Research

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INTRODUCTION

For Today's Presentation

Colloidal Silica: Cement Enhancing Admixture Product Evaluation

Application of Internal Curing to Improve Concrete Bridge Deck

M&R MATERIALS & RESEARCH

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Colloidal Silica: Cement Enhancing Admixture Product Evaluation

Preliminary Lab work

Motivation to Research

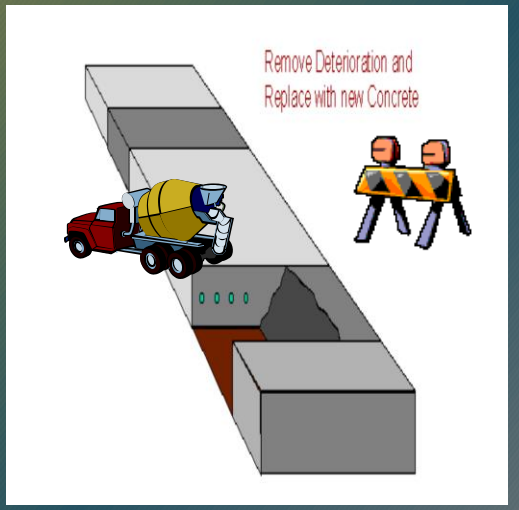
Colloidal Silica presented by Intelligent Concrete, Inc. at NCPA Conference in 2019

Product name: Nouryon's colloidal silica

- Solution to the Increase Shortage of Class F Fly Ash
  - Environmental Regulations
- ASR Mitigation Capabilities
  - CS w/F-ash Performs better than F-ash alone
- Other Benefits
  - Higher Strengths
  - Lower Permeability
  - Lower HRWR use

Purpose of the Investigation

Develop cost effective patching materials that provide sufficient early strength (a minimum 3,000 psi compressive strength in 4-8 hours) for proper traffic opening.



- Determine if CS can enhance high, early strength for use in patching and repairs.
- Determine if CS can maintain or improve ASR mitigation as F-ash content is decreased.

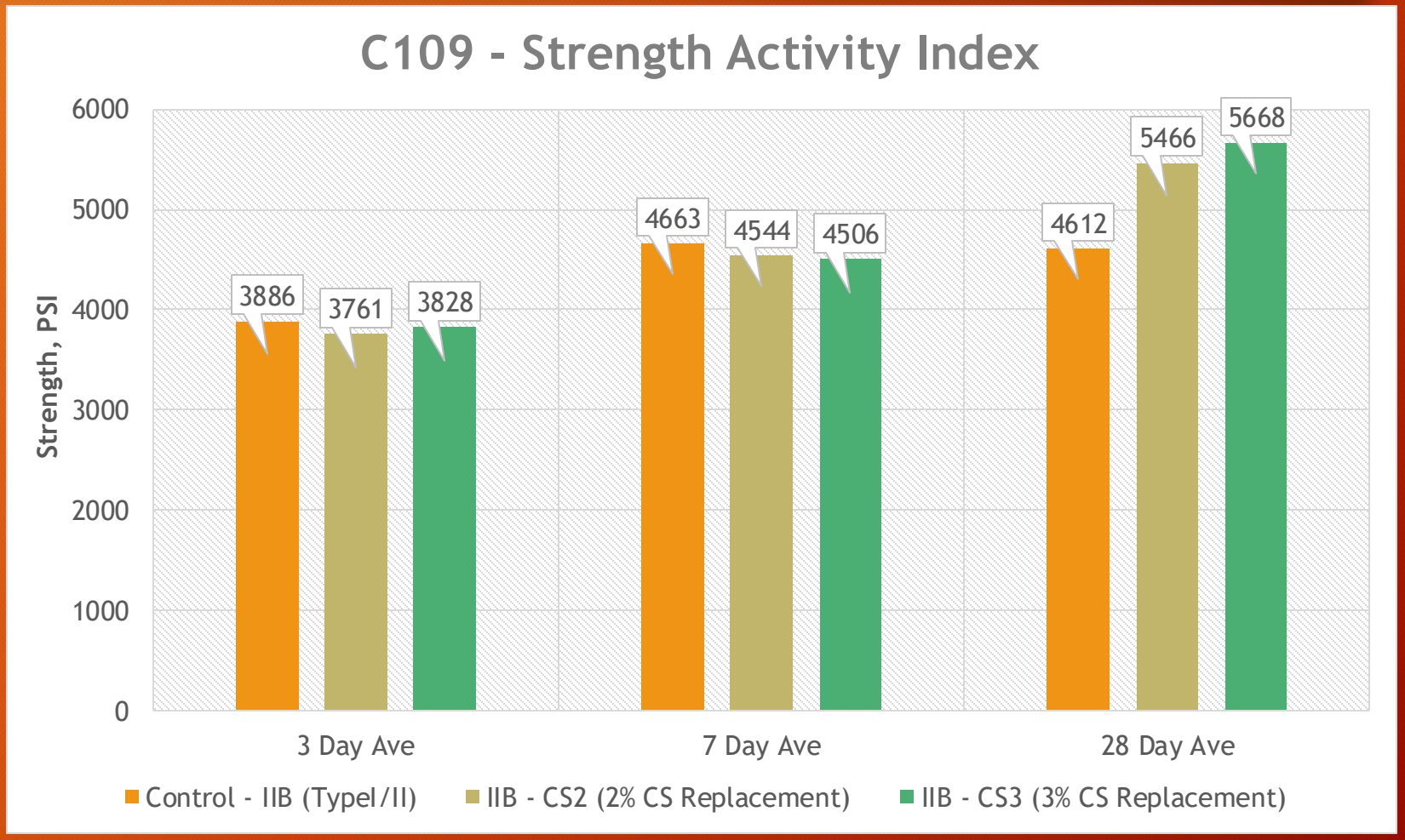
Colloidal Silica Testing
Admixture (Addition) vs. SCM (Replacement)

Summary Table: CS Addition vs. Replacement

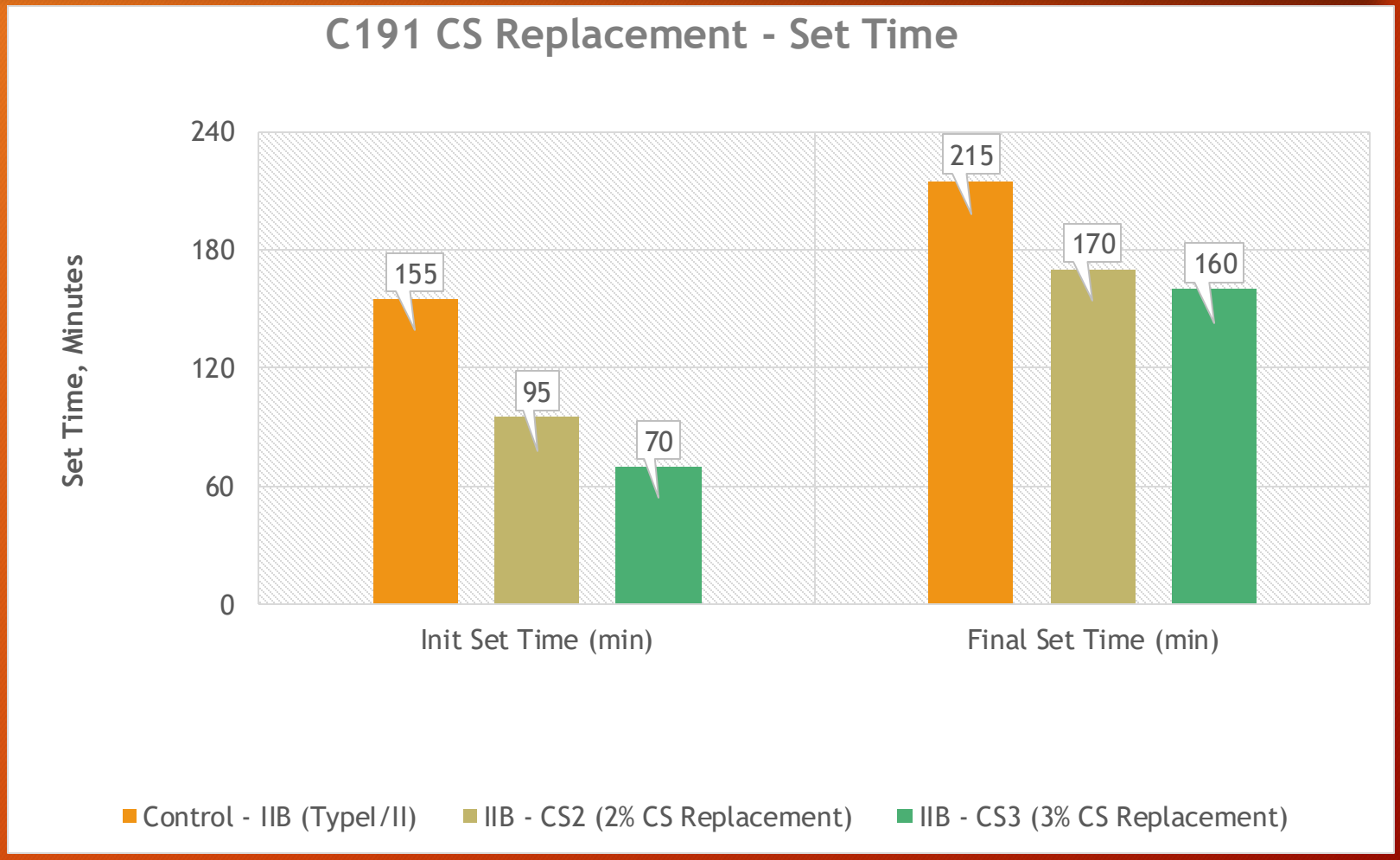
Key Differences at a Glance

Feature	Admixture (Addition)	SCM (Replacement)
CS Role	Added on top	Replaces cementitious
Total Mass	Increases	Remains constant
Cement/F-Ash Ratio	Unchanged	May change
Implementation Complexity	Low	High

Strength Activity Index : Type II
CS Replacement



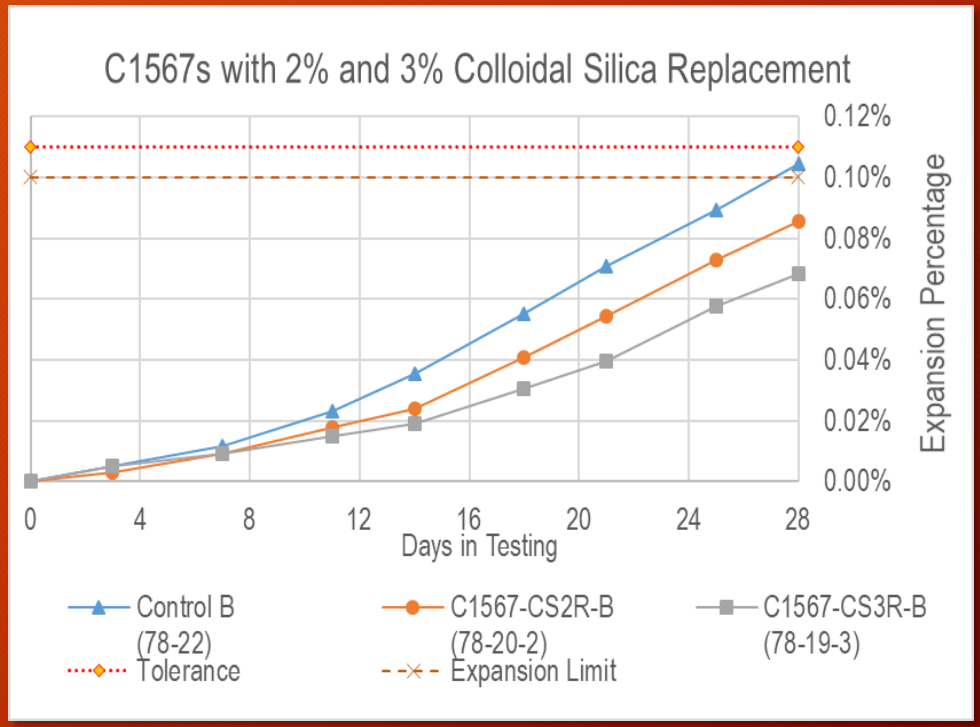
Set Time Testing: Type II Cement
CS Admixture Replacement



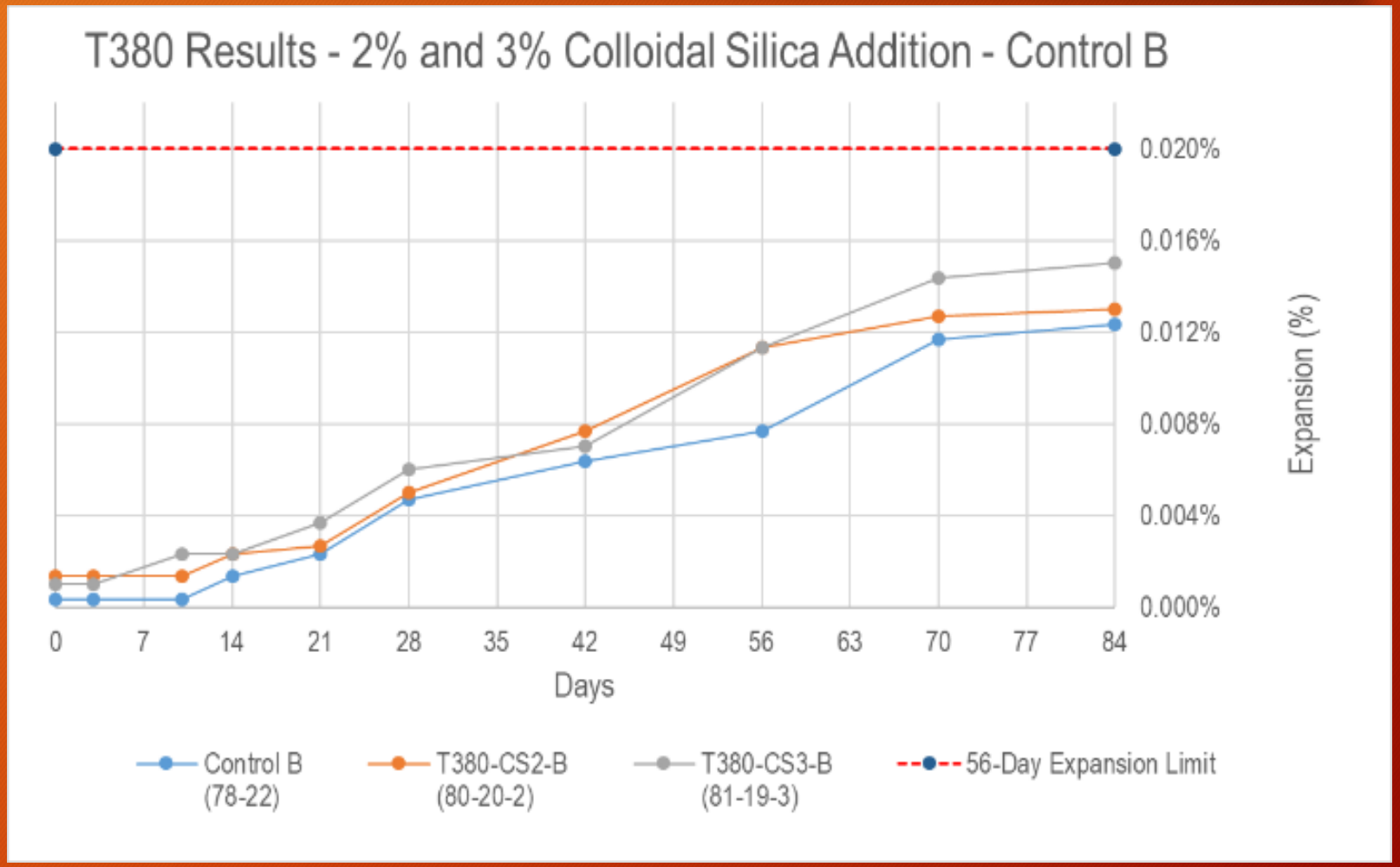
Matrix 3 – CS Replacements (SCM) for C1567s

Matrix 3				
C1567 Replacement	Percentage %			CaO/SiO_2 Ratio
	I/II	F-ash	CS	
Control B	78	22	0	1.81
C1567-CS2R-B	78	20	2	1.83
C1567-CS3R-B	78	19	3	1.85

- All Samples pass C1567
- CS at 3% replacement expanded the least, 0.07%



AASHTO T380 (Miniature Concrete Prism Test, MCPT)



Final Thoughts

- Colloidal silica (CS) is effective in mitigating Alkali-Silica Reaction (ASR) when replacing Class F fly ash at 2–3% levels.
- CS-treated cements achieved comparable or superior strength and set time performance, particularly with Type I/II cement (up to 1000 PSI strength gain at 28 days and 45–55 min faster set time).
- Material cost is a significant barrier: 3% CS increases concrete cost by approx. 66% not recommended for PR patches.

Recommendations:

- Use CS selectively in applications where:
  - ASR mitigation is critical and fly ash supply is limited.
  - Early strength gain or faster set time is needed (e.g., fast-track projects).
- CS may be cost-effective as a remedial option for:
  - Ready-mix suppliers with non-compliant IP cement.
  - Avoiding removal from NDOT's Approved Products List due to ASR issues.
- Further cost-benefit analysis and field trials are recommended before large-scale implementation.

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Internal Cured (IC) Concrete with E5 IC Admixtures

Research Main Objective

The main objective is to improve concrete durability by minimizing the shrinkage cracks. Shrinkage cracking in concrete is a key limiting factor in achieving acceptable long-term performance in concrete bridges, rails and repairs.

NDOT Through Research Targeted

Improving Mix Design

- Develop concrete mixtures with reduced-cementitious materials content (RCMC) for bridge decks and rails to minimize early-age shrinkage cracks.

Improve Curing Method

- The goal will be to cut back on the number of days of wet curing and improving current curing practices

Mix Design for Conventional Bridge Deck Applications

Class of Concrete (1)	Base Cement Type	Total Cementitious Materials Min. lb./cy	Total Aggregates	
			Min. lb./cy	Max lb./cy
47B**		564	2850	3150
47B***		564	2850	3150
47BD	IP/IT/IS*	658	2500	3000
47B-HE		752	2500	3000
BX(4)		564	2850	3150
47B-OL****		564	2850	3200
PR1	I/II/IL	752	2500	2950
PR3	III	799	2500	2950
SF(5)	I/II/IL	589	2850	3200

Table 1002.02 (Continued)

Class of Concrete (1)	Air Content % Min-Max (2)	Ledge Rock (%)	Water/Cement Ratio Max (3)	Required Strength Min. psi
47B**	6.5-9.0	-	0.45	3500
47B***	6.0-8.5	-	0.45	3500
47BD	6.0-8.5	30±3	0.42	4000
47B-HE	6.0-8.5	30±3	0.40	3500
BX(4)	6.0-8.5	-	0.45	3500
47B-OL****	5.0-7.0	30±3	0.36	4000
PR1	6.0-8.5	30±3	0.36	3500
PR3	6.0-8.5	30±3	0.45	3500

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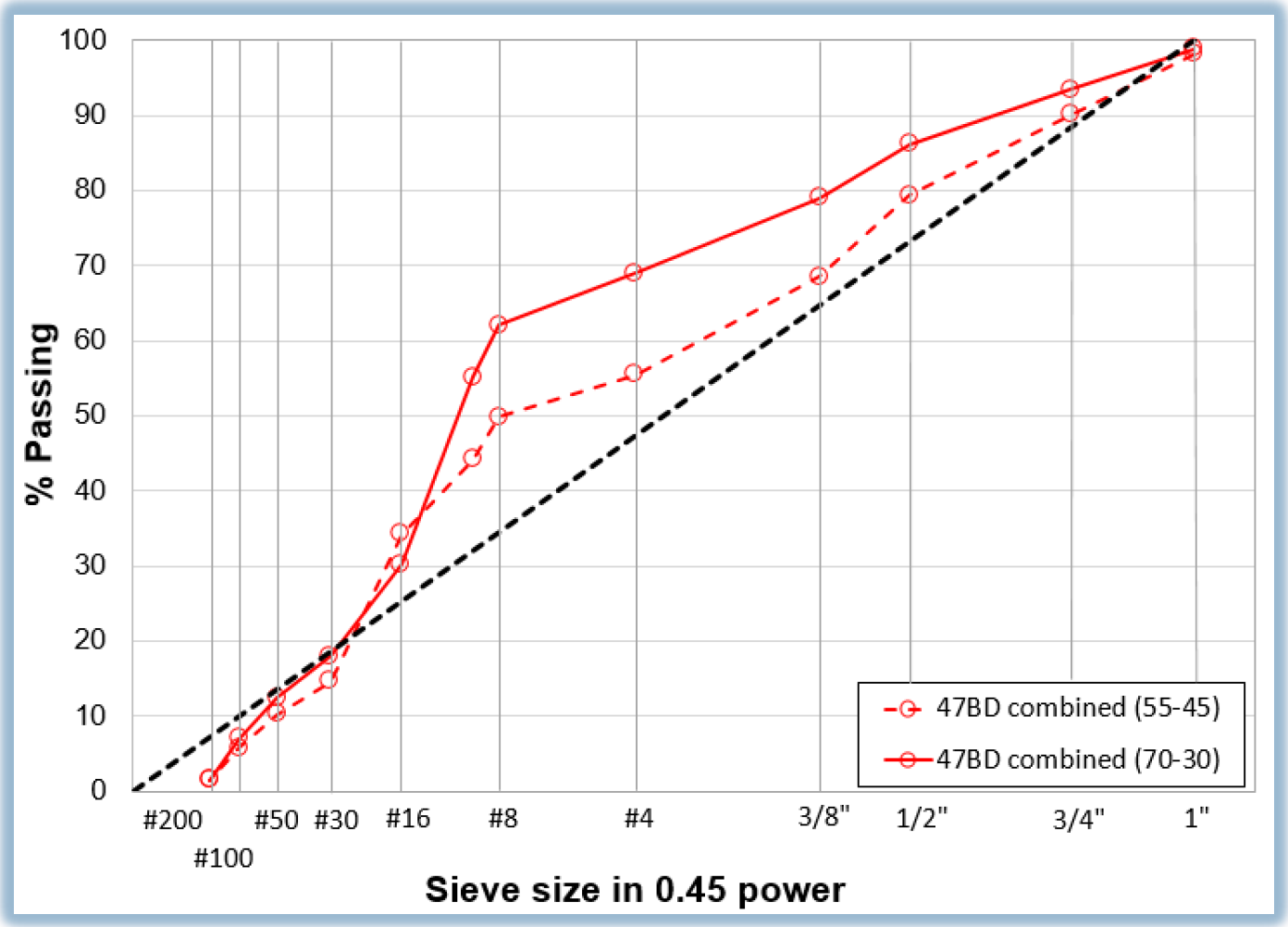
U.S.Department of Transportation
Federal Highway Administration

Research - Mix Design Proposed for Bridge Deck Applications



NEW TECNIQUES TO IMPROVE CURING

NDOT Research on Internal Curing Materials

Lightweight fine aggregate (expanded clay and expanded shale)

Admixtures

E5 NANO SILICA

Nanosilica or silica dust, is a material that, like Silica Fume, is characterized by its high SiO2 percentage, over 99%.

E5 INTERNAL CURE

Internal Curing **Expanded Shale**

NDOT Research Follow up Implementation

Completed 2023

Project: STP-50-1 (117)
Pawnee City-Southeast Bridges
ICC Test Pour

NDOT Field Implementation

All the mechanical and permeability properties were tested by Materials and Research PCC Laboratory.

Every Day Counts
Innovation for a Nation on the Move

Enhancing Performance with Internally Cured Concrete EDC-7

Internal Curing

Research Follow up Implementation

Project: STP-50-1 (117)
Pawnee City-Southeast Bridges
ICC Test Pour

Field Implementation – Mechanical and Permeability Properties

Mix Design

Mix ID	Mix Agg. Proportions	Cement (pcy)	W/SCM Ratio at placement	Measured Air Content ASTM C231	Measured Unit Weight ASTM C138 Cu.yd
47BD -Control	30%CA/70%FA	658	0.40	6.4%	140.4
47B-IC20	32% CA/52%FA/*16%EP	658	0.41	8.5%	131.2

*Lightweight Fine Aggregate (Expanded Shale)

Mechanical Properties Test Results

(Type of Mix)	Compressive Strength (Cylinders) ASTM C39 Plastic Concrete 3 Cylinders Average (Psi)				Flexure Strength ASTM C78 6 Specimen Average (Psi)
Age (Days)	7	14	21	28	
47BD	4510	5570	6110	6580	919
47BD-IC	3820	4870	5440	5550	740

Internal Curing

Research Follow up Implementation

Project: STP-50-1 (117)
Pawnee City-Southeast Bridges
ICC Test Pour

Field Implementation – Mechanical and Permeability Properties

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*Lightweight Fine Aggregate (Expanded Shale)

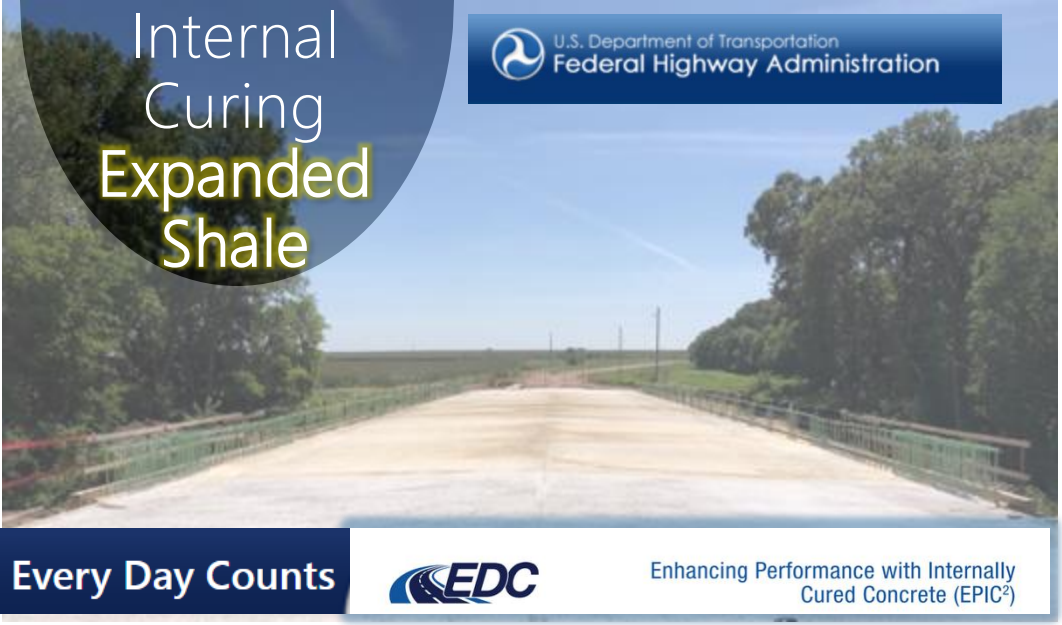
Permeability & Durability Properties Test Results –

(Type of Mix)	Shrinkage ASTM C 157 (at 64 of 64 weeks) (Percent length change) Air Test Environment	Shrinkage ASTM C 157 (at 64 of 64 weeks) (Percent length change) Wet Test Environment	Freeze and Thaw ASTM C666 Durability Factor after 300 cycles*	Rapid Chloride Ion Permeability AASHTO T277 (Coulomb Passed) 4x8 Cylinder Kohm-cm	NDOT Wet & Dry Test
47BD	-0.07% @64 weeks	-0.01% 64 weeks	70% @ 300 cycles	45.73 Very Low	Passed
47BD-IC	-0.05% @64 weeks	-0.01% 64 weeks	80% @ 300 cycles	40.205 Very Low	Passed

Note*NDOT: Durability factor > 70% and mass loss < 5% ASTM C 666: Durability Factor > 70 %

Wet & Dry Test Chamber

The NDOT Wet & Dry test evaluates the behavior of the mix under heating and cooling environment for 18 months.



Research Follow up Implementation

Project: STP-50-1 (117) Pawnee City-Southeast Bridges ICC Test Pour

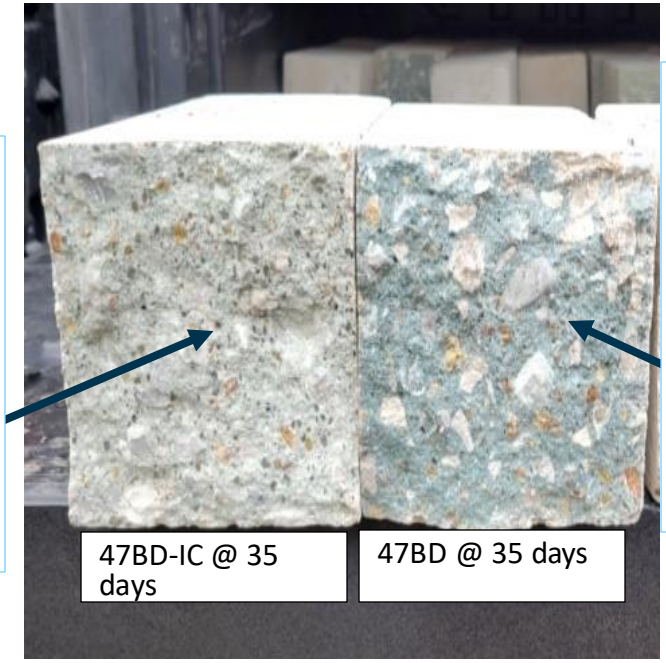
Year Performance

NDOT monitored the bridged before overlay

Visual Observations

1. 47B Control
2. 47BD-IC

This specimen shows the internal curing "supplying water into the fresh concrete place" even when using concrete containing slag as a supplemental cementitious material



This greenish hue is a normal appearance on concrete containing slag as a cementitious material. This will disappear with time, generally within a one-year period. Concrete containing slag cement does, however, have a generally lighter color.

Internal Curing Admixtures

Internal Cure

Benefits

Nanosilica or silica dust, is a material that, like Silica Fume, is characterized by its high SiO2 percentage, over 99%.

Placement

- Improved workability
- No water applied on the surface
- Longer window for finishing
- Minimal bleed rate
- Eliminate evaporative retardants (90% water)
- Consistent air entrainment
- Lower pump pressure
- Reduction in wet curing

Hardened concrete

- Cement/paste reduction
- Improved strength
- Minimal to zero cracking
- Reduced permeability


Thank you
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CONCRETE CO.
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Proposed New Mixes

NEW Mix Designs Tested

Mix ID Cements Decrease 94 lbs	Mix Agg. Proportions	Type IS Cement (pcy)	W/SCM Ratio	Measured Air Content ASTM C 231	Measured Unit Weight ASTM C138 Cu.yd	Water Reducer (floz/cwt)
O47BD – Control	**45%CA/55%FA**	**564**	**0.43**	**8.5**	**Not measure**	**3.01**
O47BD- with E5			0.45	6.3	141.4	1.60
O47BD- with E5			0.47	7.6	138.6	1.60
O47BD- with E5 w/ Liquid Fly ash			0.45	6.3	141.4	3.01
O47BD-Cements **Decrease 141 lbs** with E5 w/ Liquid Fly ash		517	0.48	7.1	139.0	2.90

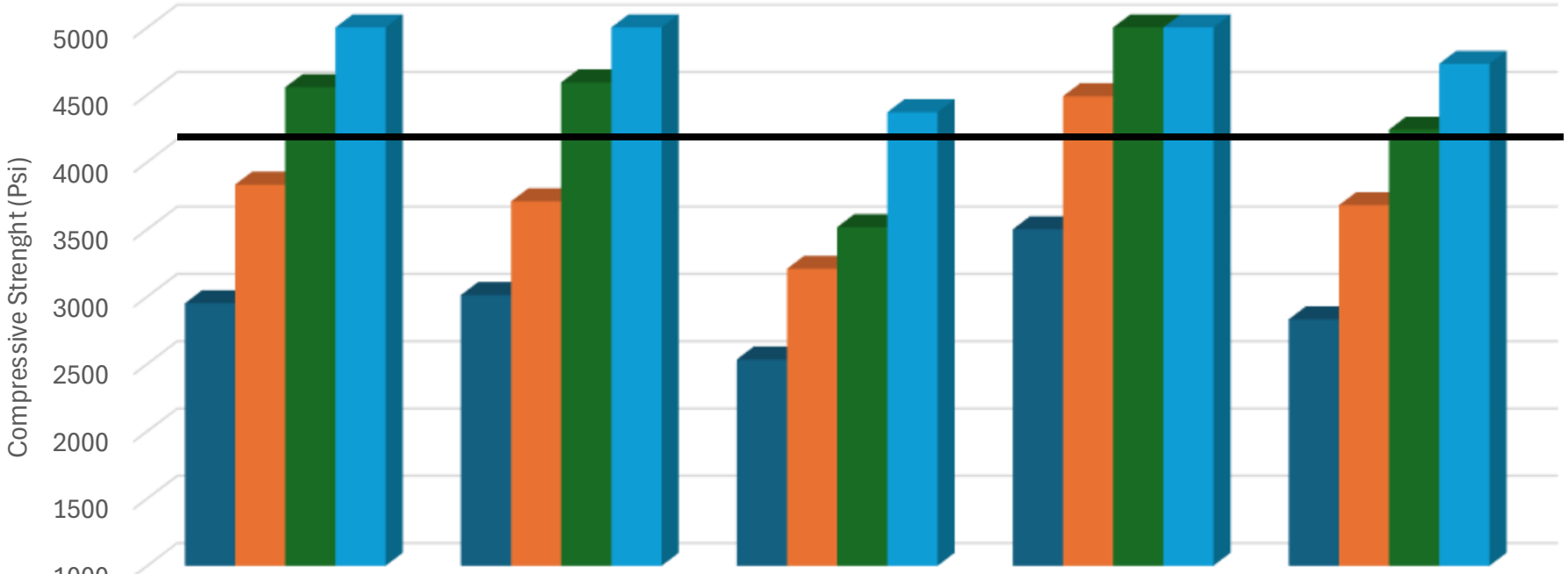
Note : E5 Admixture requires additional water due to the Nano Silica

Test

Mechanical & Durability Properties

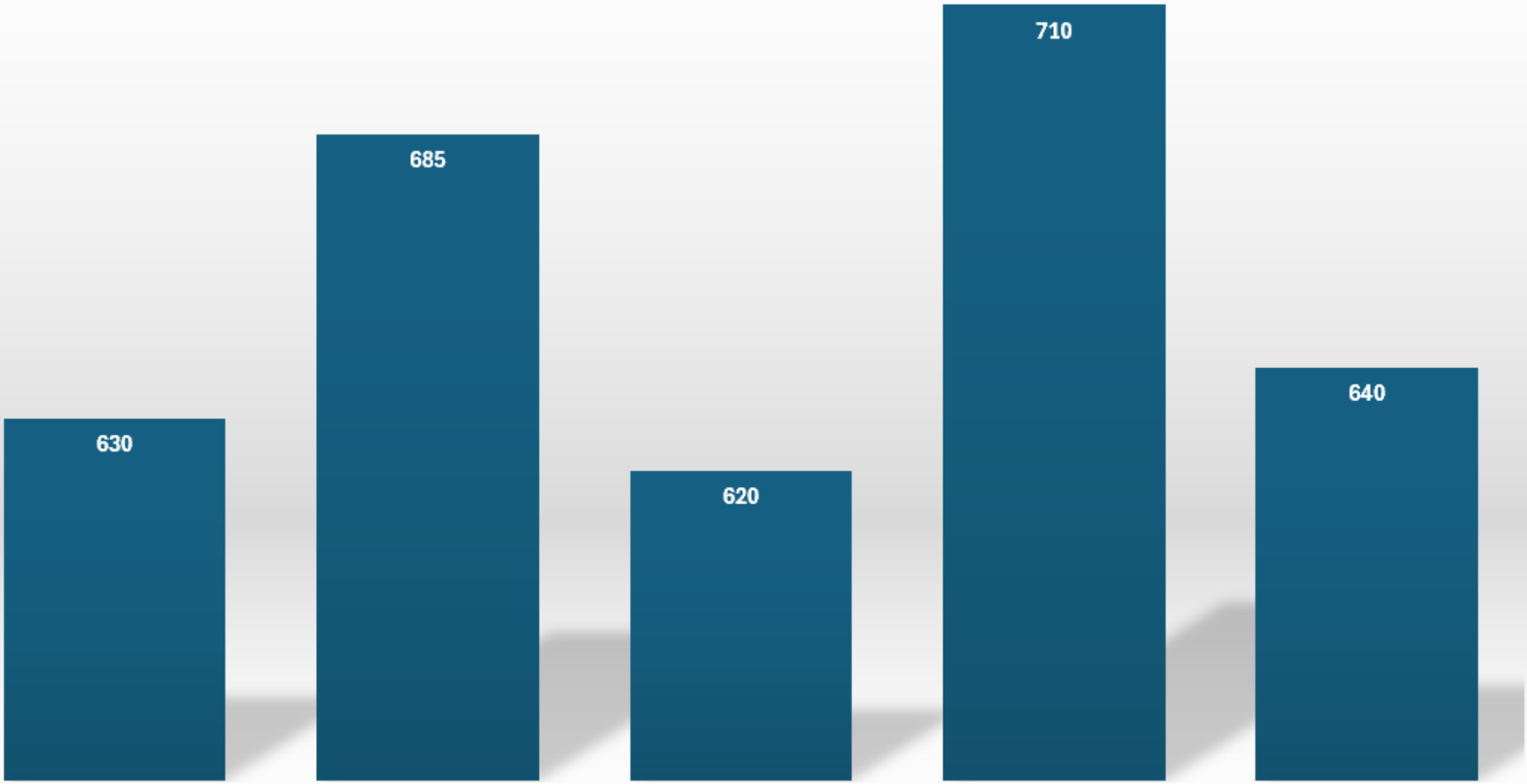
To ensure workability and constructability so that the mixes can be easily used in engineering applications

Compressive Strength ASTM C 39
Results Average 3 Cylinders



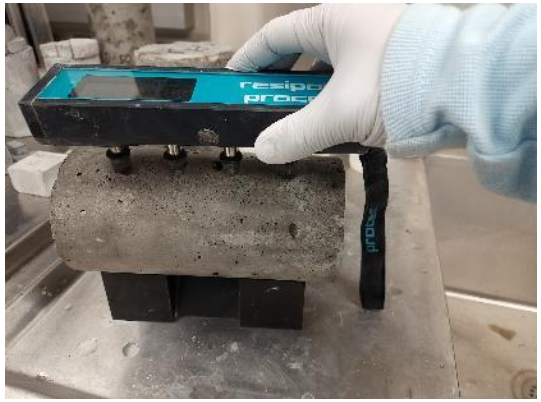
	O47BD – Control **0.43 w/c**	O47BD- with E5 **0.45 w/c**	O47BD- with E5 **0.47 w/c**	O47BD- with E5 w/ Liquid Fly ash **0.45 w/c**	O47BD-Cements Decrease 141 lbs with E5 w/ Liquid Fly ash **0.48 w/c**
7 days	2951	3012	2533	3500	2831
14 days	3832	3708	3207	4489	3680
28 days	4556	4592	3516	5062	4241
56 days	5030	5080	4370	5600	4730

Flexure Strength ASTM C 78 @ Psi 28 days
Results Average 6 Beams



Permeability Properties Test Results

Mix ID Cements Decrease 94 lbs	Rapid Chloride Ion Permeability AASHTO T277 (Coulomb Passed)** 4x8 Cylinder Kohm-cm 28 Days	Rapid Chloride Ion Permeability AASHTO T277 (Coulomb Passed)** 4x8 Cylinder Kohm-cm 56 Days	NDOT Wet & Dry Test 18 months test
O47BD – Control	**36.5 Low**	**52.18 Very Low**	**In Progress**
O47BD- with E5	**27.0 Low**	**49.55 Very Low**	
O47BD- with E5	**27.24 Low**	**48.89 Very Low**	
O47BD- with E5 w/ Liquid Fly ash	**42.25 Very Low**	**71.54 Very Low**	
O47BD- Cements **Decrease 141 lbs** with E5 w/ Liquid Fly ash	**36.25 Low**	**55.04 Very Low**	



Electrical Resistivity* (kΩ-cm)	Chloride Ion Permeability
<12	High
12-21	Moderate
21-37	Low
37-254	Very Low
>254	Negligible

Durability

Shrinkage Test is a 64 weeks Test

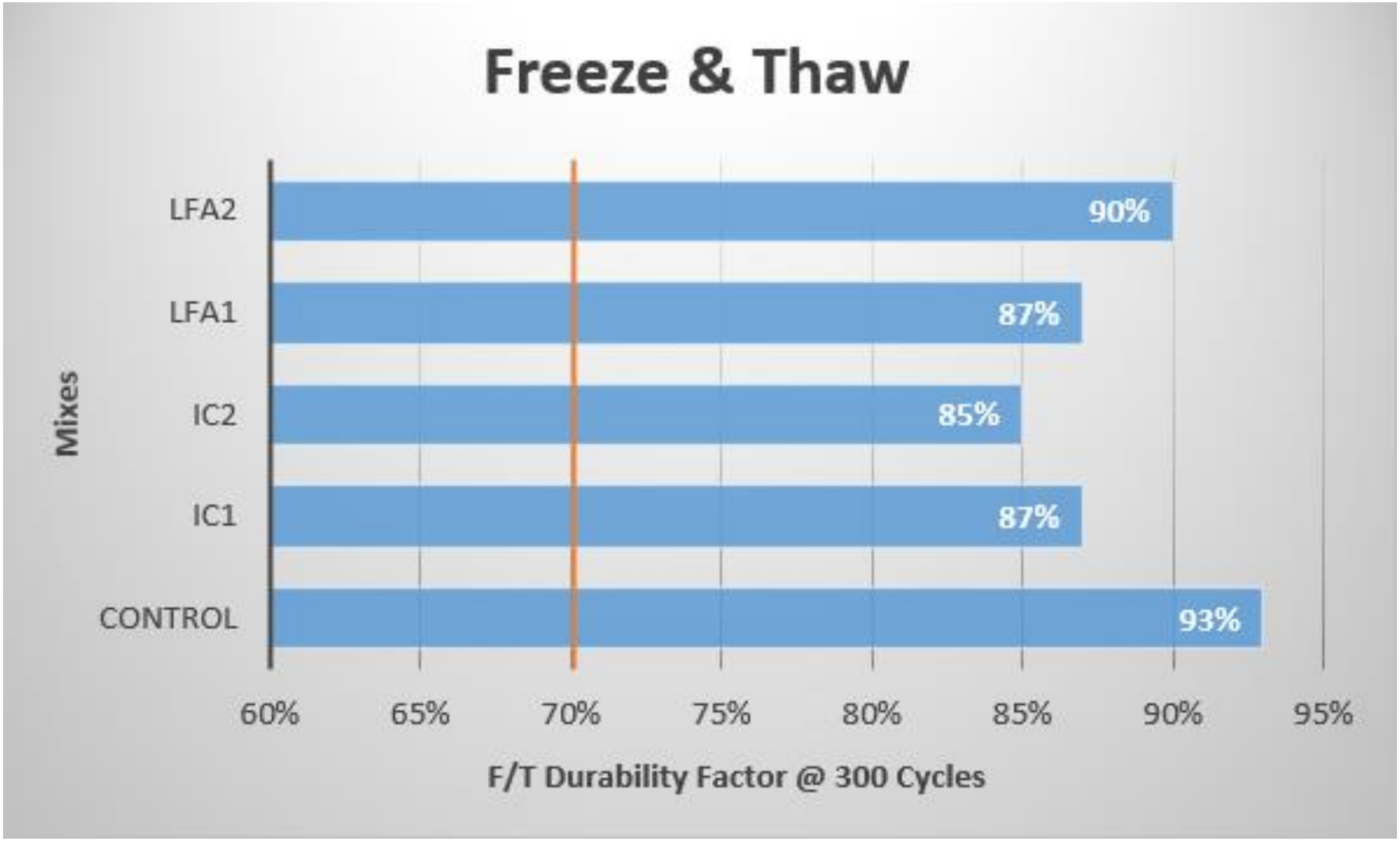
Average of 2 specimens

Mix ID Cements Decrease 94 lbs	Shrinkage ASTM C 157 (Percent length change)	W/SCM Ratio
O47BD – Control	**-0.04% @ 32 of 64 weeks**	**0.43**
O47BD- with E5	**-0.04%@ 32 of 64 weeks**	0.45
O47BD- with E5	**-0.06% @ 32 of 64 weeks**	0.47
O47BD- with E5 w/ Liquid Fly ash	**-0.02% at 32 of 64 weeks**	0.45
O47BD-Cements **Decrease 141 lbs** with E5 w/ Liquid Fly ash	**-0.05% @ 32 of 64 weeks**	0.48

Controlled Conditions Of Temp. and moisture.

Durability- Freeze & Thaw

Average of 3 specimens



NDOT: Durability factor > 70%

Mass Loss < 5% : Durability Factor

Control Mix – Visual Observation 84 days

O47 BD with E5–

Visual Observation

Internal Curing @ 84 days

047BD with E5 and LFA–

Visual Observation

Internal Curing @ 84 days

Lessons Learned

- Reduction of Cement
  - LCC Mix shows mechanical properties (Compressive Strength, Modulus of Elasticity and Flexure strength) comparable to the 47BD control.

- E5 Mixes
  - Requires more water in the mix
  - Using LFA Improved strength
  - Using E5 with LFA Reduced permeability

NEXT STEPS

- Bridge Division has identified several bridges in District 1 and District 2 to implement a bag (94 pounds) of cement reduction and the use of E5 with LFA.
- District 1
  - Control – 47BD standard mix
  - ICE5LF – O47BD
- M&R will test fresh properties, mechanical and durability properties for both mixes.
- M&R will follow up with its performance by testing and field Observations.


IT'S NOT CALLED
CEMENT IT'S
CONCRETE!!!!