Bridge Preservation
Corrosion Mitigation Option in Concrete Repair Systems

September 29, 2010
Northeast Bridge Preservation Partnership Meeting
TSP-2
TODAY WE WILL DISCUSS

- Corrosion of Bridge Decks
- Surface Applied Corrosion Inhibitors
- Advances in Surface Applied Corrosion Inhibitors
- Extension of Service Life of Bridge Decks using Advanced Corrosion Mitigation Technology
The entire process can be interfered with if a link is broken.

Corrosion is like a chain.

Water + Oxygen

Concrete

Reinforcing

Passive layer

Initiator

Fe$^{+2}$

Anode

Cathode

2 OH$^{-}$
Electrochemical Corrosion Reactions

Reactants → Products

- Fe⁺² + 2Cl⁻ → FeCl₂
- FeCl₂ + H₂O + OH⁻ → Fe(OH)₂ + H⁺ + 2Cl⁻
- 2Fe(OH)₂ + ½O₂ → Fe₂O₃ + 2H₂O anode (rust)
- ½O₂ + H₂O + 2e⁻ → 2 OH⁻ cathode

Electrolyte

Important Takeaways:
- Chlorides are not consumed in the process
- Reinforcing steel acts as both the “Anode” and “Cathode”
- [H⁺] produced drops pH and further deteriorates the passivation layer
- The electrolyte is the ion-rich pore solution in the concrete
- Anode-Cathode reactions occur at the same rate
- Need both oxygen and water to complete the reaction
WHAT IS A SURFACE APPLIED CORROSION INHIBITOR?

- Clear Penetrating Liquid
  - Low Viscosity
  - Low Surface Tension
  - Reactive (Concrete / steel)

- Application
  - Bridge Decks
  - Piles
  - Girders
  - Jersey Barriers

- Spray or Roller Applied
Conventional protection methods may prevent corrosion, but they are not as effective on active corrosion.
Silanes: Made with Different Functionality

- **Alkyltrialkoxy silane**
- **Aminoalkyltrialkoxy silane**
- **Fluoroalkyltrialkoxy silane**

**Silane Molecule**

**Substrate e.g. Concrete**
Based on FHWA Sponsored Research

- 0.47 w/c Concrete Slabs 12” x 12” x 7”
- 5/8 inch Diameter Black Bars
- One Inch Clear Cover
- Two 12 mil Cracks, One Inch Deep
- Cracks Run Along Top Bars
TEST CONDITIONS

- 48 Weeks Cyclic Salt Water Ponding
- 15% NaCl Solution
- Four Days Ponding with Salt Water @ RT
- Three Days Drying at 100°F
- Humidity Maintained at 60% to 80%
Scenario 1: PRESERVATION “New Concrete”

Two 12 mil wide cast-in cracks
RESULTS PRESERVATION “New Concrete”

![Graph showing the current in microamperes over time for untreated and treated concrete. The untreated concrete shows a sharp increase in current, while the treated concrete shows a much lower and more stable current.]
Scenario 2: RESTORATION Existing Corrosion in Concrete
RESULTS
RESTORATION Existing Corrosion in Concrete

The graph illustrates the current (µA) over weeks of salt water exposure. The black line represents the untreated condition, while the blue line represents the inhibitor-treated condition. The graph shows a significant reduction in current for the treated slabs compared to the untreated ones, indicating the effectiveness of the inhibitor in mitigating corrosion.
FHWA SUMMARY
Performance on Cracked Concrete

99% Effective in Preventing Corrosion in New Construction
92% Effective in Reducing Active Corrosion
93% More Effective Than Epoxy Coated Steel
## FHWA Protocol Summary

<table>
<thead>
<tr>
<th></th>
<th>Reduction in Corrosion</th>
<th>Increase in Resistance</th>
<th>Reduction in $\frac{1}{2}$ Cell Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Construction</td>
<td>99%</td>
<td>1090%</td>
<td>71%</td>
</tr>
<tr>
<td>Existing Corrosion</td>
<td>92%</td>
<td>386%</td>
<td>40%</td>
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</table>
## COMPARATIVE DATA
Cracked Specimens

<table>
<thead>
<tr>
<th>Material</th>
<th>Corrosion Rate (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Bars</td>
<td>4053</td>
</tr>
<tr>
<td>Epoxy, 0.004% damage</td>
<td>325</td>
</tr>
<tr>
<td>Epoxy, 0.5% damage</td>
<td>971</td>
</tr>
<tr>
<td>Copper-clad</td>
<td>111</td>
</tr>
<tr>
<td>316 SS</td>
<td>5</td>
</tr>
<tr>
<td>ORGANOSILANE CORROSION INHIBITORS</td>
<td>58</td>
</tr>
</tbody>
</table>
CASE HISTORY

Measurement of a Corrosion Inhibitor Through Online Monitoring

M. Rechler, SCK Swiss Society for Corrosion Protection, Zürich, Switzerland
Y. Schlegel, Concolor AG, Cham, Switzerland
S. Gerber, Degussa AG, Hanau, Germany

Protecting Steel in Concrete

The combination of steel and concrete provides ideal corrosion protection for steel, since the alkalinity of the concrete in combination with water and oxygen cause the formation of a thin protective oxide film on the steel surface (Figure 1(a)). This passive film decreases the corrosion rate of steel to virtually zero and increases the durability of steel-reinforced concrete structures to more than 100 years. It is well known that such natural corrosion protection of steel can be compromised by chlorides and other substances that penetrate into the concrete and diffuse to the steel surface (Figure 1(b)). In this case, significant corrosion may occur, causing decreased load capacity in the structure. Under certain conditions, corrosion rates of up to 0.7 mm/y may occur.

Chlorides, often originating from deicing salts, have caused significant corrosion damage on reinforced concrete structures. Also, carbonation—the reaction of carbon dioxide (CO₂) with concrete—may decrease the alkalinity of the concrete and activate corrosion.

Typically, repair for such corrosion involves the removal of the carbonated or chloride-contaminated concrete, followed...
PERFORMANCE
Field Evaluation Silane Based Inhibitor

Corrosion Current measured
Corrosion Potential measured

mass loss [mg]

Jan/1 May/1 Sep/1 Jan/1 May/1 Sep/1 Jan/1 May/1
0 50 100 150 200 250 300 350

Corrosion Current measured

Without inhibitor
With inhibitor
This is the nitrogen area of the curve. The admixture contains no amines, while the surface applied Corrosion Inhibitor has aminosilanes. This accounts for the higher intensity of the surface applied inhibitor.
FIELD PERFORMANCE

TEST IT!!!

It is always better to protect than to repair!
FIELD EVALUATION
Dillon Road – Chatham, ON

- July 2009 untreated testing performed by the University of Waterloo, Toronto
  - Corrosion rates were low although evidence of corrosion was apparent
  - A section was then treated with silane based SACI
- September 2009 measurements were taken on both treated and untreated areas
- Where SACI was applied, the resistivity of the concrete deck increased by 180% on average.
The resistivity at each location within the treated surface exceeded the low-to-high values of the untreated surface measurements in nearly all cases.
The vast majority of the locations show an increase in the resistivity of the concrete deck.

The inverse relationship between resistivity and corrosion rate provides excellent insight into the effectiveness of silane based SACI.
Untreated areas increased by 0.58 µA/cm².

The treated areas demonstrated virtually no change at all.

The corrosion inhibiting properties of silane based SACI had a significant impact on the corrosion rate in a relatively short period of time.
WHAT TO LOOK FOR…

- Proven Performance History
  - Lab
  - Field
- Compatibility
  - Overlays
  - Concrete Repair
- Ask: What does this do for me……
Extension of Service Life Due to SACI Treatment

Based on concrete cover of 1” average and diffusion data from concrete
Estimated Retreat Times for SACI

Chloride Ion Content, ppm

Corrosion Rate in microA/sq. cm