

PERFORMANCE ENGINEERED MIXTURES (PEM) & MOBILE CONCRETE TECHNOLOGY CENTER (MCTC) WORKSHOP

Georgia DOT
February 24, 2025



U.S. Department of Transportation
Federal Highway Administration



National Concrete Pavement
Technology Center



Agenda

- 9:00 Welcome & Introductions
- 9:15 MCTC and Emerging Concrete Technology
- 10:00 PEM Background
- 10:30 Break
- 10:45 PEM in Practice & P3C
- 11:30 New Test Methods and Technologies
- 12:15 Lunch
- 1:00 Demonstrations of PEM and other New Test Methods &
Tour the New Mobile Concrete Technology Center
- 2:00 Adjourn



Welcome and Introductions

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MCTC:
Josh Brinegar
Jerry Clemons
Nicolai Morari

National Concrete Pavement Technology Center (CP Tech Center)

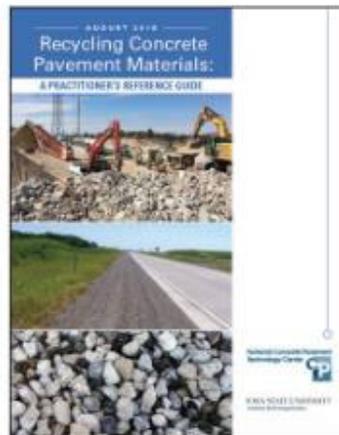
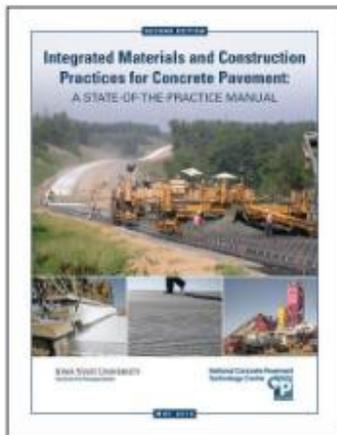
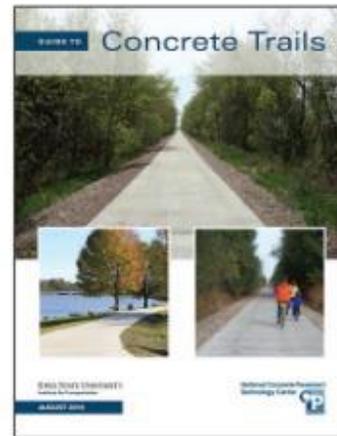
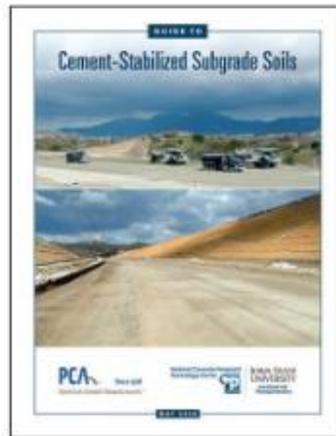
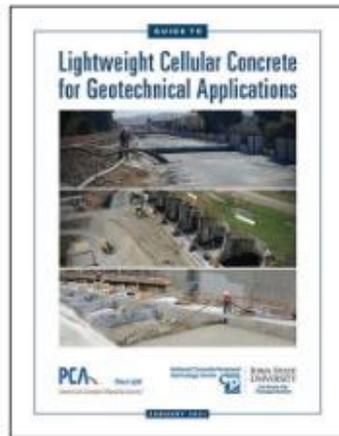
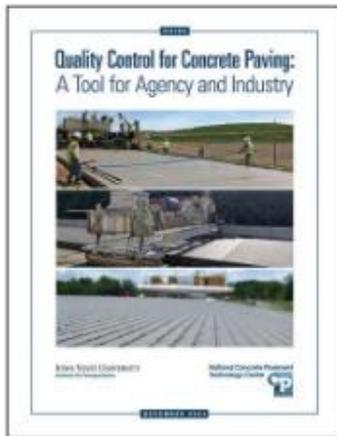
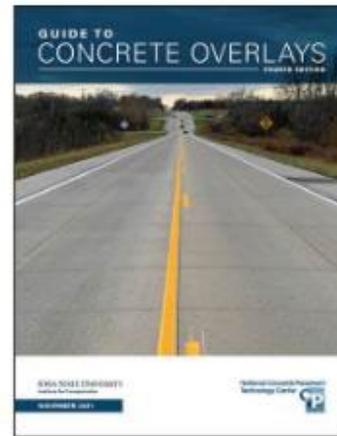
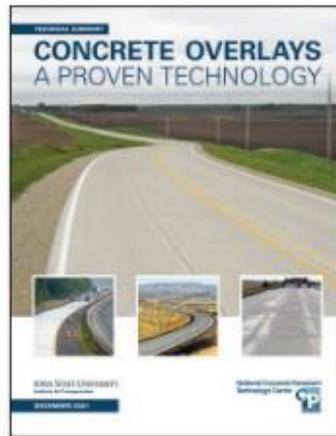
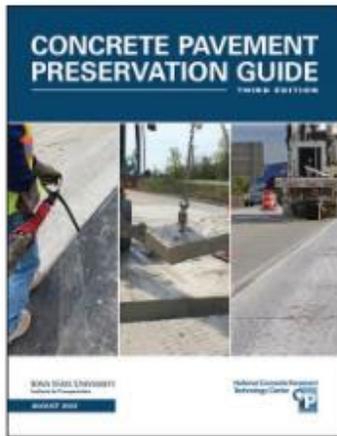
Missions:

- Advance innovative concrete pavement technologies
- Lead implementation of best practices
- Educate the concrete pavement community
- Find solutions to strategic problems
- Provide independent technical expertise

www.cptechcenter.org

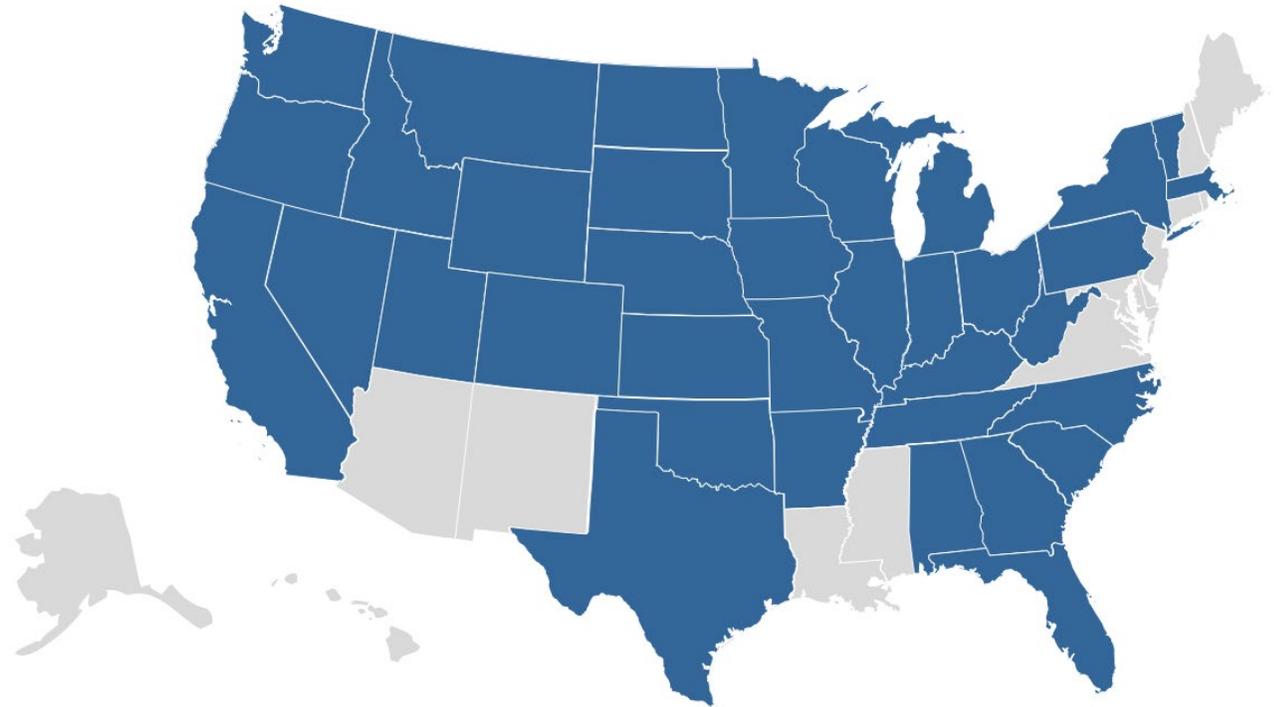


CP Tech Publications



About NC²

- **Training opportunities:**
 - IMCP
 - Overlays
 - Inspection
 - Quality Control
 - PEM
- **Other information available:**
 - E-News
 - MAP Briefs
 - Research Resources
- **Bi-annual meetings:**
 - April '25, 8-10, Rosemont, Il.
 - Fall '25, MassDOT





MCTC and Evolving Concrete Specifications



*Georgia DOT PEM Workshop
February 24, 2025*

Michael F. Praul, PE

Senior Concrete Engineer

FHWA, Office of Infrastructure



U.S. Department of Transportation
Federal Highway Administration

Disclaimer



- Except for the statutes and regulations cited, the contents of this presentation do not have the force and effect of law and are not meant to bind the States or the public in any way. This presentation is intended only to provide information regarding existing requirements under the law or agency policies.
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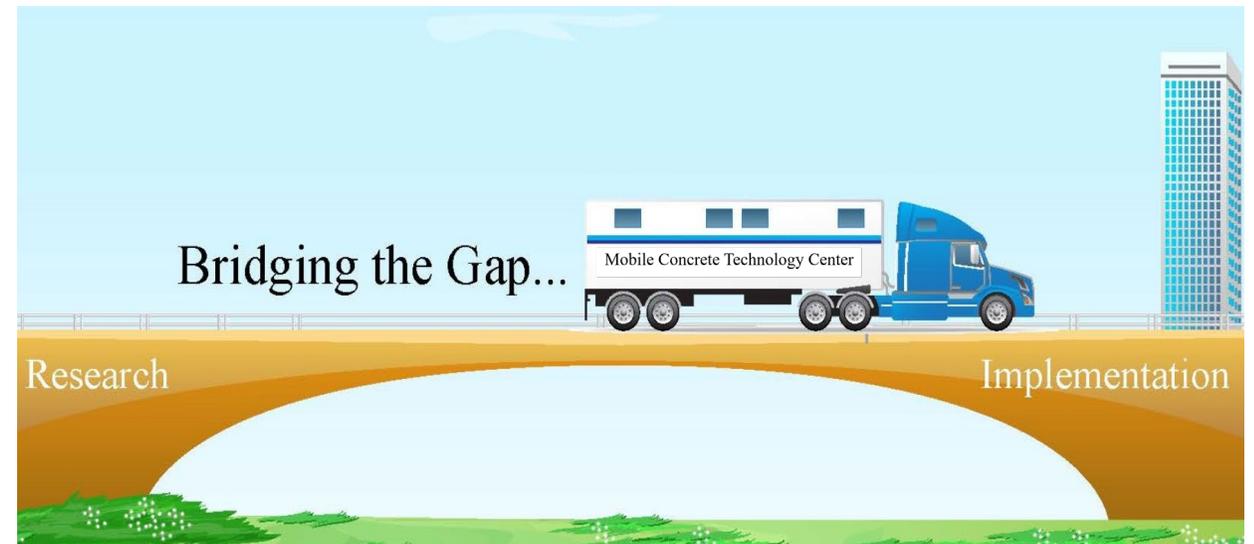
Mobile Concrete Technology Center

- Funded by the Accelerated Implementation and Deployment of Pavement Technologies Program
- Unique
- Program evolves to meet stakeholder needs



MCTC Program Mission

- Implement new & under-used concrete technologies
- Demonstrate benefits of performance specifications in both agency quality assurance (QA) programs & industry quality control (QC) applications
- Advance States' concrete programs
 - Specification review
 - Technical assistance
 - Training
 - Troubleshooting
- Better concrete





MCTC
MOBILE CONCRETE TECHNOLOGY CENTER



SURFACE RESISTIVITY
Assesses Permeability

The Surface Resistivity test is used to evaluate the electrical resistance of concrete to provide a rapid indication of chloride ion resistance to the concrete.

- This easy to use test includes rapid testing, nondestructive methods compared to the traditional methods.

- ▶ Test takes less than two minutes
- ▶ Measures resistivity to 1000 Ohm-cm
- ▶ Quality Control and Acceptance
- ▶ Surface Resistivity-AA (AASHTO T 358)
- ▶ Bulk Resistivity-AASHTO (AASHTO TP 119)

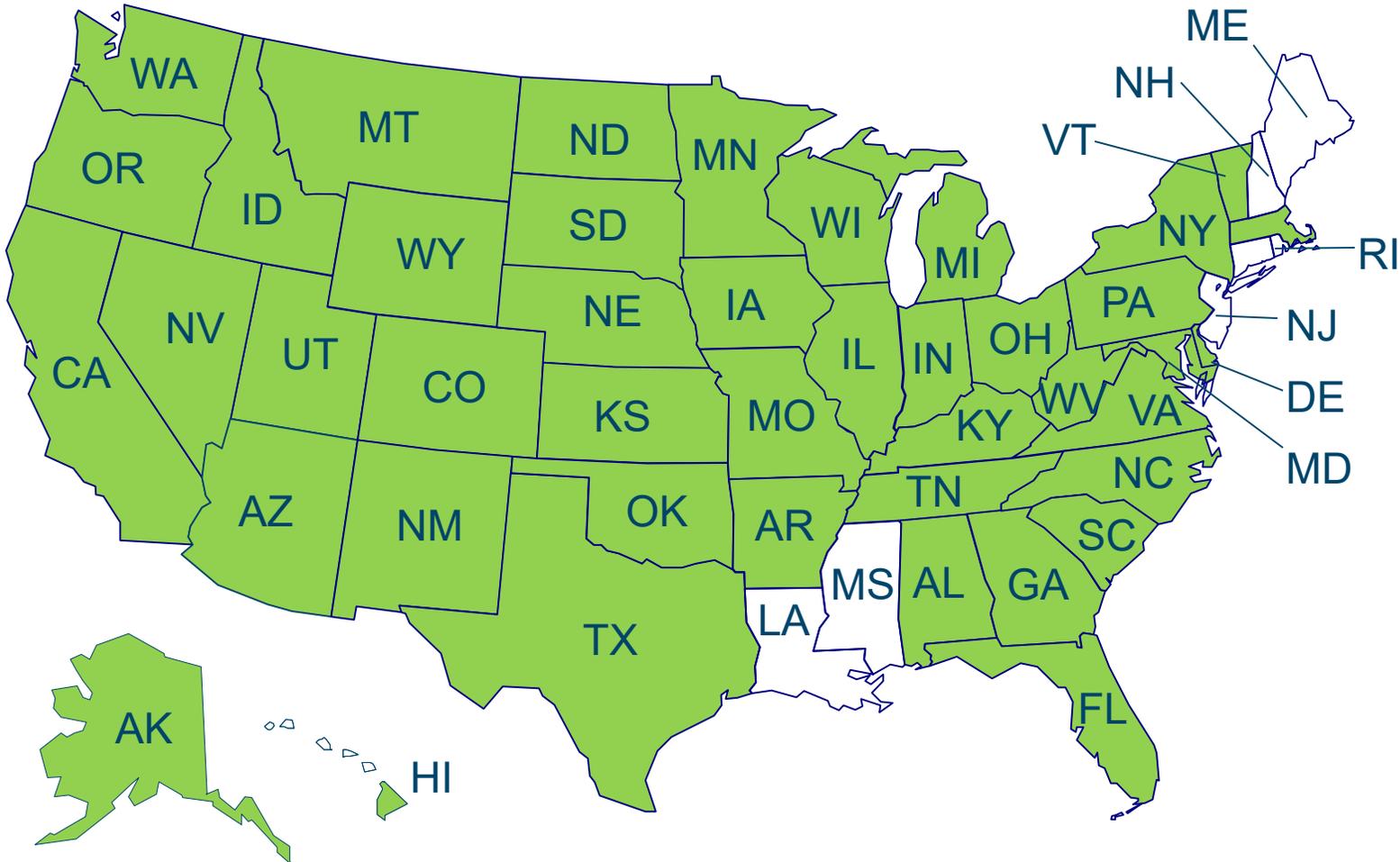


Program Activities

- Field visits to active construction projects
- Quality in the Concrete Paving Process workshops
- Equipment Loan Program
- Technical assistance/specification reviews
- Conferences/Open houses
- Support TFHRC and other research
- Publications to promote the FHWA concrete program and advance concrete technology



MCTC Field Visits (since 2008)



Quality in the Concrete Paving Process Workshop

- Two-day workshop on concrete materials and construction
- Builds off data and observations from field visit and specification review
- Agency and industry participation (50/50)
- Goal: Action plan



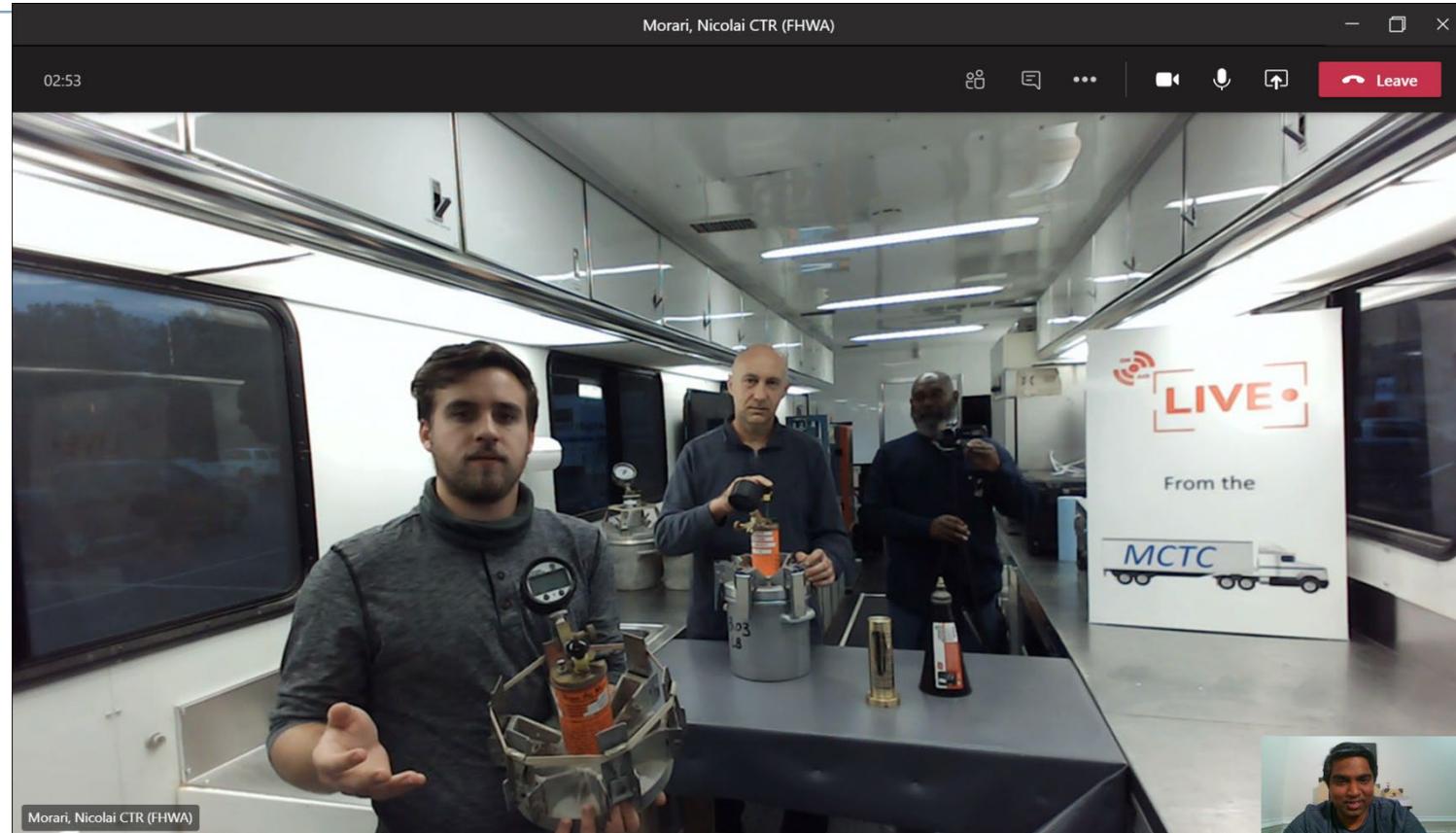
Equipment Loan Program

- Agencies or industry can borrow MCTC equipment
- MCTC staff will provide training, if desired
- PEM/AASHTO R101 focus
- Contact me/Jagan if interested

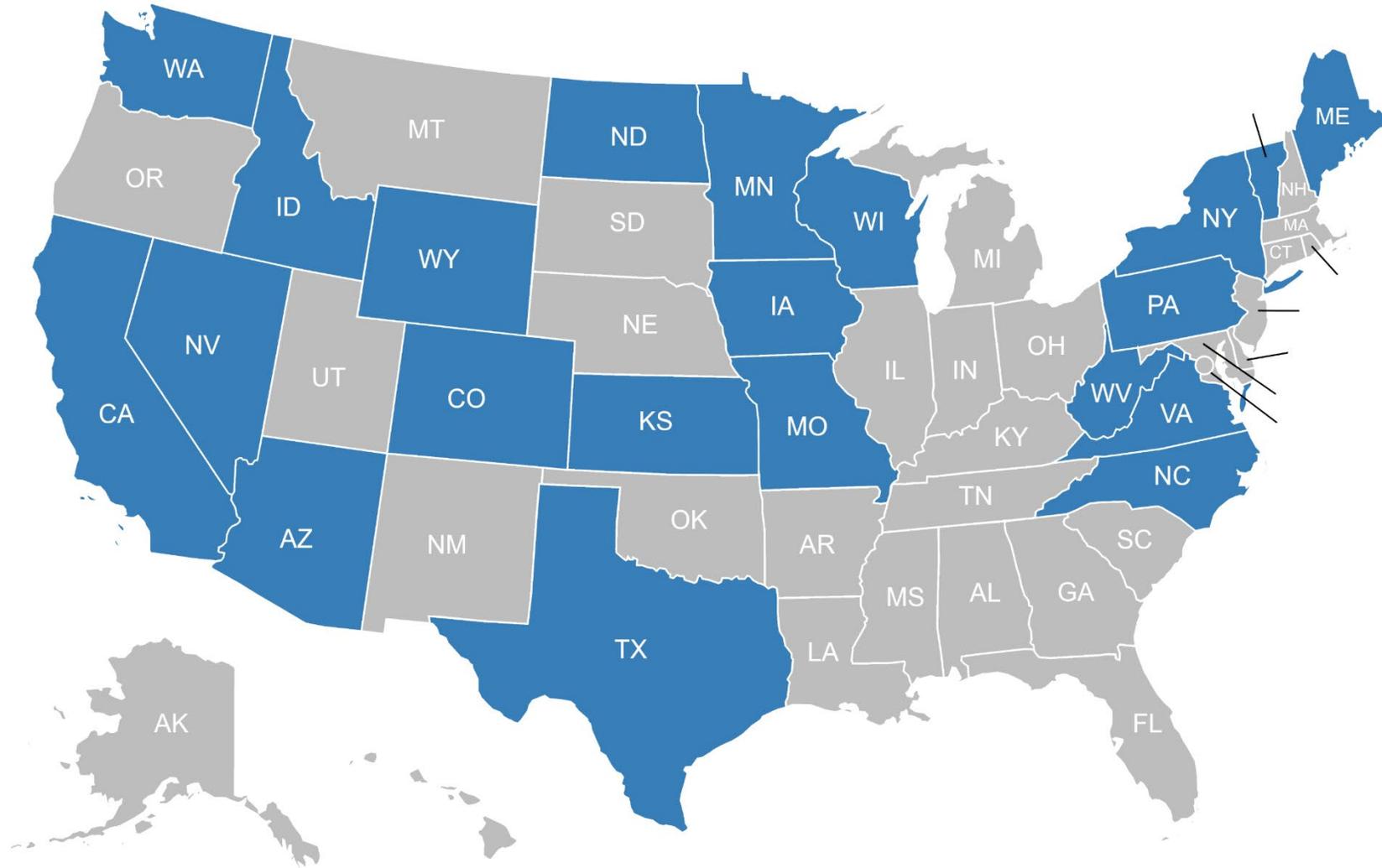


“Live From the MCTC” Training/Workshops

- Super Air Meter (SAM)
- Surface/Bulk Resistivity
- Maturity
- Box Test/V-Kelly
- Semi-adiabatic calorimeter
- Phoenix (fresh water content)
- Pulse Induction Technology (MIT-SCAN-T3)
- MIT-DOWEL-SCAN
- HIPERPAV®
- Optimized Gradation software



MCTC Virtual Sessions (2020-2021)



Technology Tour



College Program

- Practical Applications of Quality Control
- Concrete Testing Technologies
- FHWA Mobile Concrete Technology Center and Performance Engineered Mixtures



College Program

Completed

- Virginia Military Institute
- Ohio State University
- Ohio Northern University
- Case Western Reserve
- Clarkson University
- Rensselaer Polytechnic Institute
- University of Connecticut
- Cleveland State University
- Middle Tennessee State
- Auburn University

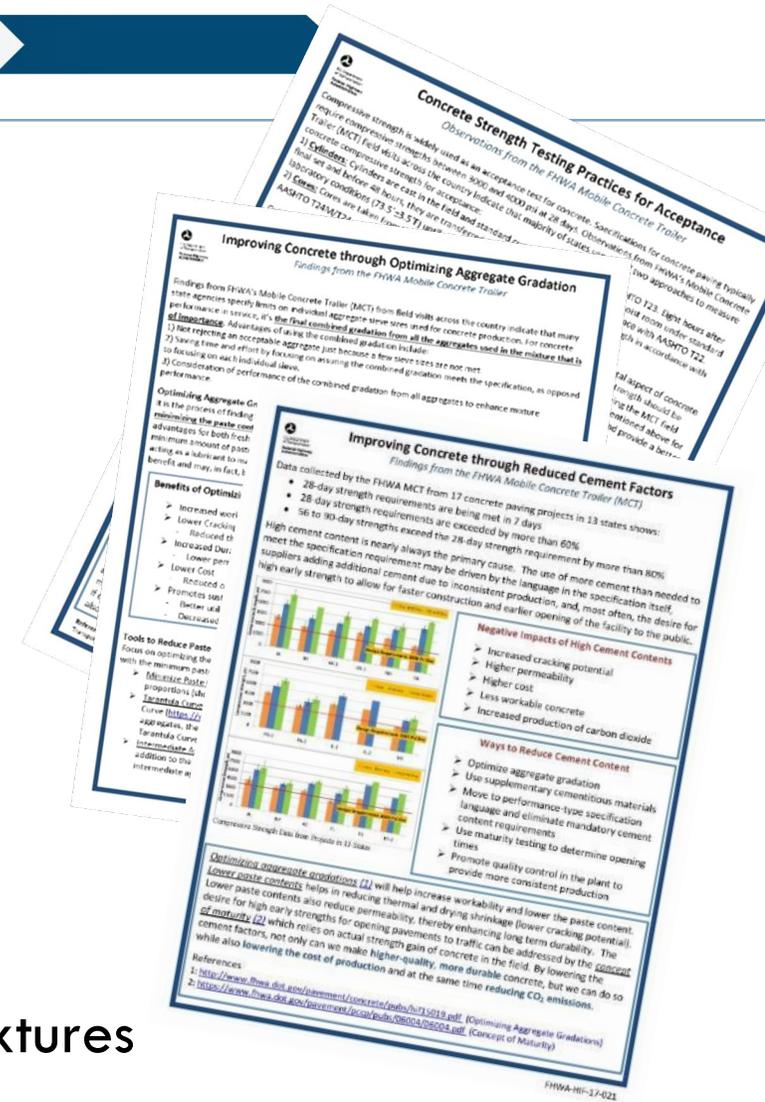
Planning

- University of Nebraska
- University of California-Chico
- University of Wisconsin



One Pager Series

- Use MCTC data and experiences
- Narrowly focused
- Meant to stir interest and point reader to resources
 - 1st: Cement content
 - 2nd: Optimized Mix Design
 - 3rd: Cores vs. Cylinders
 - 4th: NDT Pavement Thickness
 - 5th: Tining/Surface Texture
 - 6th: Surface Resistivity Test
 - 7th: Maturity
 - 8th: Curing
 - 9th: SCM's
 - 10th: Calorimetry
 - 11th: Workability
 - 12th: Air Entrainment
 - 13th: Stringless Paving
 - 14th: Water Reducing Admixtures



2025 Activities

➤ Project Site Visits

- Montana
- Georgia
- California
- Arkansas
- Puerto Rico
- Federal Lands (VA)

➤ Workshops

- Nevada
- Utah

➤ University Days

- University of Nebraska
- University of Wisconsin
- University of California-Chico

➤ Technology Tours

- Texas
- Oregon
- Maryland

➤ Conferences

- TRB
- World of Concrete
- ACPA Annual Meeting
- ACPA—PA Chapter Annual Meeting
- ACI Fall Convention (MD)
- Eastern Federal Lands Construction



Let's Have Some Fun: 4 Things To Make You Think

1. Eliminate Slump Testing for Acceptance

Changes in Slump Test

100 Years ago



Today



What has changed?

What do we really want to find out using the Slump Test?



➤ Water content?

- Historically, an indicator of water content
- Today, water reducers will change the slump with no change in water
- SCMs impact—bridge deck example

➤ Workability/flowability?

- Slump does not account for energy being added through vibration

➤ Change

- Slump can ONLY tell us something has changed
- QC tool only

Box Test



- Assesses workability and finishability
- Simple (lends itself to quality checking)
- Included in AASHTO R101 (PEM)
- **AASHTO T 396**

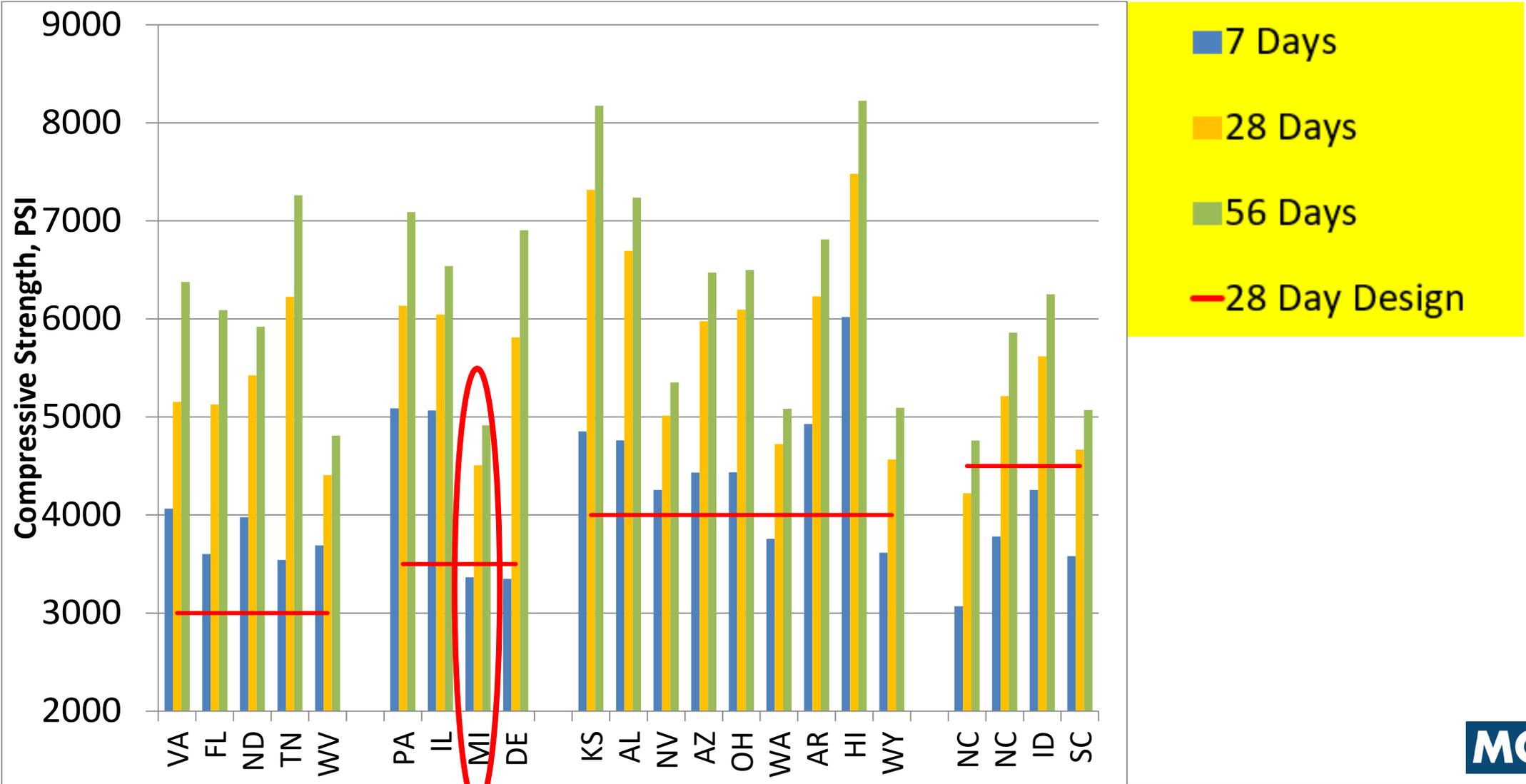


Phoenix vs. Microwave Water Content

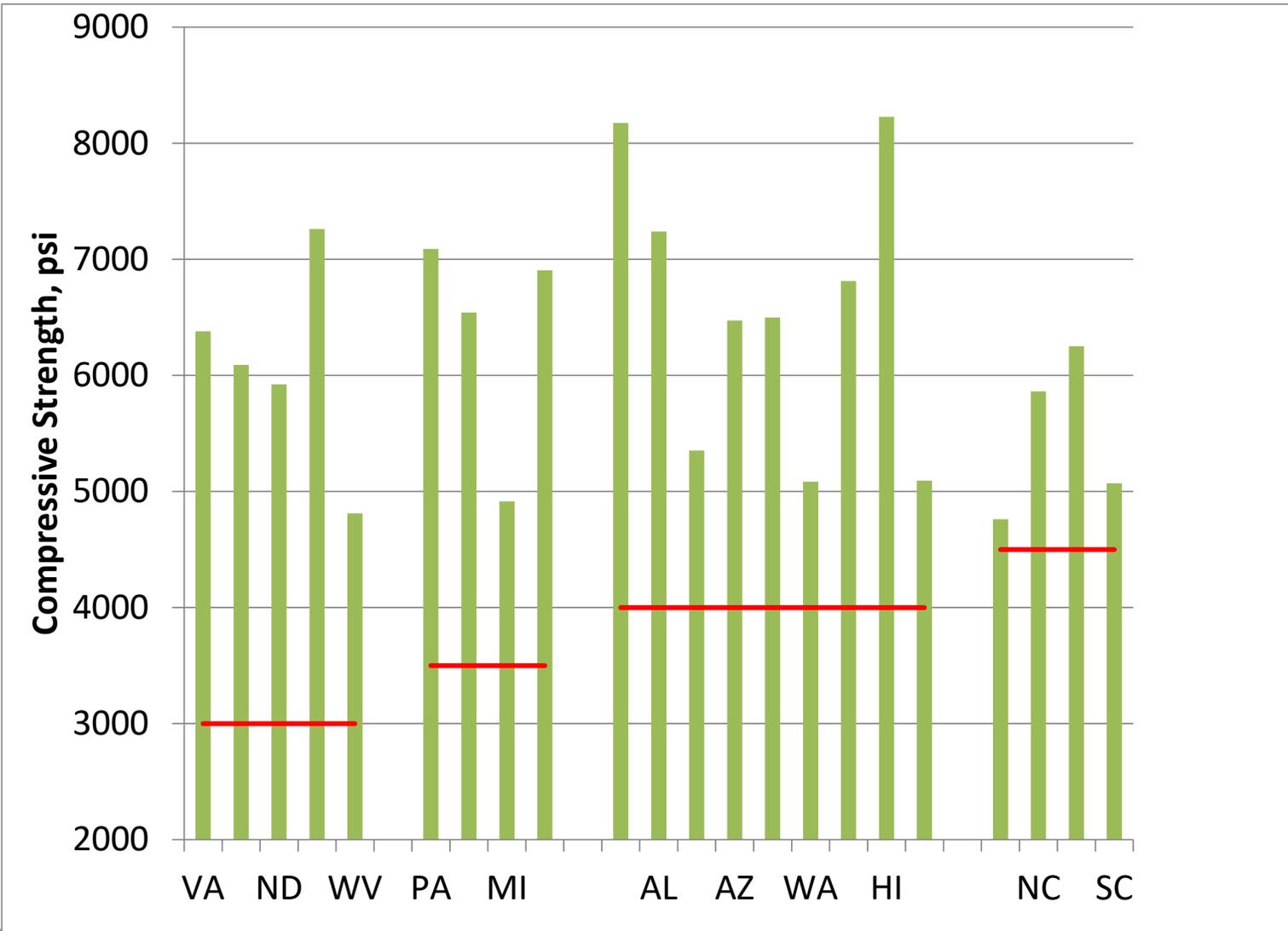


2. 56-day Testing

Compressive Strengths (MCTC Project Visits)

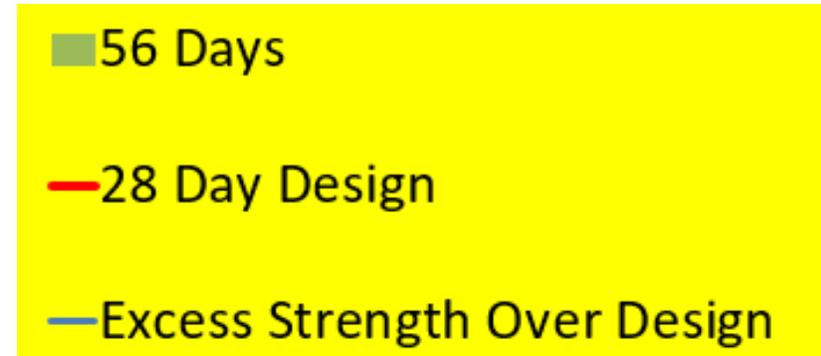
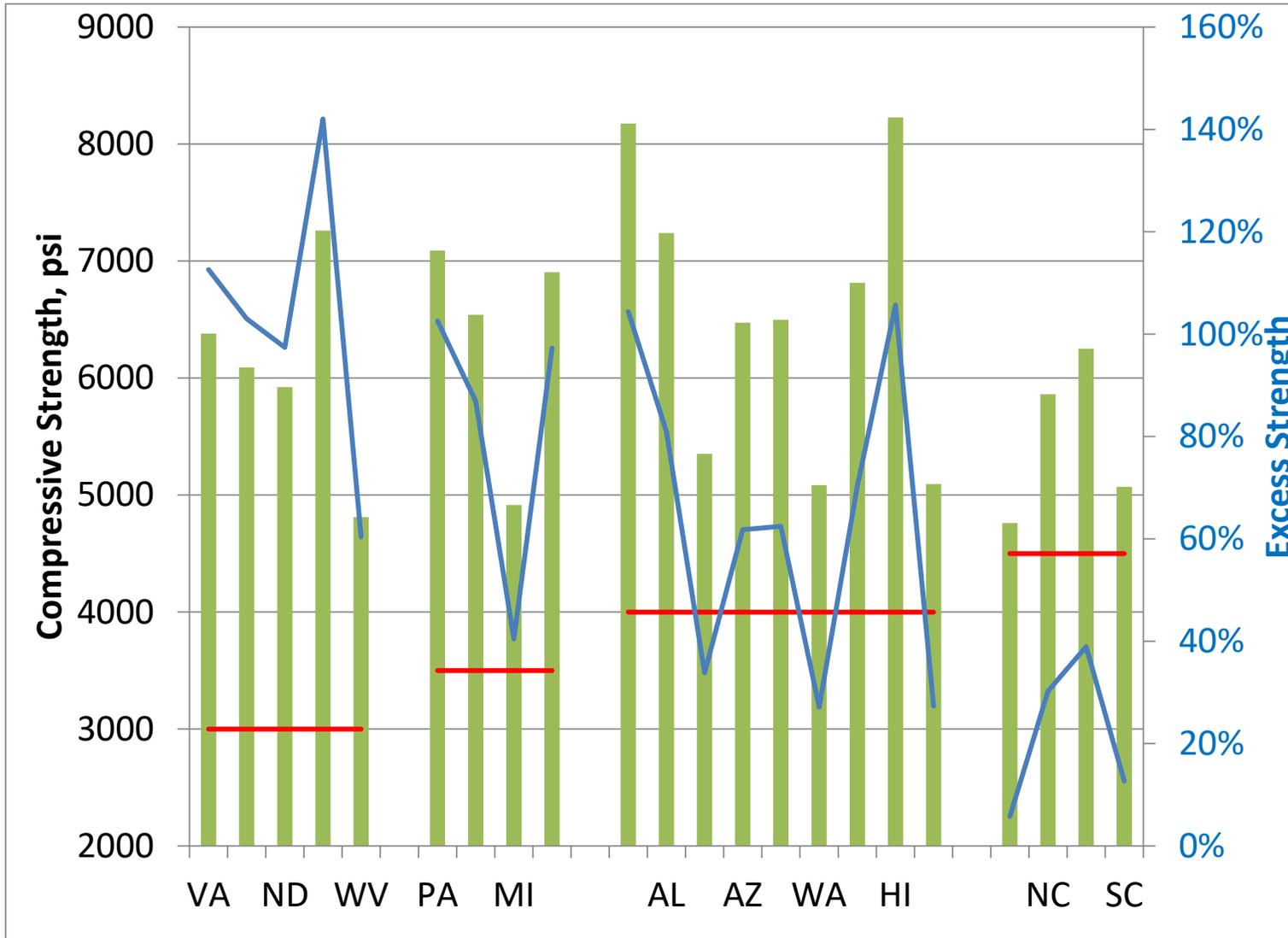


Compressive Strengths

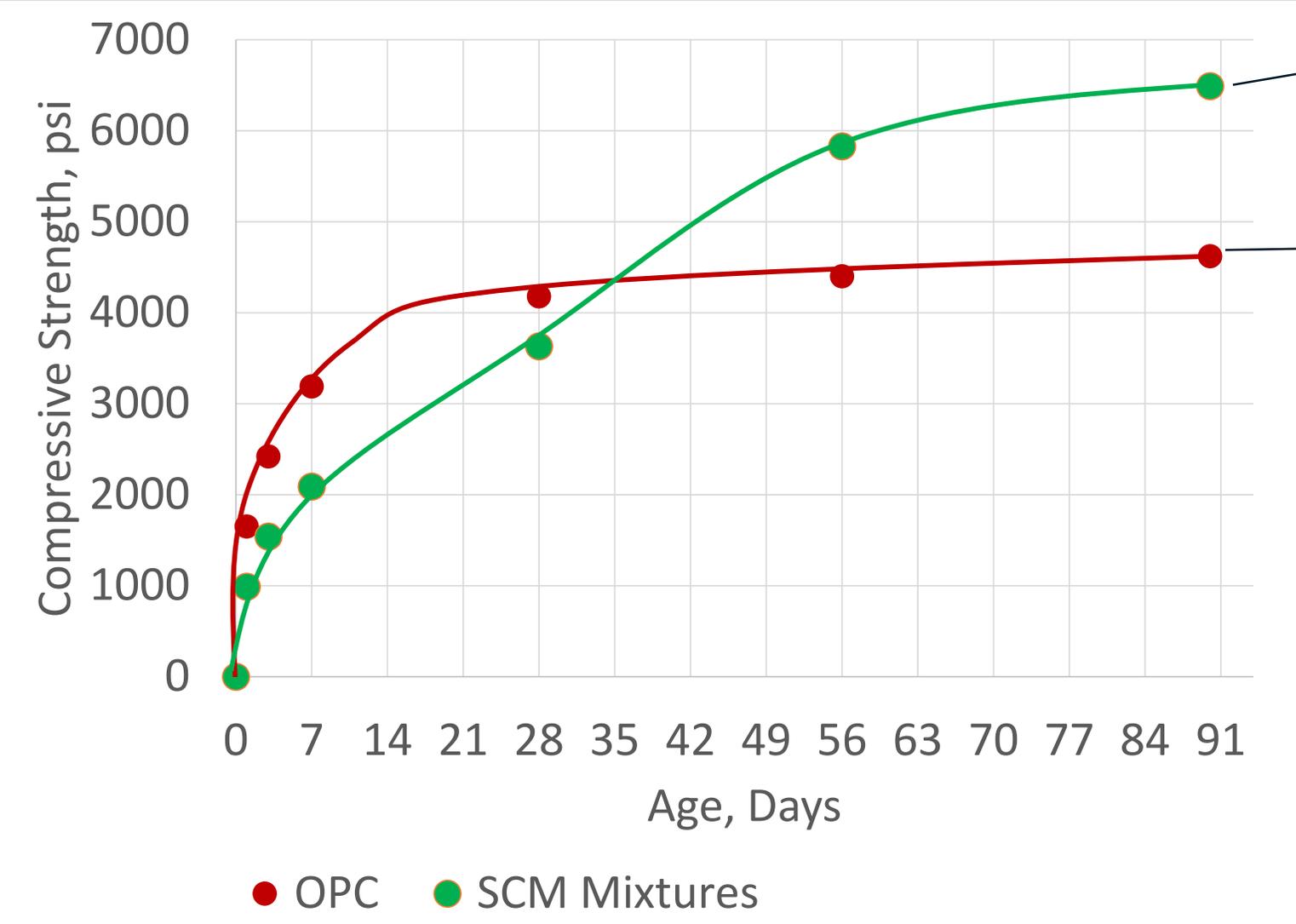


■ 56 Days
— 28 Day Design

Compressive Strengths



Strength Gain for OPC vs. SCM



Mixtures with Supplementary Cementitious Materials

Ordinary Portland Cement Mixtures

Strength Difference between 28 and 56 days for OPC Mixtures : 1-5%

Strength Difference between 28 and 56 days for SCM Mixtures : 25-50%



Concrete Acceptance Practices

➤ How do we accept concrete?

- Slump
- Strength
- Total air
- Temperature
- Thickness
- Ride

➤ How do we adjust price?

- Strength



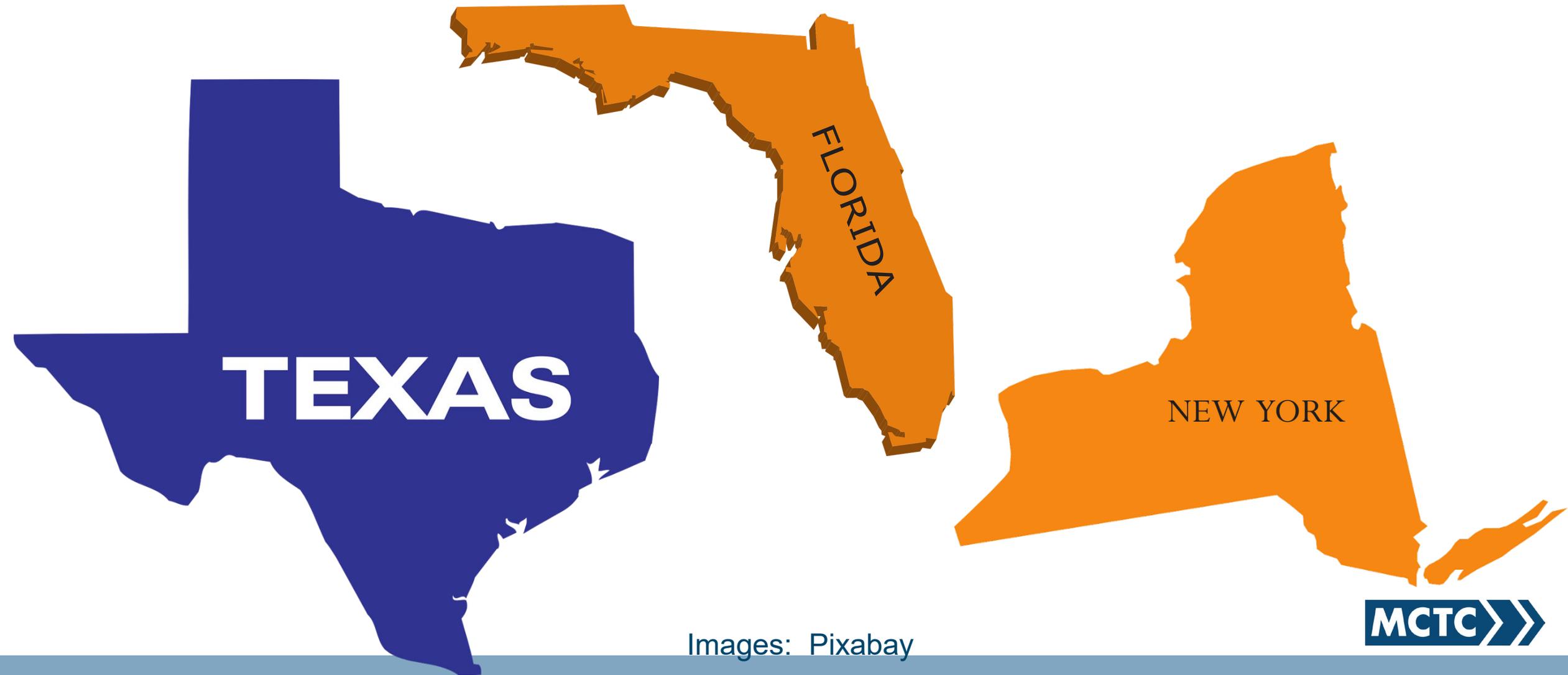
Lower Right Image: Pixabay

The Great 28

- Wrong time
- Wrong cementitious system
- Implications
 - Cost
 - Durability
 - Deck Cracking



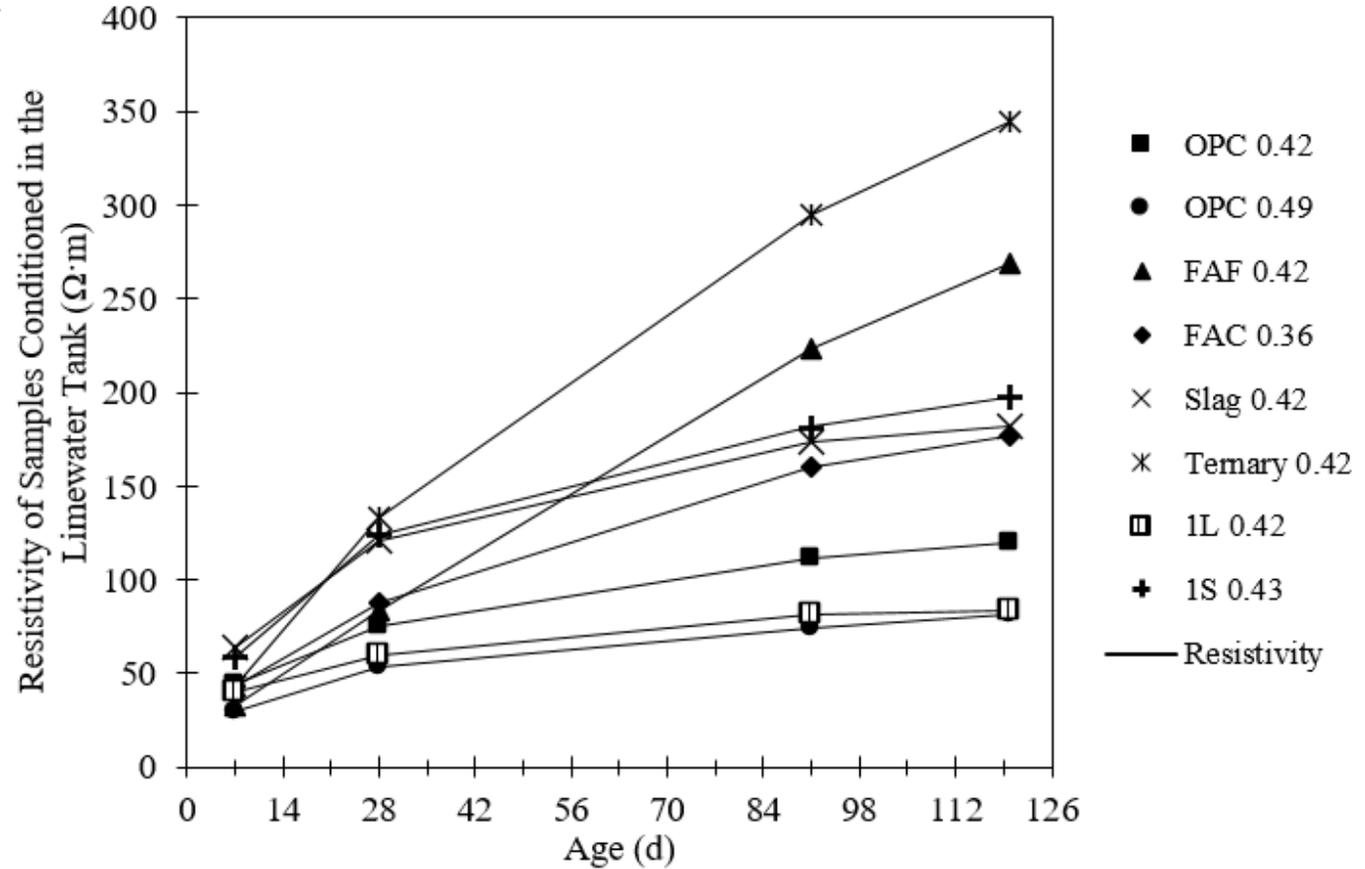
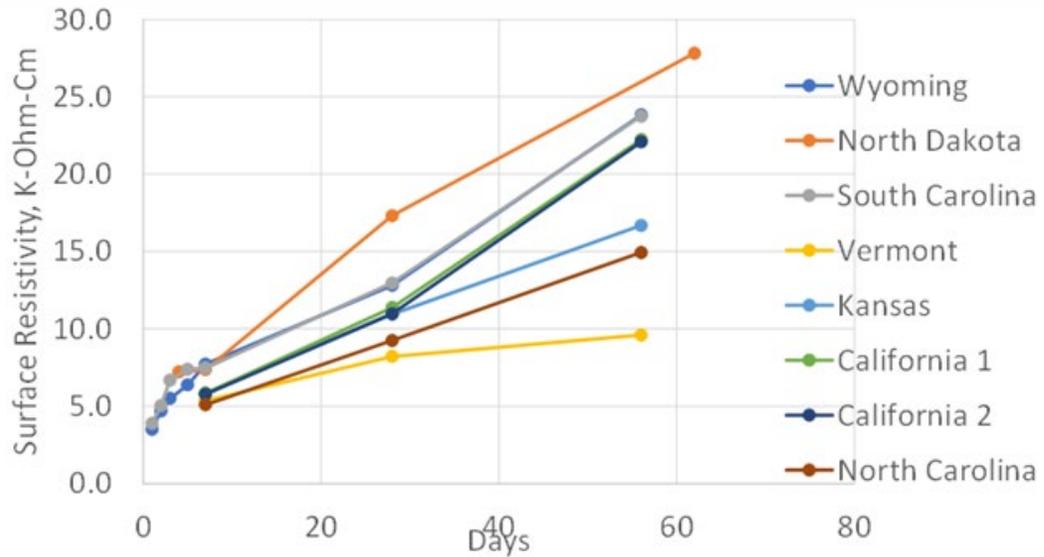
New specification



Images: Pixabay



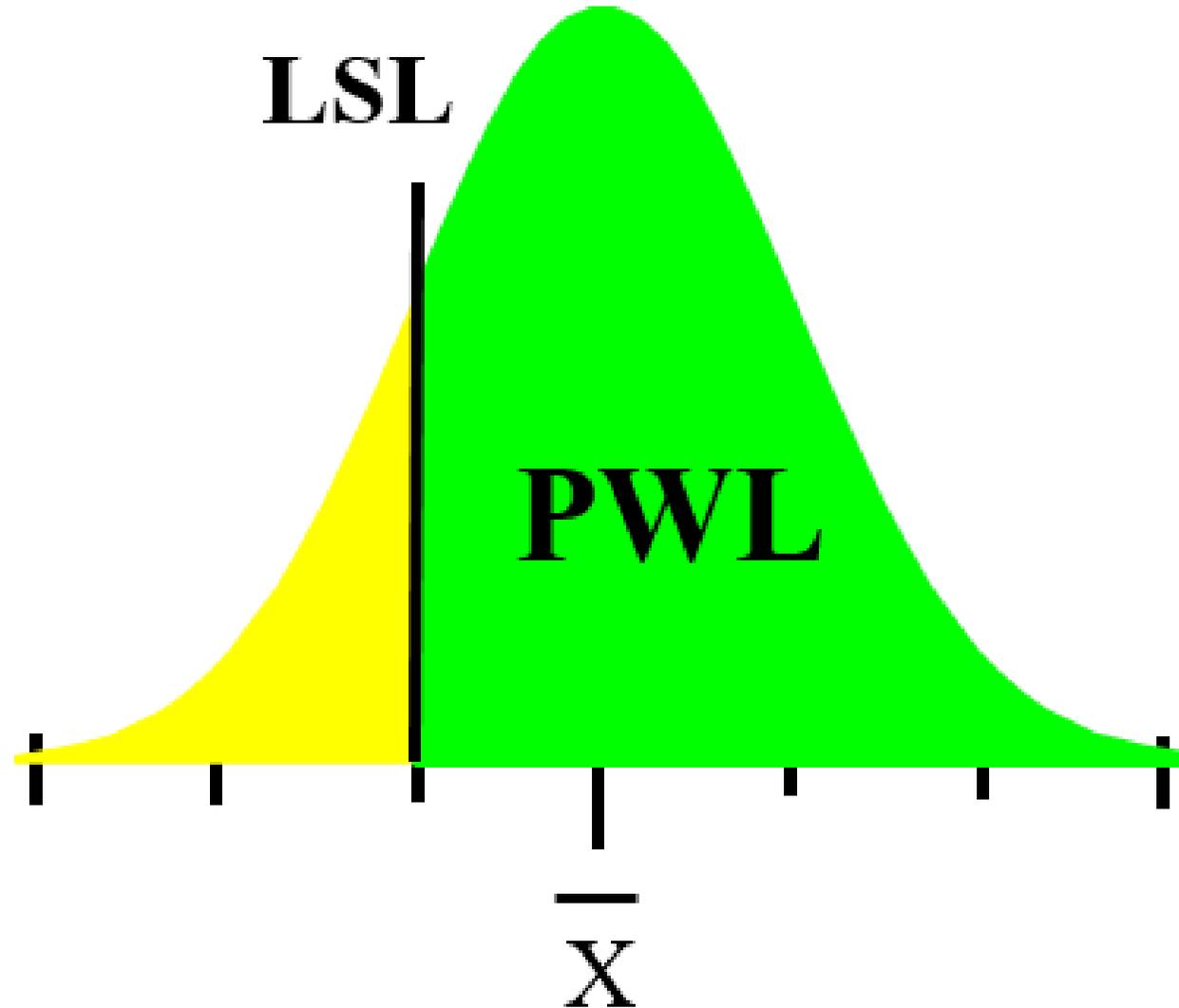
Resistivity Data (FHWA MCTC and TFHRC)



Correlating Durability Indicators to Resistivity and Formation Factor of Concrete Materials. Transportation Research Record, 2023. (Helsel, Montanari, Spragg, de la Varga, Saladi)

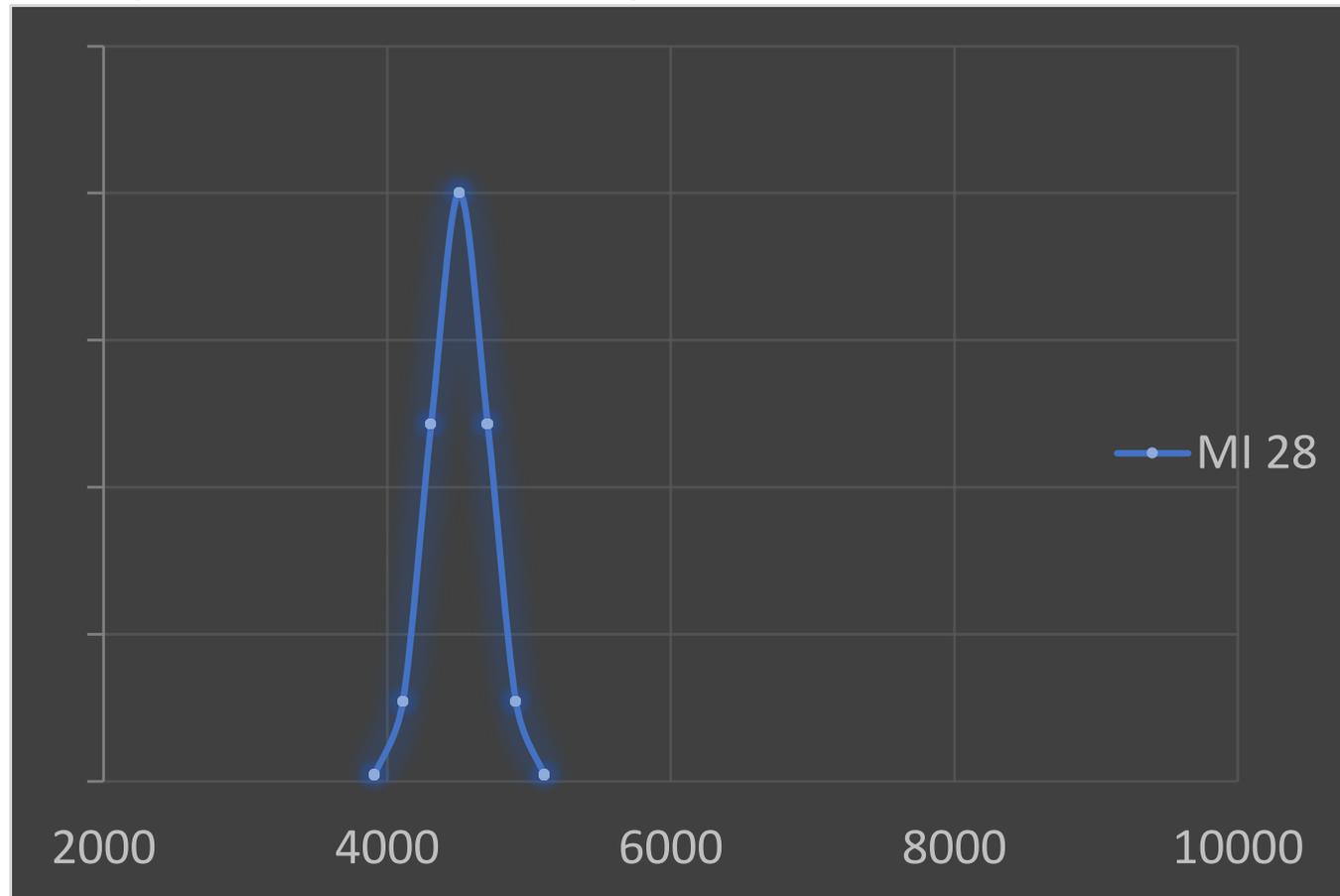
3. PWL For Strength

PWL – Concrete Strength



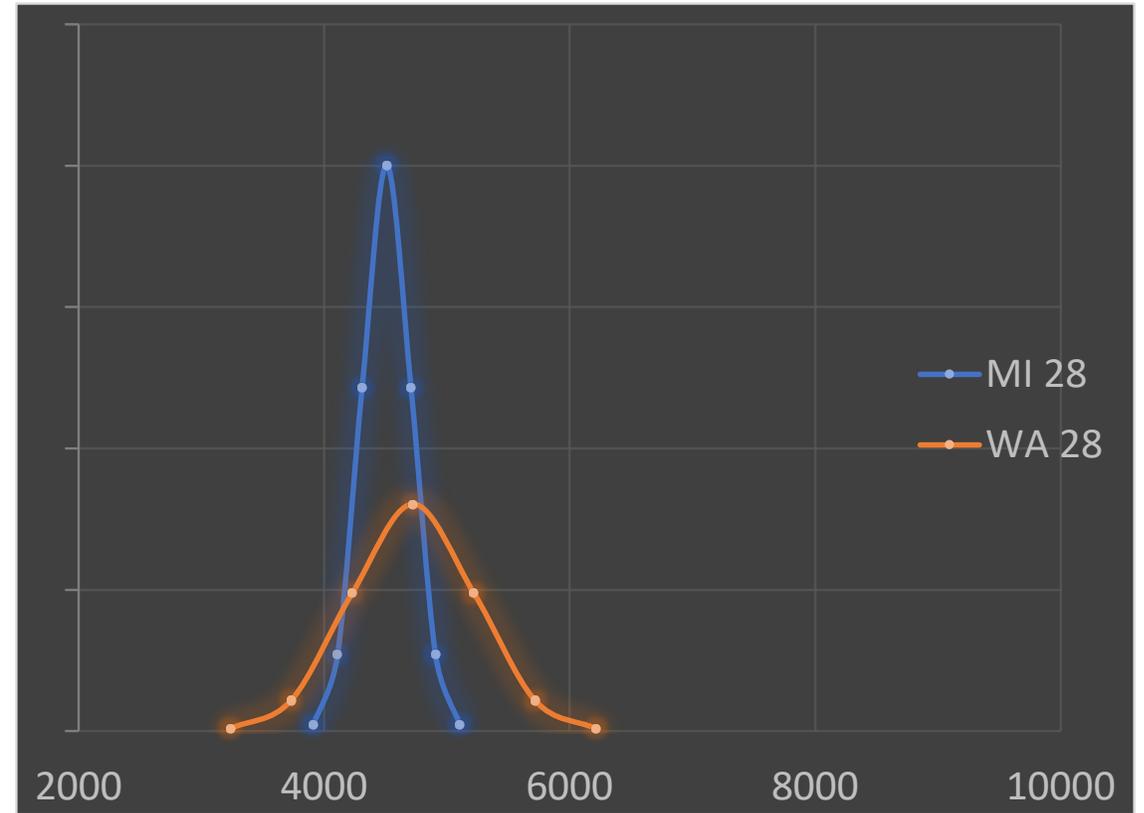
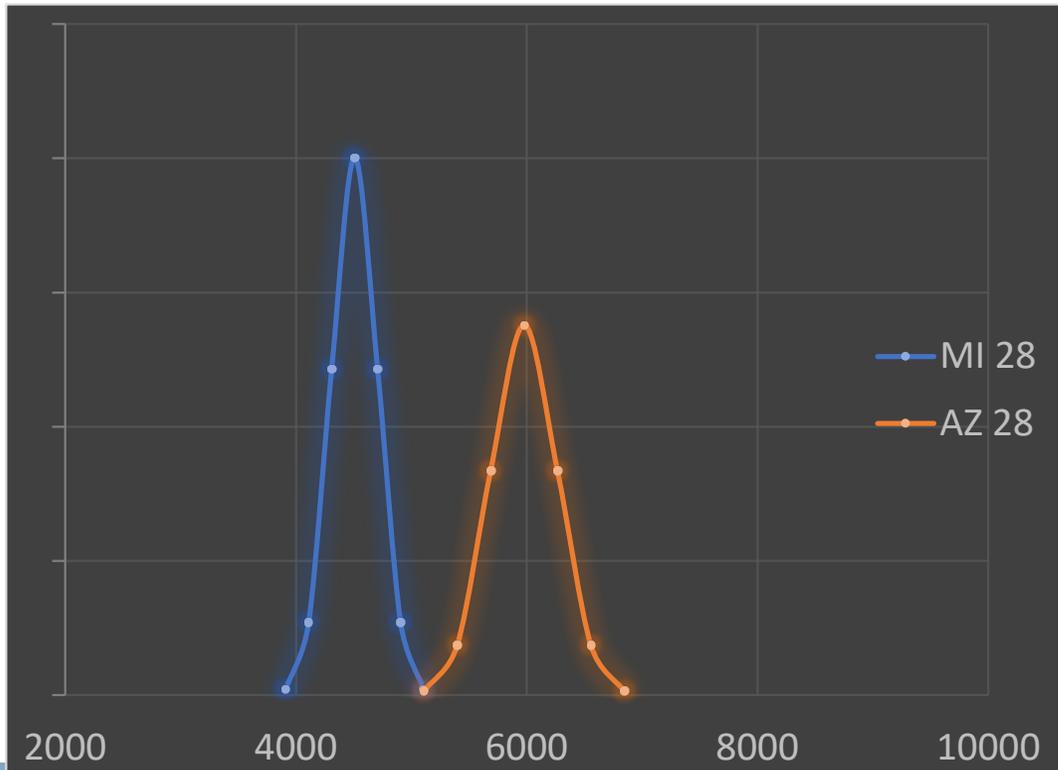
PWL for Strength Acceptance

- Michigan
- 28 Day strength requirement: 3500 psi



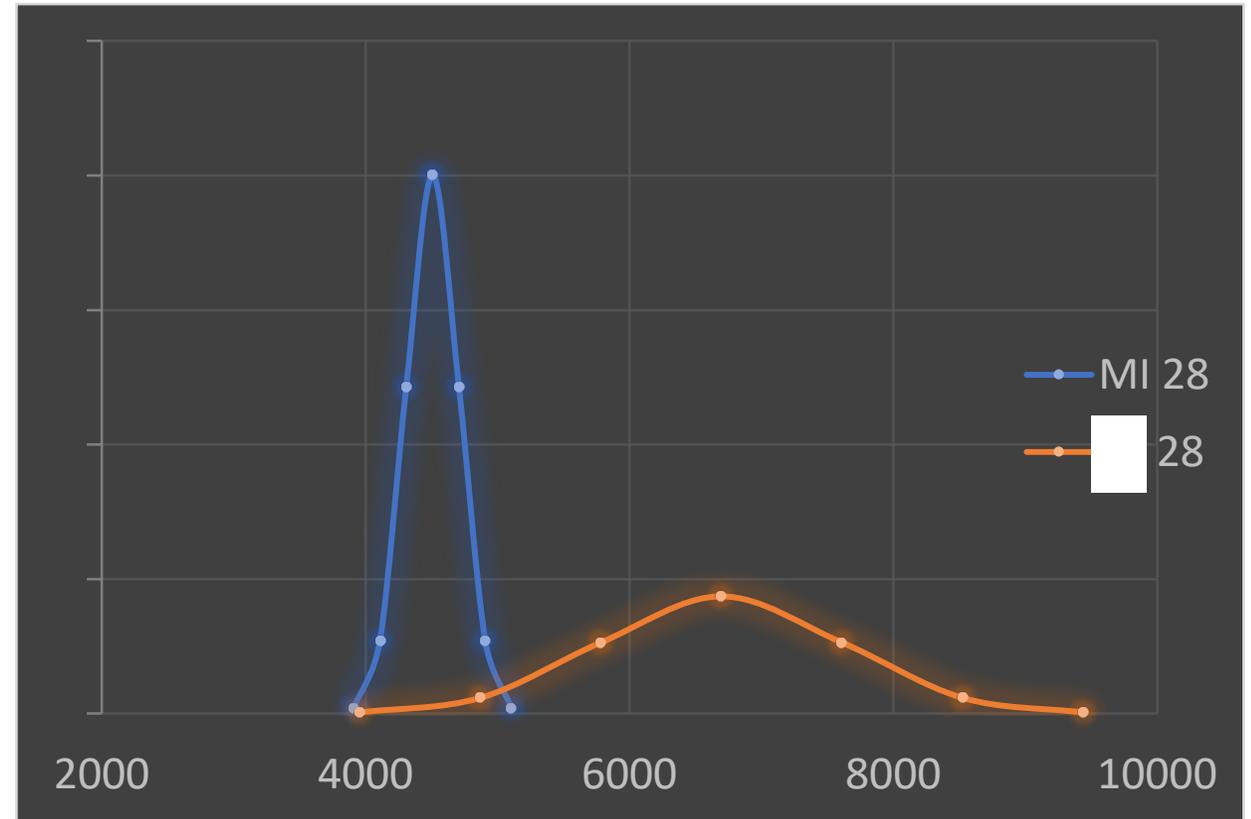
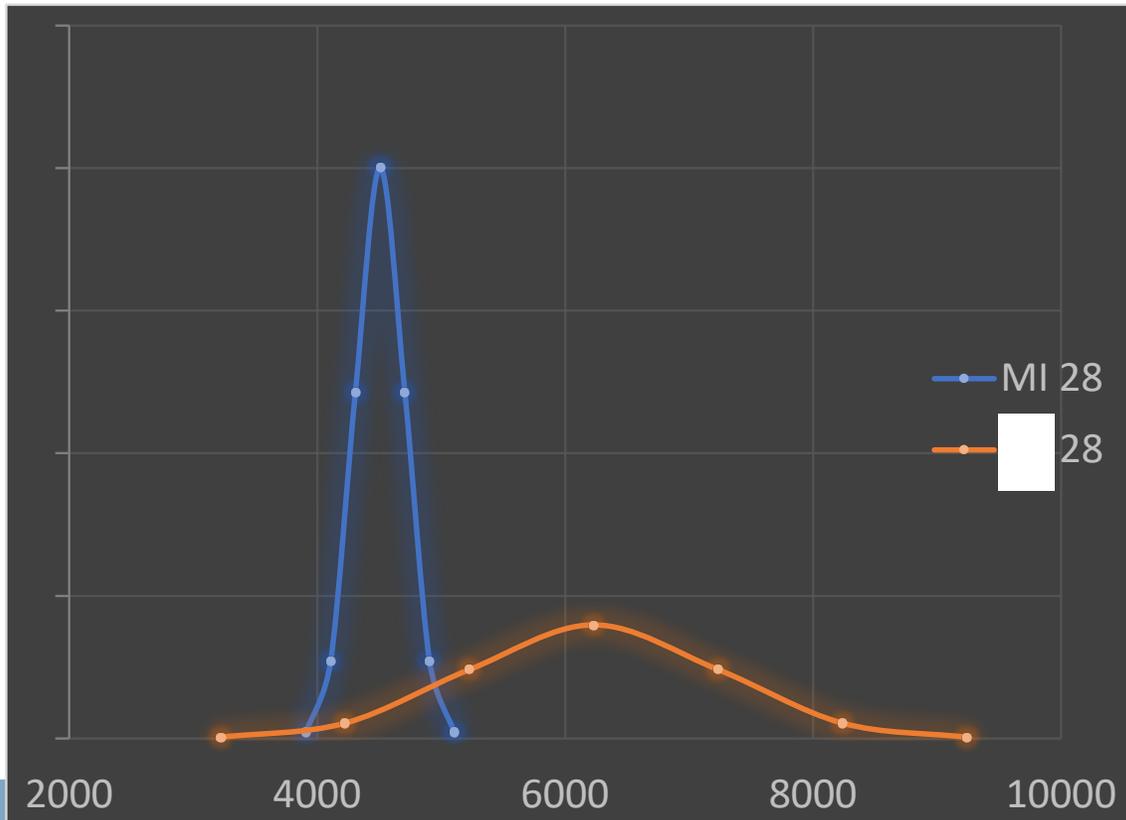
States With PWL Requirements

- 28 Day Strengths
- Lower Variability
- Lower Average Strength



States Without PWL requirements

- 28 Day Strengths
- Higher Variability
- Higher Average Strength



4. Specify Quality Control

Better Assessment of Quality?

Option 1

- QC Info: None
- Strength
- Slump
- Total Air



Option 2

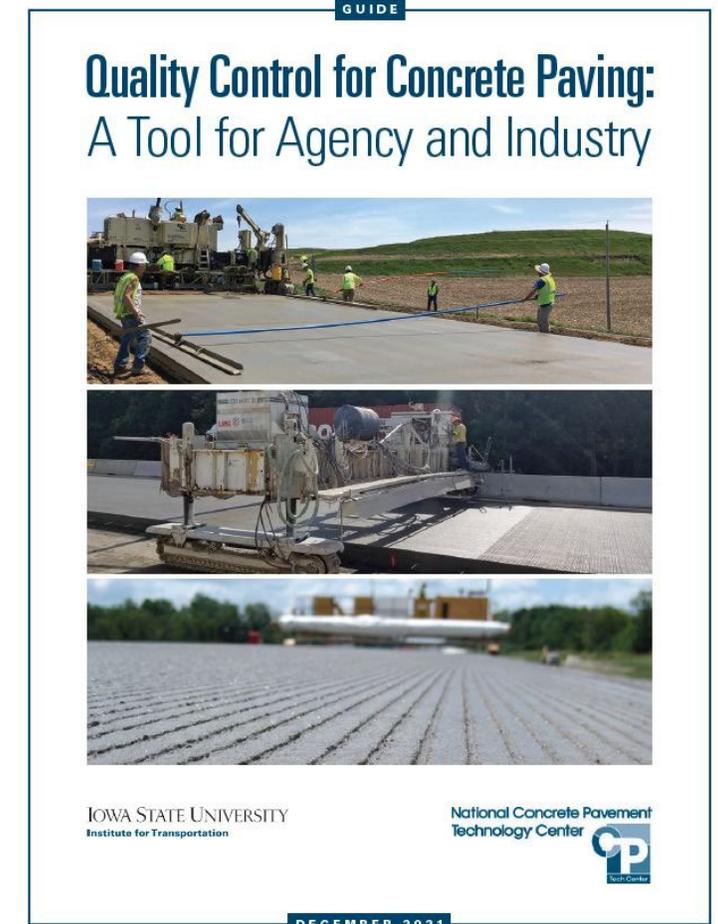
- QC Info:
 - Unit weight
 - Calorimetry
 - Water content (Phoenix)
- Resistivity
- Strength
- SAM number*
- Box/Float Test*



New!

- Guidance to leverage QC in agency specifications
- Model QC Plans (format and language)
- QC guidance for contractors
 - Establishing a QC program
 - Evaluating and improving an existing QC program
- Statistical tools
- Available on the National Concrete Pavement Technology Center website (<https://bit.ly/3uurMJV>)
- Tech Briefs and training

The report is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange under Cooperative Agreement 693JJ31950004, Advancing Concrete Pavement Technology Solutions. The U.S. Government assumes no liability for the use of the information.



TAC Roster

State Agencies	Contractors	Industry/Associations
Maine DOT – Rick Bradbury	<u>Rieth-Riley</u> – Pete Capon	ACPA – <u>Leif Wathne</u> , Gary Mitchell
Michigan DOT – <u>John Staton</u>	Cedar Valley – Craig Hughes	NRMCA/RMCREF – Colin Lobo
Ohio DOT – Dan Miller	AJAX – Hugh Luedtke	PCA – Paul Tennis
Iowa DOT – Todd Hanson	<u>Duit Construction</u> – John Privat	WCPA – Kevin McMullen
Minnesota DOT – Maria <u>Masten</u>		FHWA
Illinois Tollway – Cindy Williams		Mike Praul, Bob Conway, Sam Tyson, Dennis Dvorak, Jeff Withee

Quality Culture?



Conclusion



It's time to bring specifications and practices in line with today's materials and mixtures, testing technologies, construction advances, and in-service performance and durability demands along with the values and priorities of today's society.

Questions?



Image Pixabay

Contact info:
Michael.Praul@dot.gov

PEM Background



U.S. Department of Transportation
Federal Highway Administration



National Concrete Pavement
Technology Center



A Little History

March 11, 2022 - PEM Workshop

- Consensus to investigate optimized aggregate gradation mixtures
 - Industry support
- QC requirements
- Reduce shrinkage
- Consider maturity
- Plan to sample & demonstrate PEM tests



The Past vs. Today

The Past

- Cement, rocks, water
- Air, Slump, Strength



Today & Future

- Cement, SCMs, different sized aggregates, water, admixtures
- How does it behave? How do we test?



The Past vs. Today

The Past

- Curing was different
- Cement was coarse



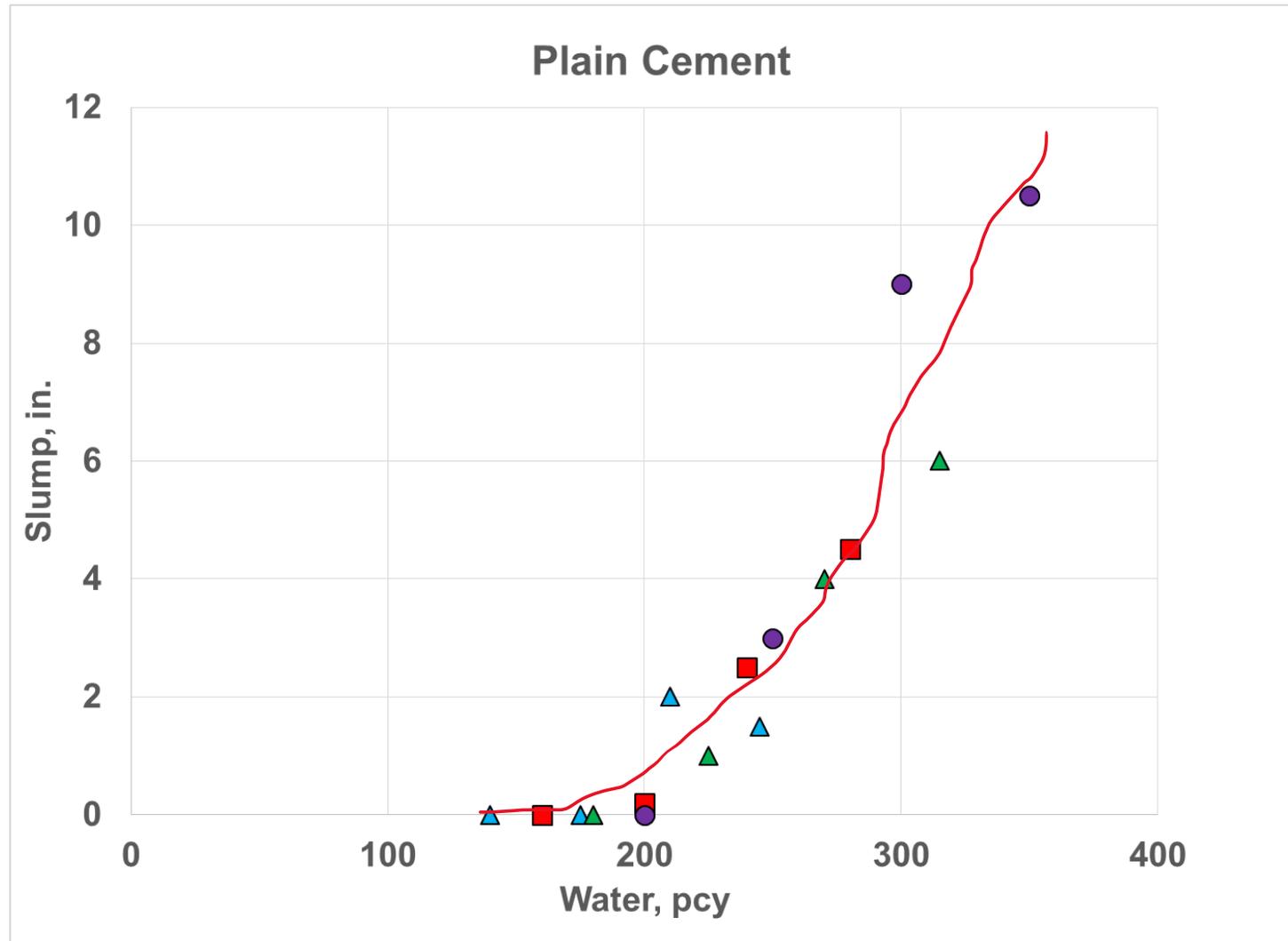
Today & Future

- Curing still critical
- Cement is different
- What do we put on our pavements?



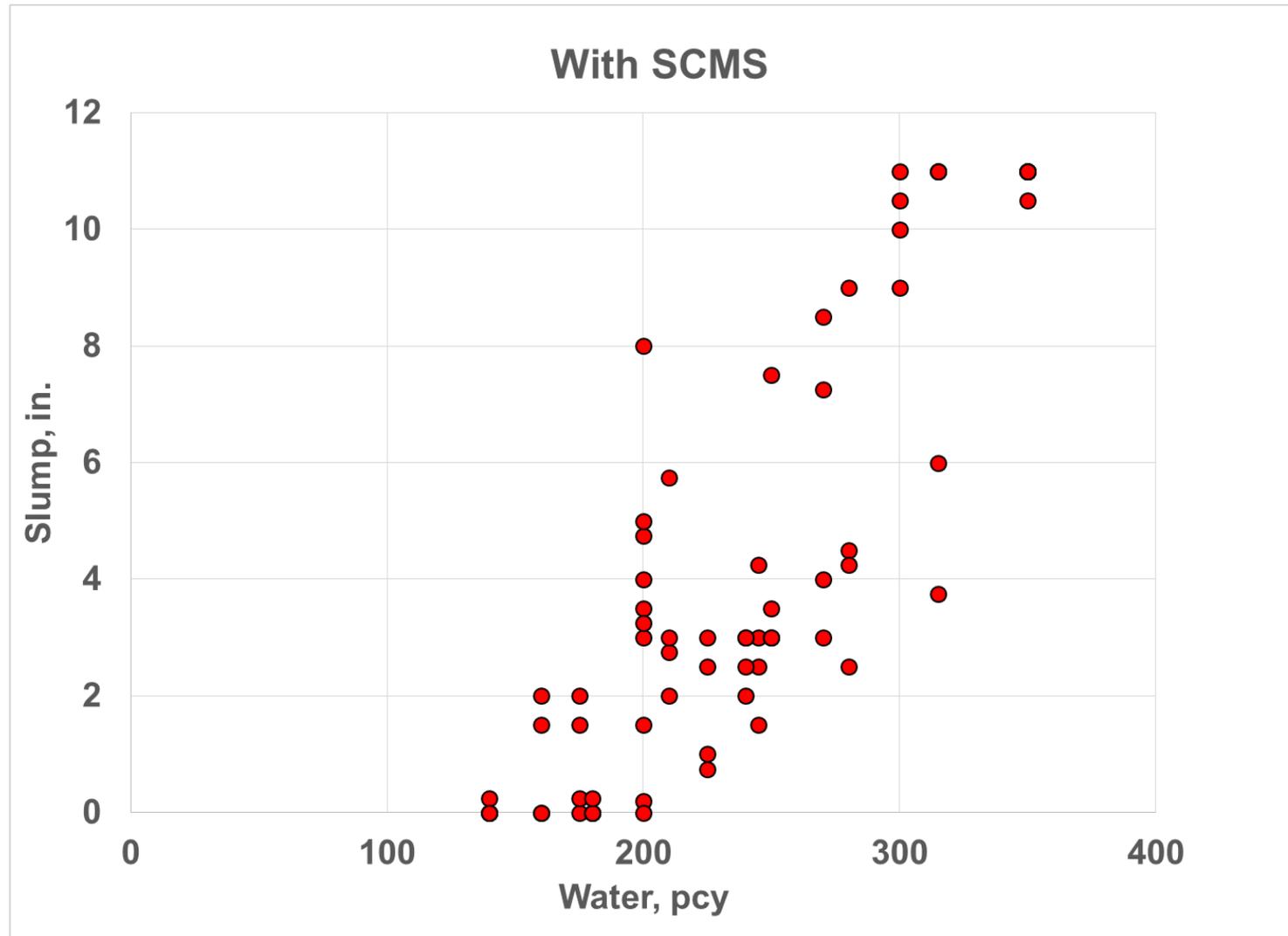
Workability – The Past

Simple relationship between slump and water content



Workability - Now

But then we have today's mixtures, not so linear



Lessons Learned - Workability

- Poor Workability
- Excessive vibration (trails)
- Aggregate segregation
- High mortar area
- Low Air <3% at vibrator
- Poor Spacing Factors > 0.01 in.
- Led to optimized aggregate gradation



Iowa DOT

The Past vs. Today

The Past

- Strength was important
- Slump was important



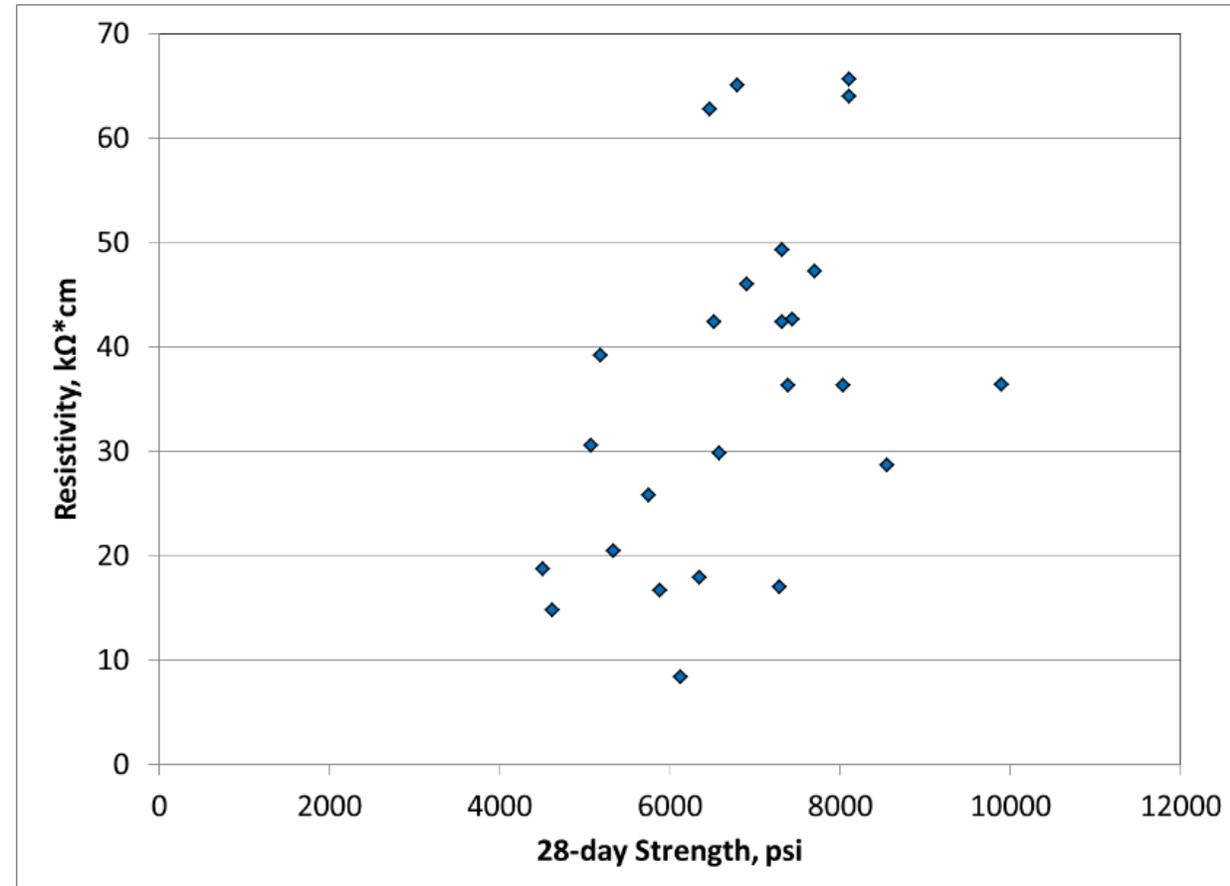
Today & Future

- Strength still important
- Slump is a consistency check



Misconceptions

- More cement = more strength
- Strength is everything
- Slump indicates quality



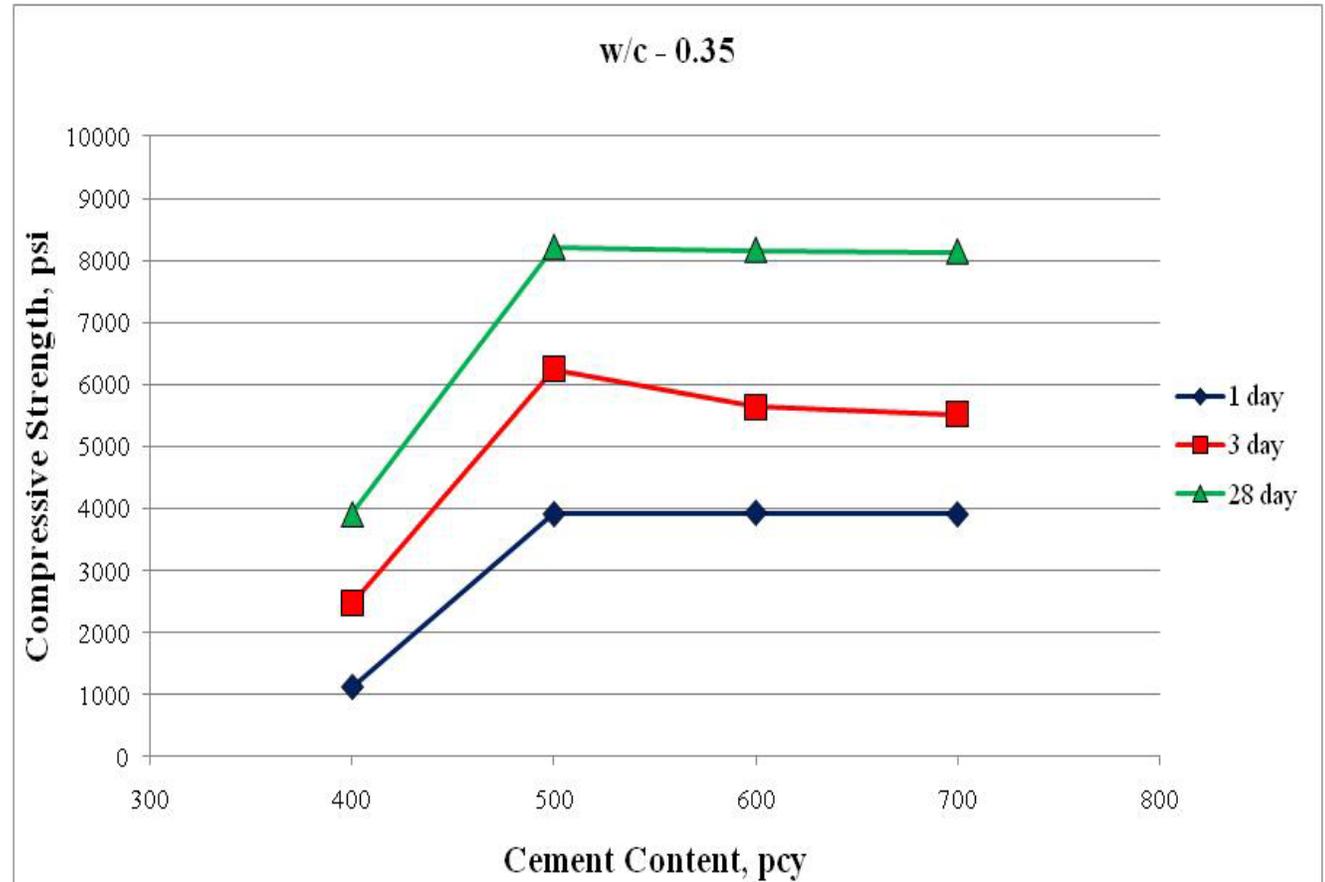
Strength

Significance

- Enough to carry loads...
- No longer a good correlation with “quality”

Factors

- w/cm
- Degree of hydration (curing)
- Air



Air Content and
Permeability of
PCC Pavements:
1909 to 2006

Final Report
For
MLR-05-02

March 2007

Highway Division



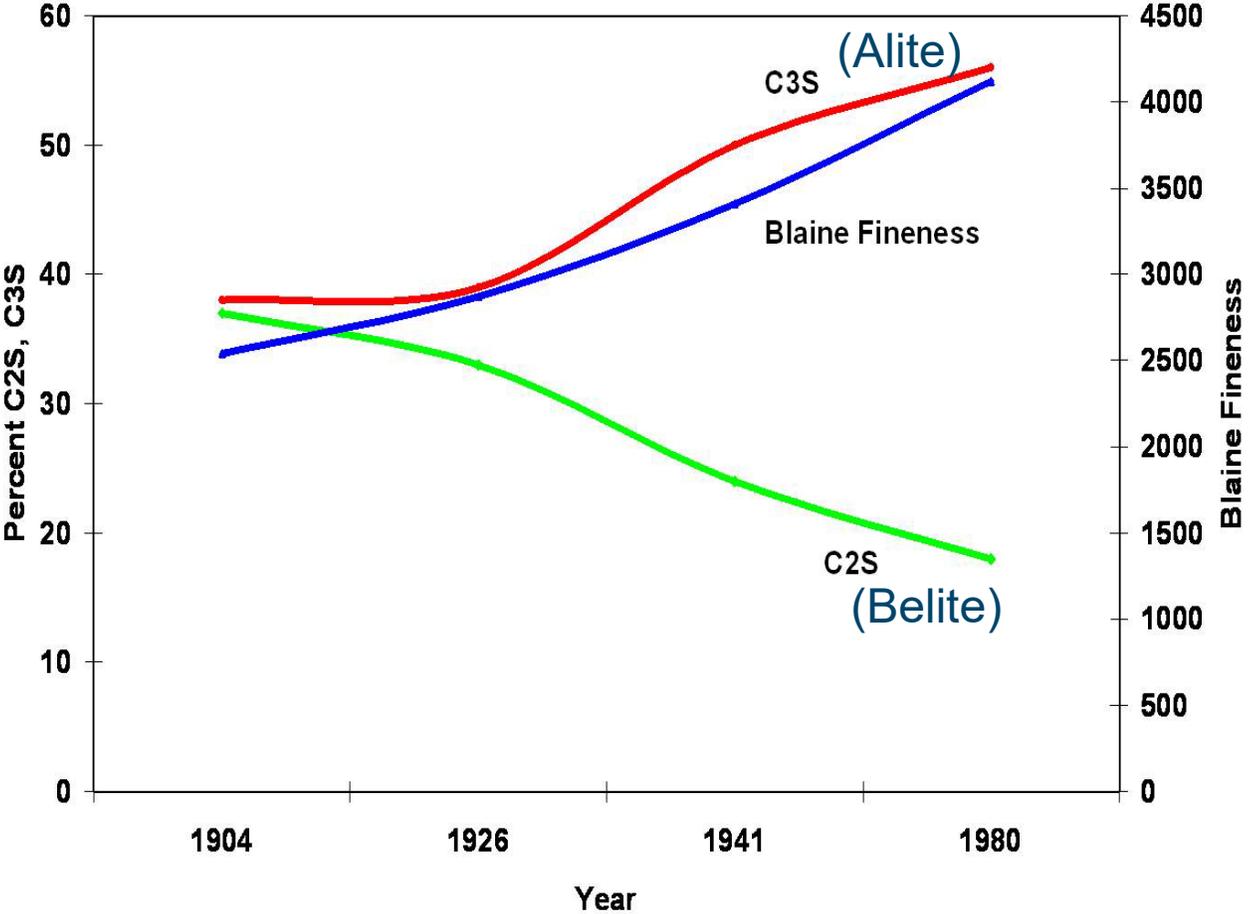
What has Changed?

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

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

What has Changed? Cement Chemistry



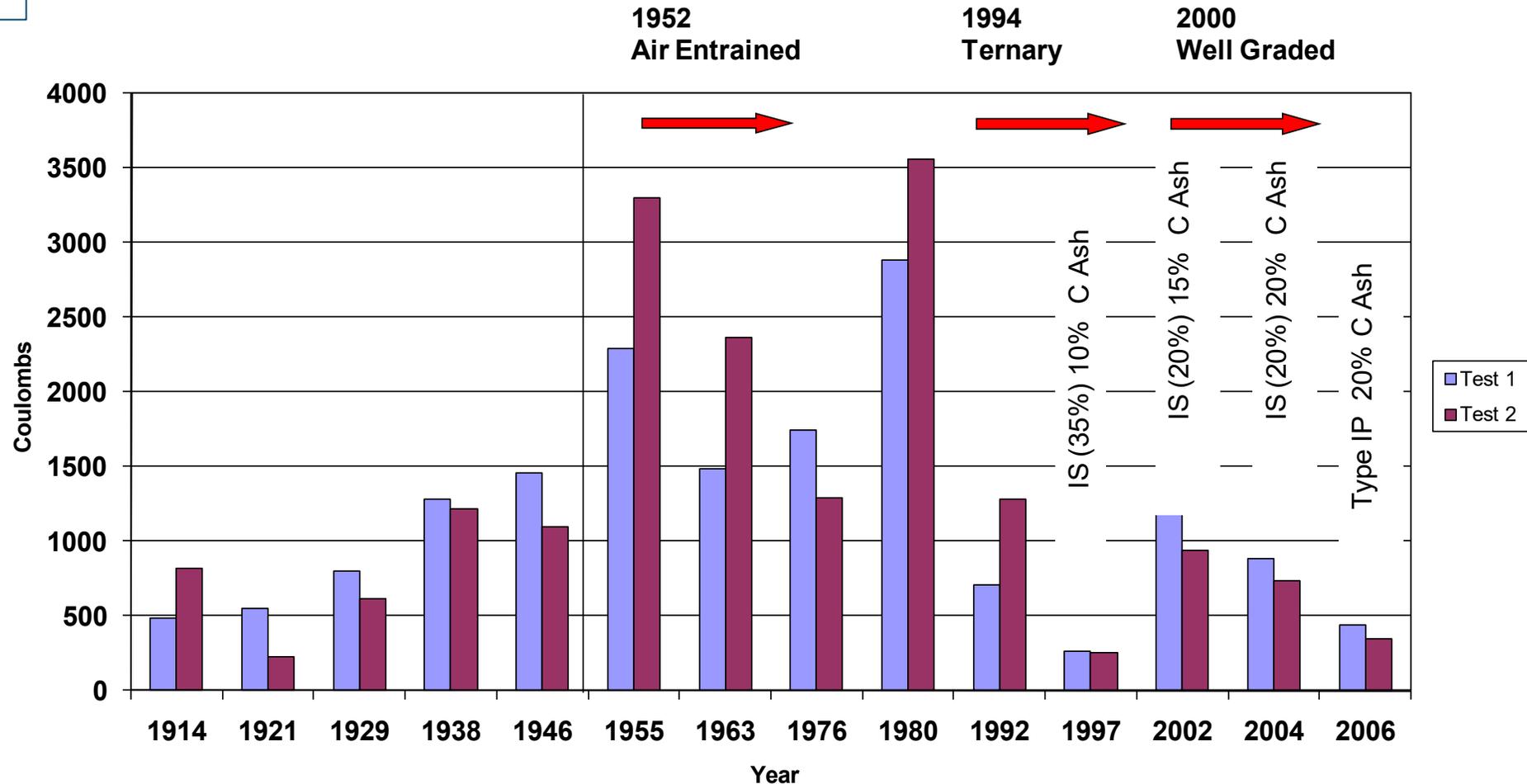
Cement chemistry has changed over the years, but we have the same or better results

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

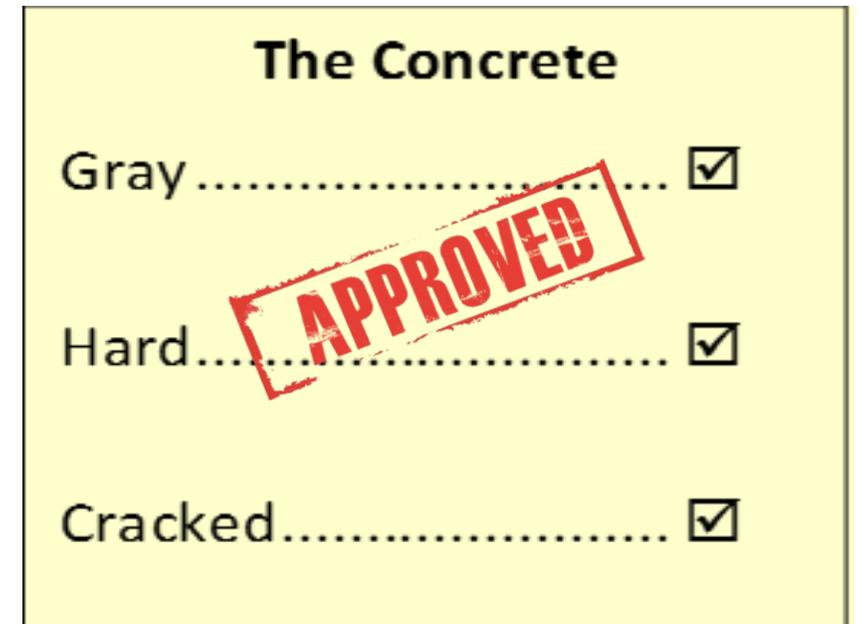
Results of Iowa DOT (MLR-05-02) Report

- Very low air content prior to 1952
- Air contents increased as specification limits increased
- Permeability of older pavements is very low
- Permeability of pavements utilizing a Shilstone type gradation and SCMs (slag and fly ash), can reduce indicated permeability to the level of older pavements

“The Reality Is...Change is needed”

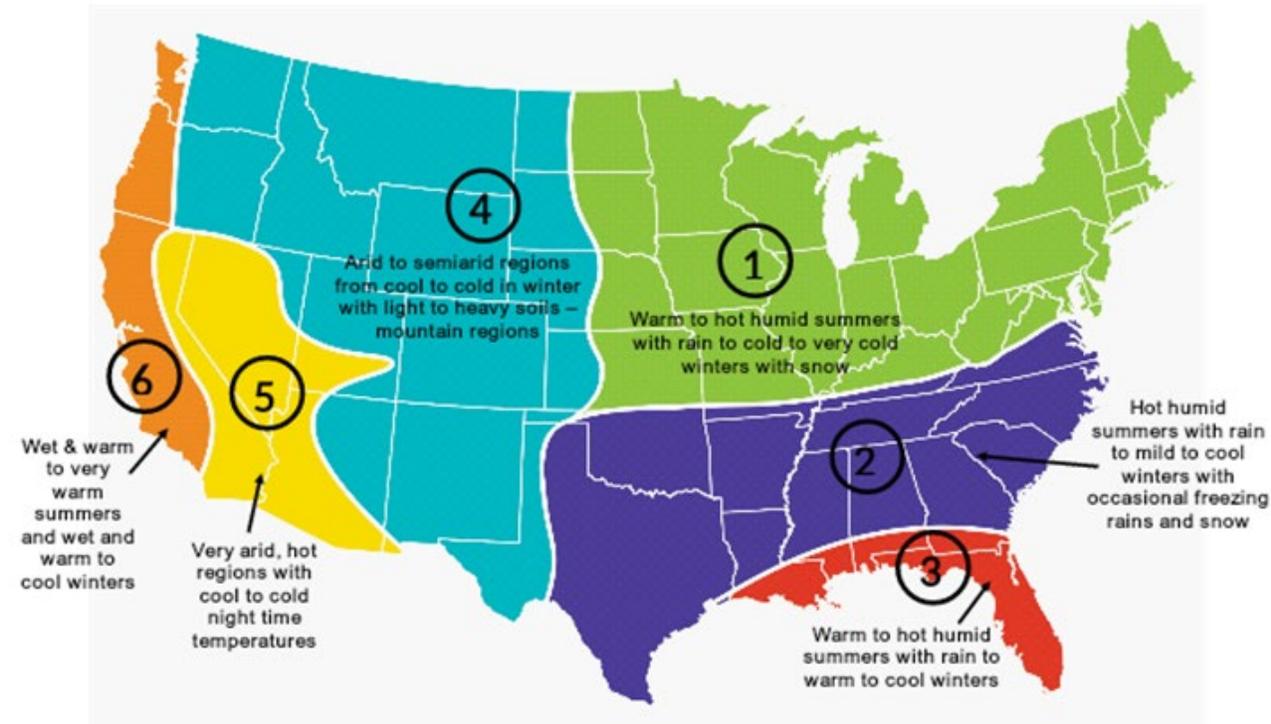
Change is hard:

- Tradition!
- Changing work force
- Understanding of the material
- Understanding test limitations
- Balancing risk



Risk

- Prescriptive – owner takes all the risk
- Performance – risk is shared, innovation is encouraged
 - Appropriate tests
 - Appropriate limits



What is **Good** concrete?

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



A Better Approach

- Transport properties (everywhere)
- Aggregate stability (everywhere)
- Strength (everywhere)
- Cold weather resistance (cold locations)
- Shrinkage (dry locations)

- Workability (everywhere)

6 Properties of PEM



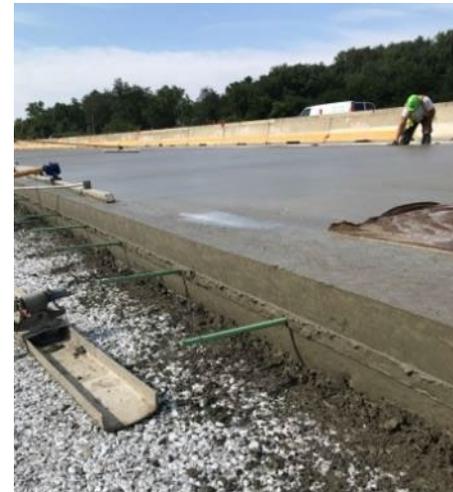
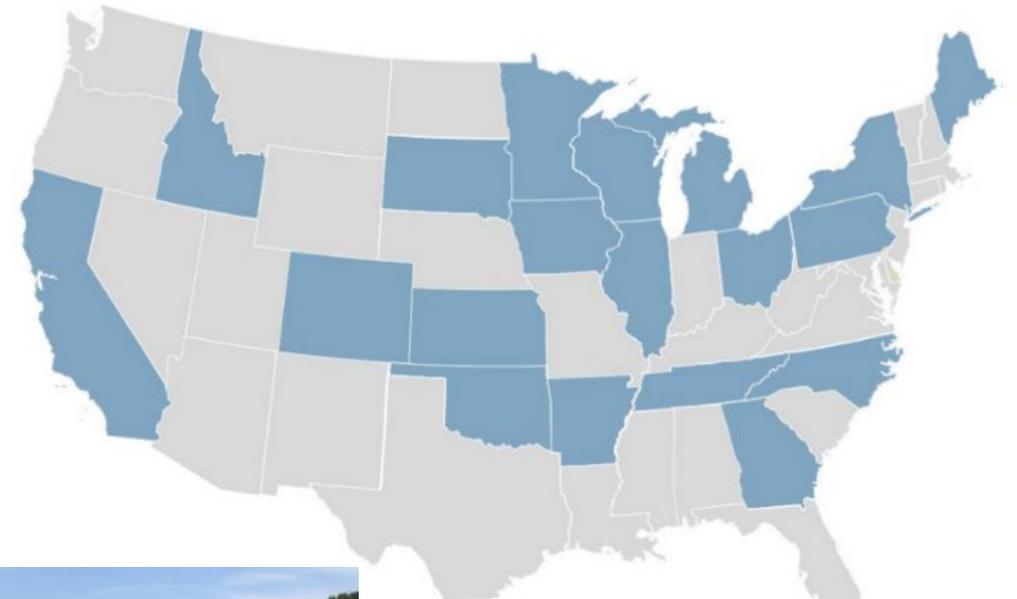
A Better Approach

- Require the things that matter
- Measure them at the right time
 - Prequalification
 - Process control
 - Acceptance
- A buffet of approaches
 - Prescriptive: w/cm, paste volume
 - Performance: Permeability



Performance Engineered Mixtures (PEM)

- Performance-Engineered Mixtures TPF-5(368) 2017-2022
- 19 states
- Assist states in adoption of test methods that will help deliver concrete durability – long term performance



PEM Research Team

FHWA - Gina Ahlstrom, P.E., Mike Praul, P.E.



Researchers – Dr. Jason Weiss, Dr. Tyler Ley, P.E.



Consultants – Dr. Tom VanDam, P.E., Cecil Jones, P.E.



Diversified
Engineering
Services, Inc.

CP Tech – Dr. Peter Taylor, P.E., Gordon Smith, P.E.,
Jerod Gross, P.E.

National Concrete Pavement
Technology Center



Performance Engineered Mixtures (PEM) - Scope

- Implementing what is known
 - Support SHAs by trying PEM
- Performance monitoring & specification refinement
 - Collecting & analyzing data
 - Review state specs
- Measuring & relating early-age properties to performance
 - New PEM tests

PEM Shadow Projects

← TIP Project I-3802B

Project
TIP Project I-3802B

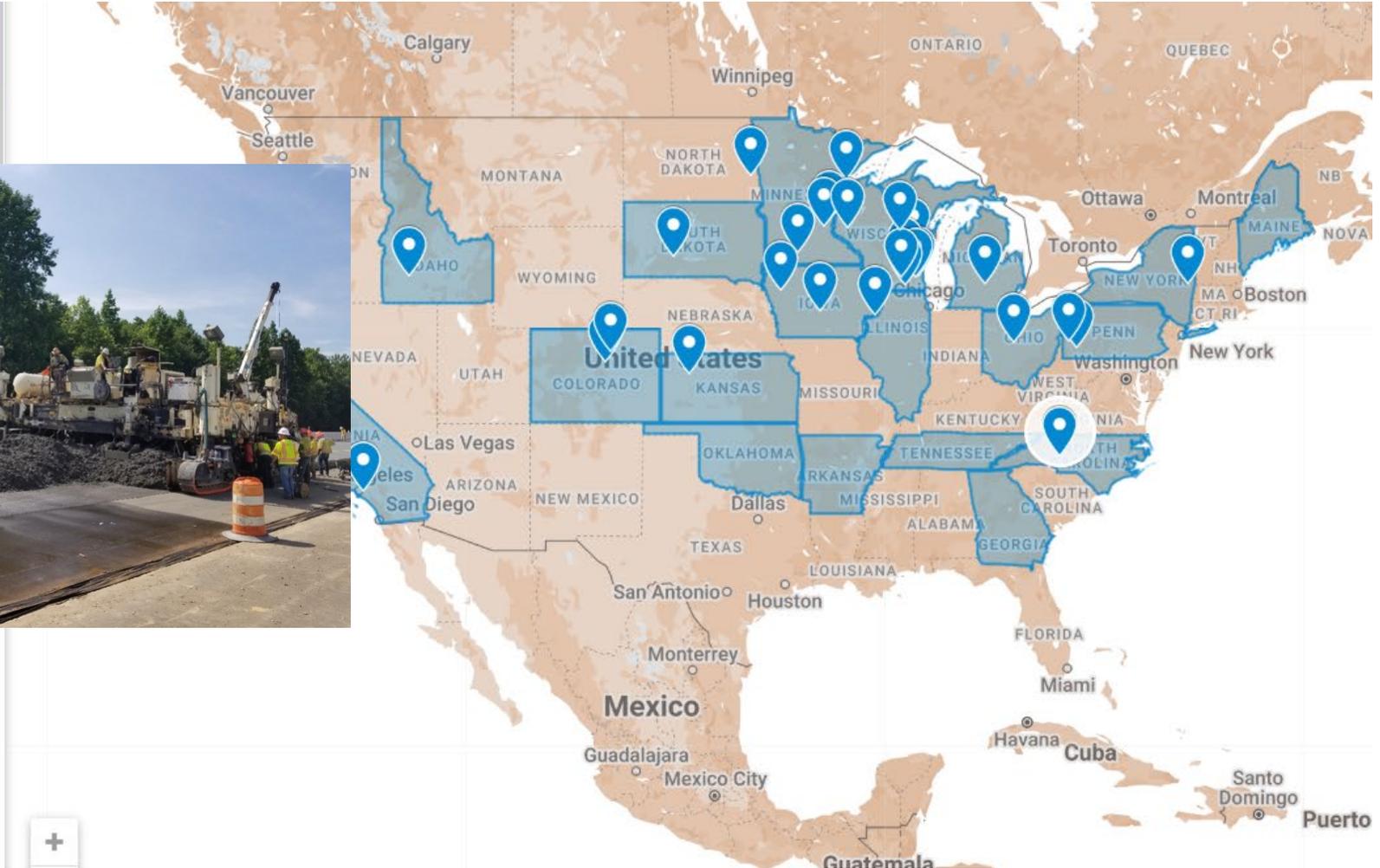
Dates
2018/2019

Location
I-85 in Rowan County, North Carolina

MCTC Present
Yes

CP Tech Present
Yes

State DOT Report
<https://intrans.iastate.edu/app/uploads/sites/7/2020/05/Post-Construction-Report-for-North-Carolina-DOT-Demonstration-Project-05-14-2020.pdf>



www.cptechcenter.org/pem

PEM State Reports

- Kansas MCTC
- Pennsylvania DOT
- New York DOT
- North Carolina MCTC & DOT
- Minnesota MCTC & DOT
- South Dakota DOT
- Iowa MCTC & DOT
- Wisconsin DOT

Shadow Project Reports

Kansas

- [Kansas MCTC Report \(August 2019\)](#)

Pennsylvania

- [Pennsylvania DOT PEM Demonstration Project Report \(November 2022\)](#)

New York

- [New York DOT PEM Demonstration Project Report \(August 2020\)](#)

North Carolina

- [North Carolina MCTC Report \(September 2020\)](#)
- [North Carolina DOT PEM Demonstration Project Report \(May 2020\)](#)

Minnesota

- [Minnesota DOT PEM Demonstration Project Report \(April 2021\)](#)
- [Minnesota DOT PEM Demonstration Project Report \(April 2020\)](#)
- [Minnesota MCTC Report \(July 2018\)](#)

South Dakota

- [South Dakota DOT PEM Demonstration Project Report \(August 2019\)](#)

Iowa

- [Iowa DOT PEM Demonstration Project Report \(June 2019\)](#)
- [Iowa MCTC Report \(July 2018\)](#)

Wisconsin

- [Wisconsin DOT PEM Demonstration Project Report \(July 2022\)](#)

www.cptechcenter.org/pem

PEM Accomplishments

- AASHTO R101
- PEM exposure
- Training
- DOT specification improvements



Standard Practice for

**Developing Performance
Engineered Concrete Pavement
Mixtures**

AASHTO Designation: R 101-22¹

Adopted: 2022

Technical Subcommittee: 3c, Hardened Concrete

AASHTO

American Association of State Highway and Transportation Officials
555 12th Street NW, Suite 1000
Washington, DC 20004

AASHTO R 101 Philosophy and Goals

- Allows an agency to specify performance characteristics rather than prescriptive
- Respects agency traditions and knowledge
 - Keep existing requirements that make sense based on local knowledge and experience
- Not a Specification – A tool to help agencies develop a specification that fits their needs

**Standard Practice for
Developing Performance
Engineered Concrete Pavement
Mixtures**

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Washington, DC 20004

AASHTO R 101

Standard practice addresses performance and prescriptive approaches

- allows agencies to make choices

Number	Title
T 358-22	Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration
T 363-22	Evaluating Stress Development and Cracking Potential due to Restrained Volume Change Using a Dual Ring Test
T 365-20	Quantifying Calcium Oxychloride Amounts in Cement Pastes Exposed to Deicing Salts
T 395-22	Characterization of the Air-Void System of Freshly Mixed Concrete by the Sequential Pressure Method – Previously TP 118
T 396-22	Box Test in Slip Form Paving of Fresh Portland Cement Concrete – Previously TP 137
T 402	Electrical Resistivity of a Concrete Cylinder Tested in a Uniaxial Resistance Test
T 403	Vibrating Kelly Ball (VKelly) Penetration in Fresh Portland Cement Concrete
TP 135-22	Total Pore Volume in Hardened Concrete Using Vacuum Saturation
TP 136-22	Degree of Saturation of Hydraulic-Cement Concrete

Publications referenced

AASHTO R101 - Table 2

Table 2—Specification Worksheet for Mixture Proportioning

Section	Property	Specified Test	Specified Value	Mixture Qualification	Acceptance	Selection Details	Special Notes
6.3 Concrete Strength							
6.3.1	Flexural Strength	T 97	4.1 MPa	600 psi	Yes	Yes	Choose either or both
6.3.2	Compressive Strength	T 22M/T 22	27.5 MPa	4000 psi	Yes	Yes	—
6.4 Reducing Unwanted Slab Warping and Cracking Due to Shrinkage (if cracking is a concern)							
6.4.1.1	Volume of Paste	—	≤25%	—	Yes	No	Choose only one
6.4.1.2	Unrestrained Volume Change	T 160	420 με	At 28 days	Yes	No	—
6.4.2.2	Unrestrained Volume Change	T 160	360, 420, 480 με	At 91 days	Yes	No	—
6.4.2.1.1	Unrestrained Volume Change	T 334	No cracking	At 180 days	Yes	No	—
6.4.2.1.2	Restrained Volume Change	T 363	<60% f _r	At 7 days	Yes	No	—
6.5 Durability of Hydrated Cement Paste for Freeze–Thaw Durability							
6.5.1.1	Water to Cementitious Ratio	—	0.45	—	Yes	Yes	^a
6.5.1.2	Fresh Air Content	T 152, T 196, TP 118	5 to 8%	—	Yes	Yes	Choose only one
6.5.1.3	Fresh Air Content/SAM	T 152, T 196, TP 118	≥4%; ≤0.20	—	Yes	Yes	—
6.5.2.1	Time of Critical Saturation	ASTM C1585	30	yr	Yes	No	^{a, b}
Variation controlled with mixture proportion observation or <i>F</i> factor and porosity measures							
6.5.3.1	Deicing Salt Damage	—	30%	SCM	Yes	Yes	Choose only one if concrete will be exposed to deicing salts
6.5.3.2	Deicing Salt Damage	M 224	—	Topical treatment	Yes	Yes	Are calcium or magnesium chloride used; use specified sealers
6.5.4.1	Calcium Oxychloride Limit	T 365	<0.15 g CaOXY/100 g paste	—	Yes	No	Are calcium or magnesium chloride used

Expansion (mortar bar)

Single Ring Test
Dual Ring Test

AASHTO R101 - Table 2

6.6 Transport Properties								
6.6.1.1	Water to Cementitious Ratio	—	≤ 0.45 or ≤ 0.50	91 days ^c	Yes	Yes	Choose only one	The required maximum water to cementitious ratio is selected based on freeze–thaw conditions
6.6.1.2	Formation Factor	Table 1	≥ 500 or ≥ 1000	91 days ^c	Yes	Yes		
6.6.2.1	Ionic Penetration, <i>F</i> Factor		25 mm at 30 yr	91 days ^c	Yes, F	Through p		Based on freeze–thaw conditions; other criteria could be selected
6.7 Aggregate Stability								
6.7.1	D Cracking	ASTM C1646, T 161	—	—	Yes	No		Procedure A
6.7.2	Alkali Aggregate Reactivity	R 80	—	—	Yes	No		—
6.8 Workability								
6.8.1	Box Test	TP 137	<6.25 mm, <30% surface void			No		—
6.8.2	Modified VKelly Test	TP 129	15–30 mm/root s			No		—

Notes:

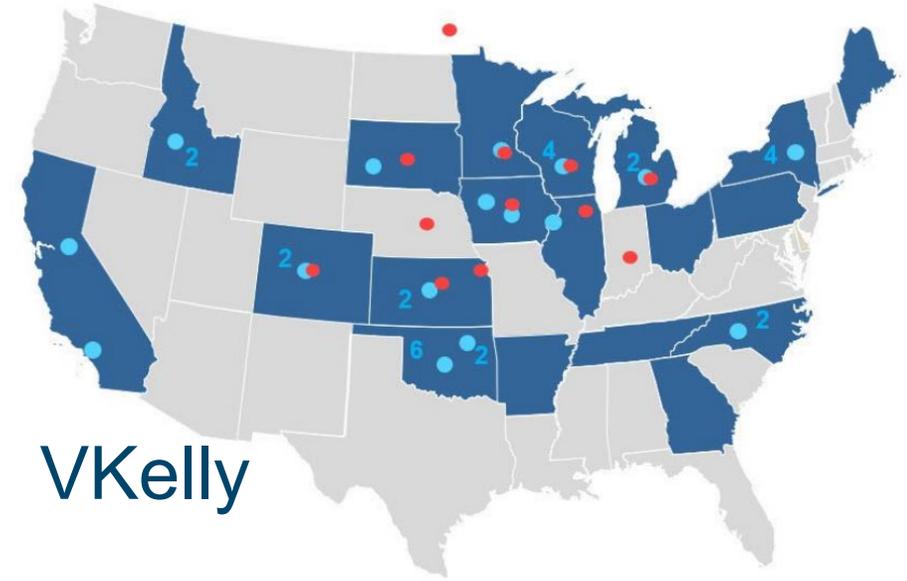
^a Choose either Section 6.5.1.1 or 6.5.2.1.

^b Choose either Section 6.5.1.2, 6.5.1.3, or 6.5.2.1.

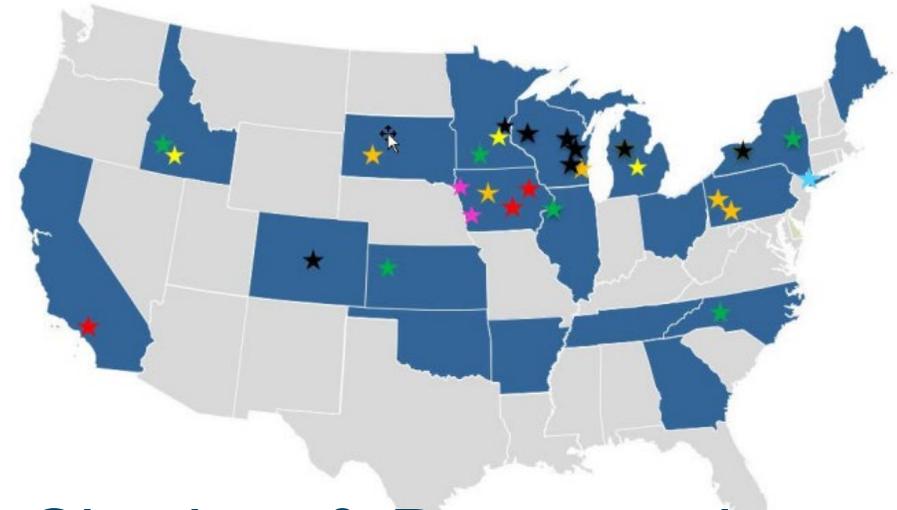
^c Other ages can be used if desired however for SCM sufficient time should be allowed for the pozzolanic reaction.

PEM Accomplishments

- PEM exposure
 - 82 Workshops
 - Open houses/Demonstrations
- Training



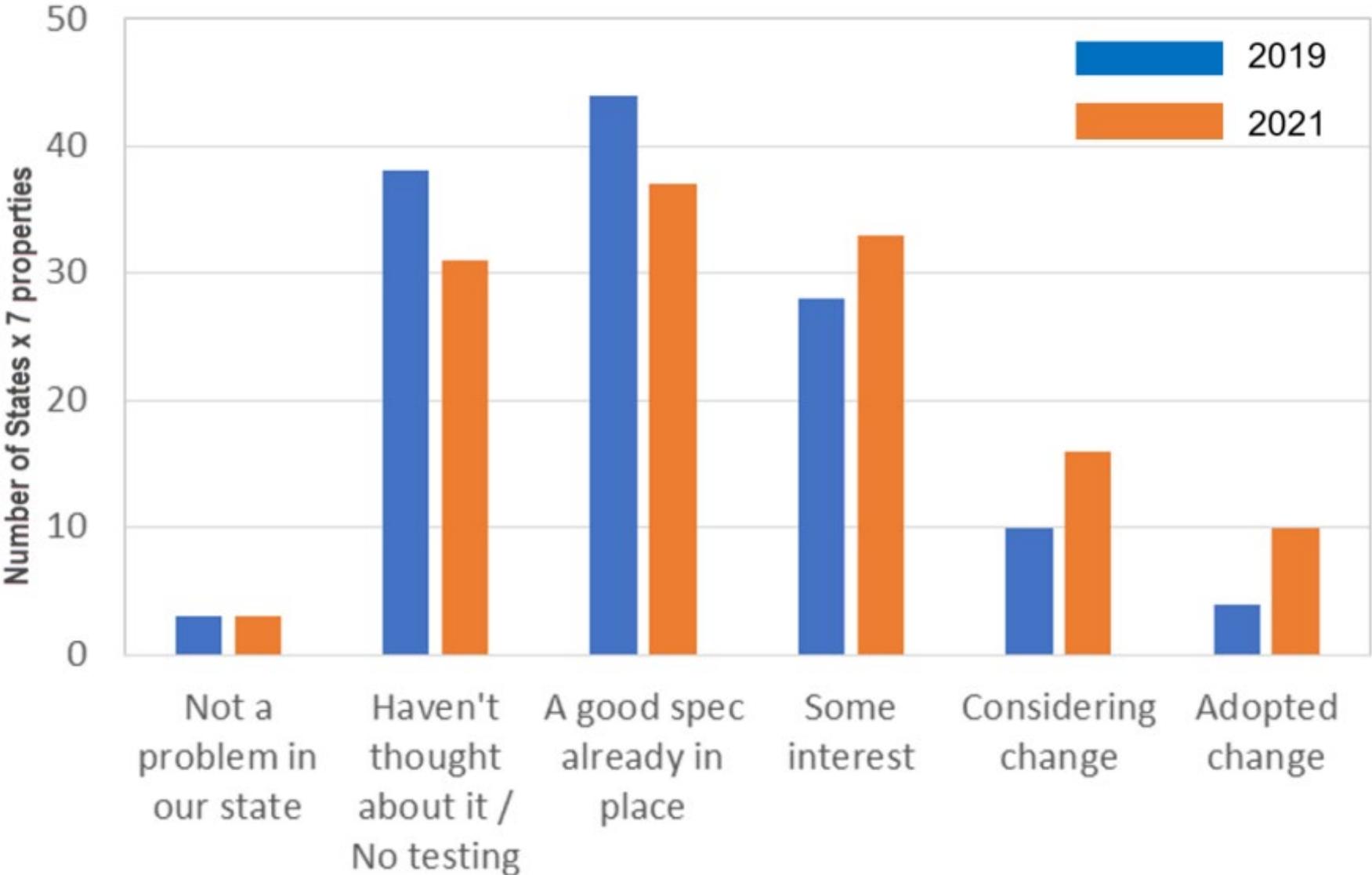
VKelly



Shadow & Demo projects

PEM Accomplishments

TPF member states specification improvements



PEM TPF-5(368) Summary

- **Each state agency is unique in the way it specifies concrete pavements;**
 - **Table 2** in AASHTO R 101 gives agencies choices on the selection of PEM properties and standard test methods in the areas of strength, shrinkage, freeze-thaw durability, transport, aggregate stability, and workability.
- **Successful PEM shadow projects were the result of coordination and communication between state agencies and industry.**
- **New test methods require training and practice** following standard methods to achieve desired results.
- **Contractors involved in shadow projects were supportive** and continue to use the tools provided.
- **Sustainability is improved** when utilizing PEM approaches.
- **Additional technology transfer is needed** for state and local agencies, industry, and the private sector to increase their exposure to PEM and its benefits.
- **The goals of the pooled fund project were achieved including implementation, education and training**, adjustment of the specification values, and continued development of tools to relate early-age concrete properties to performance.

PEM Resources

Performance-Engineered Concrete Paving Mixtures

Final Report
December 2022

National Concrete Pavement
Technology Center



IOWA STATE UNIVERSITY
Institute for Transportation

Sponsored by
Iowa Department of Transportation
(InTrans Project 17-629)
Federal Highway Administration
Transportation Pooled Fund TPF-5(368)



FALL 2023

PROJECT TITLE
PEM Evolution: Then and Now

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TPF-5(437)

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national-concrete-consortium



"Moving Advancements into Practice"

MAP Brief Fall 2023

Best practices and promising technologies that can be used now to enhance concrete paving

PEM Evolution: Then and Now

Introduction

Performance-Engineered Mixtures (PEM) is an initiative that began several years ago with discussions between the Federal Highway Administration (FHWA), American Concrete Pavement Association (ACPA), and the National Concrete Pavement Technology Center (CP Tech Center). The goal was to advance concrete pavement mixtures toward performance-based specifications with the main challenge of defining effective methods of measuring the performance characteristics of concrete that directly relate to pavement durability and structural longevity. Concluding in 2022, TPF-5(368) focused on materials and mixtures, while, currently, TPF-5(517) focuses on what happens to the mixture after it is delivered to the site. A copy of the final report *Performance-Engineered Concrete Paving Mixtures* can be accessed here: intrans.iastate.edu/app/uploads/2023/04/performance-engineered_concrete_paving_mixtures_w_cvr.pdf.

This document provides the background of PEM; outlines the accomplishments, key findings, and implementation of TPF-5(368); and provides a look at what is current with PEM regarding construction practices (Figure 1).

Problem Statement and Project Justification

State transportation agencies and concrete pavement professionals have traditionally accepted concrete based on measurements like strength, slump, and air content. These measurements have had very limited correlation to future performance. However, recent developments in concrete testing technologies have yielded methods that are better predictors of long-term performance.



Todd Hanson, Iowa DOT, used with permission

Figure 1. Paving on US 20 using PEM test procedures

Questions?



BREAK





Performance Engineered Mixture Experiences



*Georgia MCTC & PEM Workshop
February 24, 2025*

Michael F. Praul, PE

Senior Concrete Engineer

FHWA, Office of Infrastructure



U.S. Department of Transportation
Federal Highway Administration

Moving to PEM

Evolution of Concrete Testing

Concrete

Slump Cone



1922
ASTM C143

Pressure Meter



1949
ASTM C231

Rapid Chloride Penetrability Test



1981
FHWA/PCA

Cars



Image Pixabay



1920

1940

1960

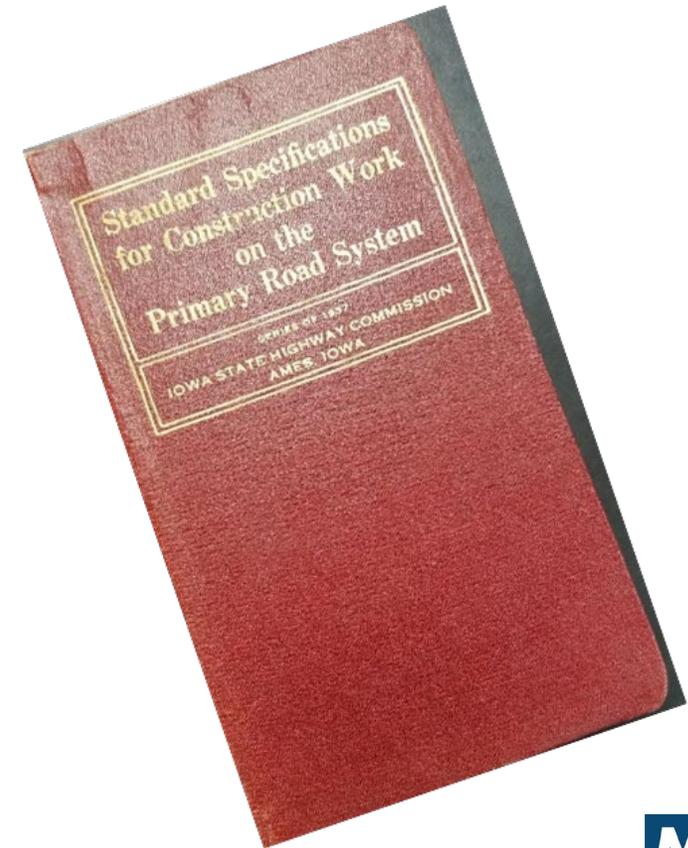
1980

2000

Current Specifications

We get what we are willing to accept...strong concrete, not durable concrete.

- Strength
 - No correlation to durability
- Slump
 - No correlation to durability
 - Do not assess quality
- Total air content
 - Poor correlation to durability
 - Does not assess air system



Performance Engineered Mixture Concepts



- Get beyond slump, strength, and total air content as determinants of concrete quality
- Incorporate tests that correlate to service life durability
- Appropriately apply those tests in agency acceptance and contractor quality control programs
- Develop specifications and practices to leverage quality control
- Remove prescriptive restraints from specifications
 - Minimum cement content
 - Single aggregate gradation
 - Slump

Better Assessment of Quality?

Option 1

- QC Info: None
- Strength
- Slump
- Total Air

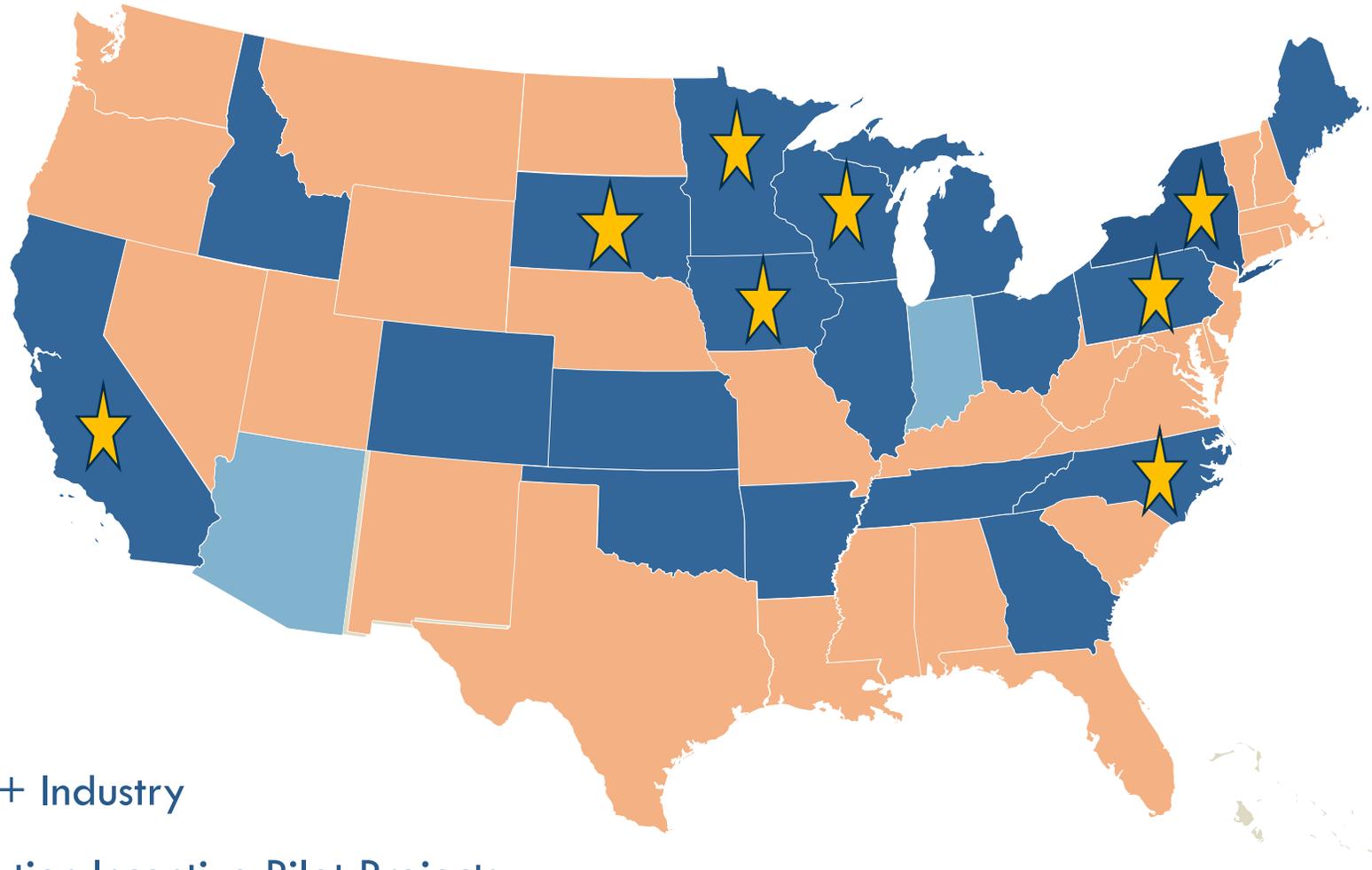


Option 2

- QC Info:
 - Unit weight
 - Calorimetry
 - Water content (Phoenix)
- Resistivity
- Strength
- SAM number*
- Box/Float Test*



PEM Pooled Fund and Incentive Projects



19 States + FHWA + Industry

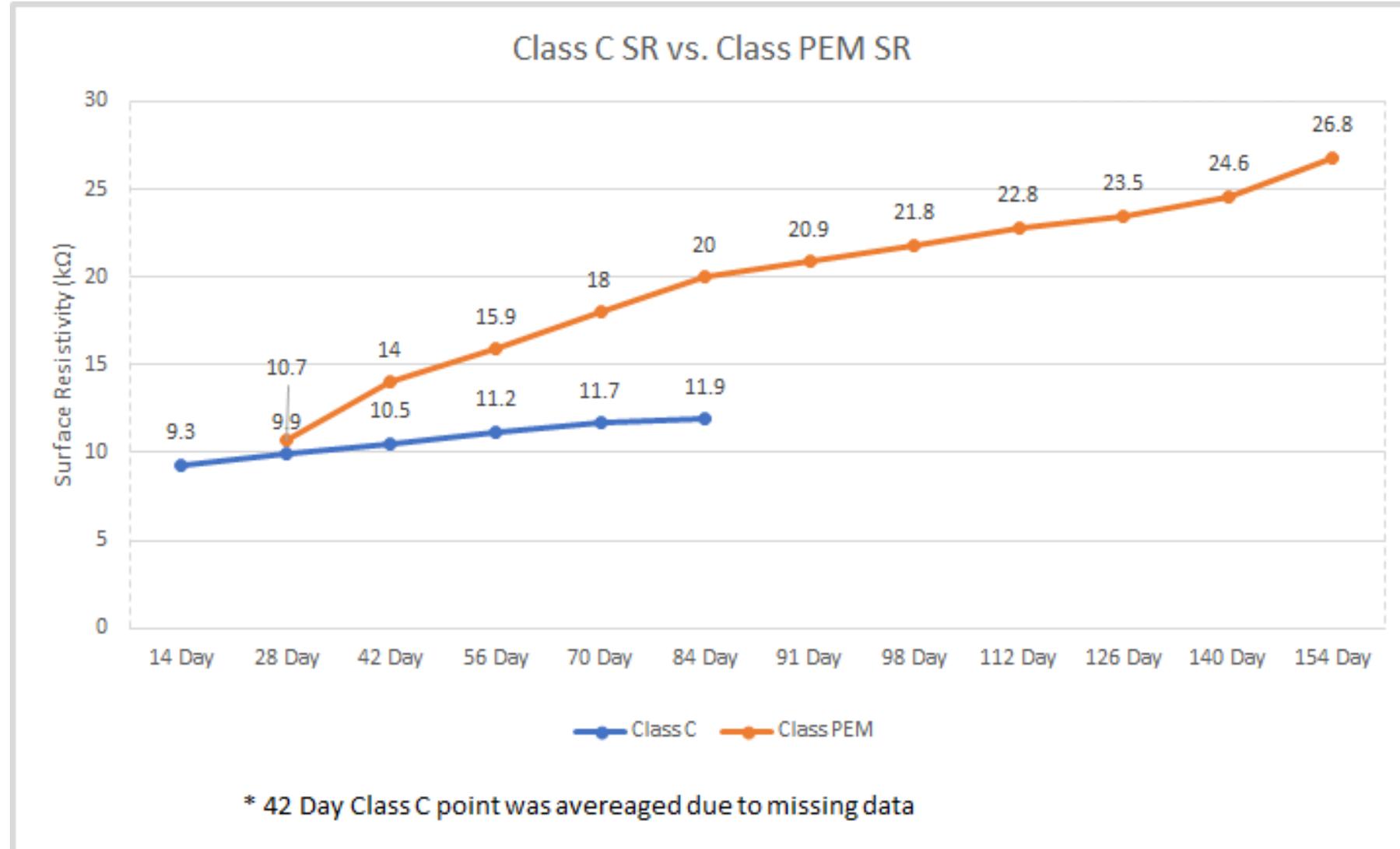
★ PEM Implementation Incentive Pilot Projects

New York Highlights



- PEM approach typically is beneficial to State and industry
- PEM mix tested better in all tests vs. Class C
- 2nd supplier was reluctant to participate
 - Determined QC requirements were not much more than they currently do
 - Mix looked and placed better than Class C
- Needs
 - Training in new tests
 - Understanding roles and responsibilities in a performance specification (including QC monitoring)
 - Consider 56-day testing for resistivity
- 2023/24: Expanding to meet sustainability goals/requirements

New York Resistivity Data Comparison



Iowa Project Highlights



- Box Test: 45#/cy reduction in cement
 - Contractor now using to develop mixes
- Super Air Meter comments
 - Need for technician training
 - Attention to detail for correlation testing
 - Concern with gauge durability
- Surface Resistivity
 - Invaluable information for agency and industry
 - Easy to perform, no changes needed
- Expanded typical QC requirements
- 2020 project use proposed by contractor. Approved!

North Carolina Project Highlights--QC



Successive trial batches with mixture proportions changed to improve consistency.

Image: Fred White, Lane Construction

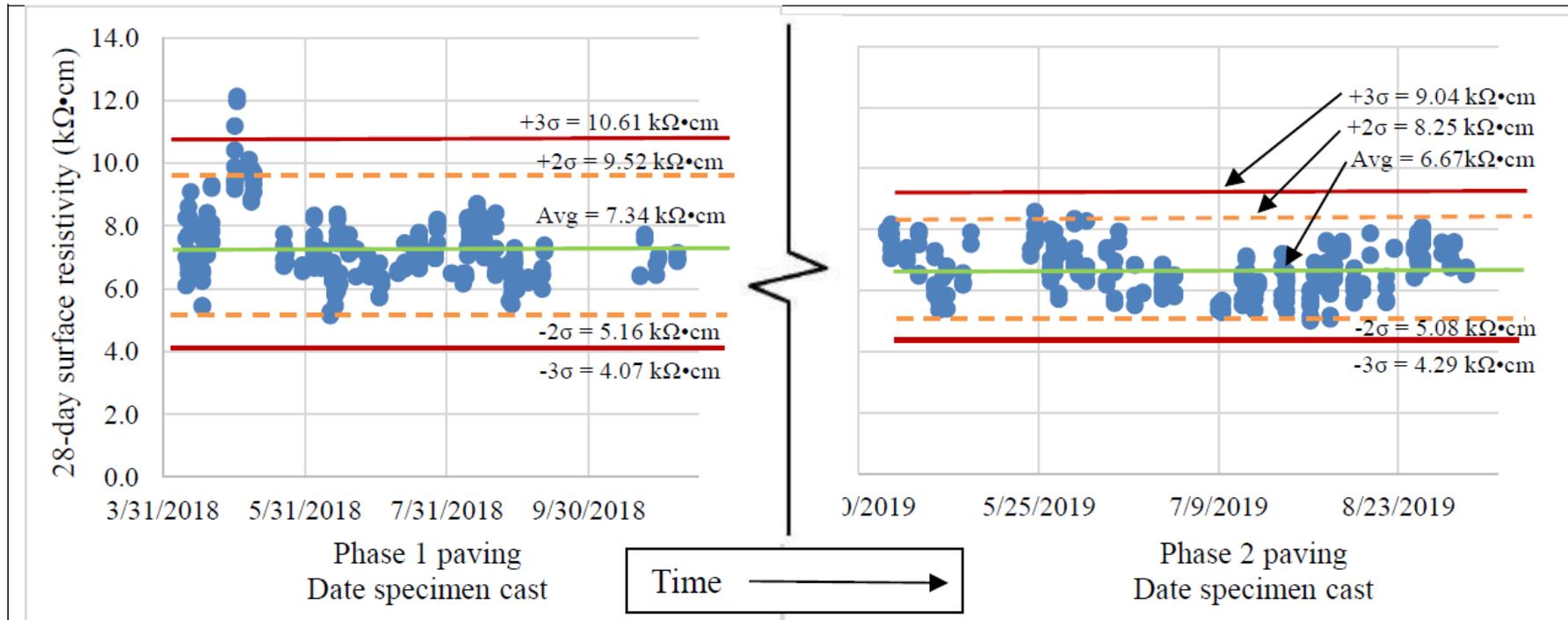


Image: Dr. Tara Cavalline, UNCC

Figure 6: Control chart showing 28-day resistivity for mixture 460SLNS during Phase 1 and Phase 2

North Carolina Project Highlights



- “Valuable experience” (contractor and NCDOT)
- “Due to project schedule, we were unable to apply the PEM criteria during the preliminary mix design phase. However, going forward, we intend to implement PEM guidelines on future PCCP projects.” (contractor)
- “The Department will continue to explore PEM to see how these tests and other AASHTO PP 84 provisions will work with our daily operations.” (NCDOT)
- NCDOT piloted PEM bridge project. Currently developing PEM specification.

Colorado Project Highlights

- MCTC Open House (2018)
- Spec revision (2019)
 - Removed max and min cement content
 - Allows optimized aggregate gradation
 - Box Test in mix design
 - Resistivity
 - Max shrinkage
- Industry supports PEM

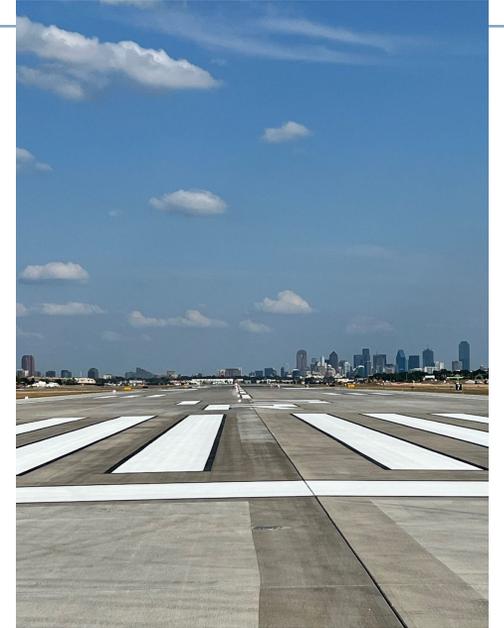


Moving Forward With PEM

- Pennsylvania
- Ohio
- California
- Connecticut
- South Carolina
- Alaska
- Massachusetts
- Others
- FAA-US Department of Defense
 - PEM for runways and airfields
 - Strong focus on consistency



Photo courtesy: Greg Dean, ACPA SE Chapter



Photos courtesy: Harold Honey, FAA

State PEM Experiences

Iowa

- US 20 Holstein, Iowa, Aug. 2018
- Allowed Optimized Aggregate Gradation since late 1990s
- Lowered paste 4% for this project
- Reduced cement by 35 pcy
- Contractor has continued to use PEM Mix



PEM Mix – Box Test



PEM Mix - Shoulders

A Mix	Abs. Vol.	lbs/CY
CEMENT:	0.083	440
FLY ASH:	0.025	110
WATER: w/c=0.474	0.155	261
FINE AGGREGATE (45%):	0.305	1357
COARSE AGGREGATE (55%):	0.372	1680
INTERMEDIATE AGG.:	0	0
AIR:	0.06	0
Paste Content, %	26.3	

PEM Mix	Abs. Vol.	lbs/CY
CEMENT:	0.078	412
FLY ASH:	0.024	103
WATER: w/c=0.40	0.122	206
FINE AGGREGATE (44%):	0.315	1401
COARSE AGGREGATE (44%):	0.315	1422
INTERMEDIATE AGG. (12%):	0.086	387
AIR:	0.06	0
Paste Content, %	22.4	

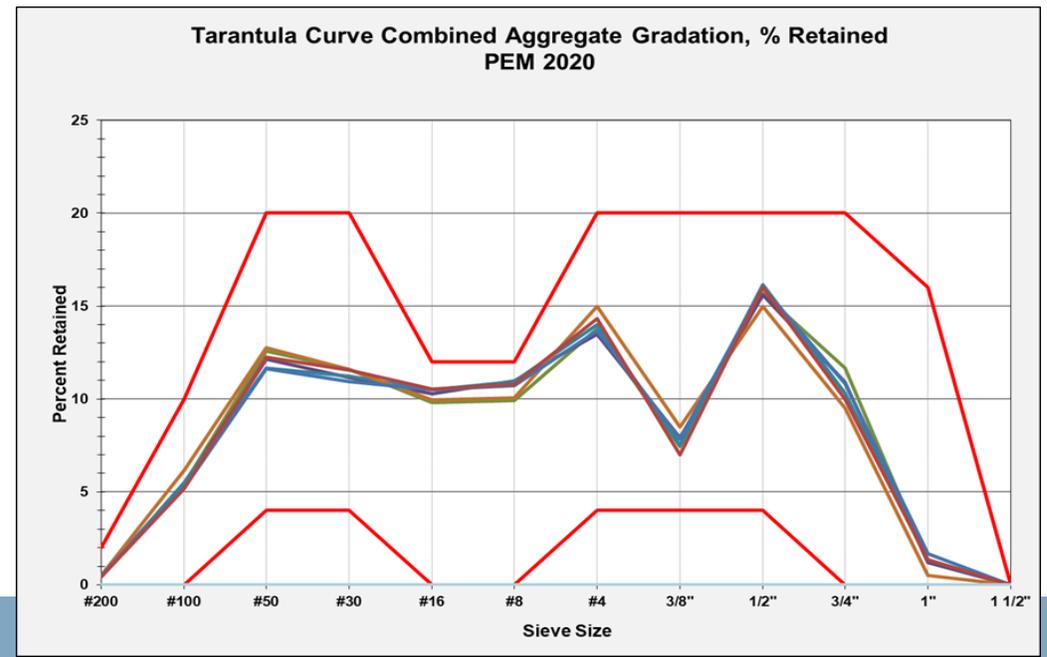
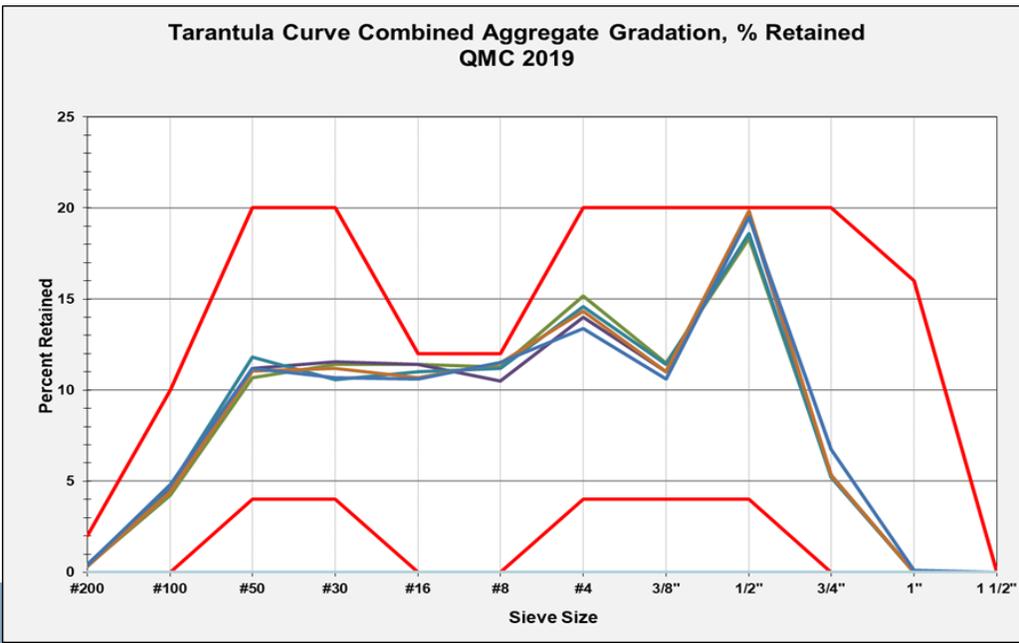
I-29 Harrison QMC vs PEM - Iowa

QMC Mix Design 2019	
Material	Weight (lbs/yd ³)
Ash Grove IP Cement	426
Nebraska City Fly Ash (20%)	107
Weeping Water CA (45%)	1427
N. Valley Cl. V. Aggregate (55%)	1708
Water (basic w/c=0.40) 0.42 max	213

533 lbs

PEM Mix Design 2020	
Material	Weight (lbs/yd ³)
Ash Grove IP Cement	399
Nebraska City Fly Ash (20%)	100
Ft. Calhoun CA (45%)	1441
N. Valley Cl. V. Aggregate (55%)	1752
Water (basic w/c 0.40, 0.42 max.)	200

499 lbs



State PEM Experiences

Michigan

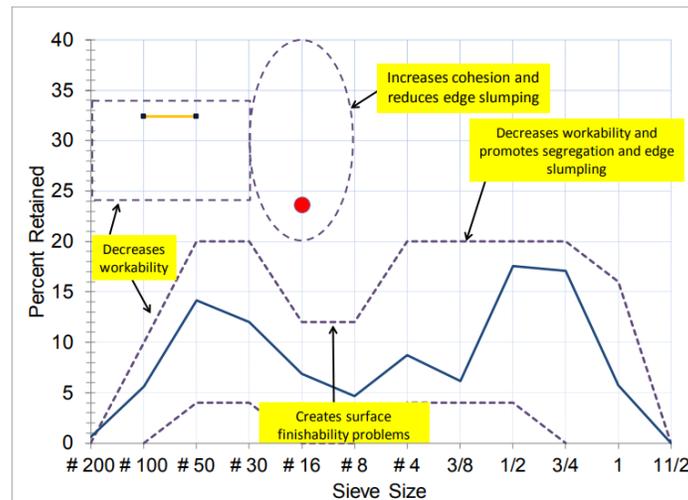
- High performance concrete pavement mix. 470 pcy (5-sack) to 564 pcy (6-sack)
- Allow 25% - 40% SCM to lower cement
- Utilized Optimized Aggregate Gradation since late 1990s in pavements and started in structural mixes a few years ago
- Benefits: decrease in permeability, decrease in paste while an increase in strength and workability



State PEM Experiences

Minnesota

- I-35W, June 2018
- TH-60, July 2019
- Using Phoenix for w/cm
- w/cm 0.40 max
- Optimized aggregate gradation since 2007
- Maturity method



State PEM Experiences

New York

- May 2019, Route 7 north of Albany, NY
- 2020 Route 29 bridge over Batten Kill, Greenwich, NY structural PEM application
- 25% - 27% paste content
- 38,850 pounds of cement saved
- Utilized Optimized Aggregate Gradation & Tarantula curve



State PEM Experiences

North Carolina

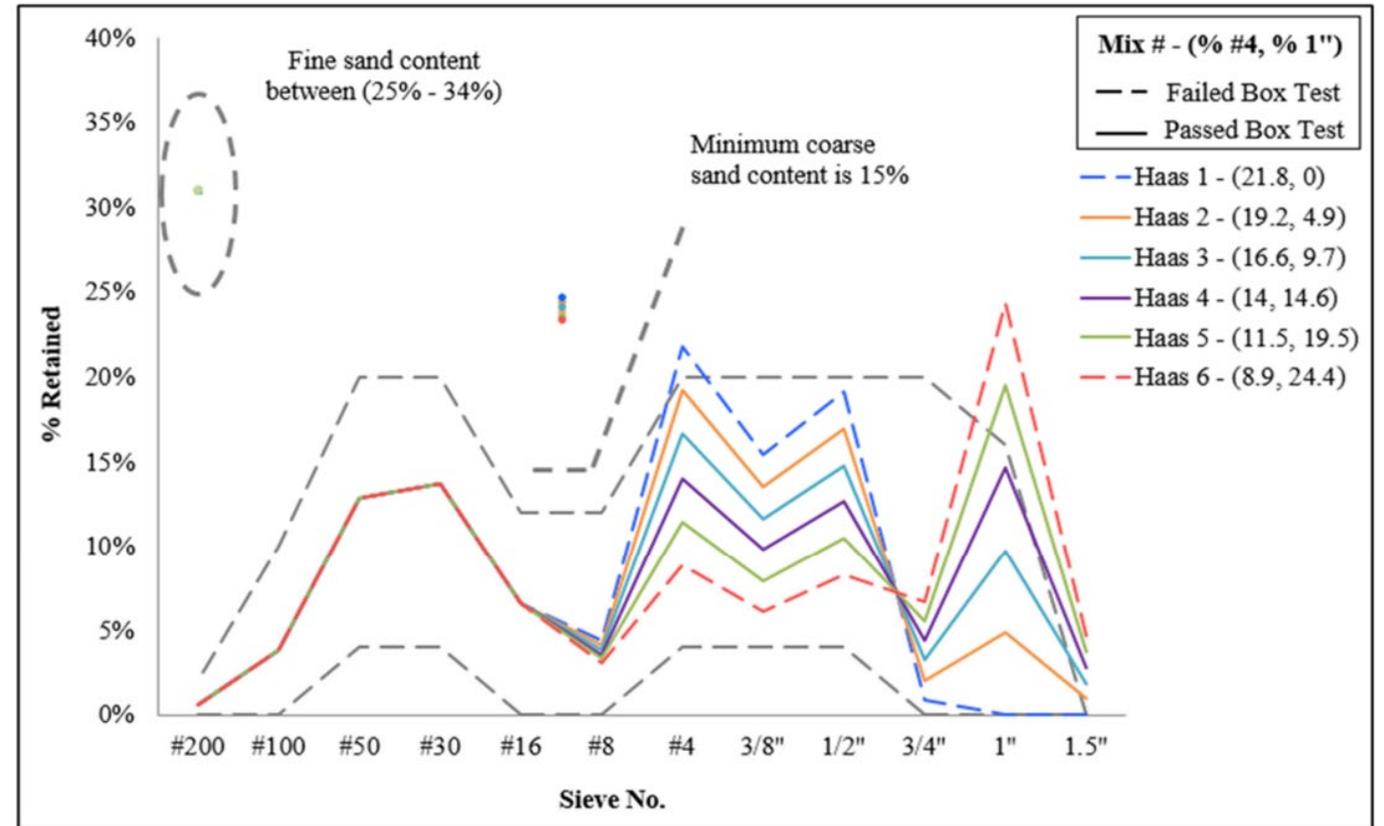
- I-85, May 2019
- Targeting Surface Resistivity, SAM, and Shrinkage
- Utilized Optimized Aggregate Gradation
- Paving contractor has continued to use PEM Mix
- I-485 D-B project in south Charlotte, Structural concrete mixture



State PEM Experiences

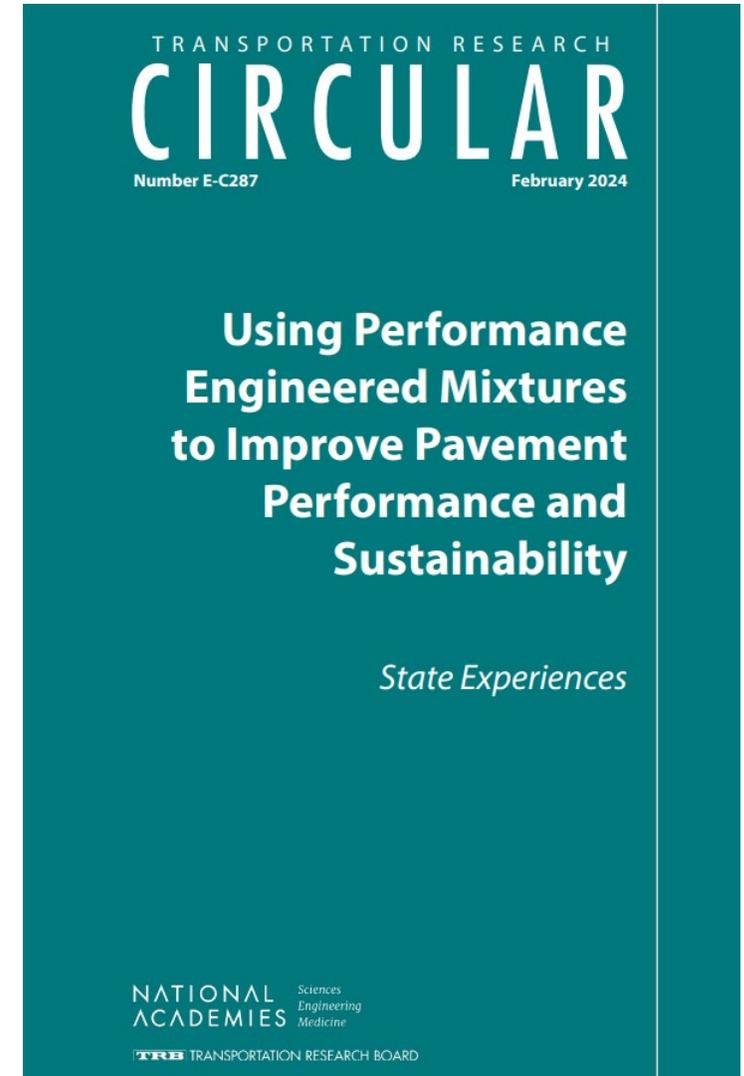
Wisconsin

- WisDOT 5-year, 7-site PEM research study
- Optimized aggregate gradation
- Variations in gradation had no change in compressive strength, surface resistivity, or shrinkage
- WisDOT implemented optimized aggregate gradation in 2022 Standard Specifications



TRB Circular – PEM State Experiences

- Iowa
- Minnesota
- Wisconsin
- Michigan
- New York
- North Carolina



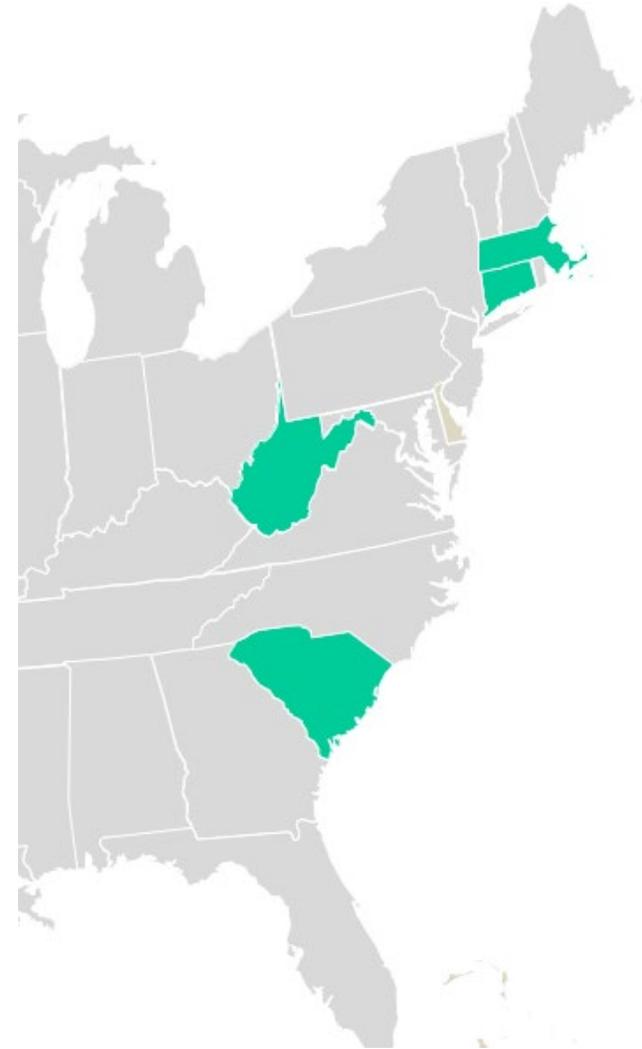
State Improvements

	Workability	Aggregate stability	Transport	Freeze thaw	Salt attack	Strength	Shrinkage	w/cm	Reduced binder content	Remove slump	Optimized gradation	56-day strength
Arkansas	Confirmed	Confirmed				Confirmed			Confirmed	Confirmed		
California		Confirmed				Confirmed						
Colorado	Confirmed	Confirmed	Confirmed			Confirmed	Confirmed		Confirmed		Confirmed	
Connecticut		Confirmed	Confirmed			Confirmed						
Florida		Confirmed				Confirmed		Confirmed				Confirmed
Georgia		Confirmed				Confirmed						
Idaho		Confirmed				Confirmed			Confirmed		Confirmed	
Illinois		Confirmed				Confirmed						
Iowa	Confirmed	Confirmed	Confirmed	Confirmed		Confirmed			Confirmed	Confirmed	Confirmed	
Kansas	Confirmed	Confirmed	Confirmed	Confirmed		Confirmed	Confirmed	Confirmed	Confirmed		Confirmed	
Maine		Confirmed				Confirmed						
Massachusetts	Confirmed	Confirmed	Confirmed	Confirmed	Confirmed	Confirmed	Confirmed	Confirmed	Confirmed	Confirmed	Confirmed	Confirmed
Michigan	Confirmed	Confirmed		Confirmed		Confirmed		Confirmed	Confirmed		Confirmed	
Minnesota		Confirmed				Confirmed		Confirmed	Confirmed	Confirmed		
Montana		Confirmed				Confirmed					Confirmed	
New York	Confirmed	Confirmed	Confirmed	Confirmed		Confirmed	Confirmed		Confirmed	Confirmed	Confirmed	
North Carolina	Confirmed	Confirmed	Confirmed	Confirmed		Confirmed			Confirmed		Confirmed	
North Dakota		Confirmed		Confirmed	Confirmed	Confirmed			Confirmed		Confirmed	Confirmed
Ohio		Confirmed				Confirmed						
Oklahoma		Confirmed				Confirmed						Confirmed
Pennsylvania		Confirmed	Confirmed			Confirmed	Confirmed	Confirmed				
South Carolina	Confirmed	Confirmed	Confirmed			Confirmed					Confirmed	
South Dakota		Confirmed				Confirmed		Confirmed	Confirmed		Confirmed	
Tennessee		Confirmed	Confirmed	Confirmed		Confirmed	Confirmed	Confirmed				
Utah	Confirmed	Confirmed	Confirmed			Confirmed	Confirmed	Confirmed	Confirmed	Confirmed	Confirmed	Confirmed
West Virginia		Confirmed	Confirmed	Confirmed		Confirmed			Confirmed		Confirmed	
Wisconsin	Confirmed	Confirmed		Confirmed		Confirmed			Confirmed	Confirmed	Confirmed	
Wyoming	Confirmed	Confirmed	Confirmed			Confirmed			Confirmed		Confirmed	

KEY Confirmed Changing Changed In place

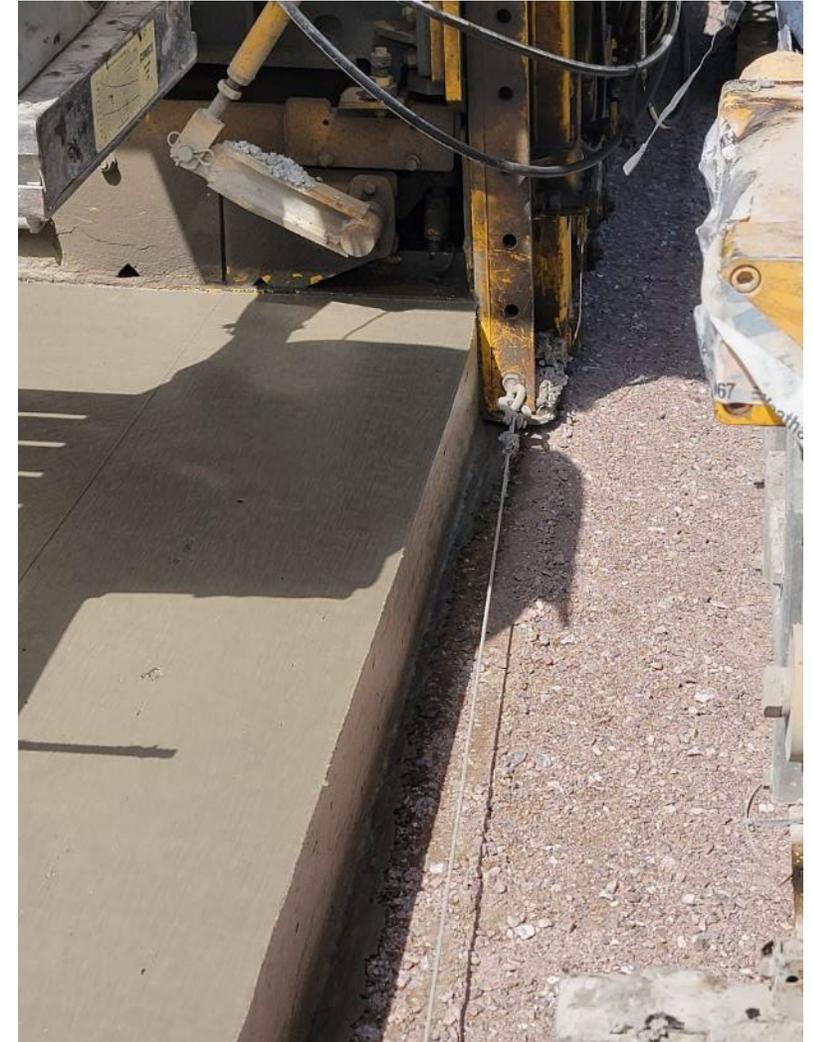
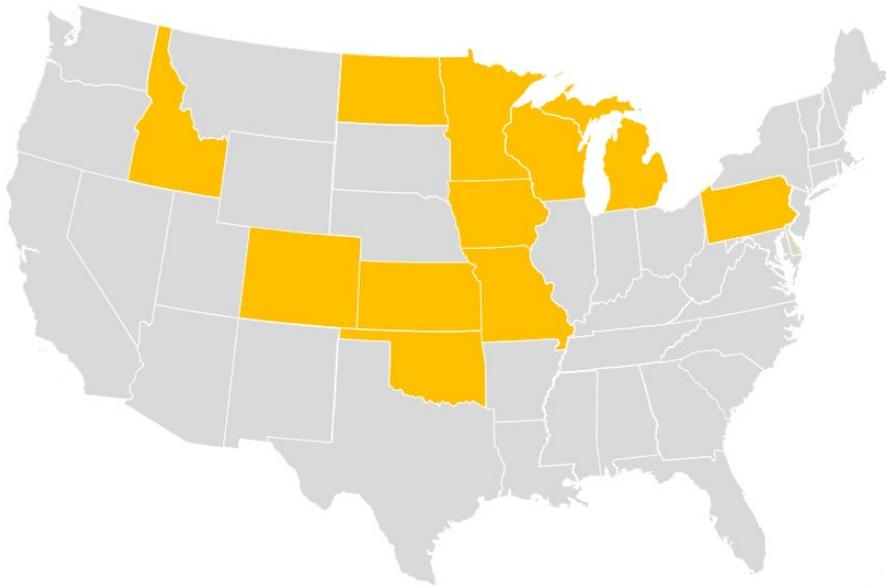
Non-PEM States

- West Virginia
 - Tarantula for optimized aggr. grad. (bridge deck), SR, SAM
 - Option to lower cm by 40 pcy
 - MCTC training
- Massachusetts
 - New PEM spec. (FHWA assist)
- Connecticut
 - Resistivity spec (FHWA assist)
- South Carolina
 - Tarantula curve -major projects, MCTC visit, resistivity, box



What is Next? P3C

- 2024 - Performance Centered Concrete Construction (P3C) TPF-5(517)
- What happens after the batch plant?



What should be measured on site?

- Fundamentally
 - Water
 - Air
- Because they influence
 - Workability
 - w/cm
 - Consolidation
 - Freeze thaw



What should be measured on site?

And

- Thickness
- Finish/Texture
- Smoothness
- Curing
- Saw Time
- Joint Activation
- Opening time



Priority Topics

For each topic

- Conduct a review of the fundamental needs, and systems currently available
- Select at least one system for evaluation
- Conduct laboratory and field testing to confirm their viability
- Refine or improve the tools as needed
- Develop and implement tech transfer activities

Priority Topics

- Water content
- Air void system
- Curing
- Smoothness
- Finish/Texture
- Consolidation
- Opening



Water Content

- Fundamental influence on performance
- Factors that matter
 - Aggregate moisture
 - Washout water
 - Evaporation
 - Retempering



Water Content

- Potential tools
 - Workability tools
 - Microwave
 - Phoenix
 - Embedded moisture sensor



Air Void System

- Controls freeze/thaw resistance
- Want many small bubbles close together
- Potential tools
 - Pressure pot
 - SAM

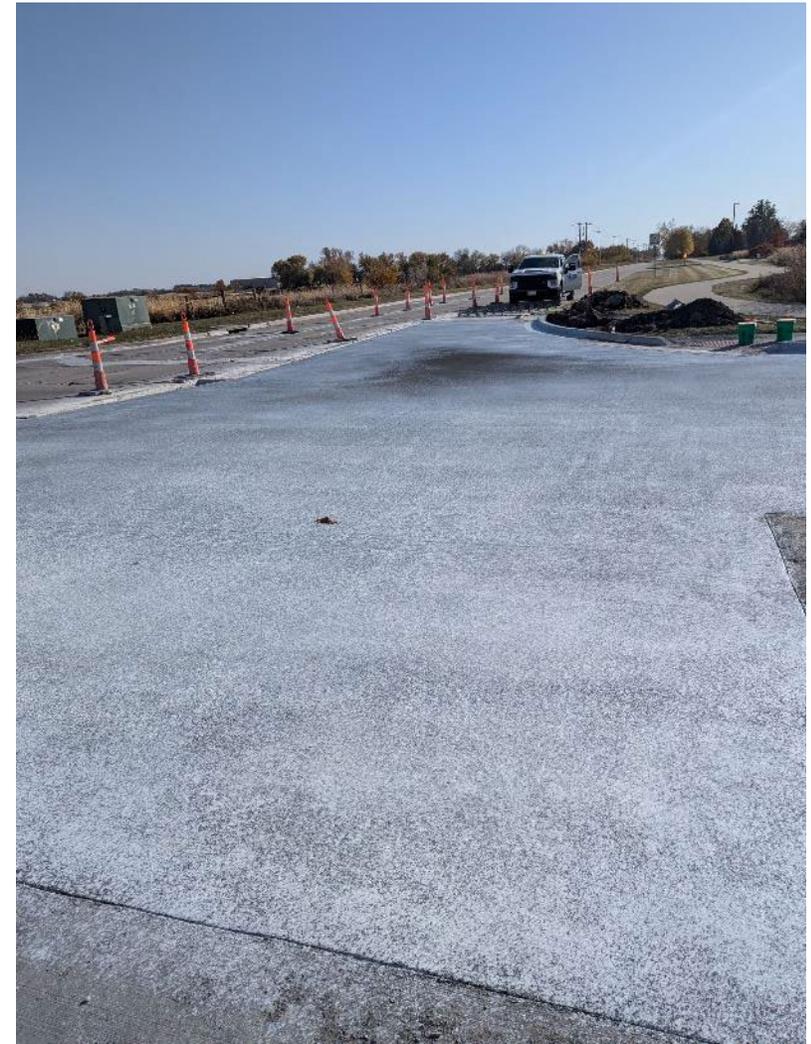


Curing

- Promotes hydration
- Reduces gradients

- Flooding
- Blankets
- Curing compounds

- When?
- How much?
- How long?



Curing

Potential tools

- Image analysis
- Resistivity sensor (Dr. Kevern)



Smoothness

- How the public sees us
- How the agencies plan maintenance
- Changes with time and weather
 - Curling / warping
- Real Time Smoothness



Finish / Texture

- Friction
- Noise
- Tining vs Burlap drag?
- Next Generation?

- How do we test it?
- Sand Patch
- Laser



Consolidation

- Can affect strength
- How bad is bad?

- Potential tools
 - MIRA
 - Dielectric Profiling Systems



Opening to Traffic

- Influences construction progress
- Significant for short closing windows
- What do we need?
- How do we measure?
 - Maturity
 - Wavelogix Rebel?

Standard Method of Test for

Estimating the Early Opening Strength of Concrete Pavements by Maturity Tests

AASHTO Designation: T-413-25

First Published: 2024

Technically Revised: 2025

Technical Subcommittee: 3c, Hardened Concrete

AASHTO

American Association of State Highway and Transportation Officials
555 12th Street NW, Suite 1000
Washington, DC 20004

Others

- Joint activation
- Saw time
 - Tran, Roesler – Non-contact ultrasonic testing technique



P3C - Summary

- Continue to assist state agencies on specification improvements
- Continue to offer training
- Investigate tools to monitor the mixture through the paving process
- Investigate feedback loop approaches



Discussion



New Test Methods & Technologies



U.S. Department of Transportation
Federal Highway Administration



National Concrete Pavement
Technology Center





FHWA Mobile Concrete Technology Center

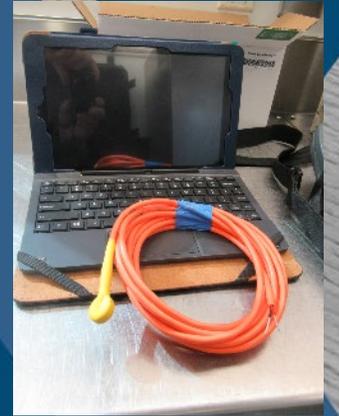
New and Innovative Concrete Testing Technologies

Jagan Gudimettla, P.E.



U.S. Department of Transportation
Federal Highway Administration

Innovative Technologies / Tests



Material Testing

Construction

How does concrete fail?

- Spalling
- Shrinkage
- Freeze-thaw
- Sulphate reaction
- High Permeability
- Poor consolidation
- Joint Deterioration
- Alkali Silica Reactivity



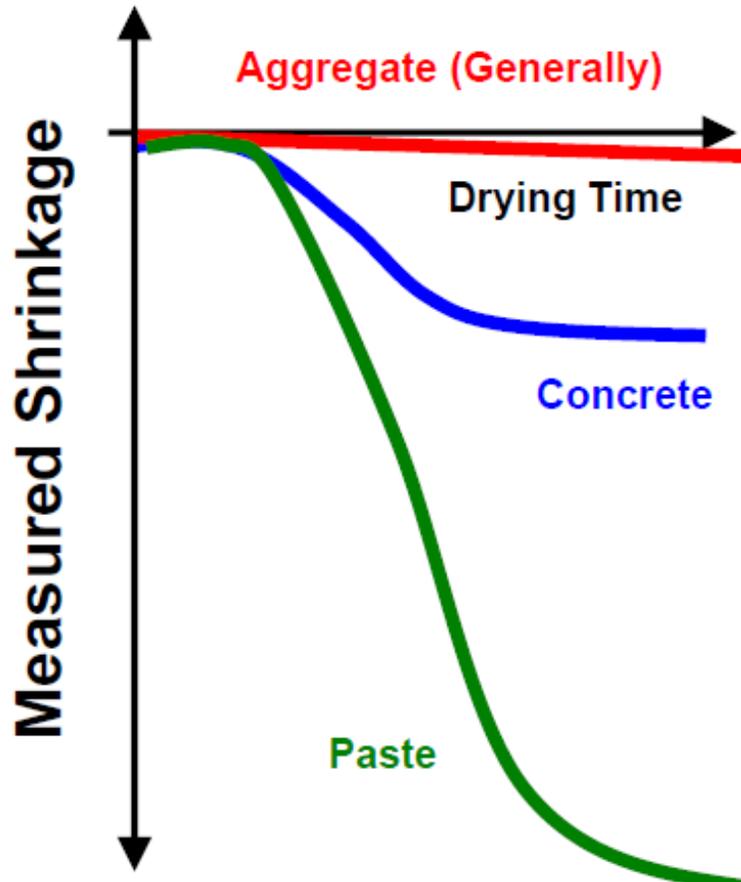
We're getting strong concrete

We're NOT getting durable concrete

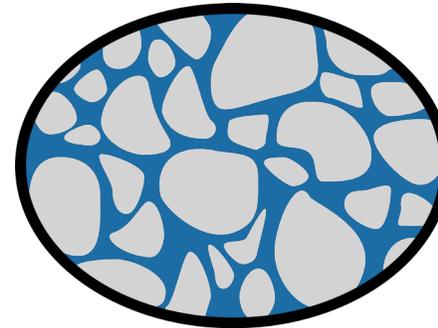
Strength ≠ Durability

Concrete Durability

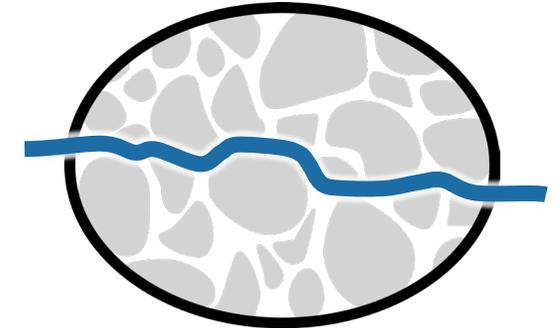
➤ Shrinkage



➤ Permeability



Amount of Pores
(porosity)



How pores are connected
(tortuosity)

Paste is the weakest link

Traditional Concrete Practices

- Focus on strength
- Minimum cement content
- Two aggregates used (mostly)

- Lead to high paste volumes (higher cement)
 - All kinds of distresses
 - Expensive
 - Not sustainable



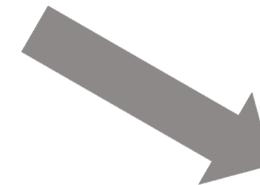
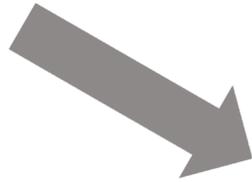
How do we solve this problem?



Optimizing Aggregate Gradations

Optimize Aggregate Gradation

Put in more aggregates



Take out cementitious

Optimized Aggregate Gradation

- Consideration of the combined gradation
- Utilize an intermediate size aggregate
- No minimum cement content requirement



Non-Optimized
Mixture



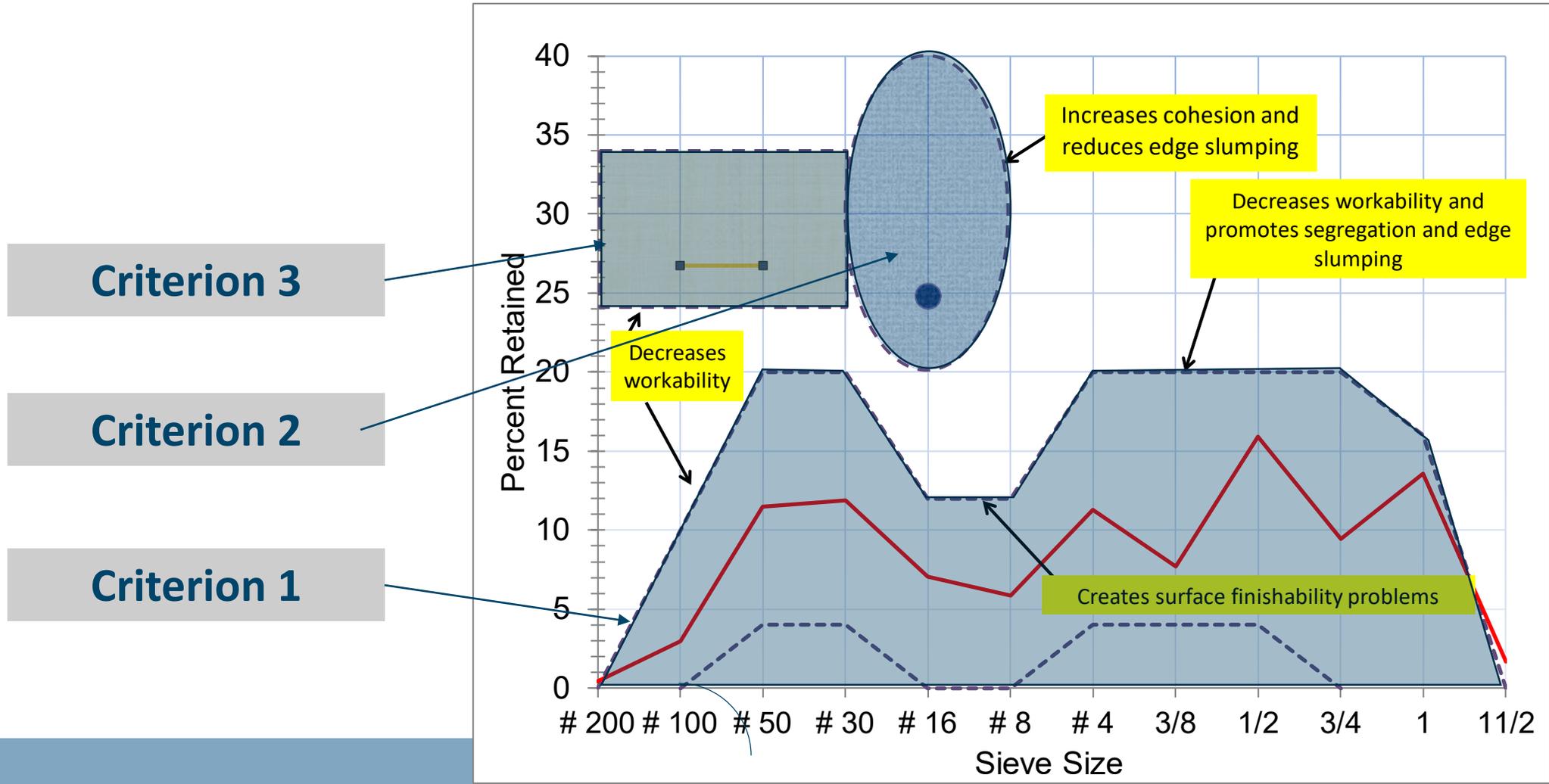
Optimized
Mixture

Maximize the filling of the space with aggregate

Leads to minimizing paste content

The Tarantula Curve

➤ Tool to optimize aggregate gradation



Optimized Gradation and Paste Content

The TARANTULA Curve!!!

- How do we achieve it?
- Spreadsheet available

Wisconsin					
Sieve Size, in	Fine 1 Agg	Fine 2 Agg	Inter Agg	Coarse Agg	Combined % Passing
2"	100		100	100	100
1.5"	100		100	93	99
1"	100		100	39	91
3/4"	100		98	5	85
1/2"	100		55	1	67
3/8"	100		33	1	58
No. 4	98		3	0	45
No.8	85		1	0	39
No.16	68		1	0	31
No.30	38		1	0	18
No.50	9		1	0	5
No.100	2		1	0	1
No.200	1		1	0	1
Weights					
%s	45%		40%	15%	100%



Fine



Inter

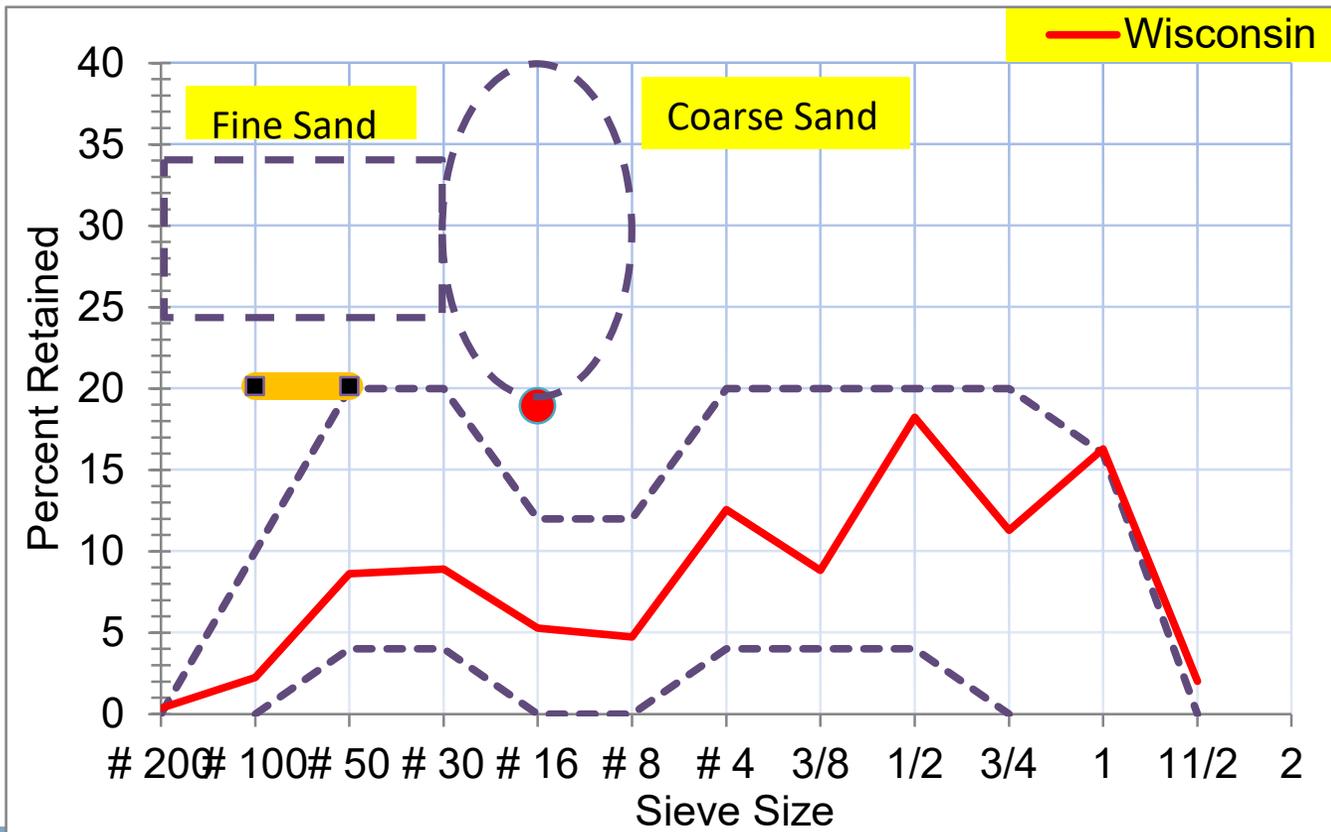


Coarse

Optimized Gradation

Wisconsin				
Sieve Size, in	Fine 1 Agg	Fine 2 Agg	Inter Agg	Coarse Agg
%'s	30%		40%	30%

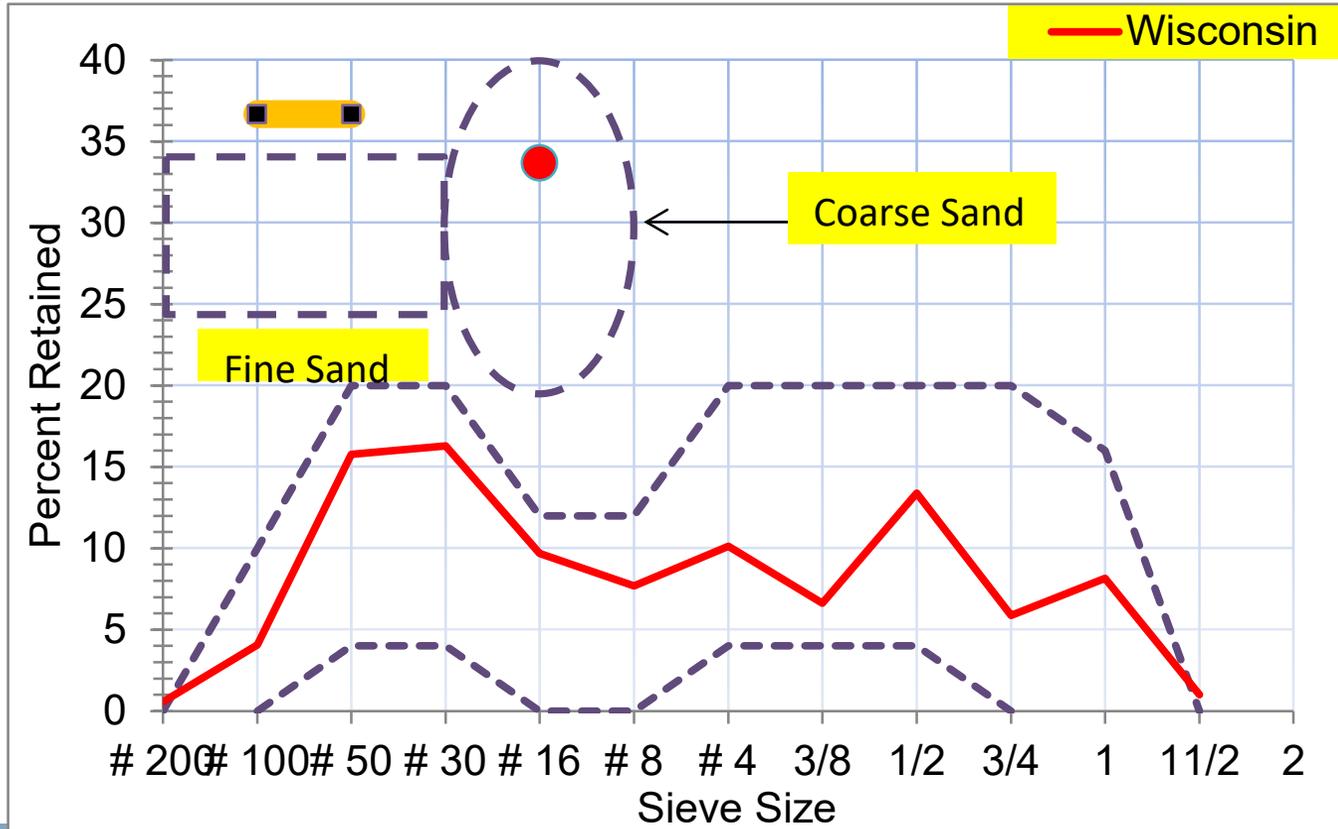
Too Coarse



Optimized Gradation

Wisconsin				
Sieve Size, in	Fine 1 Agg	Fine 2 Agg	Inter Agg	Coarse Agg
%s	55%		30%	15%

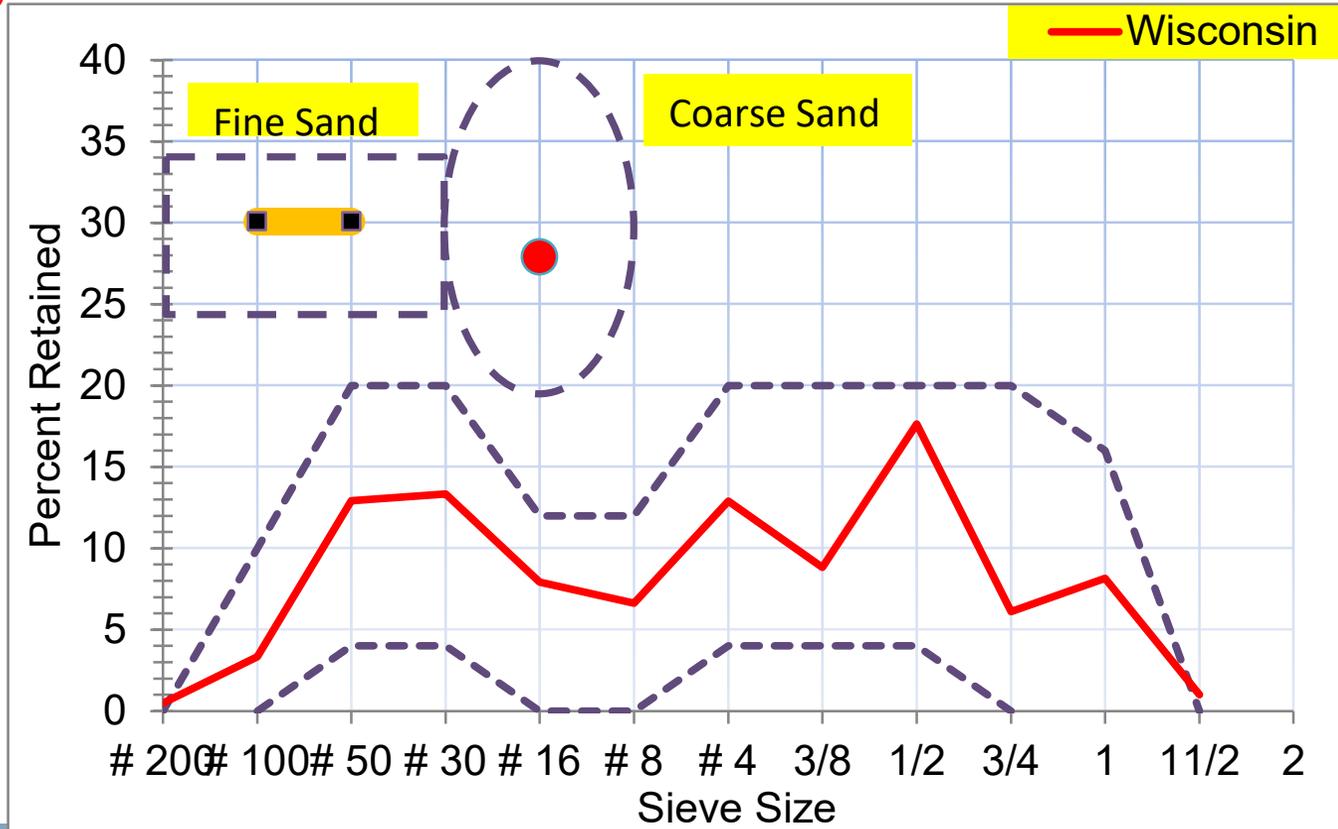
Too Fine



Optimized Gradation

Wisconsin				
Sieve Size, in	Fine 1 Agg	Fine 2 Agg	Inter Agg	Coarse Agg
%'s	45%		40%	15%

Optimum?



Optimized Aggregate Gradation

What will it do for me?

- Improved workability
- Reduce segregation potential
- Reduce cost
- Equal or higher strength
- **Improve sustainability**



Less paste=> Lower permeability

Less paste=> Reduced thermal shrinkage

Less paste=> Reduced drying shrinkage



Box Test

The Box Test



- A workability test
- Simple
- Best use is for mixture design
- Will it go through the paver?

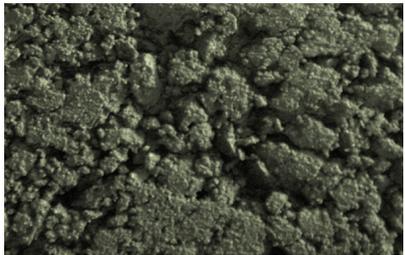


The Box Test

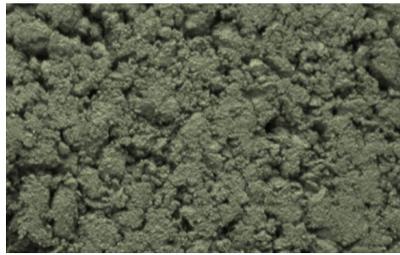


➤ Consolidation Ranking

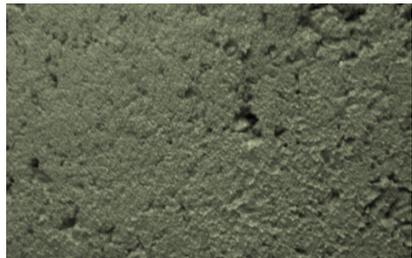
➤ Edge Slump Potential



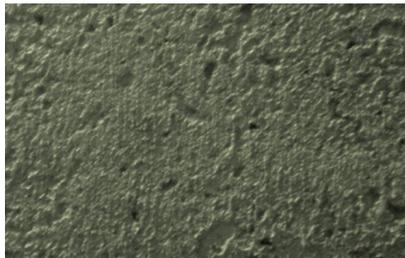
4



3

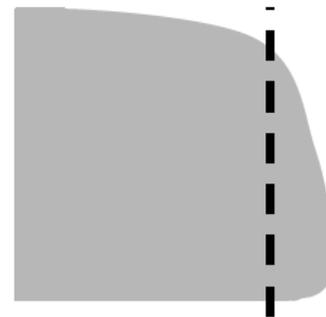


2

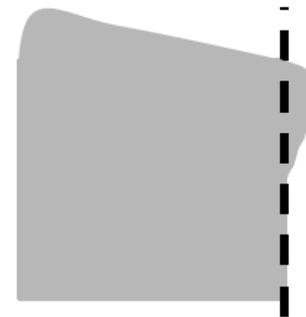


1

Consolidation Issues



Bottom Edge Slumping



Top Edge Slumping

If deflection is more than 1/4" then it fails

Edge Slump Issues

The Box Test



- Consolidation Ranking
- Edge Slump Potential



Consolidation Issues



Edge Slump Issues

Workability and Constructability



Box Test

Project A

Project B



Finishability
Issues



Edge slump
Issues

MCTC >>>

Workability and Constructability



Box Test

Project C

Good Edge and Finish

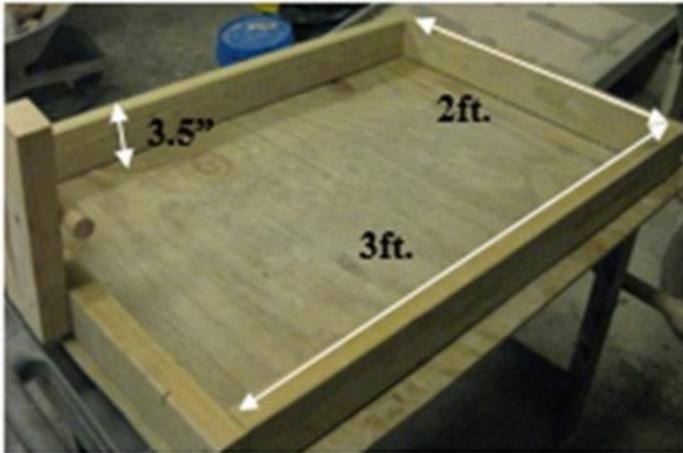


V-Kelly – Workability Test for Paving Concrete



The Float Test

➤ General Steps in the Float Test



Place
Template



Create
Holes

Photos: Dr. Dan Cook

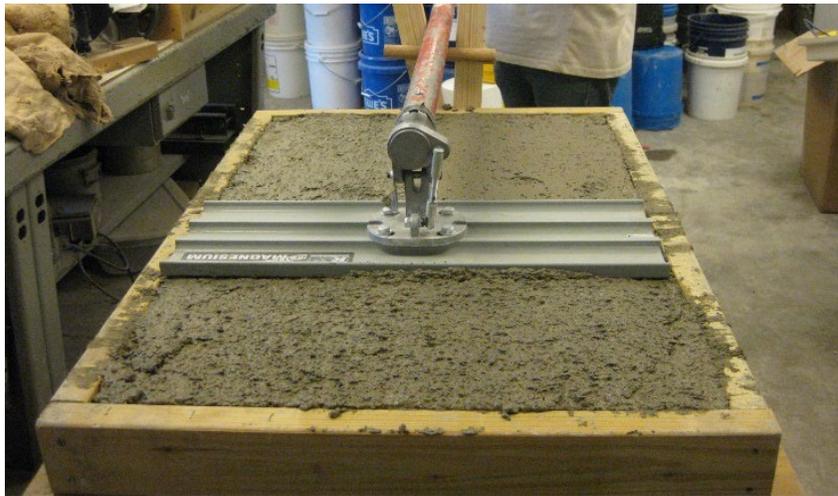


The Float Test

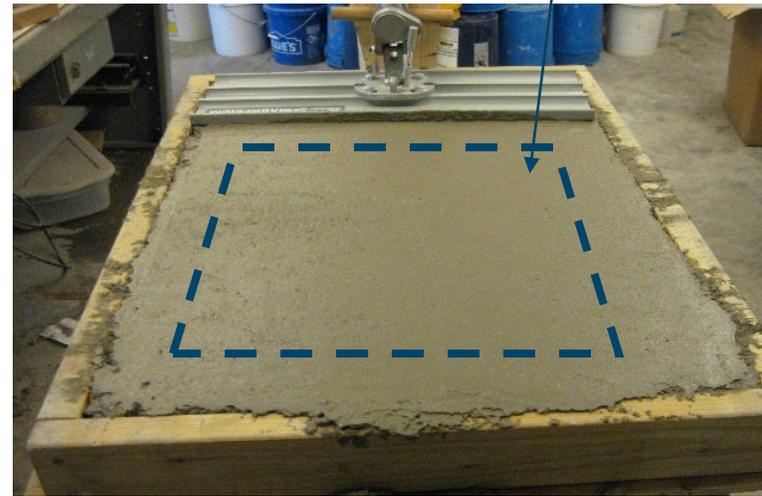
➤ General Steps in the Float Test

- The float is trimmed to only ride on the concrete
- The yolk keeps the angle constant

First Pass
with Bull Float



Evaluate only this area

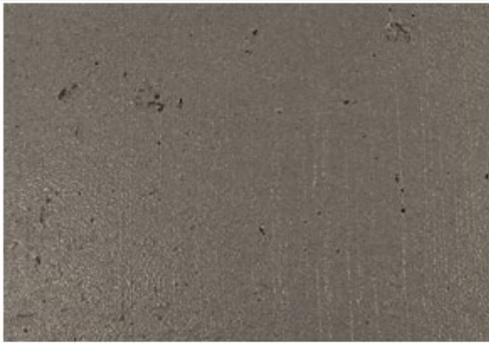


Last Pass
with Bull Float

The Float Test

➤ Measurement 1

➤ Number of passes to remove blemishes

	
4 Over 50% of area was textured	3 30 to 50% of area was textured
	
2 10 to 30% of area was textured	1 Less than 10% of area was textured

The Float Test

➤ Measurement 2

➤ Number of passes to remove holes



0 Passes



2 Passes



4 Passes

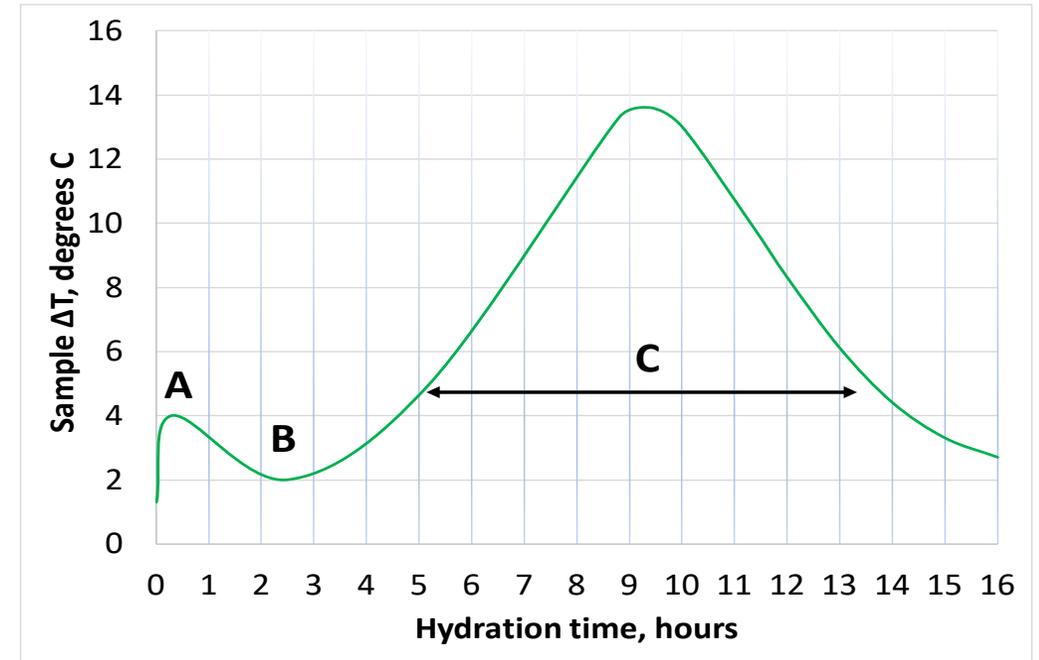


Semi-Adiabatic Calorimetry

Semi-Adiabatic Calorimeter



- Heat Signature
- Cementitious system
- Uniformity
- Incompatibilities
- Strength development
 - Time of set
 - Sawing window



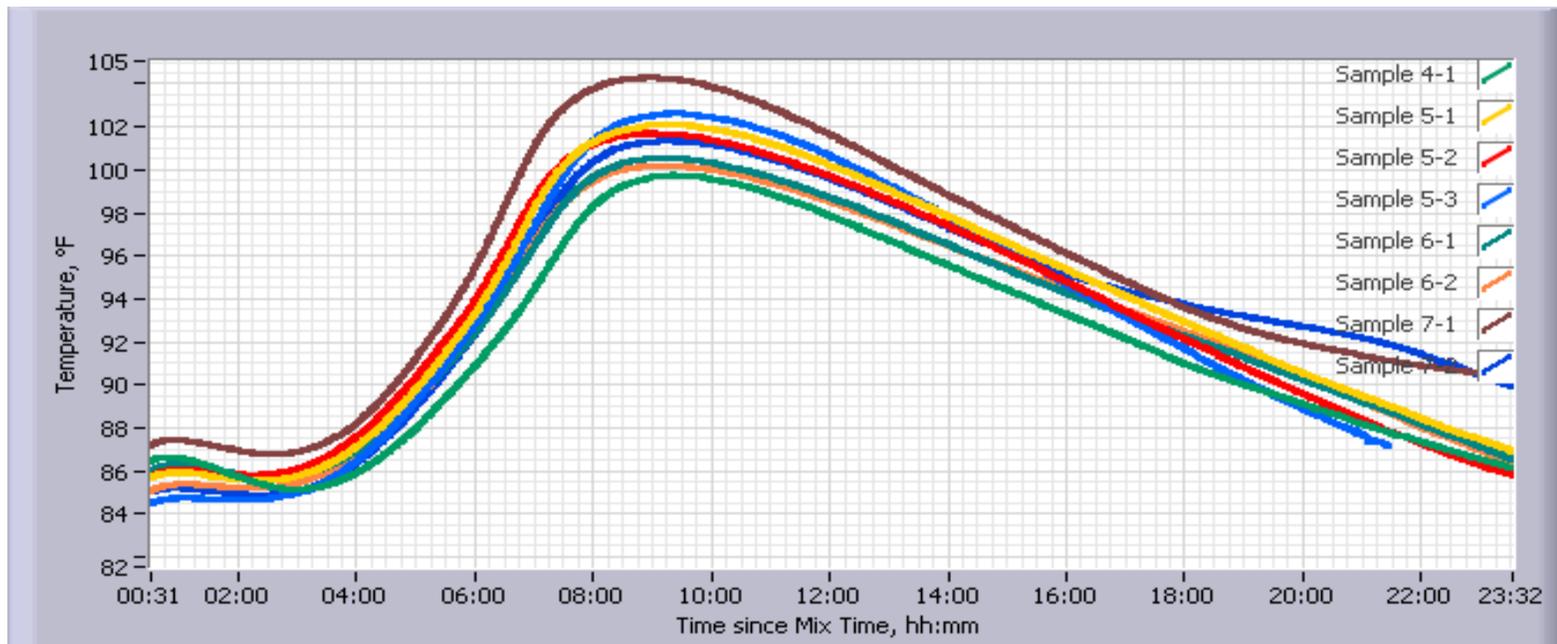
A - initial aluminates (C_3A) hydration
B - dormancy period
C - main peak (C_3S) hydration

Mixture Consistency



Production

➤ Consistent Heat Signature Curves

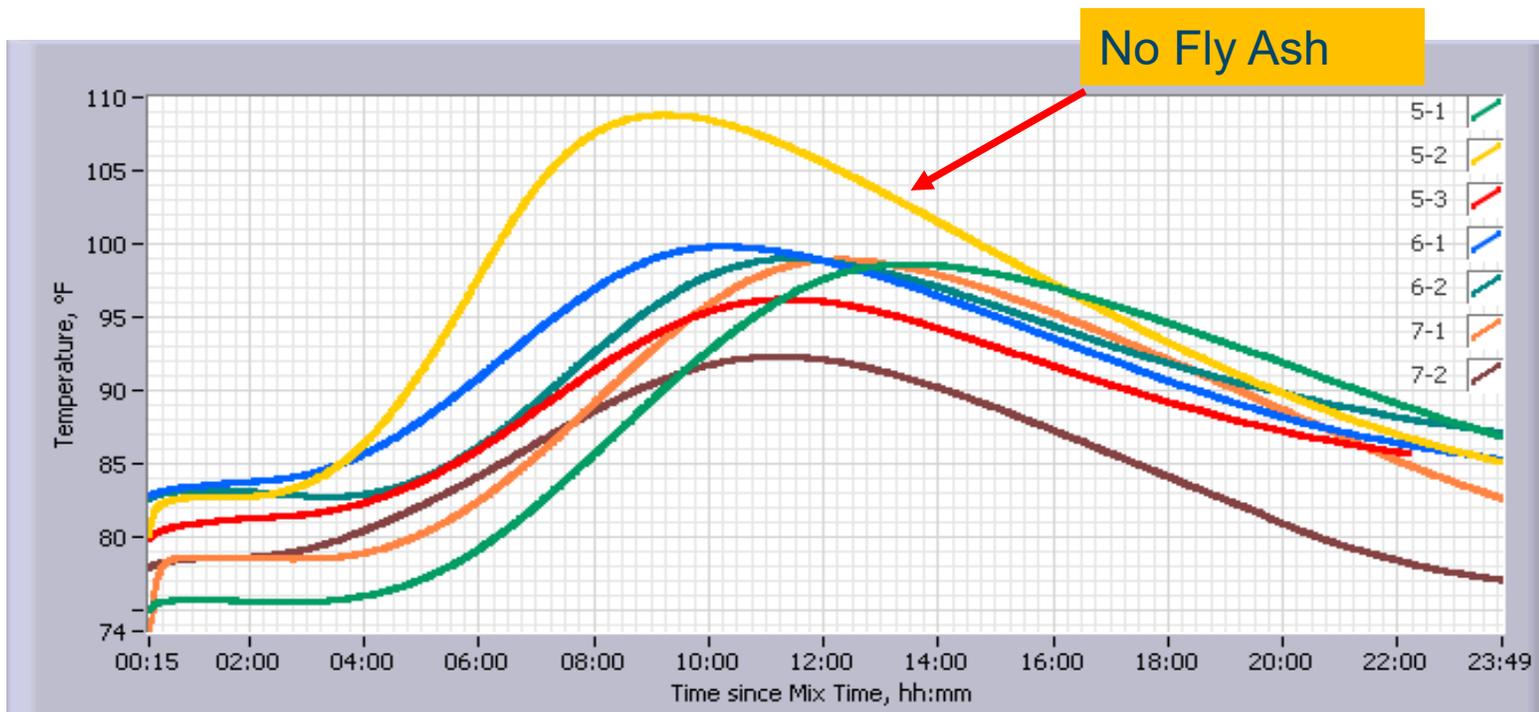


Mixture Consistency



Production

➤ Inconsistent Heat Signature Curves





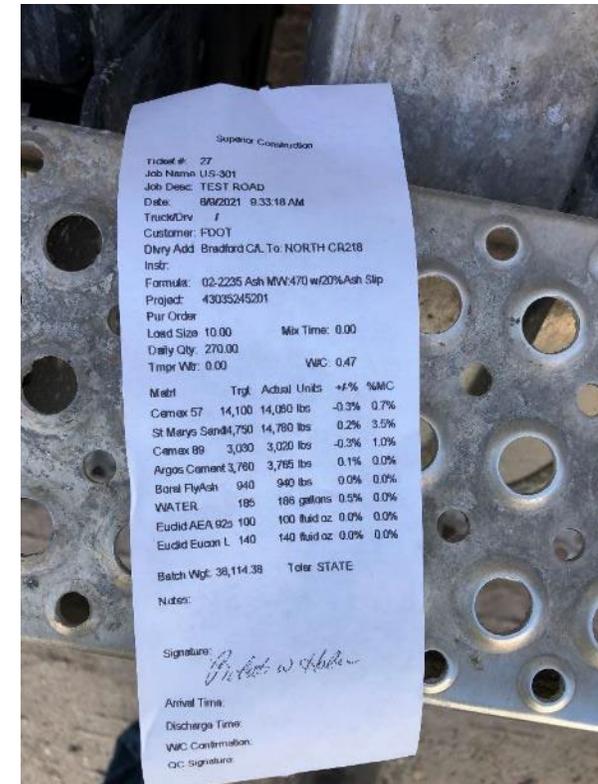
Phoenix

Water Content / Water Cementitious Ratio



= w/cm

Traditional Method Batch Tickets



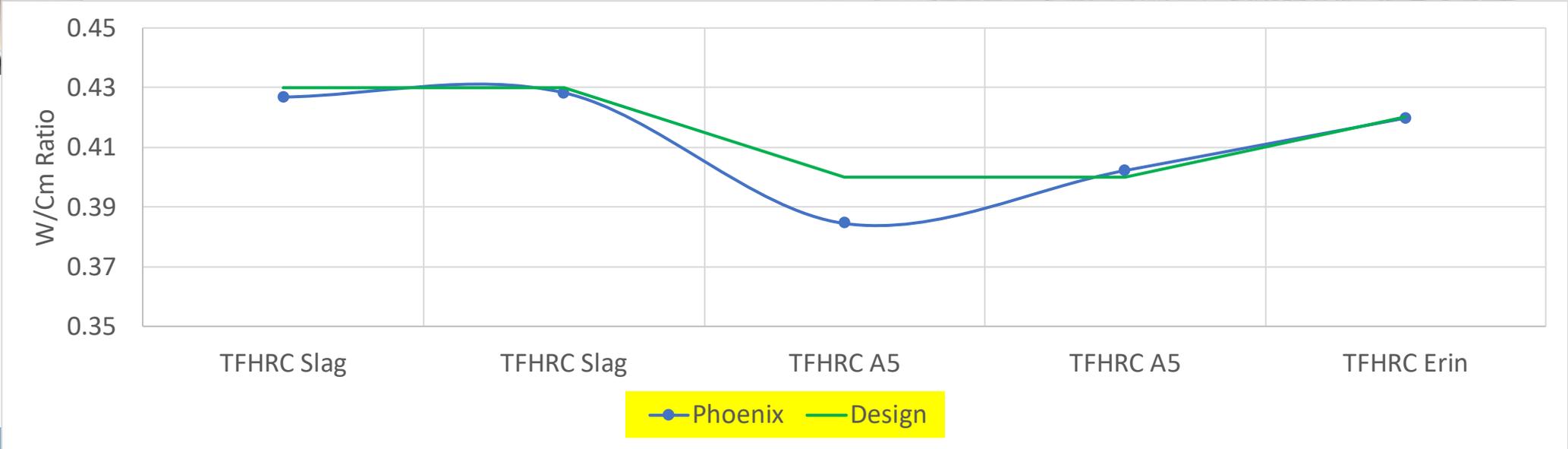
Phoenix - Water Cementitious Ratio



- Test results from the MCTC visit to OK paving project
- New test to measure the water in fresh concrete
- Developed by Dr. Tyler Ley, Oklahoma State University
- Easy to operate
- Once the test begins, no attention is required



Phoenix – MCTC / TFHRC Study





Surface Resistivity Testing

Rapid Chloride Penetrability Test



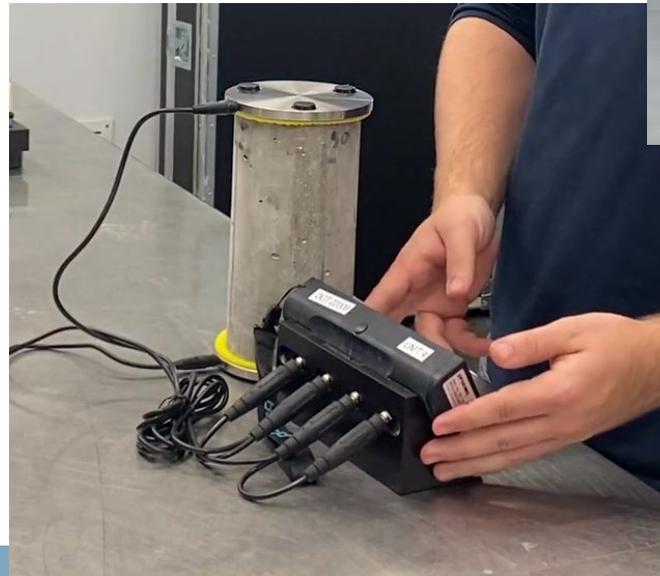
- Became standard in 1981
- Most common test
- Indicator of vulnerability to water and chloride ingress
- Generally, 24 hours to condition and 6 hours for testing
- AASHTO T277



Surface /Bulk Resistivity Test



- Instant results on hardened concrete
- Easily measures the right property
- Non-destructive test
- AASHTO T 358



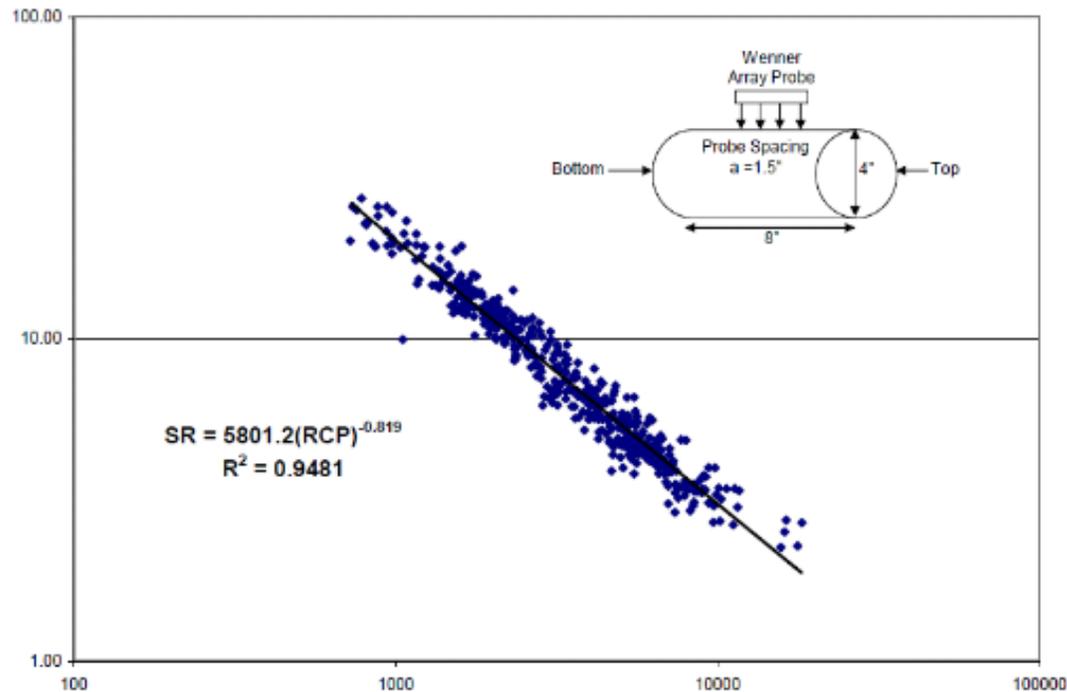
Permeability of Concrete



Surface Resistivity Test matches well with Rapid Chloride Permeability Test



Surface Resistivity (KOhm-cm)



RCP (Coulombs)





Super Air Meter

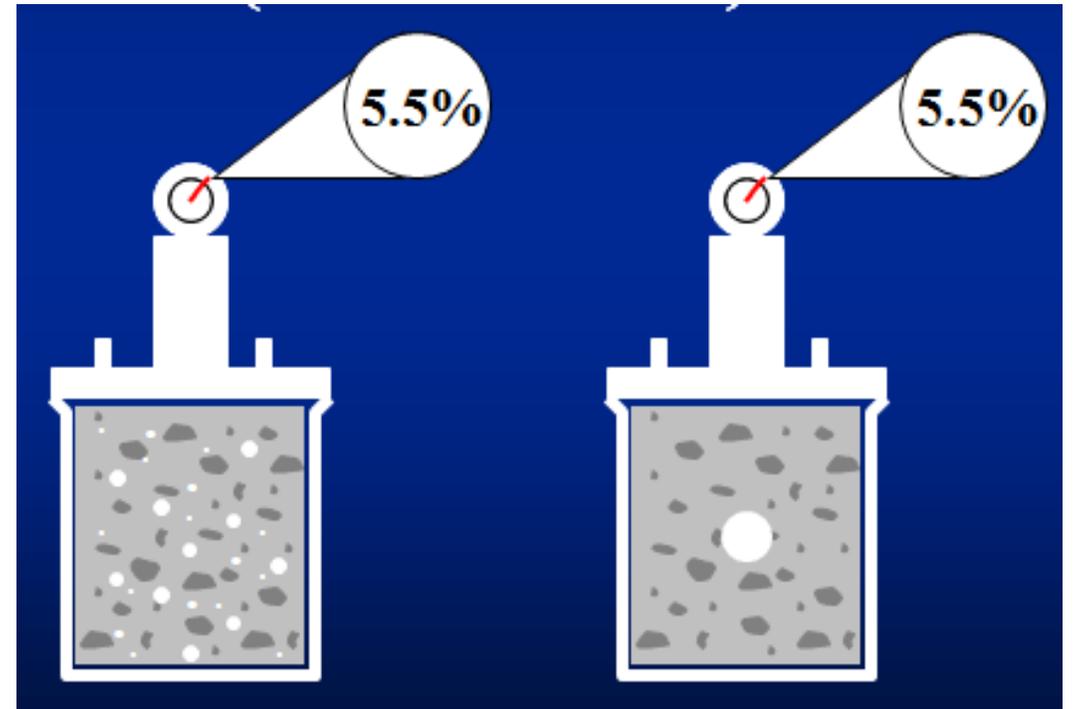
Pressure Meter - Air Content



- **Entrained air**
 - **4.0% - 8.0% of concrete**
- **Pressure Meter**
 - **Does not measure air void system**

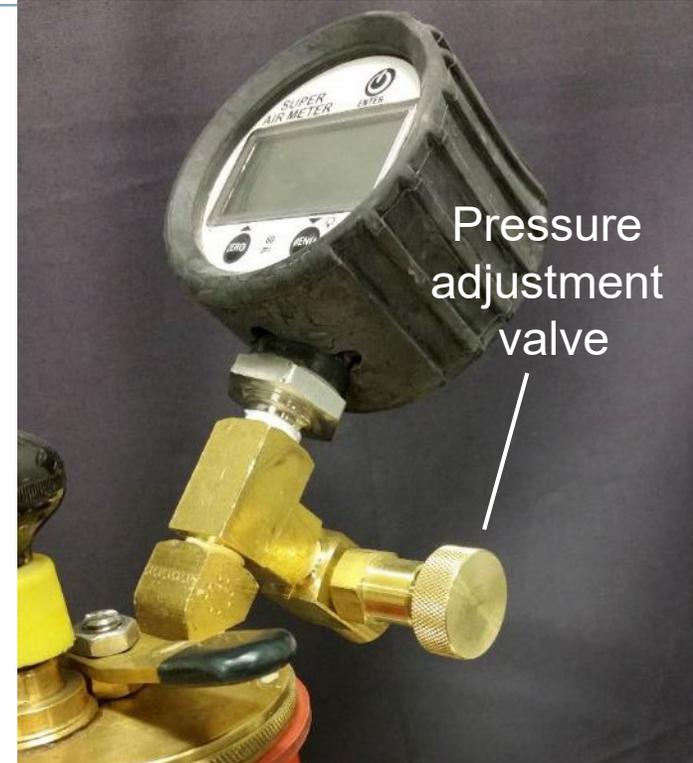
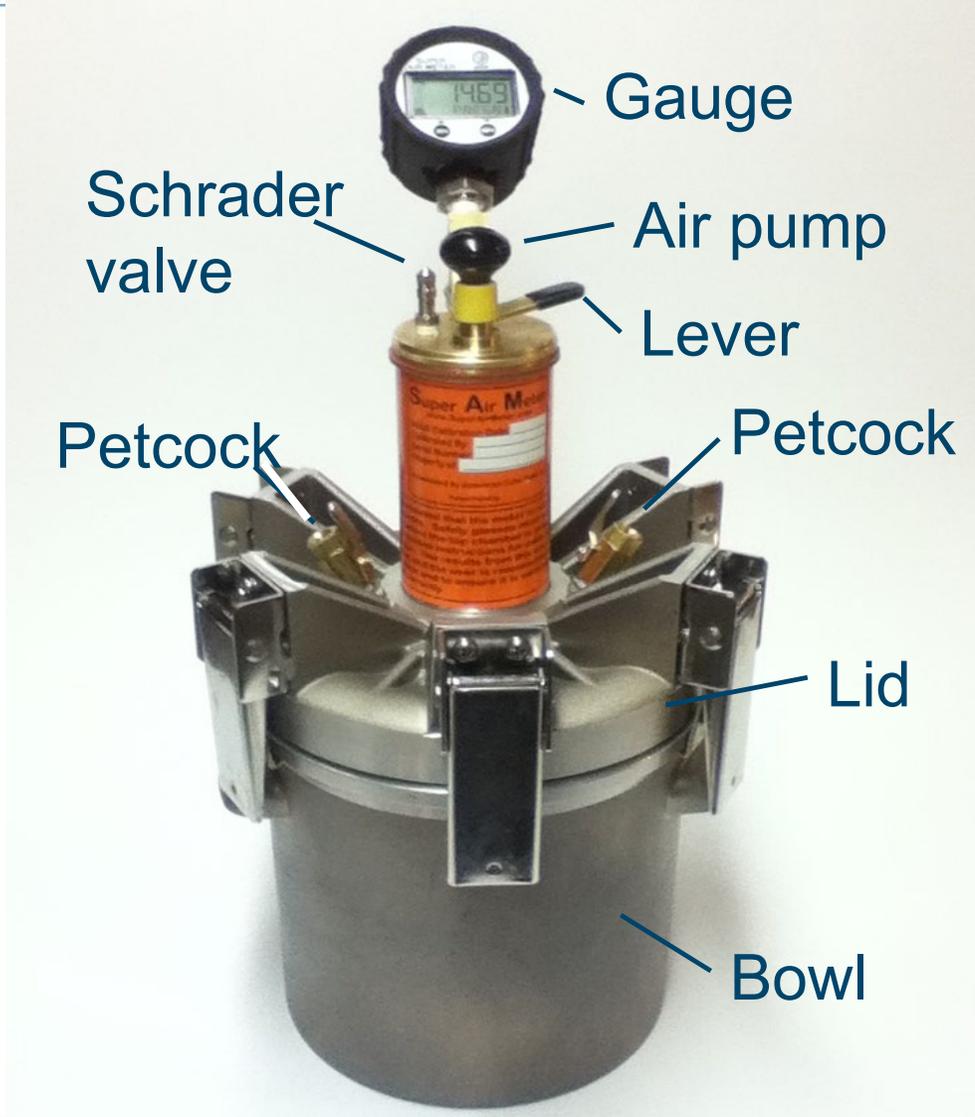


Freeze-Thaw Durability

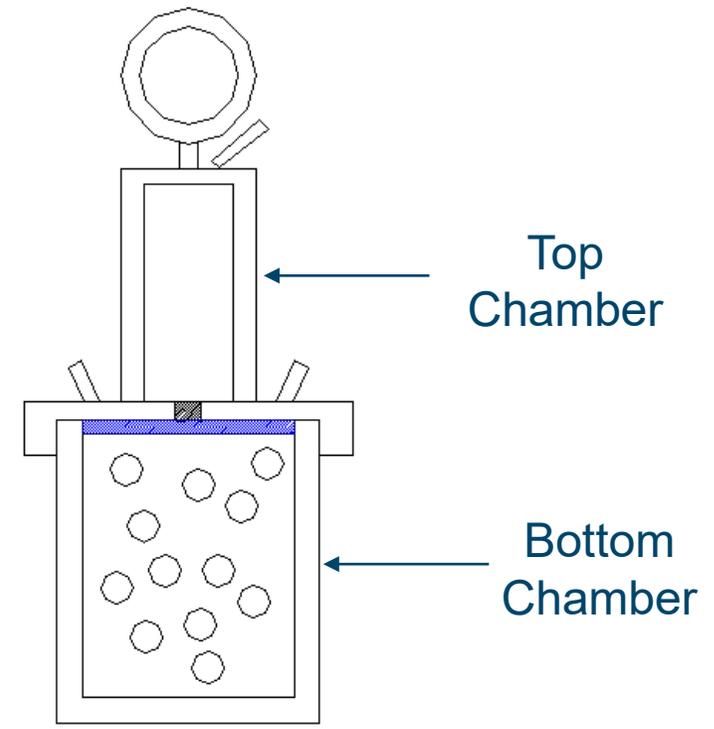
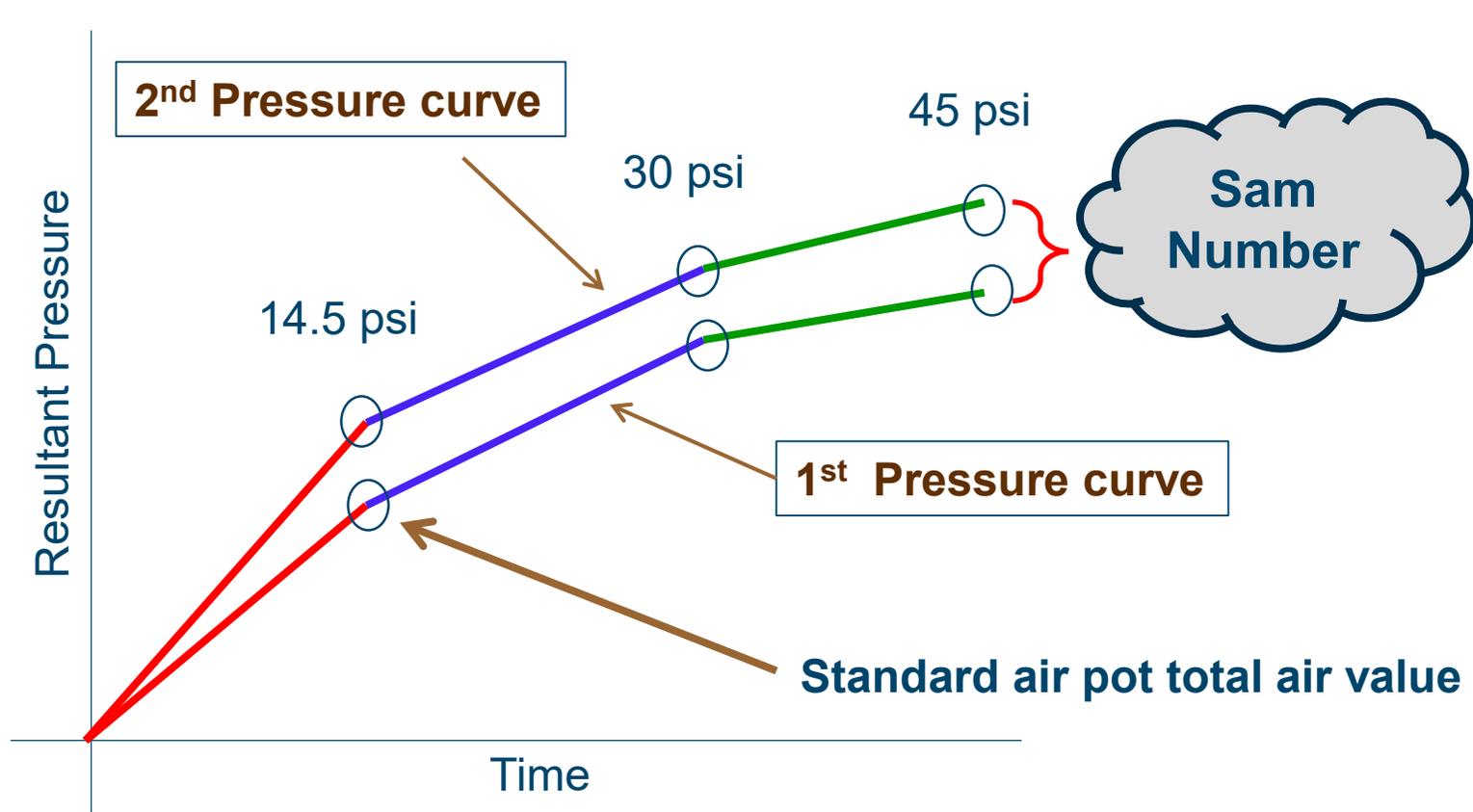


Which situation is more desirable?

Super Air Meter



SAM Principle



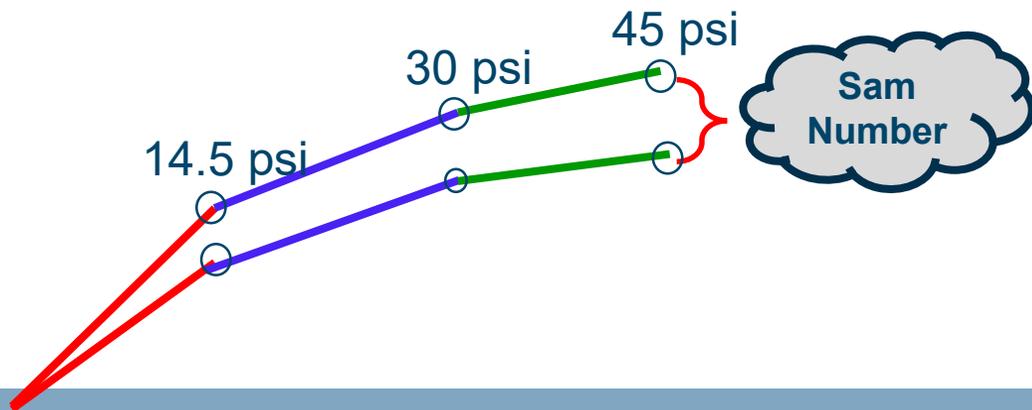
SAM Principle



Bad Air System

High Spacing Factor-Far Apart

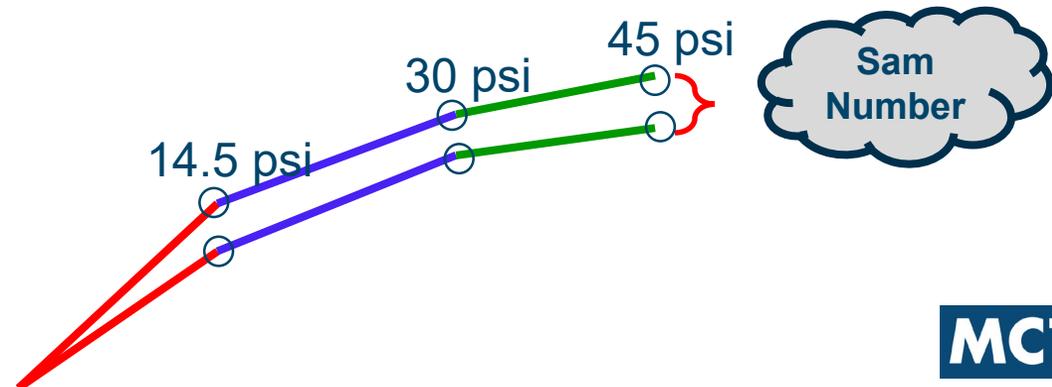
- Greater than 0.008 in (ASTM 457)
- Almost all sizes of bubbles dissolve
- Don't come back
- Second series is much different
- Higher SAM number



Good Air System

Low Spacing Factor- Close together

- Smaller than 0.008 in (ASTM 457)
- Bubbles don't dissolve as much
- Many bubbles will come back
- Second series is about the same
- SAM number difference is small

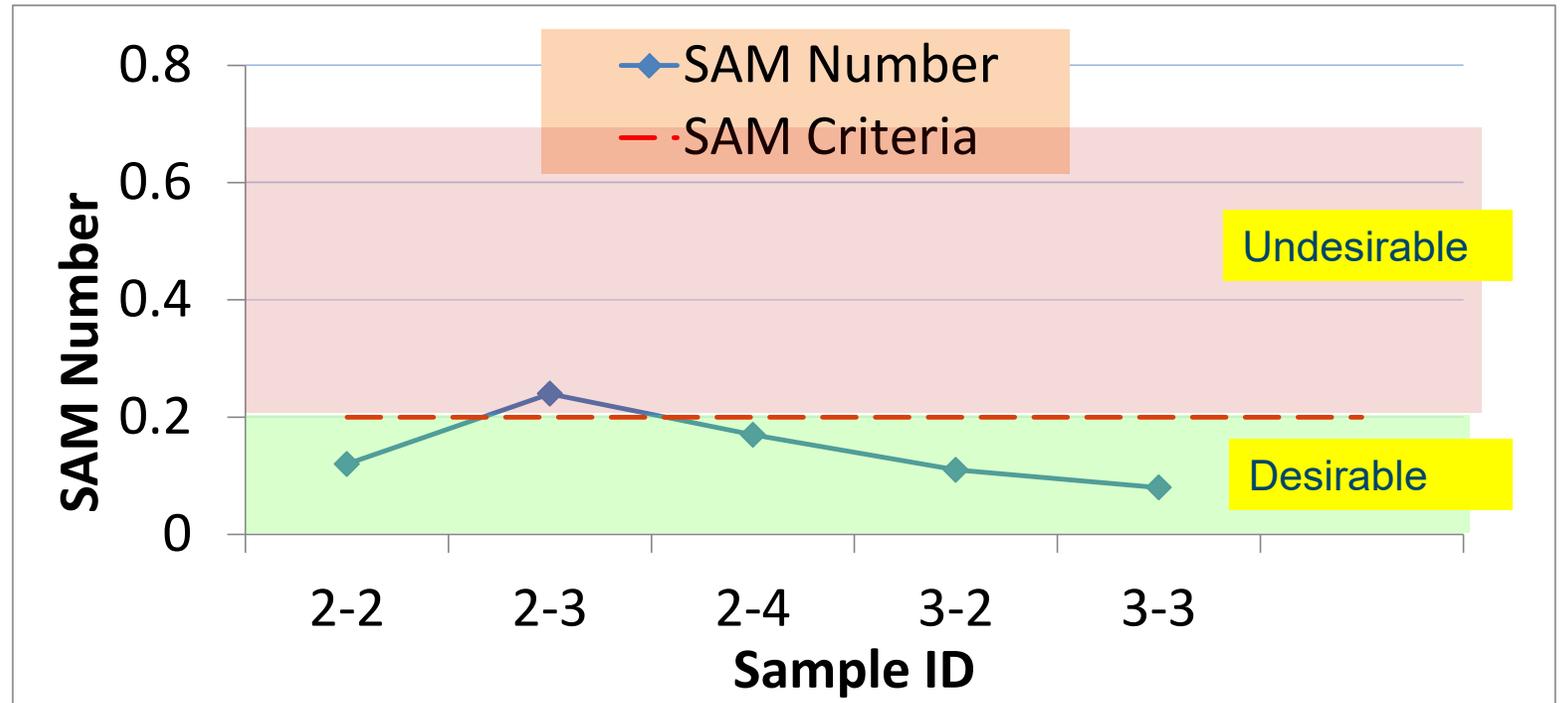


SAM Principle



SAM Number

- Range from 0 to 0.8
- Lower the better
- Mixture design target
 - 0.2 SAM



Pavement Thickness Measurement



- Pavement life is influenced by thickness
- Important QA activity
- Coring
 - Destructive
 - Expensive
 - Time Consuming
 - Core
 - Inspect
 - Handle
 - Measure
 - Patch core holes
- Not real-time



Probing
(Quality Control)



Coring
(Acceptance)



Pavement Thickness Measurement



Pulse Induction Technology (MIT SCAN T3)

- Nondestructive
- Quality Control and Agency Acceptance
- AASHTO T 359 and ASTM E3209



Step 1: Place the target



Step 2: Pave over it

Photo: Iowa DOT



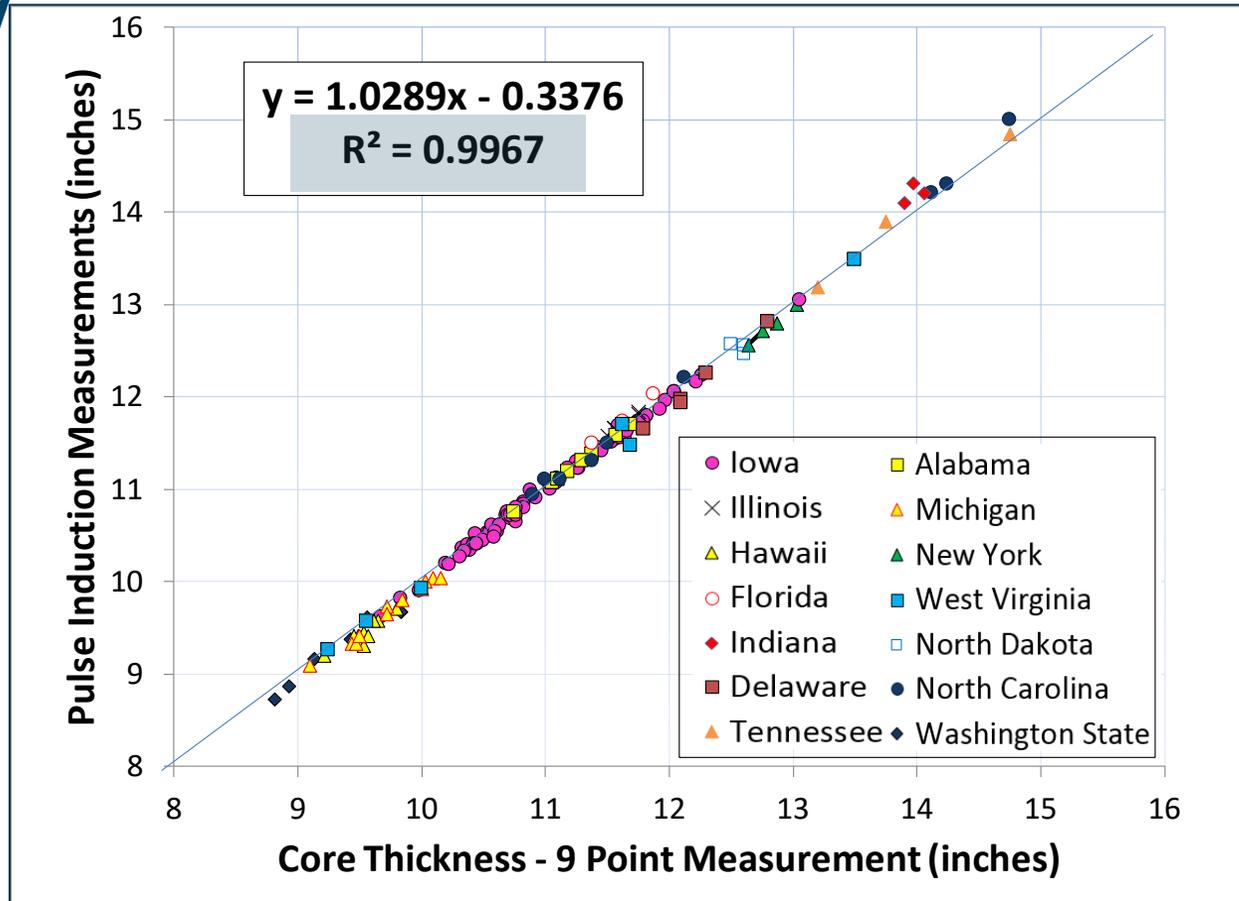
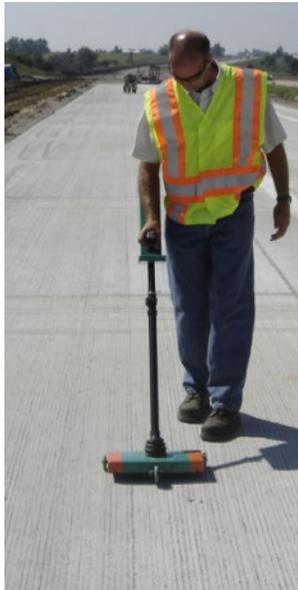
Step 3: Find the target and measure thickness

Pavement Thickness Measurement



Pulse Induction Technology

➤ Accuracy



Data Source:
FHWA Mobile Concrete
Technology Center



When Is It Okay to Drive On?



Maturity: ASTM C1074 versus the New AASHTO Test Method

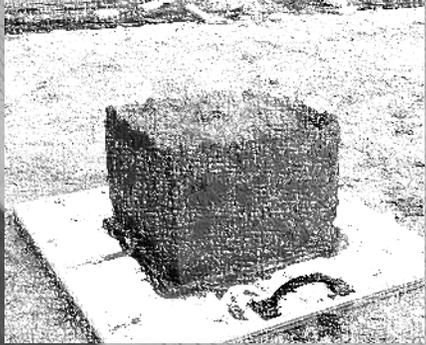
➤ ASTM C1074

- **Burdensome for contractors**
- **Applicable to all concrete elements**
- **Involved approach**
 - Datum temperature needs to be measured / calculated
 - Maturity curves are built in a laboratory
- **Excessive number of cylinders / beams utilized**
 - Strength cylinders / beams are tested through 14/28 days
- **Cautious in approach**
 - Precision is the focus

➤ New AASHTO Test Method (T413)

- **Can be attractive to contractors**
- **Applicable to only pavements**
- **Simple approach**
 - Uses a standard Datum temperature
 - Maturity curves can be built in the field during construction
- **Fewer cylinders / beams utilized**
 - Only two strength points are needed after the required strength is achieved (typically less than 7 days)
- **Practical in approach**
 - Precision is less critical in pavements

Innovative Technologies / Tests



Material Testing

Construction



Open House Sign-in Sheet



Thank You!!



2022 Priorities

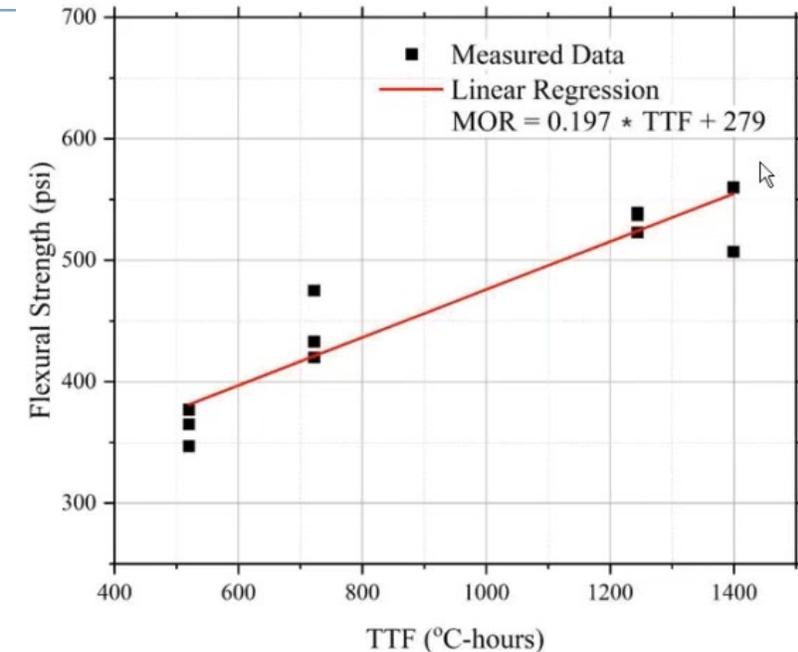
- Optimized Aggregate Gradation
 - Special provision (remove min. cement, provide gradation, % paste)
 - Allowing for contractor submittal of mixture
 - Agency providing mixture gradation (with assistance from CP Tech)
 - Plant monitoring by agency (limited frequency) and contractor (more frequent) as part of QC plan
 - Adjustments if needed taken by contractor
 - Georgia has monitoring program in place currently
 - Industry (aggregate suppliers) seem to be ready to supply #89 stone, can blend #89 and #57 stone if 3rd bin is an issue
 - Pilot project candidates may include ramps, maintenance projects or structural bridge deck project
- Shrinkage – will improve with Optimized Aggregate Gradation
- Resistivity
 - Take resistivity measurements as part of pilot projects, look at results at 28 days and 56 days
- Maturity

2022 Discussion cont.

- DOT is considering purchase of SAM and Resipod equipment
 - Equipment could be purchased as part of a project
- Contracting industry comments:
 - Will have concern if timing of testing differs from conventional
 - Need enough construction days to actually do the paving
 - Lowering of opening strength is favorable
 - Optimized gradation (blended aggregate) is a ready mix item

Maturity Method AASHTO T413

- **Focus on early strength development - establish curve during construction**
- 12 specimens (compression or flexural)
- 2 specimens need temperature sensor
- Test min. 2 specimens at 4 ages, first strength test must be 18 - 24 hours
- First test has to be less than 85% of target opening strength
- Minimum 2 sensors/probes placed per day with one at the end of the day



CP Tech Webinar on Maturity