Fighting Corrosion & Preserving Bridges

by

Siva Venugopalan
Principal Engineer
Siva Corrosion Services, Inc.

Siva@SivaCorrosion.com
Corrosion-Related Concrete Damage

Condition of Structure

Cost of Maintenance

- Good: Preserve
- Fair: Extend Life
- Poor: Replace

Potential Failure

Critical Point

Damage Accelerates

Cost-Effective Rehab

First Visible Damage

Internal Damage

Reinforced concrete: address here

PS/PT: address here
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 (in²/yr.) of:
    - 0.01 in²/yr. – Excellent durability,
    - 0.03 in²/yr. – Good to fair durability,
    - 0.09 in²/yr. – Poor Durability
Time to Concrete Damage for Various Rebar Depth

Low Cover ~ 20 – 50 years

High Cover ~ 30 to 230 years

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

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

• Visual survey
• Delamination survey
• Concrete cover
• Chloride profile analysis
• Carbonation
• Petrographic analysis
• Service life modeling
## Inspection Findings

<table>
<thead>
<tr>
<th>Element</th>
<th>% Damage</th>
<th>Avg. Cover (in)</th>
<th>95% Cover (in)</th>
<th>Cl% over 1000 ppm</th>
<th>Cl% over 500 ppm</th>
<th>Avg. Diffusion Coeff. (in²/yr)</th>
<th>Carbonation Depth (in)</th>
<th>Petro. Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pier Caps</td>
<td>25.3</td>
<td>2.06</td>
<td>1.01</td>
<td>60%</td>
<td>60%</td>
<td>0.070</td>
<td>0.50</td>
<td>Generally good quality concrete</td>
</tr>
<tr>
<td>Pier Columns</td>
<td>17.3</td>
<td>2.50</td>
<td>1.48</td>
<td>17%</td>
<td>17%</td>
<td>0.018</td>
<td>1.15</td>
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<tr>
<td>Abutments</td>
<td>4.2</td>
<td>2.67</td>
<td>1.15</td>
<td>25%</td>
<td>25%</td>
<td>0.039</td>
<td>0.64</td>
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</tbody>
</table>
Service Life Analysis

• Using chloride profile, cover, and concrete damage, develop time to corrosion initiation and future concrete damage.
Service Life Processing – Pier Caps

- 25.3% Damage in 2016
- 50.3% Damage in 2037
Service Life Processing – Pier Columns

Projected Concrete Damage of Pier Columns

- 17.3% Damage in 2016
- 50.3% Damage in 2048
- 25.8% Damage in 2024
Service Life Processing - Abutments

Projected Concrete Damage of Abutments

- 4.2% Damage in 2016
- 25.1% Damage in 2054
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

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