Corrosion Webinar Series
Intro to Corrosion & Corrosion Control

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U.S. Department of the Interior
Bureau of Reclamation
Intro to Corrosion & Corrosion Control

- Why do we care about it?
- What is it?
- What types are found on Reclamation structures?
- How can we prevent it?
  - Protective coatings
  - Cathodic protection
Why is Corrosion Important?

First and foremost:

Public Safety!

June 28, 1983: Mianus River Bridge, Greenwich, CT (TIME photo archive)

July 17, 1995, Folsom Dam, Spillway Gate No. 3

April 28, 1988, Aloha Airlines 737
Why is Corrosion Important?

Economic Cost

Global Cost of Corrosion: $2.5 trillion USD

Total Annual Estimated Direct Cost of Corrosion in USA:
• $451 billion
• 2.7% of the country’s GDP

15-35% of total cost could be saved via corrosion control!
Why is Corrosion Important?

Loss of Utility / Capacity

Reclamation assets...

• Deliver water to over 31 mil. people and 10 mil. acres of farmland.

• Produce 40 billion kilowatt-hours of electricity annually.

July 17, 1995 Folsom Dam Spillway Gate No. 3
What is Corrosion?

…the deterioration of a material and/or its properties caused by adverse reaction with its environment.
The Corrosion Reaction

Reaction between a Metal and an Electrolyte

*oxidation (rusting) of steel in water or soil*

- Seminoe Dam Bulkhead Gates, 2012
- Canyon Ferry Dam Stop Log Guides, 2007
- El Vado Dam Spillway, 1995
Forms of Corrosion

- Uniform or General Attack
- Galvanic Corrosion
- Crevice Corrosion
- Pitting
- Microbially-Induced Corrosion
- Corrosion in Reinforced Concrete
- Intergranular Corrosion
- Dealloying or Selective Leaching
- Erosion Corrosion
- Environmentally-Induced Corrosion
General or Uniform Corrosion

- Uniform over the surface
- Steady and predictable rate
- Greatest metal loss
- Often expected / “allowable”

**Mitigation:**
- Use corrosion-resistant material
- Apply protective coatings
- Apply cathodic protection

El Vado Dam Spillway, 1995
Galvanic Corrosion

- Two dissimilar metals in contact
- One metal corrodes faster
- Basis of galvanic anode cathodic protection

**Mitigation:**
- Use electrochemically similar metals
- Avoid large cathode-to-anode ratios
- Use insulating fittings
- Apply protective coatings
- Apply cathodic protection
### Galvanic Series in Soils and Water

*Typical, as referenced to a Cu/CUSO₄ reference electrode*

<table>
<thead>
<tr>
<th>Noble or Cathodic</th>
<th>Material</th>
<th>Potential (V) (approximate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistant to Corrosion</td>
<td>Gold</td>
<td>+0.20</td>
</tr>
<tr>
<td></td>
<td>Stainless Steel</td>
<td>-0.3 to +0.1</td>
</tr>
<tr>
<td></td>
<td>Copper, Brass, Bronze</td>
<td>-0.2 to -0.3</td>
</tr>
<tr>
<td>Active or Anodic</td>
<td>Mild Steel</td>
<td>-0.5</td>
</tr>
<tr>
<td></td>
<td>Cast Iron</td>
<td>-0.5</td>
</tr>
<tr>
<td></td>
<td>Aluminum Alloy</td>
<td>-1.0</td>
</tr>
<tr>
<td>Easy to Corrode</td>
<td>Zinc</td>
<td>-1.1</td>
</tr>
<tr>
<td></td>
<td>Magnesium</td>
<td>-1.7</td>
</tr>
</tbody>
</table>
Galvanic Corrosion

Mild Steel Anchor Bolts with Stainless Steel Guides

*Protective environment of the concrete/grout* is not enough to prevent corrosion due to the galvanic couple.
Crevice Corrosion

- Intensive localized corrosion within crevices and under coatings

- Mitigation:
  - Avoid designs with crevices (e.g. bolting or riveting, etc.)
  - Use non-absorbent gaskets
  - Design equipment for complete drainage
  - Avoid stagnant, wet deposits
  - Close crevices in lap joints (via welding or caulking)
  - Remove any observed deposits
Avoid Skip Welding! Seal Joints!
Pitting Corrosion

• Localized attack in an otherwise resistant surface
• Often occurs when protective coating breaks down

• Mitigation:
  – Select suitably resistant material (316 vs. 304 SS)
  – Apply protective coating
  – Apply cathodic protection
  – Avoid designs where stagnation, or alternate wetting and drying, can occur in pits
Dealloying or Selective Leaching

• Preferential corrosion of one element from a solid alloy with no appreciable change in appearance
  Example: Graphitic Corrosion (Fe leaches from cast iron, leaving porous low-strength graphite)

• Mitigation:
  – Use a different alloys
  – Apply cathodic protection
  – Apply protective coating

Graphitic corrosion in cast iron gas mains caused several fatal explosion in Allentown, PA, area from 1979-2011.
Graphitic corrosion - not apparent on visual inspection; extent of corrosion could only be realized by tapping with hammer to observe loss in strength due to iron leaching.
Corrosion in Reinforced Concrete

• Corrosion starts.

• Corrosion products take up more room than the steel did.

• Corrosion products impose a stress on the concrete.

• The stress causes the concrete to fracture.
Corrosion products from the steel cause cracking or spalling of the concrete. This exposes more steel and increases vulnerability.
Corrosion in Reinforced Concrete

Mitigation:

• Use high quality concrete mix
• Increase cover depth
• Ensure proper curing of concrete
• Apply coating to surface of concrete
• Apply cathodic protection
• Use galvanized or stainless steel
Corrosion Mitigation Methods

Materials Selection
Protective Coatings
Cathodic Protection
How Corrosion Control Works

Corrosion
- Anodic and cathodic regions exposed to an electrolyte react with each other resulting in corrosion

Four things needed for corrosion:
- Anode – the corroding metal
- Cathode – the metal that doesn’t corrode
- Metallic Return Path – ex. the steel pipe
- Electrolyte – the soil or water
How Corrosion Control Works

Mitigation - Coating

• Primary defense against corrosion acting as a barrier between metal and electrolyte

• May contain defects where corrosion can occur

Four things needed for corrosion:

• Anode – the corroding metal
• Cathode – the metal that doesn’t corrode
• Metallic Return Path – ex. the steel pipe
• Electrolyte – the soil or water

WATER OR SOIL

-0.5 V

-0.7 V

cathode

anode

STEEL STRUCTURE
How Corrosion Control Works

Mitigation - Cathodic Protection
- Control the corrosion by making the structure the cathode
- This takes a huge amount of current for a bare structure - not economical.

Four things needed for corrosion:
- **Anode** – the corroding metal
- **Cathode** – the metal that doesn’t corrode
- **Metallic Return Path** – ex. the steel pipe
- **Electrolyte** – the soil or water

![Diagram showing cathodic protection](image-url)
How Corrosion Control Works

Mitigation - Coating with CP

• Coating - provides barrier and limits amount of bare steel
• CP - protects exposed steel only at defects in the coating

Four things needed for corrosion:

• Anode – the corroding metal
• Cathode – the metal that doesn’t corrode
• Metallic Return Path – ex. the steel pipe
• Electrolyte – the soil or water

Diagram:
- Anode labeled as "anode" with a voltage "V" connecting to cathode labeled as "cathode".
- Electrolyte labeled as "WATER OR SOIL" and "STEEL STRUCTURE".
A coating is the primary defense against corrosion.

Cathodic protection works with the coating to protect the structure at defects in the coating.

The most effective corrosion protection system for buried and submerged structures involves a good bonded coating and cathodic protection.
Protective Coatings
Why Use Protective Coatings?

“The total annual U.S. cost for organic and metallic protective coatings is $108.6 billion. 50% of all corrosion costs are preventable, and approximately 85% of these are in the area of coatings.” -NACE website, 2013

Protective coatings (including paint) are the primary means employed by Reclamation to control corrosion.

The most important aspect to achieving a good coating is proper surface preparation.
Components of a Coatings Job

Cost Breakdown:
- Materials - 10-20%
- Surface Prep - 40-50%
- Application - 30-40%

However, the majority of the success of a coating job depends on … surface preparation, surface preparation, surface preparation!

Long Coating Service Life
Types of Protective Coatings

Coating = Binder + Pigment/Filler + Solvent/Diluent

- **Barrier** - forms a barrier between metal and electrolyte and electrically isolates metal (most common)
  - Coal Tar Enamel, Polyurethane, Epoxy, Vinyl

- **Sacrificial** - provides galvanic protection to ferrous metal via coating with a more reactive metal
  - Zinc rich coatings, Galvanizing, Metallizing
# Protective Coating Selection

<table>
<thead>
<tr>
<th>Coatings</th>
<th>Service</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy, coal tar epoxy</td>
<td>Immersion, buried</td>
<td>Most common, not UV stable, moderate corrosion protection in immersion, coal tar epoxy and zinc rich primer in marine exposures, novolacs for fuels</td>
</tr>
<tr>
<td>Polyurethanes</td>
<td>Atmospheric</td>
<td>Good UV protection for aliphatic, aromatic used for immersion, some polyurea use in immersion</td>
</tr>
<tr>
<td>Vinyl, lacquers</td>
<td>Impacted immersion</td>
<td>Long term protection in alternating immersion and atmospheric, aluminum topcoat on high-UV areas</td>
</tr>
<tr>
<td>Moisture cured</td>
<td>Atmospheric</td>
<td>Polyurethanes and polysiloxanes; humidity must typically be at least 30% for proper cure</td>
</tr>
<tr>
<td>Alkyd and acrylic</td>
<td>Atmospheric</td>
<td>Silicone alkyd for high heat, acrylic for buildings</td>
</tr>
</tbody>
</table>
Surface Preparation

Definition – The cleaning or treating of metal or any other material surface to ensure the best possible bond between coating and the surface.

✓ Grind sharp edges, irregular surfaces, and pits
✓ Surface Profile - average distance between peaks and valleys
✓ Degree of Cleanliness - absence of soluble salts, oil and grease, blast media, corrosion products, etc.
Surface Preparation Methods

- Hand Tool Cleaning
- Power Tool Cleaning
- Dry Abrasive Blast Cleaning
- Wet Abrasive Blast Cleaning
- Water Jetting
Coating Application

• Follow manufacturers’ technical data sheets for proper application procedures
  – Equipment, air pressures, gun type, mixing proportions, time between coats, surface cleanliness and surface profile, DFT per coat, dry to touch, pot life, etc.

• Use shop application, as opposed to field application, where possible

• Safety Data Sheets
  – Consult for potential hazards and safety precautions
Application Methods

• Brush
• Roller
• Pressure Roller
• Conventional Spray
• High Volume Low Pressure
• Airless
• Air Assisted Airless
• Electrostatic Spray
• Plural Component
• Cartridge Gun
Cathodic Protection
Where will you find CP?

Burial:

- Pipelines
- Tanks/ Tank Bottoms
- Metallic Fittings

GACP, Mesa Verde National Park, 2013

Navajo Nation Municipal Pipeline, 2009
Where will you find CP?

**Immersion:**
- Gates
- Tank Interiors
- Air Chambers
- Pipe Interiors
- Trash Racks
- Fish Screens
- Pumps

Delta-Mendota Canal, February 2013
Nimbus Radial Gate Hoist Ropes, 2010
CP System on Pump Columns in Sump, 1990
Parker Dam Penstock Gates, Dec 2015
Nimbus Radial Gate Hoist Ropes, 2010
Galvanic Anode CP System

- Also known as Sacrificial Anode Cathodic Protection

- This system provides a cathodic protection current by galvanic corrosion or by sacrificing one material to prevent corrosion of the other material

Features:
- Low current requirements
- Typically protect smaller surface areas
- No external power needed
- Low maintenance

Both the structure and the anode must be in contact with the electrolyte (water or soil)

Anodes:
- Soil- Magnesium and Zinc
- Fresh Water- Magnesium
- Salt and Brackish Water- Aluminum
Anode Placement - Burial

Place anodes within right-of-way and at “remote earth” (a point such that the pipe-to-soil resistance is no longer changing much with distance)
Anode Placement - Immersion
Impressed Current CP System

Rectifier

CATHODE

ANODE
Impressed Current CP System

- This system provides a cathodic protection current from an external power source

- A direct current power source forces current to discharge from anodes, through the electrolyte, and onto the structure to be protected

Features:

- High flow of water
- High current requirements
- Can handle large or poorly coated structures

Anodes:

- Graphite, High-Si Cast Iron, Mixed Metal Oxide, Platinum
Corrosion Webinar Series

- **https://www.usbr.gov/tsc/training/training.html**
- **Topics:**
  - Protective Coatings 101
  - Corrosion Control System Construction Projects
  - Cathodic Protection 101
  - Coatings Maintenance Assessments
  - Corrosion Mitigation of Gates
  - Cathodic Protection System Testing
  - Corrosivity Testing and Intro to Cathodic Protection
  - Intro to Corrosion
- **Contact Jessica Torrey to get on the mailing list for webinar announcements**