Electrochemical Treatments to Significantly Extend the Service Life of Reinforced Concrete Structures

Presented by
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Outline

• Corrosion basics
• What are electrochemical treatments and how do they work?
• Project case histories
  – I-480 – Omaha, Nebraska – Electrochemical chloride extraction
  – University of Chicago – Re-alkalization
Corrosion

- Electrochemical reaction
- Requires
  - Moisture
  - Electrolyte – concrete
  - Metallic path – steel
- Anode
  - Where rust is formed
- Cathode
  - No section loss
Corrosion of Reinforced Concrete

- Concrete is naturally alkaline
  - pH of about 13
- Steel is naturally passive at this alkalinity
  - Formation of passive layer
- Passive layer can be destroyed by;
  - Chlorides
  - Carbonation
Chloride Induced

• Chloride ions diffuse into concrete and destroy steel’s passive layer

• Source of chlorides
  – Marine environments
  – De-icing salts
  – Chemical/processing plants
  – Cast into concrete

• Chlorides are not consumed in corrosion reaction, therefore, once threshold concentration reached, corrosion can occur unabated
Carbonation

• Carbon dioxide permeates into concrete
• Reduces pH of concrete
  – CO2 reacts with free lime, Ca(OH) 2, resulting in CaCO3 and H2O
• Reduced pH de-passivates steel
• Often seen when
  – Concrete permeability is high
  – Industrial sites
  – Very old structures – carbonation is a result of time and exposure
CONCRETE PRESERVATION PROCESS

PROBLEM
- Cracks
- Spalls
- Delaminations
- Corrosive Environment
- Water Leakage
- Change of Use
- Deflection
- Hazardous Event
- Life Extension
- Wear

EVALUATION
- Visual Inspection
- Non-Destructive Testing
  - GPR
  - Sonic / Ultrasonic
  - Remnant Magnetism
  - Sounding
  - Corrosion Potentials
  - Corrosion Rate
- Destructive Testing
  - Coring/Strength
  - Petrography
  - Chloride Profile
  - Carbonation
- Structural Monitoring

CAUSE
- Environmental Exposure
  - Corrosive
  - Chemical Attack
  - Fire
- Concrete Problems
  - Shrinkage
  - ASR
  - Freeze/Thaw
  - Permeability
- Other
  - Overloading
  - Change of Use
  - Code Change

REPAIR ANALYSIS
- Owner Criteria
  - Urgency
  - Cost
  - Expectations
  - Service Life
  - Aesthetics
- Engineering Criteria
  - Structural
  - Constructability
  - Environment
  - Safety
- Historical Considerations
- Preservation
  - Reduced Footprint
  - Repurpose
- Sustainability
- Environmental Responsibility

REPAIR STRATEGY
- Concrete Repair Methods
  - Crack Repair
  - Surface Repair
  - Structural Repair
  - Stabilization
  - Shotcrete
  - Strengthening
  - Waterproofing
  - Post-Tension Repair
- Cementitious:
- Calcium Silicate
  - LECA
  - Activated Slag
  - Fume

QUALITY CONTROL
- Demolition
- Surface Preparation
- Dough
- Placing
- Finishing
- Cure
- Curing
- Mortar
- Concrete
- Sand
- Stone
- Pre-Cast
- Structural
-ACI
- AGC
- Quality Control
- QC / QA Plan
- Mock-Ups
- Non-Destructive Testing
  - Sounding
  - Sonic/Ultrasonic
- Destructive Testing
  - Bond Strength
  - Compressive Strength
- Record Keeping
  - Batch Numbers & Bag Weights
  - Verification of Quantities
  - Environmental Conditions
  - Material Testing
  - Other Documentation
- Environmental Monitoring
  - Safety
  - Aesthetics
  - Leakage
- Structural Catastrophe
- Service Life Extension
- Use Dysfunction
- Effects on the Environment
- Preventative Maintenance
- Life Cycle Costing
- Rebuild

ARE REPAIRS REQUIRED?

YES

REPAIR / PRESERVATION CONSIDERATIONS
- Safety
- Aesthetics
- Leakage
- Structural
- Service Life
- Use Dysfunction
- Effects on the Environment
- Preventative Maintenance
Electrochemical Chloride Extraction
Electrochemical Chloride Extraction

• Application of temporary impressed current to draw chlorides out of concrete and repassivate the steel.
• Addresses the root cause of chloride induced corrosion
• Chloride levels in concrete are significantly reduced by ECE
• Alkalinity is increased at the level of the steel
  – Increases the chloride concentration required to reinitiate corrosion
• Reinforcing steel is returned to a passive, non-corroding state
  – For as long as chlorides can be kept from the steel
DC Power Source

Concrete

Temporary Anode

Conductive Media

Reinforcement

Cl⁻
DC Power Source

Concrete

Reinforcement

Cl

OH⁻
I-480 Omaha

- Rehabilitation to I—480 included deck replacement and substructure rehabilitation
- ECE completed on hammer head piers in 2002
I-480 Omaha
Chloride Concentration (lbs per yd³ of concrete)

<table>
<thead>
<tr>
<th>Sample Depth (in)</th>
<th>Percent Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>0&quot;-1&quot;</td>
<td>66%</td>
</tr>
<tr>
<td>1&quot;-2&quot;</td>
<td>76%</td>
</tr>
<tr>
<td>2&quot;-3&quot;</td>
<td>80%</td>
</tr>
</tbody>
</table>

Before ECE

After ECE
Re-Alkalization
Anode Electrolyte

+ve

Electrolyte

Concrete

-ve

Reinforcement
Anode Electrolyte Reinforcement

Concrete

Na$_2$CO$_3$ & NaHCO$_3$
University of Chicago
University Hall Façade Repair

- Corrosion deterioration occurring due to carbonation of the concrete
- Re-alkalization conducted to façade
  - 72,300 ft² of concrete surface area
  - Completed spring of 2018
Prior to Treatment
Temporary Anode
Connection to Reinforcement
Post Treatment
Post Treatment
Sustainability I-480

• 6,700 yd$^3$ of concrete preserved prevents
  – 6,530 pounds of nitrous oxides
  – 3,663 tons of carbon dioxide
    • Equivalent to annual emissions of about 833 people.
  – 13,191 tons of natural resources
  – Potable water to fulfill the daily needs of 1,695 people,
  – Waste generation 15,975 tons
  – Heat to boil 20 Olympic-sized swimming pools.
Sustainability University of Chicago

- 1,300 yd$^3$ of concrete preserved prevents
  - 1,267 pounds of nitrous oxides
  - 711 tons of carbon dioxide
    - Equivalent to annual emissions of about 162 people.
  - 2,559 tons of natural resources
  - Potable water to fulfill the daily needs of 329 people,
  - Waste generation 2,633 tons
  - Heat to boil 4 Olympic-sized swimming pools.
• ICRI
  – 510.1-2013 – Electrochemical Techniques to Mitigate the Corrosion of Steel

• NACE
  – SP 0390 – Maintenance and Rehabilitation Considerations for Corrosion Control of Atmospherically Exposed Existing Steel-Reinforced Concrete Structures
  – SP 0107 – Electrochemical Realalkalization and Chloride Extraction for Reinforced Concrete

• FHWA
  – Bridge Preservation Guide
  – Long-Term Effects of Electrochemical Chloride Extraction on Laboratory Specimens and Concrete Bridge Components FHWA-HRT-10-069
  – Several other SHRP studies on ECE and Realalkalization

• ACI
  – 222.3R-03 - Design and Construction Practices to Mitigate Corrosion of Reinforcement in Concrete Structures
Thank you.
Questions?