ICRI
CONCRETE REPAIR
Restore | Repurpose | Renew

2024 SPRING CONVENTION

APRIL 21-24, 2024
ICRI.ORG

Evaluation of ECE, FRP, and Sealers for Corrosion Mitigation in Reinforced Concrete Bridges

Bridge Substructure Repair: Harvesting 1998 Research for Success

Paul Pilarski, Bridge Construction Engineer

Mark Chauvin, Principal and Unit Manager

APRIL 21-24, 2024

ICRI.ORG

What's in it for me?

1. Learn about 3 techniques researched in 1998 to give better service life extension to existing reinforced concrete substructure

2. Review initial research findings as compared to long term results

3. Understand the #1 thing to make above ground reinforced concrete last

Study Bridge

ICRI
CONCRETE REPAIR
Restore | Repurpose | Renew

I-394 over Dunwoody (MN Bridge No. 27831)

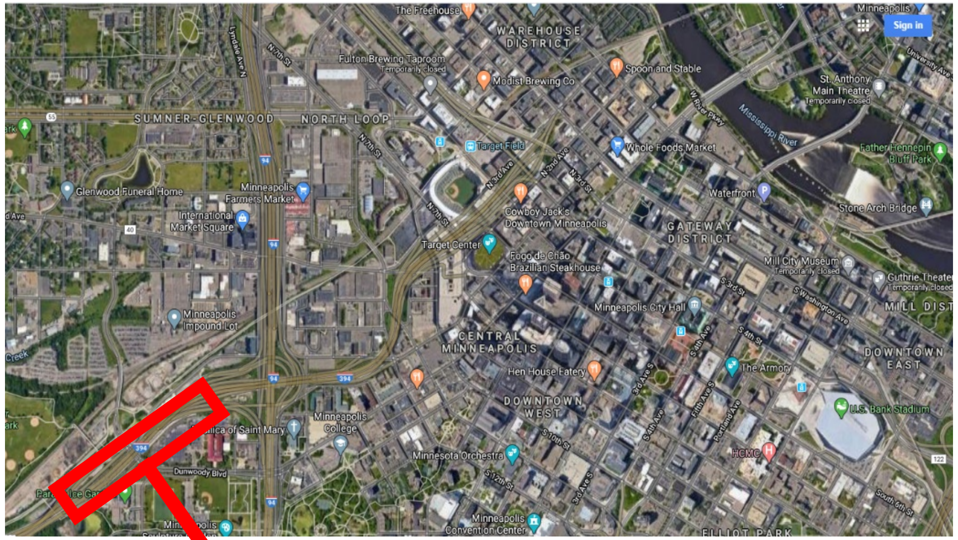
- Concrete Deck
  - Joints every 3rd pier
- Prestressed girders
- Reinforced concrete piers
  - black bar

History:

- Built 1967
- New deck joints → 1977, 1987, 2004

Why this bridge?

- High number of piers
- History of pier corrosion
- Very accessible

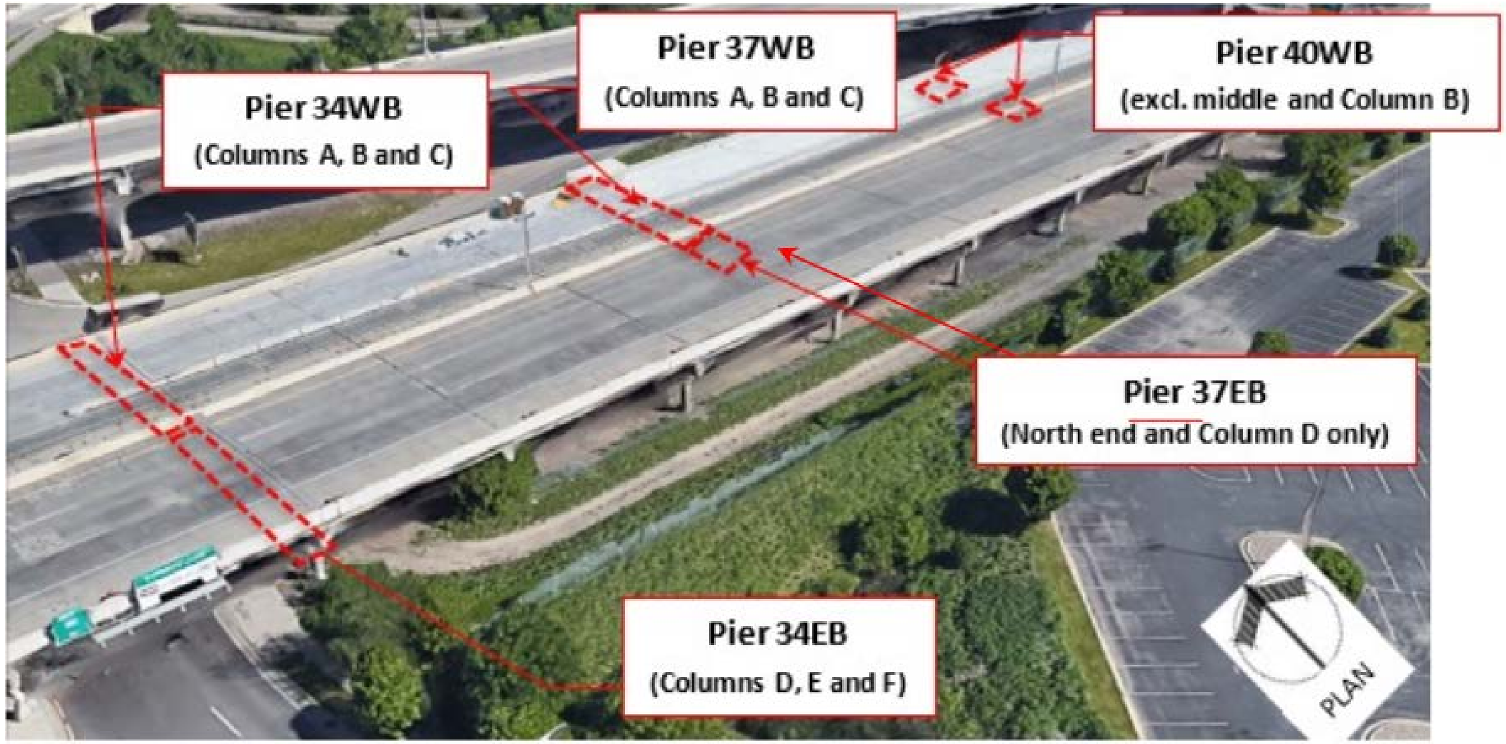


1998 Study

Dr. Shield, University of Minnesota
Mark Chauvin, U of MN grad student

- U of MN | MnDOT partnership

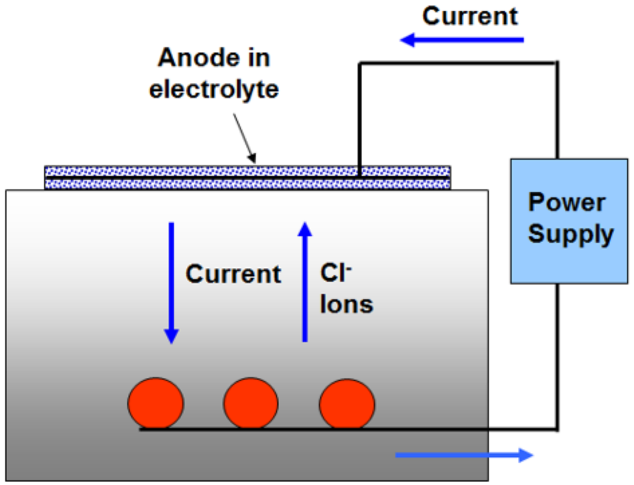
- Evaluate "new" corrosion mitigation techniques on substructures
  - Electrochemical chloride extraction (ECE)
  - Fiber reinforced polymer (FRP) wraps
  - Sealers

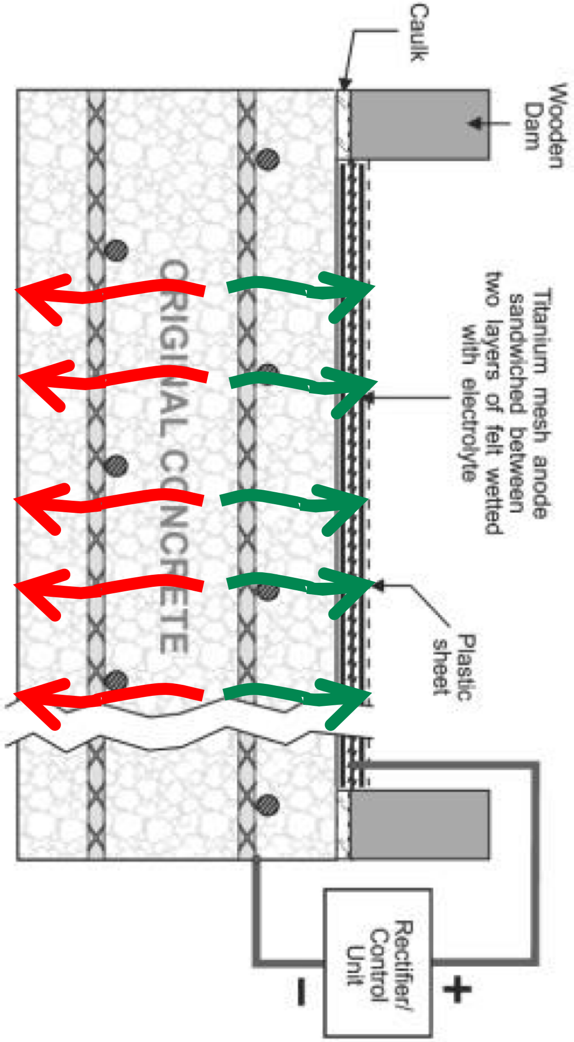


1998 Study

ECE:

- Remove chloride ions (cause corrosion) from concrete
- Uses water and electricity
- Typ. Duration → 3 to 6 weeks
- Can restore to near original condition
- $$$





1998 Study

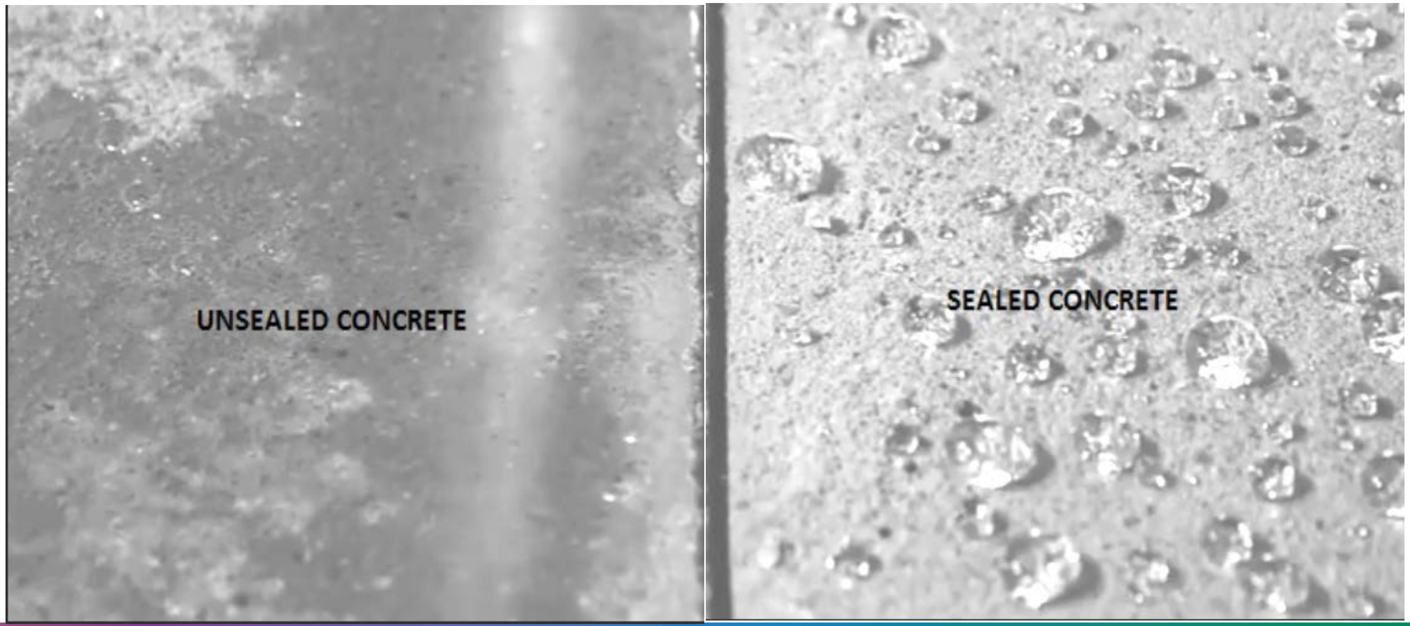
Fiber Wrap (FRP):

- Confines concrete against cracking
- Limits water ingress
- Can partially replace any lost/corroded steel
- Concern: Does corrosion continue under wrap?
- $$

1998 Study

Sealers (silanes):

- Sealant absorbed into concrete
- Limits water ingress
- Short-lived effectiveness?
- Concern: Is moisture trapped in concrete?
- $



1998 Study

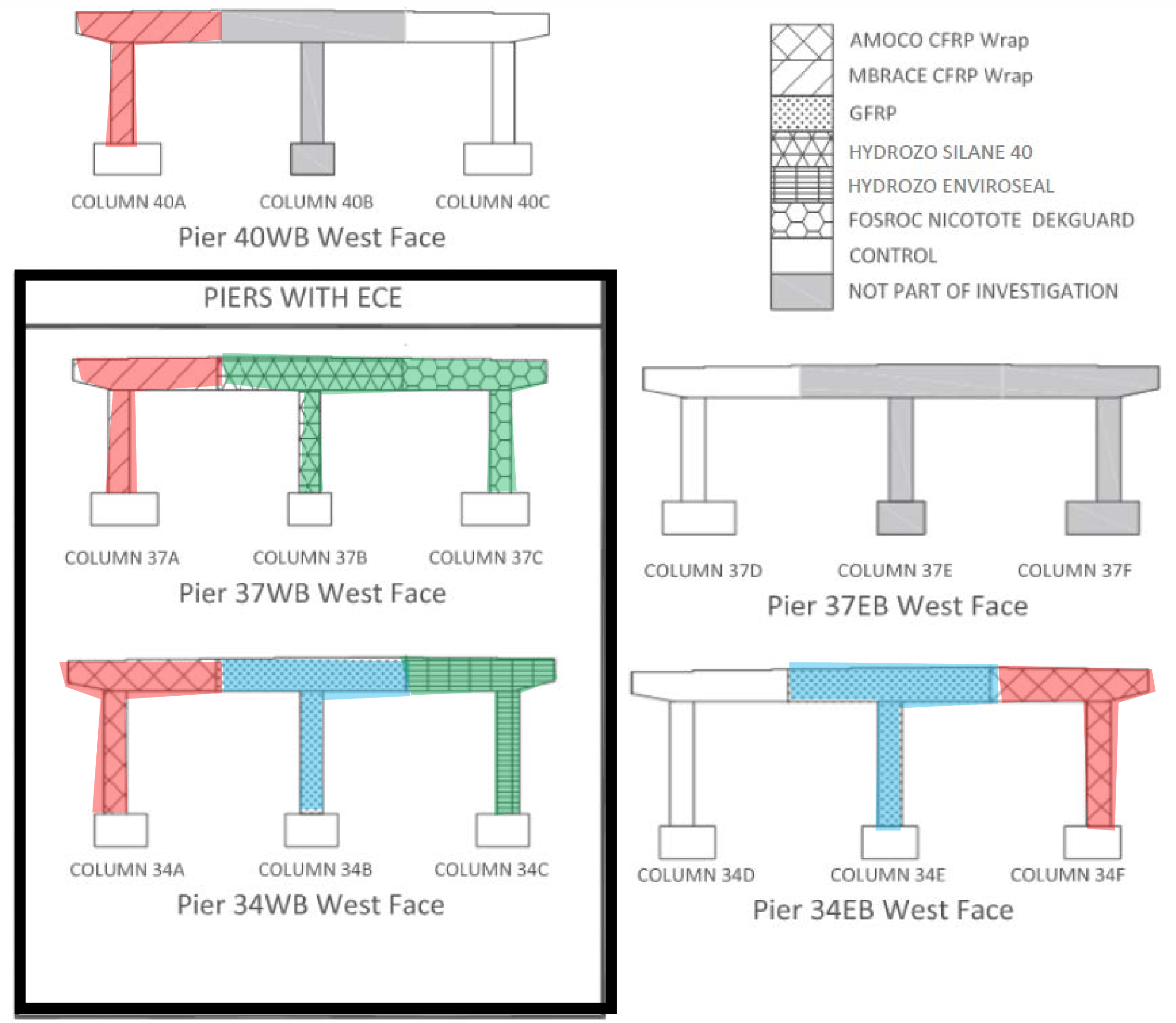
Carbon FRP

GFRP

Sealer

Control

Not included



1998 Study

Shotcrete repairs (1997)

- No anodes

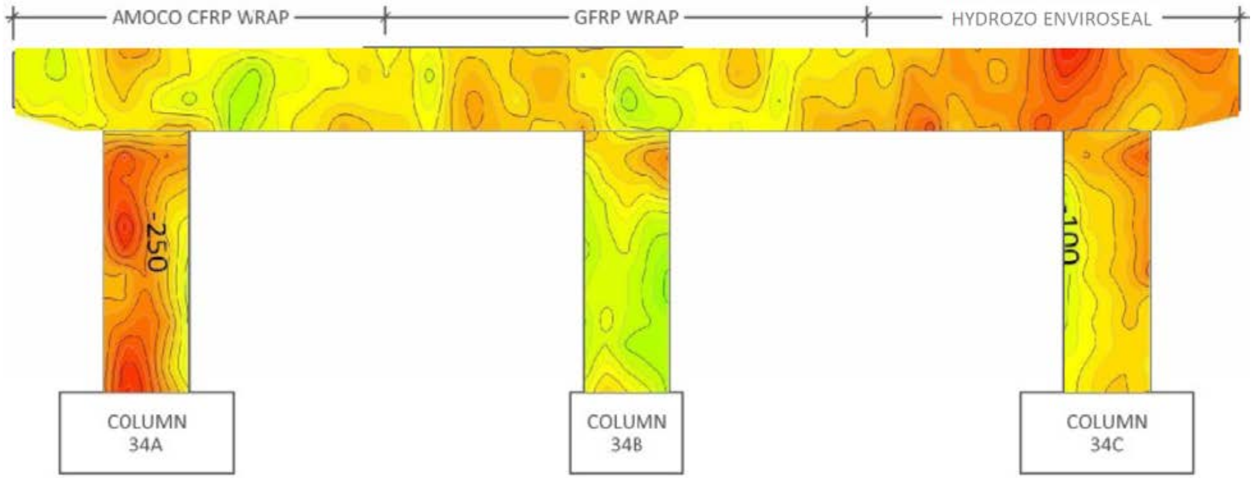
1998 Study

ECE (1998)

- Pier 34WB
- Pier 37WB

1998 Study

- Chloride testing
  - Before and after ECE
- Half-cell potential testing
  - Before and after ECE
- Resistivity
  - After ECE



Pier 34WB West Face [ECE]

Post 1998 Study

Typical service conditions and…

- Continued half-cell/resistivity testing (1998-2005)
  - Data collected approx. quarterly

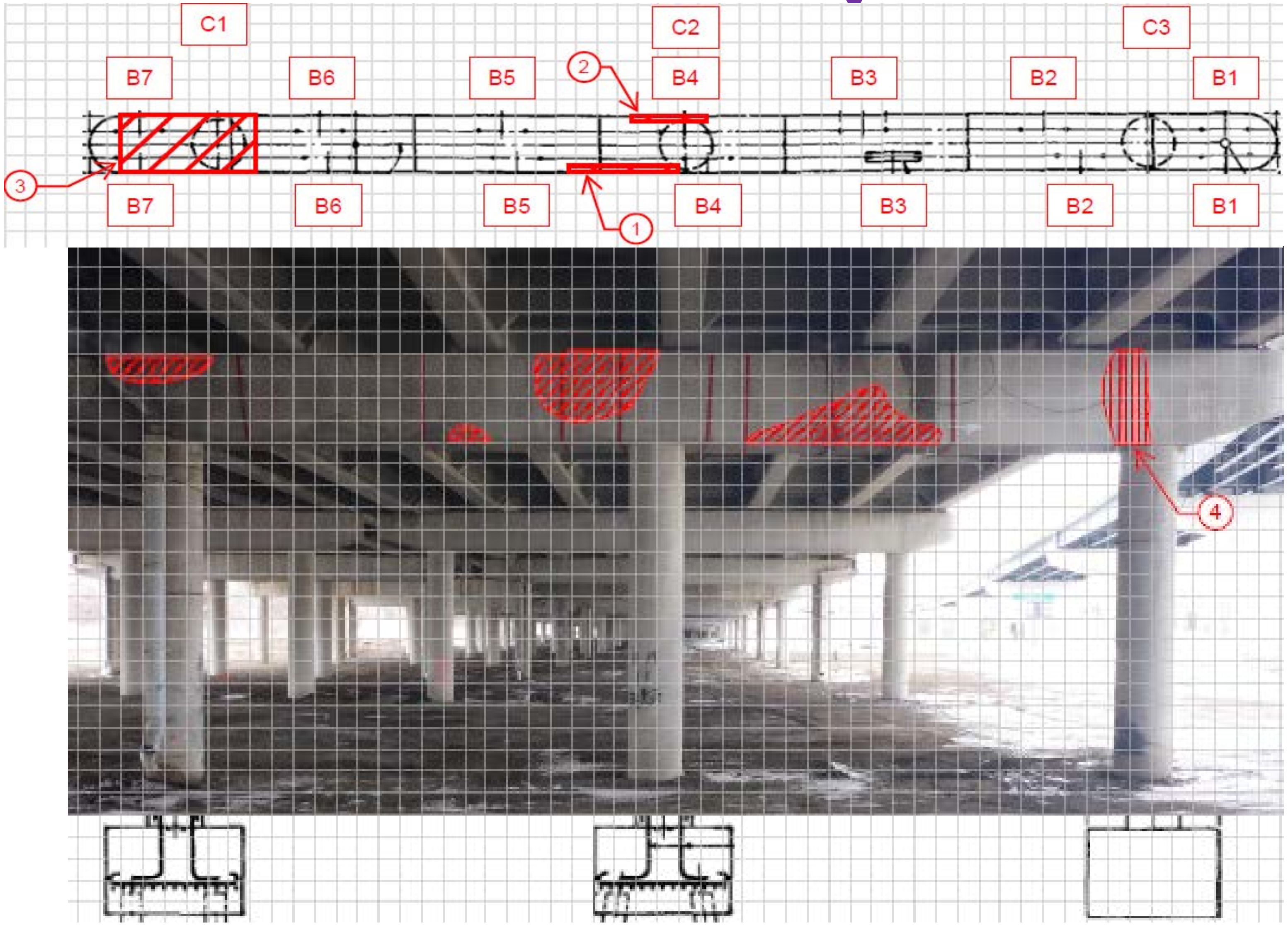
- New deck joints (2004)

- Fire! (2007)

WB Pier 34, West Face, North End (2018)

2017-18 repair planning

Inspection contract for bridge substructure repair needs in 2019 project



2018 Study Initiates

- 1998 study intended to identify best practice for long-term durability
  - Value and Effectiveness

- Unique research opportunity
- Harness evidence to close loop on 1998 study
  - Real traffic and environment (not lab)
  - Real project needs for data

2018 Study

Mirror 1998 study

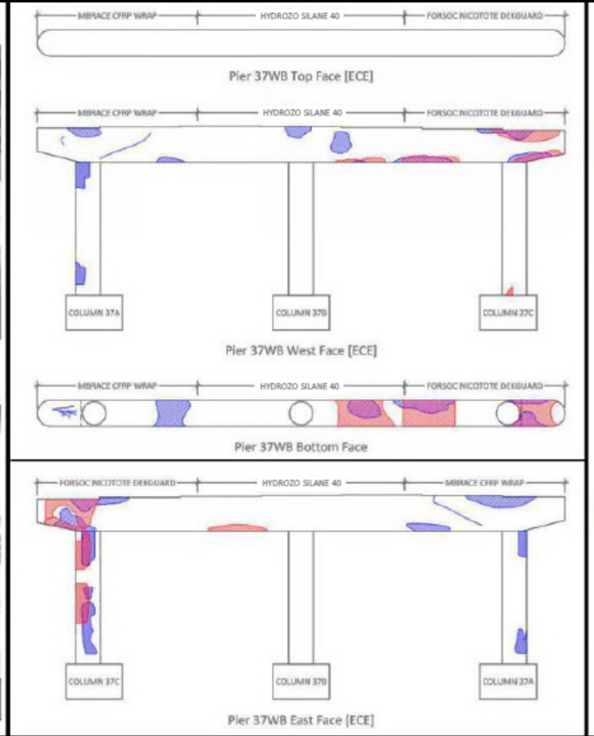
- Delamination mapping/repair areas (Collins Engineers)
- Visual inspection
- FRP openings
- Half-cell testing
- Chloride testing adjacent to 1998 pre/post ECE locations

ICRI CONCRETE REPAIR
Restore | Repurpose | Renew

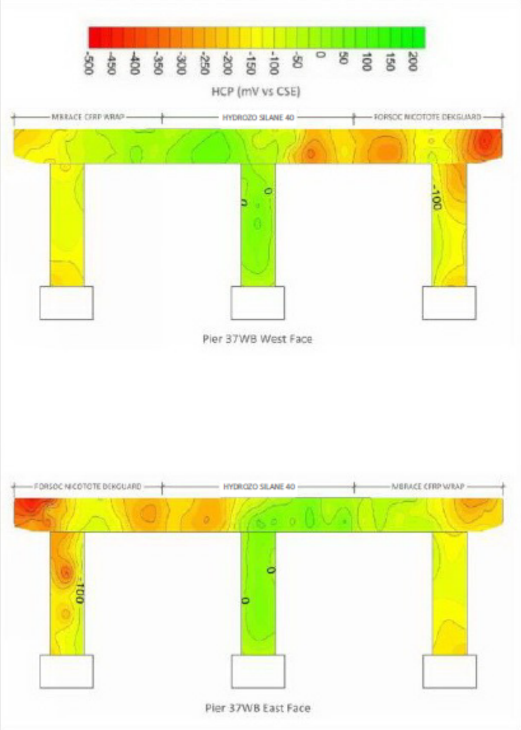
2018 Study - Findings

Images (2018) - Chloride Sample Locations Identified

Comparison of Concrete Distress - 1998 (Blue) vs. 2018 (Red)



Half-Cell Potential (2018) - Contour Plot



20 Year Review - Comparison of Chloride Content at Depth of Reinforcing Steel (1.5 - 2.5") vs. Corrosion Threshold (0.035% by weight of concrete)

Sample Location	Pier Cap						Column A		Column B		Column C	
Sample ID	37N-W1	37N-W3	37N-W4	37N-E1	37N-E2	37N-E3	37A-1	37A-2	37B-1	37B-2	37C-1	37C-3
1998 - Pre-ECE	0.021	0.006	0.018	0.040	0.041	0.011	0.002	0.005	0.002	0.035	0.004	0.001
1998 - Post-ECE	0.006	0.008	0.007	0.016	0.014	0.008	0.004	0.007	0.004	0.015	0.009	0.001
Surface Treatment	MBrace	Silane	Fosroc	Silane	Fosroc	MBrace	MBrace	MBrace	Silane	Silane	Fosroc	Fosroc
2018	0.128	0.039	0.094	0.108	0.113	0.022	0.009	0.008	0.008	0.008	0.129	0.018

20 Year Review - Comparison of Concrete Surface Distress

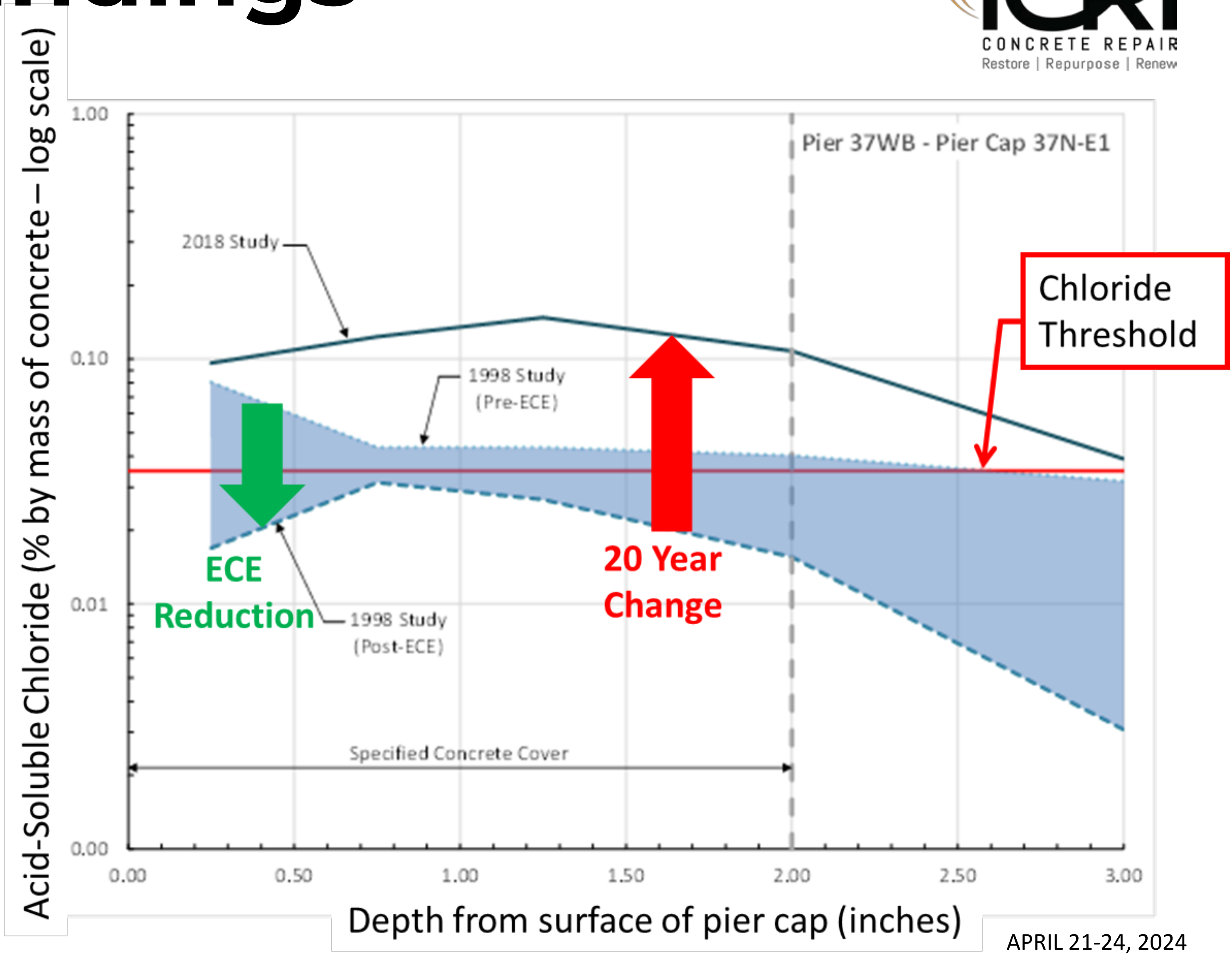
Element	*Locations*		*Corrosion Mitigation Strategy*			*Concrete Surface Distress*			
						1998 [Pre-ECE]		2018	
	Pier Cap	Column	ECE	FRP	Surface Treatment Type	Approximate Quantity (sf)	Distress Ratio (%)	Approximate Quantity (sf)	Distress Ratio (%)
Pier 37WB	North End	A	Yes	Yes	CFRP	35	11	0	0
	Middle	B	Yes	No	Sealer	20	5	30	7
	South End	C	Yes	No	Sealer	45	15	50	16

2018 Study - Findings

Pier	Treatment	Sample ID	Depth (in.)	Acid-Soluble Chloride Concentration Results (% by mass of concrete)					
				1998 Study			2018 Study		
				Pre-ECE	Post-ECE	Change (%)	Sample ID	Chloride Level	Change (%)
37WB	ECE + Sealer	37N-E1	0 - 0.5	0.080	0.017	-78.8		0.096	464.7
			0.5 - 1	0.044	0.031	-29.5		0.123	296.8
			1 - 1.5	0.044	0.027	-38.6	1737N-E1	0.148	448.1
			1.5 - 2.5	0.040	0.016	-60.0		0.108	575.0
			2.5 - 3.5	0.032	0.003	-90.6		0.039	1200.0
	ECE + Sealer	37N-E2	0 - 0.5	0.018	0.026	44.4		0.138	430.8
			0.5 - 1	0.028	0.028	0.0		0.152	442.9
			1 - 1.5	0.025	0.007	-72.0	1737N-E2	0.150	2042.9
			1.5 - 2.5	0.041	0.014	-65.9		0.113	707.1
			2.5 - 3.5	0.029	0.017	-41.4		0.058	241.2
	ECE + MBrace CFRP	37N-E3	0 - 0.5	0.032	0.016	-50.0		0.051	218.8
			0.5 - 1	0.017	0.018	5.9	1737N-E3	0.073	305.6
			1 - 1.5	0.013	0.018	38.5		0.037	105.6
			1.5 - 2.5	0.011	0.008	-27.3		0.022	175.0
			2.5 - 3.5	0.008	0.003	-62.5		0.019	533.3
	ECE + Sealer	37N-E4	0 - 0.5	0.016	0.010	-37.5		N/A	N/A
			0.5 - 1	0.041	0.017	-58.5		N/A	N/A
			1 - 1.5	0.041	0.011	-73.2	N/A	N/A	N/A
			1.5 - 2.5	0.044	0.003	-93.2		N/A	N/A
			2.5 - 3.5	0.037	0.002	-94.6		N/A	N/A

ECE Reduction

20 Year Change



2018 Study - Findings

Chlorides over threshold at depth of steel (2 inches):

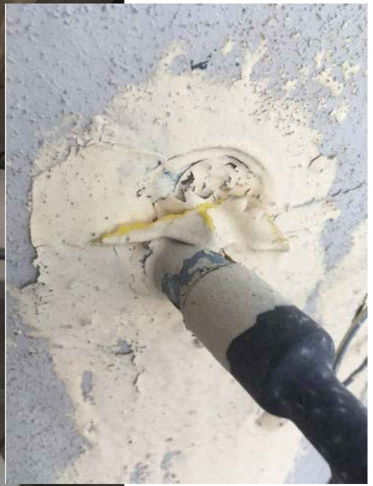
- **86%** of all core locations in pier caps
- **68%** of all core locations
- **54%** of all core locations in ECE treated piers
  - Was **0%** in 1998 post-ECE

Chloride increases NOT influenced by type of surface protection

2018 Study - Findings

Why CL- so high?

- FRP coverage incomplete
- Cores vs. powder
    - PPM vs. % by mass
- Samples only to 3-1/2” depth
- Location adjustments
- <u>**Significantly**</u> more exposure
    - Salt usage WAY up since 1998



2018 Study - Findings

ECE + FRP

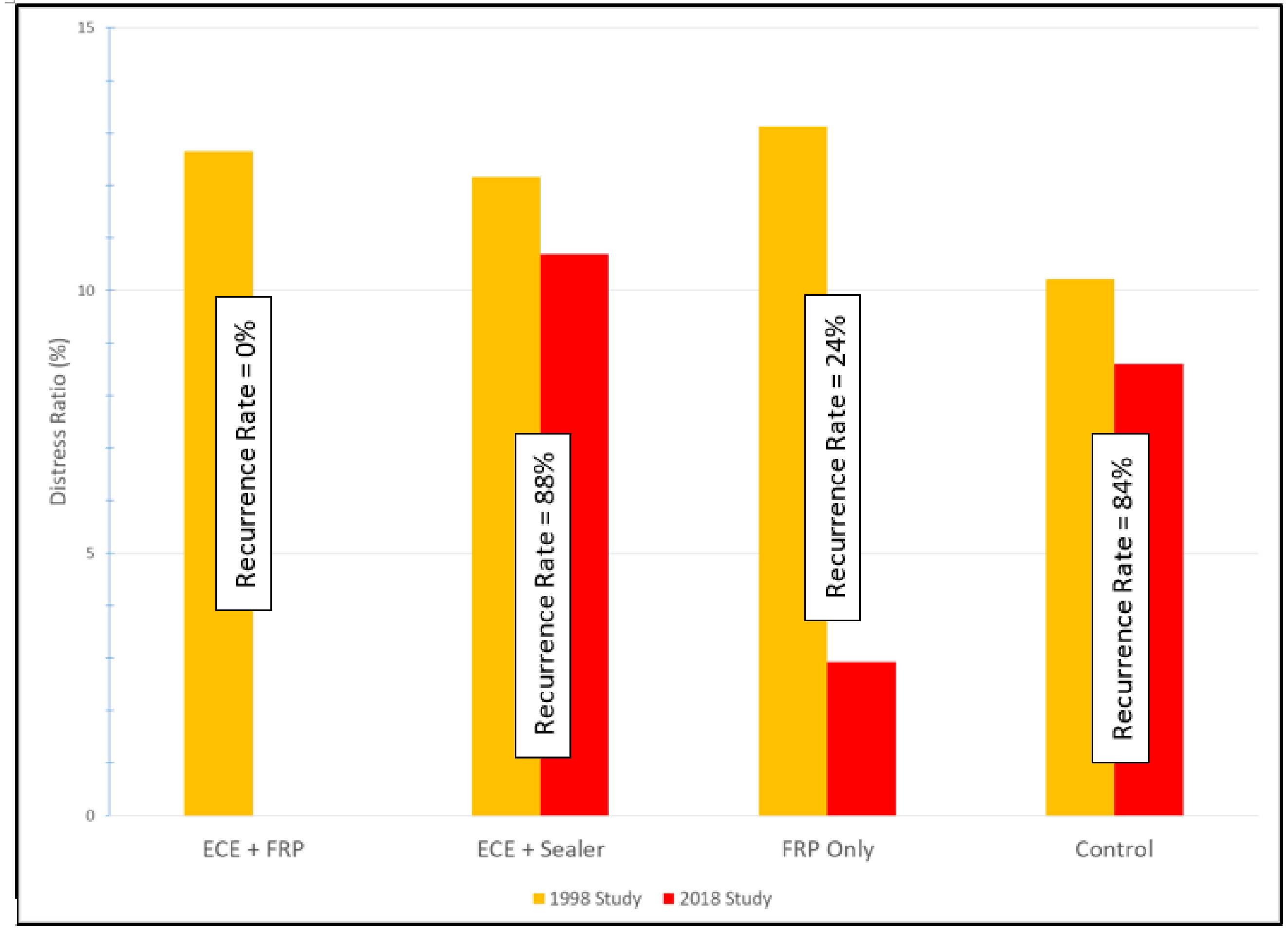
- No recurrent distress
- HCP typically passive

ECE + Sealer

- Recurrent distress ~ controls

FRP Only

- Recurrent distress in area of water exposure/joint leakage



2018 Study - Findings

Corrosion Mitigation Strategy					Risk Factors for Future Corrosion			
Description		Installation Locations			2018 Study Data			
ECE	Surface Treatment Type	Pier	Section of Pier Cap	Column	Risk of Corrosion as identified by Half-Cell Potential Testing[2]		Chloride Level over threshold at Depth of Reinforcement?	
					Pier Cap	Column	Pier Cap	Column
Y	FRP Wrap	34WB	North End	A	Low	Low	Yes	Yes
		34WB	Middle	B	Low	Low	Yes	Yes
		37WB	North End	A	Moderate	Low	Yes	No
Y	Sealer	34WB	South End	C	Moderate	Low	Yes	Near[3]
		37WB	Middle	B	Moderate	Low	Yes	No
		37WB	South End	C	High	High	Yes	Yes
Y	None							
N	FRP Wrap	34EB	Middle	E	Low	Low	Yes	Yes
		34EB	South End	F	Moderate	Moderate	Yes	Yes
		40WB	North End	A	High	High	Yes	Yes
N	Sealer							
N	None	34EB	North End	D	Low	Low	Yes	Yes
		37EB	North End	D	N/A	N/A	No	Yes
		40WB	South End	C	Moderate	Low	Yes	No

ICRI CONCRETE REPAIR
Restore | Repurpose | Renew

Cost vs benefit

1998 treatment and cost				
Description		Installation Cost[1] (Approximate square feet treated)		
ECE	Surface Treatment Type	ECE	Surface Treatment	Mobilization/ Demobilization
Y	FRP Wrap	$33,805 (1025)	$51,625 (900)	$5,160
Y	Sealer	$33,805 (1025)	N/A	$5,160
N	FRP Wrap	0	$51,625 (900)	$5,160
N	None	0	0	$0

Cost vs benefit

1998 treatment and cost					Concrete Repairs - 2019			
Description		Installation Cost[1] (Approximate square feet treated)						Total Cost[4,5] (1998 + 2019)
ECE	Surface Treatment Type	ECE	Surface Treatment	Mobilization/ Demobilization	Approximate Quantity[2] (SF)	Shotcrete Repair[3] ($/SF)	Approximate Total Cost[4]	
Y	FRP Wrap	$33,805 (1025)	$51,625 (900)	$5,160	0	$165	0	$91,000
Y	Sealer	$33,805 (1025)	N/A	$5,160	130		$22,000	$61,000
N	FRP Wrap	0	$51,625 (900)	$5,160	35		$6,000	$63,000
N	None	0	0	$0	95		$16,000	$16,000

Outcomes

1. ECE+ FRP → good performance | high cost + long construction time
2. ECE + Sealer → poor performance
3. FRP in presence of leaking joints → high recurrence
4. FRP without leaking joints → performed well
5. Concrete repair without other treatment was cost effective
   (*if structural damage can be tolerated)*

Fixing leaking joints most important to success

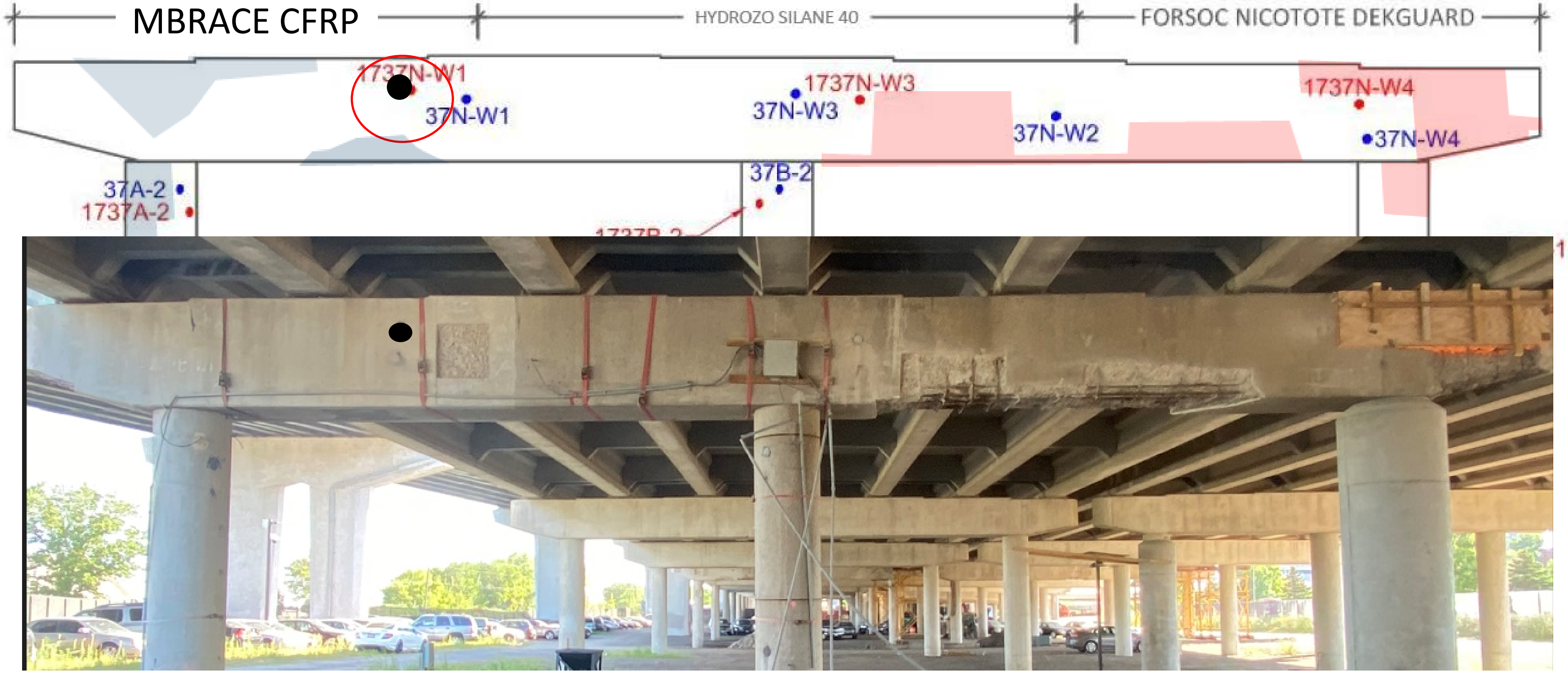
Additional Outcomes

6. ECE treatment significantly and immediately reduced chloride contamination present at the pier caps and columns. These conditions were not sustained over the 20-year life.

7. Significant chloride contamination occurred in all five piers over 20 years between studies.
    1. FRP/sealers did not prevent ingress of new chlorides.
    2. High chlorides did not result in rebar corrosion unless water leakage accompanied.

8. Instrumentation did not prove to be a reliable indicator of corrosion activity.

Additional Follow-up

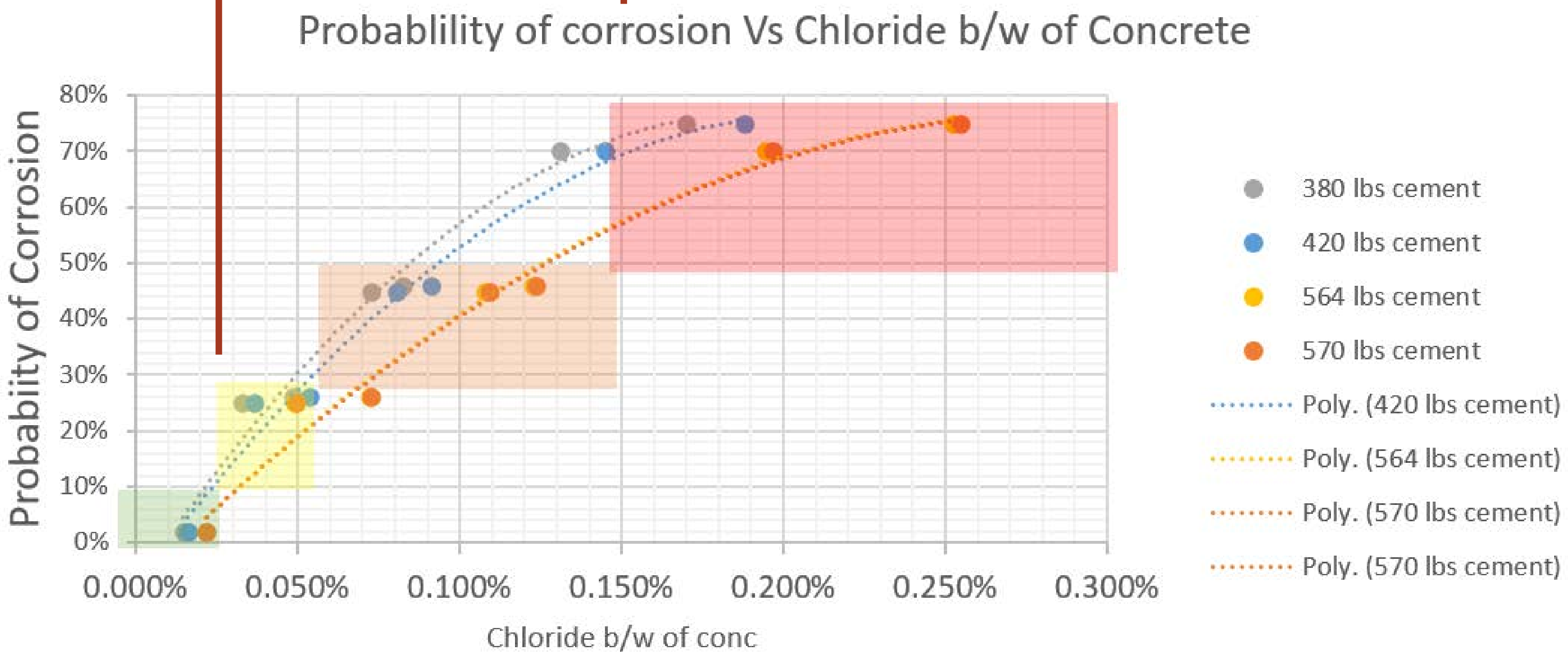


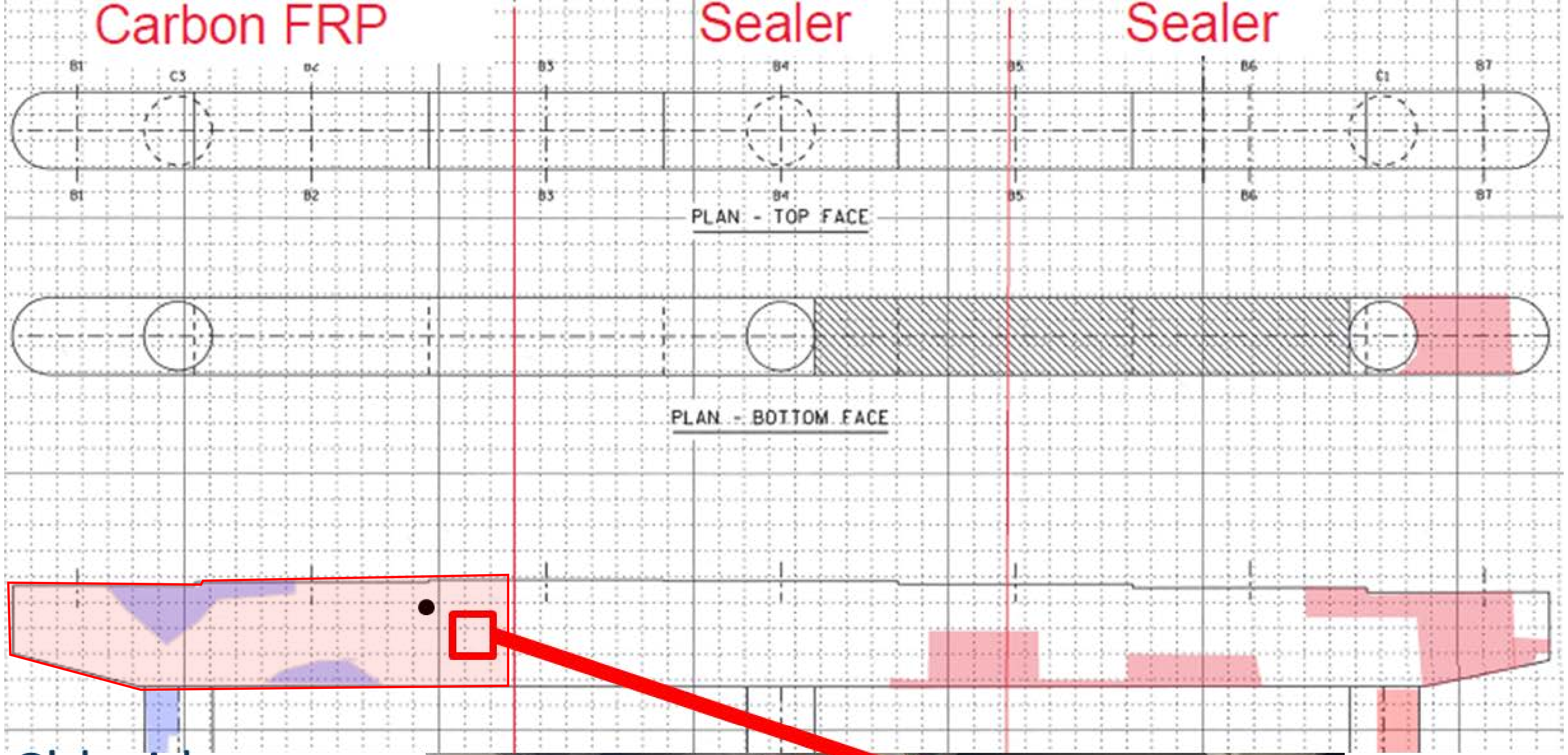
Chloride Influence?
West Face - WB Pier 37 – ECE Treated

Chloride risk and corrosion

Very low corrosion risk

High corrosion risk





2022 Chloride content around rebar = 0.066% by weight of concrete

MnDOT has used 0.035% threshold

Additional Follow-up

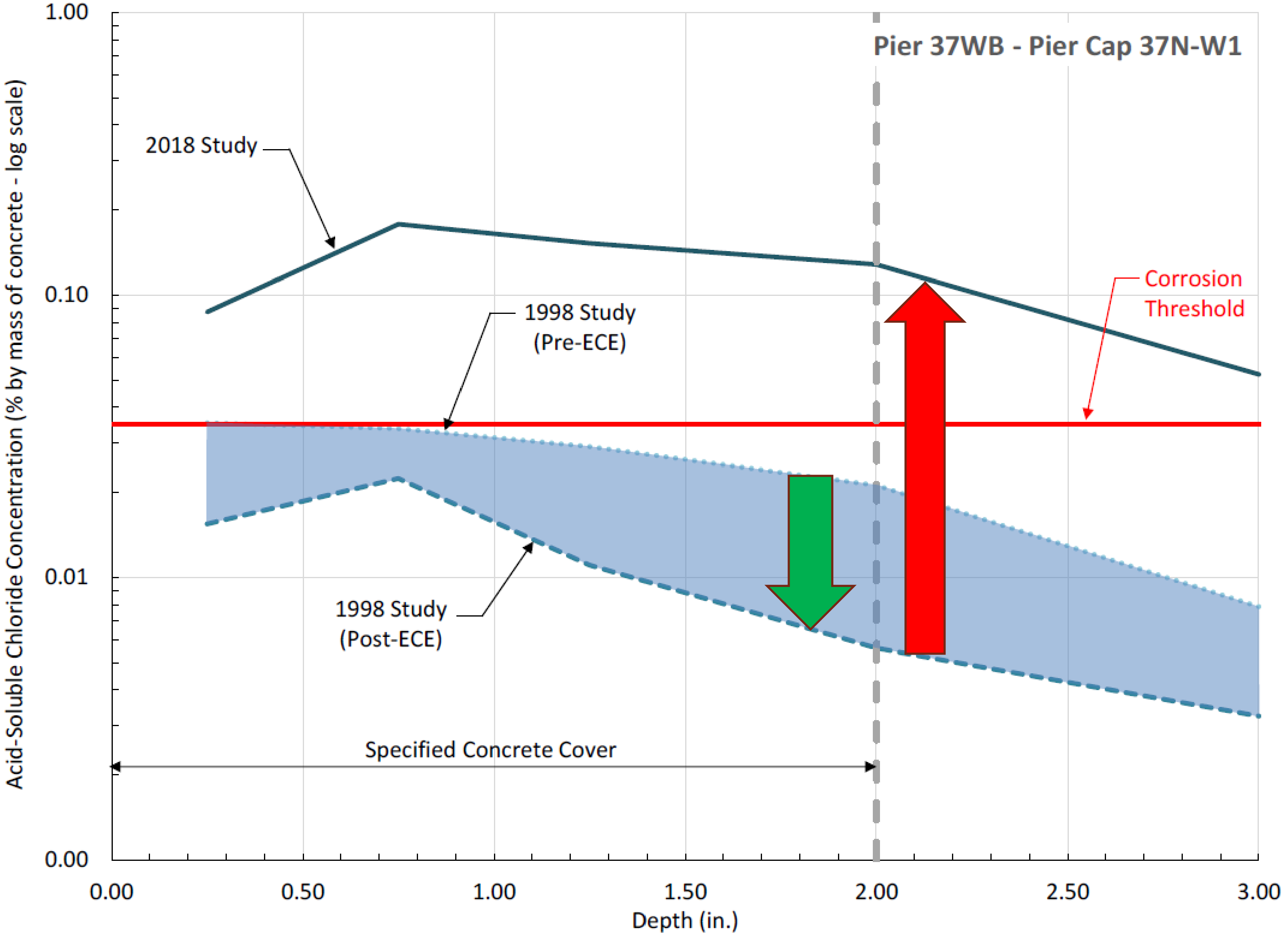
Chloride Influence?

West Face
WB Pier 37
ECE Treated

2022 Chloride content around rebar = 0.066% by wt of concrete

MnDOT has used 0.035% threshold

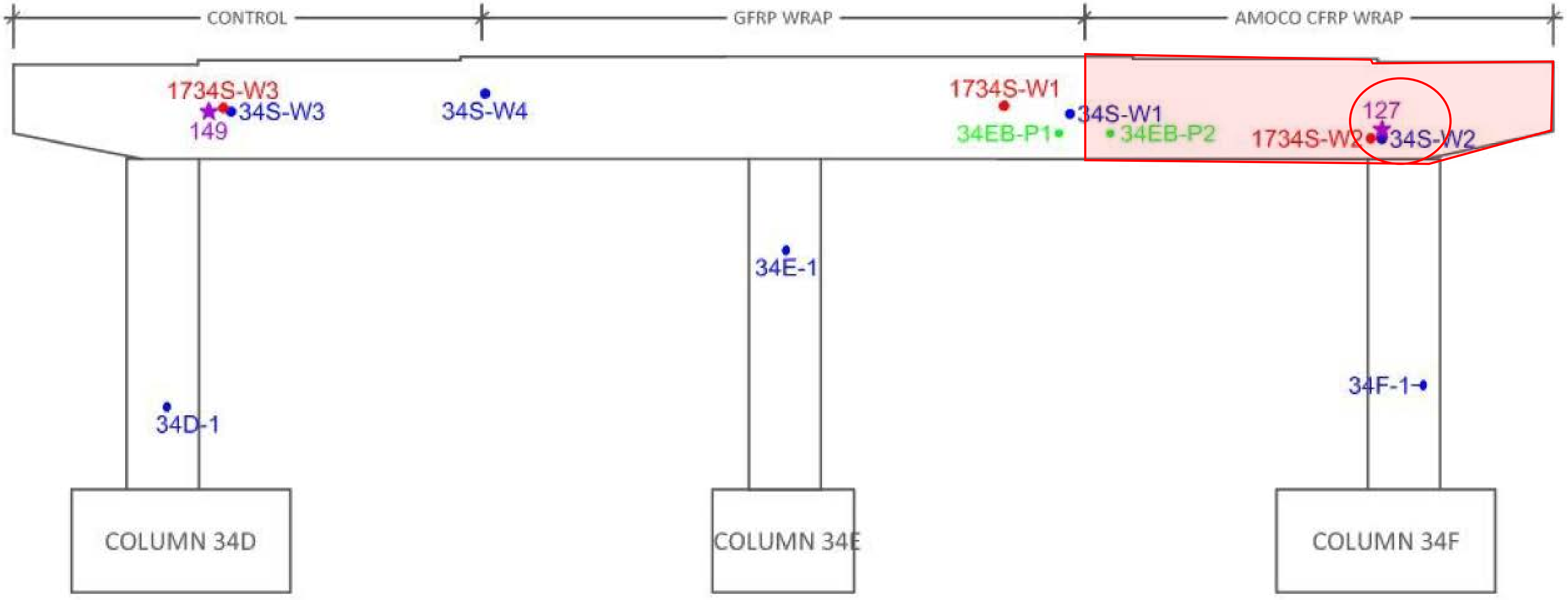
Additional Follow-up



Chloride Influence?

West Face
WB Pier 37
ECE Treated

Additional Follow-up

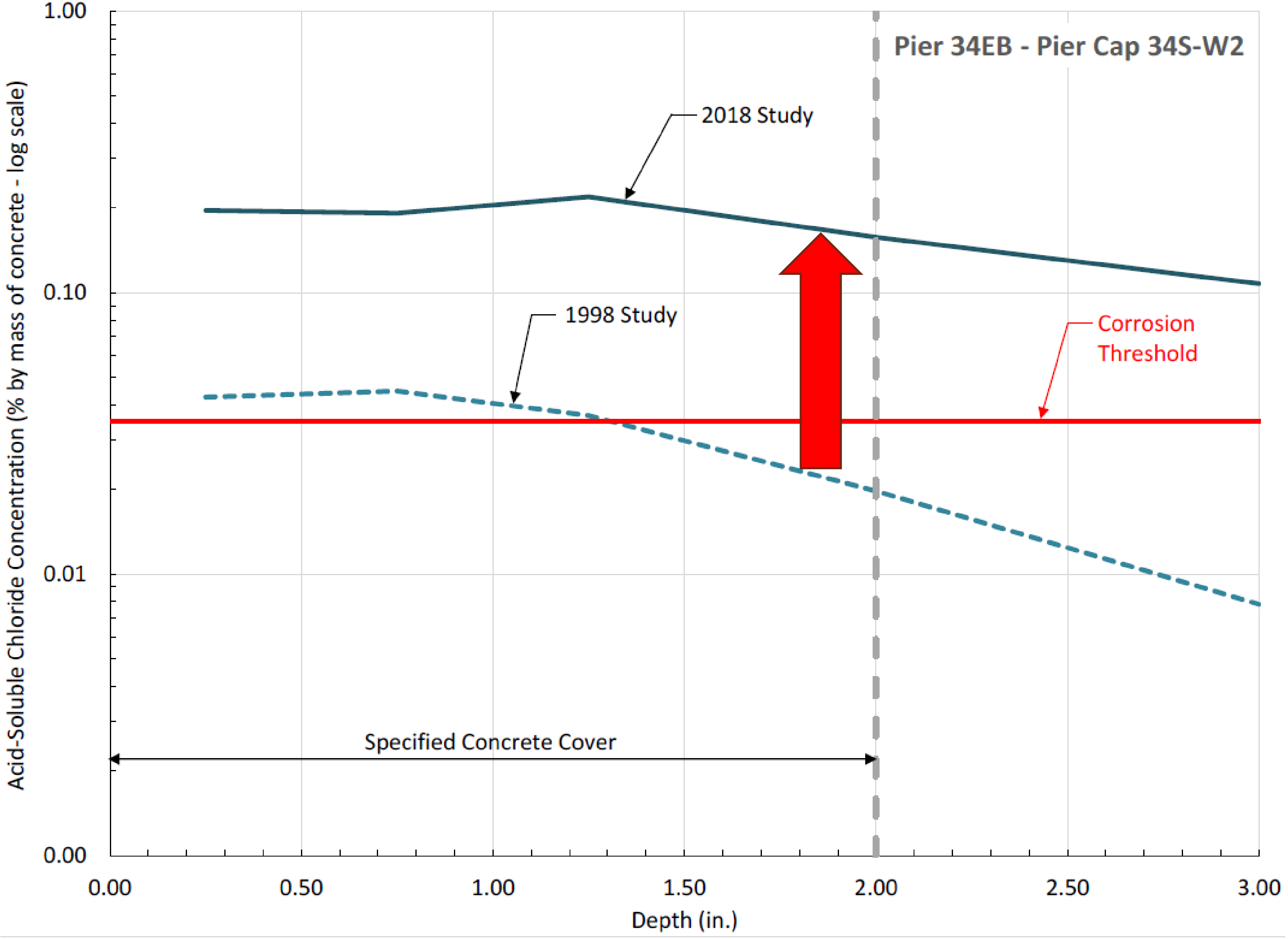


Pier 34EB West Face

Chloride Influence?

West Face
EB Pier 34
No ECE

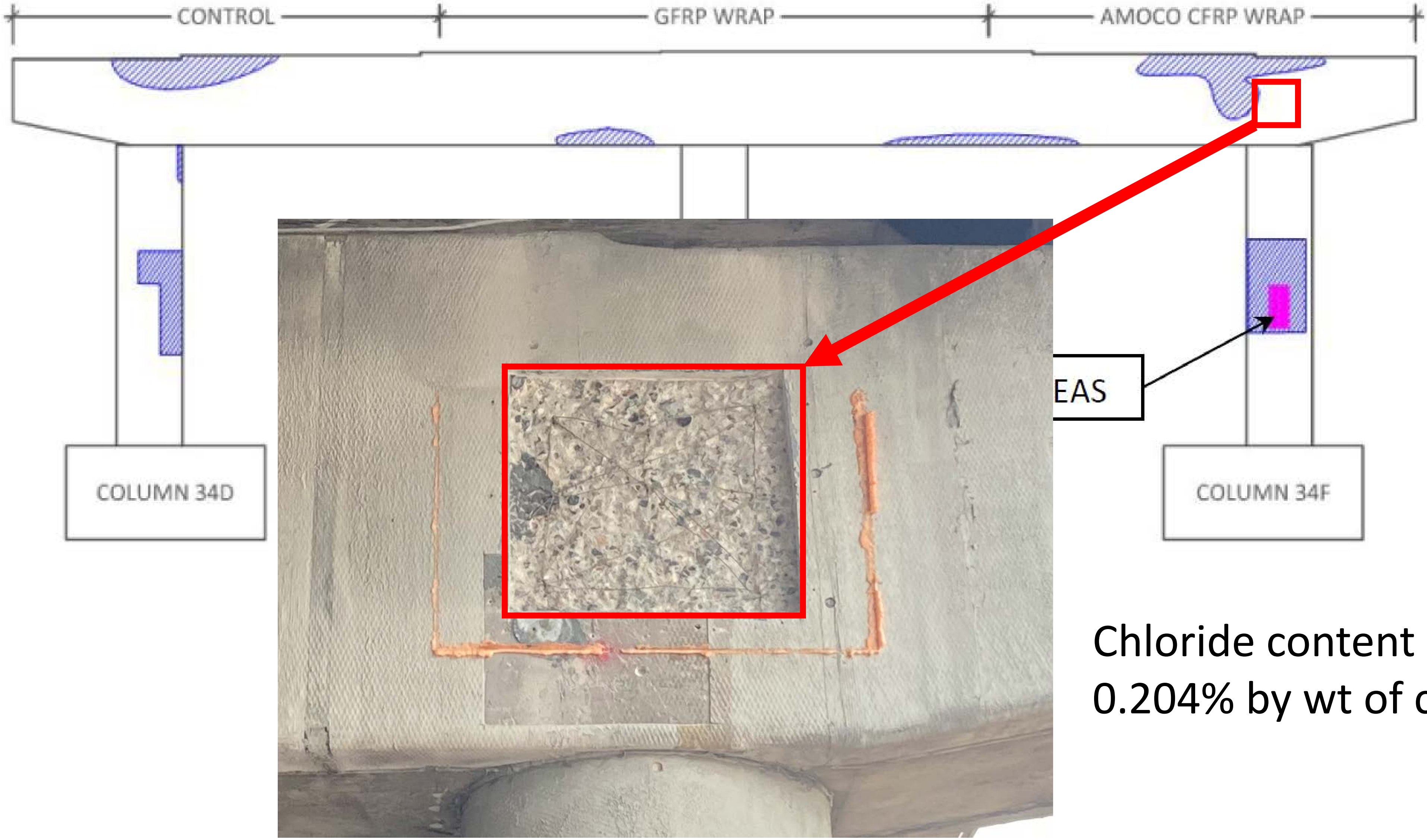
Additional Follow-up



Chloride Influence?

West Face
EB Pier 34
No ECE

Additional Follow-up



Chloride Influence?

West Face
EB Pier 34
No ECE

Chloride content around rebar = 0.204% by wt of concrete

Additional Follow-up

Rebar corrosion marginal and not apparently increased since 1998 repair

Chloride Influence?

West Face
EB Pier 34
No ECE

Chloride content around rebar = 0.204% by wt of concrete

NCHRP 558 Corrosion threshold = 0.025% to 0.033%

MnDOT has used 0.035%

Additional Follow-up

Chloride Influence?

West Face
EB Pier 34
No ECE

- No drainage scuppers or downspouts
- Least expansion joint failures

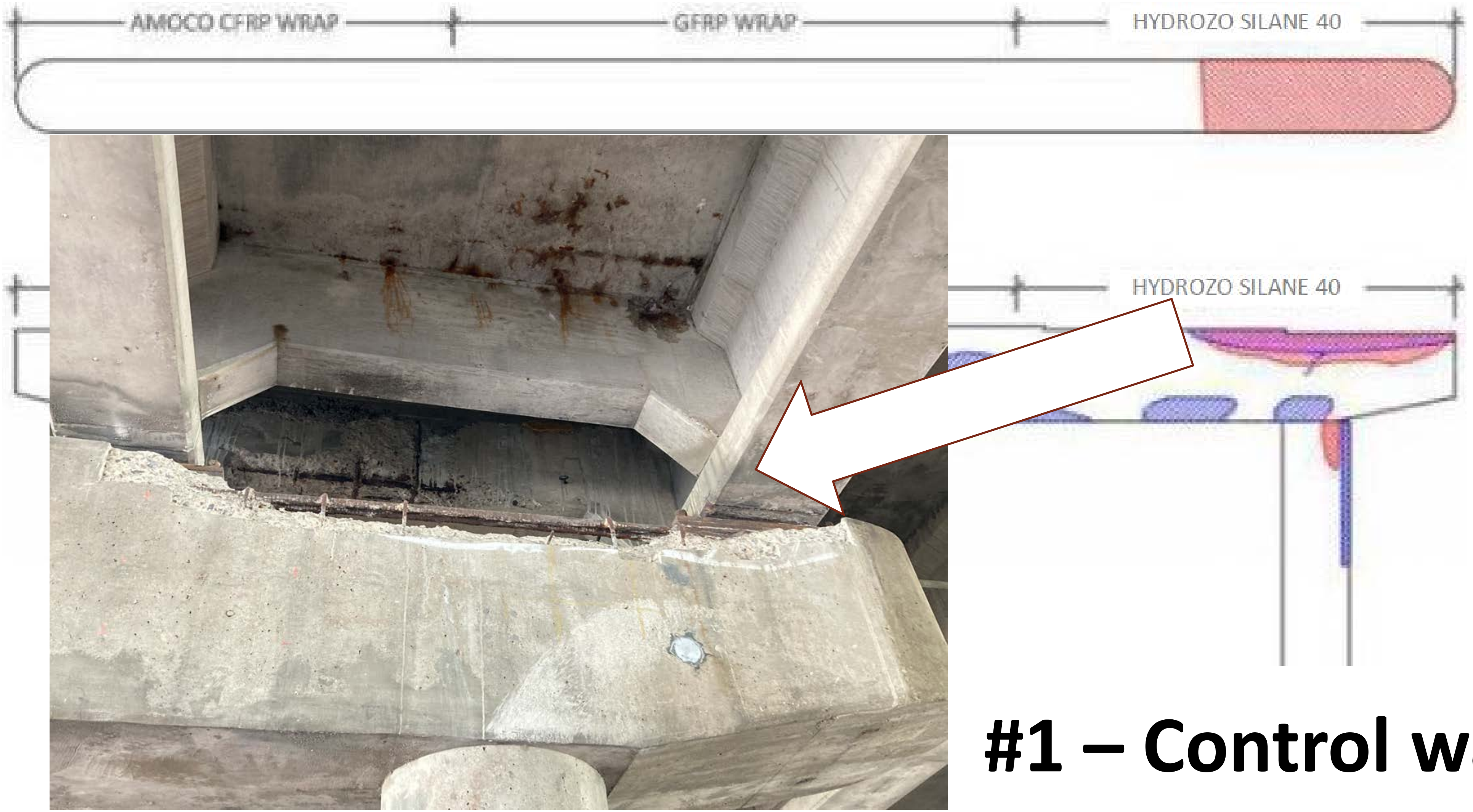
Additional Follow-up

Chloride Influence?

West Face
WB Pier 34
ECE Treated

- Deck joint failures

Additional Follow-up



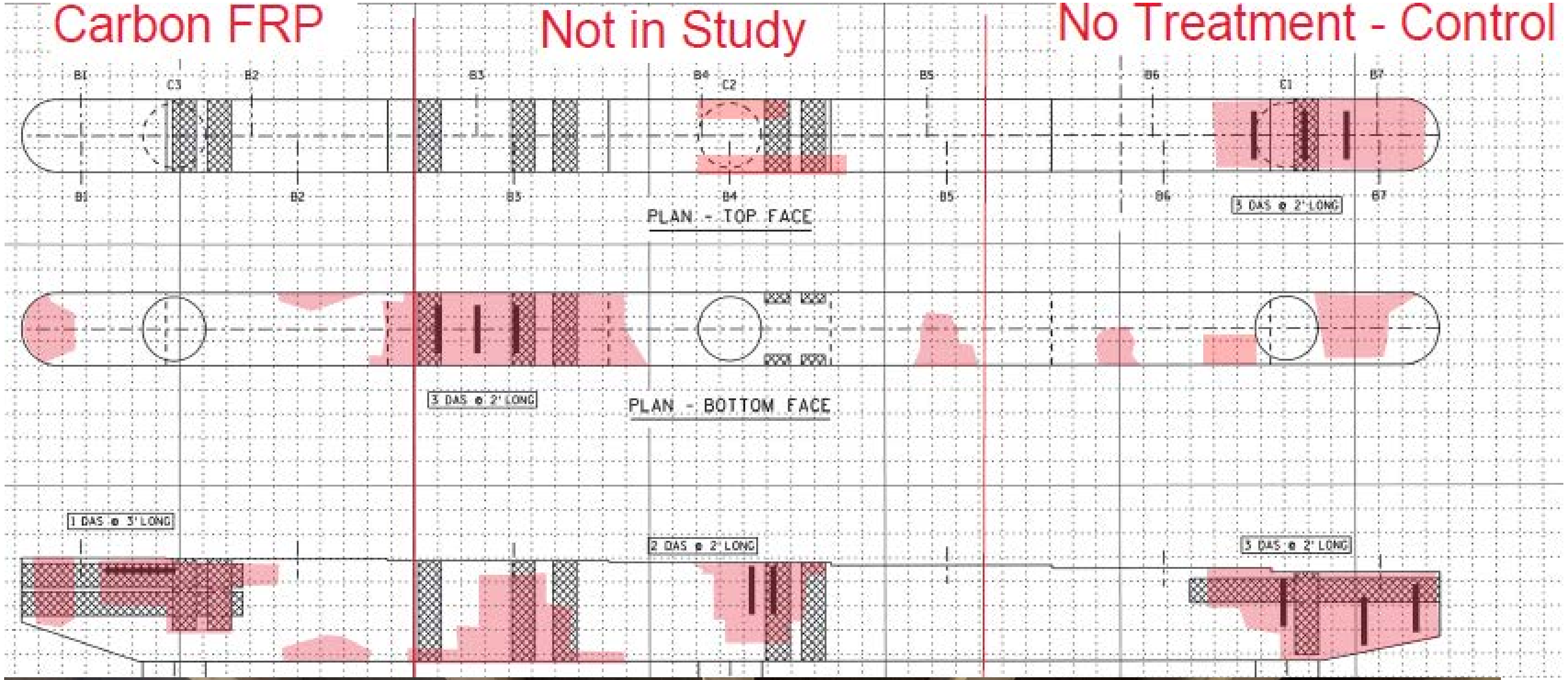
- Deck joint failures

Chloride Influence?

West Face
WB Pier 34
ECE Treated

#1 – Control water!

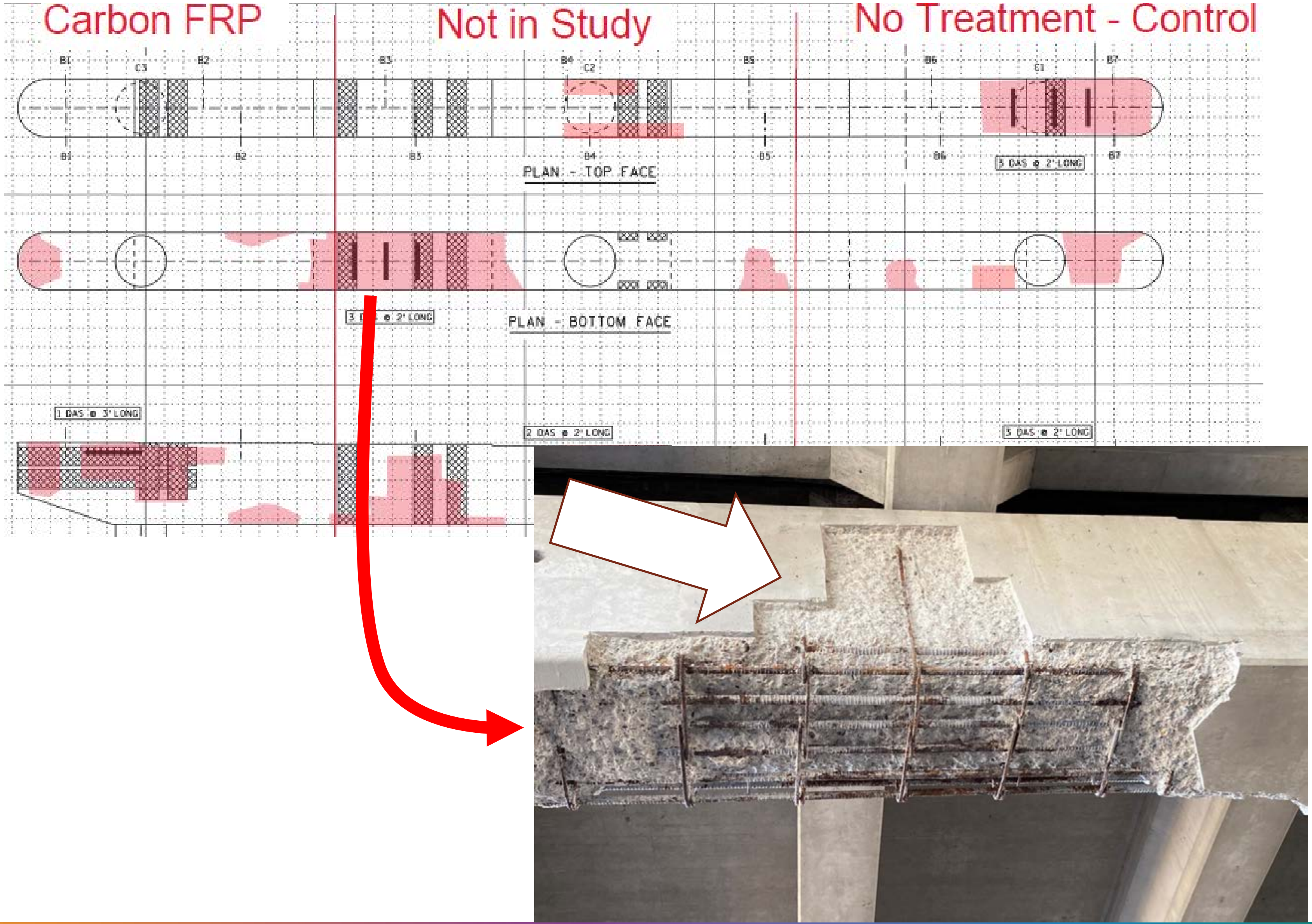
Additional Follow-up



West Face
WB Pier 40
No ECE

#1 Control water!

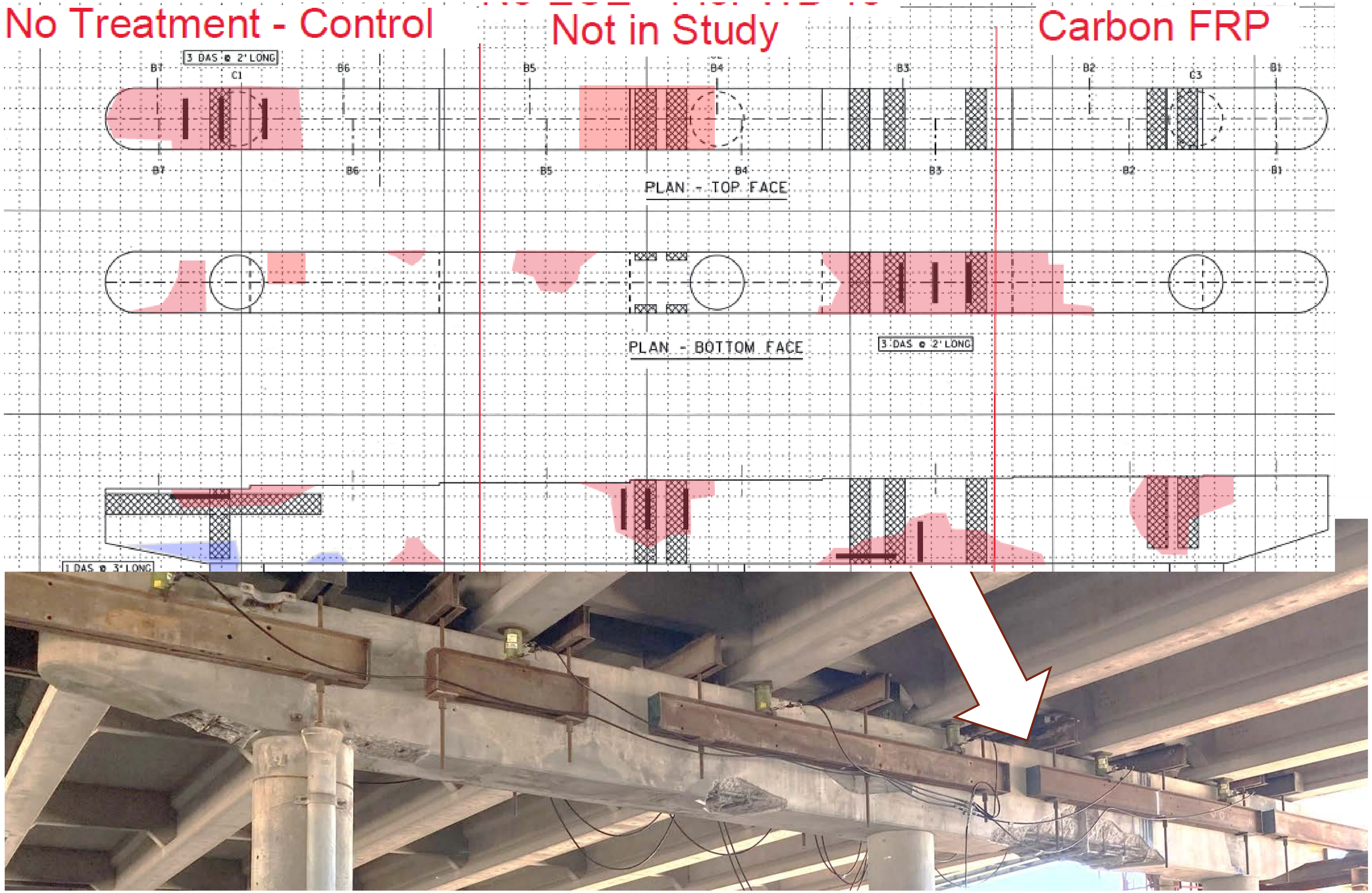
Additional Follow-up



West Face
WB Pier 40
No ECE

#1 Control water!

Additional Follow-up



East Face
WB Pier 40
No ECE

#1 Control water!

Additional Follow-up

East Face
WB Pier 40
No ECE

#1 Control water!

Observations

Glass or carbon FRP?

- Little price premium carbon vs. glass when considering install cost
- Confining concrete repair materials can improve life
- No good way to make up for steel section loss

  Carbon FRP can add strength and durability
- Focus on fixing distress and water exposure **first**

Current Owner Approach

- Minimize deck joints
- Identify CS3 joints for bridge scoping selection – replace expansion joints
- Develop best drainage pipe detailing practices (research)
- Use galvanic anodes within repairs where rebar in contact with old concrete
- Consider ECE where substructure repair difficult, there is good access, and limited rebar loss (e.g. hammerhead piers)

Thank you!

Paul Pilarski, DOT Bridge Constr. Engr.
State of Minnesota

Mark Chauvin, Principal and Unit Manager,
Wiss Janey Elsner Assoc. Inc.

https://www.dot.state.mn.us/research/projects.html

Final Report 2019-45

DEPARTMENT OF TRANSPORTATION

WJE