Field Evaluations of Epoxy-Coated Bars in Inland and Marine Bridges

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Causes of corrosion

Deicing Salts

Marine Salts
HISTORY OF EPOXY-COATED REINFORCING STEEL
1960 Clear roads policy

• Led to widespread use of deicing salts
• Causing rapid deterioration of bridge decks
  – 5 to 10 years
1970s NBS study

• Clifton, Beeghly and Mathey
  – 42 coatings evaluated

• Recommended
  – Fusion bonded epoxy

First epoxy-coated bars used in 1973
Epoxy-coated reinforcing steel

ASTM A775: Green
Bendable

ASTM A934: Purple or Grey
Non-bendable

Used in over 70,000 bridges
EPOXY-COATED BAR MANUFACTURING PROCESS
Reinforcing steel

- Manufactured from scrap metal
- Melted and cast into billets
- Billets rolled into reinforcing steel
- Reinforcing steel delivered to coating plant
As-received and shot-blasted

Cleanliness, chloride, mill scale, profile (roughness)
Induction heating
Powder application
Coated bars
Quality checks

- CRSI Certification
- Continuity
  - Holidays
- Thickness
- Flexibility
- Cathodic debonding
1993 WVDOT survey

• Bridges built in the mid-1970s
• Uncoated bars (19 decks)
  – 1% to 29% delamination (all decks)
• Epoxy-coated bars (14 decks)
  – 0% to 1% delamination
  – Distress identified on only three decks
I-79 Bridges 1993

• Eight bridge decks on I-79
  – Uncoated bars (4)
  – Epoxy-coated bars (4)

• Similar age

• Exposed to identical conditions and traffic
  – Uncoated bars
    • 8.5% delamination
  – Epoxy-coated bars
    • Essentially no delamination (1 ft²)
2009 Survey

- Updated the 1993 survey
- Wiss, Janney and Elstner Associates
- WVDOT bridge engineers
  - All decks constructed with uncoated bar have been rehabilitated with latex-modified or microsilica overlays since 1993.
FIELD SURVEY 2009
## Decks studied

<table>
<thead>
<tr>
<th>Bridge</th>
<th>ECR</th>
<th>Year Built</th>
<th>ADT</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>2668</td>
<td>Both</td>
<td>1976</td>
<td>10700</td>
<td>39200</td>
</tr>
<tr>
<td>2672N</td>
<td>Top</td>
<td>1976</td>
<td>10000</td>
<td>7000</td>
</tr>
<tr>
<td>2672S</td>
<td>Top</td>
<td>1976</td>
<td>10000</td>
<td>7000</td>
</tr>
<tr>
<td>2673</td>
<td>Top</td>
<td>1975</td>
<td>500</td>
<td>17000</td>
</tr>
<tr>
<td>2930</td>
<td>Both</td>
<td>1974</td>
<td>7000</td>
<td>17800</td>
</tr>
<tr>
<td>2953</td>
<td>Both</td>
<td>1975</td>
<td>6000</td>
<td>9000</td>
</tr>
</tbody>
</table>
I-79 Bridges
I-79 Bridges

2672S

2672N
Low traffic bridge
Moderate traffic bridges
SURVEY METHODS
Delamination and crack survey
Cover survey and cores
Electrical continuity
West Virginia 2009

Black - Delaminated concrete after 17 years

Epoxy - No delaminations after 34 years

Deck with both epoxy and black bar sections
## Deterioration

<table>
<thead>
<tr>
<th>Bridge</th>
<th>Area Surveyed (ft²)</th>
<th>Area Delamination (ft²)</th>
<th>Area Delamination (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2668</td>
<td>12444</td>
<td>9</td>
<td>0.07</td>
</tr>
<tr>
<td>2672N</td>
<td>4272</td>
<td>6</td>
<td>0.14</td>
</tr>
<tr>
<td>2672S</td>
<td>4272</td>
<td>3</td>
<td>0.07</td>
</tr>
<tr>
<td>2673</td>
<td>16618</td>
<td>25</td>
<td>0.15</td>
</tr>
<tr>
<td><strong>2930 ECR</strong></td>
<td>13722</td>
<td>0</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>2930 Black</strong></td>
<td>3050</td>
<td>165</td>
<td>5.41</td>
</tr>
<tr>
<td><strong>2953</strong></td>
<td>8306</td>
<td>0</td>
<td>0.00</td>
</tr>
</tbody>
</table>

~0.1% delam.
Laboratory analysis

- Bar extracted
  - Visual inspection
  - Adhesion
  - Backside cleanliness
  - Coating thickness

- Cores
  - Acid-soluble chloride analysis
  - Chloride surface concentration
  - Diffusion coefficient
Coating thickness

Current ASTM
Chloride at bar level

Assumed threshold for black bars

Threshold for epoxy ~3 times black

% samples

Chloride (% by weight concrete)
Tutti Model - West Virginia

- Black Bar
  - Damage: 20 years
  - No damage: 35 years

- Epoxy-coated Bar
  - Damage: 35 years
  - No damage: No data

Time:

Damage:
Conclusions from WV study

• Decks of similar design, concrete, location
• Black bar decks repaired
  – 18 to 21 years
• Epoxy bar decks
  – Good to excellent condition
  – Deterioration observed only at cracks and construction joints
• Deck with both epoxy and black bar spans
  – Epoxy exhibited no delamination
  – Black exhibited more than 5 percent
Conclusions from WV study

• Active corrosion in the epoxy-coated bars correlated to three factors:
  – high chloride concentration
  – low coating thickness
  – extended exposure to high chloride concentrations

• Many more years of service life are expected
FLORIDA BRIDGES
Background

• Florida
  – 11,803 bridges
  – 300 structures with epoxy-coated reinforcing steel in substructure
  – 55 with epoxy-coated reinforcing steel in deck
Observations

• Severe corrosion in five bridges
  – Built between 1978 and 1983

• Defects
  – Portions had very low cover
  – 2% allowable damage to the epoxy
  – Bare steel tie wires
  – High permeability concrete
Bridge groups

- **Group 1**
  - Poor concrete
  - Poor cover
  - 5 bridges

- **Group 2**
  - Poor concrete
  - Good cover
  - 4 bridges

- **Group 3**
  - Good concrete
  - Good cover
  - ~290 bridges
# Bridge groups

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover</td>
<td>Cover</td>
<td>Cover</td>
</tr>
<tr>
<td>3 in.</td>
<td>3.5 in.</td>
<td>4 in.</td>
</tr>
<tr>
<td>$D_{\text{eff}}$ (m$^2$/s)</td>
<td>$D_{\text{eff}}$ (m$^2$/s)</td>
<td>$D_{\text{eff}}$ (m$^2$/s)</td>
</tr>
<tr>
<td>$2 \times 10^{-11}$</td>
<td>$1.3 \times 10^{-12}$</td>
<td>$3 \times 10^{-13}$</td>
</tr>
</tbody>
</table>
Damage rates over time

![Damage rates over time graph](image)
Damage rates over time

![Graph showing damage rates over time for different bridge ages. The x-axis represents bridge age (y years) ranging from 0 to 30, and the y-axis represents damage ranging from 0 to 5. The graph includes multiple lines for different bridge types, each labeled with specific notations such as NIL, 7MI, LOK, INK, CH5, CH2, SNK, VA1/2, and CHO.](image)
Florida predictions

Most structures containing epoxy reinforcement are predicted to have a 100 year life.
Florida bridges

- Good concrete
- Good cover
- Aggressive environment
- Well manufactured and stored reinforcement

Good quality concrete and coatings lead to long life
New York State Department of Transportation 2009

- Statistical analysis of 17,000 structures
- Structural decks with epoxy-coated reinforcement perform significantly better than those with uncoated reinforcement, especially in the later years.
CURRENT USE
Lake Champlain
Vermont and New York Departments of Transportation
Indian River Inlet Bridge
Delaware Department of Transportation

Image courtesy of Skanska USA and Eric Crossland
St. Louis Bay Bridge
Mississippi Department of Transportation
Skyway Bridge
California Department of Transportation
Galena Creek Bridge
Nevada Department of Transportation
CONCLUSIONS
Conclusions

• Epoxy-coated reinforcing bars have performed well in both marine and inland environments

• Side-by-side analysis shows epoxy at least doubling life in West Virginia structures

• Florida analysis shows 100 year design life in marine waters

• Improved coating thickness will reduce damage and corrosion
Additional Information

Inspectors

Field Crews