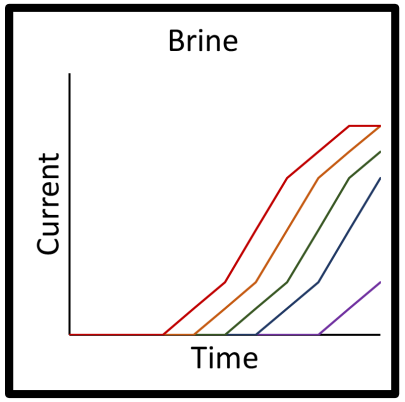
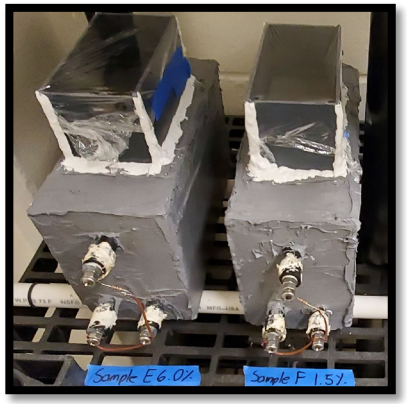
Influence of Cracking and Chloride Concentration on Corrosion Testing





Aaron J. Strand, Matthew P. Adams, Matthew J. Bandelt
J.A. Reif, Jr., Department of Civil and Environmental Engineering
New Jersey Institute of Technology

matslab
materials and structures laboratory at NJIT

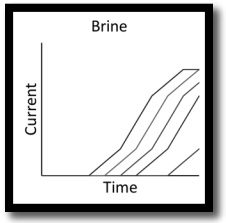
NJIT

21st Annual NJDOT Research Showcase
Innovation Breakout Session #2
Conference Center at Mercer
23rd October 2019

OUTLINE

Introduction to Bridge Corrosion

Testing Procedure



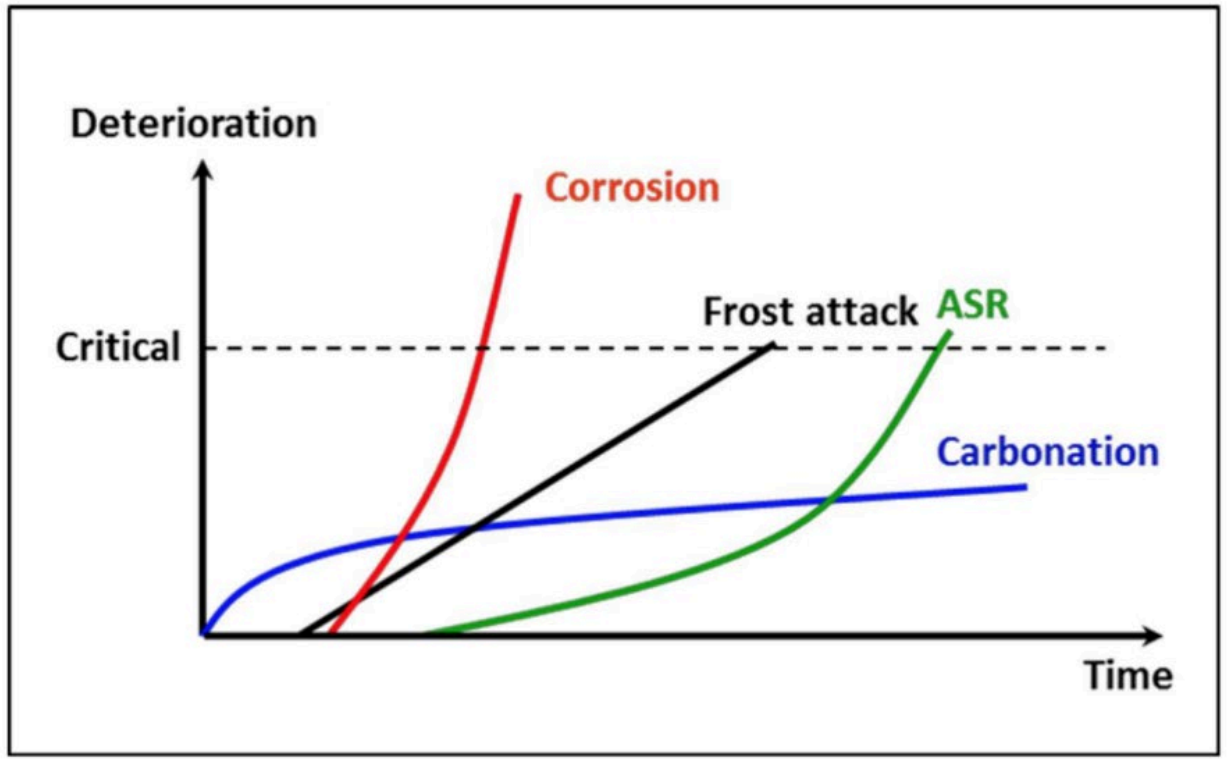
Macrocell Current Results

Conclusions

Corrosion of Concrete Structures

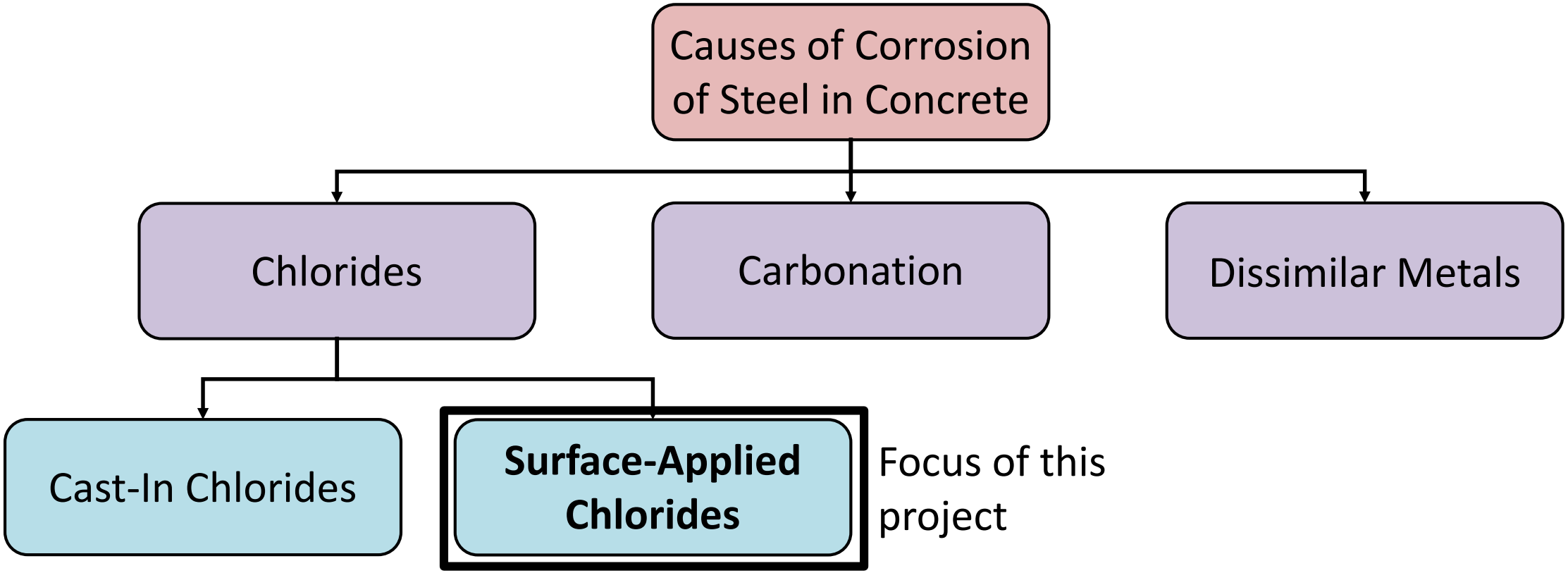
- 2002 Study: Corrosion cost and preventative strategies for highway bridges was **$8.3 Billion**

- In reinforced concrete bridges primary cause is **chloride-induced corrosion**



Simplified deterioration mechanism (Aboutaha, 2004)

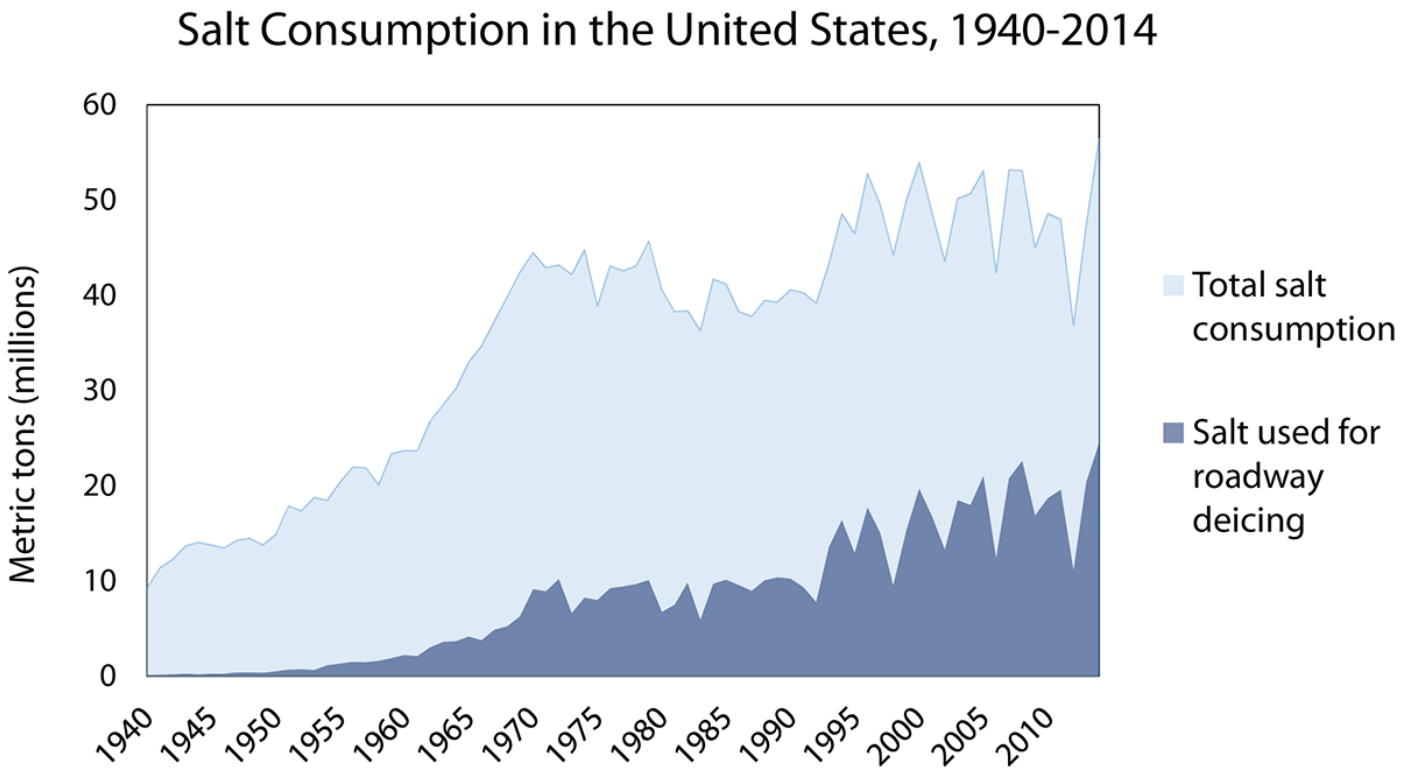
Causes of Corrosion of Steel in Concrete



Source: Design Guide for Bridges for Service Life 2014

ROAD SALTING

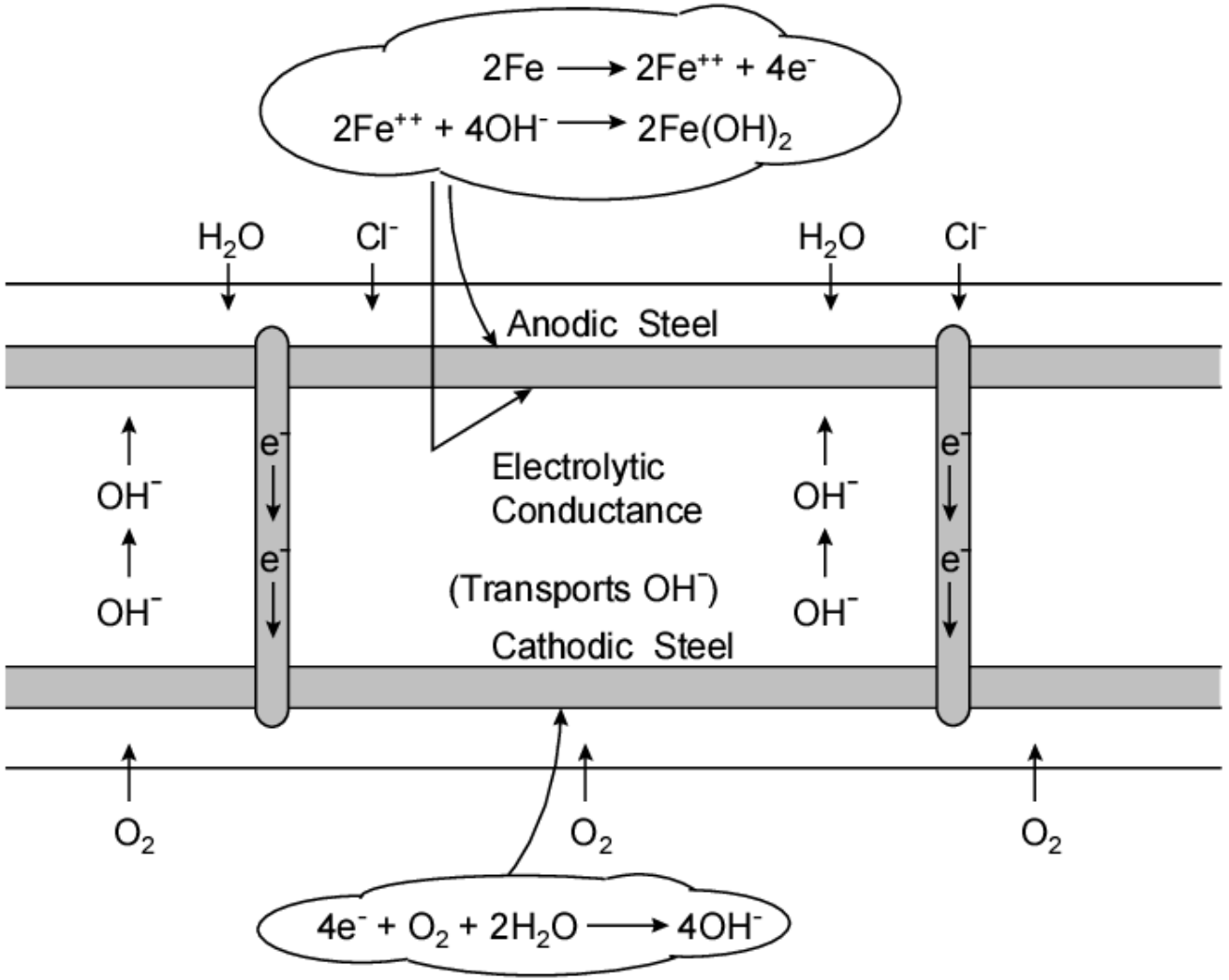
- 2014 road consumption
  - 24.5 million metric tons
- Forms of salt used
  - Rock Salt
  - Brine (23.3% for -6°F freezing)
- NJDOT Winter 2018-2019 Material Usage
  - Salt - 391,447 tons
  - Liquid calcium chloride – 803,709 gallons
  - Brine - 687,370 gallons



Sources: Winter Readiness, *NJDOT*;
Minerals Yearbook 2014 Salt, *U.S. Geological Survey*;
Special Report 235: Highway Deicing, *National Research Council*

MACROCELL CORROSION

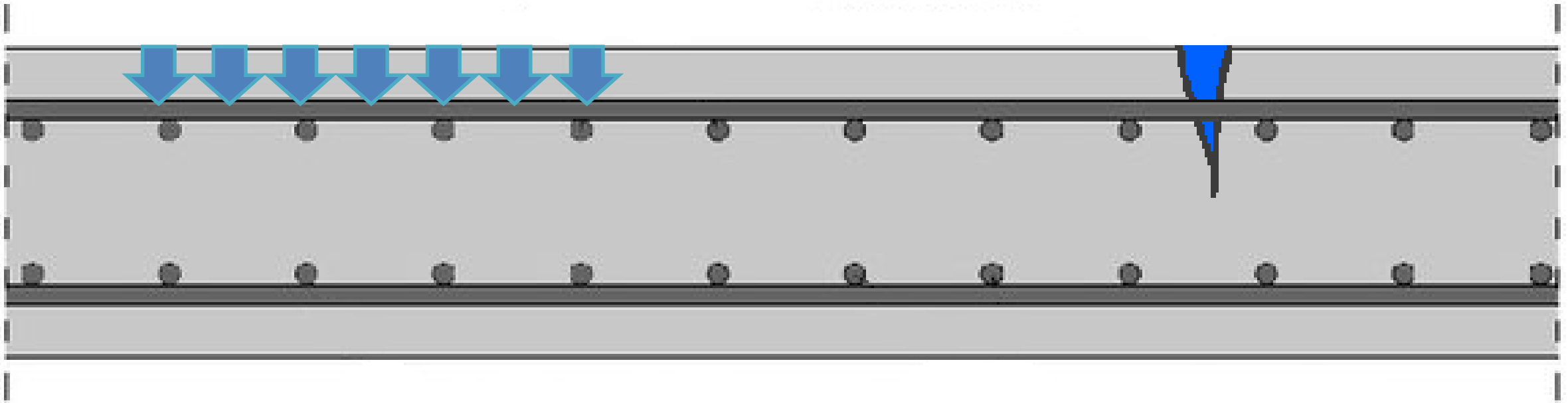
- Local anode and large cathode
- Frequently occurs in chloride induced corrosion
- In bridge decks this form is accelerated due to large cathode/anode area ratio
- Macrocell forms between upper layer reinforcement and lower mat



Source: Kahhaleh 1998

Chloride Ingress

- Diffusion
  - Chlorides need to penetrate concrete to reach reinforcement
  - Concentration gradient
- Direct access
  - Chlorides have concentrated path to reinforcement



Sources of Bridge Deck Cracking

- Plastic Shrinkage
- Drying Shrinkage
- Surface Tears (Finishing)
- Flexure/Deflection of the Deck
- Reflection of Underlying Cracks and Joints
- Temperature Related Mechanisms

Source: Missouri Department of Transportation

GOVERNING QUESTION

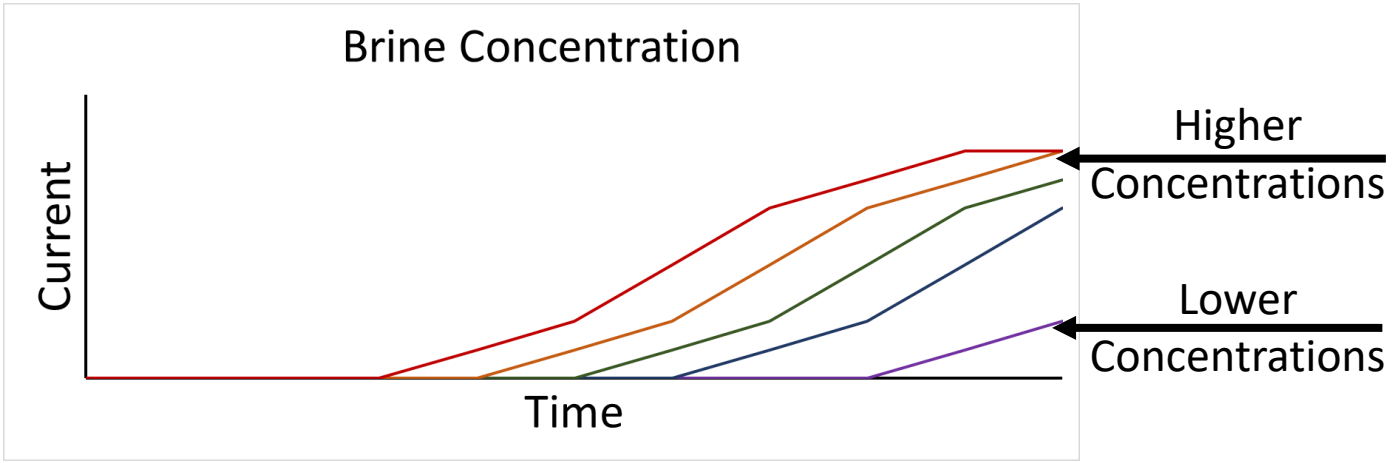
- Does current testing take into account possible real world considerations?

- Amount of salt placed on roads
- Salt placement cycles
- Integrity/condition of bridge deck

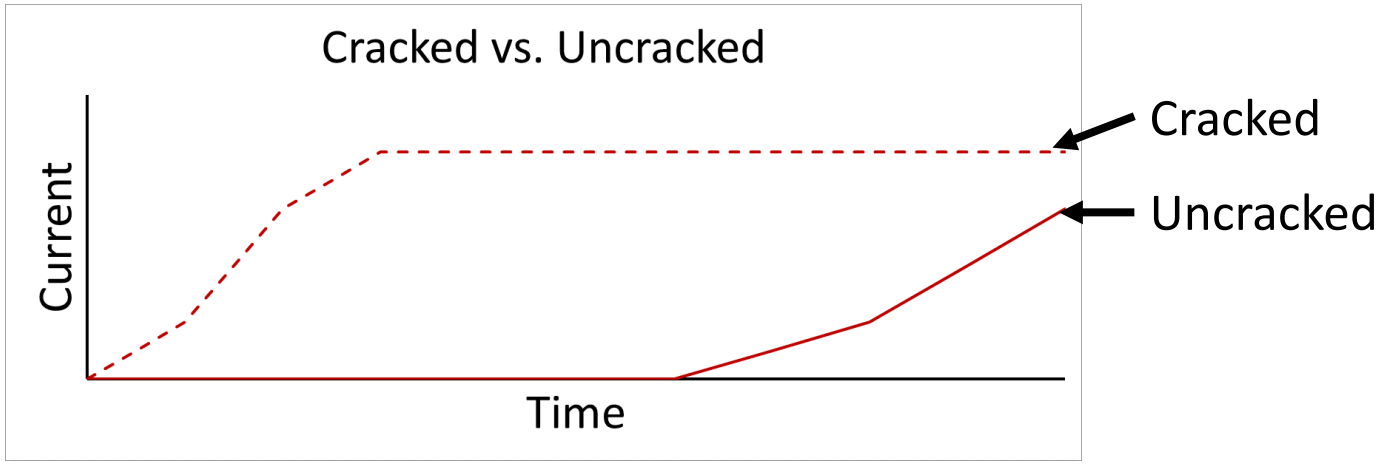
Image Sources: Indiana Department of Transportation, and theconstructor.org

VARIABLES OF INTEREST

- Impact of **salt brine concentration**
  - How does the concentration of the chloride brine impact the time to corrosion?



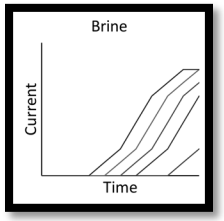
- Impact of **cracking**
  - How does the presence of cracks to the reinforcing steel impact the time to corrosion?



OUTLINE

Introduction to Bridge Corrosion

Testing Procedure

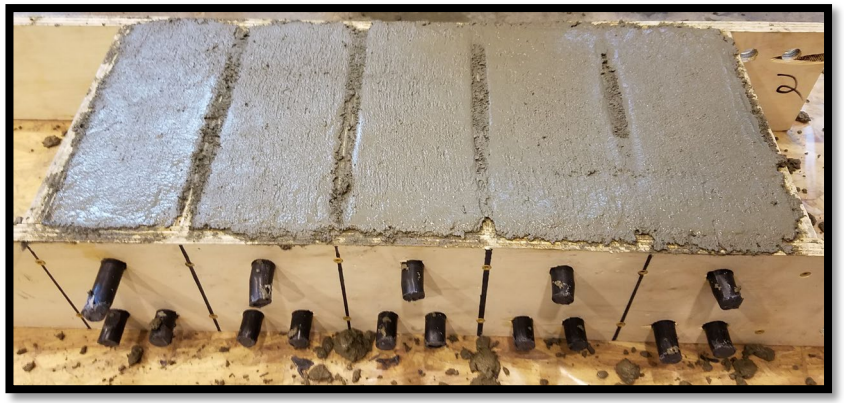


Macrocell Current Results

Conclusions

Specimens for Testing

- ASTM G109 for macro-cell current
  - Assumed no initial chlorides in concrete
  - Corrosion only from chloride ingress

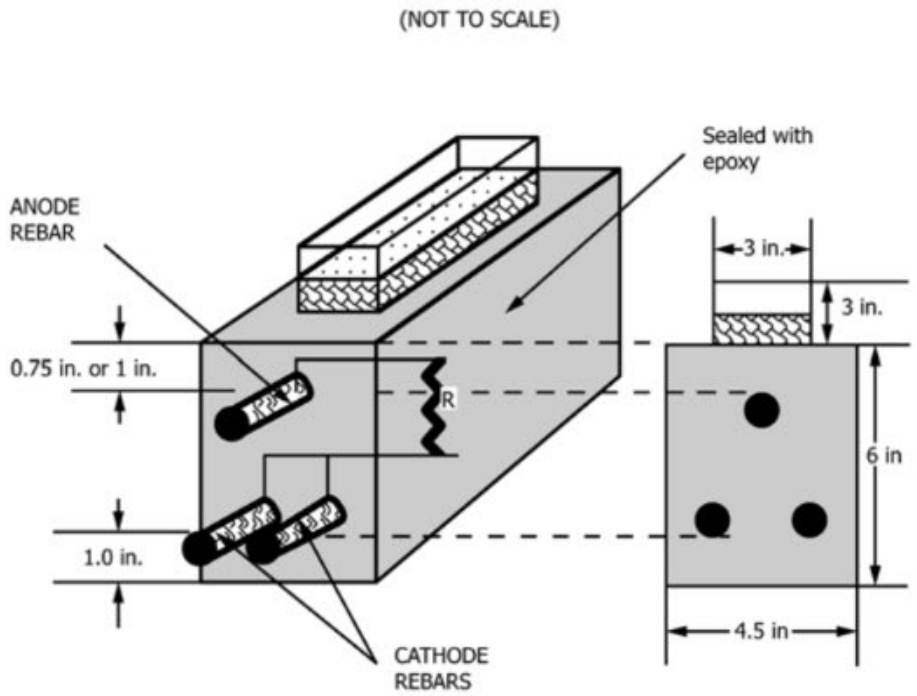


- Design compressive strength of 4500 psi

- Tested compressive strength:
  - Set 1 Specimens - 5620 psi
  - Set 2 Specimens - 6660 psi

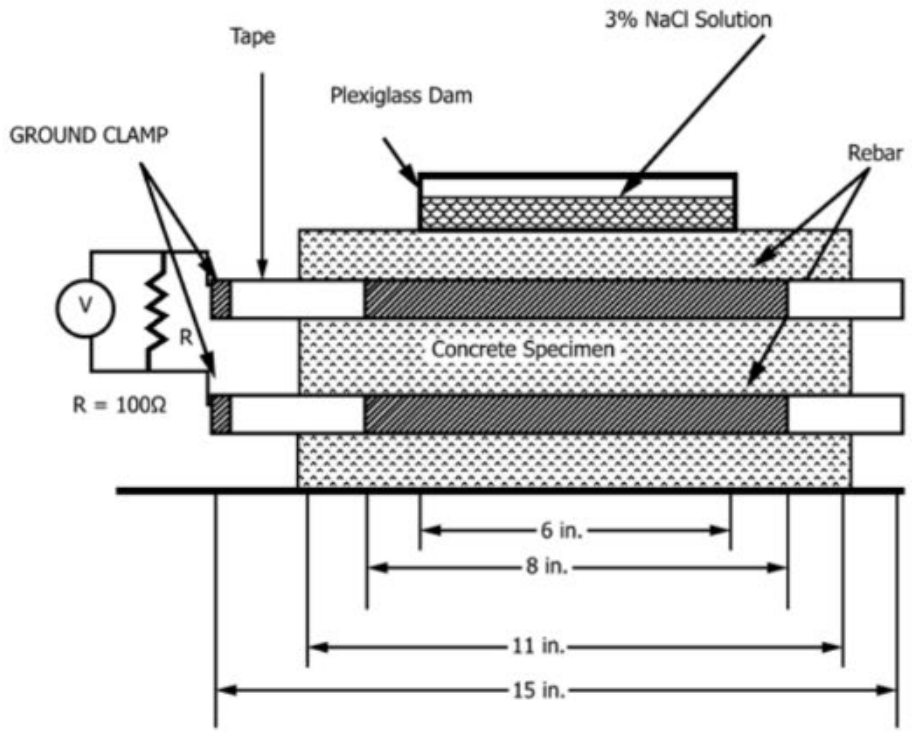
CHLORIDE PONDING SPECIMEN DIMENSIONS

- Dimensions are in accordance with ASTM G109



NOTE 1—All measurements in inches (25.4 mm = 1 in.).

FIG. 1 Concrete Beam



NOTE 1—All measurements in inches (not to scale) (25.4 mm = 1 in.).

FIG. 2 Concrete Beam (Side View)

Material Specimen Conditions

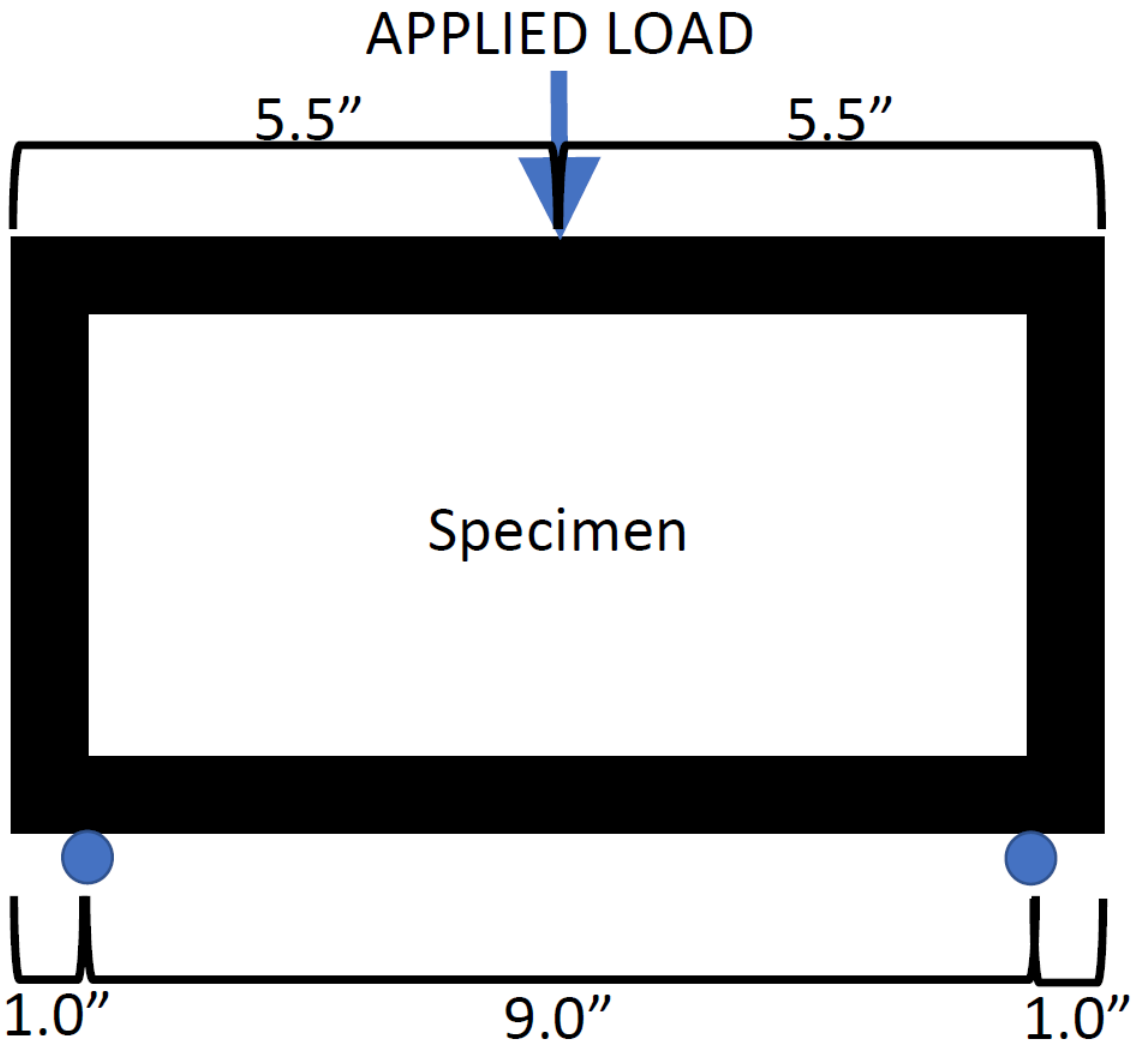
- Five brine solutions were used
  - 1.5% NaCl solution
  - 3.0% NaCl solution (specified in ASTM G109)
  - 4.5% NaCl solution
  - 6.0% NaCl solution
  - 9.0% NaCl solution

- Pre-cracking per salt level
  - One uncracked specimen
  - One flexure pre-cracked specimen

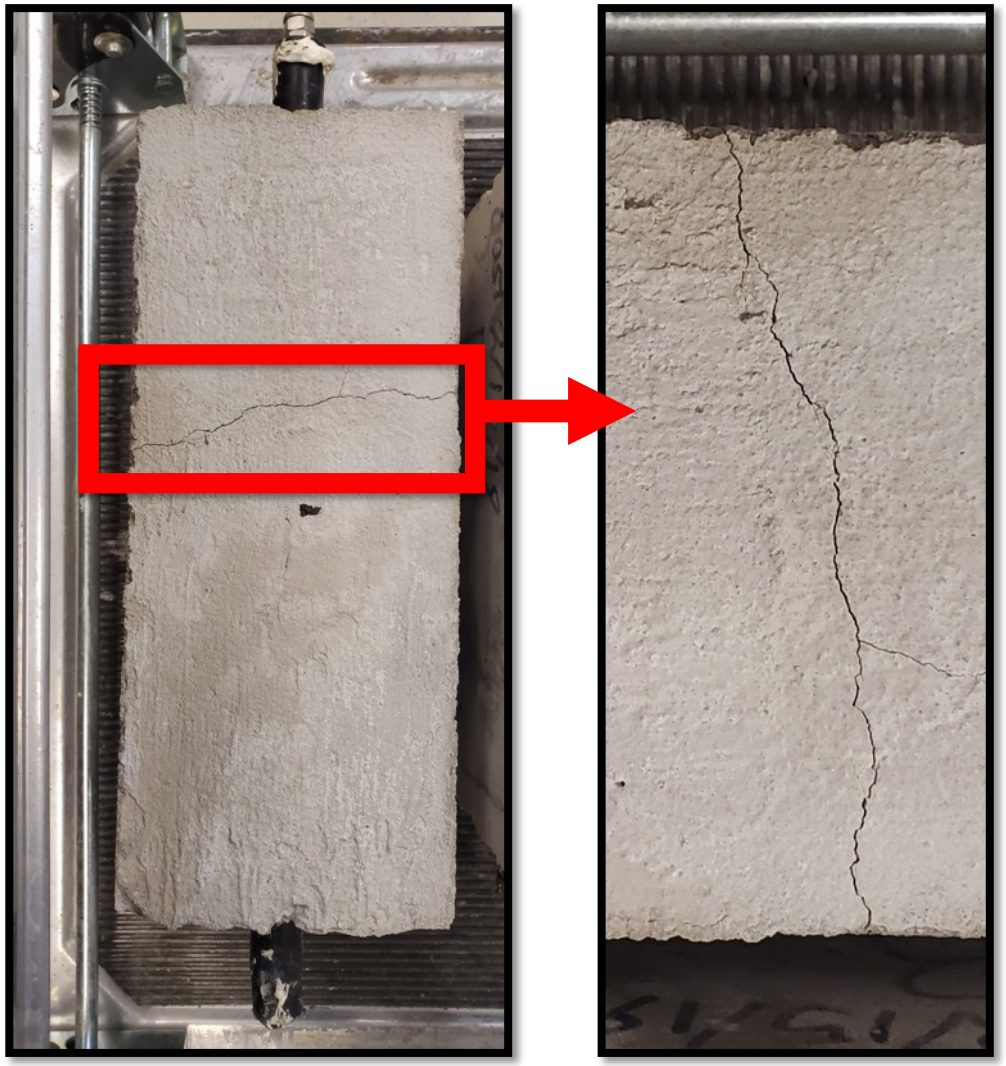
Source: indiamart.com, FHWA-RD-03-047

LOADING SPECIMENS TO FORM CRACK

- Single Point load
  - Load at midspan
- Loaded until 14.5 kips (Cracking moment of 2.75 k-ft)
  - Stopped if deformation but no additional load was observed (Crack has formed)
  - Loaded at 5000 lb./min

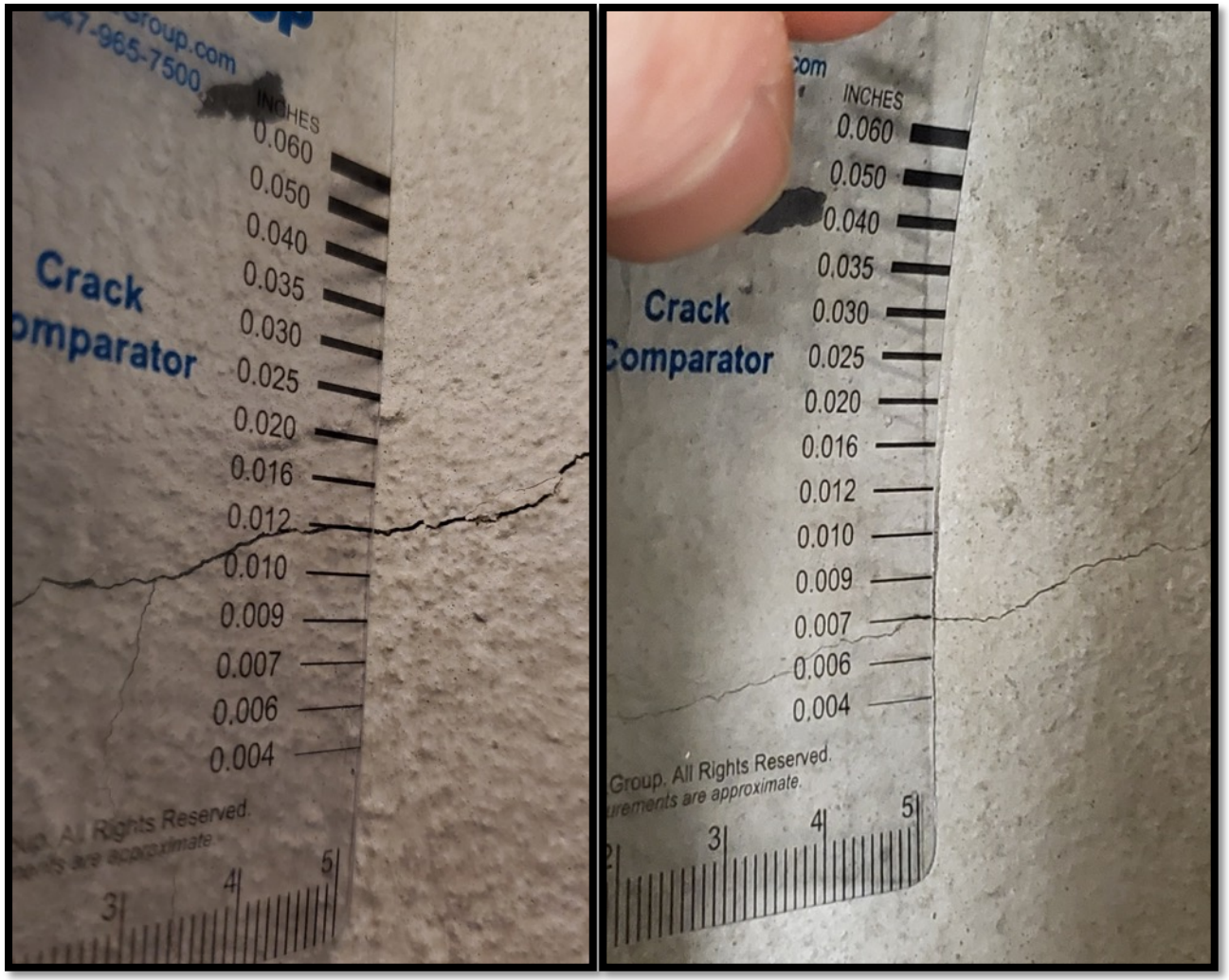


Photos of Cracked Specimens



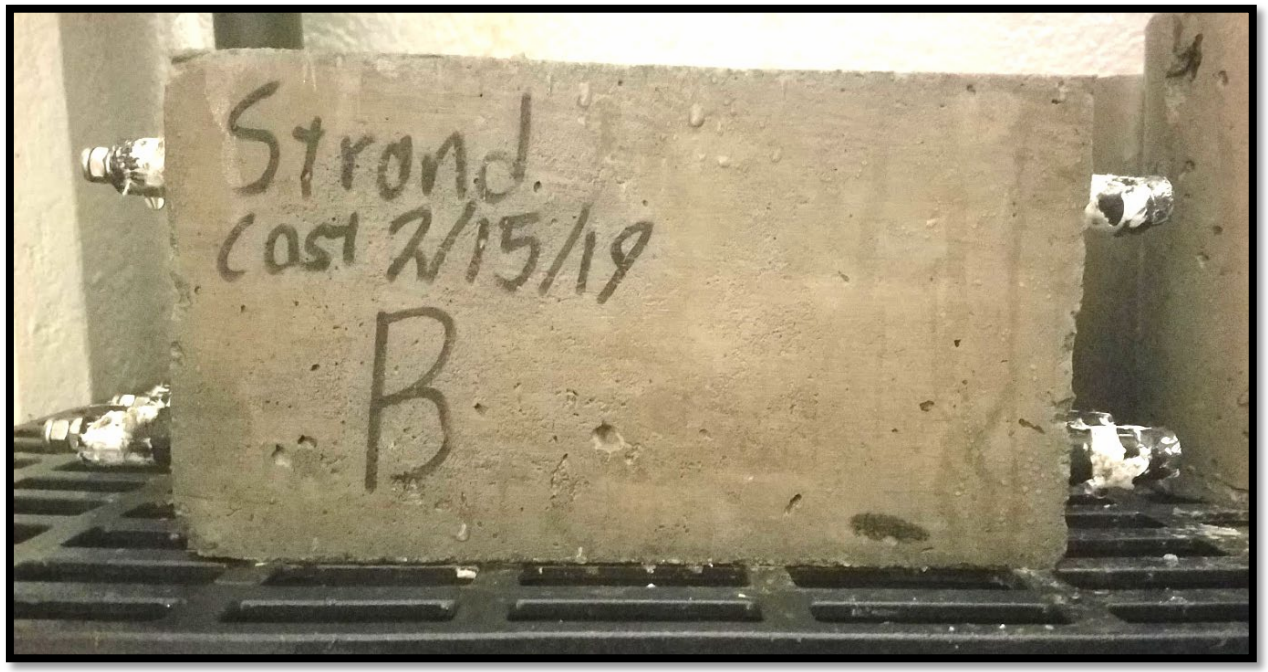
CRACK WIDTH

- Crack Width Range
  - 0.004 - 0.012 in.
  - 0.15 – 0.30 mm



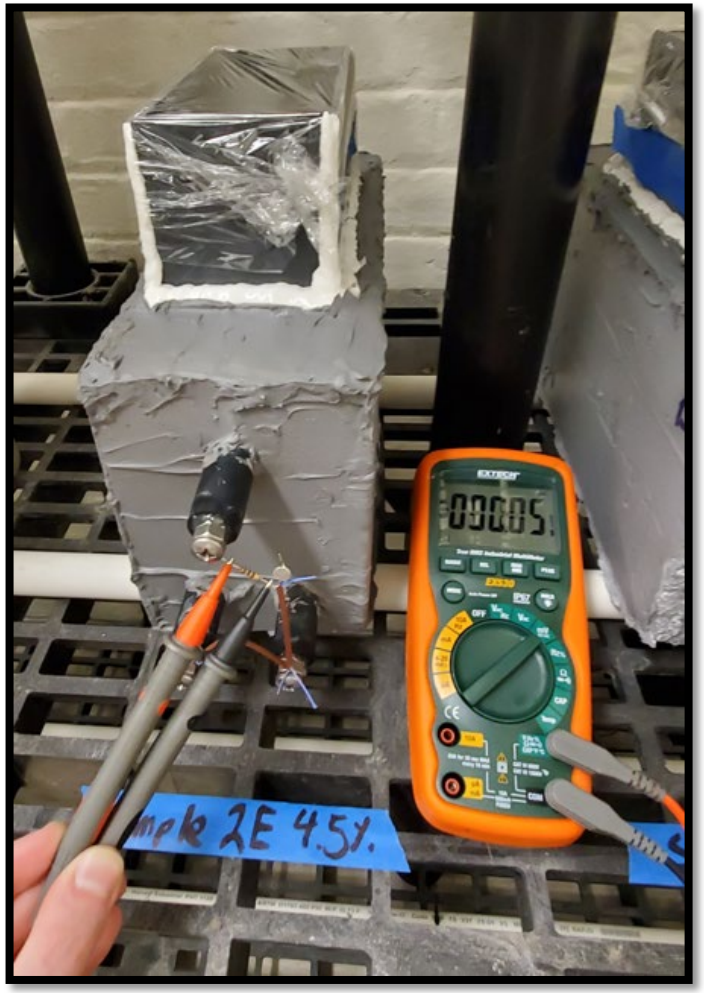
Material Specimen Procedure

- Curing regimen after casting
  - 28 days at >95% RH
  - 28 days at 50 ± 5% RH
  - Start of ponding cycles
  - 14 days w/salt solution
  - 14 days w/o salt solution
  - Repeat ponding cycles



Data Collection Timing

- ASTM G109
  - Every month, one week into ponding
- This project
  - Every third day and on biweekly salt solution addition or removal



MATERIAL SPECIMEN TESTING

- Measure voltage across resistor and calculate macrocell current
  - A macrocell current value above 10 μA is indication of chlorides reaching reinforcement steel (from ASTM G109)

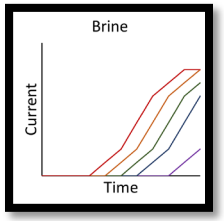
$$I_j = V_j/100$$

I_j is macrocell current,
V_j is measured voltage across 100 Ω resistor in volts

OUTLINE

Introduction to Bridge Corrosion

Testing Procedure



Macrocell Current Results

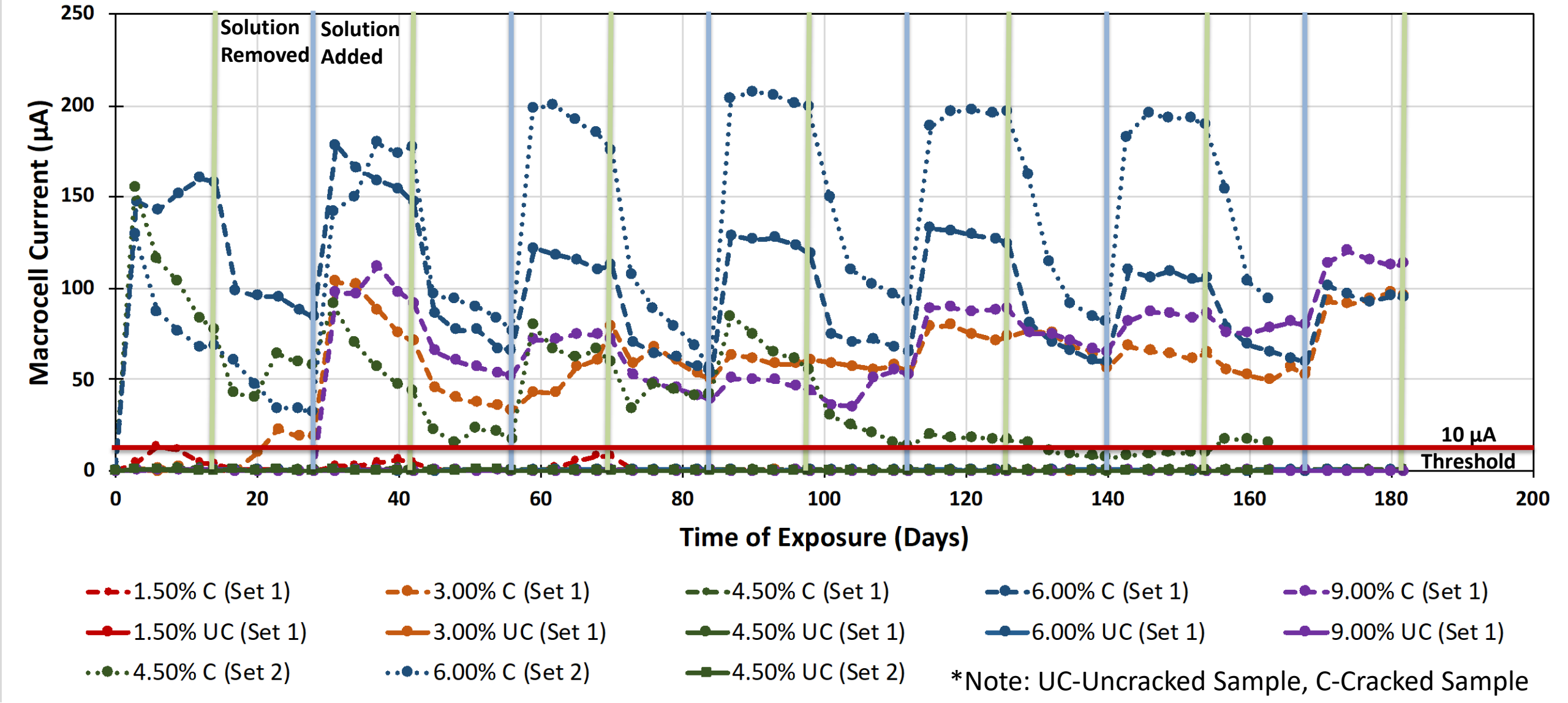
Conclusions

One Cycle Macrocell Current Results

Time of Exposure (Days)	Set 1 Ponding Cycle 5										Set 2 Ponding Cycle 5			
	1.50%		3.00%		4.50%		6.00%		9.00%		4.50%		6.00%	
	UC	C	UC	C	UC	C	UC	C	UC	C	UC	C	C	
Day 115	0.2	0.5	0	**79.0**	0.3	0.7	0.5	**133.0**	0	**89.0**	0	**20.2**	**188.7**	Solution Added
Day 118	0.3	0.7	0	**79.8**	0	0.8	0.5	**131.5**	0	**89.5**	0	**17.8**	**196.3**	
Day 121	0	0.9	0	**75.0**	0	0.8	0.4	**129.2**	0	**87.3**	0	**18.2**	**198.0**	
Day 124	0	1.0	0	**71.4**	0	0.8	0.5	**127.1**	0	**88.3**	0	**17.4**	**195.8**	
Day 126	0	1.1	0	**73.7**	0	0.8	0.4	**124.6**	0	**88.8**	0	**17.2**	**196.6**	Solution Removed
Day 129	0	0.6	0	**76.5**	0	0.9	0	**81.0**	0	**75.4**	0	**15.6**	**162.6**	
Day 132	0	0.5	0	**75.5**	0	0.8	0.4	**70.7**	0	**74.8**	0	**10.9**	**114.6**	
Day 135	0.3	0.5	0	**68.2**	0.3	0.7	0.5	**66.0**	0.1	**71.6**	0	9.0	**91.8**	
Day 138	0	0.6	0	**65.4**	0.4	0.7	0.5	**60.2**	0	**66.6**	0.1	8.0	**84.8**	
Day 140	0.4	0.6	0.3	**56.0**	0	0.8	0.6	**59.9**	0.4	**65.1**	0	7.5	**81.6**	Solution Added

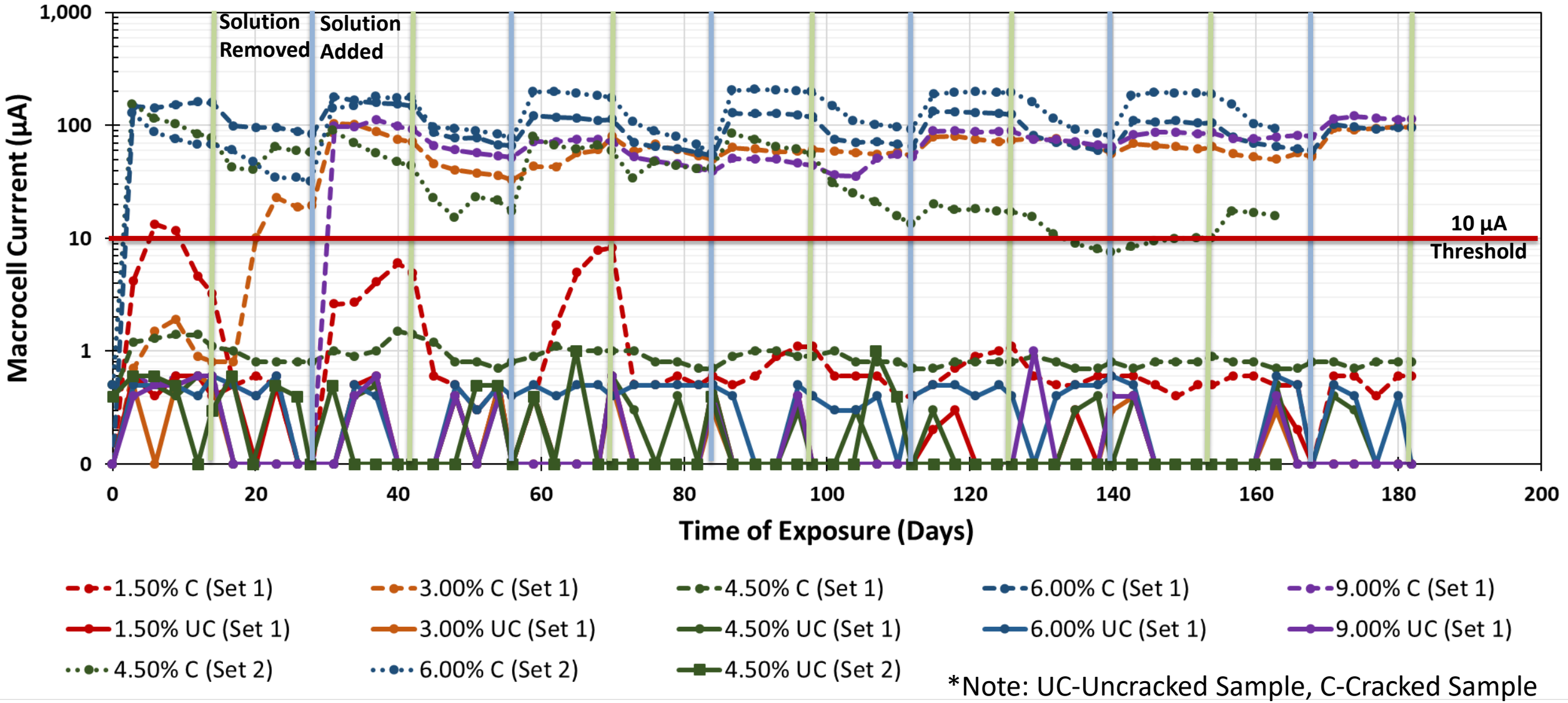
*Notes: 1) Bolded values represent current values above 10 µA (specified in ASTM G109), indication of chlorides reaching reinforcement steel, 2) UC for Uncracked specimens and C for Cracked specimens

ALL SPECIMENS MACROCELL CURRENT RESULTS



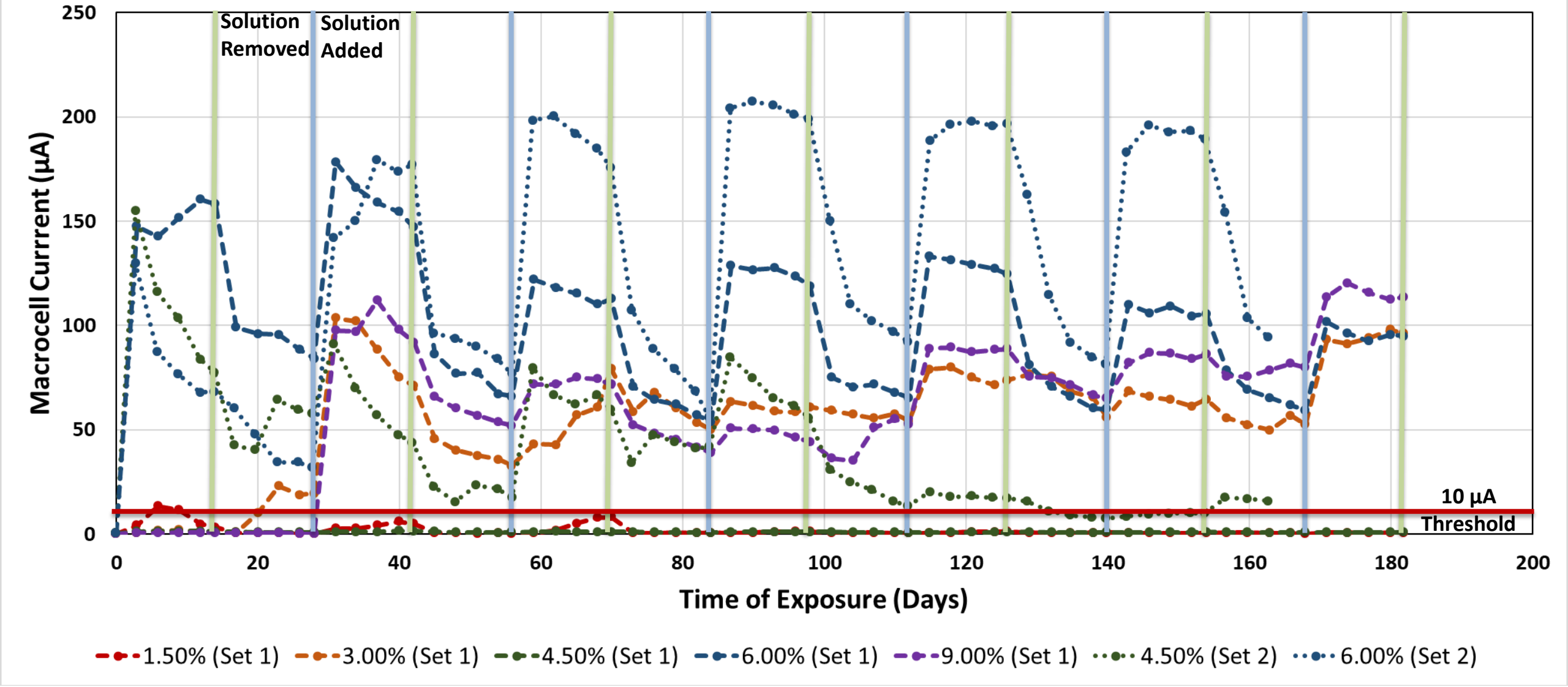
*Note: UC-Uncracked Sample, C-Cracked Sample

ALL SPECIMENS MACROCELL CURRENT RESULTS

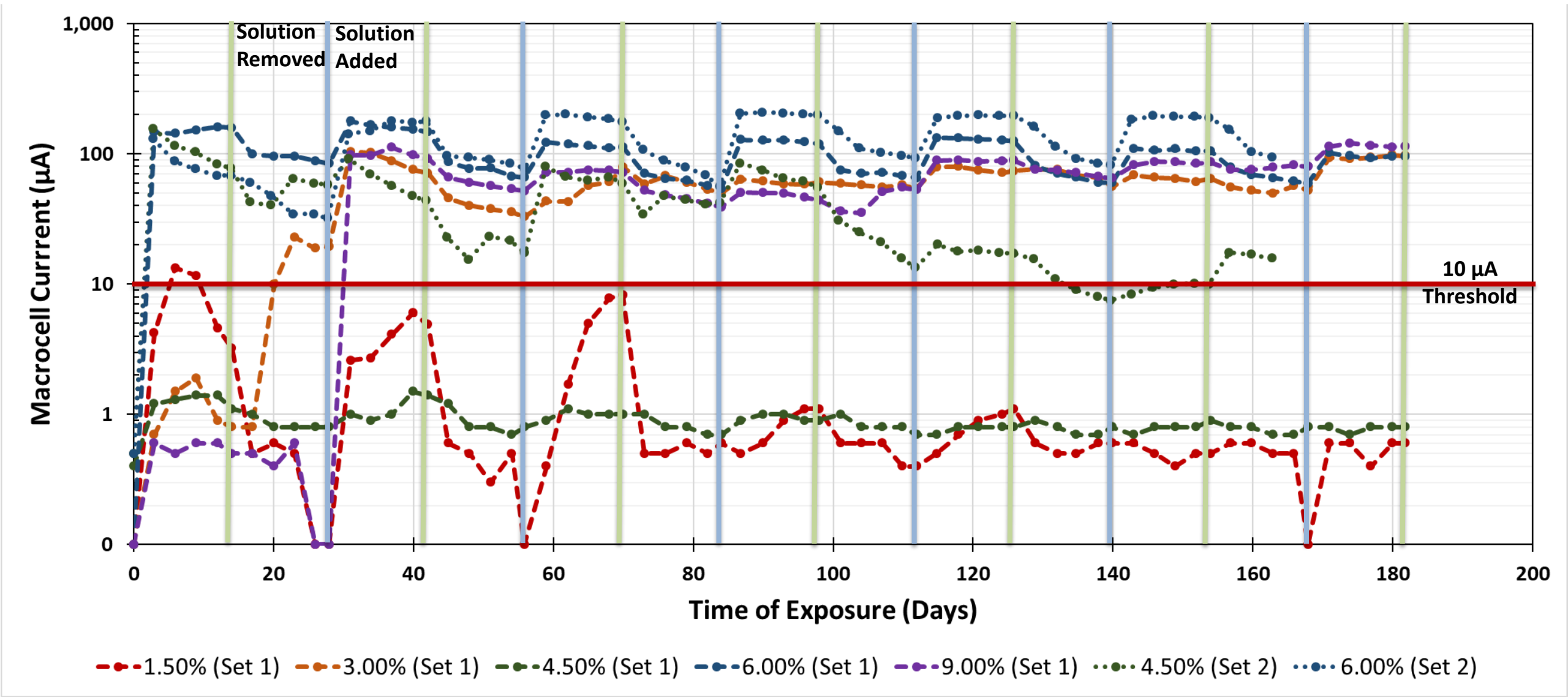


*Note: UC-Uncracked Sample, C-Cracked Sample

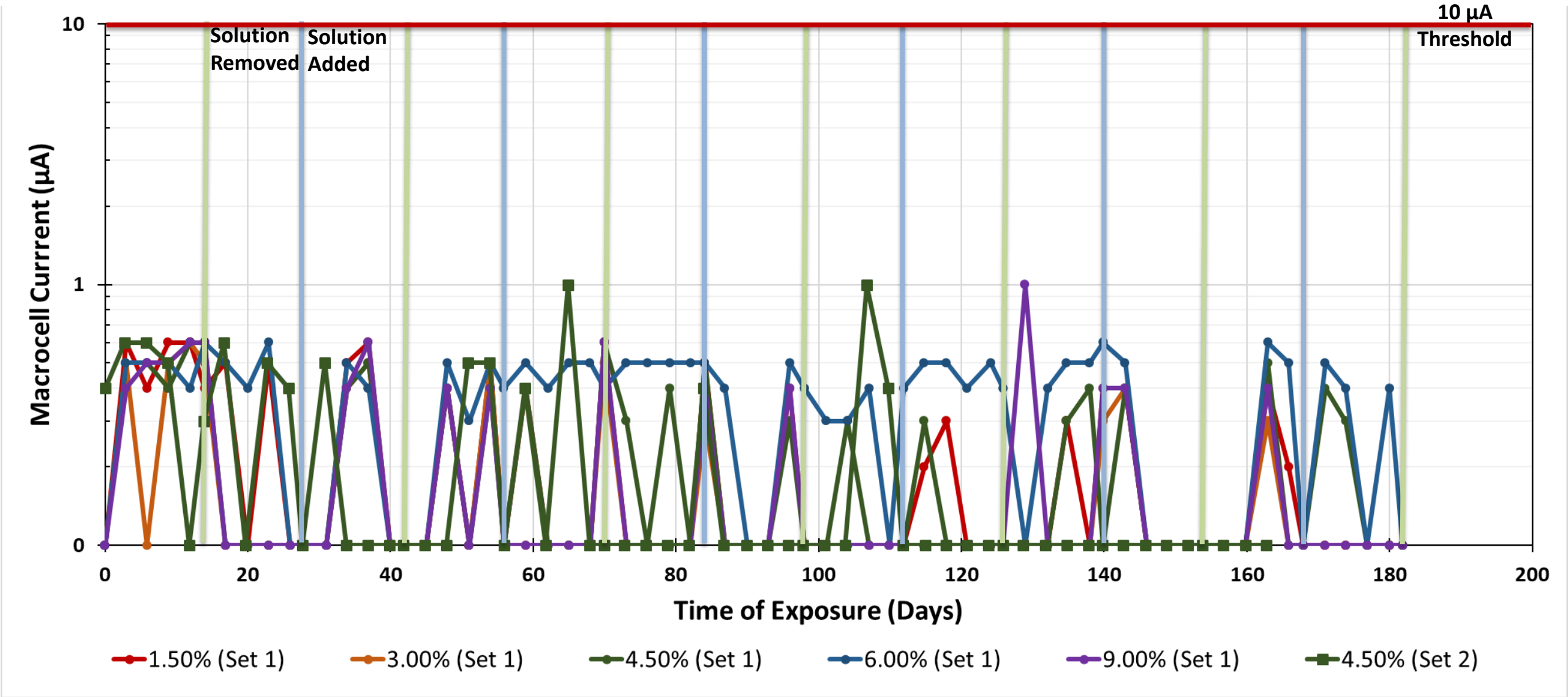
CRACKED SPECIMENS MACROCELL CURRENT RESULTS



CRACKED SPECIMENS MACROCELL CURRENT RESULTS



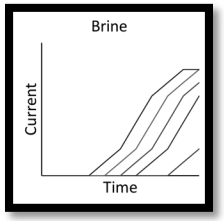
UNCRACKED SPECIMENS MACROCELL CURRENT



OUTLINE

Introduction to Bridge Corrosion

Testing Procedure



Macrocell Current Results

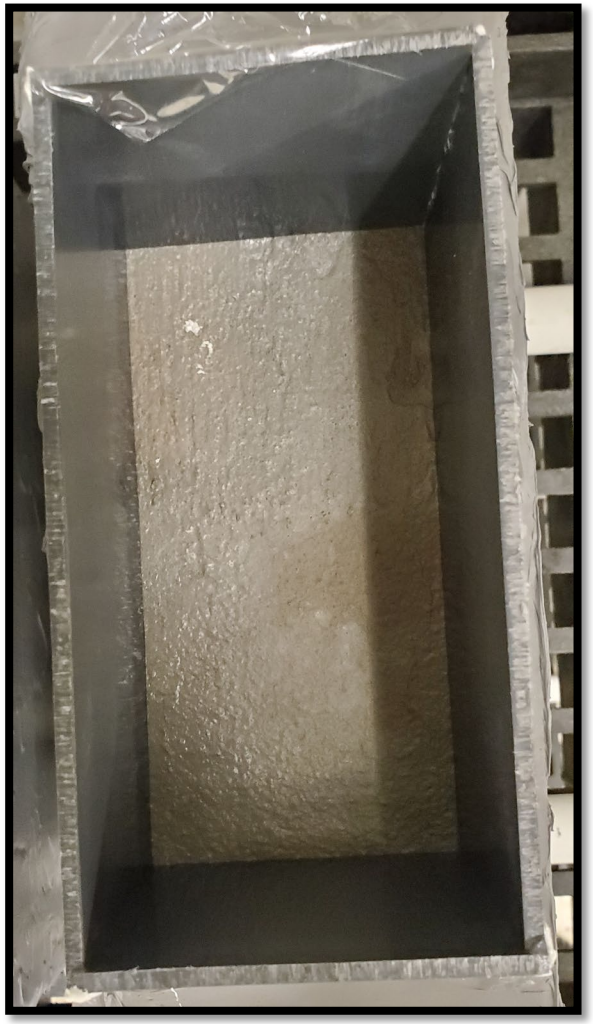
Conclusions

CRACKED VS. UNCRACKED FINDINGS

- For **cracked** specimens:
  - Threshold met for solutions **greater than 3%.**
  - Reached at a **greatly accelerated rate**

- For **un-cracked** specimens:
  - At **all** chloride levels no corrosion appears to have initialized

Cracked

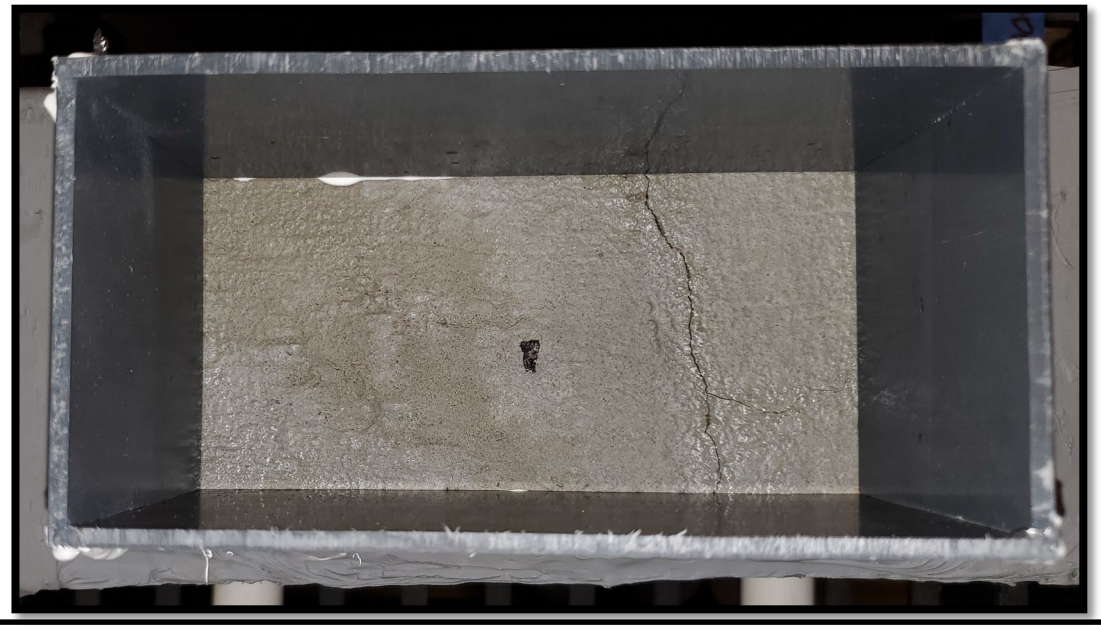


Uncracked

CRACK WIDTH FINDINGS

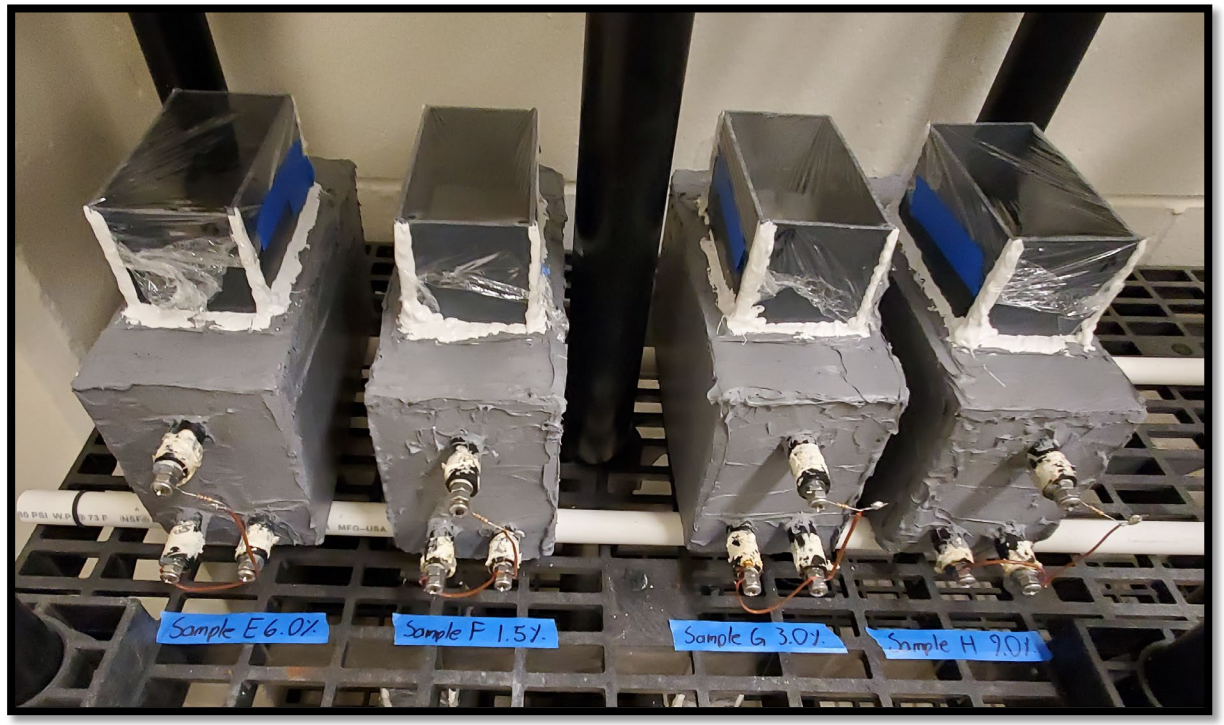
- Impact of **crack width** is currently **inconclusive**

- For more representative results, testing focusing on crack width and depth should be performed



Ponding Solution Findings

- At this point in testing:
  - In cracked specimens at concentrations **above 3%** threshold has been reached
  - **No difference** in current results for uncracked at current date



Future Plans

- Continue ponding cycles until uncracked (diffusion) specimens reach threshold
- Use specimens for chloride profile analysis

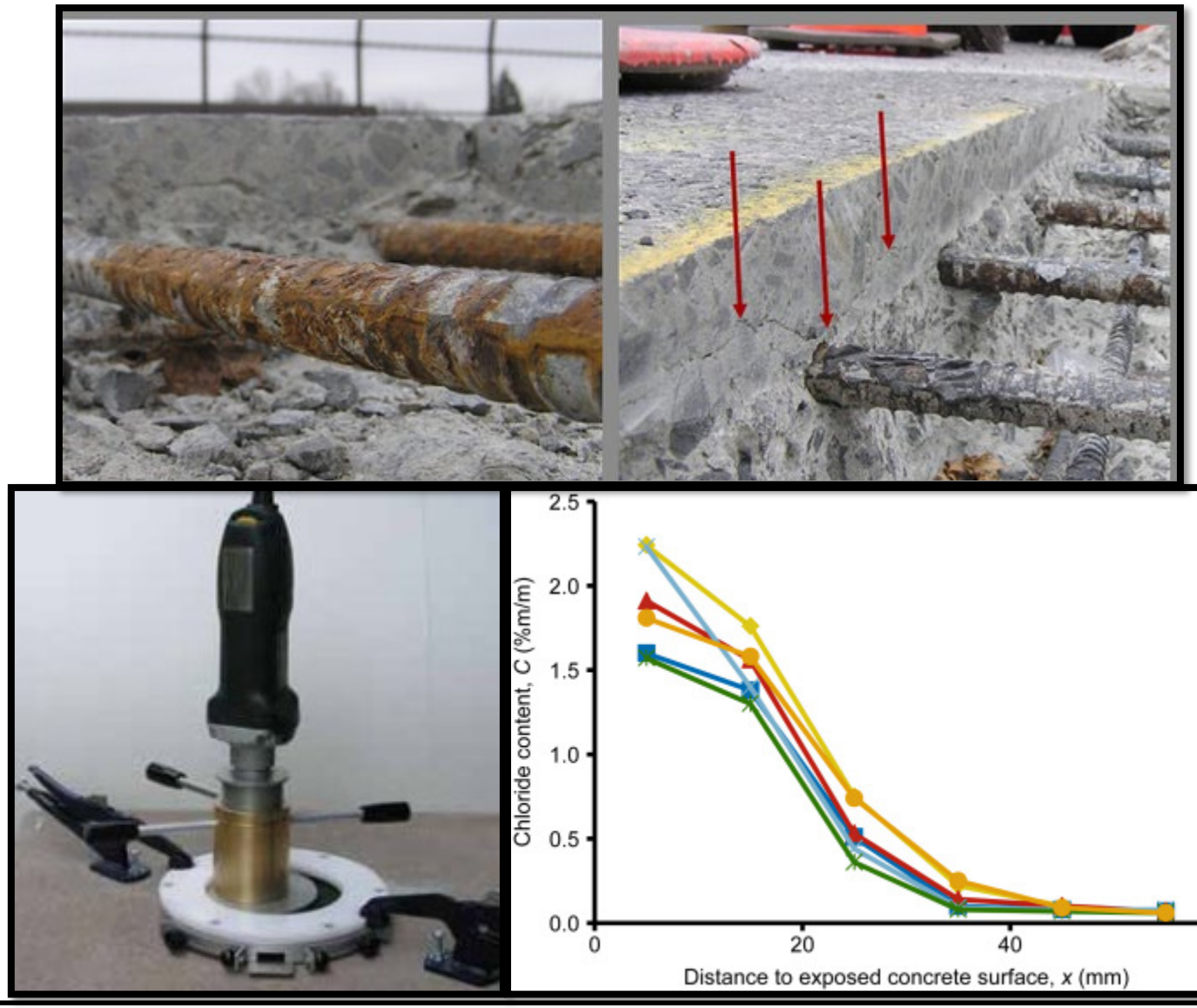


Image Sources: Gucunski et al. 2012; Germann Instruments; Gulikers 2016

THANK YOU / QUESTIONS?