



Durability of Concrete Bridge Decks

Project Investigators

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Corrosion of steel & concrete spalling



Plywood boards

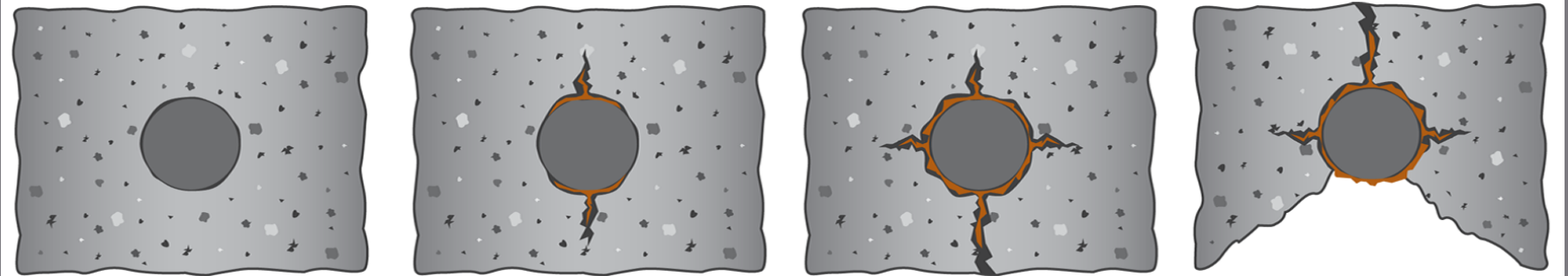
Study aims to **quantify the factors** controlling the onset of concrete spalling



Research Objective

- To develop performance based thresholds and procedures to identify concrete bridge decks experiencing high risk for falling concrete
- Scope
 - Laboratory investigation to quantify the development of concrete degradation and steel corrosion
 - freeze-thaw & salt-water exposure
 - repeated loading.
 - Field exploration to quantify in-service concrete degradation

Corrosion Development



- Corrosion rates up to $100 \mu\text{m}/\text{year}$
- Critical chloride levels in concrete
 - 5 ± 4 lbs/cyd for black steel
 - 8 ± 7 lbs/cyd for epoxy coated steel
- Concrete PH levels $< 9-11$

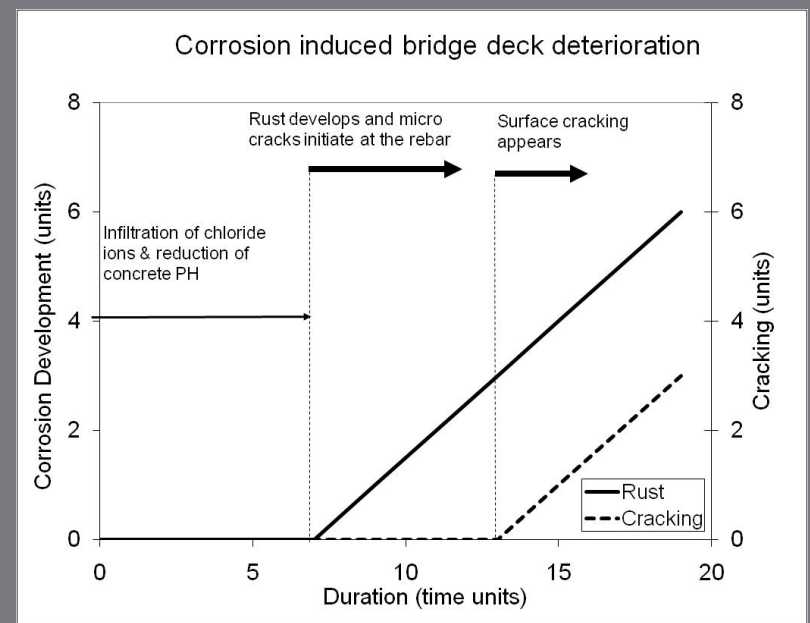


Image adapted from <http://frpdistributors.com>

This study

LABORATORY INVESTIGATION

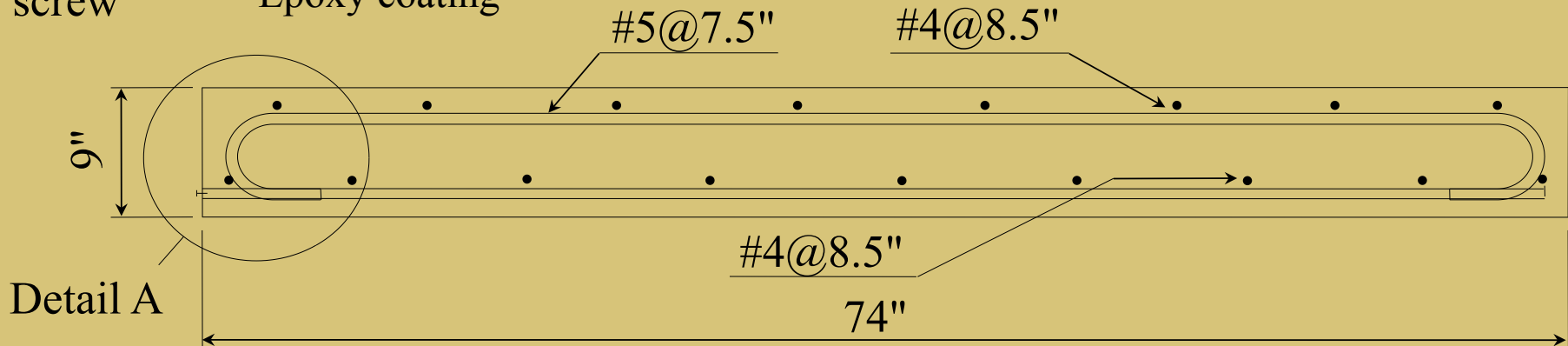
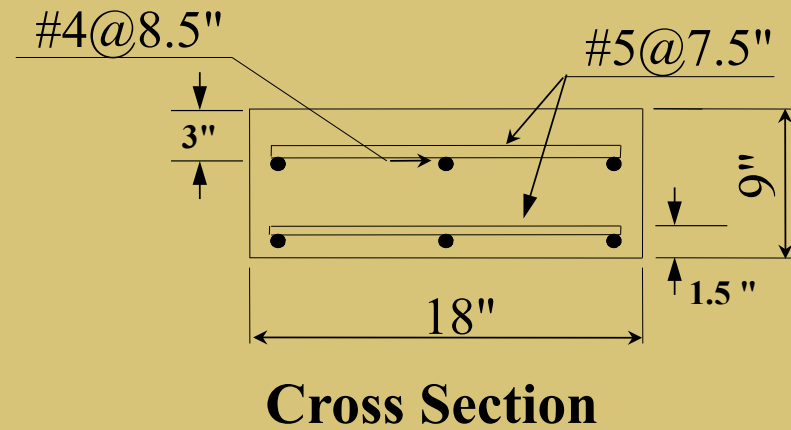
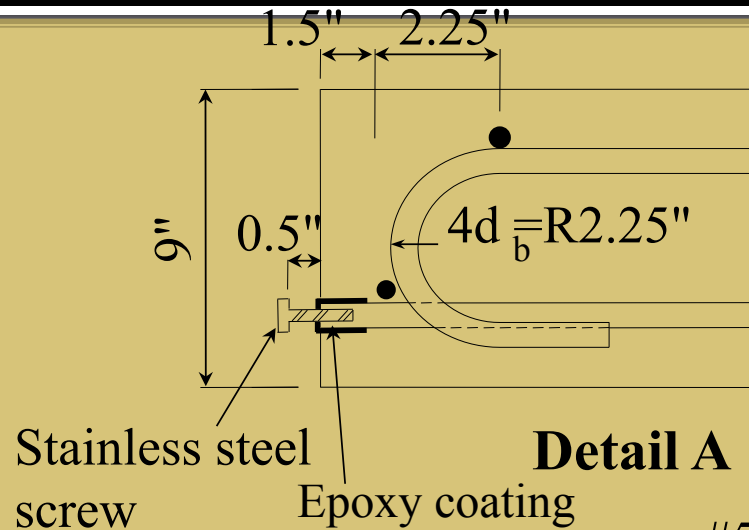


FIELD INVESTIGATION





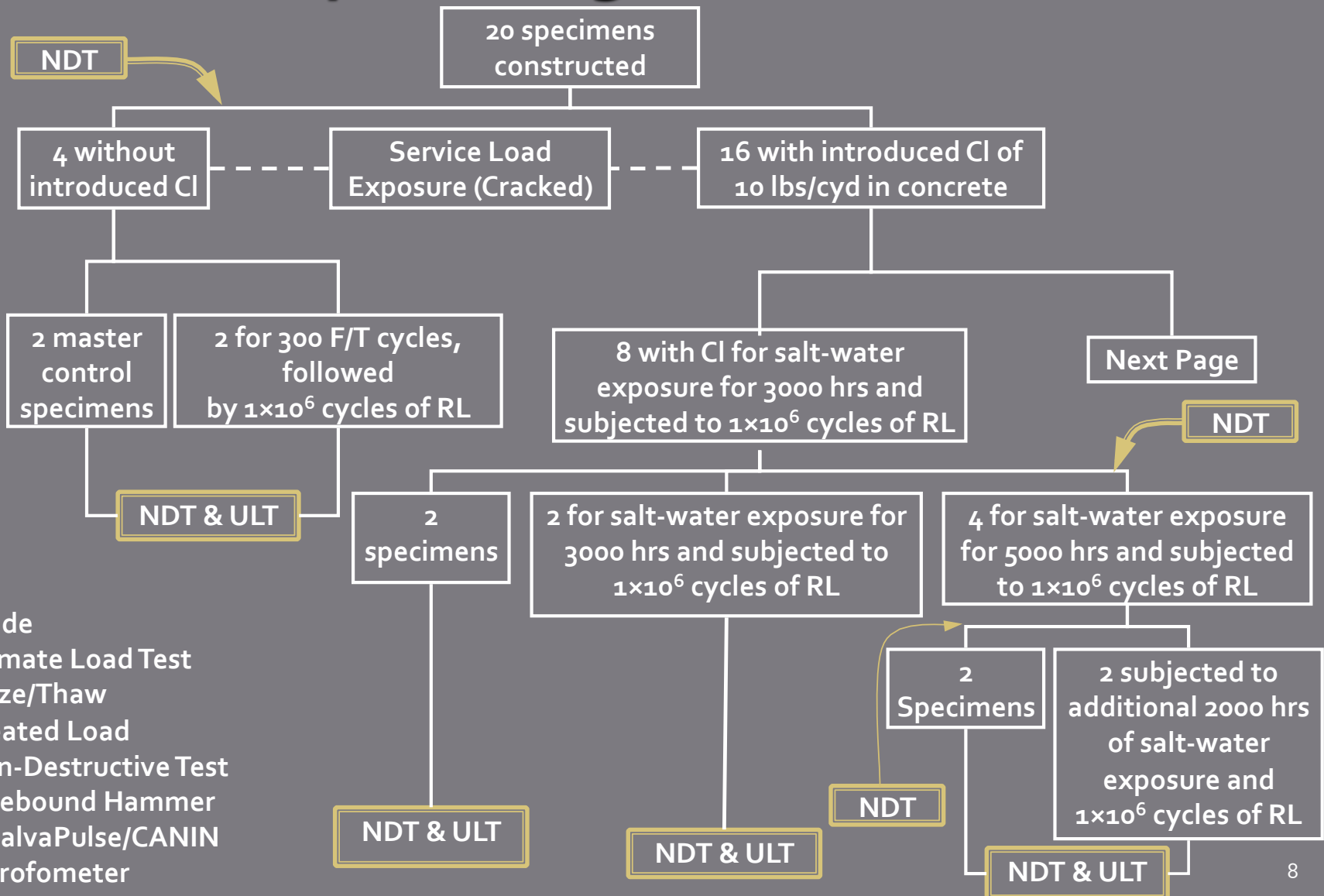
Reinforcement Details for Specimen



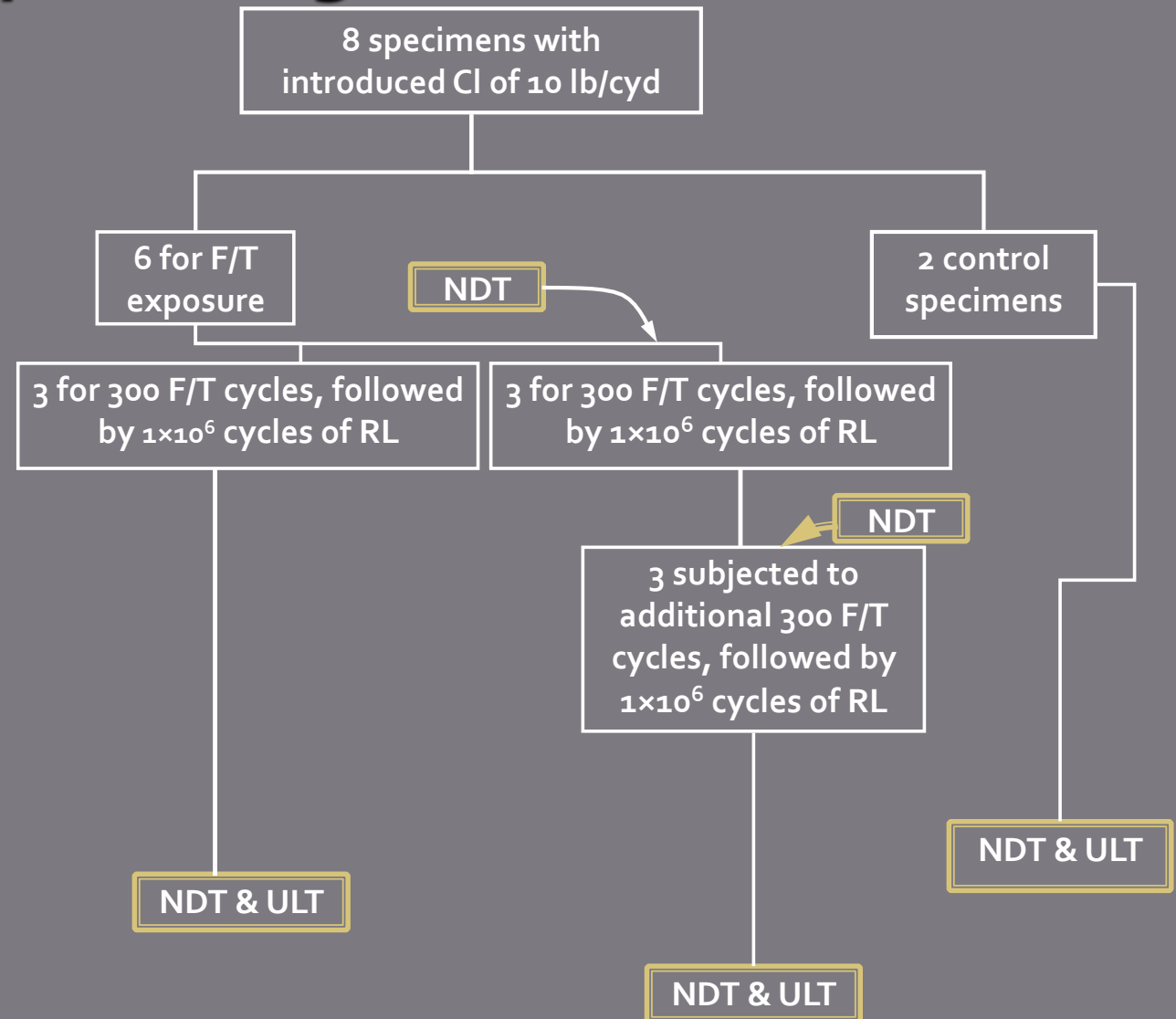
#According to MDOT Standard Slab Design
(Load Factor Design)

Elevation

Laboratory Investigations



Laboratory Investigations



Cl: Chloride

ULT: Ultimate Load Test

F/T: Freeze/Thaw

RL: Repeated Load

NDT: Non-Destructive Test

(1) Rebound Hammer

(2) GalvaPulse/CANIN

(3) Profometer



Reinforcement Cage & Form Work



Concreting of Specimens



Finishing the top surface



Finished Specimens
(prior to moist curing)

Concrete Mix Proportions

Concrete Mix Design (D-MR)

Ingredients	Quantity (lbs/ cft)	Standards
Cement	24.4	ASTM C-150
Fine Aggregate	42.5	ASTM C-33
Coarse Aggregate - <i>Manitoulin Dolo.</i>	69.1	ASTM C-33
Water	9.9	ASTM C-94
Air entraining Admixture	0.8 oz	ASTM C-260
Water reducing Admixture	4 oz	ASTM C-494
Mid-range water reducing Admixture	7 oz	ASTM C-494
<i>CACL (Equivalent Calcium Chloride)</i>	<i>17.7 oz</i>	<i>ASTM D-98</i>

Without
Introduced Cl

With
Introduced Cl

Concrete Info

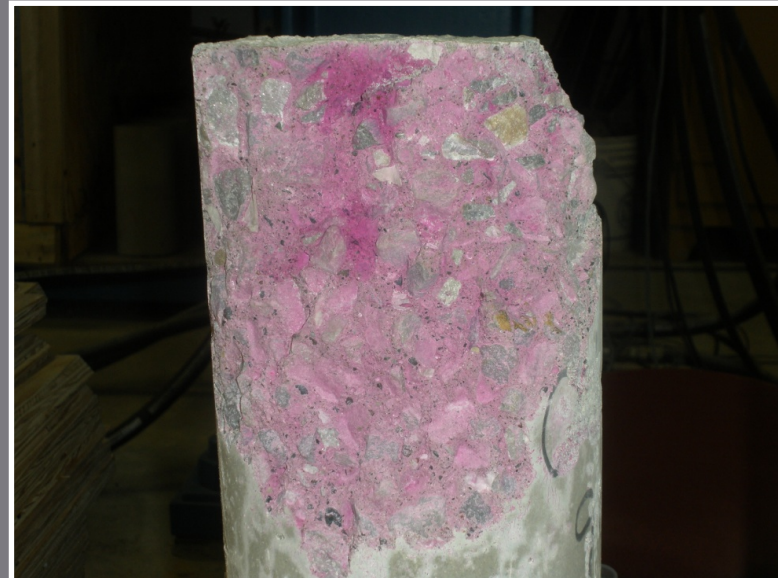
Test Age (Days)	Without Introduced Cl	With Introduced Cl
	Average Compressive Strength (psi)	Average Compressive Strength (psi)
1	2,672	3,554
3	3,439	4,459
7	3,968	5,040
28	4,898	6,070
90	5,172	6,891
% Chloride by weight		
Rapid Chloride Test (RCT) (Acid Soluble)	0.07%	0.28%
RCT-Water Soluble	0.07%	0.25%

PH at 90 day

WITH CHLORIDE

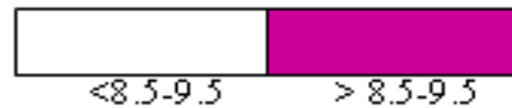


WITHOUT CHLORIDE



Deep Purple Indicator:

Color:
pH:



Flexural Strength

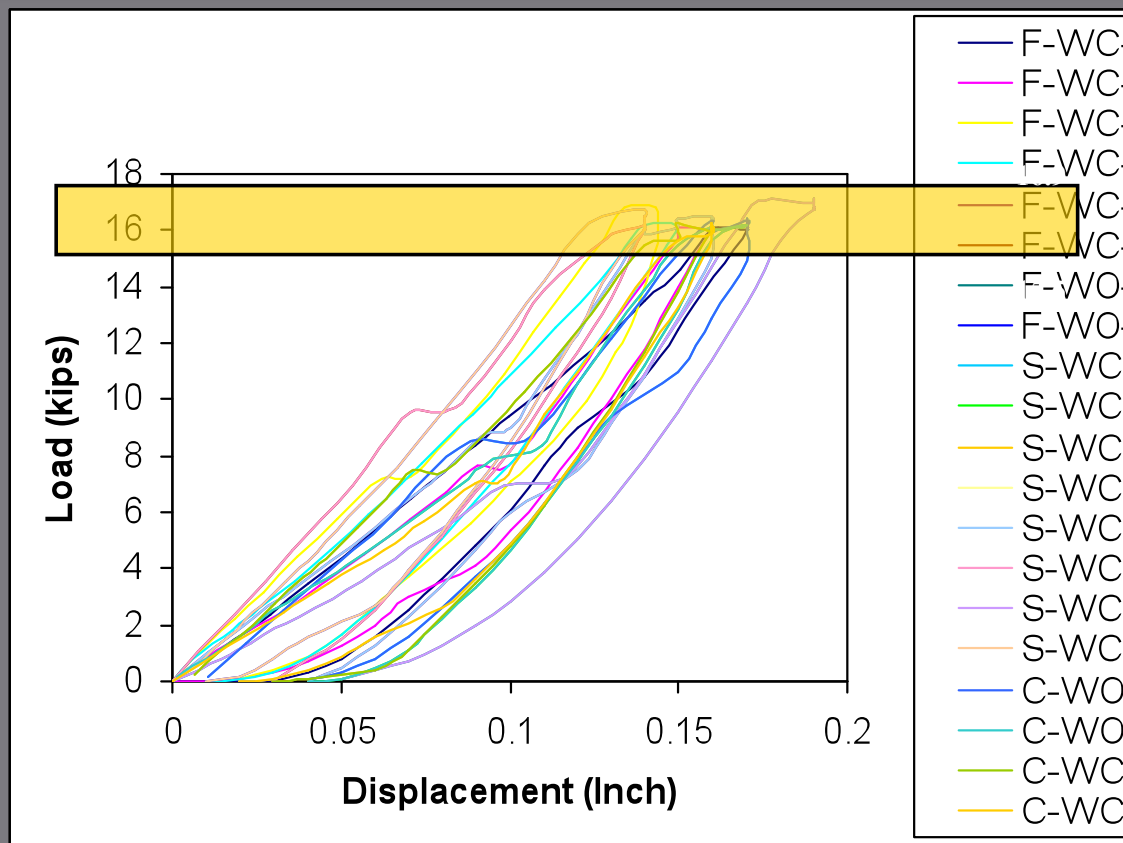
28 Day Flexural Strength (psi), ASTM C 78

Beam No.	Without Introduced CI	Average (psi)	With Introduced CI	Average (psi)
1	767	756	691	741
2	755		760	
3	763		750	
4	731		740	
5	744		820	
6	780		687	

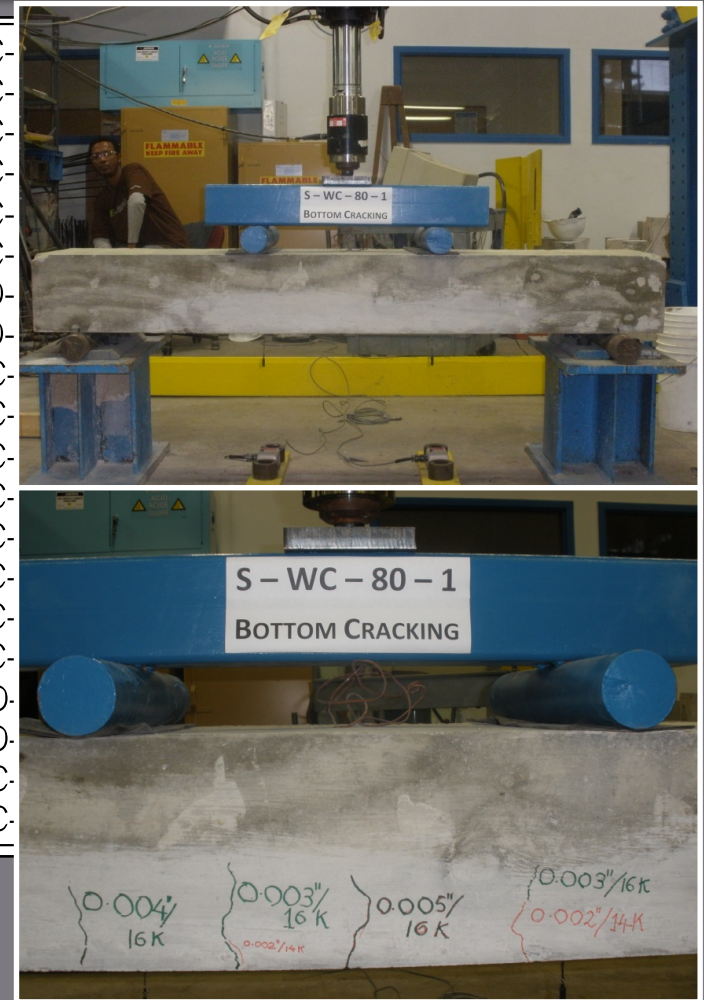
Beam Dimension: 6"x6"x20"



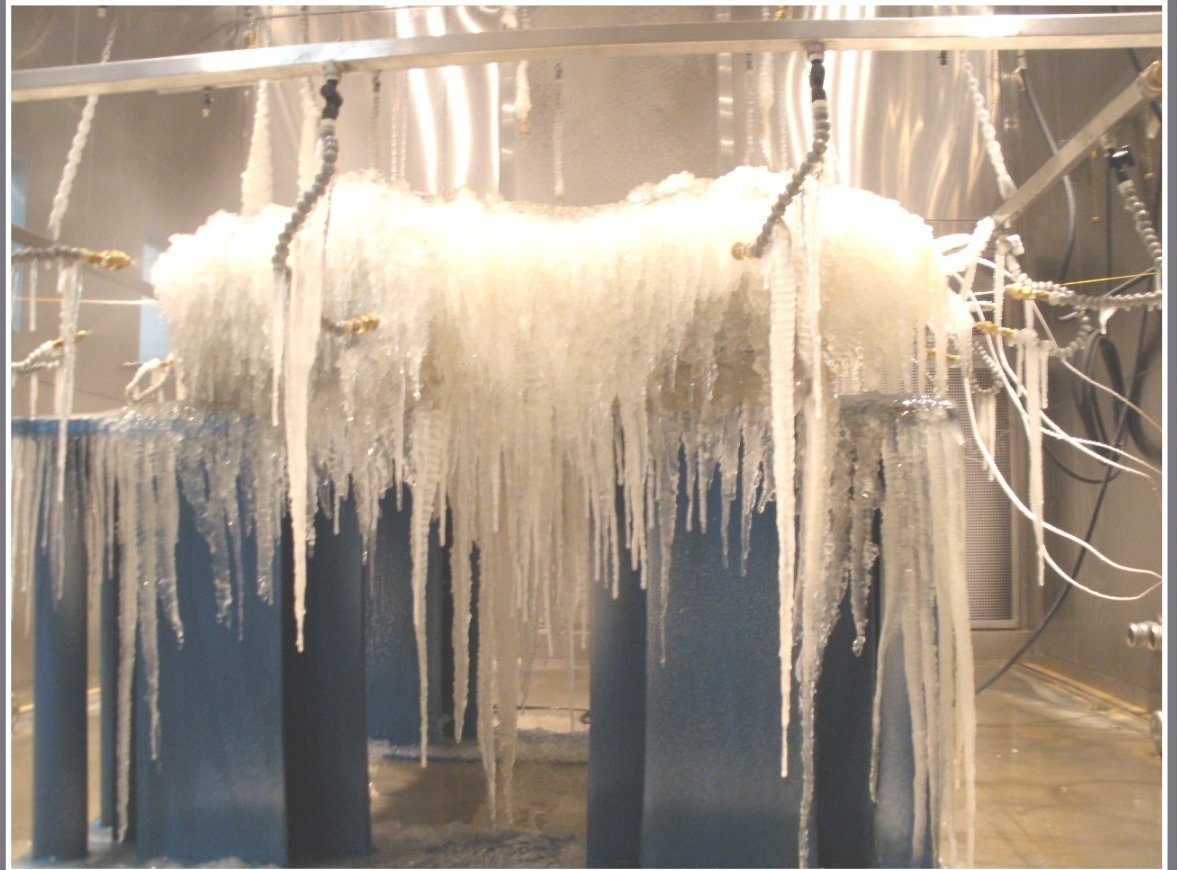
Cracking – prior to durability testing



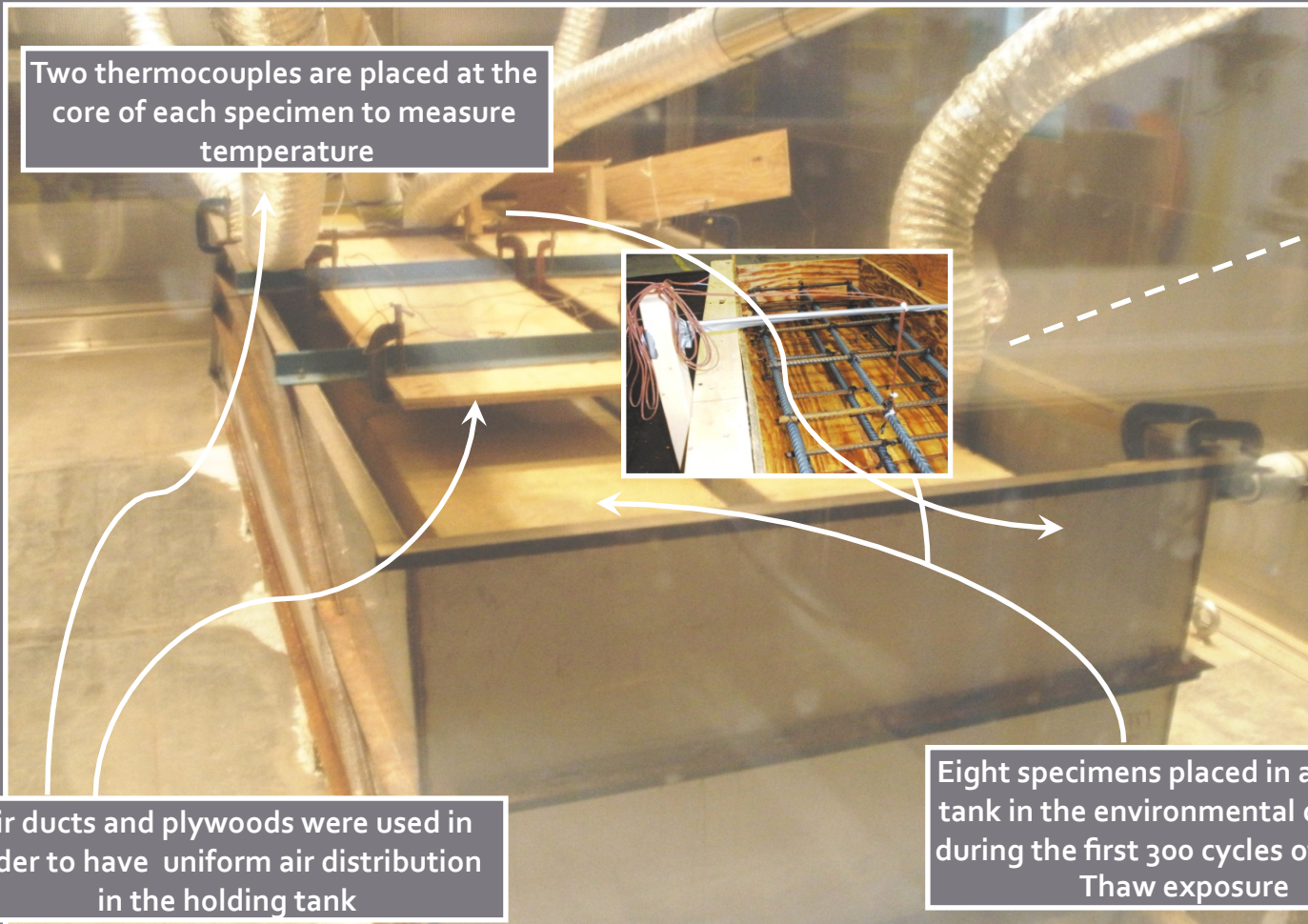
Cracks width ranged from 0.001 to 0.005 inch (ACI 224-01)



Environmental Chamber



Environmental Chamber , F-T



Two thermocouples are placed at the core of each specimen to measure temperature

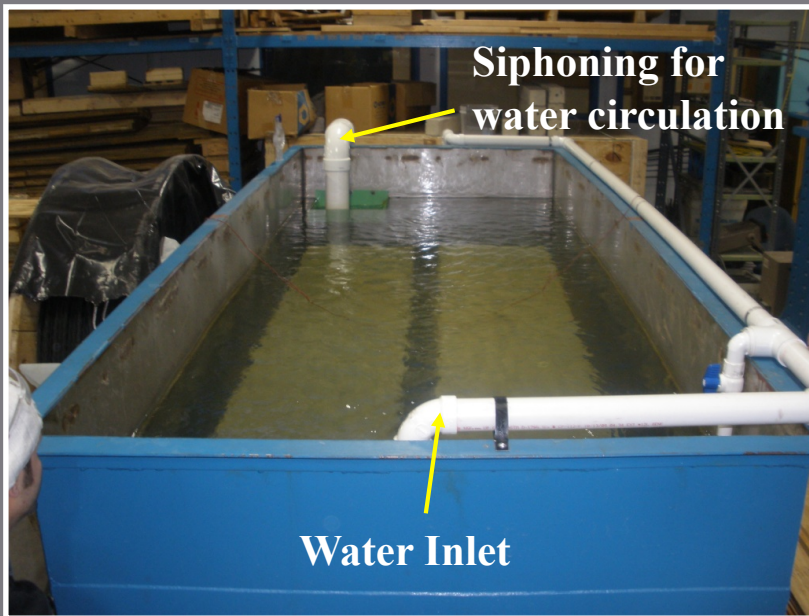


Temperature readings have been collected for 24 hours/day

Air ducts and plywoods were used in order to have uniform air distribution in the holding tank

Eight specimens placed in a holding tank in the environmental chamber during the first 300 cycles of Freeze-Thaw exposure

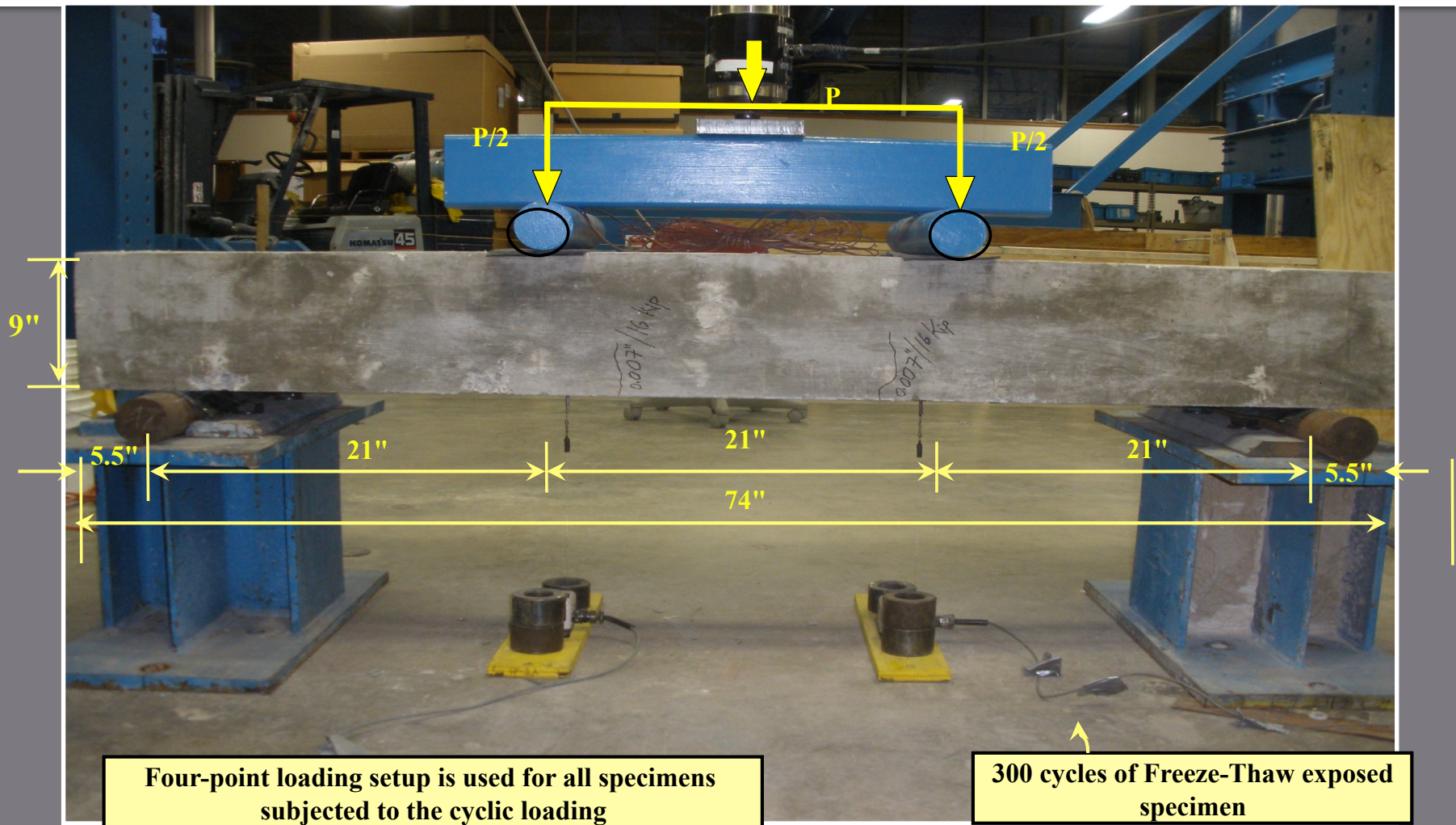
Salt-Water Exposure



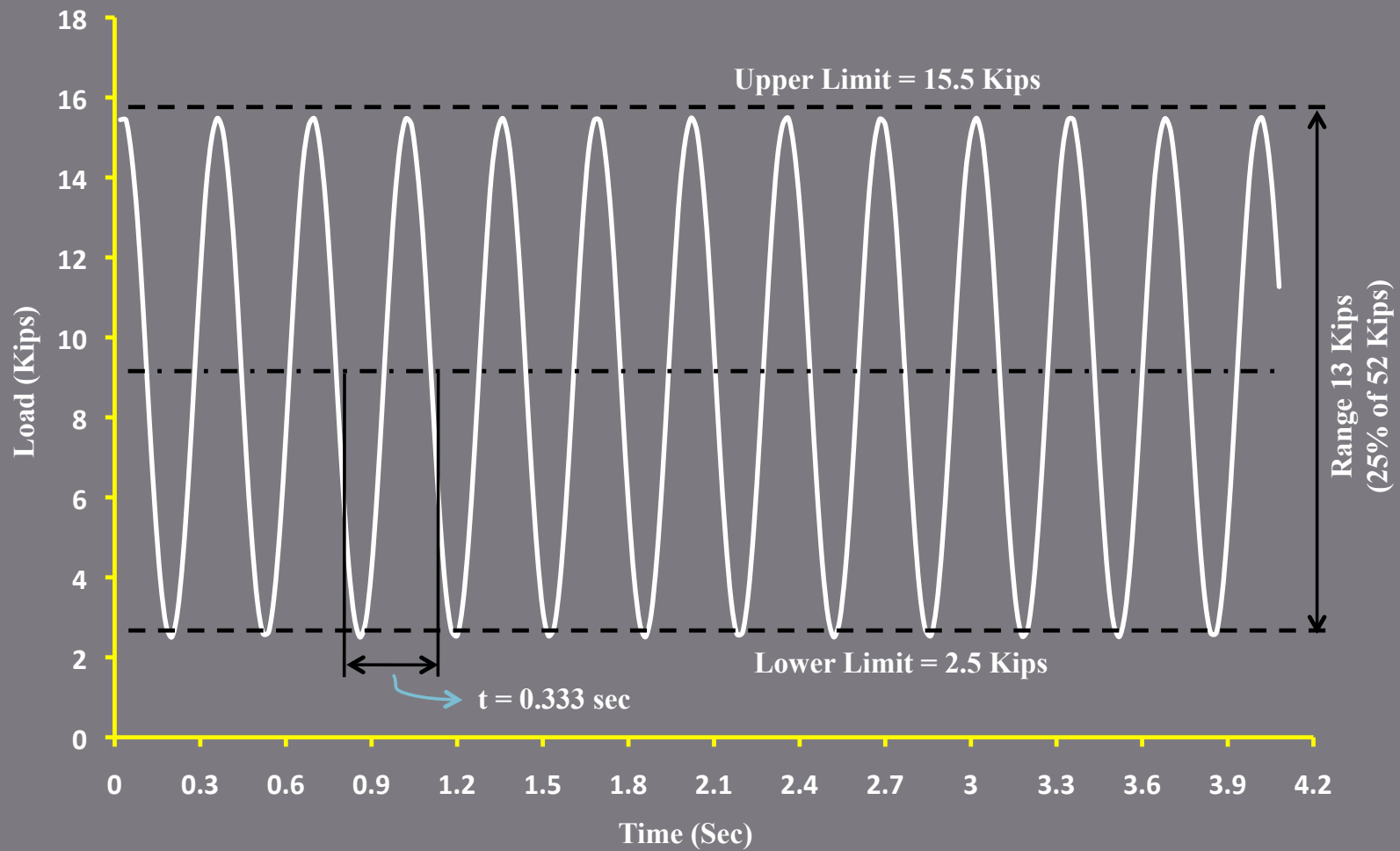
Specimens placed inside the Salt Water Tank



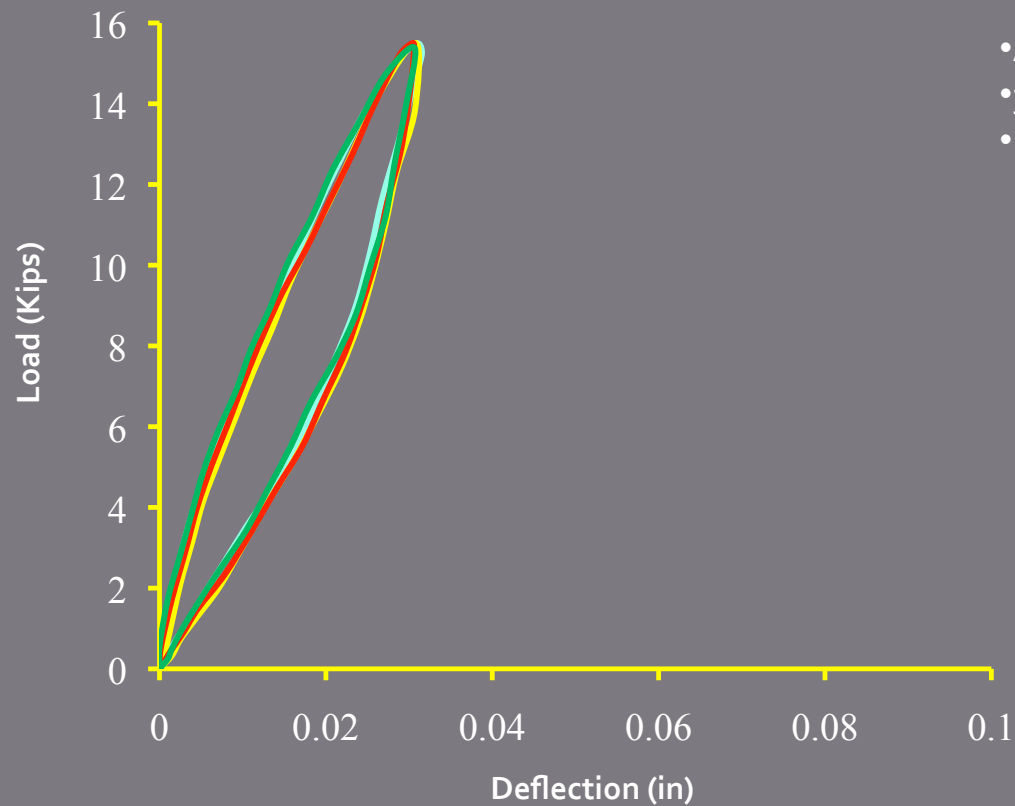
Loading Setup used for Cyclic Loading



Typical Load-Time Response



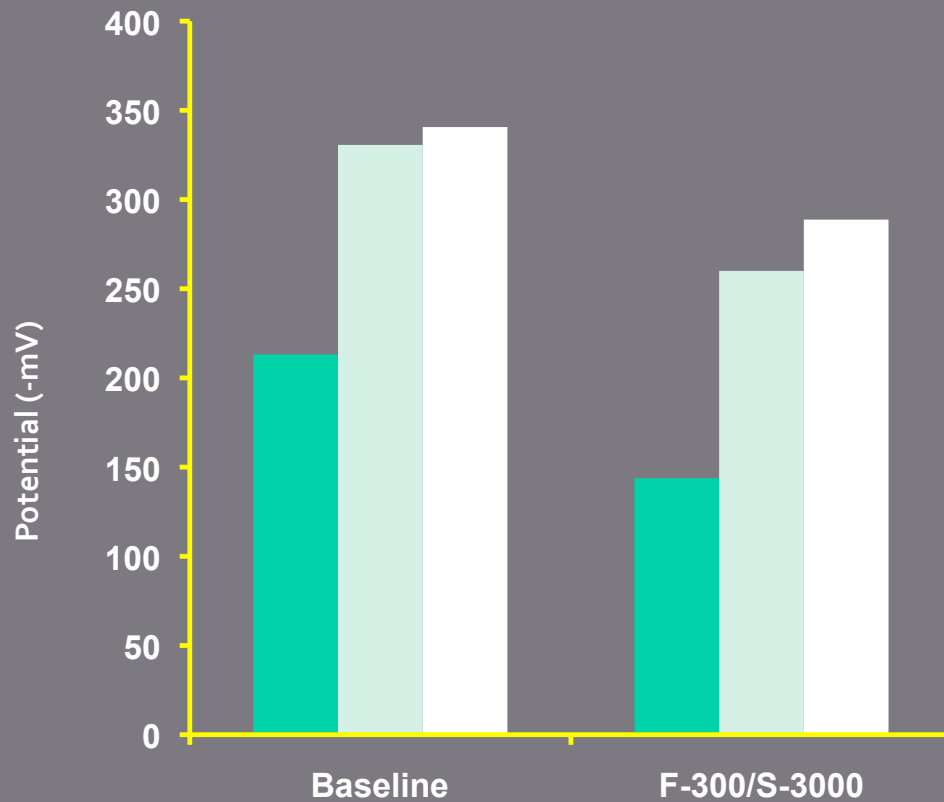
Typical Load-Displacement Response



- After 300 F-T cycles, or
- 3000 hours of salt-water exposure, or
- Control

250000
500000
750000
1000000

Corrosion Potential



CANIN Instruments
(Copper Sulfate)

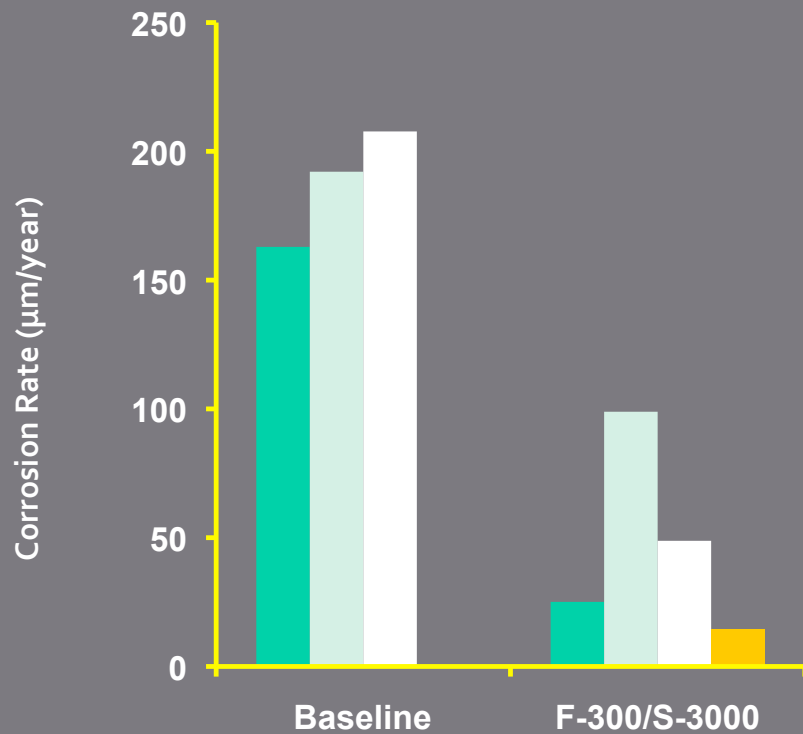
- Control
- 300 cyc. F-T
- 3000 hrs. Salt-Water

F-300: after 300 F-T cycles;

S-3000: after 3000 h of Salt-Water exposure

Baseline: after 28 days of moist curing

Corrosion Rate Assessment



GalvaPulse Instrument

- Control
- 300 cyc. F-T
- 3000 hrs. Salt-Water
- Extra Specimen

F-300: after 300 F-T cycles; S-3000: after 3000 h of Salt-Water exposure
Baseline: after 28 days of moist curing

Summary of Laboratory Investigation

- Active corrosion developing in CL doped members
 - > 50% risk of corrosion
 - $\approx 50 - 100 \mu\text{m}/\text{year}$
- Load response not affected by concrete degradation at this stage
- Exposure sequence continued

This study

LABORATORY INVESTIGATION



FIELD INVESTIGATION



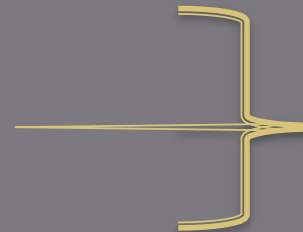
Selected Bridges

1. 63174-S05-1 I-75 NB 14 MILE RD
2. 63022-S02-3 I-96 WB MILFORD RD
3. 63022-S01 I-96 KENT LAKE RD



Poor
Performers

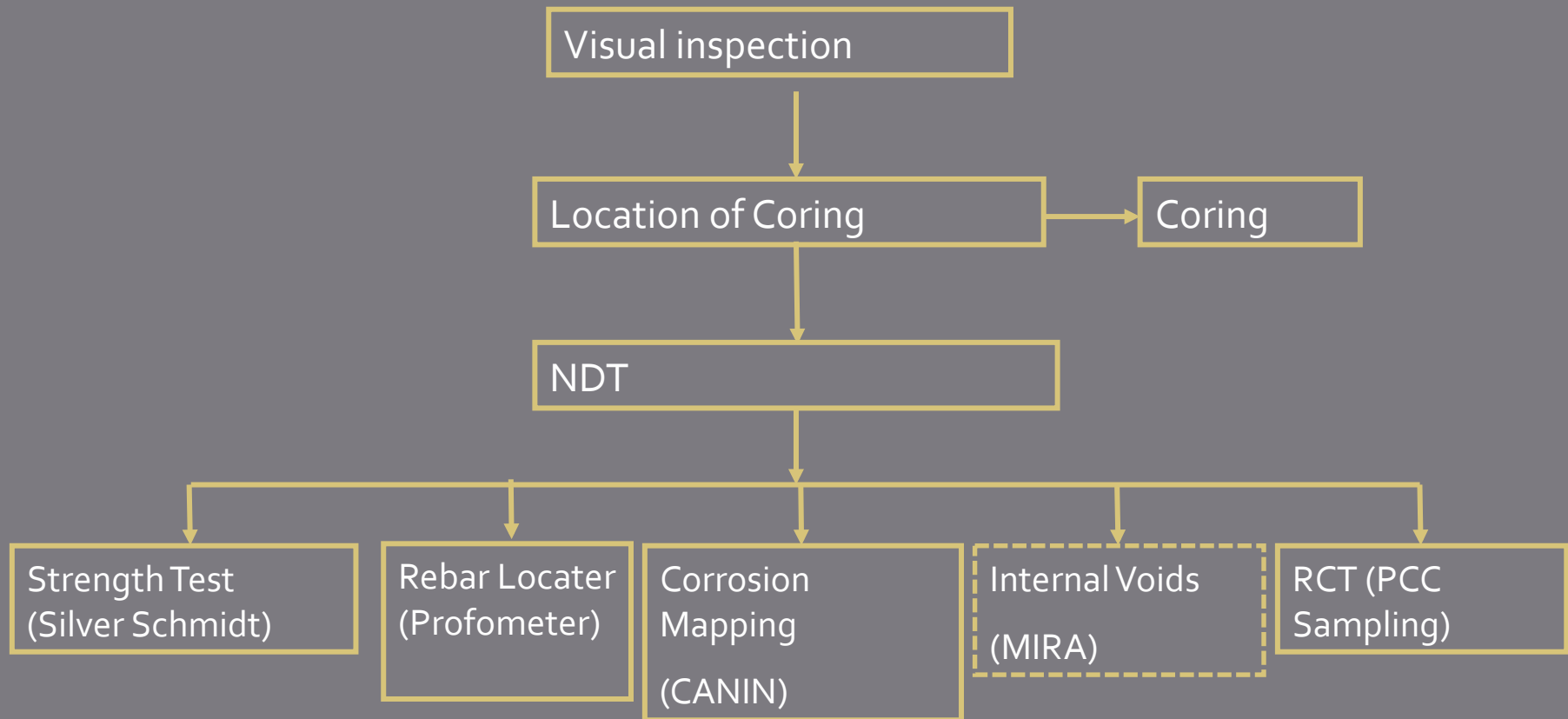
4. 63172-S11 I-75 NB BALDWIN RD
5. 63043-S03-1 M-59 SQUIRREL RD



Good
Performers

* Based on MDOT performance index

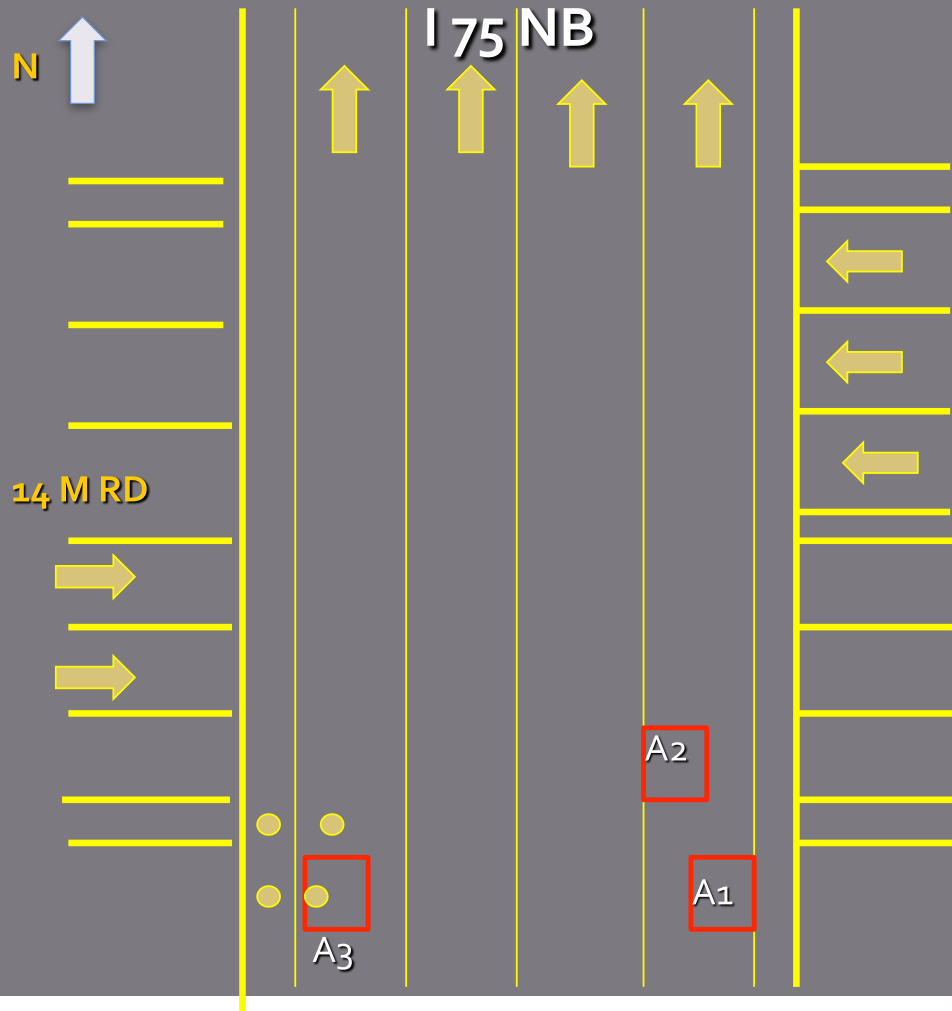
Work Plan - Field



Example (I-75 over 14 Mile Rd, Troy, MI)



63174-S05-1 I-75 NB 14 MILE RD



LEGEND

A1: NDT over walk path and embankment

A2: NDT over EB 14 mile Rd

A3 : NDT over walk path and embankment

Visual inspection (above & below)

● : Coring location

NB: Areas A1 and A2 in deceleration lane

Coring by MDOT Personnel



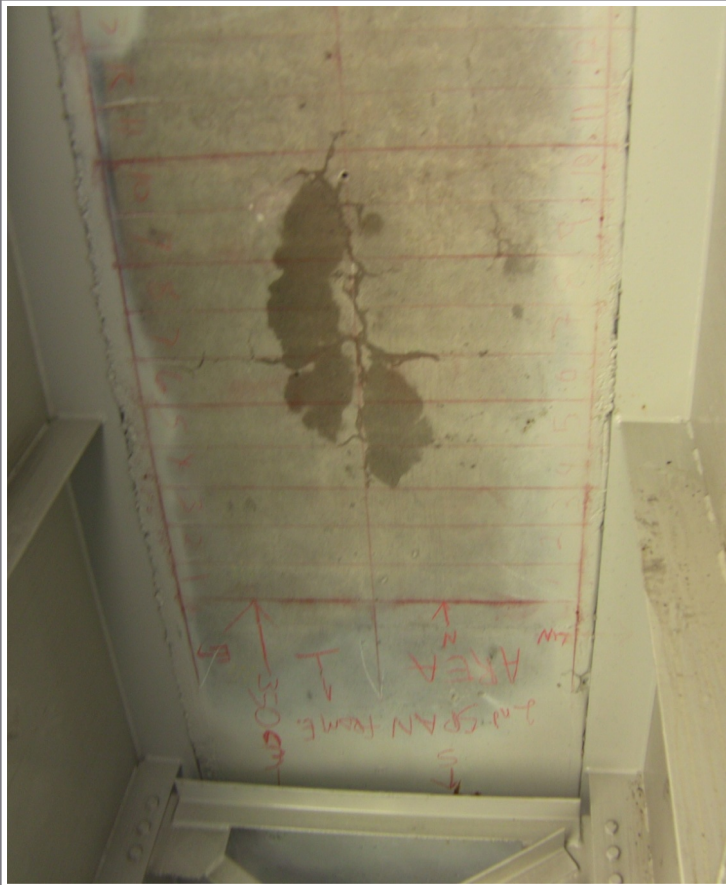
Coring full depth of the deck



Collecting the core

63174-S05-1 I-75 NB 14 MILE RD

NDT Performed on Slab Bottom



Test grid in survey area



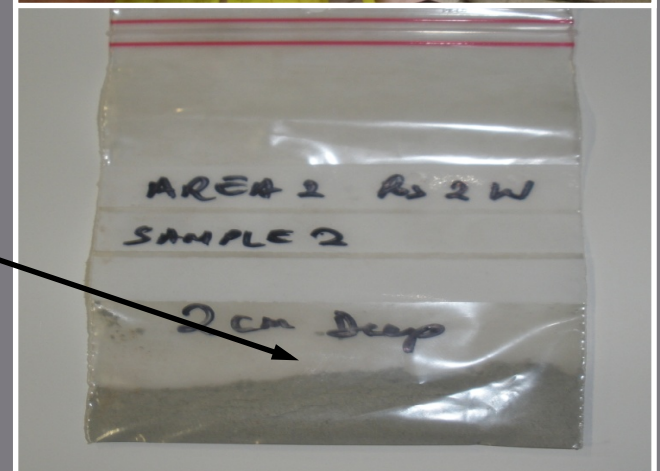
Measurement of Electrical Potential 32

Chloride Sampling – Rapid Chloride Test

12 - 16 samples collected from different depth.

Average weight of sample is 9.0 gm

Sample of concrete dust from Area 2 at a depth of 2cm.



Risk of Corrosion

63174-S05-1 I-75 NB 14 MILE RD

Location	Area 1	Area 2	Area 3
Average Potential (mV)	-315	-220	-150
Mean \pm Standard deviation (mV)	-357 -273	-251 -189	-161 -138
Risk of rebar corrosion	50%	50%	5%

Risk of Corrosion

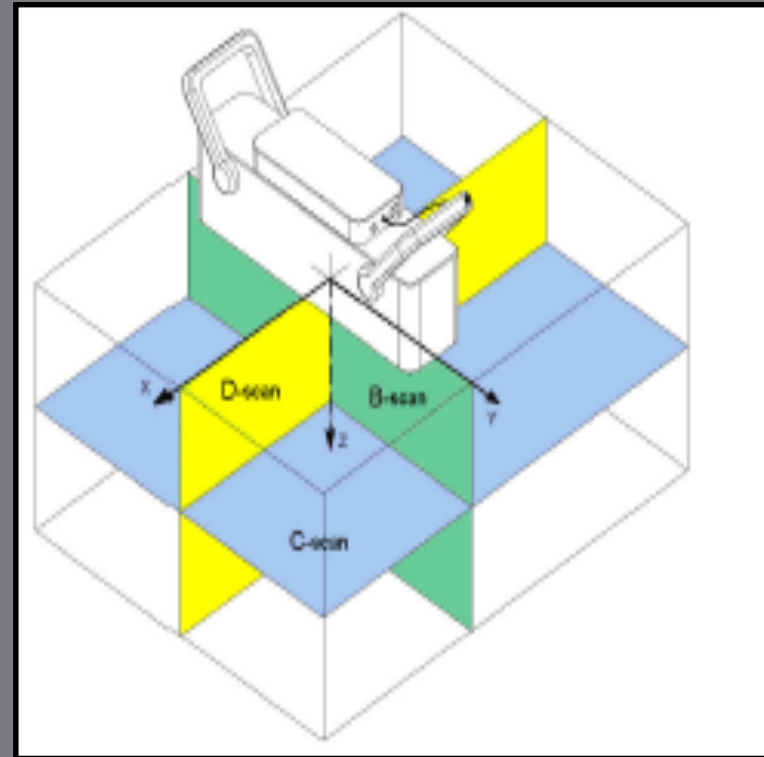


Deck replacement scheduled

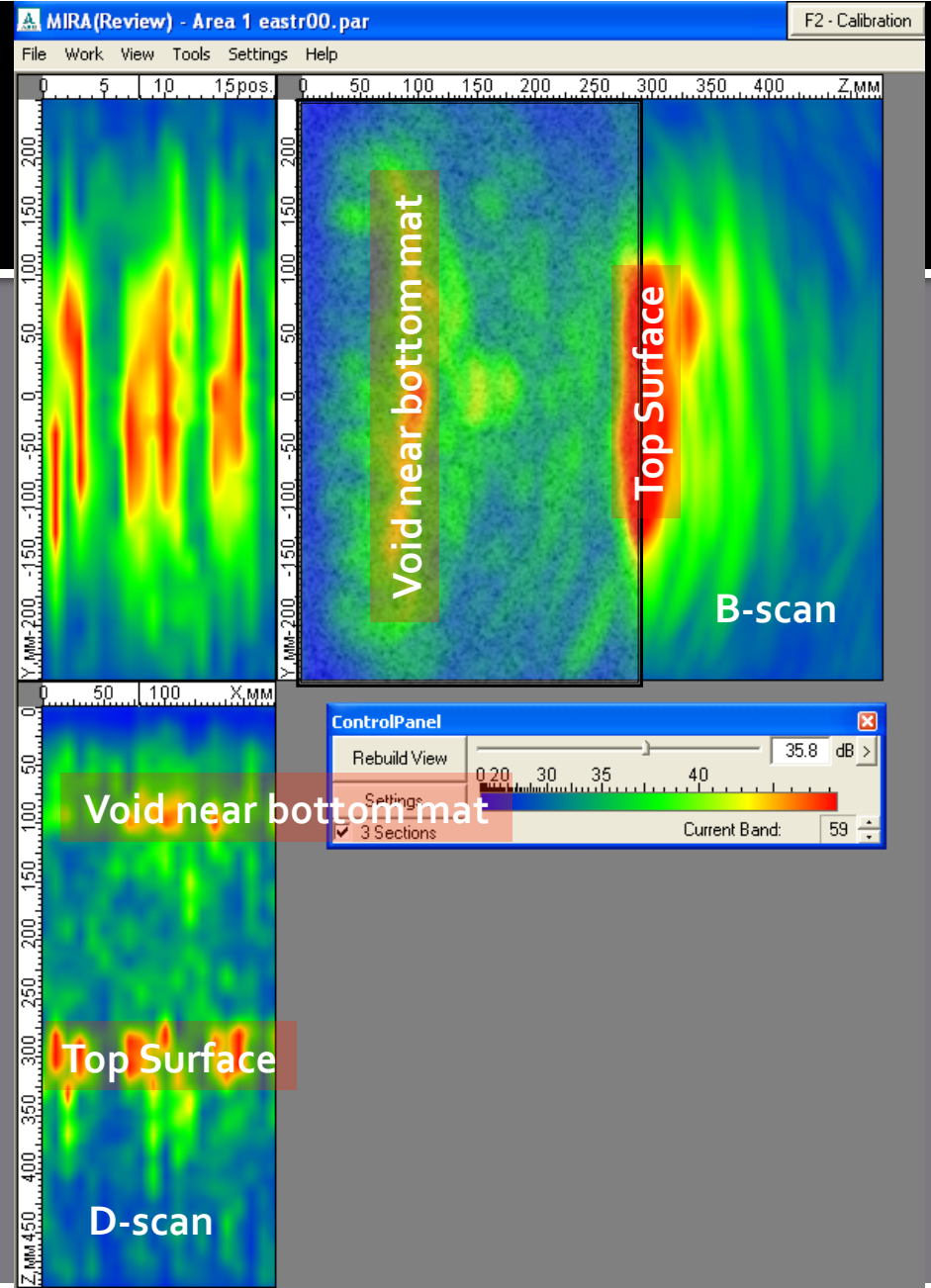
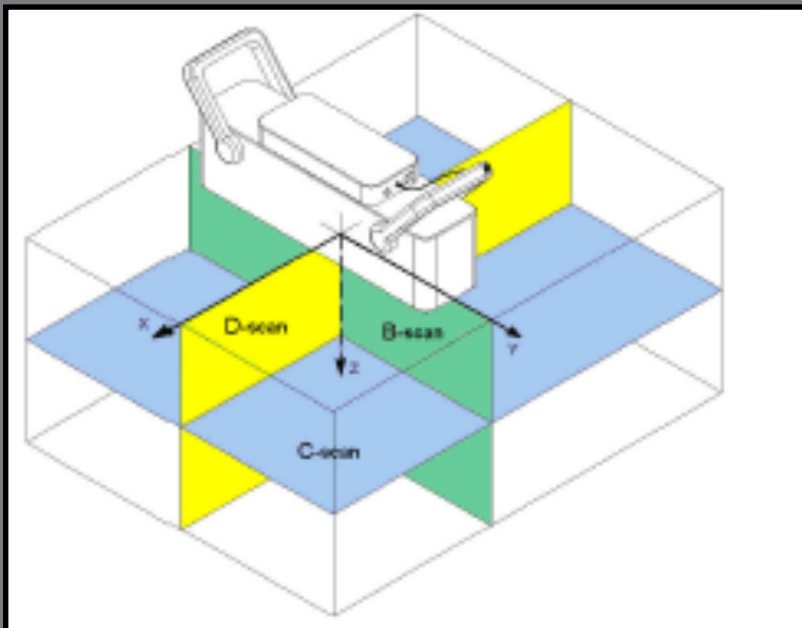
3D Tomography



MIRA
(50 Hz shear waves)



3D Tomography



Summary of Field Investigation

- Results from NDT measurements are in excellent agreement with other indicators (3 sites)
- Coring to be completed by November 2010
- Chloride content is being determined
- 2 site visits scheduled for early summer 2011

Acknowledgements

- Michigan Department of Transportation
 - (Project No. 108621)
- Center for Innovative Material Research, Lawrence Tech