Fighting Corrosion & Preserving Bridges

by

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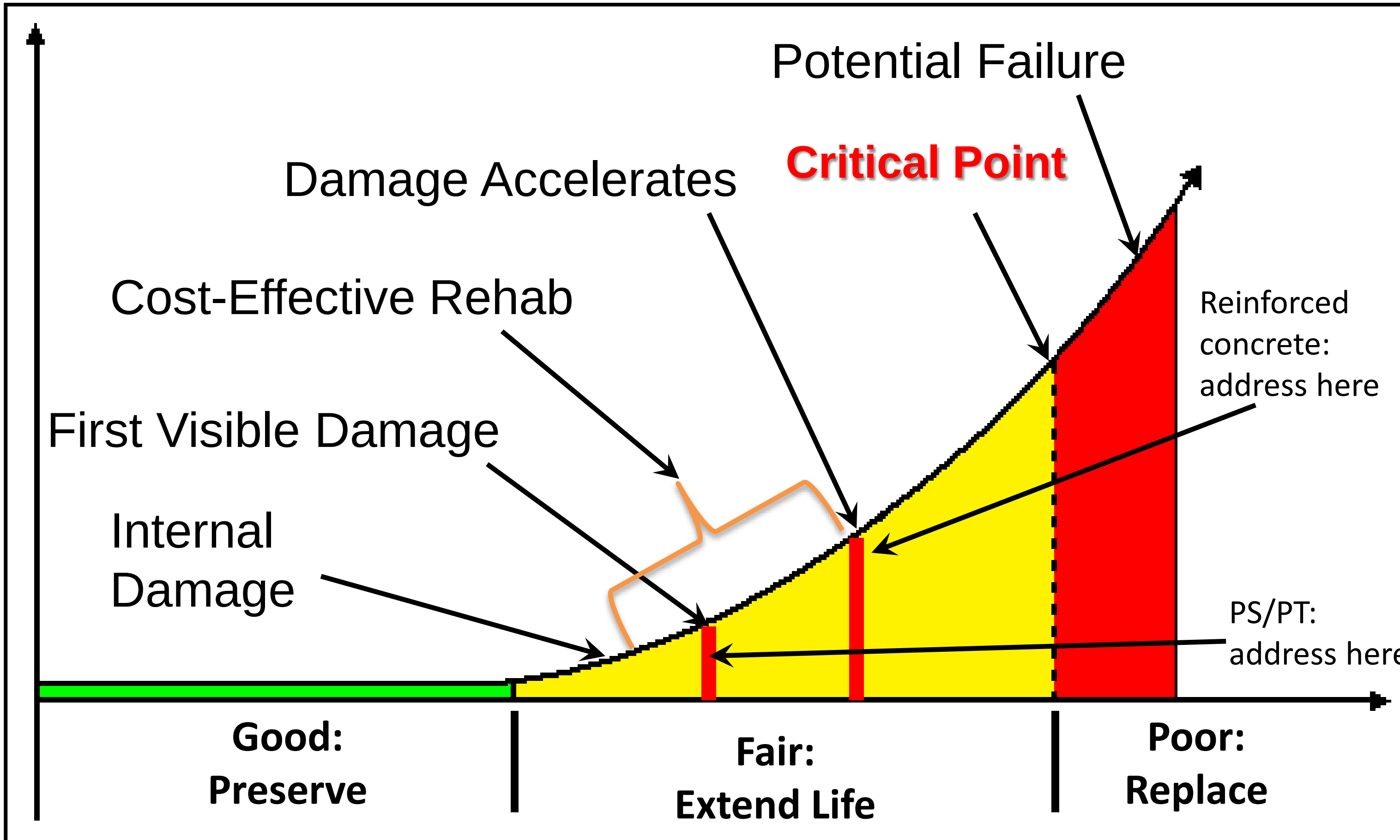
Corrosion-Related Concrete Damage

Cost of Maintenance



Condition of Structure

Penn DOT - I-95 in Philadelphia

Corrosion in bridges leads to emergency closures and expensive repairs.

Concrete Quality for 100-Year Life

- Concrete should have the following properties:
  - Strength, workability
  - Resistance to freeze thaw
  - Resistance to chloride penetration
  - Resistance to sulfate attack
  - Resistance to Alkali-Silica Reaction
  - Abrasion resistance

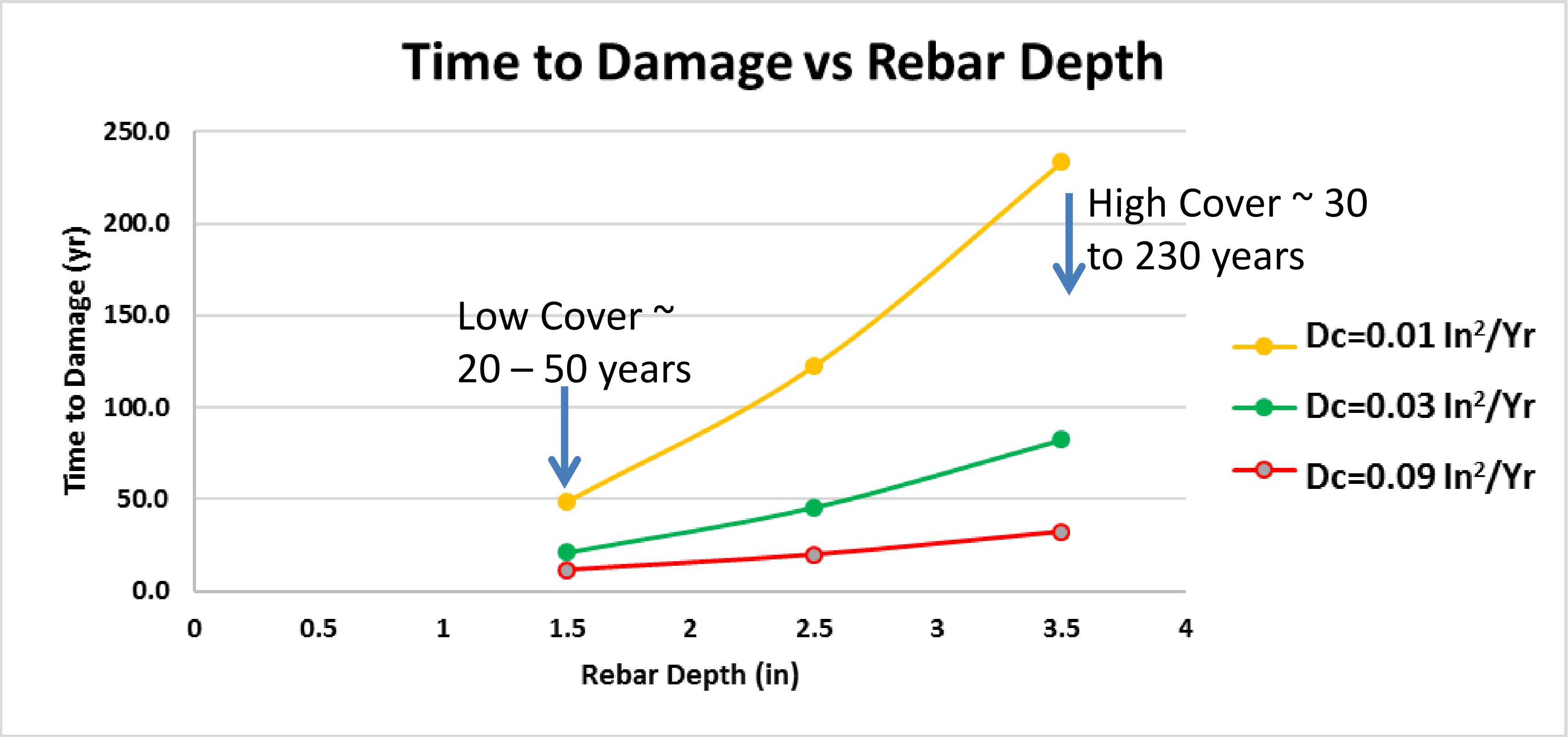
Time to Corrosion Initiation

Diffusion Equation:

$$C_{x,t} = C_o \left[1 - erf\left(\frac{x}{2\sqrt{Dt}}\right)\right]$$

- **Using**
  - **Age (years)**
  - **Rebar Cover** of 1.5", 2.5", and 3.5"
  - **Average surface chloride** for deck, substructure, and piles in marine environments
  - Chloride at the rebar = 400 ppm
  - **Diffusion coefficients** (in^2/yr.) of:
    - ✓ 0.01 in^2/yr. – Excellent durability,
    - ✓ 0.03 in^2/yr. – Good to fair durability,
    - ✓ 0.09 in^2/yr. – Poor Durability

Time to Concrete Damage for Various Rebar Depth



Diffusion property and cover varies within a bridge

Chloride-Induced Corrosion

- Chloride from deicing salt application diffuses into concrete
- When chloride at rebar level exceeds 1.2 lb/CY, passive film breaks down and corrosion initiates
- If pH <11, corrosion can initiate at lower chloride levels
- If sulfate is present, chloride may not be required for corrosion to begin

Diagnosis before Treatment

- When a bridge experiences corrosion, we want to answer the questions:
  - How bad is bad?
  - What is the rate of deterioration?
  - How do we cost effectively extend the life?
- SCS develops a strategic inspection/evaluation plan to quickly indentify/quantify problems.
- Average preservation cost for owners: **20 to 25%** compared to replacement.

Assessment of Concrete Structures

1. Non-Destructive Evaluation (earlier identification)
    - Identify and quantify deterioration of concrete and steel
2. Electrochemical Testing
    - Quantify time-to-failure, corrosion rates, future section losses
3. Laboratory Testing
    - Additional material and corrosion analysis
4. Estimate Service Life
    - Recommend cost effective solution

Non-Destructive Testing (NDT)

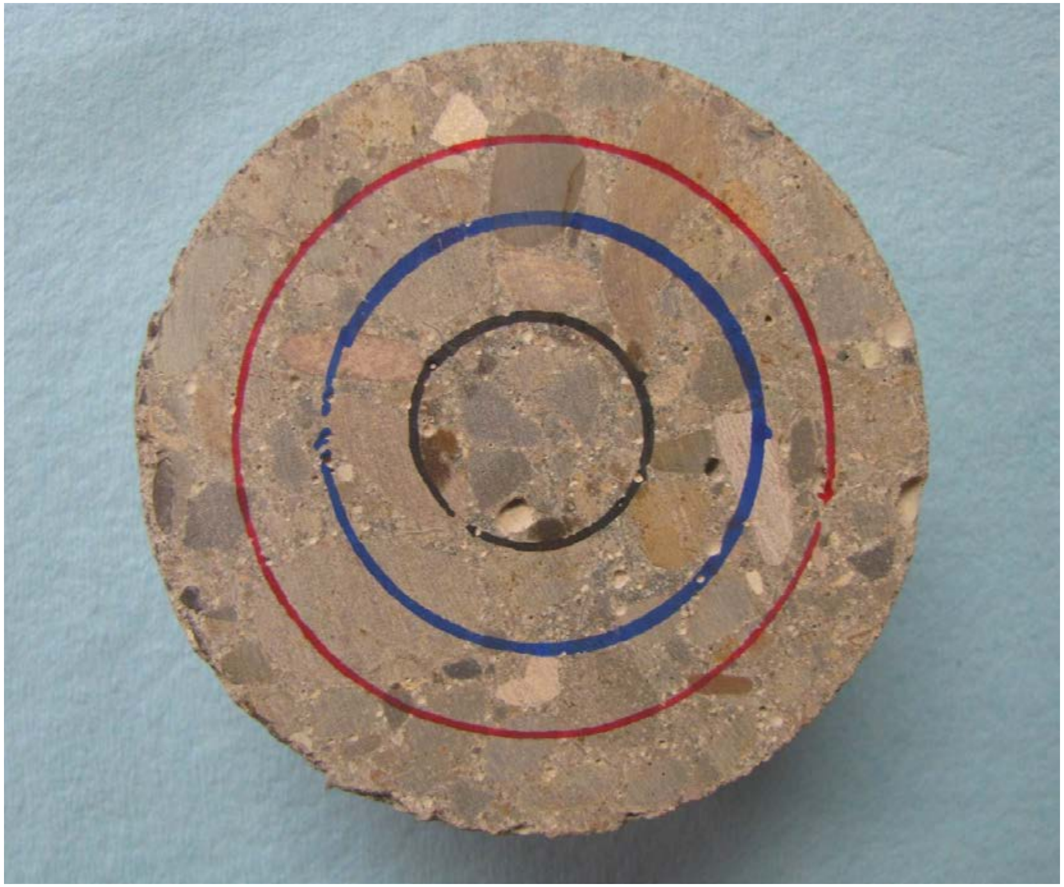
- Use NDT to see hidden problems
- Minimize inspection time and damage to the structure
- Primary NDT tools:
  - Ground Penetrating Radar (GPR)
  - Infrared Thermography
  - Impact-Echo
  - Ultrasonic Tomography

Laboratory Testing

- Laboratory Testing
  - Chloride Content Profiling (AASHTO T-260, ASTM C1152)
  - Chloride Migration Test NS State (NT Build 492)
  - Apparent diffusion coefficient (ASTM C1556, NT BUILD 443)
  - pH Indicator (Phenolphthalein)
  - Rapid Chloride Permeability (ASTM 1202)
  - Compressive Strength (ASTM C39)
  - Petrographic Analysis to Examine:
    - General Concrete Properties (density, air-void, w/cm) (ASTM C876)
    - Alkali-Silica Reactivity
    - Freeze-Thaw Damage (ASTM C472)

Sampling Size

- Chloride cores shall be 4-inch diameter



A smaller core or powder samples can lead to significant variation in chloride level .

More sampling locations needed

Processing Chloride Cores

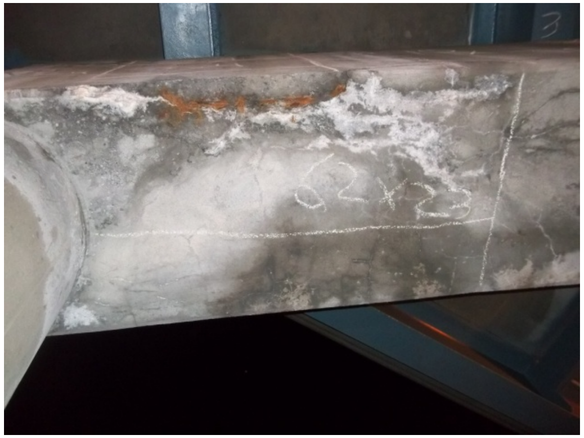
- Mark 0.5-inch horizons along the depth of the core.
- Dry cut through the core at each horizon into concrete discs (slices).
- Pre-crush each slice into ~0.25-inch maximum size pieces.
- Pulverize each pre-crushed slice and pass through #50 sieve.
- Thoroughly clean after each pre-crush and pulverize session.
- Digest each sample in acid to extract chloride from the concrete powder.
- Titrate each sample to determine the chloride content.
- Process titration data to obtain chloride content.
- Perform chloride test at various depths of the core to obtain chloride profile for each core.
- Tabulate chloride data at various depths for analysis and service life calculations.

Case Study 1
I -581 over Williamson Road, Roanoke, VA

Bridge Information

- Built: 1968
- Regular reinforced concrete
- 5 Spans, 4 piers, 2 abutments

Visual Conditions



SCS Approaches

- Visual survey
- Delamination survey
- Concrete cover
- Chloride profile analysis
- Carbonation
- Petrographic analysis
- Service life modeling

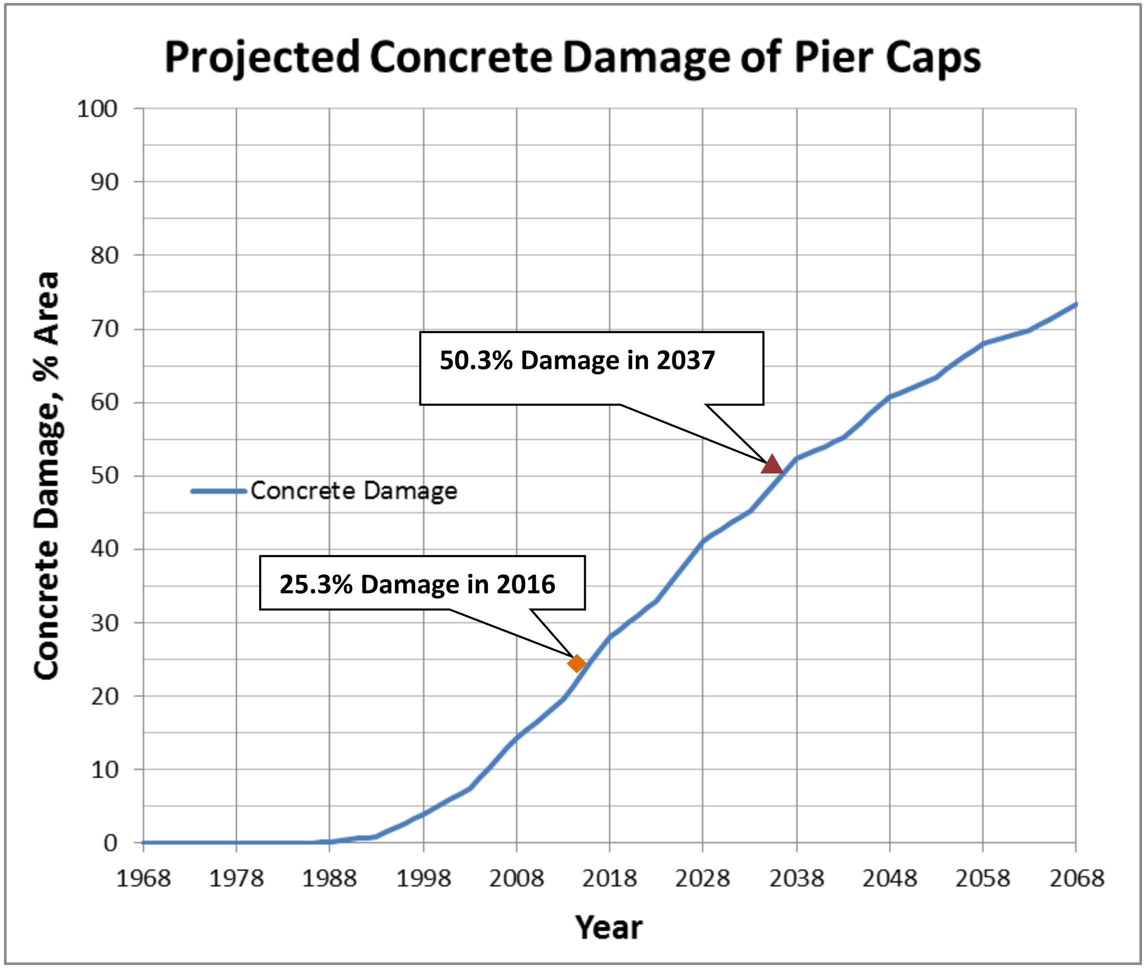
Inspection Findings

Element	% Damage	Avg. Cover (in)	95% Cover (in)	Cl% over 1000 ppm	Cl% over 500 ppm	Avg. Diffusion Coeff. (in^2/yr)	Carbonation Depth (in)	Petro. Analysis
Pier Caps	25.3	2.06	1.01	60%	60%	0.070	0.50	Generally good quality concrete
Pier Columns	17.3	2.50	1.48	17%	17%	0.018	1.15	
Abutments	4.2	2.67	1.15	25%	25%	0.039	0.64	

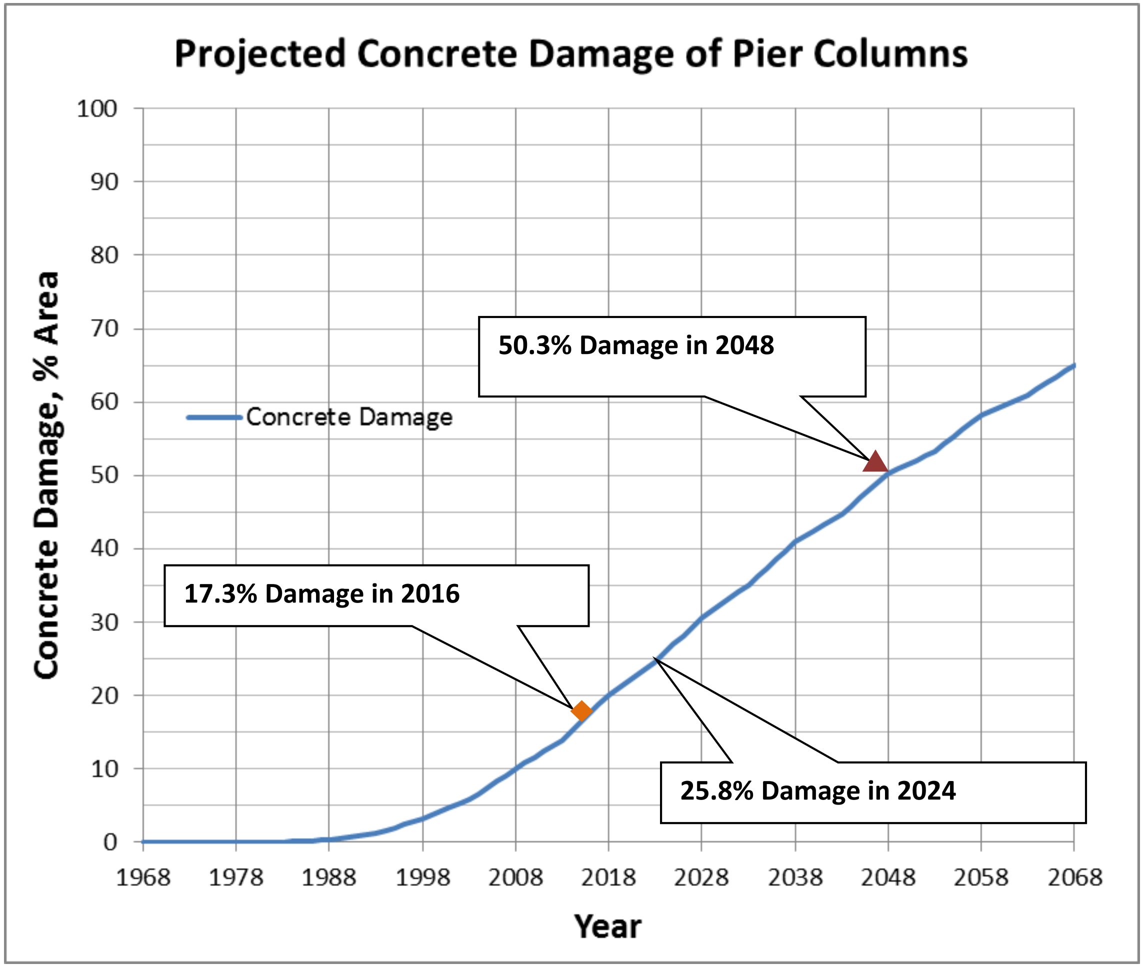
Service Life Analysis

- Using chloride profile, cover, and concrete damage, develop time to corrosion initiation and future concrete damage.

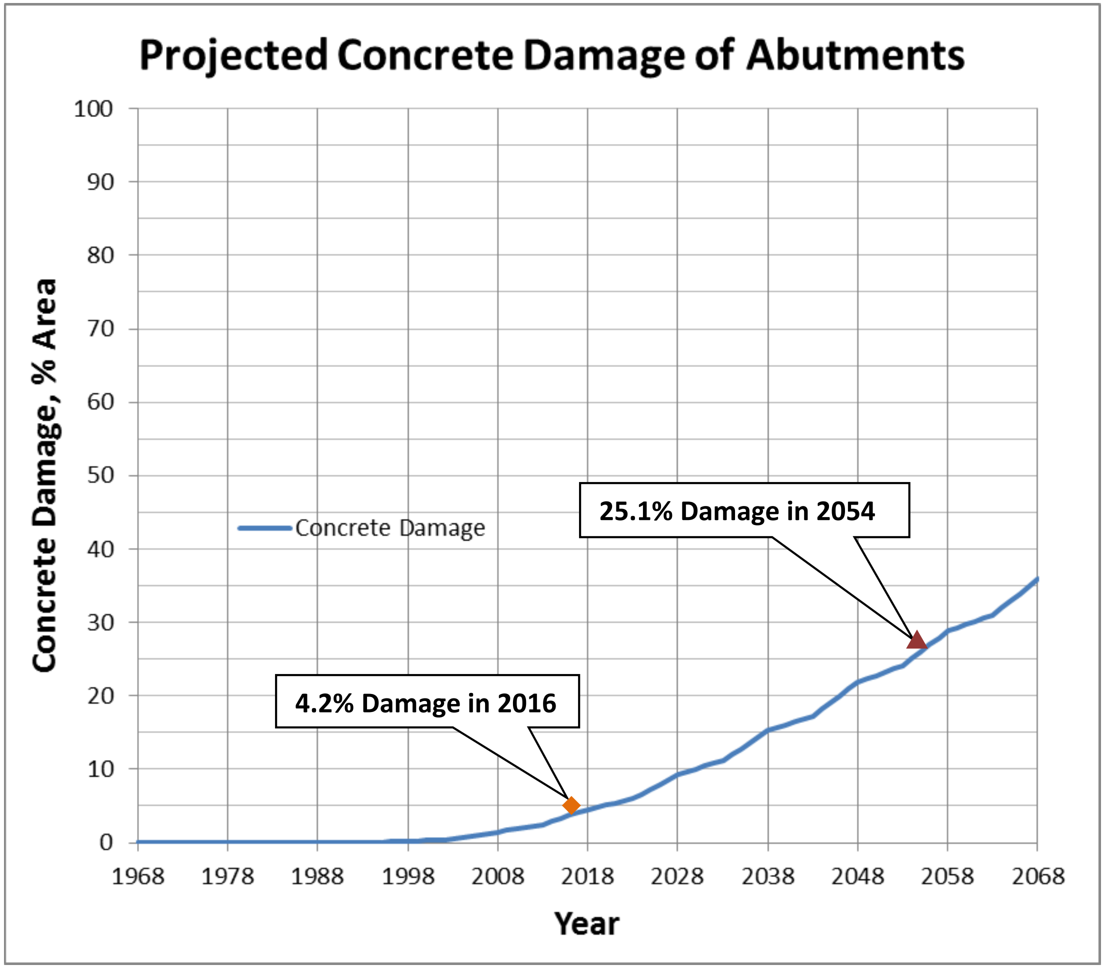
Service Life Processing – Pier Caps



Service Life Processing – Pier Columns



Service Life Processing - Abutments



Conclusions and Viable Options - Piers

- Viable repair options:
  - A. Patch repairs + Impressed Current Cathodic Protection (ICCP)
  - B. Patch repairs + Electrochemical Chloride Extraction (ECE) + a breathable sealer, or
  - C. Patch repairs + sprayed Galvanic Cathodic Protection (GCP) system

Conclusions and Viable Options - Abuts

- The viable repair options:
  - A. Patch repairs + discrete GCP anodes + seal
  - B. Patch repairs + thermal sprayed GCP, or
  - C. Patch repairs + ECE + a breathable sealer

Life Cycle Cost Estimate

Bridge Element	Description	Initial Cost	Additional Repair Cost (50 years)	Additional MOT Cost (50 years)	Total
Pier Caps	Patch + ECE	$784,849	$147,311	$0	$932,160
Pier Columns	Patch + ECE + Seal	$231,000	$85,633	$18,206	$334,839
	~~Patch + ICCP~~	~~$229,032~~	~~$147,311~~	~~$0~~	~~$376,343~~
Abutments	Patch + Anodes + Seal	$12,589	$49,250	$0	$61,840
Subtotals		**$1,028,438**	**$282,194**	**$18,206**	**$1, 328,839**

SCS Recommendations

- Pier Caps – Patch + ECE + Seal
- Pier columns – Patch + ECE + Seal
- Abutments – Patch + Discrete Anode + Seal

Limitations of ECE

- ECE is not suitable for structures with high strength steel
- ECE is not suitable for structures with moderate to severe ASR

ECE AND SPRAYED ZINC ANODE ON 11 BRIDGES IN RICHMOND, VA











ECE on Pier – 11 Bridges

ECE on Pier – 11 Bridges

Thank you!

Questions