Service Life Modeling and Preservation of Reinforced Concrete Structures

Presented
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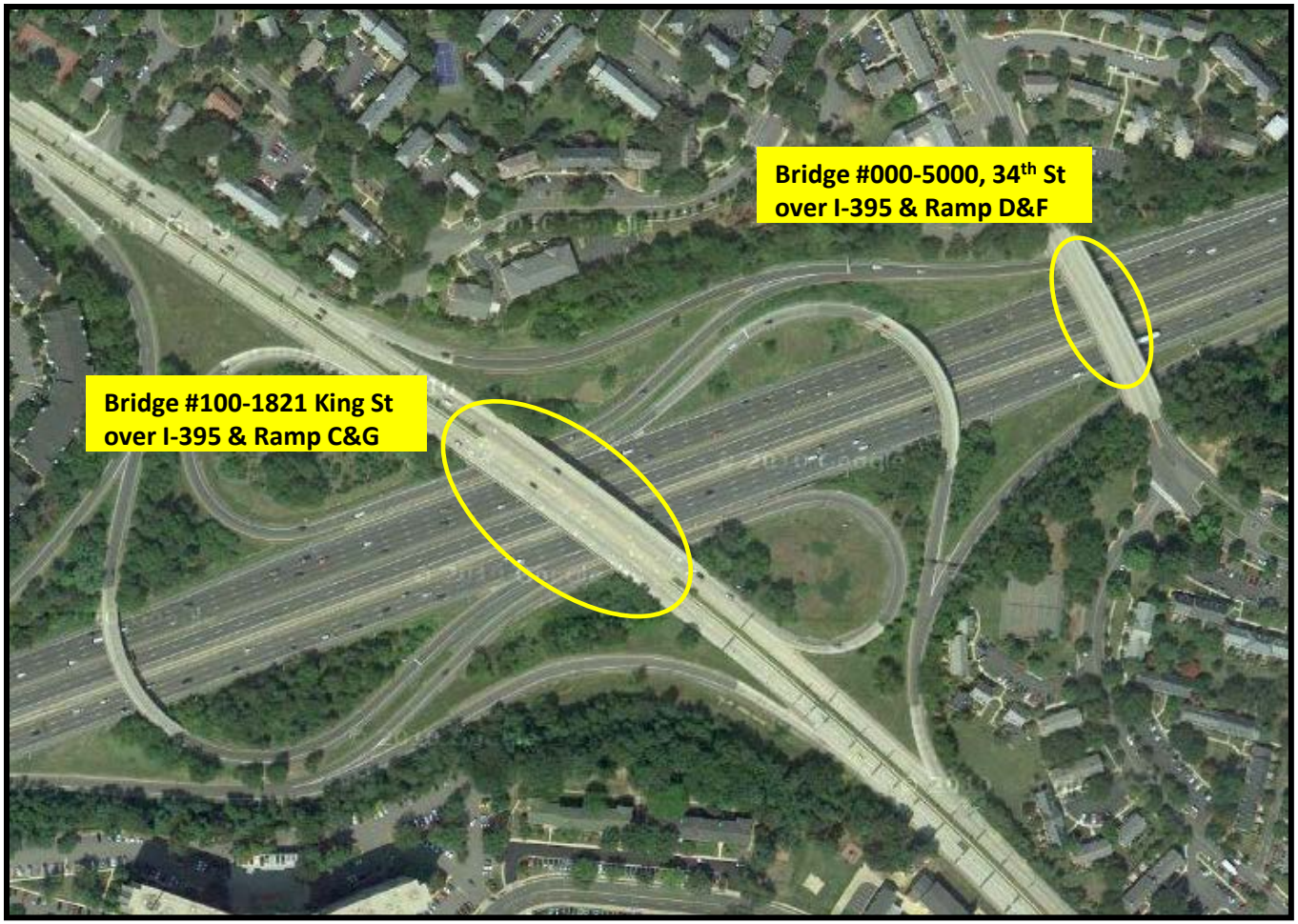
March 5-6, 2015

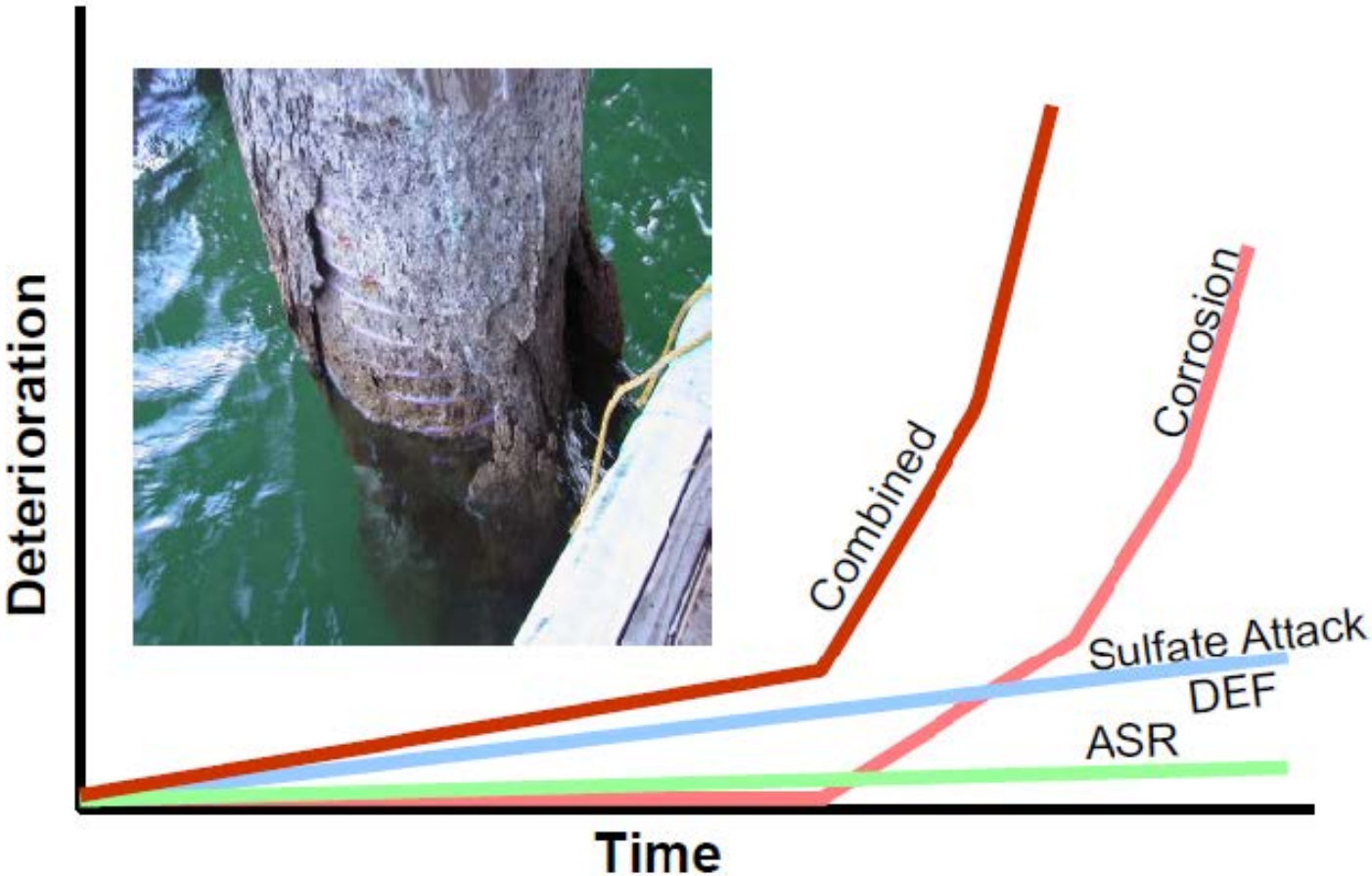
Virginia Concrete Conference

Deteriorating Structure

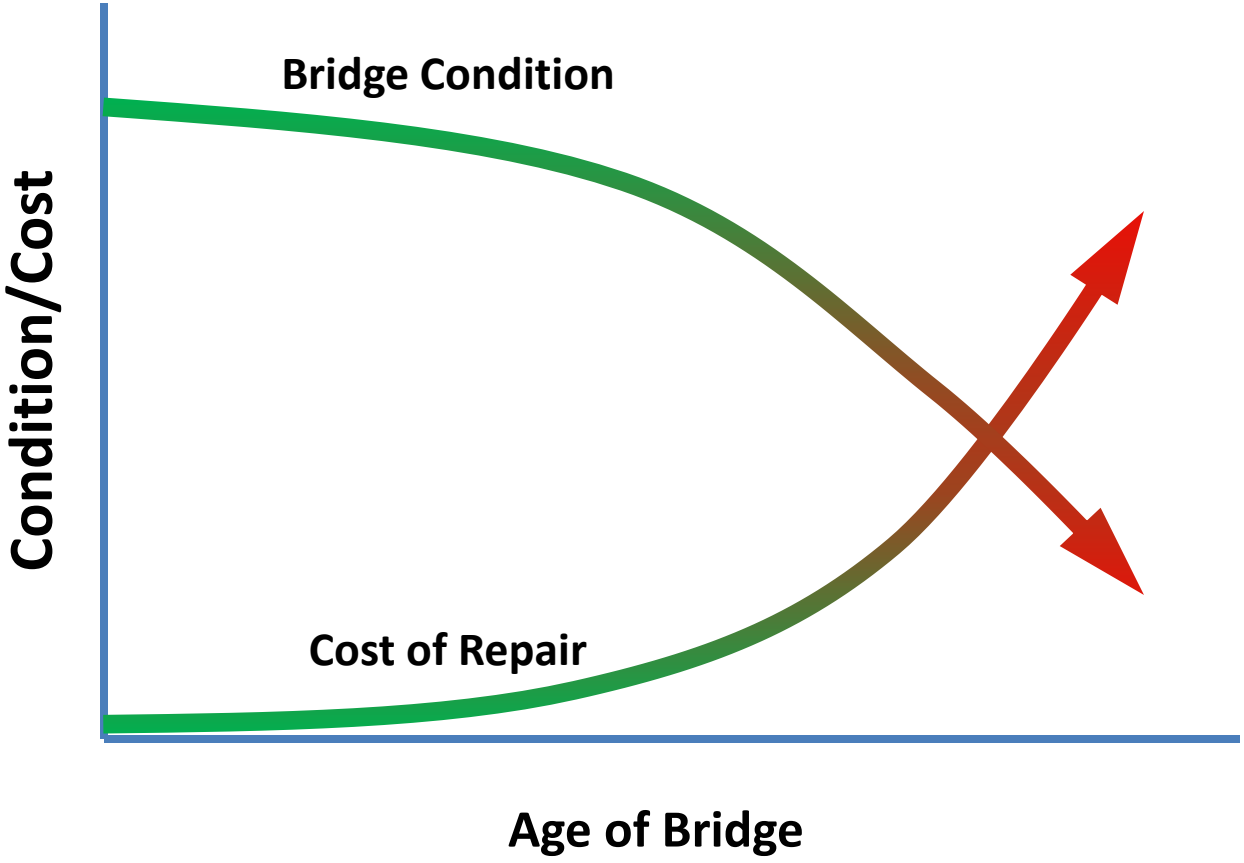
King St. Interchange, VA



Deterioration Mechanism

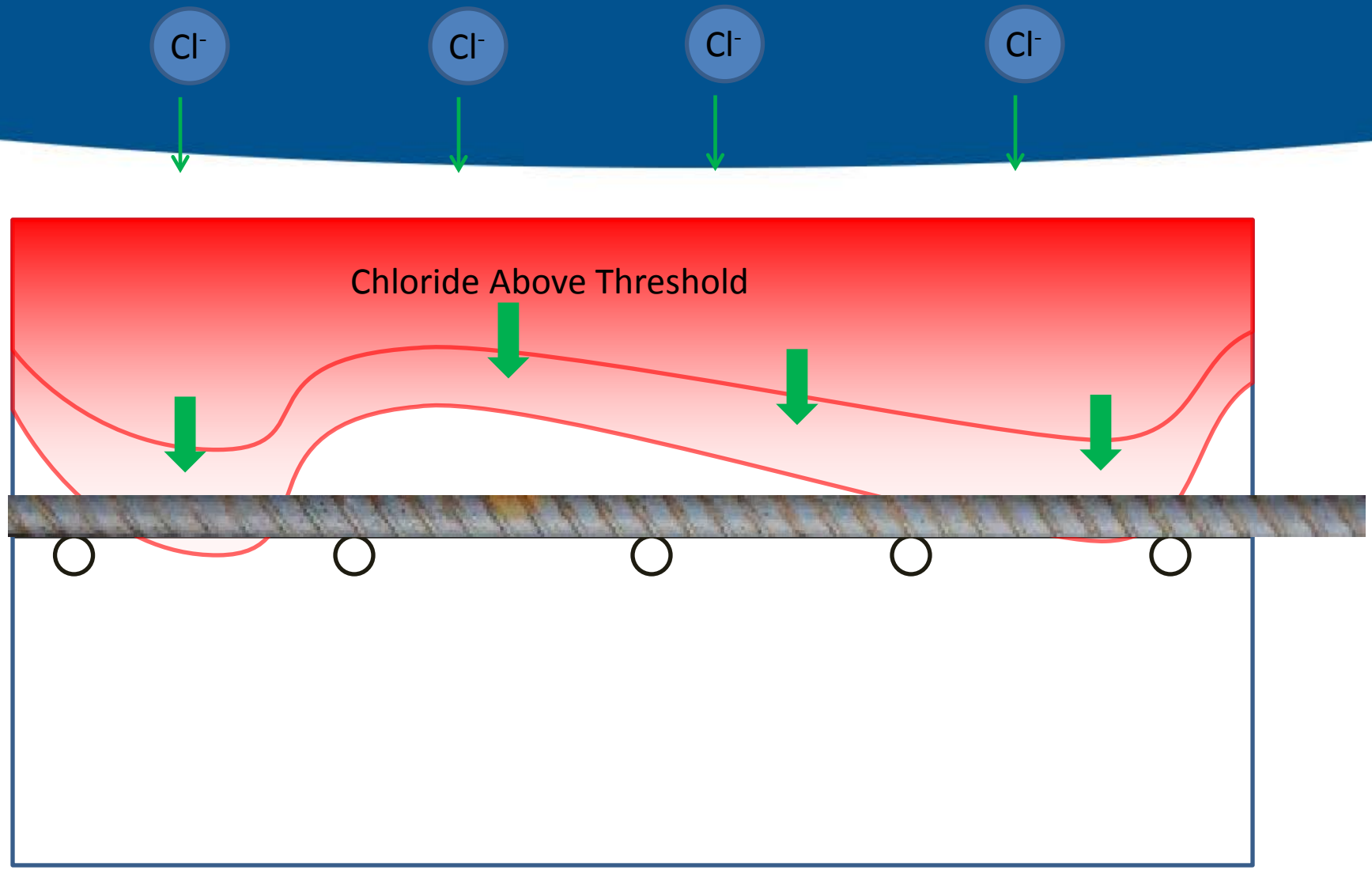


Cost of Rehabilitation



Problem

- Four (4) bridges along the I-395 and King Street Interchange in Alexandria, VA exhibit evidence of ongoing corrosion.
- Corrosion is leading to concrete damage and reinforcement section losses.
- The structures may not achieve 50 years of additional life without some form of rehabilitation.
- SCS evaluated the deck and substructure of two (2) of four (4) bridges to determine whether corrosion mitigation methods can be used to extend their service life by 50 years.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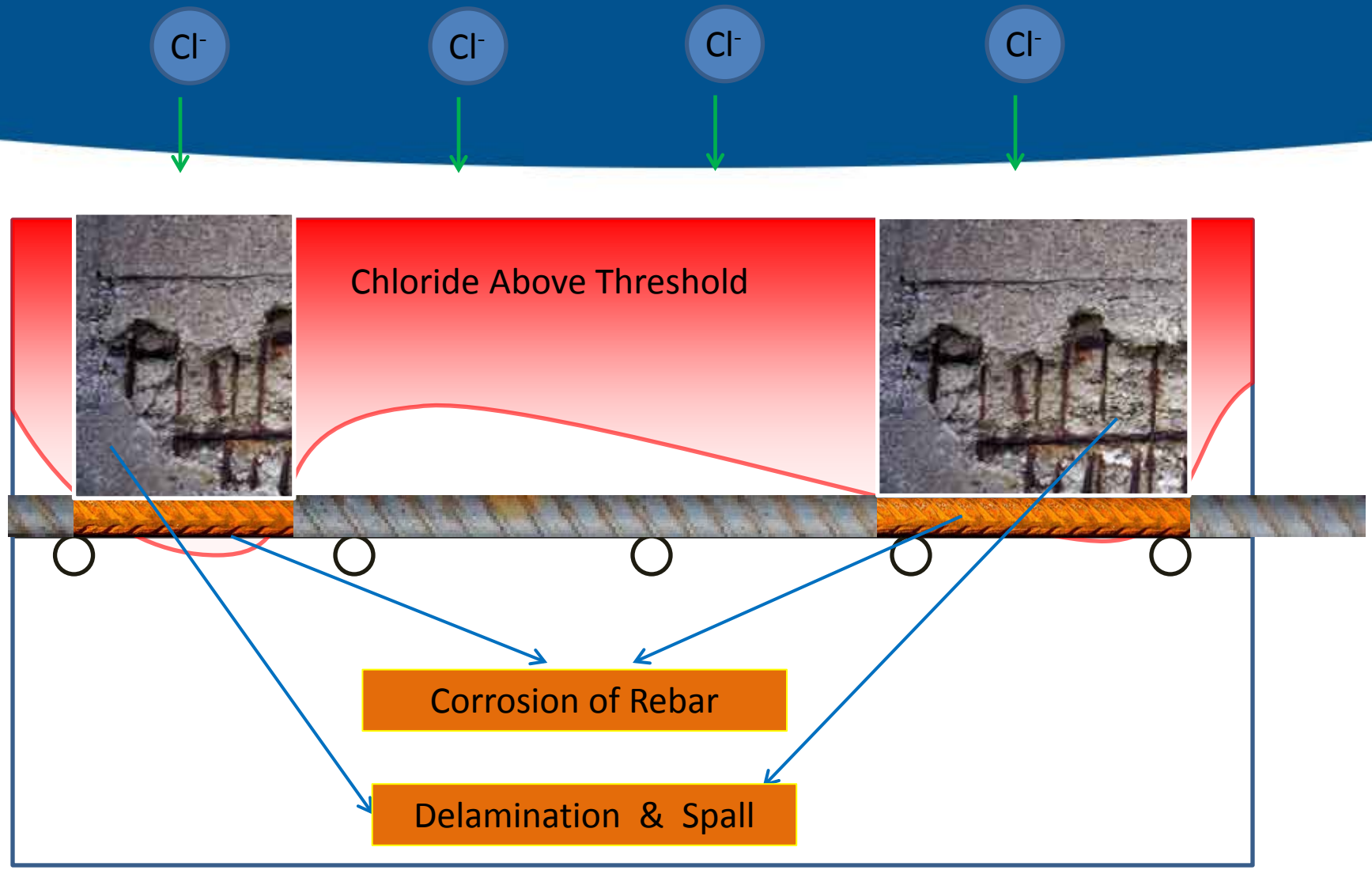
Chloride Above Threshold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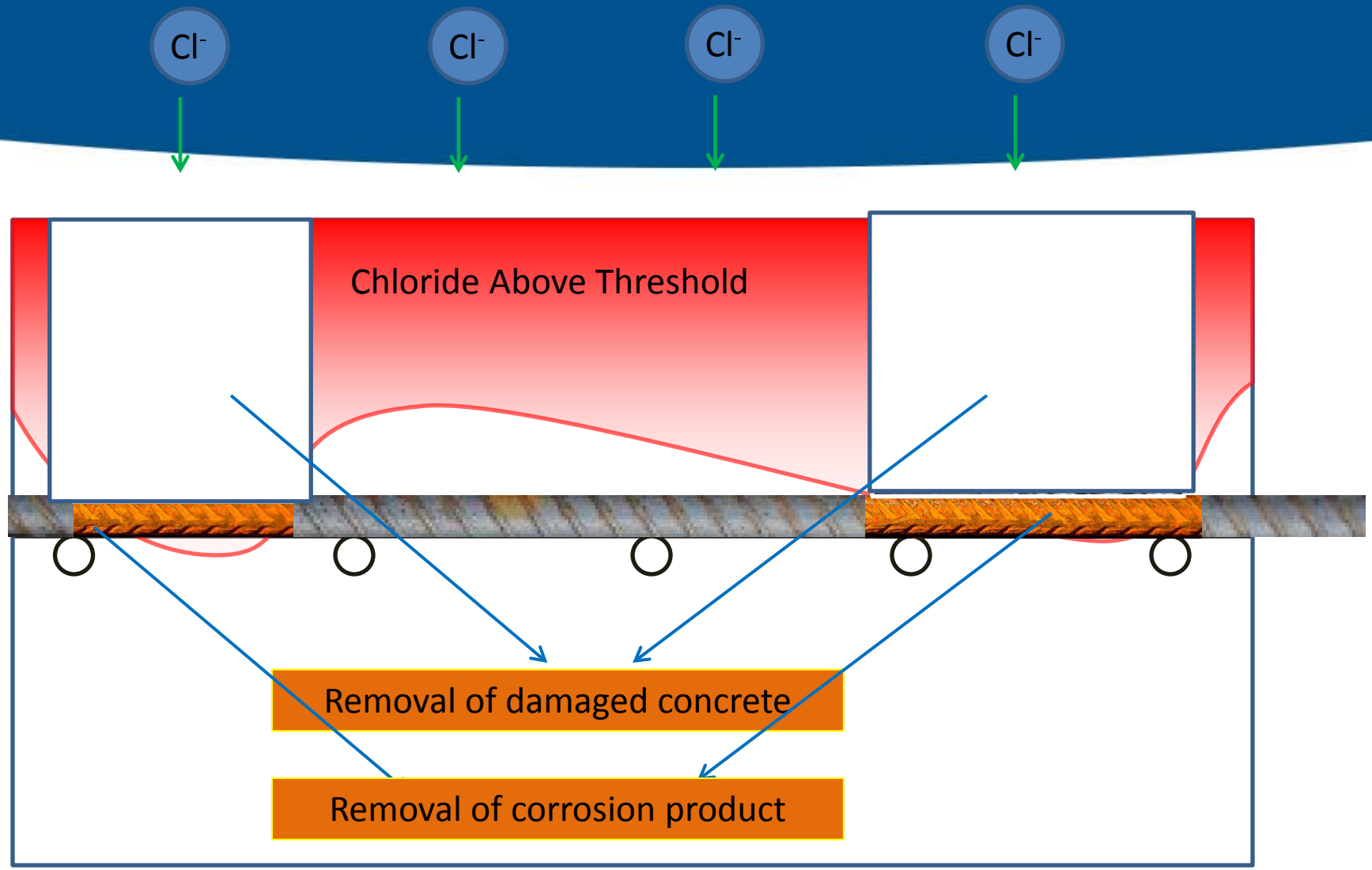
Chloride Above Threshold
Corrosion of Rebar
Delamination & Spall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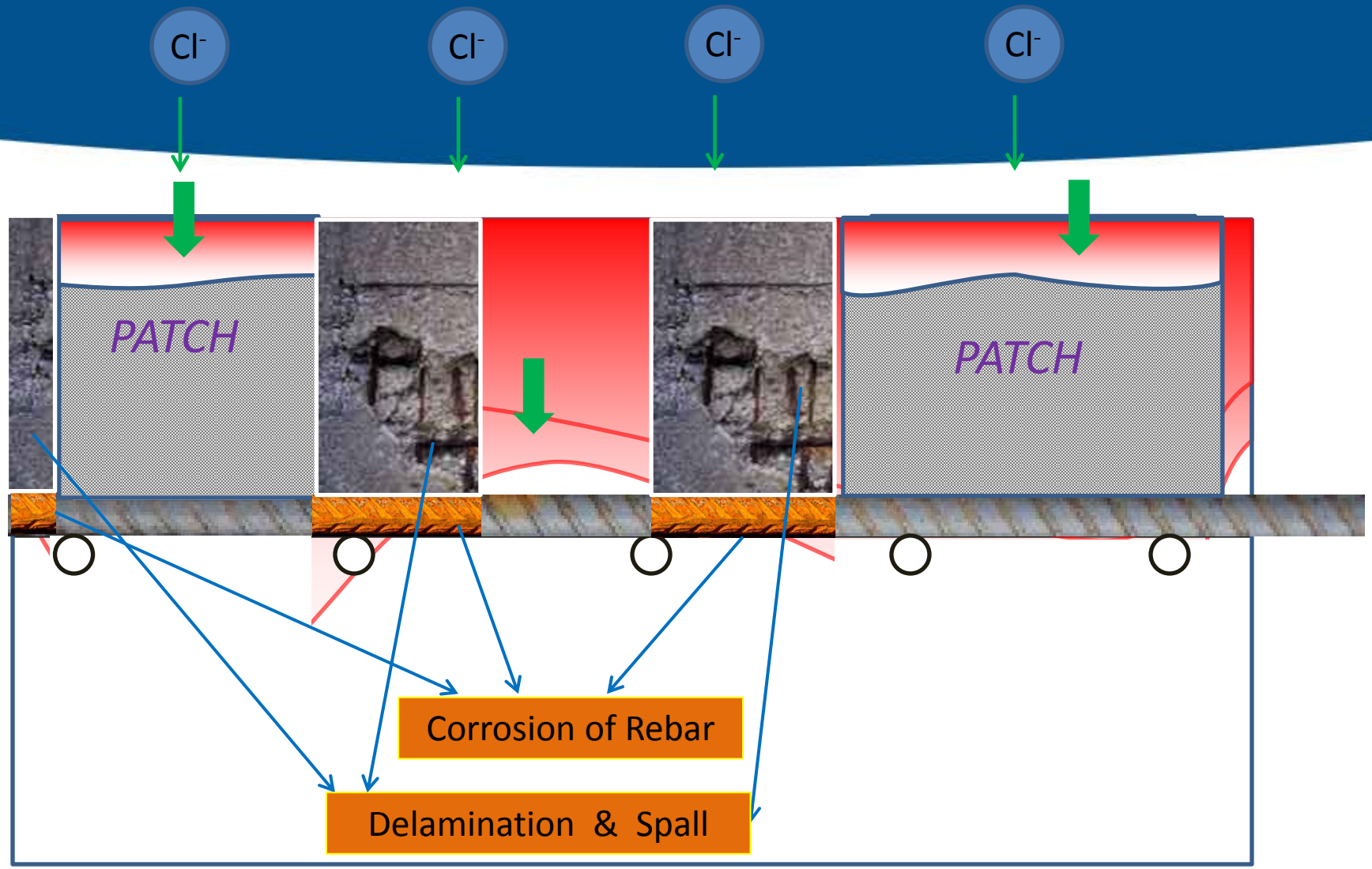
Chloride Above Threshold
Removal of damaged concrete
Removal of corrosion product


Cl-
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PATCH
PATCH
Corrosion of Rebar
Delamination & Spall

Preservation Approach

- Determine Current Condition
- Identify cause of deterioration
- Quantify the rate of deterioration
- Estimate Future Condition (Service Life Modeling)
- Identify viable Preservation Options
- Select cost-effective solution (LCCA)

Service Life

- Important to project future condition of existing structures
- Excellent tool for asset management programs
- Effective to sort through wide range of protection systems (past, present, and future)
- Great tool for new construction
- Drives innovation within industry

Service Life Software

- Applicable to new and existing infrastructure
- Impact analyses on the service life of numerous protection solutions:

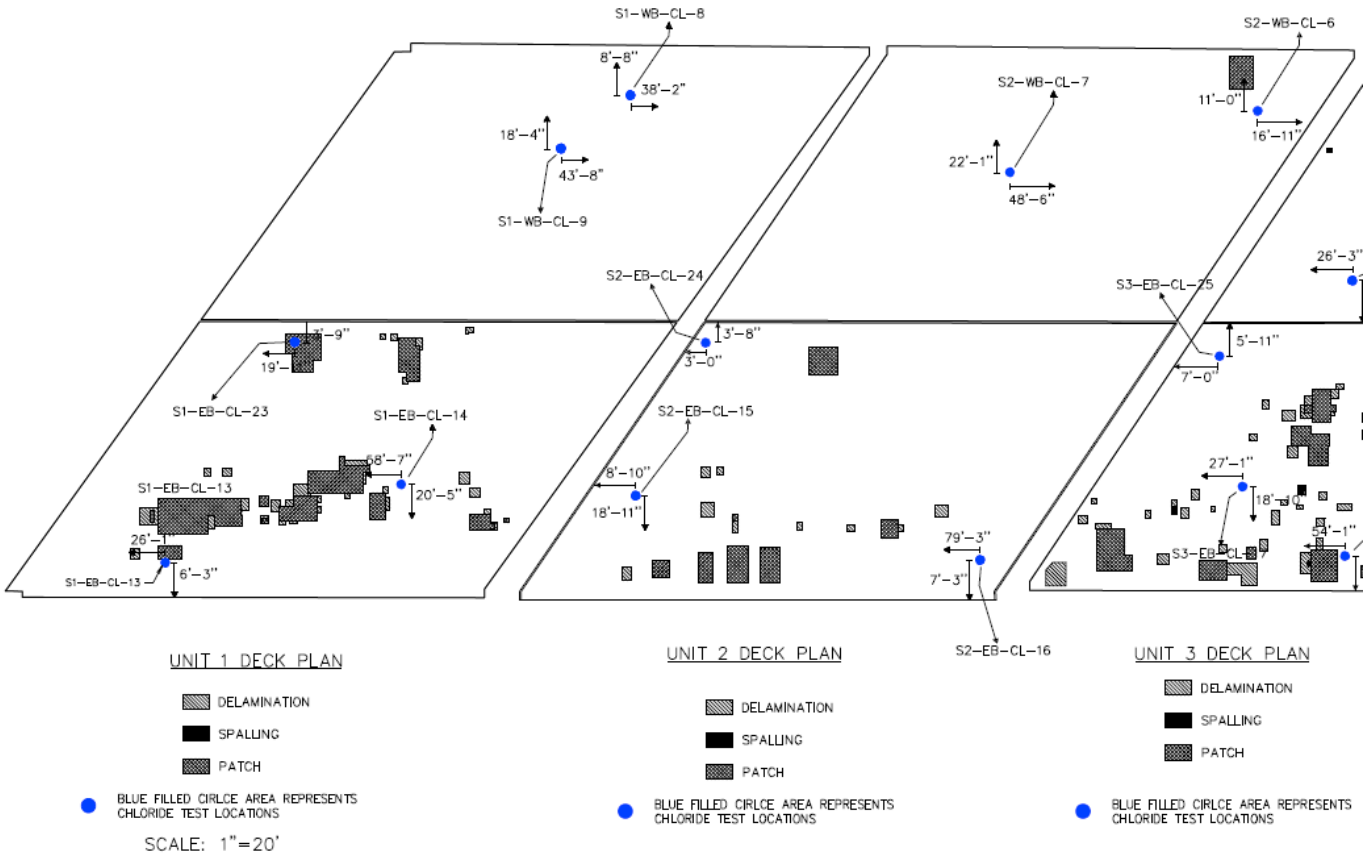
➢ Sealers
➢ Membranes
➢ Thin and Rigid overlays
➢ Coatings
➢ High Performance Concrete and reinforcements
➢ Corrosion Mitigation (GCP, ICCP, ECE)

SCS Approach

- SCS collected specific data to determine the condition of the Decks and to project future concrete damage
  - Delam/Spall Survey
  - Continuity
  - Cover Survey
  - Chloride Analysis
  - Carbonation
  - Service Life & Life Cycle Cost

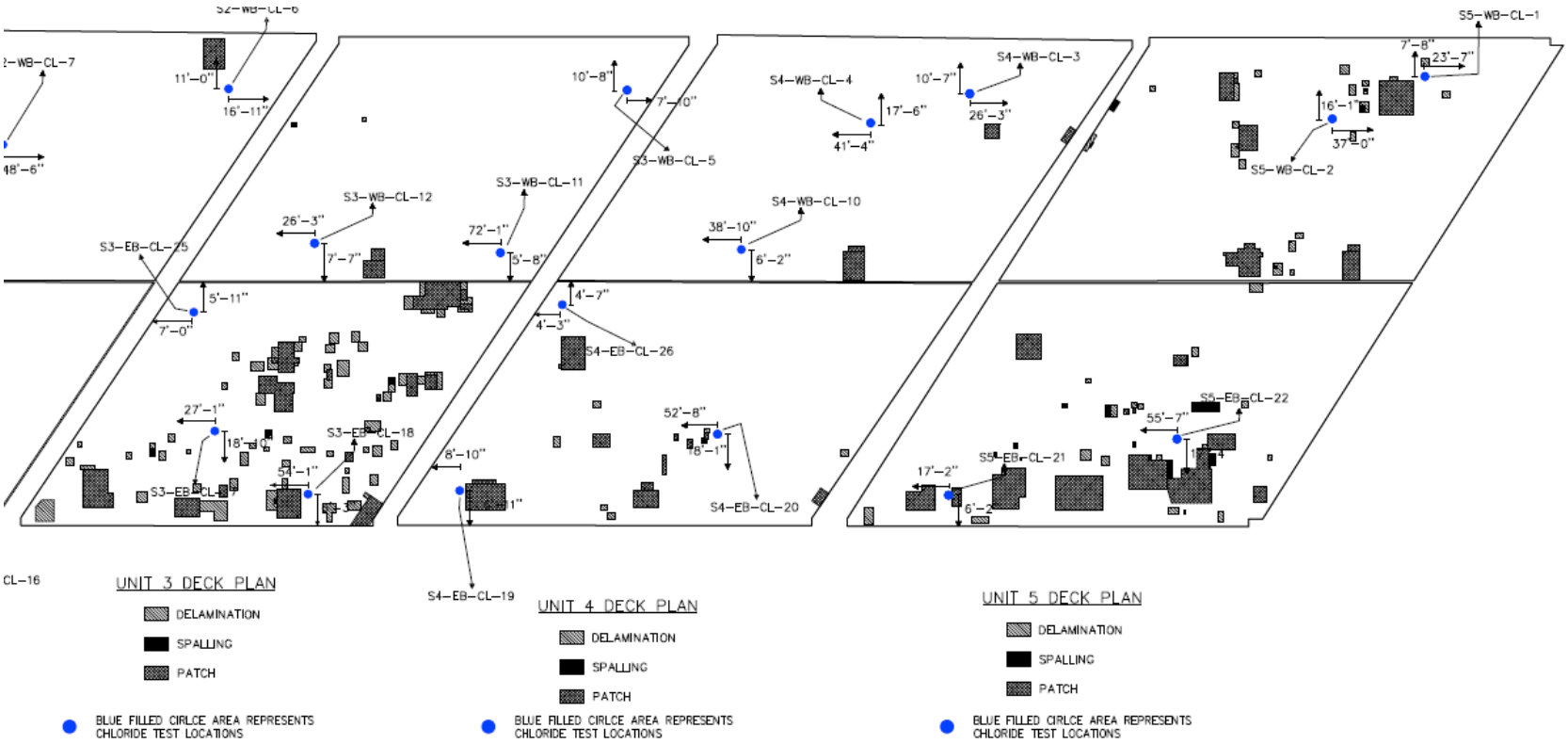
King Street - Concrete Damage and Core Locations

- King St. Deck



King Street - Concrete Damage and Core Locations

- King St. Deck cont.



King Street Top Deck Concrete Damage

Location	Total Area (ft^2)	Total Delam/Spall Area (ft^2)	Total Patch Area (ft^2)	Percent Damaged
Westbound	15959	53	225	1.74%
Eastbound	15959	371	1,038	8.83%
Total	**31918**	**424**	**1,263**	**5.28%**

King Street - Reinforcement Cover

Description	# of readings	Average	Std. Dev.	Max.	Min.	90%	95%
Westbound	106	1.76	0.28	2.41	1.20	1.40	1.29
Eastbound	72	1.69	0.23	2.37	1.24	1.39	1.30
Entire Deck	178	1.73	0.26	2.41	1.20	1.39	1.29

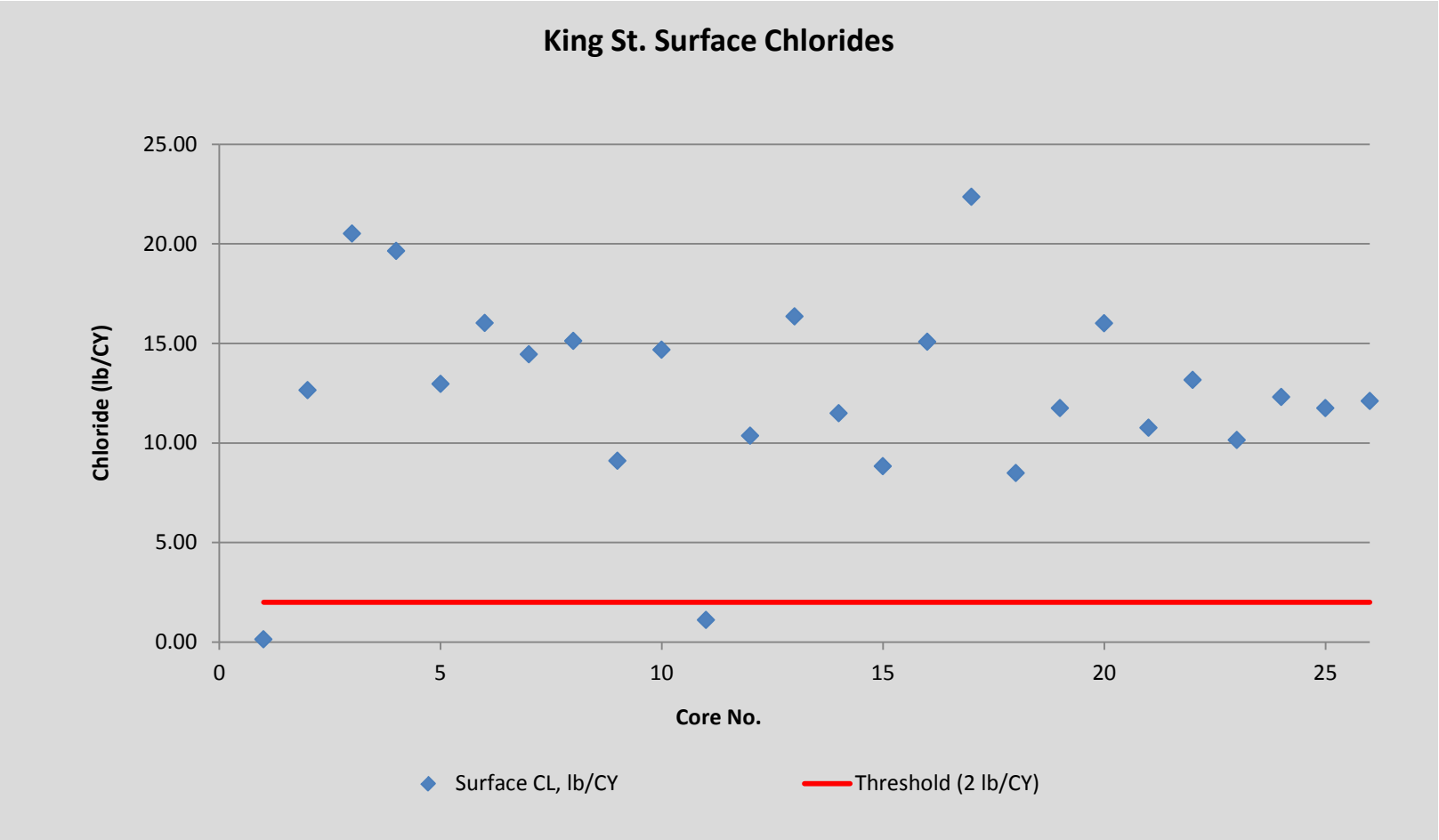
King Street – Deck Underside

- A total of 5400 sq. ft of the deck underside was sounded. A total of 2.9 sq. ft. (.054%) of damage (delam & spall) was recorded.
- A total of 228 cover readings were recorded with rebar cover meter and analyzed statistically.
  - Minimum = 1.00 in
  - Maximum = 1.79 in
  - Average = 1.25 in
  - Standard deviation = 0.10 in
  - 95% of the deck has cover greater than 1.29 in.

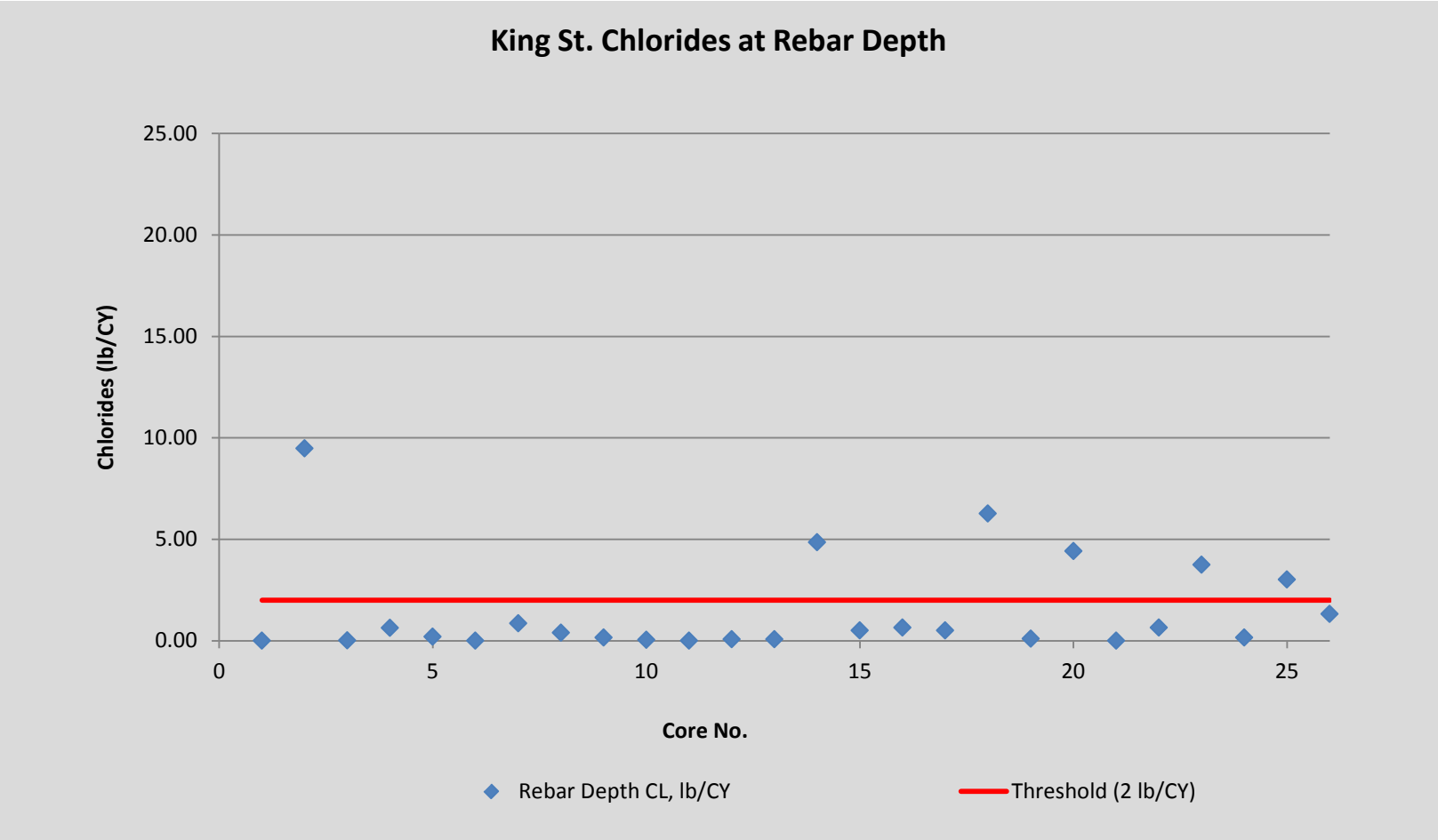
King Street - Continuity & Carbonation

- Continuity – All locations tested for continuity were found to be continuous with all other locations in their respective span. Continuity was not tested between spans.
- Carbonation – Little to no carbonation was observed at each of the tested locations.

King Street - Chlorides



King Street - Chlorides



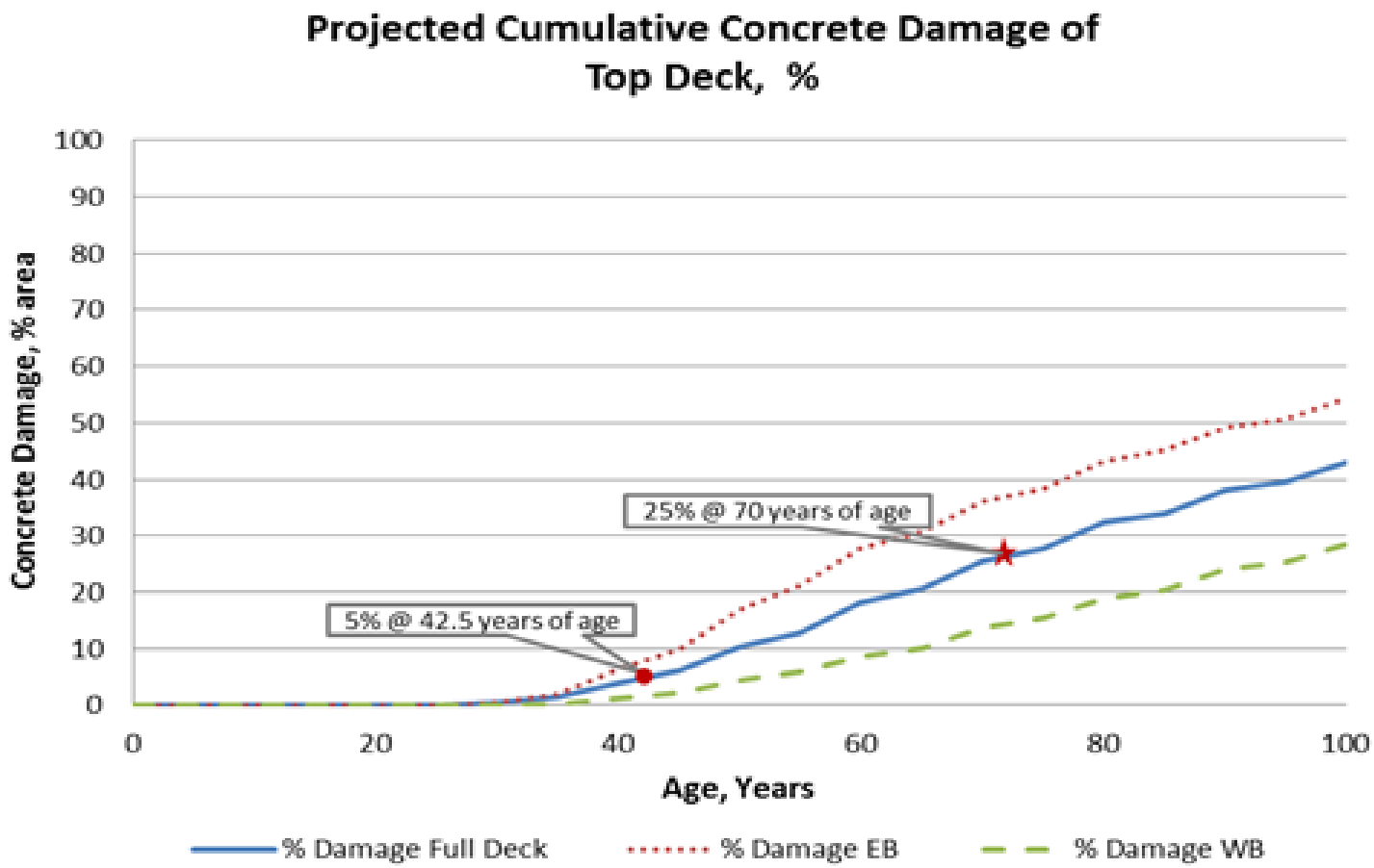
King Street Deck– Petrographic results

- Estimated water/cement ratio is 0.42 (normal for this age and deck concrete).
- Total air void content is 6.8% (more than the minimum required for freeze thaw resistance). The structure does not exhibit any freeze thaw damage after 42 years.
- The unit weight is 149 lb/ft^3
- Carbonation is less than 1mm and is not a concern from corrosion stand point.
- A small amount of Alkali-Silica Reaction (ASR) was observed but no cracking associated with ASR was noticed.

King Street Deck – Service Life Estimates

- Using NCHRP 558 service life modeling, the deck is projected to experience 39% of concrete damage 50 years from today.
- The deck has a total compromised area of 28% (5.28% delam + 23% chloride above threshold).
- The SR for this structure is 56.1.
- The deck is eligible for replacement (if no viable cost effective rehabilitation is available).

Service Life – Projected Damage



King Street – Repair Options Considered

- Mill the top 1 inch of salt contaminated deck and install ICCP & 1.5 inch LMC overlay.
- Remove 1 inch by milling and additional 3.5 inches by hydro-demolition and replace with 5.5 inch of concrete with Low Permeability Concrete (LPC).
- Repair existing concrete damage and perform ECE treatment of the entire deck surface.
- Replace the entire deck.

Unit Cost Table for Life Cycle Analysis

Description	Unit rate, $	Unit	Life, Years	Comments
Type B Deck Patch	300	SY	5	
Type C Deck Patch	400	SY		
Substructure Repair	1200	SY	5	
Type A milling	18	SY		
Hydro Demolition (3.5” deep)	62	SY		
Asphalt Overlay Removal	15	SY		
Air/Grit Blasting	3	SY		
Low Permeability Concrete (5.5” thick)	120	SY	25	
LMC Overlay placement	100	SY	25	
Sealer	9	SY		
GCP Sprayed	23	sq. ft.	10	
GCP Discreet Anode	17	sq. ft.		
ECE	42	sq. ft.	25	
ICCP, Deck	12	sq. ft.	40	
ICCP, Substructure	40	sq. ft.	40	
MOT	1000	day	-	Less than 45 MPH
MOT	1500	day	-	More than 45 MPH
Deck Replacement	60	sq. ft.		
User Cost	Not Included			

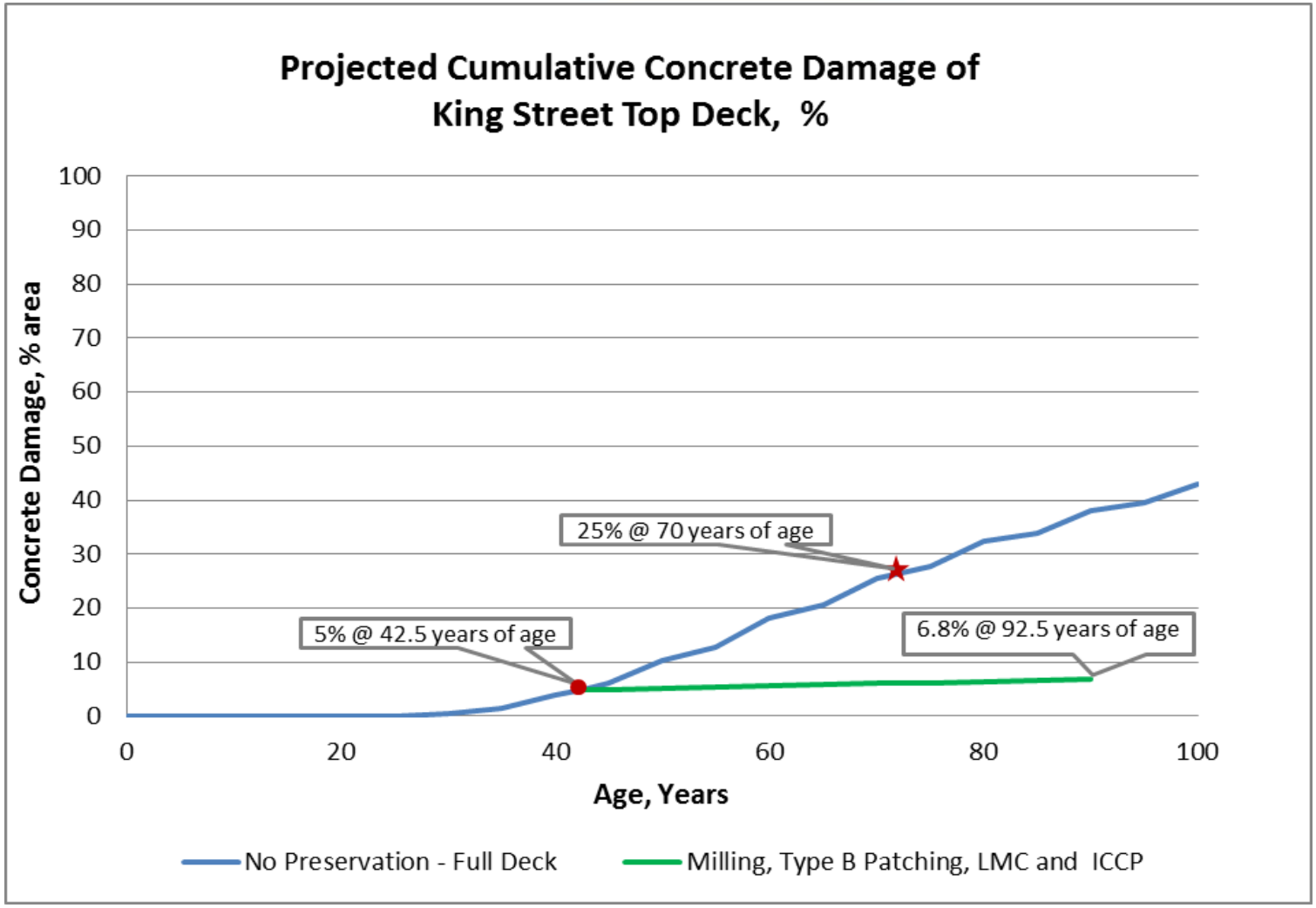
King Street Repair Options and Life Cycle Cost

Life Cost of Deck Repair Options		Life Cycle Cost	MOT Cost	Total LCC
A	Patch + LPC	$ 1,581,643	$ 126,431	$ 1,708,074
B	Patch+LMC+ICCP	$ 1,145,818	$ 0	$ 1,145,818
C	Patch+ECE	$ 1,574,182	$ 345,231	$ 1,919,413
D	Replace	$ 2,451,083	$ 36,500	$ 2,487,583

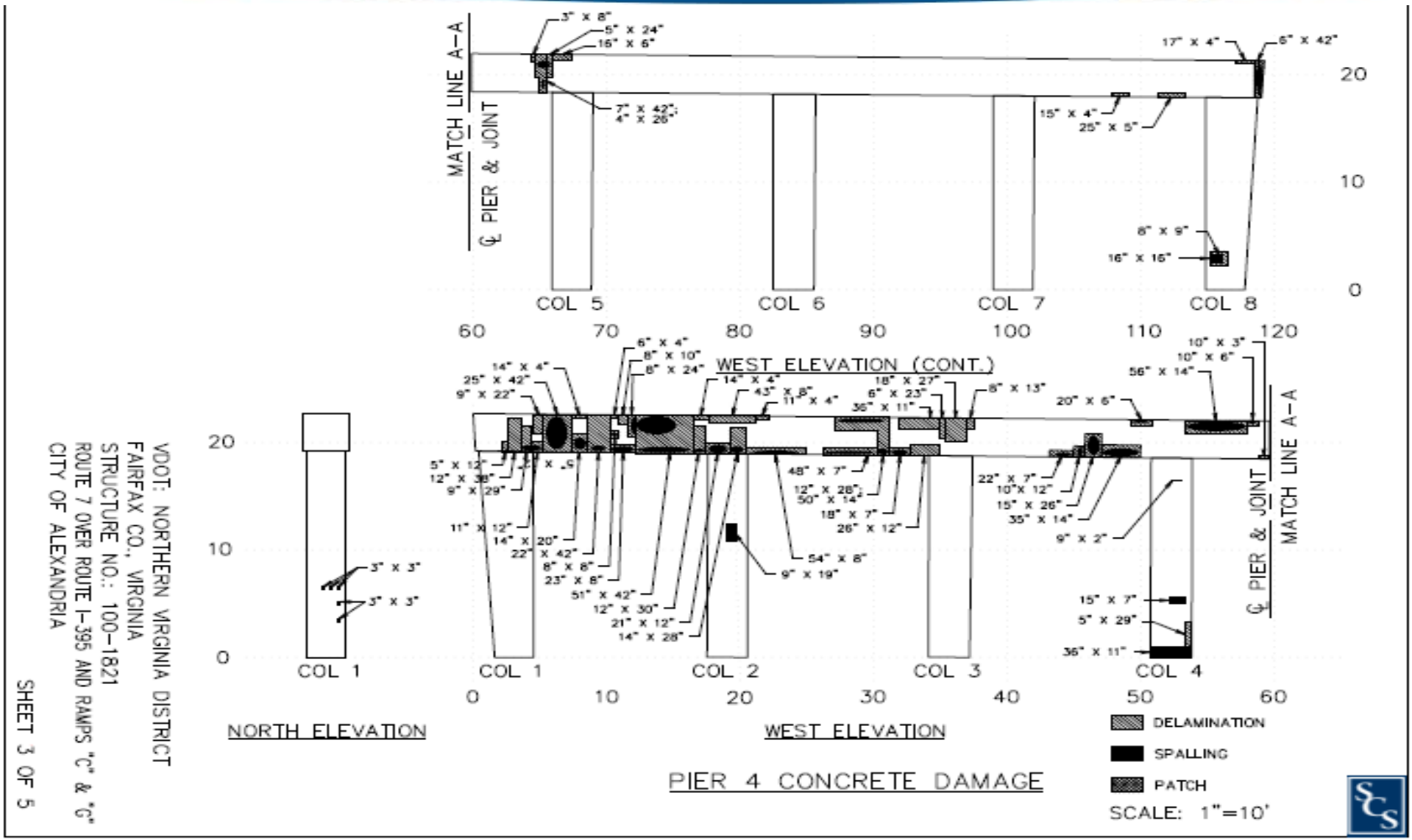
King Street Recommendations

- Remove the top 1 inch of chloride contaminated concrete and replace it with an ICCP in a new LMC overlay.
- The life cycle cost of this option is $1,145,458.

Deck Life with Corrosion Mitigation



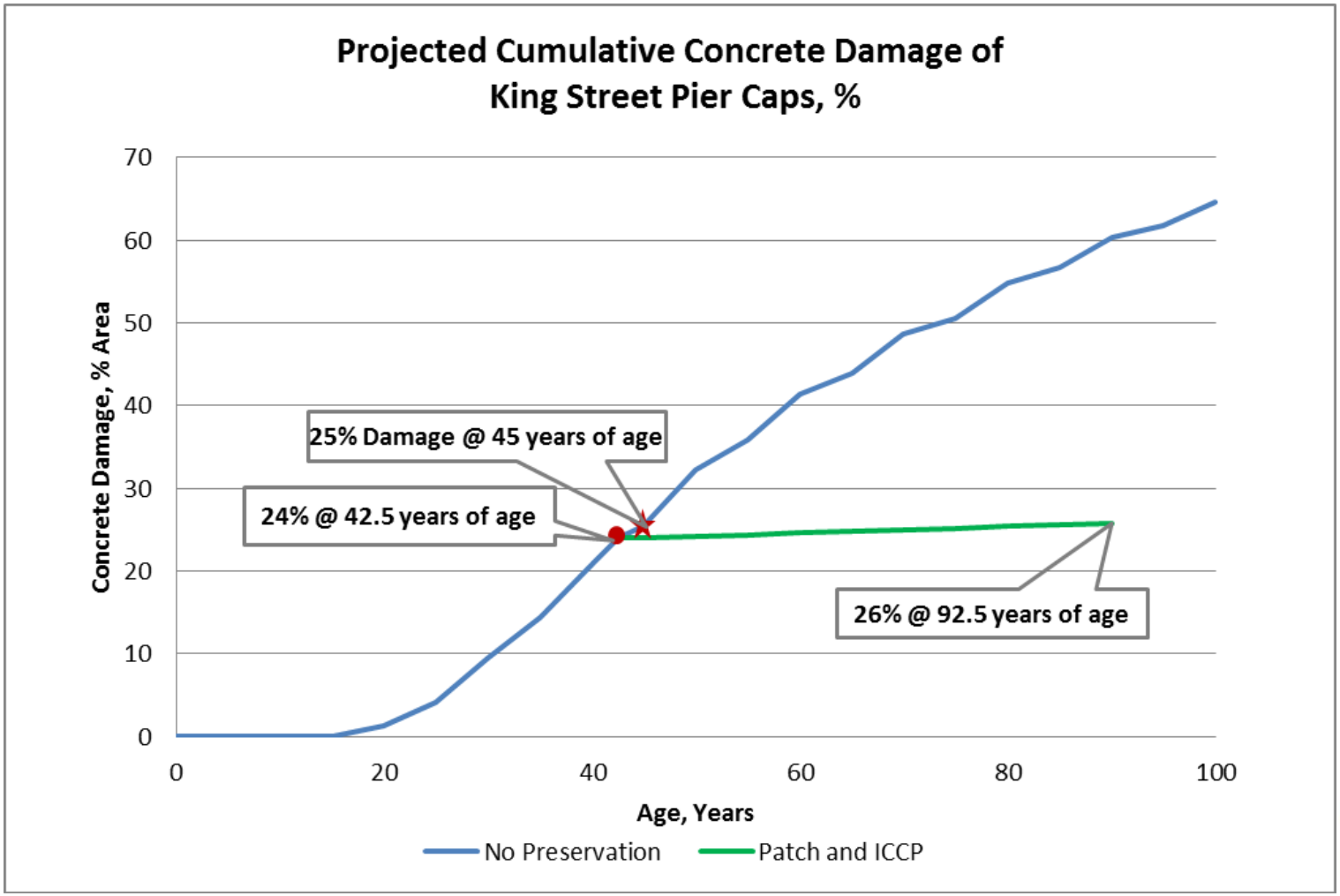
King Street – Pier Concrete Damage



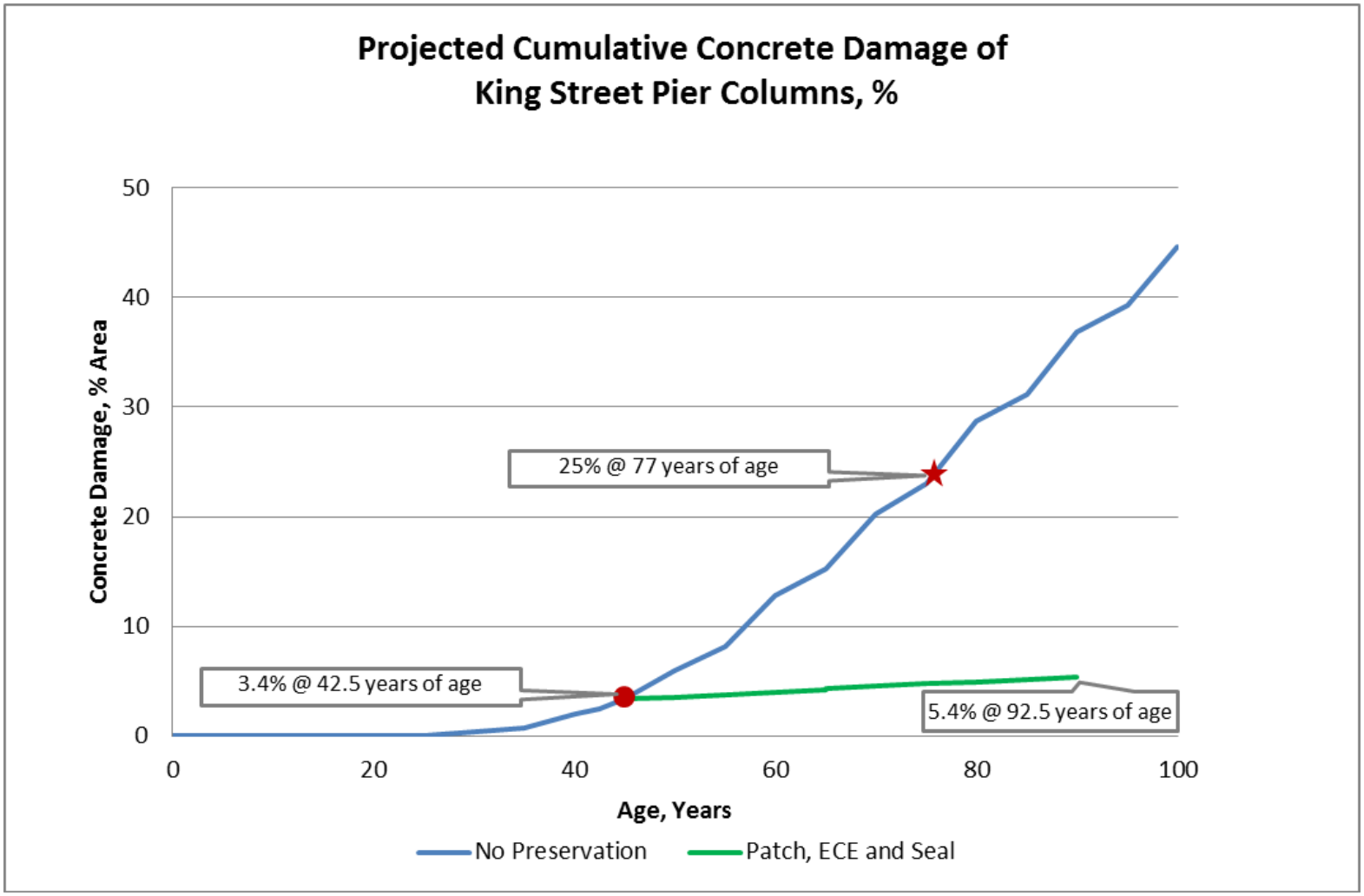
King Street Recommended Repair Options and Life Cycle Cost

Bridge Element	Description	Initial Cost	Additional Life Cost (50 yr)	MOT Associated w/LCC only	Total
Concrete Repair/Rehabilitation					
Pier Cap	Patch + ICCP	$ 435,200	$ 76,655	$ 0	$ 511,855
Pier Column	Patch + ECE + Seal	$ 291,392	$ 130,987	$ 26,971	$ 449,350
Abutments	Patch + ECE + Seal	$ 77,769	$ 34,958	$ 13,486	$ 126,213

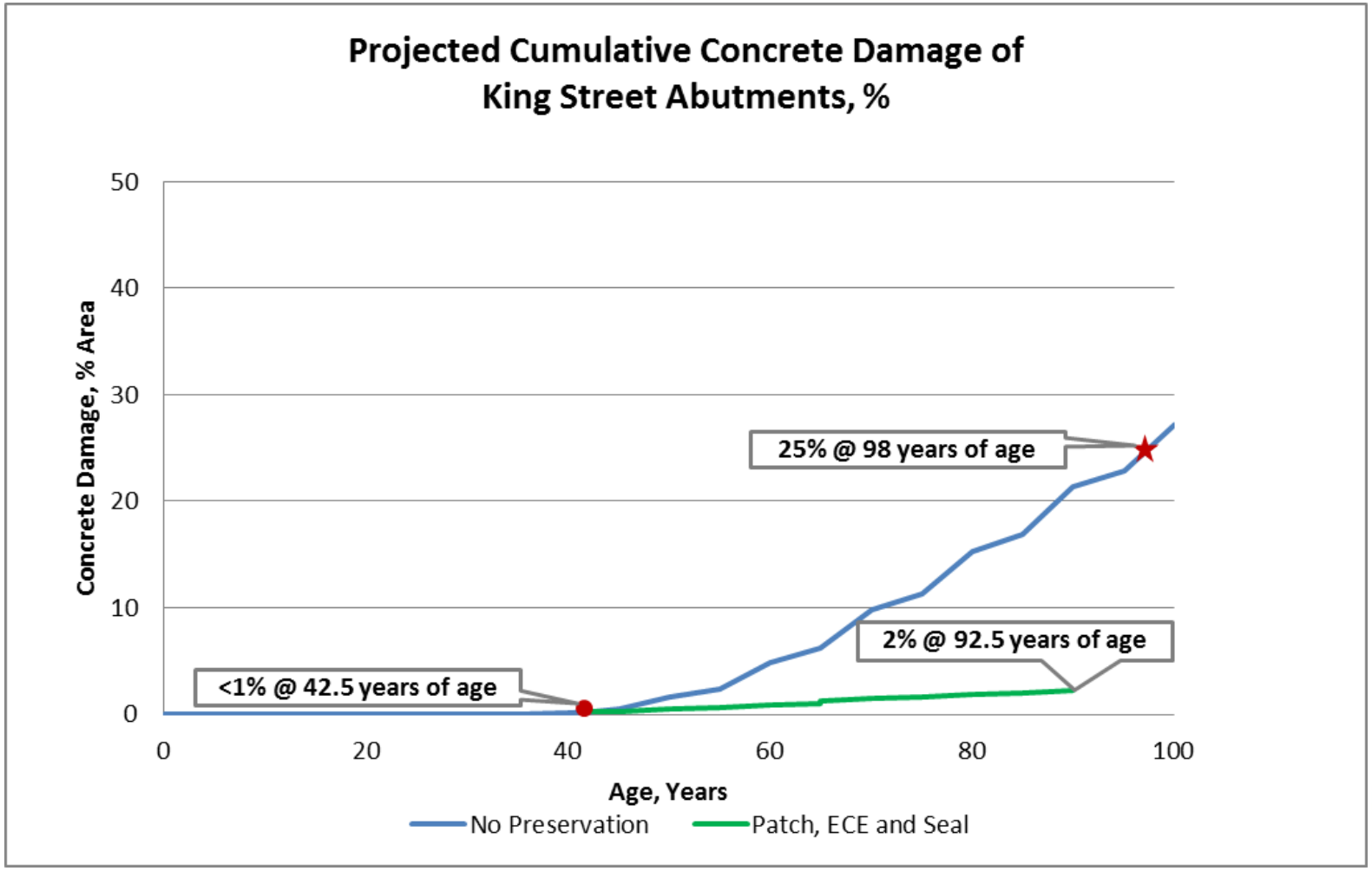
Pier Cap Life with Corrosion Mitigation



Pier Column Life with Corrosion Mitigation



Abutment Life with ECE



Benefits of Preservation

- Responsible preservation
  - Environmental Benefits
  - Sizeable Capital Savings

Brandywine Bridge in Delaware

- Built in early 60's with several rehabilitation
- SCS & TY Lin - Preserving and extending the service life

Questions

Thank You!