Determining Service Life & Life Cycle Costs to Preserve Substructures

“Right Action at the Right Time”

by

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Deterioration Mechanism

![Graph showing deterioration over time with various mechanisms including combined, corrosion, sulfate attack, DEF, and ASR.](image)

- Combined
- Corrosion
- Sulfate Attack
- DEF
- ASR
Service Life Performance

Cost of Maintenance

Condition of Structure

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

First Visible Damage
Internal Damage
Use NDT
Damage Accelerates

Potential Failure

Critical Point

Reinforced concrete: address here
PS/PT: address here
Use NDT
Service Life

• Project future deterioration
• Combine existing condition with future deterioration for better asset management
• Evaluate effectiveness of various corrosion mitigation options
• Design concrete mix for new construction
• Adopt better preservation methodology
Projecting Future Deterioration

Future Deterioration depends on:

• the quality of the concrete (how effective it is in slowing down the chloride penetration)
• the depth of cover (how far the chlorides must travel to reach the rebars)
• Concentration of chlorides at the concrete surface and through the depth of cover
• the existing concrete damage (model future damage based on existing damage)
Service Life Software

- Applicable to new and existing structures
- Allows impact analysis of corrosion mitigation solutions such as:
  - Eliminating/reconstructing Joints
  - Sealers
  - Membranes
  - Thin and Rigid overlays
  - Coatings
  - High Performance Concrete and reinforcements
  - Corrosion Mitigation (GCP, ICCP, ECE)
Service Life – Case Study

Projected Damage of Repair Options
- Pier Caps

- 25% Damage Eligible for Replacement
- Total Damage - No Repairs
- Visual Damage - No Repairs

Year
- 1970
- 1980
- 1990
- 2000
- 2010
- 2020
- 2030
- 2040
- 2050
- 2060

Concrete Damage, % Area
- 0
- 5
- 10
- 15
- 20
- 25
- 30
- 35

- Initial Cost Option - Patch Only - Total Damage
- Initial Cost Option - Patch Only - Visual Damage
- LCC Option - ECE - Total Damage
- LCC Option - ECE - Visual Damage
- No Repairs - Total Damage
- No Repairs - Visual Damage

Patch only
- ECE
Case Study#1
King Street Deck- Alexandria, VA
Data required to determine the condition of the Deck & Substructure and to calculate the remaining life:

- Delam/Spall Survey
- Cover Survey
- Chloride Analysis
- Carbonation
- Service Life
King Street – Pier Concrete Damage
King Street – Quality of the Concrete

- Existing concrete damage is 24.4% for pier caps and 2.55% for pier columns
- Minimum concrete cover for 90% of the structure is 0.99 inches
- Carbonation is not a controlling factor for pier deterioration.
- ASR gel is present, but the petrographic report indicates that ASR is not expected to be an issue in the future
Service Life – Projected Concrete Damage

Projected Cumulative Concrete Damage of Pier Caps, %

- 24% at 42.5 years of age
- 25% damage at 45 years of age

Replace at 25% damage
King Street – Repair Options Considered

**Piers caps**

1. Patch repair
2. Patch repair with sprayed GCP
3. Patch and install ICCP.

**Pier columns**

1. Patch repair and breathable surface sealer
2. Patch repair with discreet anode
3. Patch repair, ECE, and sealer.
## Unit Cost Table for Life Cycle Analysis

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

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

Projected Cumulative Concrete Damage of King Street Pier Caps, %

- 25% Damage @ 45 years of age
- 24% @ 42.5 years of age
- 2% @ 92.5 years of age

Replace at 25% damage
Case Study # 2
Eleven Bridges - VDOT

- Constructed in 1950’s (60 years old)
- Heavy traffic corridor
- Full replacement: costly, disruptive
PROBLEM
SCS Approach

SCS performed specific tests to quantify the extent of damage and determine the rate of deterioration.

– Cover Survey
– Corrosion Potential Survey
– Chloride Sampling
– Corrosion Rate Testing
– Continuity Testing
– Hammer Sounding
Spall and Delamination Comparison over Boulevard
2009 Siva Corrosion Services and 1997 Alpha Corporation

<table>
<thead>
<tr>
<th>Bridge Member</th>
<th>1997 Structure Damage (ft²)</th>
<th>2009 Structure Damage (ft²)</th>
<th>Damage Increase Percentage (1997-2009)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pier 1 - Southbound Cap - North Face</td>
<td>52</td>
<td>120</td>
<td>131%</td>
</tr>
<tr>
<td>Pier 1 - Southbound Cap - South Face</td>
<td>42</td>
<td>122</td>
<td>190%</td>
</tr>
<tr>
<td>Pier 1 - Southbound Cap - West Face</td>
<td>2</td>
<td>11</td>
<td>450%</td>
</tr>
<tr>
<td>Pier 1 - Southbound Cap - East Face</td>
<td>5</td>
<td>9</td>
<td>80%</td>
</tr>
<tr>
<td>Pier 1 - Southbound Cap - Top Face</td>
<td>3</td>
<td>18</td>
<td>500%</td>
</tr>
<tr>
<td>* Pier 1 - Southbound Cap - Bottom Face</td>
<td>127</td>
<td>99</td>
<td></td>
</tr>
<tr>
<td><strong>Total Pier 1 - Southbound Cap</strong></td>
<td>231</td>
<td>379</td>
<td>64%</td>
</tr>
</tbody>
</table>

* Patch work for steel columns has caused a decrease in damaged concrete. Patches constitute 25% of bottom surface area. Patches are included in total surface area.

| Total Pier 1 - Column 1-4                  | 168                          | 302                          | 80%                                    |
| Total Pier 1 - SB Cap & Column 1-4         | 399                          | 681                          | 71%                                    |

Notes:
- 1997 structure damage supplied by Alpha Corporation.
- 2009 structure damage supplied by Siva Corrosion Services.
- All calculations & pictorial representations of concrete damage are an estimation of actual concrete damage, based on dimensions & locations (insert notes).
- Siva Corrosion Services conducted spall and delamination survey for approximately 50% of the total structure.
<table>
<thead>
<tr>
<th>S. No.</th>
<th>Structure</th>
<th>Replacement cost</th>
<th>Repair cost</th>
<th>Cost Savings</th>
<th>Repair cost/Replacement cost, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Boulevard</td>
<td>$1,931,202</td>
<td>$402,300</td>
<td>$1,528,902</td>
<td>21%</td>
</tr>
<tr>
<td>2</td>
<td>Hermitage Road</td>
<td>$3,240,312</td>
<td>$619,720</td>
<td>$2,620,592</td>
<td>19%</td>
</tr>
<tr>
<td>3</td>
<td>Laburnum Avenue</td>
<td>$1,730,258</td>
<td>$380,480</td>
<td>$1,349,778</td>
<td>22%</td>
</tr>
<tr>
<td>4</td>
<td>Lombardy/CSX</td>
<td>$5,821,420</td>
<td>$2,019,420</td>
<td>$3,802,000</td>
<td>35%</td>
</tr>
<tr>
<td>5</td>
<td>Overbrook Road</td>
<td>$1,147,005</td>
<td>$312,240</td>
<td>$834,765</td>
<td>27%</td>
</tr>
<tr>
<td>6</td>
<td>Ramp-A</td>
<td>$926,000</td>
<td>$146,440</td>
<td>$779,560</td>
<td>16%</td>
</tr>
<tr>
<td>7</td>
<td>Robin Hood Road</td>
<td>$1,877,817</td>
<td>$568,560</td>
<td>$1,309,257</td>
<td>30%</td>
</tr>
<tr>
<td>8</td>
<td>Sherwood Avenue</td>
<td>$1,595,045</td>
<td>$397,700</td>
<td>$1,197,345</td>
<td>25%</td>
</tr>
<tr>
<td>9</td>
<td>Upham Brook Run</td>
<td>$2,287,719</td>
<td>$429,620</td>
<td>$1,858,099</td>
<td>19%</td>
</tr>
<tr>
<td>10</td>
<td>Westwood Avenue</td>
<td>$3,592,000</td>
<td>$402,440</td>
<td>$3,189,560</td>
<td>11%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>$24,148,778</td>
<td>$5,678,920</td>
<td>$18,469,858</td>
<td>24%</td>
</tr>
</tbody>
</table>
Solution Implementation
Electro-Chemical Extraction (ECE)
Solution Implementation

Galvanic Cathodic Protection (GCP)

Galvanic Cathodic Protection was Applied
GCP Effectiveness Monitoring
Preservation
Ribault River Bridge (SR-115)
Little Cedar Creek Bridge (I-95)
Cedar Creek Bridge (I-95)
Trout River Bridge (US-17)
Moncrief Creek Bridge (SR-111)
Trout River Bridge (SR-115)
Broward River Bridge (US-17)
San Pablo River Bridge (SR-10)
Cresent Beach Bridge
Patches Accelerate Corrosion

Good Encapsulation – New Corrosion

Courtesy of FDOT
Infrared Thermography (IRT)
Pier & Footers
Patch Corrosion Continues

Conventional encapsulation allows continued corrosion

Courtesy of FDOT
Removal of Existing CP Jacket
Six Inch Annulus
Encapsulation of a Titanium Anode within a Standard Pile Jacket

1) A fiberglass form is placed around the pile leaving an annular space between pile and form.
2) Form is filled with mortar/concrete.
Sacrificial Cathodic Protection

Arc-sprayed Zinc Anode
In Closing...

• Take right action at the right time
• Service Life - Project future condition of the structure
• Corrosion mitigation is successfully used to extend the service life
Questions?

Thank you!