Current and Future Condition Based Preservation Options

by

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In This Presentation

• Selecting Preservation Option
• Service Life Model
• Life-Cycle Cost Analysis
• Case Studies (Reinforced Concrete Structures)
• Conclusion
Current Status

• Average age of bridges is 42, close to design life.
• Majority of them require repair/replacement.
• More capacity is required in many routes.
• Investment for new and existing structure.
• All happening at the same time.
• Funding is scarce.
• Staggering replacement is necessary.
• Preservation is a inevitable.
Bridge preservation is defined as actions or strategies that prevent, delay or reduce deterioration of bridges or bridge elements, restore the function of existing bridges, keep bridges in good condition and extend their life. Preservation actions may be preventive or condition-driven. **Source: FHWA Bridge Preservation Expert Task Group, May 2011.**
Bridge Preservation

• When a bridge experiences corrosion, we want to answer the questions:
  – What is the current condition? How bad is bad?
  – What is the rate of deterioration?
  – How do we cost-effectively extend the life?

• Average preservation cost savings for owners: \( 75\%-80\% \) compared to replacement.
Decision Process

- 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)
Determine Current Condition

• Corrosion can be a hidden process
Determine Current Condition

• Corrosion can be a hidden process
Determine Current Condition

• Inspection necessary to quantify past and future deterioration

• Inspection tools:
  – Past Reports
  – Visual
  – NDT
  – Select Laboratory Testing
Quantify Rate of Deterioration

• Key Factors:
  – Existing concrete damage
  – Existing prestressing section loss
  – Chloride profile
  – Reinforcement Cover
  – Materials degradation (freeze-thaw, ASR)
Service Life Modeling

- Based on past damage and rate of deterioration, estimate future performance
Service Life Modeling

• Understand factors contributing to corrosion
• Select model
  – NCHRP 558
  – Stadium
  – Life 365
• Engineering judgment still required
Manual on Service Life of Corrosion-Damaged Reinforced Concrete Bridge Superstructure Elements

- **Input:**
  - Age
  - Concrete damage
  - Chloride profile
  - Rebar cover

- **Output:**
  - Determines apparent diffusion coefficient and threshold for corrosion
  - Estimates future concrete damage
NCHRP 558

Percent Damage versus Age

- 1.2% Damage in 2013
- 22% Damage in 50 years (2063)
Identify Viable Repair Options

• Based on present and future damage, select appropriate repair/rehabilitation options

• Repair option must:
  – Rectify structural issues (in concert with structural firms)
  – Address corrosion/material degradation
  – Achieve desired service life
Identify Viable Repair Options

- Patching (with/without corrosion protection)
- Sealers and Membranes
- Overlay (with milling or hydrodemo)
  - Thin Epoxy
  - Rigid (LMC, LPC)
- Fiber Wrap with Corrosion Mitigation
- Electrochemical
  - ECE (Electrochemical Chloride Extraction)
  - GCP (Galvanic Cathodic Protection)
  - ICCP (Impressed Current Cathodic Protection)
- Combination of two or three of the above
<table>
<thead>
<tr>
<th>Activity</th>
<th>Life, Years</th>
<th>Unit</th>
<th>Unit Cost ($)</th>
<th>Presumed Maintenance during Usable Life</th>
<th>MOT for Repairs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Deck Activity</strong></td>
<td></td>
<td></td>
<td></td>
<td>------------------------------------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Air/Grit Blasting</td>
<td>N/A</td>
<td>Sq. ft.</td>
<td>$0.33</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Type A Milling (1&quot; typical)</td>
<td>N/A</td>
<td>Sq. ft.</td>
<td>$2.00</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Hydrodemolition</td>
<td>N/A</td>
<td>Sq. ft.</td>
<td>$6.89</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Type B Top Deck Patch Repair</strong></td>
<td>5</td>
<td>Sq. ft.</td>
<td>$33.33</td>
<td>Repair every 2 years based on the results of the service life model quantity times 2.</td>
<td>2 days/closure</td>
</tr>
<tr>
<td><strong>Type C Deck Patch Repair</strong></td>
<td>5</td>
<td>Sq. ft.</td>
<td>$44.44</td>
<td>Only at initial repair</td>
<td>Included in Type B MOT</td>
</tr>
<tr>
<td>Thin Epoxy Overlay</td>
<td>15</td>
<td>Sq. ft.</td>
<td>$5.22</td>
<td>Replace overlay every 15 years. Perform 5% Type B Repair at time of replacement.</td>
<td>2 days/closure</td>
</tr>
<tr>
<td>Rigid Concrete Overlay</td>
<td>25</td>
<td>Sq. ft.</td>
<td>$11.11</td>
<td>2% at 10 years and 2% patching every 2 years thereafter until 20 years. Replace at 25 years.</td>
<td>11 days/closure (7 days of curing), barrier closure</td>
</tr>
</tbody>
</table>
LCCA

- Past performance to model performance of various repair options
- Compare performance and cost
  - Service life
  - Initial cost
  - Life-cycle cost
  - Compare yearly life-cycle cost of each option
  - Practicality/schedule to make final decision
Case Study #1

2807- Alexandria, VA

Bridge # 100-2807
King Street over I-395, RAMP B (A7)

Bridge # 100-2834
I-395 NB over RAMPS & 4 MILE RUN (A8)
Problem

- Ongoing corrosion in Bridges 2807 & 2834 along I-395 in Alexandria, VA.
- Corrosion related concrete damage and reinforcement section losses.
- Desired additional life - 50 years.
- Is it possible? What is the cost?
Built in 1970, LMC overlay placed in 1995
Five Span Bridge
SCS Approach

SCS performed the following tests to determine the condition of the Deck & Substructure and to calculate the remaining life:

– Delam/Spall Survey
– Continuity
– Cover Survey
– Impact Echo
– Chloride Analysis
– Carbonation
– Service Life & Life Cycle Cost
2807- Delam Survey

- 5.4% total damage observed

<table>
<thead>
<tr>
<th>Location</th>
<th>Total Area (ft²)</th>
<th>Delam/Debond Area (ft²)</th>
<th>Percent Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit 1</td>
<td>1234.3</td>
<td>65.3</td>
<td>5.3</td>
</tr>
<tr>
<td>Unit 2</td>
<td>1444.8</td>
<td>24.9</td>
<td>1.7</td>
</tr>
<tr>
<td>Unit 3</td>
<td>1421.3</td>
<td>75.9</td>
<td>5.3</td>
</tr>
<tr>
<td>Unit 4</td>
<td>1510.3</td>
<td>114.7</td>
<td>7.6</td>
</tr>
<tr>
<td>Unit 5</td>
<td>1187.3</td>
<td>87.2</td>
<td>7.3</td>
</tr>
<tr>
<td>Total</td>
<td>6798.0</td>
<td>368.0</td>
<td>5.4</td>
</tr>
</tbody>
</table>

- Used Impact-Echo (IE) - to identify debonding at overlay or at rebar level.
- Cores - at IE locations to confirm IE result.
2807 – Impact Echo (IE)

Frequency Response of Debonded Overlay in Span 5

Extracted core confirming debonding
2807 Deck - Petrographics

- Water/cement ratio range was 0.40 to 0.45 (normal for this age and deck concrete).
- Petrographics concluded that concrete has freeze thaw resistance.
- No destructive ASR activity was observed in the cores.
- ASR will not adversely affect corrosion mitigations such as ECE, GCP, and ICCP.
2807 Deck – Service Life Estimates

Figure 7. Projected Concrete Damage for Top Deck

- 0.0% Damage in 2013
- 25% Damage in 19 Years (2032)
SCS performed in-depth testing on 2 Piers and 1 Abutment based on visual damage
2807 Substructure – Service Life Estimates (Open Joint)

**Figure 2**  Projected Concrete Damage for the Pier Caps (Open Joint)

- 1.2% Damage in 2013
- 22% Damage in 50 Years (2063)
• SCS evaluated the service life if joints were eliminated.
• If the joints are removed, less moisture and chloride will contaminate the substructure.
• At this rate, the pier cap damage would reach 12% within 50 years and the pier column damage would reach 15% within 50 years if no other corrosion mitigation is performed.
2807 Substructure – Service Life Estimates (Closed Joint)

**Percentage Damage versus Age**

- **1.2% Damage in 2013**
- **12% Damage in 50 Years (2063)**

*Figure 11: Projected Concrete Damage for the Pier Caps (Closed Joint)*
## 2807 – Life Cycle Cost Estimate

### Lowest Life Cycle Cost Repair Options

<table>
<thead>
<tr>
<th>Bridge Element</th>
<th>Description</th>
<th>Initial Cost</th>
<th>Additional Life Cost (50 years)</th>
<th>MOT (associated w/ LCCA only)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concrete Repair/Rehabilitation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deck</td>
<td>Patch+LMC</td>
<td>$ 162,927</td>
<td>$ 103,804</td>
<td>$ 42,144</td>
<td>$ 308,875</td>
</tr>
<tr>
<td>Pier Caps (Open Joints)</td>
<td>Patch+ECE+Seal</td>
<td>$ 72,501</td>
<td>$ 32,591</td>
<td>$ 26,971</td>
<td>$ 132,063</td>
</tr>
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<td>$ 72,501</td>
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<tr>
<td>Pier Columns (Open Joints)</td>
<td>Patch+ECE+Seal</td>
<td>$ 95,696</td>
<td>$ 43,017</td>
<td>$ 26,971</td>
<td>$ 165,684</td>
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<td>$ 95,696</td>
<td>$ 43,017</td>
<td>$ 26,971</td>
<td>$ 165,684</td>
</tr>
<tr>
<td>Abutments</td>
<td>Patch+ECE+Seal</td>
<td>$ 16,806</td>
<td>$ 7,555</td>
<td>$ 13,486</td>
<td>$ 37,847</td>
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</tbody>
</table>
## Lowest Initial Cost Repair Options

<table>
<thead>
<tr>
<th>Bridge Element</th>
<th>Description</th>
<th>Initial Cost</th>
<th>Additional Life Cost (50 years)</th>
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<td></td>
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<tr>
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<td>$162,927</td>
<td>$103,804</td>
<td>$42,144</td>
<td>$308,875</td>
</tr>
<tr>
<td>Pier Caps (Open Joints)</td>
<td>Patch Repairs</td>
<td>$2,601</td>
<td>$51,006</td>
<td>$217,433</td>
<td>$271,040</td>
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<tr>
<td>Pier Caps (Closed Joints)</td>
<td>Patch Repairs</td>
<td>$2,601</td>
<td>$25,503</td>
<td>$217,433</td>
<td>$245,537</td>
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<tr>
<td>Pier Columns (Open Joints)</td>
<td>Patch Repairs</td>
<td>$3,433</td>
<td>$65,628</td>
<td>$217,433</td>
<td>$286,494</td>
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<tr>
<td>Pier Columns (Closed Joints)</td>
<td>Patch Repairs</td>
<td>$3,433</td>
<td>$32,814</td>
<td>$217,433</td>
<td>$253,680</td>
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<tr>
<td>Abutments</td>
<td>Patch Repairs</td>
<td>$1,119</td>
<td>$15,178</td>
<td>$108,716</td>
<td>$125,013</td>
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</table>
# Initial vs Life Cycle Costs

## Initial vs. Life-Cycle Cost Repair Options

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<thead>
<tr>
<th>Bridge Element</th>
<th>Description</th>
<th>Initial Total Cost</th>
<th>Life Cycle Total Cost</th>
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<tbody>
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<td><strong>Concrete Repair/Rehabilitation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deck</td>
<td>Patch+LMC</td>
<td>$308,875</td>
<td>$308,875</td>
</tr>
<tr>
<td>Pier Caps (Open Joints)</td>
<td>Initial - Patch Repairs</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Life Cycle - Patch + ECE + Seal</td>
<td>$271,040</td>
<td>$132,063</td>
</tr>
<tr>
<td>Pier Caps (Closed Joints)</td>
<td>Initial - Patch Repairs</td>
<td></td>
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<tr>
<td>Abutments</td>
<td>Initial - Patch Repairs</td>
<td></td>
<td></td>
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<td></td>
<td>Life Cycle - Patch + ECE + Seal</td>
<td>$125,013</td>
<td>$37,847</td>
</tr>
</tbody>
</table>
**2807 - SCS Recommendation**

**Deck**
Remove the existing chloride-contaminated overlay concrete (2” deep via hydrodemolition) and remove any remaining loose/deteriorated concrete underneath the overlay. Install a new LMC overlay (2” thickness).

**Piers**
Repair existing concrete damage, perform ECE on the piers and seal the surface.

**Abutments**
Repair existing concrete damage, perform ECE on the abutments and seal the surface.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Deck</th>
<th>Piers</th>
<th>Abutments</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-2807 King St. over I-395, Ramp B (A7)</td>
<td>Patch + LMC</td>
<td>Patch + ECE + Seal</td>
<td>Patch + ECE + Seal</td>
</tr>
</tbody>
</table>
Deck

*Modeling indicates that the lowest cost repair is biennial patch repairs.* However, due to exposed aggregate, SCS recommended installing a thin epoxy overlay. This addressed the deck condition at minimal additional cost.

**Piers**

Repair existing concrete damage, install ICCP on the piers and

**Abutments**

Repair existing concrete damage, install ICCP on the abutments

<table>
<thead>
<tr>
<th>Structure</th>
<th>Deck</th>
<th>Piers</th>
<th>Abutments</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-2807 King St. over I-395, Ramp B (A7)</td>
<td>Patch + Thin Epoxy Overlay</td>
<td>Patch + ICCP</td>
<td>Patch + ICCP</td>
</tr>
</tbody>
</table>
Case Study #2
Grand Island, NE – 2 Bridges

B R I D G E  #  U 1 0 4 5 W 3 9 0 4
S O U T H  F R O N T  S T R E E T  O V E R
S Y C A M O R E  S T R E E T  U N D E R P A S S

B R I D G E  #  U 1 0 4 5 J 3 9 0 7
N O R T H  F R O N T  S T R E E T  O V E R  E D D Y
S T R E E T  U N D E R P A S S

Constructed in 1950 (63 years old)
Case Study #2
Grand Island, NE – 2 Bridges
Case Study #2
Grand Island, NE – 2 Bridges
Problem

• The bridges are over 60 years old.
• Decks and substructures showed signs of corrosion-related concrete damage.
• Needed to extend the life of the bridges by 30 additional years.
• SCS was retained to quantify damage and evaluate the cost of repair vs. replacement.
Problem

Delaminations
North Front - Service Life Model

Projected Cumulative Damage -- Top Deck

- **5.4% Damage in 2013**
- **25% Damage in 2046**
North Front - Service Life Model

Projected Cumulative Damage -- East Abut.

- 17.6% Damage in 2013
- 25% Damage in 2025
North Front - Service Life Model

Projected Cumulative Damage -- East Retaining Wall

4.3% Damage in 2013
## North Front - Summary of Lowest Life Cycle Cost Repair Options

<table>
<thead>
<tr>
<th>Bridge Element</th>
<th>Description</th>
<th>Initial Cost</th>
<th>Additional Life Cost (30 years)</th>
<th>MOT (associated w/ LCCA only)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concrete Repair/Rehabilitation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deck</td>
<td>Patch + Anode</td>
<td>$74,885</td>
<td>$20,384</td>
<td>$38,690</td>
<td>$133,959</td>
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<tr>
<td>Abutment Walls</td>
<td>Patch + GCP Sprayed</td>
<td>$38,787</td>
<td>$22,497</td>
<td>$12,420</td>
<td>$73,705</td>
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<tr>
<td>Retaining Walls</td>
<td>Patch + Anode</td>
<td>$22,290</td>
<td>$49,020</td>
<td>$56,035</td>
<td>$127,345</td>
</tr>
<tr>
<td><strong>Subtotal Concrete</strong></td>
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<td><strong>$135,962</strong></td>
<td><strong>$91,901</strong></td>
<td><strong>$107,145</strong></td>
<td><strong>$335,009</strong></td>
</tr>
</tbody>
</table>
South Front - Deck
South Front – Service Life Model

Percent Damage versus Age

- 6.9% Damage in 2013
- 25% Damage in 2030
## South Front – Life Cycle Cost Analysis

### South Front - Summary of Lowest Life Cycle Cost Repair Options

<table>
<thead>
<tr>
<th>Bridge Element</th>
<th>Description</th>
<th>Initial Cost</th>
<th>Additional Life Cost (30 years)</th>
<th>MOT (associated w/ LCCA only)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Concrete Repair/Rehabilitation</strong></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Deck</td>
<td>Replacement</td>
<td>$215,605</td>
<td>$0</td>
<td>$0</td>
<td>$215,605</td>
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<tr>
<td>Abutments</td>
<td>Patch Repair + Seal</td>
<td>$34,594</td>
<td>$22,880</td>
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<td>$85,492</td>
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<tr>
<td>Retaining Walls</td>
<td>Patch + Anode + Seal</td>
<td>$55,261</td>
<td>$130,461</td>
<td>$56,035</td>
<td>$241,757</td>
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<tr>
<td><strong>Subtotal Concrete</strong></td>
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<td>$305,460</td>
<td>$153,341</td>
<td>$84,053</td>
<td>$542,854</td>
</tr>
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</table>
Conclusions

• Deterioration is like cancer – typically hidden
• Use past and current damage to project future deterioration
• Good data to make sound decisions to achieve the service life that the owner requires
Cost of Rehabilitation

- **Bridge Condition**
- **Cost of Repair**

Age of Bridge

Condition/Cost
Conclusions

• Early evaluation results in lower maintenance costs and longer service lives
• Preservation is key to maximizing budgets
• Service life modeling and LCCA helps owner make data driven decisions
Questions?

Thank You!