RECLAMATION

Managing Water in the West

Corrosion Webinar Series

Intro to Corrosion & Corrosion Control

Presented by Mike Walsh

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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

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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

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Why is Corrosion Important?

Economic Cost

Global Cost of Corrosion: $2.5 trillion USD

"IMPACT Study- International Measures of Prevention, Application, and Economics of Corrosion Technology Study," *NACE International*, 2016.

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!

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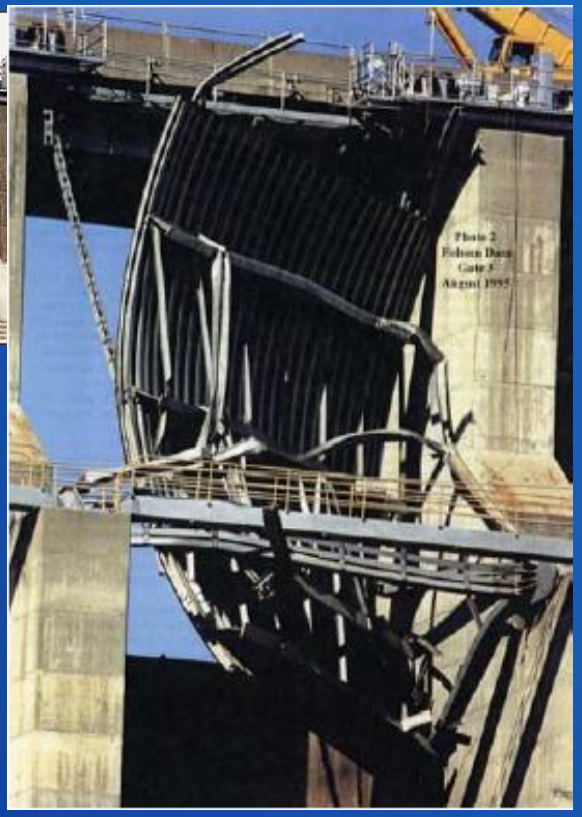
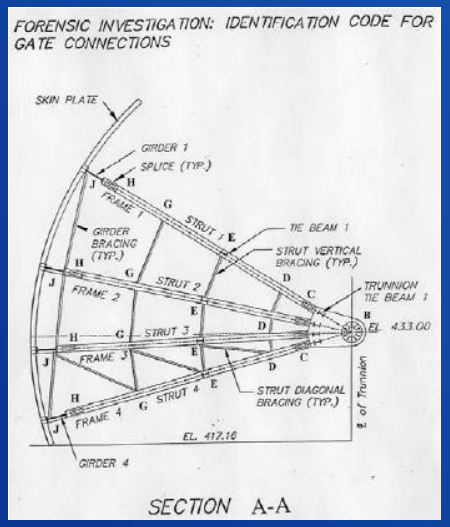
Why is Corrosion Important?

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

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What is Corrosion?

…the deterioration of a material

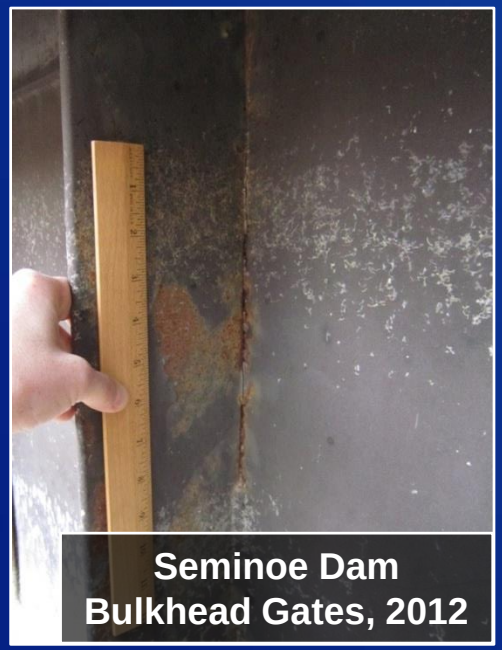
and/or its properties

caused by adverse reaction with its environment.

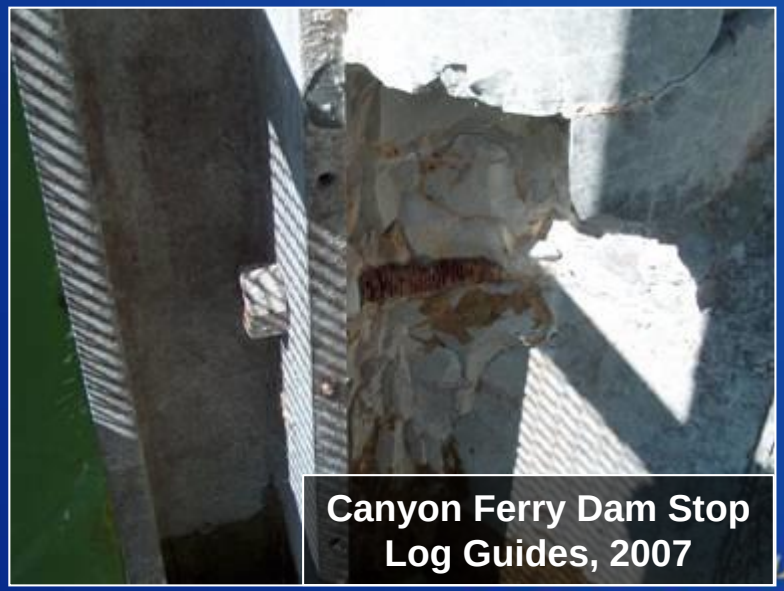
The Corrosion Reaction

Reaction between
a Metal and an Electrolyte

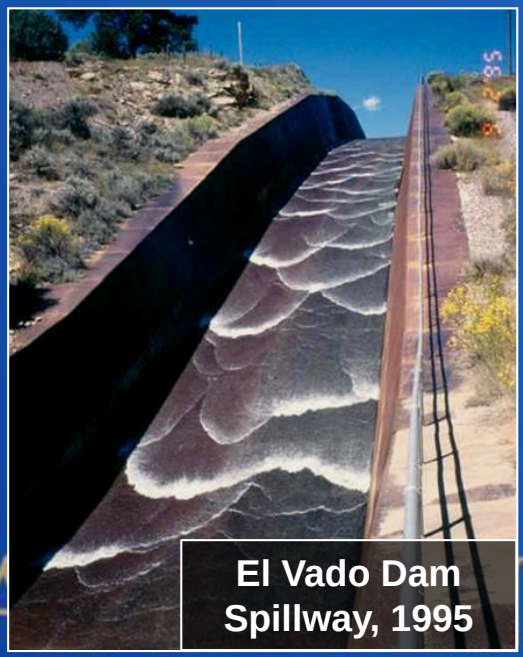
oxidation (rusting) of steel in water or soil



Seminoe Dam Bulkhead Gates, 2012



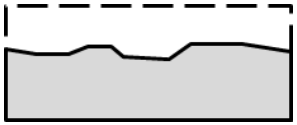
Canyon Ferry Dam Stop Log Guides, 2007

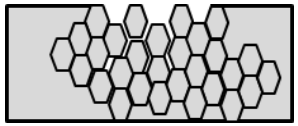


El Vado Dam Spillway, 1995

Forms of Corrosion

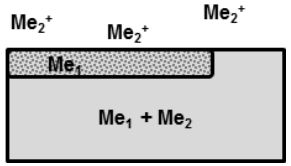
Uniform or General Attack





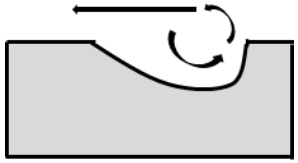
Intergranular Corrosion

Galvanic Corrosion

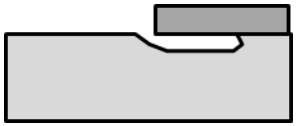


Dealloying or Selective Leaching

Forms of Corrosion

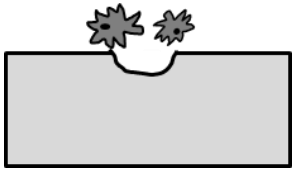


Erosion Corrosion

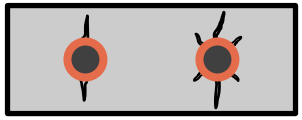


Crevice Corrosion

Environmentally -Induced Corrosion



Microbially-Induced Corrosion



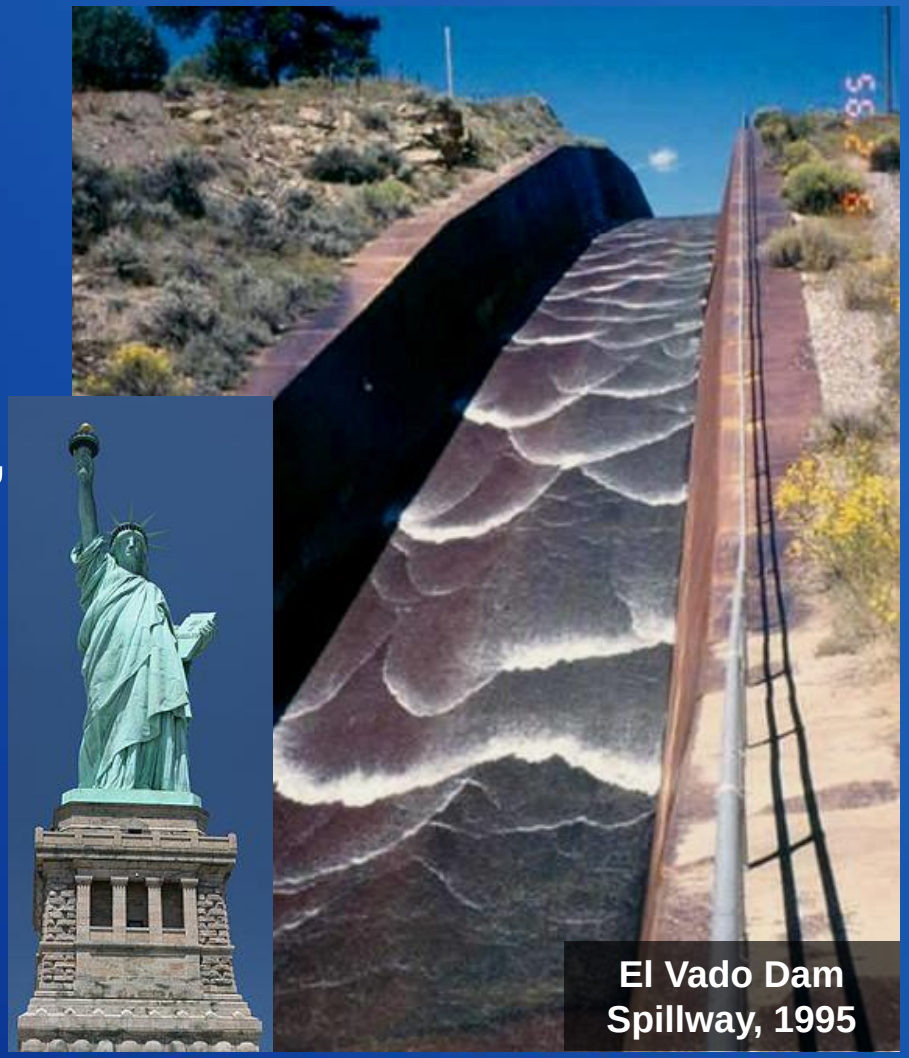
Corrosion in Reinforced Concrete

Pitting

General or Uniform Corrosion

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

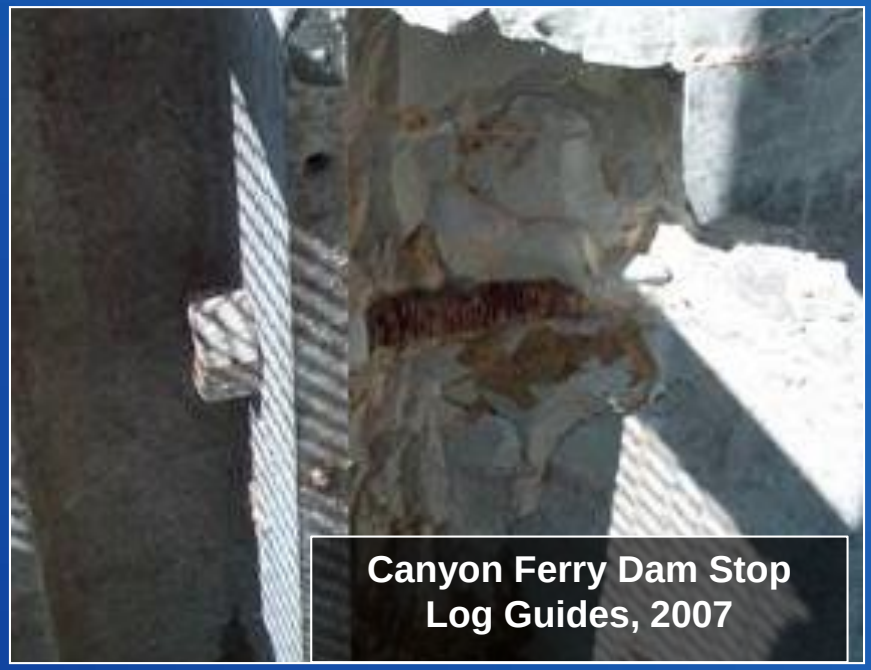
- **Mitigation:**
  - Use corrosion-resistant material
  - Apply protective coatings
  - Apply cathodic protection



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

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Galvanic Series in Soils and Water

*Typical, as referenced to a $Cu/CUSO_4$ reference electrode

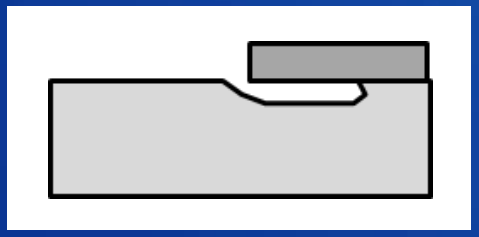
	Material	Potential (V) (approximate)
Resistant to Corrosion ↑ Noble or Cathodic	Gold	+0.20
	Stainless Steel	-0.3 to +0.1
	Copper, Brass, Bronze	- 0.2 to -0.3
	Mild Steel	-0.5
Active or Anodic	Cast Iron	-0.5
	Aluminum Alloy	-1.0
	Zinc	-1.1
↓ Easy to Corrode	Magnesium	-1.7

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.**

Canyon Ferry Dam Stop Log Guides, 2007

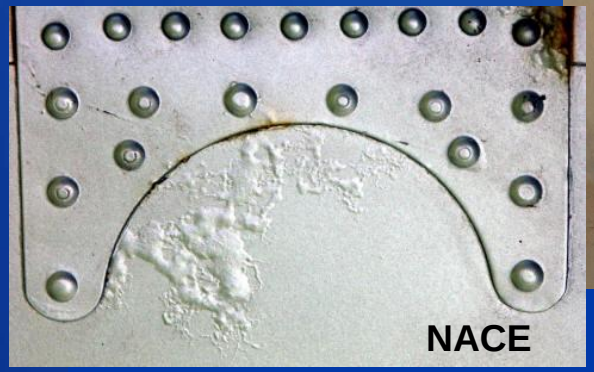


Crevice Corrosion

- **Intensive localized corrosion within crevices and under coatings**

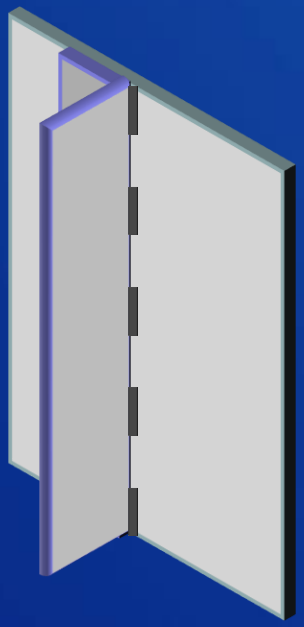
- **Mitigation:**
  - –Avoid designs with crevices
    (e.g. bolting or riveting, etc.)
  - –Use non-absorbent gaskets
  - –Design equipment for complete drainage
  - –Avoid stagnant, wet deposits
  - –Close crevices in lap joints
    (via welding or caulking)
  - –Remove any observed deposits

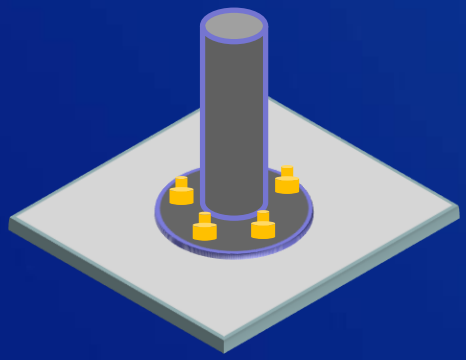
Palo Verde Diversion Dam
Radial Gates, 2013

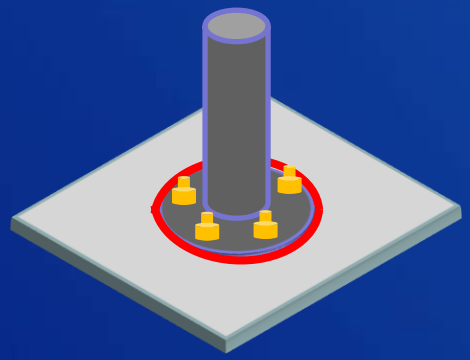


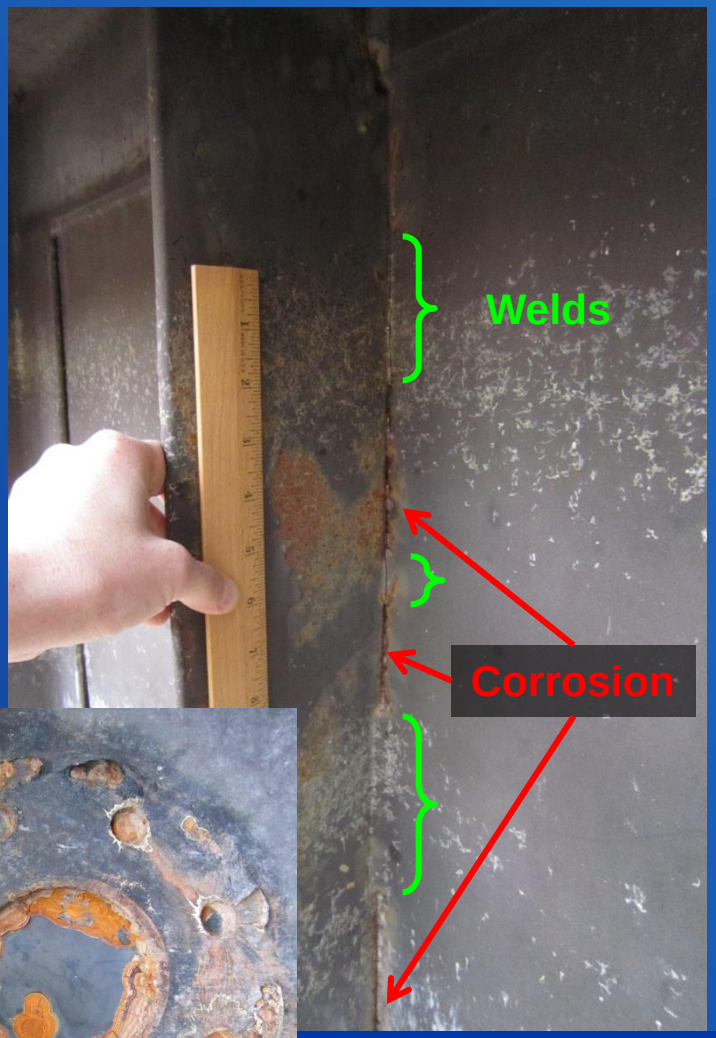
NACE

Avoid Skip Welding! Seal Joints!





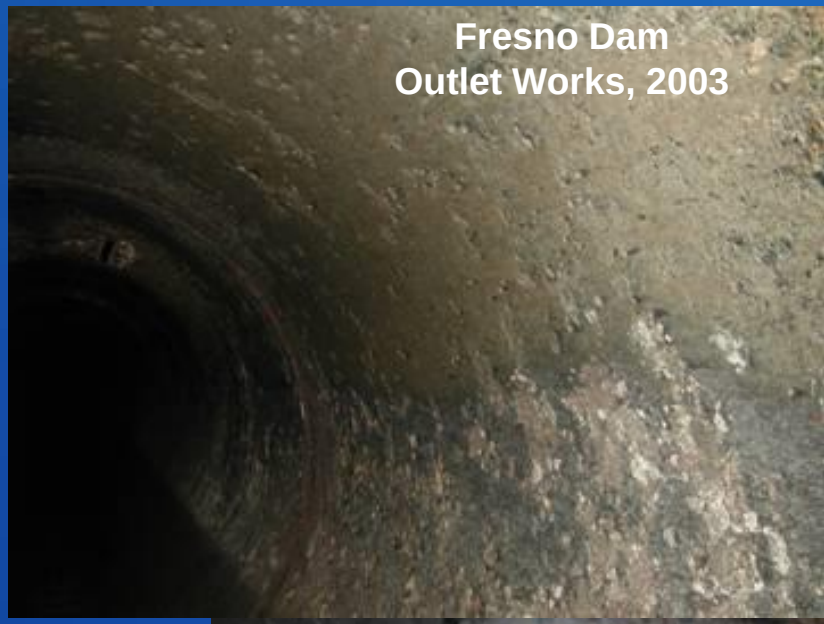




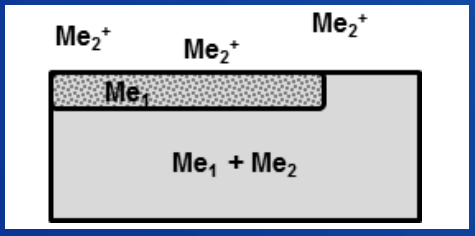
Seminoe Dam Bulkhead Gates, 2012

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

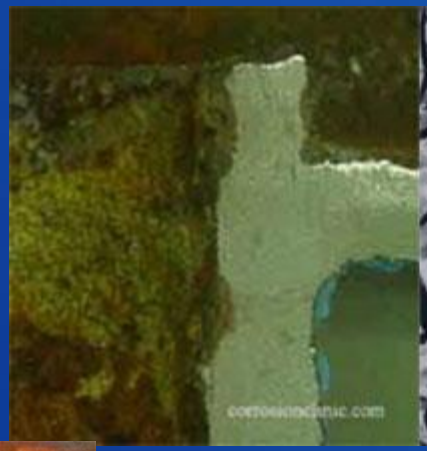


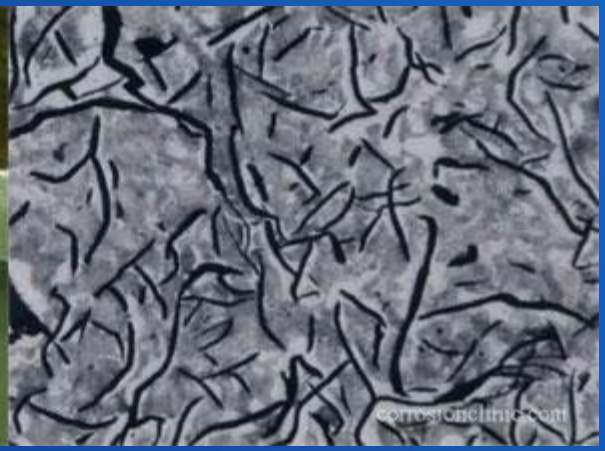
Dealloying or Selective Leaching

- **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.

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Denver Federal Center, 2004

Fountain Valley Conduit, 2007

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

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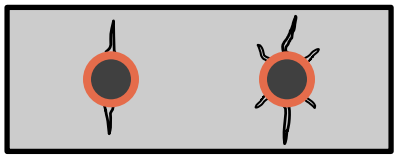
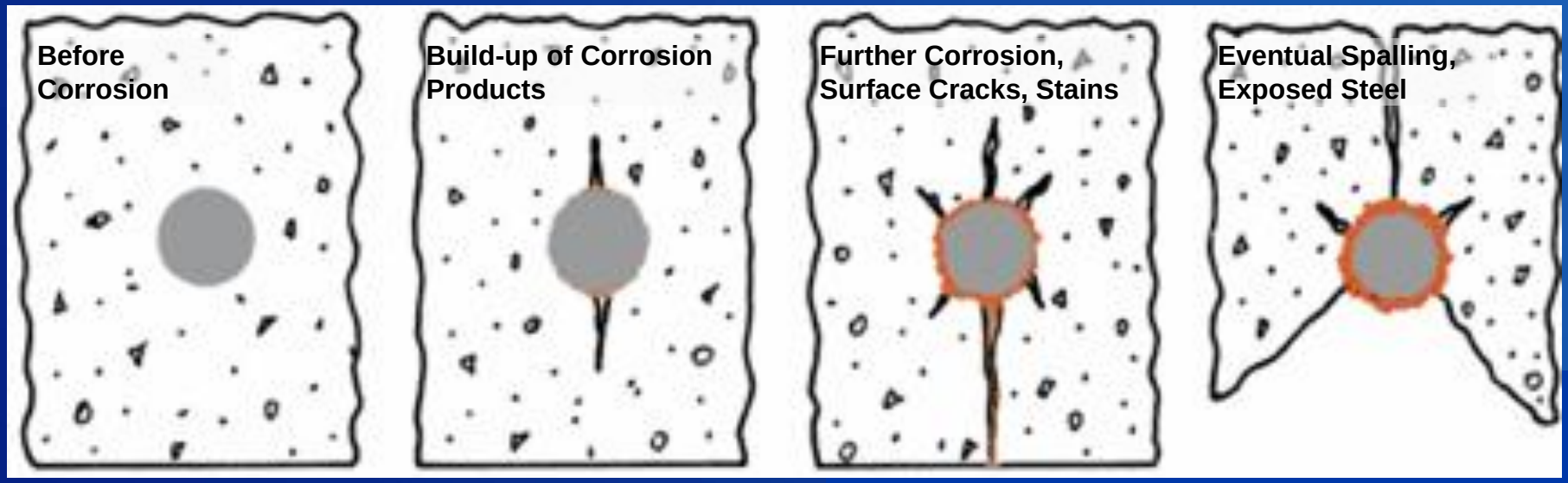
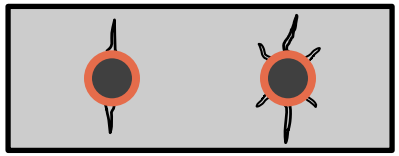


Corrosion in Reinforced Concrete

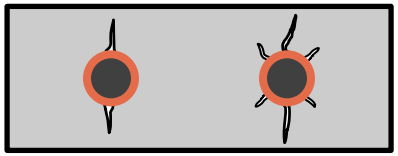
- Corrosion starts.
- Corrosion products take up more room than the steel did.
- Corrosion products impose a stress on the concrete.
- The stress causes the concrete to fracture.





Corrosion in Reinforced Concrete

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

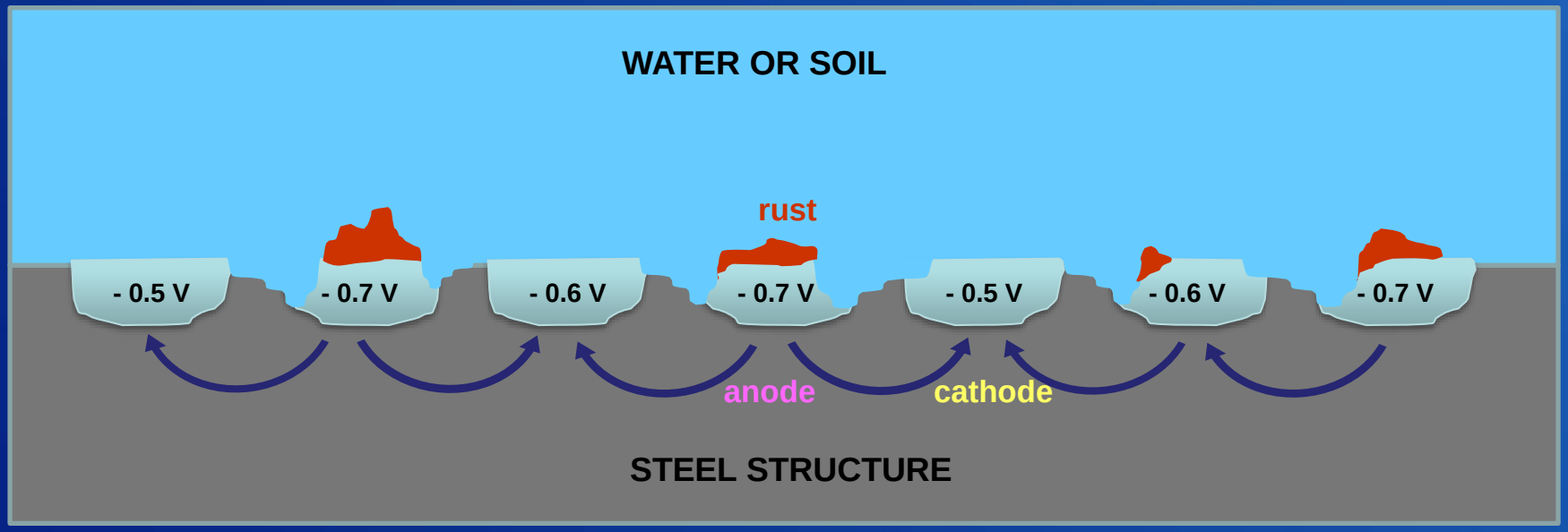
How Corrosion Control Works

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*



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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*
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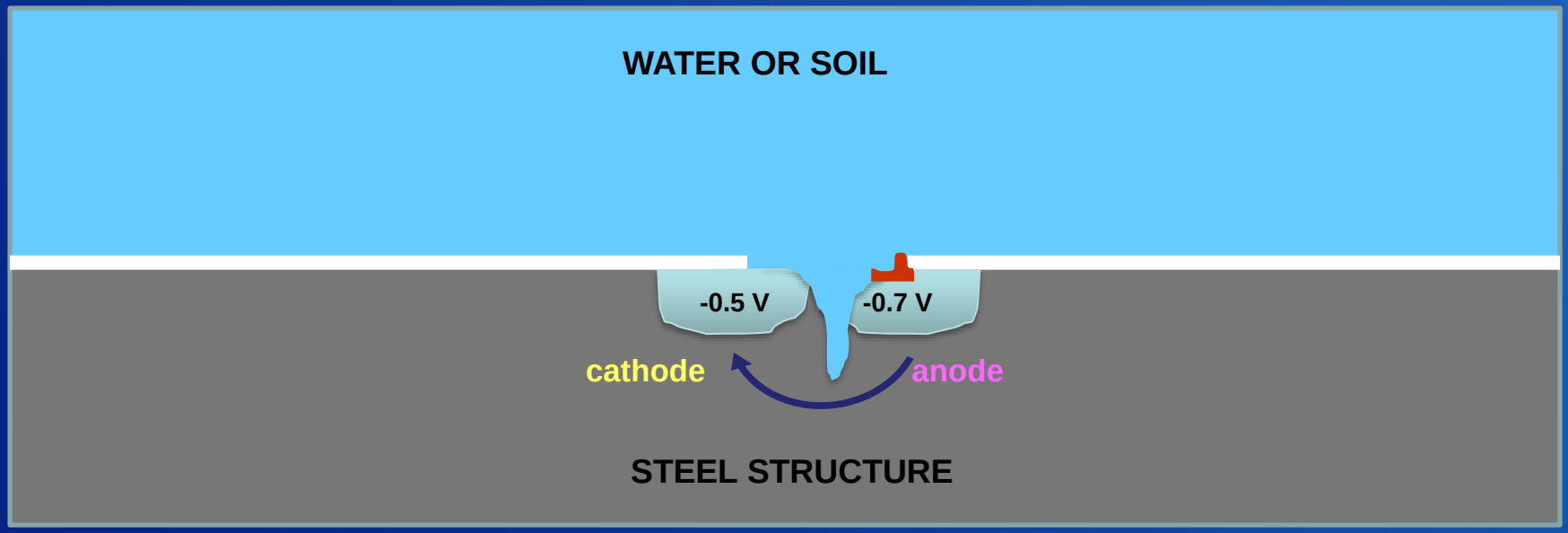

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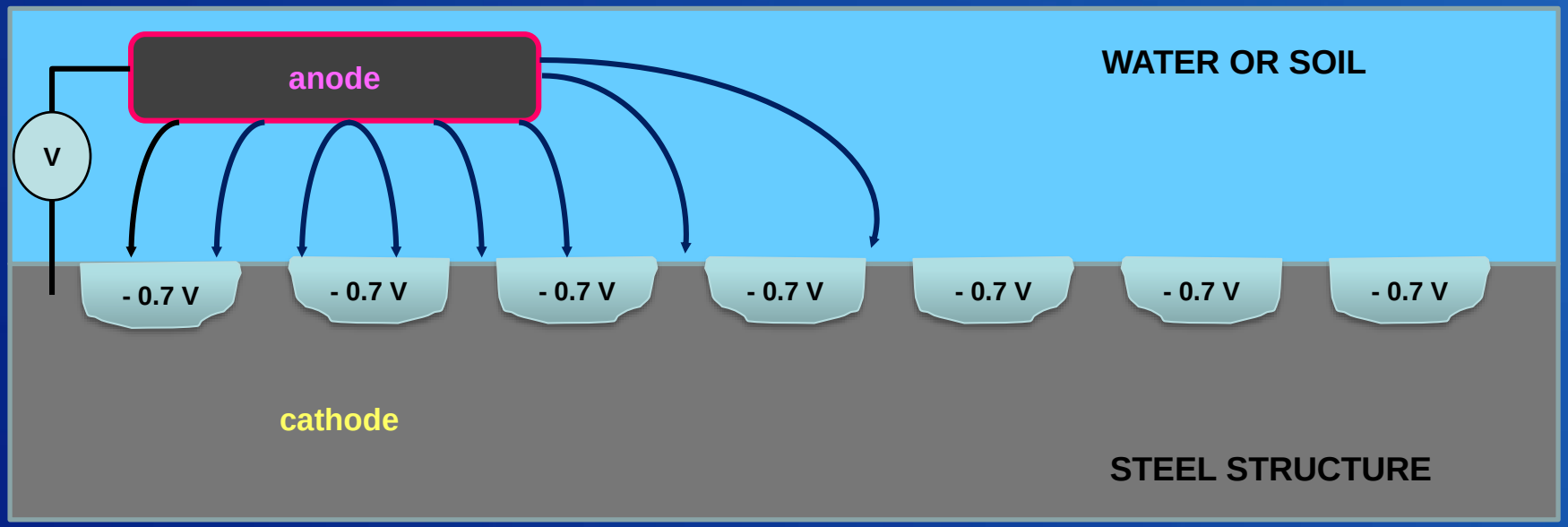
How Corrosion Control Works

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*



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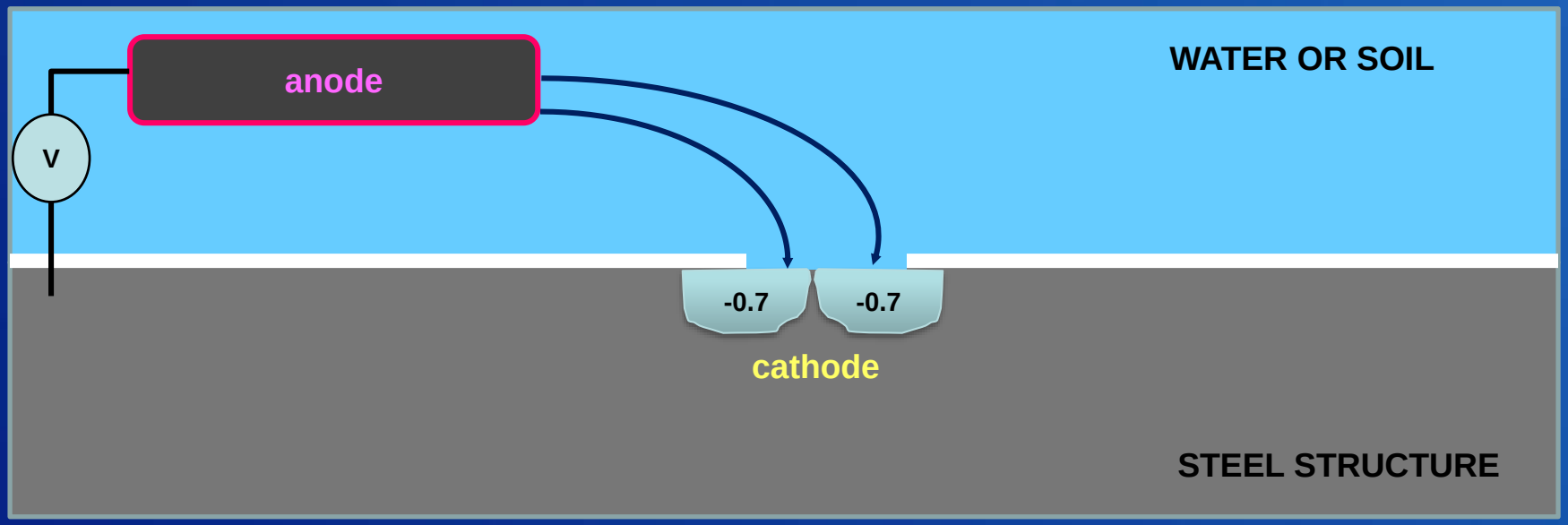
How Corrosion Control Works

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*



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Big Picture

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

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Why Use Protective Coatings?

Pentstock, Shosone PP, 6/2007
(Operated by Exel Energy)

"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.

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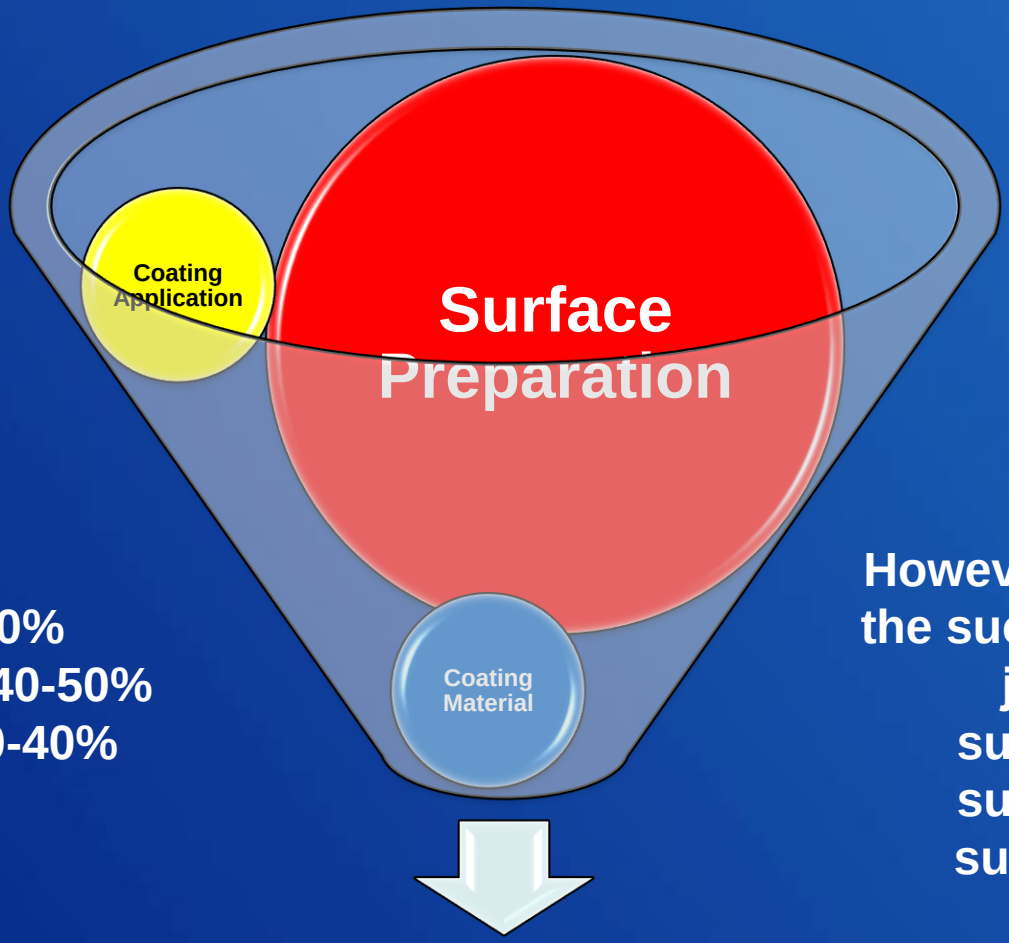
Components of a Coatings Job



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

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Types of Protective Coatings

Coating = Binder + Pigment/Filler + Solvent/Diluent

polymer solid particles liquid

- **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

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

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

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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**

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Application Methods

- Brush
- Roller
- Pressure Roller
- Conventional Spray
- High Volume Low Pressure
- Airless
- Air Assisted Airless
- Electrostatic Spray
- Plural Component
- Cartridge Gun

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Cathodic Protection

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Where will you find CP?

Burial:

- Pipelines
- Tanks/ Tank Bottoms
- Metallic Fittings

Navajo Nation Municipal Pipeline, 2009

GACP, Mesa Verde National Park, 2013

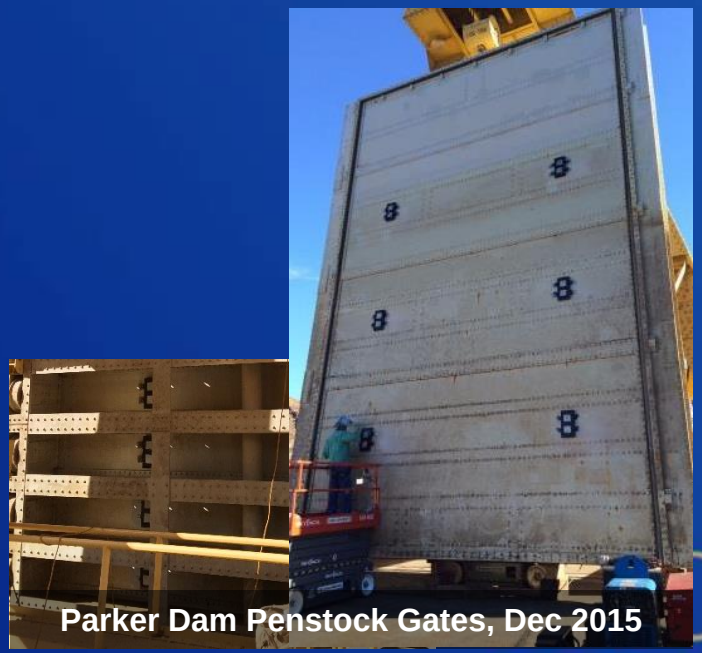
Where will you find CP?

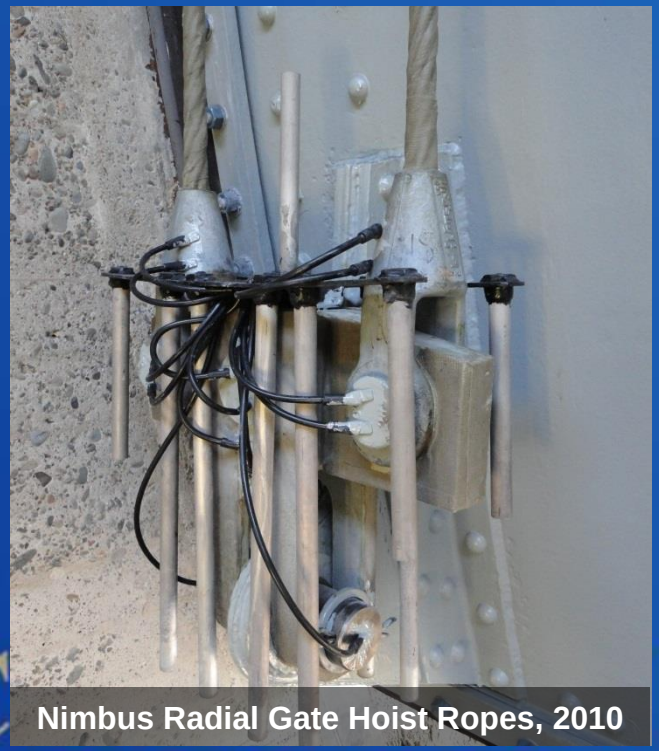
Immersion:

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

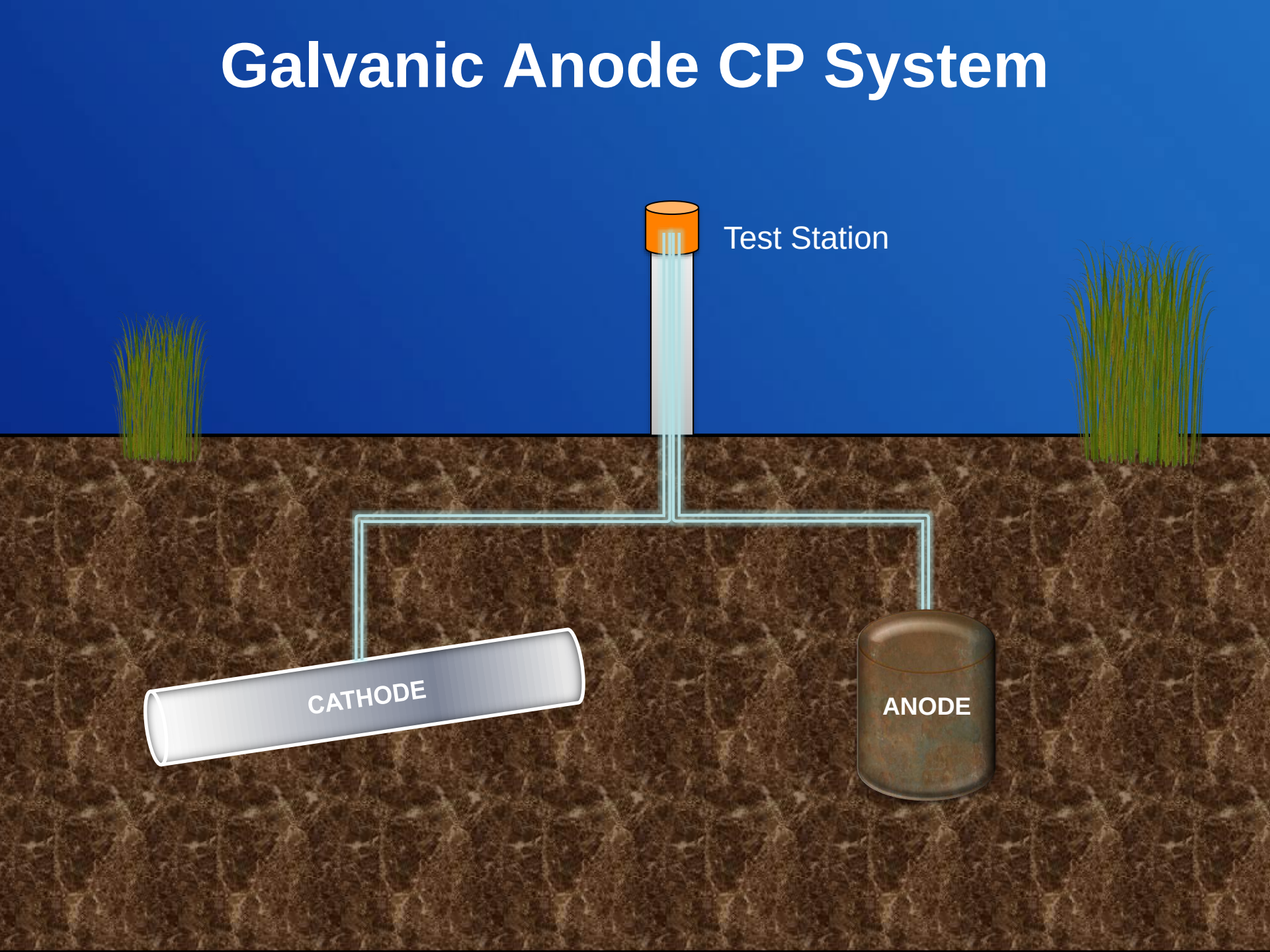

Delta-Mendota Canal, February 2013


CP System on Pump Columns in Sump, 1990


Parker Dam Penstock Gates, Dec 2015


Nimbus Radial Gate Hoist Ropes, 2010

Galvanic Anode CP System



Galvanic Anode CP System


Palo Verde Diversion Dam Radial Gate, January 2013

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

Features:

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

New vs. Old Mg Anode

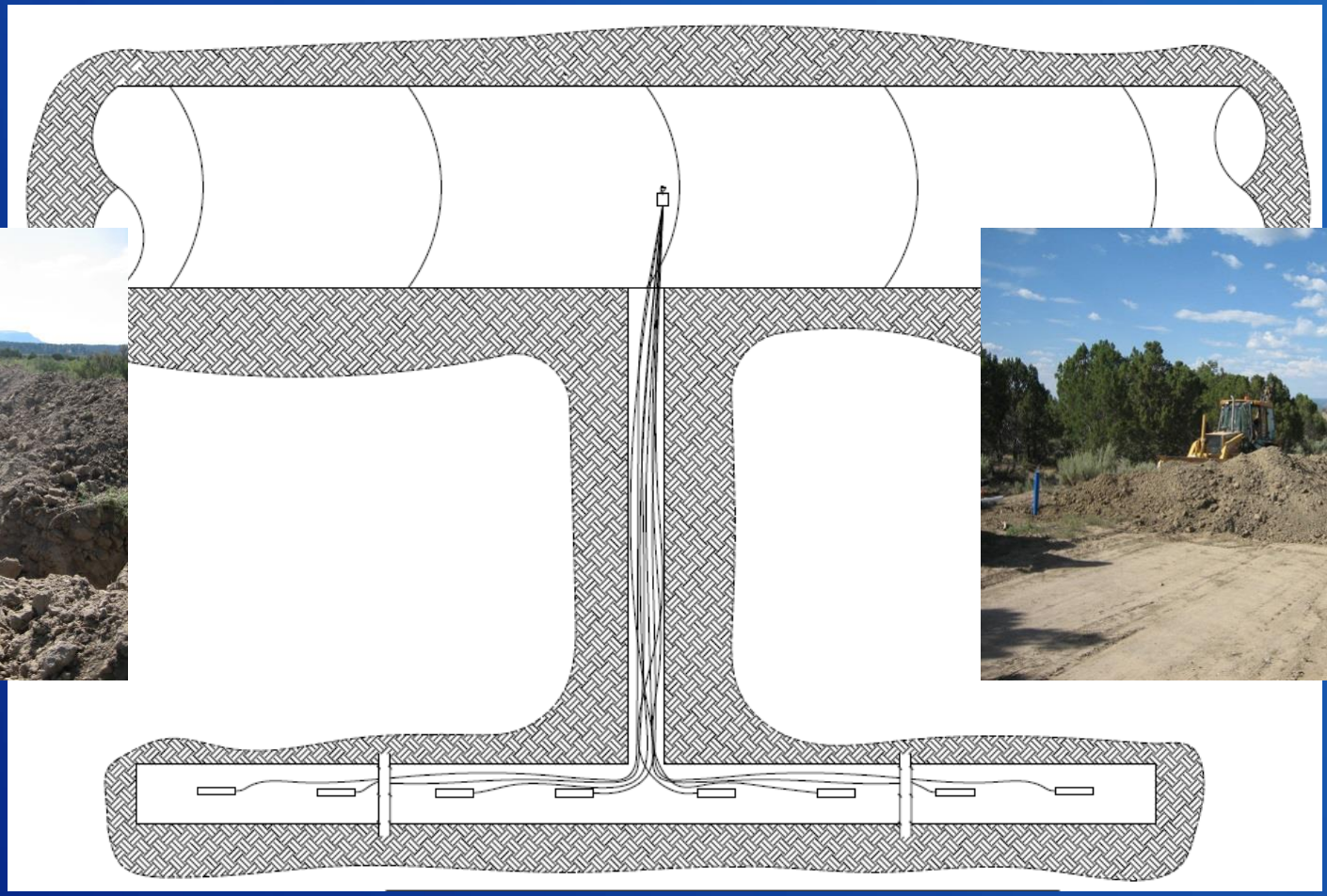
Mg Anode for Burial

Anodes:

- Soil- Magnesium and Zinc
- Fresh Water- Magnesium
- Salt and Brackish Water- Aluminum

RECLAMATION

Anode Placement- Burial

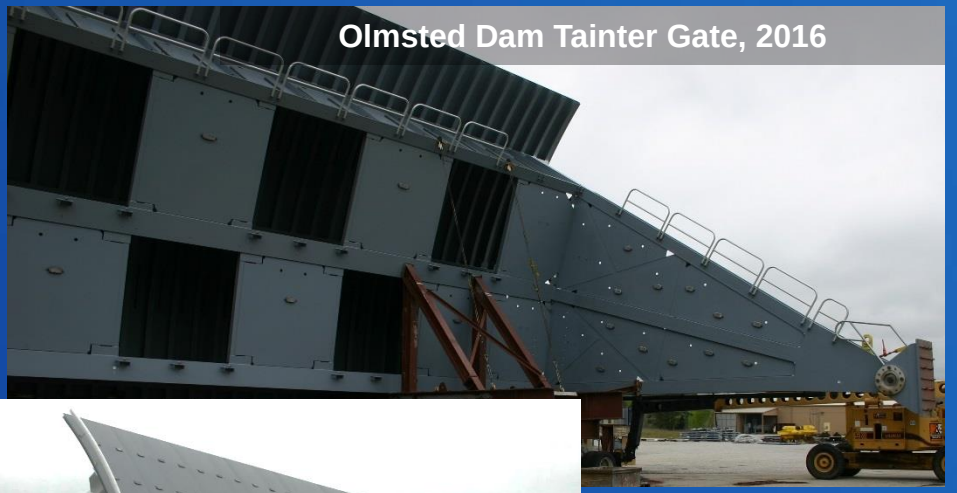


Place anodes within right-of-way and at “remote earth” (a point such that the pipe-to-soil resistance is no longer changing much with distance)

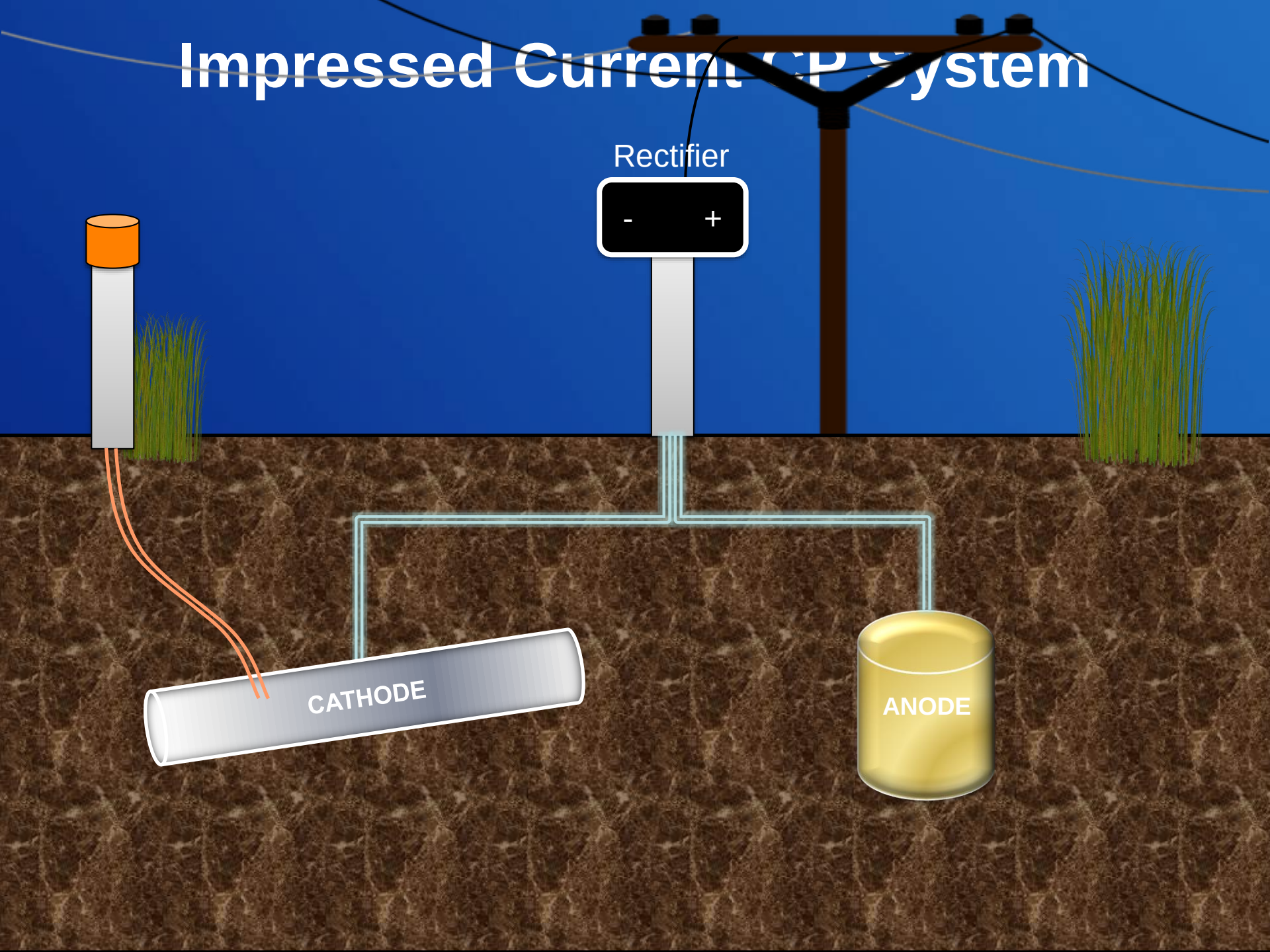
RECLAMATION

Anode Placement- Immersion


Tracy Fish Collection Facility, March 2004


Olmsted Dam Tainter Gate, 2016


Angostura Dam Radial Gates, May 2011


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
- Both the structure and the anode must be in contact with the electrolyte

Features:

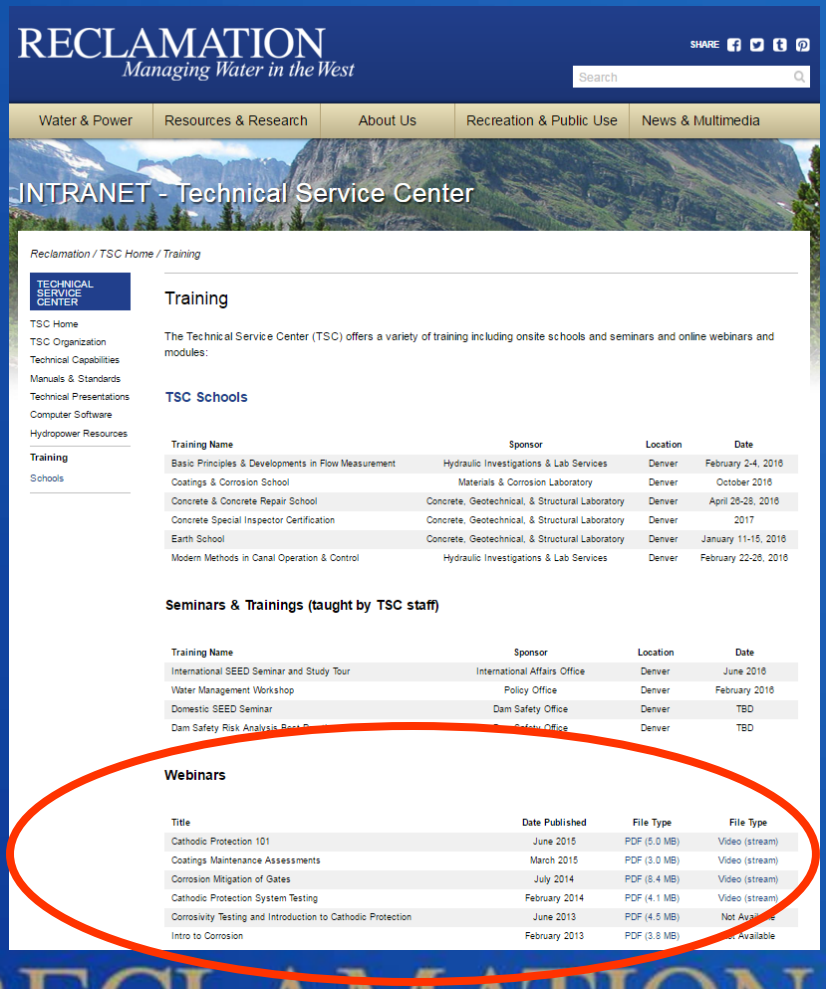
- High flow of water
- High current requirements
- Can handle large or poorly coated structures

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**



RECLAMATION

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RECLAMATION