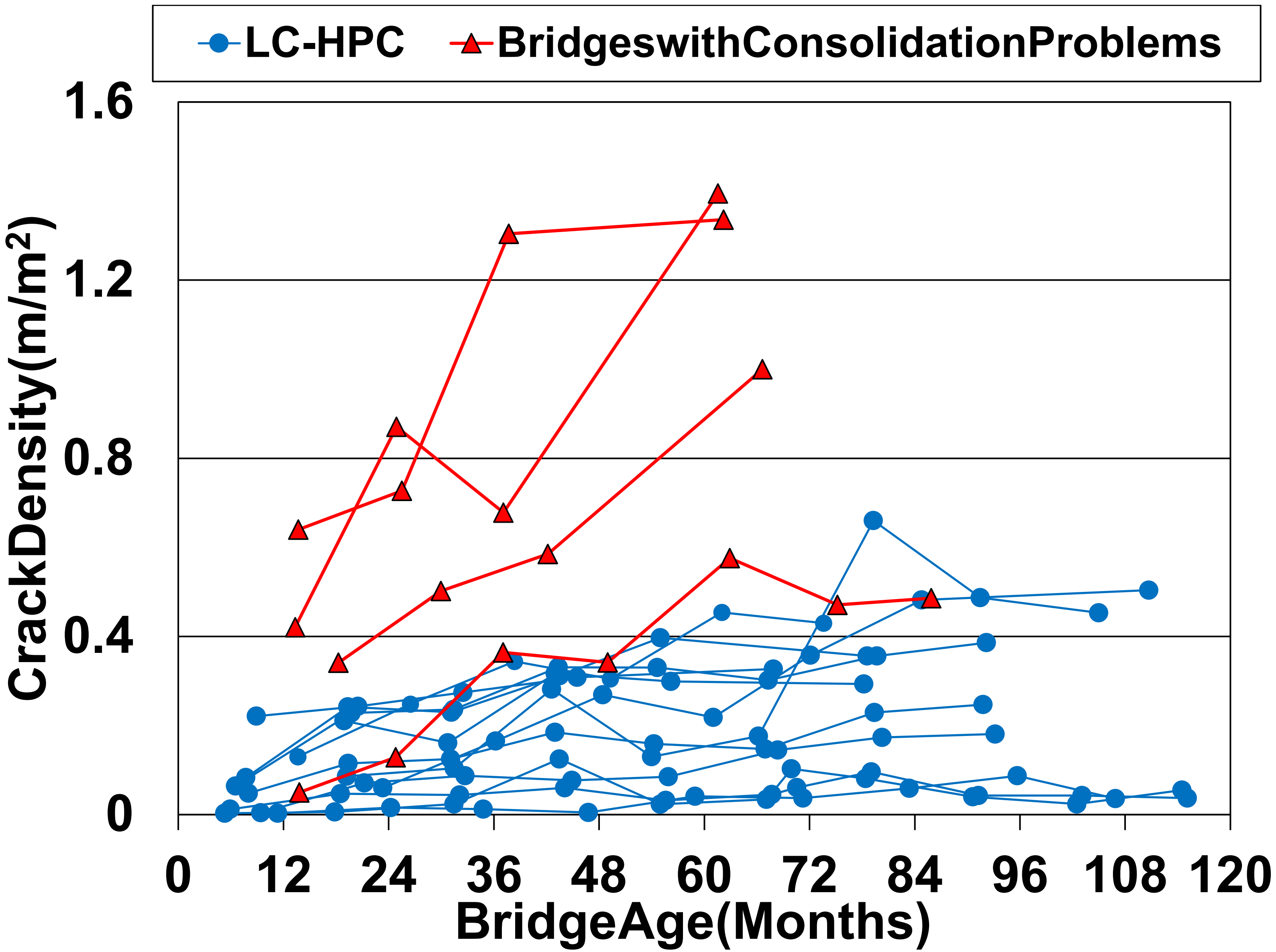
- Internal curing with pre-wetted lightweight aggregate combined with slag cement and silica fume
- Shrinkage reducing admixtures
- Shrinkage compensating admixtures
- Rheology modifying admixtures
- Synthetic fibers

Cracking Performance: IC-LC-HPC



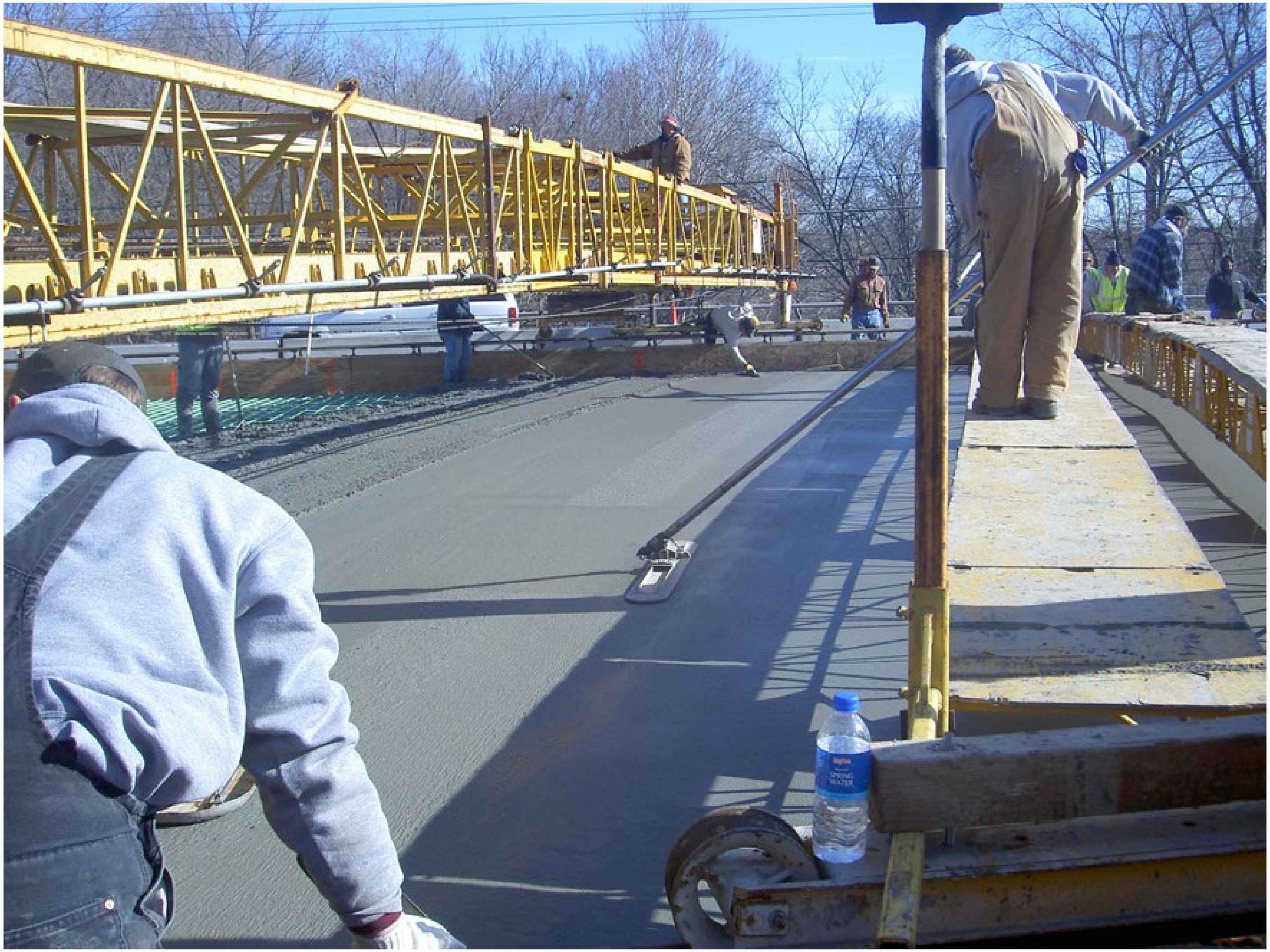
Importance of construction procedures

Is having a low shrinkage concrete enough to reduce bridge deck cracking?

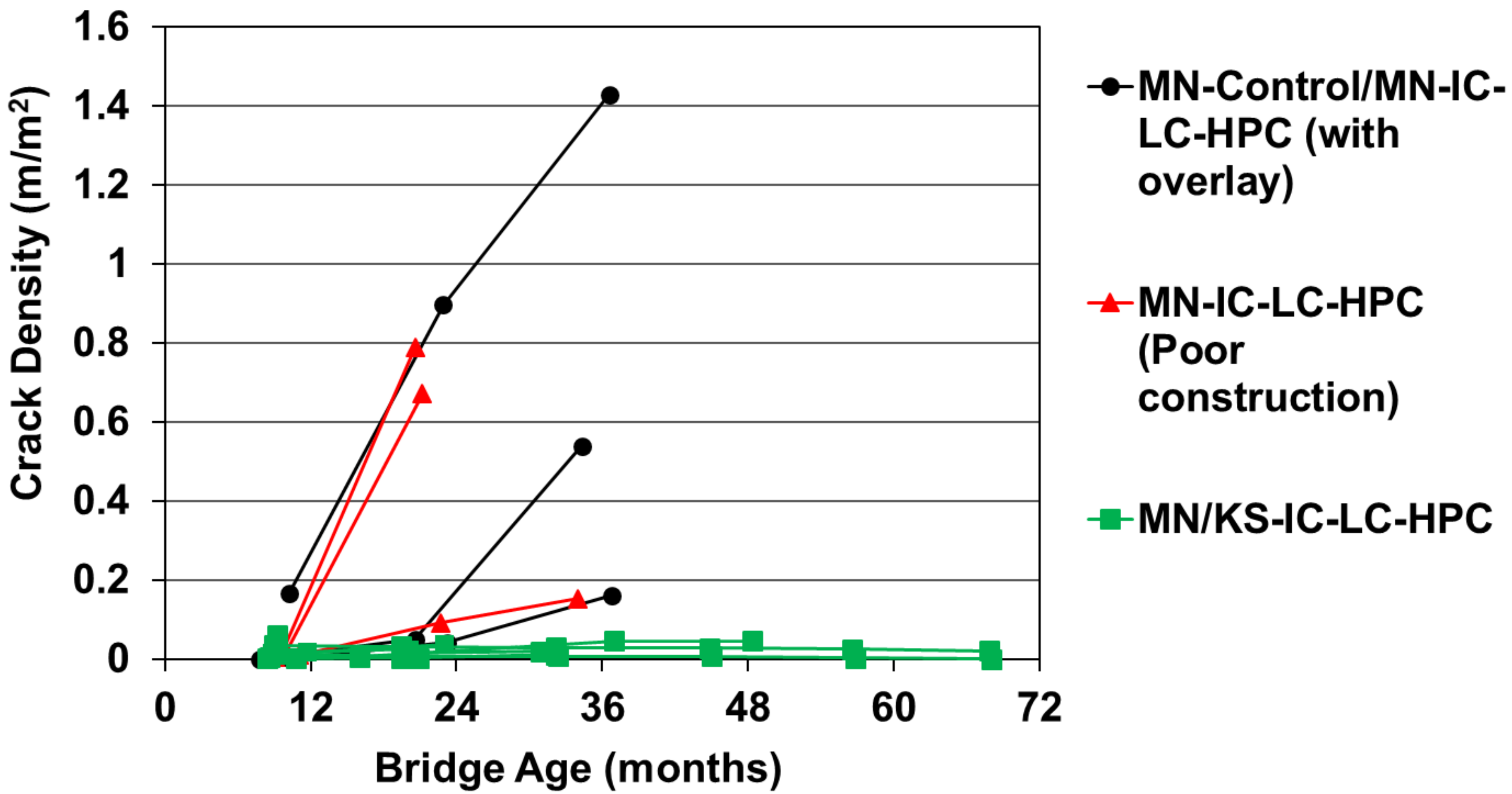

LC-HPC
BridgeswithConsolidationProblems
1.6
1.2
0.8
0.4
0
CrackDensity(m/m²)
0
12
24
36
48
60
72
84
96
108
120
BridgeAge(Months)

What happened in the red lines?

- Poor consolidation
- Over finishing
- Delayed curing



Cracking Performance: IC-LC-HPC



How much can crack-reducing technologies help when construction goes wrong?

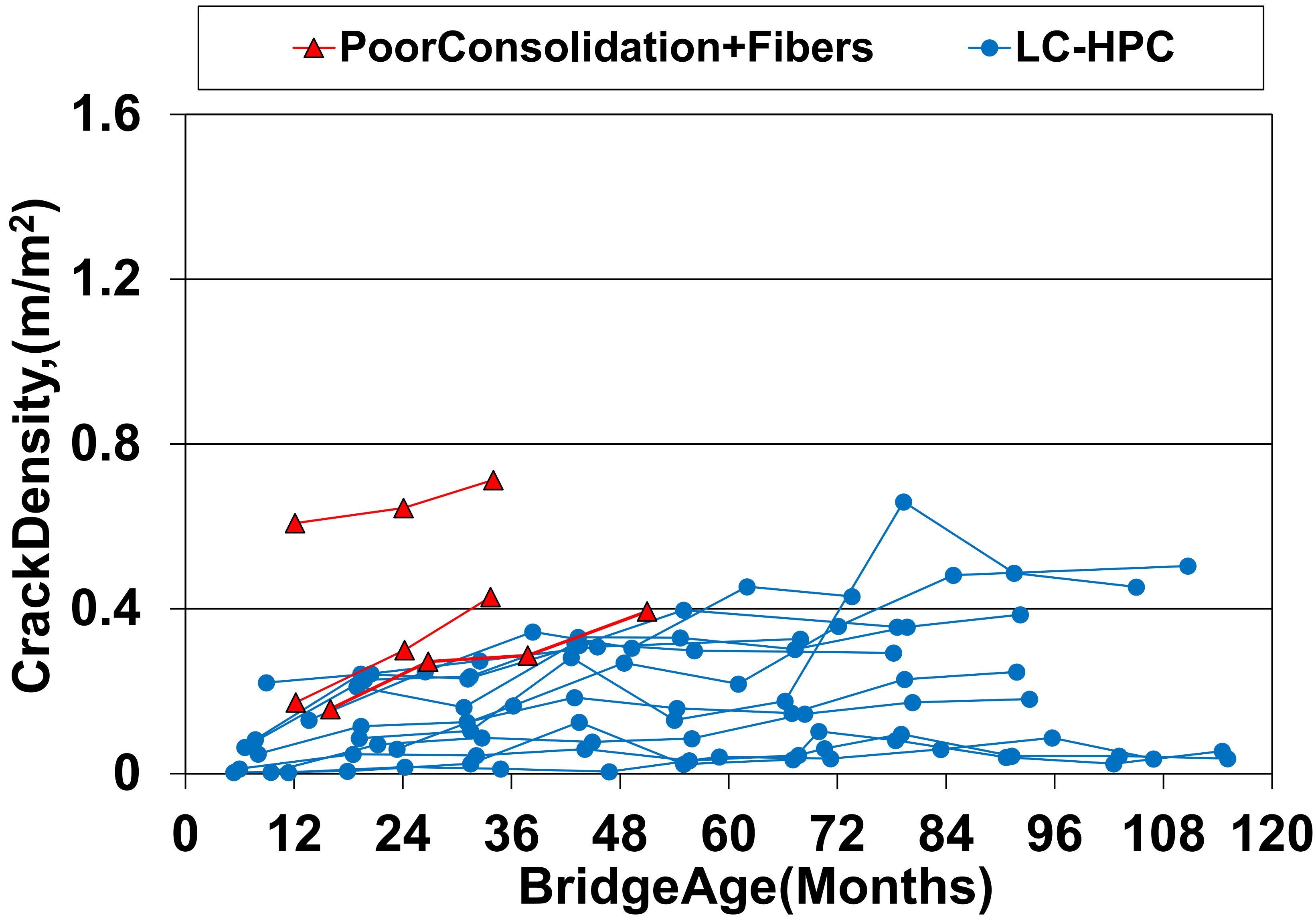
How about if concrete is disturbed after consolidation?

One of several examples:
Fiber Deck Construction

The same contractor constructed two fiber decks for a total of three placements

Topeka Fiber Bridges

Project	F3	F4P1	F4P2
Cement, lb/yd^3	521	521	521
Target *w/cm*	0.40	0.40	0.40
PasteVolume, %	22.2	22.2	22.2
Fiber, lb/yd^3	1.5	1.5	1.5
FiberType	F-4	F-4	F-4
AirContent, %	6.5	6.5	6.7
AverageSlump, in.	3.15	3.14	3.28
28dStrength, psi	5230	5330	5530


PoorConsolidation+Fibers
LC-HPC
CrackDensity,(m/m²)
1.6
1.2
0.8
0.4
0
0
12
24
36
48
60
72
84
96
108
120
BridgeAge(Months)

Summary

- Cement paste content, temperature range on day of casting, and construction procedures are principal factors controlling cracking in bridge decks

- These factors are more important than slump, strength, or air content

Summary

Use:

- Paste contents below 27%
- Thorough consolidation
- Minimum finishing
- Early and extended curing
- Casting at night

Summary

- Best performance requires adherence to all aspects of the specifications

The University of Kansas

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Bridge Deck Crack Prevention

Shared By: Craig Knapp
Caltrans
Division of Engineering Services, Bridge Design
Structural Concrete Committee Chair

Deck cracking was a long-standing problem.

Annually deck crack mitigation costs were,

$50 Million.

Webber Creek Bridge Deck Study*

Division of Highways (Caltrans)

1972 Final Report

8-year study of the Webber Creek Bridge Deck.

***M. Horn, C., Stewart, and R. Boulware; "Webber Creek Deck Crack Study Final Report", State of California, Division of Highways, Bridge Department. March 1972**

Webber Creek Bridge Deck Study

- **The deck was divided into 8 sections, each section consisting of a 137 foot simple span.**
- **The variables were 2 aggregate sources, 2 cement types and 2 rebar loadings.**
  1. *Aggregate: Sandstone and Quartz*
  2. *Cement: Type 1 and Type II cement*
  3. *Rebar: "Typical" & added longitudinal rebar*

Webber Creek Bridge Deck Study

- Type II cement and the denser rebar spacing had some beneficial effect reducing deck cracking.
- After 8 years the spans having the Type II cement and "dense rebar" were again compared:

Webber Creek Bridge Deck Study

- Quartz aggregate - 26 ft of soffit cracking with no leaking cracks
- Sandstone aggregate - 533 ft of soffit cracking with 18 cracks leaking.

Webber Creek Bridge Deck Study

Conclusion:

"Aggregate…was the most important factor regarding deck cracking."

The Structural Engineers Association of Calif.'s Committee on Shrinkage of Concrete reported in May 1965:

- 28 day shrinkage on 4X4 prisms
  - Represent about 40% of ultimate
  - Ultimate occurs in approximately 64 weeks.
  - Based on 20 years of testing done by Troxell, Raphael & Davis.

The Report rated concrete based on 28 day shrinkage as follows:

- Class A - shrinkage ≤ .032%
- Class B - .032%<shrinkage ≤ .048%
- Class C - .048%< shrinkage ≤ .064%

The California Producers Committee on Volume Change

"Drying Shrinkage of Concrete"

March 1966*

Reported that for aggregates in California:

- 5% could produce Class A (.032%)
- 90% could produce Class B (.048%)

*R Gaynor, R. Barneyback, E. Howard, E. Jumper, R. Tobin; "Drying Shrinkage of Concrete"; prepared & published by The California Producers Committee on Volume Change and Affiliated Technical Organizations, March, 1966

The best bridge deck performance obtained at the Webber Creek Bridge could only be achieved in the best of circumstances.

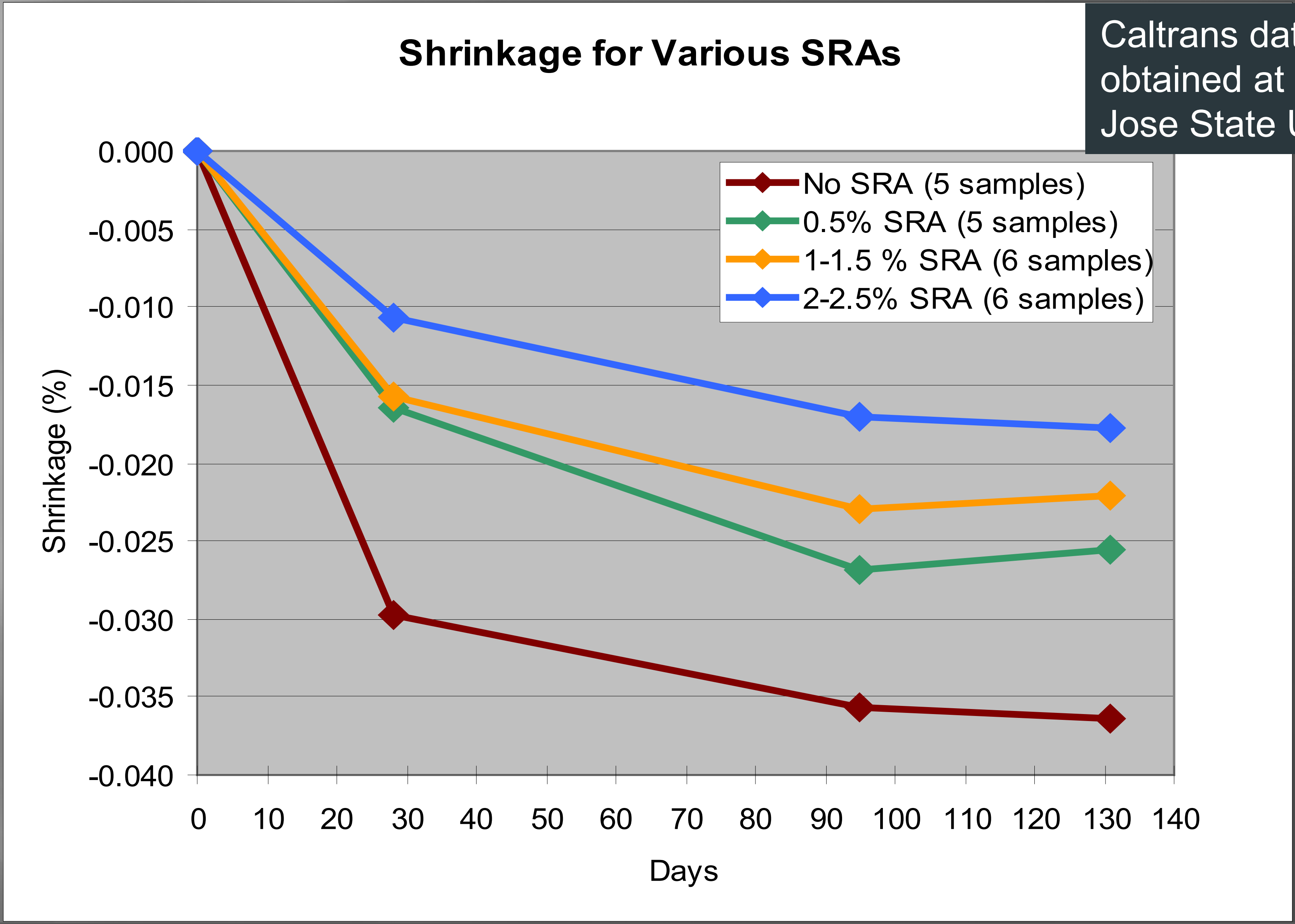
Historically we have

- Limits on water.
- Min and Max cement content
- Gradation requirements
- Aggregate property requirements
- And

Cracked Decks

With the introduction of Shrinkage Reducing Admixture (SRA), we now have a practical solution.

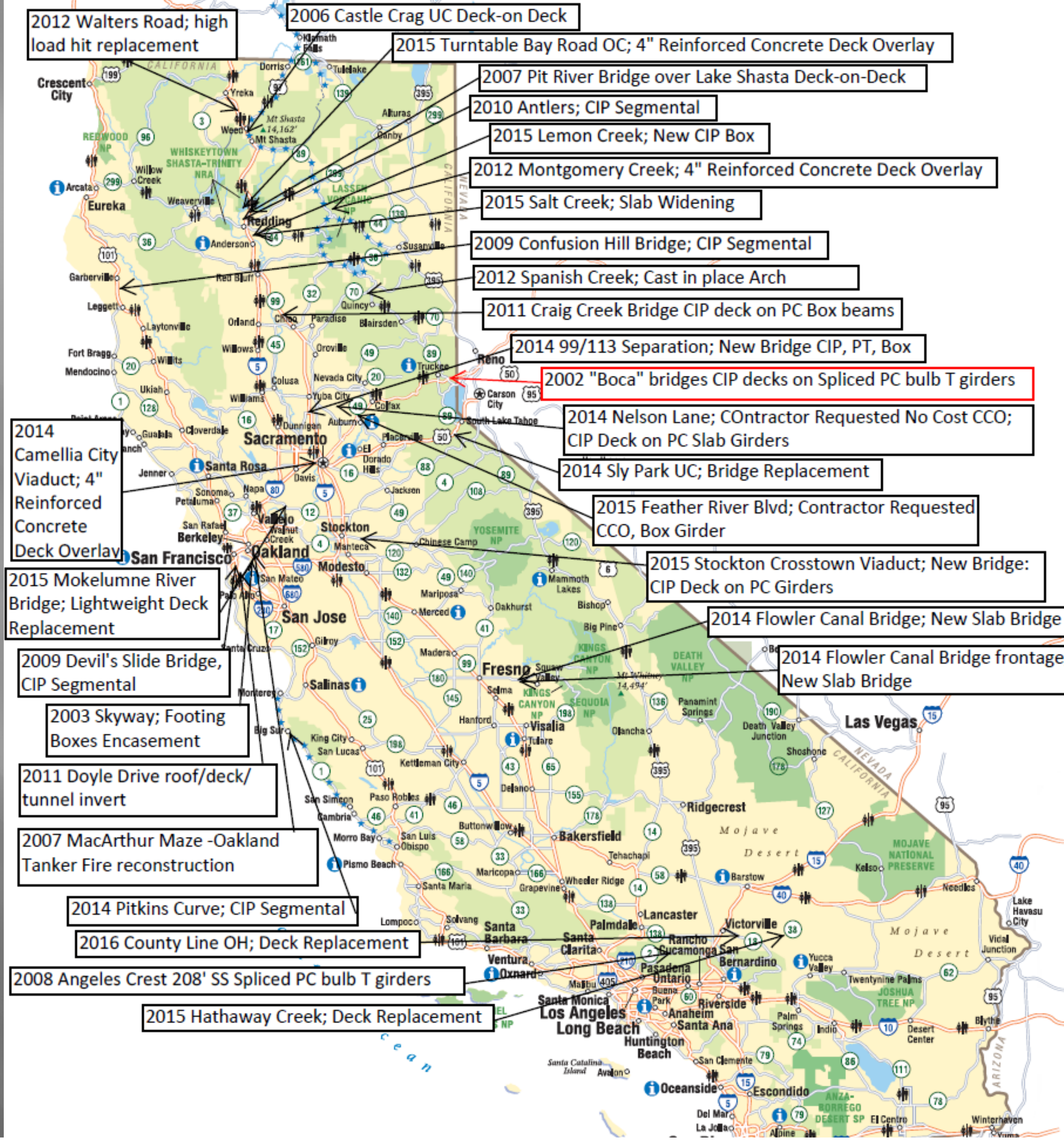
Caltrans data obtained at San Jose State U.



22 concrete batches. Concrete had w/c ratio of 0.33, 631 lb/cy cementitious with fly ash at 20%, 25% or 30%, and 5% either Silica Fume or Metakaolin.

Boca Bridges - 2002 SRA

Widening - see Deck soffit – <u>without SRA</u> Prior year ~ Note Efflorescence ~	Deck Concrete <u>with SRA</u> used after first stage, this is also how it looks today!



Indicates coverage of climate and diversity of local concrete mixes.

Specifications

- The 28 day shrinkage required maximum of 0.030%.
- Min SRA ¾ gal/cy
- Require 1 lb/cy of micro fibers and 3lb/cy of macro fibers.
- Continuous misting from finished strike off until curing medium is applied.

Misting

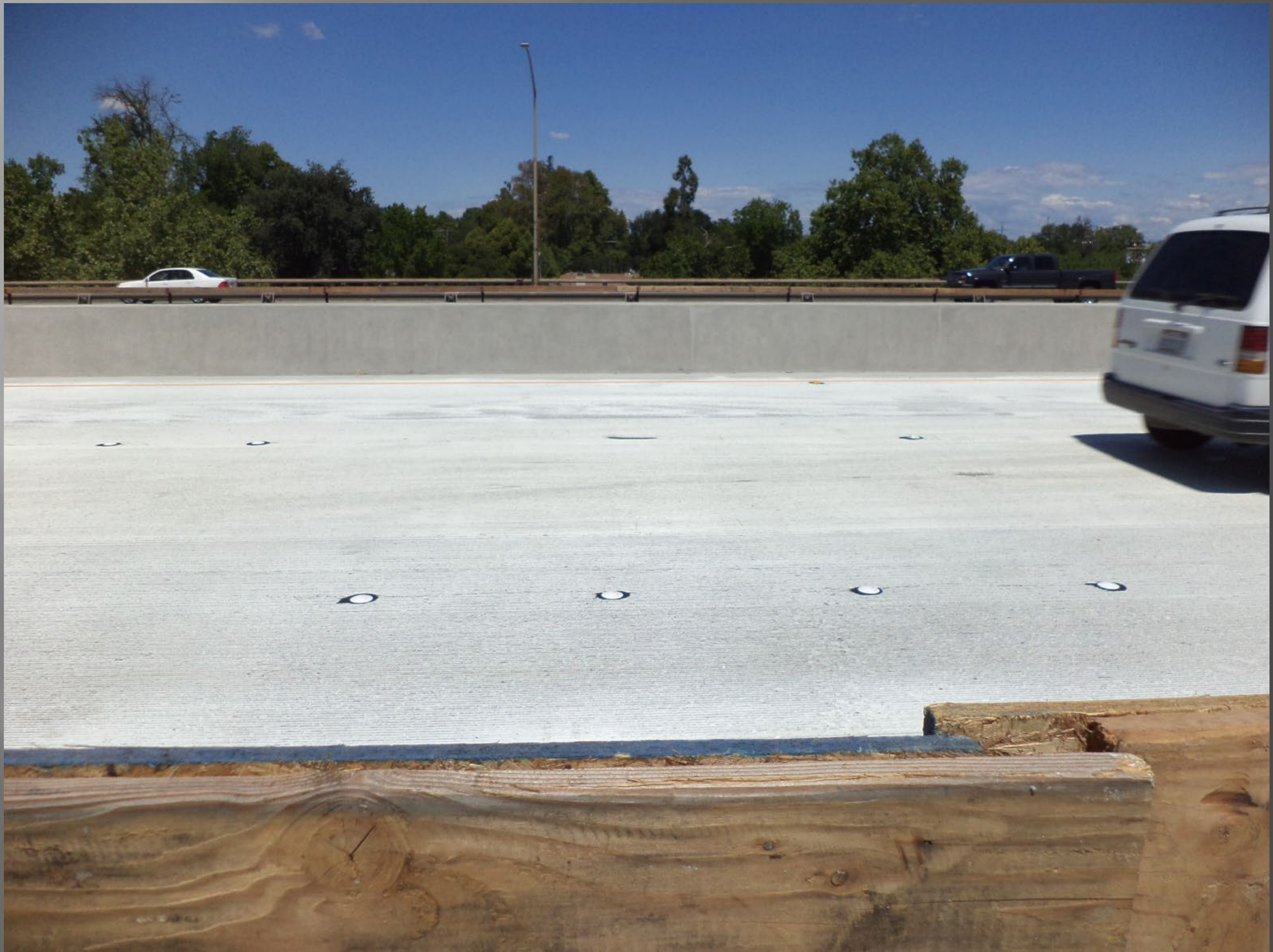
This is what it costs.

- The pilot projects show no measurable change to the price bid for structure concrete.
- When implemented via CCO the cost has been about:
  - SRA @ 1 Gal/CY = $25/CY
  - Fibers @ 4 lb/CY = $25/CY

7 years old

7 years old

11 years old



14 years old

14 years old

For more information:

[Crack-less(TM) Bridge Decks, How We Made It - YouTube]

Controlling Shrinkage Cracking

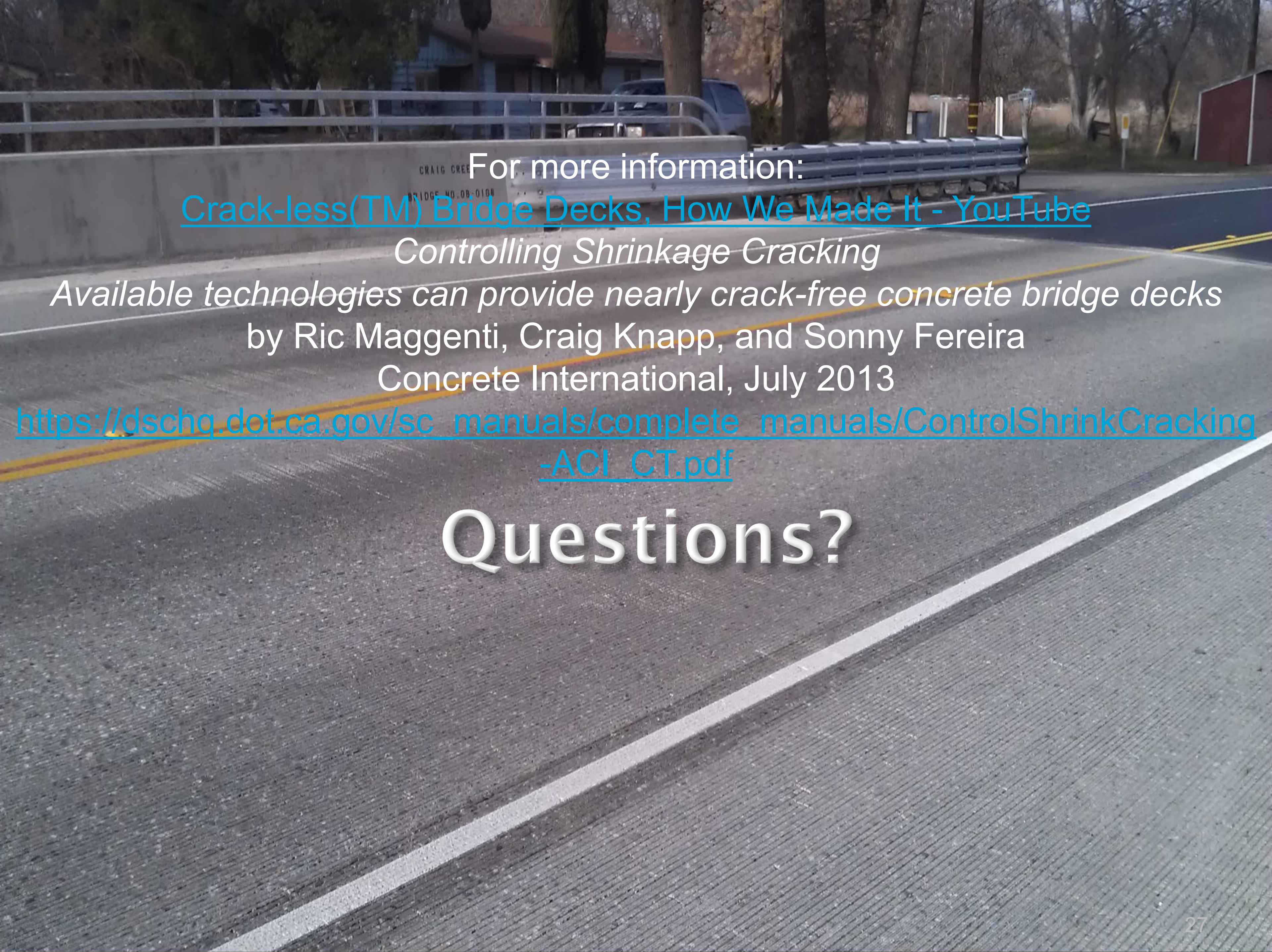
Available technologies can provide nearly crack-free concrete bridge decks

by Ric Maggenti, Craig Knapp, and Sonny Fereira

Concrete International, July 2013

https://dschq.dot.ca.gov/sc_manuals/complete_manuals/ControlShrinkCracking-ACI_CT.pdf

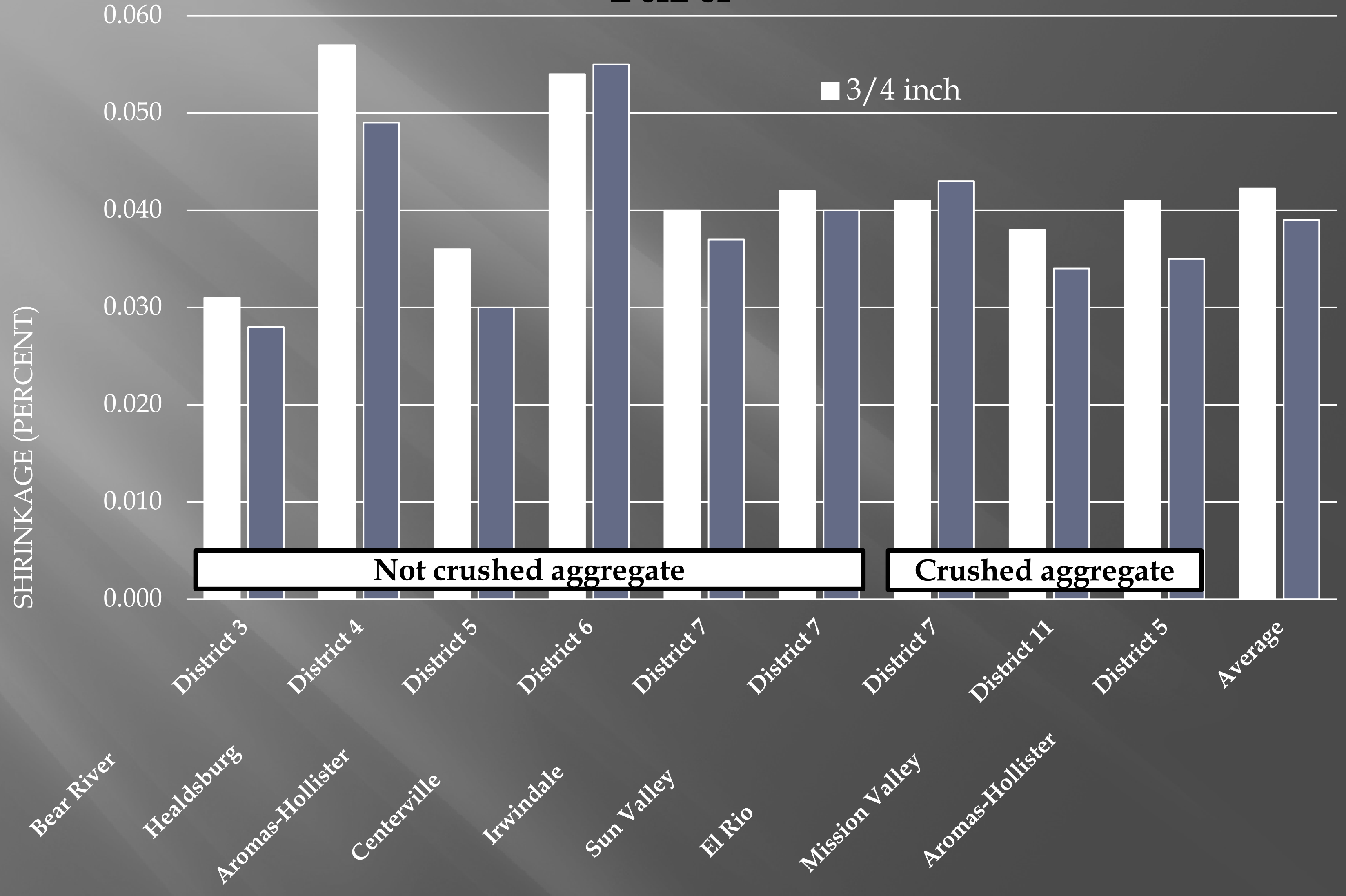
Questions?



28 shrinkage = .030 with SRA

28 shrinkage = .030 without SRA

Drying Shrinkage (Percent) 28-Days Drying at 7 ½ Sacks per Cubic Yard



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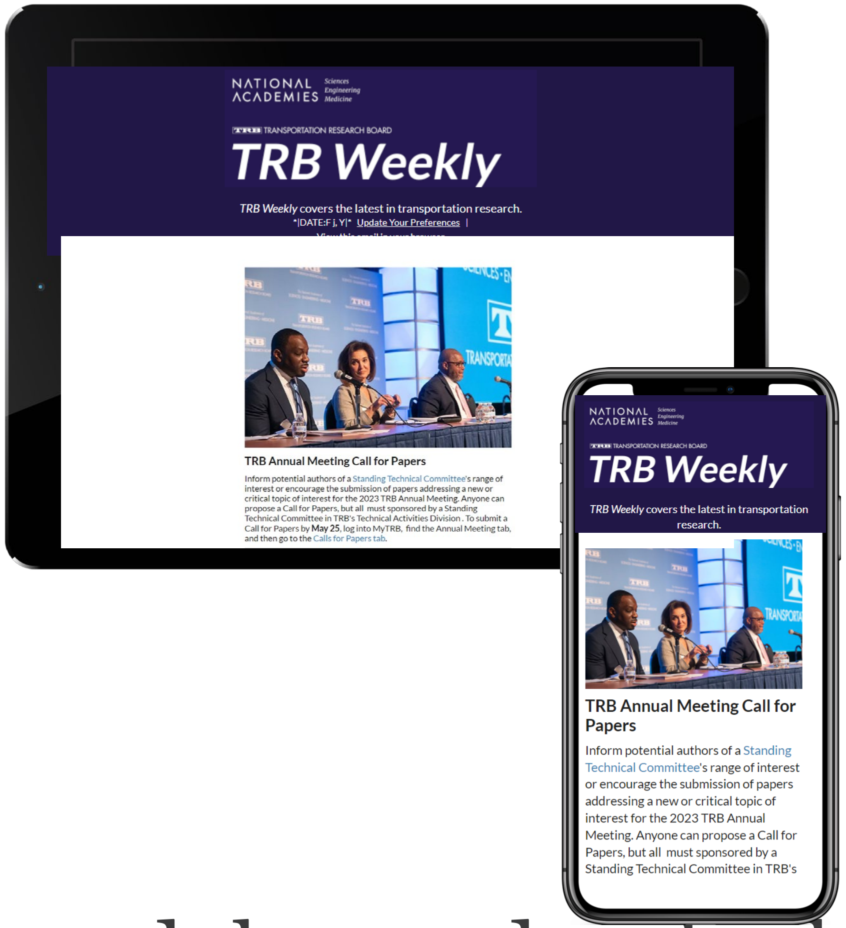

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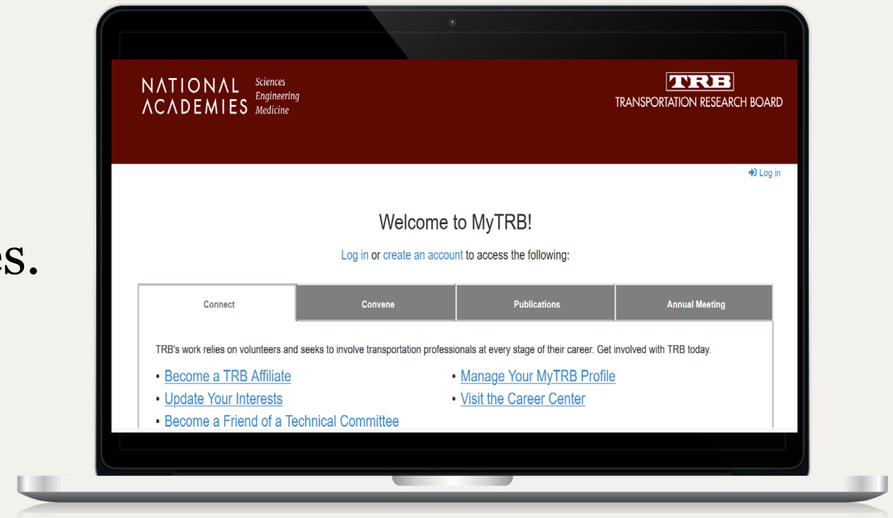

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