Corrosion Issues for Port Facilities

Presented by
Brian Pailes, Ph.D., P.E., NACE CP-3
Senior Project Manager
Vector Corrosion Services
Outline

• Corrosion background
  • How and why does it happen

• Reinforced concrete structures
  • Deterioration process
  • Special considerations

• Steel structures
  • Deterioration process

• Corrosion mitigation solutions
  • Galvanic and impressed current cathodic protection
Corrosion Background
ASCE Report Card (2017)

• Port Infrastructure
  • C+

• Inland waterways
  • D

• Funding Provided $22 Billion USD
• Investment Needed $37 Billion USD
• Deficit of $15 Billion USD
NACE Cost of Corrosion (2002)

• Infrastructure
  • $22.6 Billion USD
  • Waterways and Ports
    • $0.3 Billion USD

• Transportation
  • $29.7 Billion USD
  • Ships
    • $2.2 Billion USD
Corrosion

- Electrochemical reaction
- Requires
  - Moisture
  - Electrolyte – water or concrete
  - Metallic path – steel

- Anode
  - Where rust is formed
- Cathode
  - No section loss
Corrosion Macro-Cell

Cathode

Anode
Reinforced Concrete Structures
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
Chloride Concentration Threshold

- Generally accepted chloride thresholds
  - 350 ppm of \textit{concrete}
  - 0.035\% by mass of \textit{concrete}
  - 1.5 lbs per cubic yard of \textit{concrete}
  - 3000 ppm by mass of \textit{cement}
  - 0.3\% by mass of \textit{cement}

![Chloride Concentration with Depth](chart.png)
Carbonation

- Carbon dioxide permeates into concrete
- Reduces pH of concrete
  - $\text{CO}_2$ reacts with free lime, $\text{Ca(OH)}_2$, resulting in $\text{CaCO}_3$ and $\text{H}_2\text{O}$
- 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
Corrosion Induced Damage

- Damage resulting from
  - Metal section loss and
  - Formation of iron oxide (rust)
  - Expansive properties of iron oxide create tensile stresses in concrete
  - Leads to cracking, delamination, and eventual spalling
Corrosion Induced Damage

• Conventional mild reinforcing bar
  • In most cases loss of steel section not primary concern
  • Damage to concrete becomes significant and observable prior to severe section loss

• High strength steel
  • Minor section loss can have significant effect on strength
  • Can have significant section loss without significant concrete damage
Patch Accelerated Corrosion

Chloride Contaminated Concrete

$\text{Fe} \rightarrow \text{Fe}^{2+} + 2e^-$

$\text{Fe}^{2+} + 2\text{Cl}^- \rightarrow \text{FeCl}_2$

$\text{FeCl}_2 + 2\text{OH}^- \rightarrow \text{Fe(OH)}_2 + 2\text{Cl}^-$

$2\text{Fe(OH)}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{Fe}_2\text{O}_3 + 2\text{H}_2\text{O}$

Chloride-Free Patch

$\frac{1}{2}\text{O}_2 + \text{H}_2\text{O} + 2e^- \rightarrow 2\text{OH}^-$

$2\text{OH}^- \rightarrow \frac{1}{2}\text{O}_2 + \text{H}_2\text{O} + 2e^-$

Anode

Cathode
Steel Structures
Steel Structures

• Directly exposed to environment
• Primary factors affecting corrosion
  • pH
  • Temperature
  • Moisture
    • Wetting drying cycles
  • Ion content
    • Chlorides, sulfates, etc.
  • Oxygen Content
  • Water Velocity

Source – techknowserv.com
Dissimilar Metals – Galvanic Corrosion

- Dissimilar metals in direct electrical contact with each other will result in the less noble metal corroding
- Principal used in galvanic cathodic protection to protect a metal while sacrificing another metal.

<table>
<thead>
<tr>
<th>Half-cell</th>
<th>Metal</th>
<th>Standard Electrode Potential (E_0) (volts) vs. SHE*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au/Au(^{+++})</td>
<td>Gold</td>
<td>+1.498</td>
</tr>
<tr>
<td>Pt/Pt(^{++})</td>
<td>Platinum</td>
<td>+1.200 Less Noble</td>
</tr>
<tr>
<td>Cu/Cu(^{++})</td>
<td>Copper</td>
<td>+0.345 Metal</td>
</tr>
<tr>
<td>H(_2)/2H(^+)</td>
<td>Hydrogen</td>
<td>0.000</td>
</tr>
<tr>
<td>Pb/Pb(^{++})</td>
<td>Lead</td>
<td>−0.126</td>
</tr>
<tr>
<td>Ni/Ni(^{+++})</td>
<td>Nickel</td>
<td>−0.250</td>
</tr>
<tr>
<td>Fe/Fe(^{++})</td>
<td>Iron</td>
<td>−0.440</td>
</tr>
<tr>
<td>Zn/Zn(^{++})</td>
<td>Zinc</td>
<td>−0.763</td>
</tr>
<tr>
<td>Al/Al(^{+++})</td>
<td>Aluminum</td>
<td>−1.662</td>
</tr>
<tr>
<td>Mg/Mg(^{++})</td>
<td>Magnesium</td>
<td>−2.363</td>
</tr>
</tbody>
</table>

*Standard Hydrogen Electrode
Corrosion Mitigation
Cathodic Protection

• Cathodic protection (CP) is a method of corrosion control through the application of direct current to a metal under protection, forcing it to become a cathode
  • Anode is where rust occur and the cathode is protected from section loss

• Two main types of CP
  • Galvanic
  • Impressed current
Impressed vs Galvanic

• Galvanic
  • Typically very low maintenance
  • Self regulating current output based on environment
    • Current output limited
  • Typically less expensive
    • Not always though
  • Limited life span – between 10 to 30 years

• Impressed
  • Provides significantly more current
    • Can reduce number of anodes
  • Long life span
    • Can be over 50 years depending on application
  • Requires maintenance
Galvanic CP

• Uses the concept of dissimilar metal corrosion in order to protect steel reinforcing.
  • Anode types;
    • Zinc
    • Aluminum
    • Magnesium
  • All are less noble than steel
Steel Sheet Pile Construction

Anodes

Soil Anodes

ELEVATION (VARIES)

SCOUR STONE

CONCRETE CAP

LANDSCAPE CORRIDOR

PUBLIC ACCESS PROMENADE

MARINA PATRON PROMENADE

MARINA PATRON PROMENADE

SERVICE CORRIDOR (TBD)

STEEL TIEROD AT EVERY PIPE

COMBINATION WALL

VARIABILITY, REFER TO PLAN

-2.0m

-1.5m

+4.0m

+4.25m

+4.00m

+1.6m

+1.5m

CONCRETE CAP

VECTOR CORROSION SERVICES
Sheet Pile Galvanic CP
Piles

• Jacketing is the most common repair strategy
  • Critical to have cathodic protection in jackets
  • FDOT discovered accelerated corrosion in jackets without CP

Galvanic CP – Pile Jackets

- Several different types of jackets
- Dependent on the environment
  - Chloride content of water
  - Tidal range
Jacket Installation
Zinc Mesh – Tidal Jacket

• Used only in salt water environments where most of the pile length is within the tidal region
  • Requires constant exposure to salt water to keep zinc active
Above Tidal Jacket

- Commonly referred to as “wicking” jackets
- Zinc wrapped in absorbent fabric
  - Draw salt water above tidal region to keep zinc active
- Still uses a bulk anode below the water line
Alkali Activated Jackets

- Can be used in salt water, above tidal, brackish, freshwater, or non marine environments
  - Uses pH of mortar to activate zinc instead of salt water
Jacket Research

- VCS in partnership with Vector Corrosion Technologies and Florida Department of Transportation have been trialing new jacket methods on a bridge in the gulf.
Zinc Mesh
Wicking Jackets

[Graph showing data over time with various labels such as B2 P1 (North Top), B2 P1 (West Bottom), B2 P1 Bulk, B2 P2 (East Top), B2 P2 (West Bottom), and B2 P2 Bulk.]
Comparison

Graph showing data comparison with dates from June 29, 2016, to November 11, 2017. The graph includes lines for Mesh, Wicking, and Alkali.
Metalizing
Both Galvanic and Impressed
Impressed Current

• Steel elements
  • Bulk anodes
  • Submerged or buried applications

• Concrete elements
  • Ribbon anodes
  • Discrete rode anodes
Power Source
Questions