

# Research



*By*  
**Wally Heyen – NDOT PCC Engineer**



# Lightweight Fine Aggregate (LWFA) and Colloidal Silica Admixture in Bridge Decks



# “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

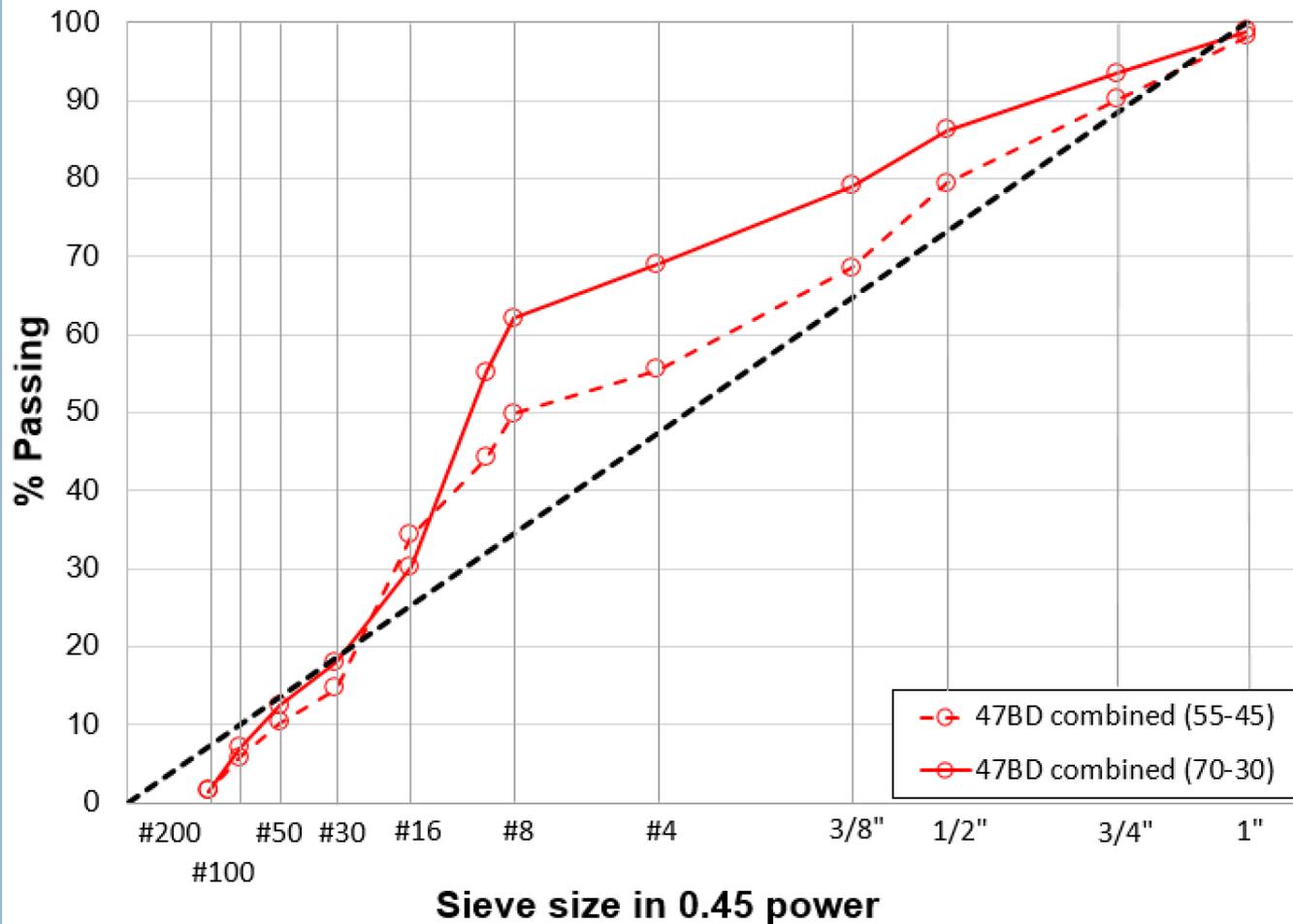


Class of Concrete (1)	Base Cement Type	Total Cementitious Materials Min. lb/cy	Total Aggregate	
			Min. lb/cy	Max. lb/cy
47B**		564	2850	3150
47B***		564	2850	3150
47BD	IP/IT*	658	2500	3000
47B-HE		752	2500	3000
BX <sub>(4)</sub>		564	2850	3150
47B-OL****		564	2850	3200
PR1	I/II	752	2500	2950
PR3	III	799	2500	2950
SF <sub>(5)</sub>	I/II	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 <sub>(4)</sub>	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
SF <sub>(5)</sub>	6.0 - 8.5	50±3	0.36	4000

# Research - Mix Design Proposed for Bridge Deck Applications



# NEW TECHNIQUES TO IMPROVE CURING



## NDOT Research on Internal Curing Materials

Lightweight fine aggregate  
(expanded clay and expanded shale)



Neal Creative ©

## Admixtures



Nanosilica or silica dust, is a material that, like Silica Fume, is characterized by its high SiO<sub>2</sub> percentage, over 99%.



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.



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)
	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

### 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)

### 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 %



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

Wet & Dry Test Chamber

# Internal Curing Expanded Shale



U.S. Department of Transportation  
Federal Highway Administration



Every Day Counts



Enhancing Performance with Internally Cured Concrete (EPIC<sup>2</sup>)

## Research Follow up Implementation

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

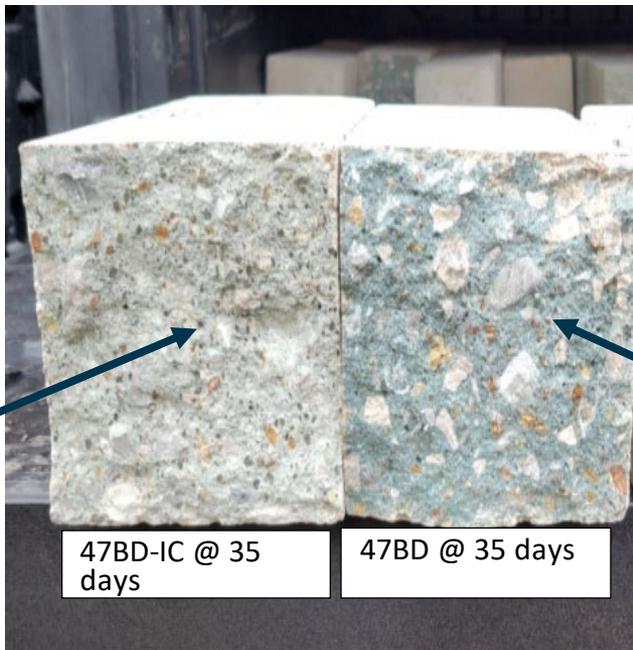
### Year Performance

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



47BD-IC @ 35 days

47BD @ 35 days

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  
Expanded  
Shale



U.S. Department of Transportation  
Federal Highway Administration

Every Day Counts



Enhancing Performance with Internally  
Cured Concrete (EPIC<sup>2</sup>)

## Research Follow up Implementation SUMMARY

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

### LWFA Presoaking & Handling

- Presoaking cycle: 6 hrs on / 6 hrs off
- Spec requirement:
  - 72 hrs watering + 13 hrs drainage
- Actual:
  - 18 hrs drainage due to placement delay
- Recommendation:
  - Revisit LWFA moisture control specifications

# Internal Curing Expanded Shale



U.S. Department of Transportation  
Federal Highway Administration

## Research Follow up Implementation- **SUMMARY**

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

Every Day Counts



Enhancing Performance with Internally  
Cured Concrete (EPIC<sup>2</sup>)

### Implementation Challenges

#### Unexpected Heavy Rain:

- Site access impacted
- Delay in operations

#### Pumping Issues:

- Caused by 50 ft of horizontal rubber hose
- Resulted in delay for first 2 trucks
- Root Cause: Inadequate priming with cement slurry

### **Conclusion**

LWFA-supported internal curing is **viable** for bridge **decks**

### **Concrete performance met NDOT standards**

- Key Recommendations:
  - Improve pumping practices (proper priming)
  - Tighter control on LWFA moisture content
  - Minor spec revisions for future implementations

# Internal Curing Expanded Shale



U.S. Department of Transportation  
Federal Highway Administration



Every Day Counts



Enhancing Performance with Internally Cured Concrete (EPIC<sup>2</sup>)

## 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- Longitudinal Cracks  
47B Control



# Internal Curing Expanded Shale



U.S. Department of Transportation  
Federal Highway Administration



Every Day Counts



Enhancing Performance with Internally  
Cured Concrete (EPIC<sup>2</sup>)

## 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- No Cracks  
47BD-IC



# Internal Cure

## Benefits



Nanosilica or silica dust, is a material that, like Silica Fume, is characterized by its high SiO<sub>2</sub> 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  
Platte River Concrete



**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 (fl.oz/cwt)
<b>O47BD – Control</b>	<b>45%CA/55%FA</b>	<b>564</b>	<b>0.43</b>	<b>8.5</b>	<b>Not measure</b>	<b>3.01</b>
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 <b>Decrease 141 lbs</b> 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

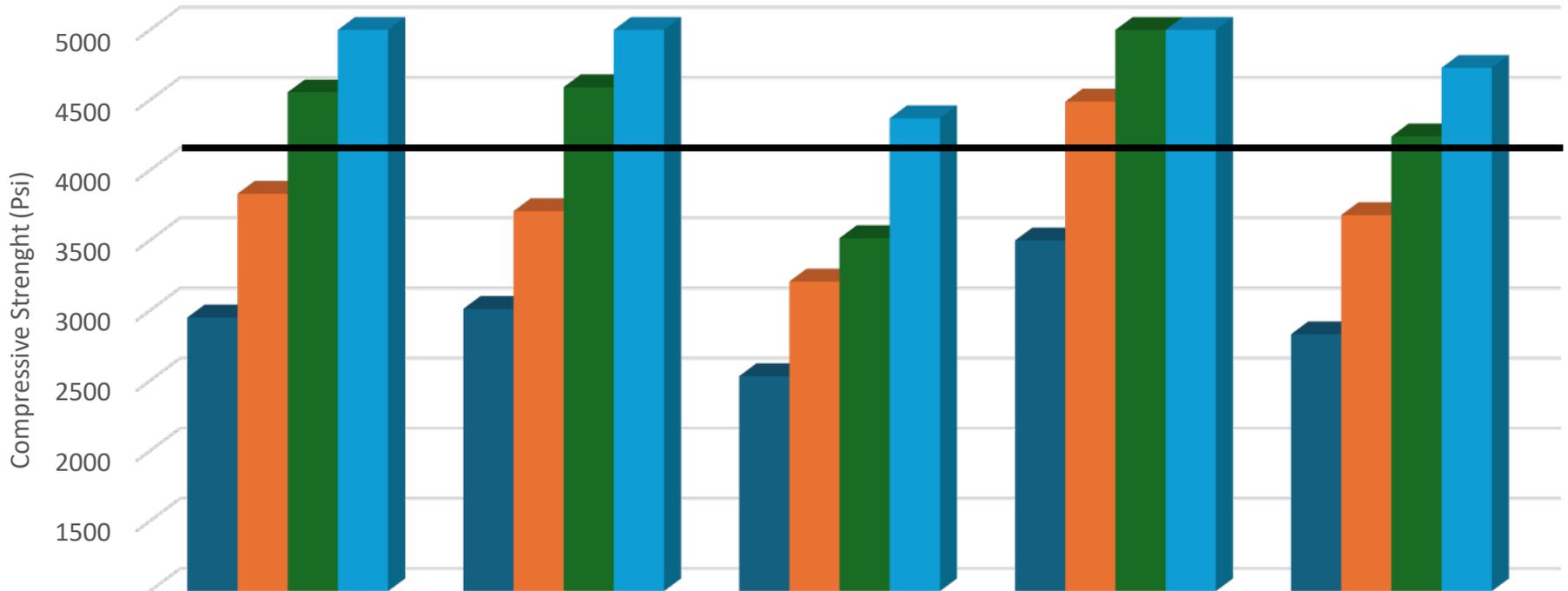
**Test**

**Mechanical  
&  
Durability  
Properties**



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

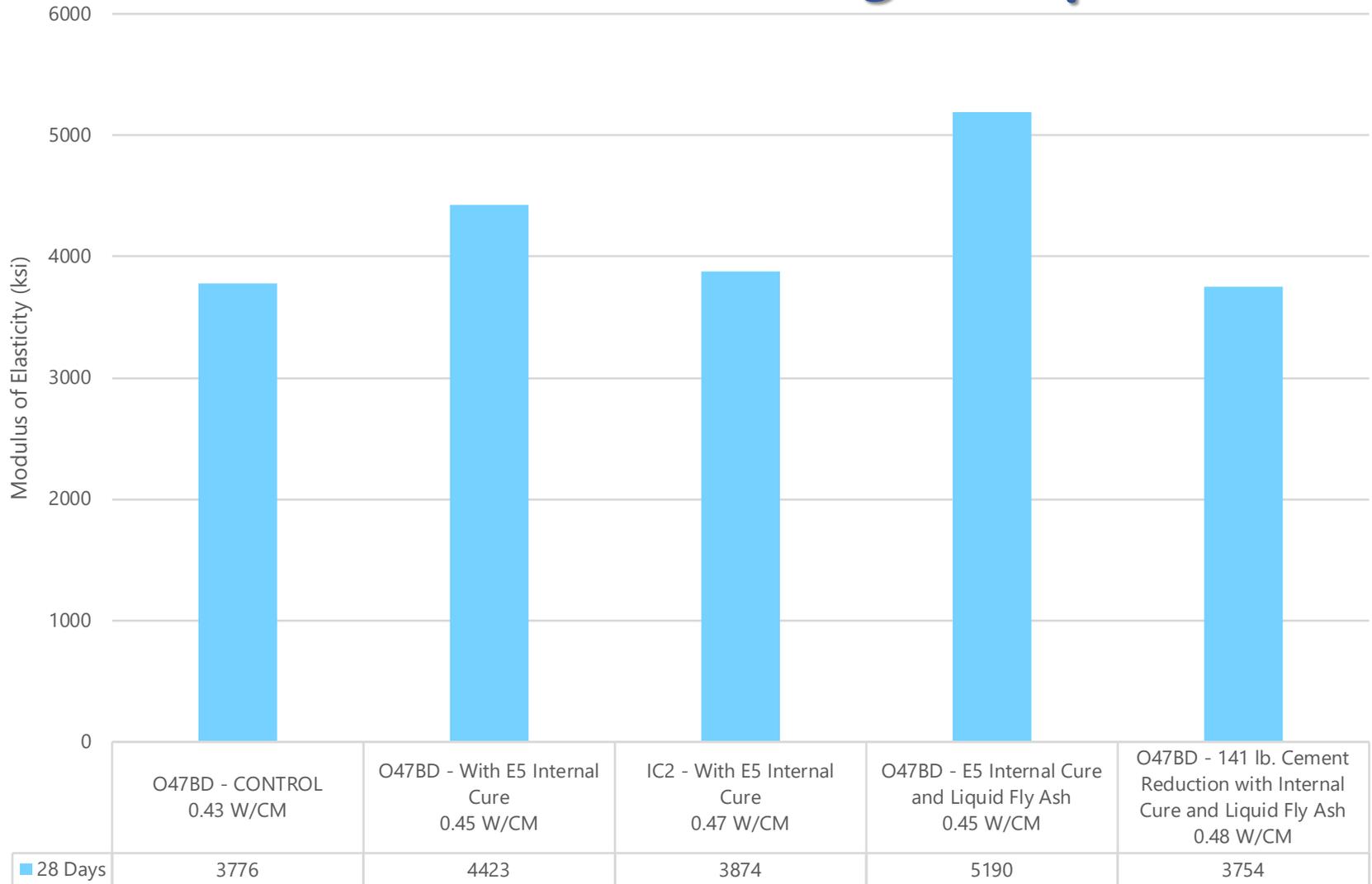
# Compressive Strength ASTM C 39 Results Average 3 Cylinders



	047BD – Control 0.43 w/c	047BD- with E5 0.45 w/c	047BD- with E5 0.47 w/c	047BD- with E5 w/ Liquid Fly ash 0.45 w/c	047BD-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

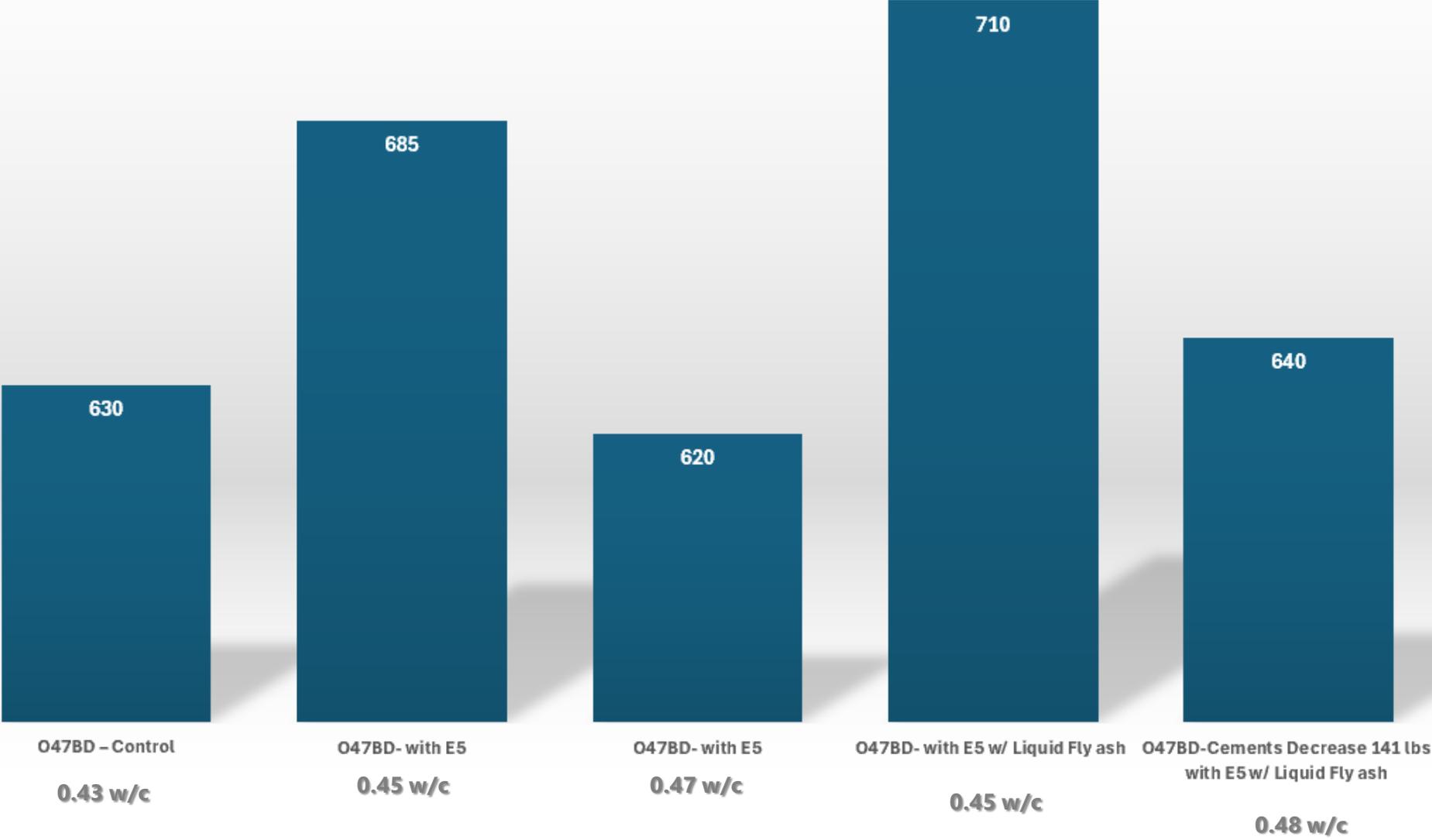
# Modulus of Elasticity of Concrete

## ASTM C469 Results average 2 specimens



# 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

NDOT plans to perform in future field implementation the Modified Test Method for Permeability

# Durability

## Shrinkage Test is a 64 weeks Test

Average of 2 specimens

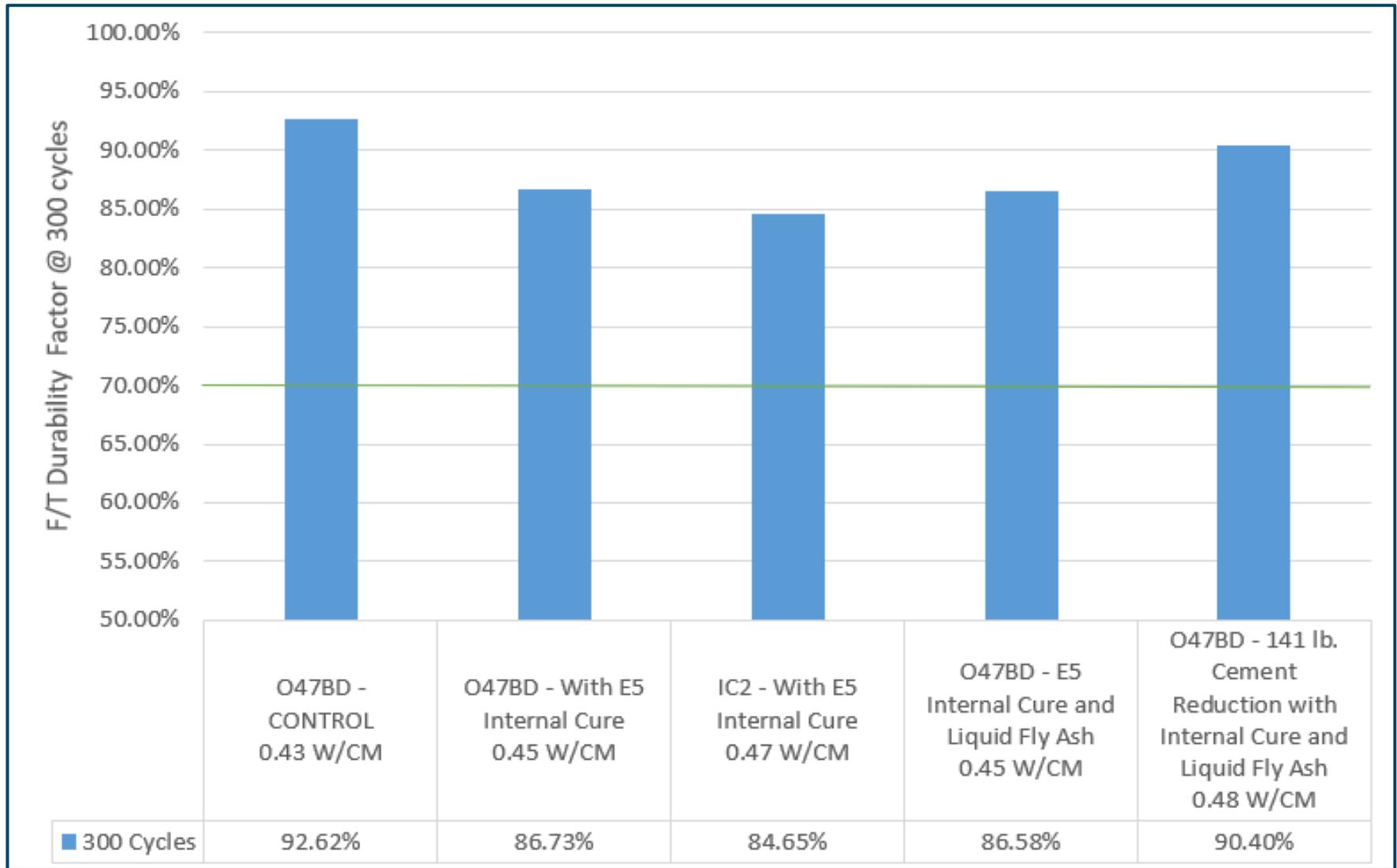
Mix ID Cements Decrease 94 lbs	Shrinkage ASTM C 157 (Percent length change)	W/SCM Ratio
O47BD – Control	-0.04% @ 32 of 64 weeks	0.43
O47BD- with E5	-0.04% @ 32 of 64 weeks	0.45 ↑
O47BD- with E5	-0.06% @ 32 of 64 weeks	0.47 ↑
O47BD- with E5 w/ Liquid Fly ash	-0.02% at 32 of 64 weeks	0.45 ↑
O47BD-Cements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



**O47BD 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
- NDOT M&R will test fresh properties, mechanical and durability properties for both mixes.
- NDOT M&R will follow up with its performance by testing and field Observations.



# Questions/Discussion

**NEBRASKA**

Good Life. Great Journey.

---

DEPARTMENT OF TRANSPORTATION