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Managing Water in the West

Corrosion Mitigation of Gates

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Bureau of Reclamation

Today's Topic: Gates

- Review of Corrosion, Coatings, and Cathodic Protection
- Why Protect Submerged Structures?
- CP System Components
- Typical Gate Protection Design
- CP System Components
- Installation Overview
- Testing and Inspection Guidelines
- MICA and Corrosion Database Research

Review of Corrosion and Cathodic Protection (CP)

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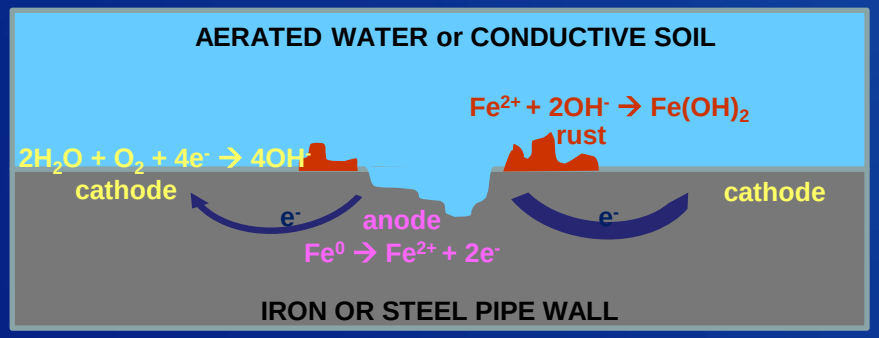
The Corrosion Reaction

ex. oxidation, “rusting,” electroplating, anodizing

Electrochemical Reaction Between a Metal and an Electrolyte

ex. steel, copper, aluminum

ex. soil, water



Four Required Components for Corrosion:

1. **Anode (Corrodes)**
2. **Cathode (Protected)**
3. **Electrolyte (Usually Soil or Water)**
4. **Metallic Return Path (ex. Pipe)**

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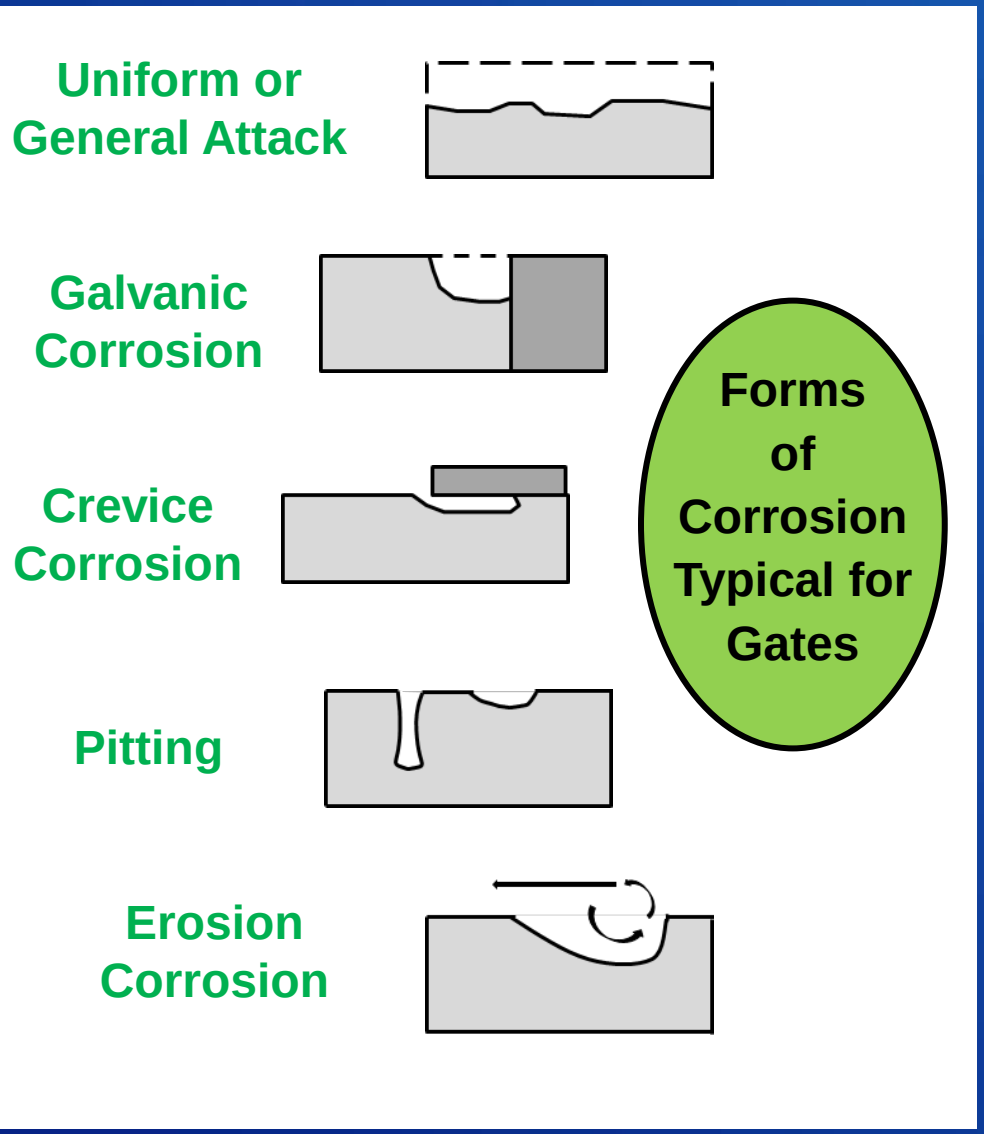
Forms of Corrosion



Dealing with Corrosion:

- Create barrier between metal and electrolyte- Coating
- Eliminate potential differences on a structure's surface- Cathodic Protection
- Avoid use of dissimilar metals- ex. mild steel gate with stainless steel guides
- Eliminate crevices- ex. no skip welding!
- Prevent standing water- ex. install drain holes

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Protective Coatings

Coating repair vs. unrepaired section, Seminoe Dam Gate, 2012

- "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, 2014

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

  - Coating acts as a barrier between the metal and the water to electrically isolate the metal

Laboratory Coupon Testing

  - Examples of Coatings for Immersion:
    - Epoxies & Coal Tar Epoxies
    - Moisture Cured Polyurethanes and Siloxanes
    - Galvanized coating

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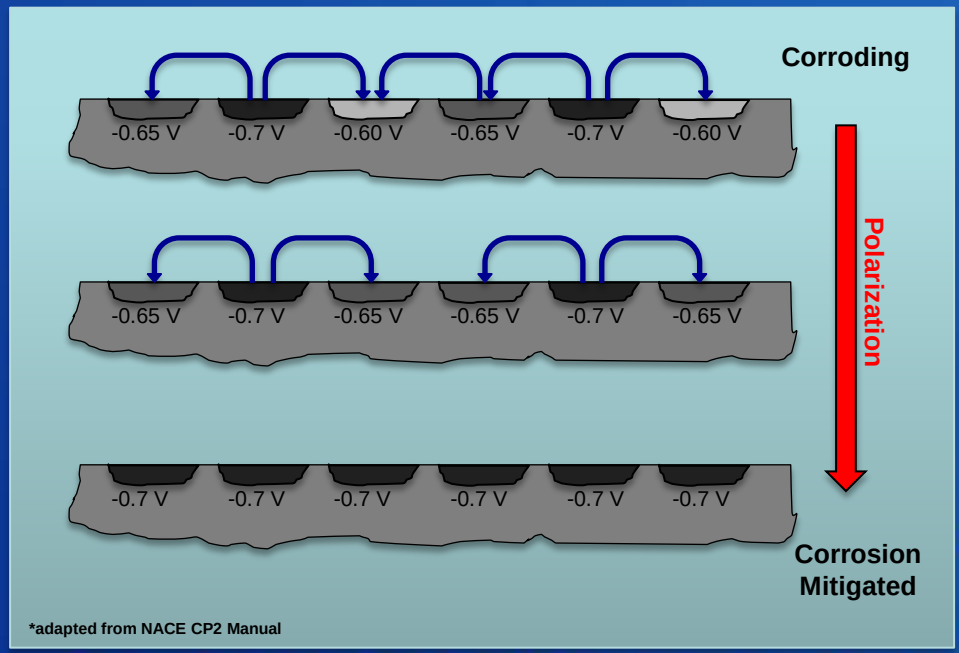
Cathodic Protection

- **Current flows through Electrolyte from Anode to Structure**
  - **Polarizes structure to eliminate potential differences between anodic and cathodic areas on structure surface**
  - **Corrosion rate ceases or is greatly reduced**

- **Electrons are provided from source outside the structure**
  - **Via a more active metal to be sacrificed- galvanic anode CP**
  - **Via a rectifier- impressed current CP**

- **CP works with coating to protect structure at holidays and prevent undercutting of coating**

- **The most effective corrosion protection system for buried and submerged structures involves a good bonded coating and cathodic protection.**



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

Features:

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

New Mg Anode

Old Mg Anodes

Anodes:

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

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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, an 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

Mixed Metal Oxide Disk Anode

Graphite Anodes

Anodes:

- Graphite, High-Si Cast Iron, Mixed Metal Oxide, Platinum
- Anodes Normally Connected Through Calibrated Shunts in Junction Box

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Why Protect Submerged Structures?

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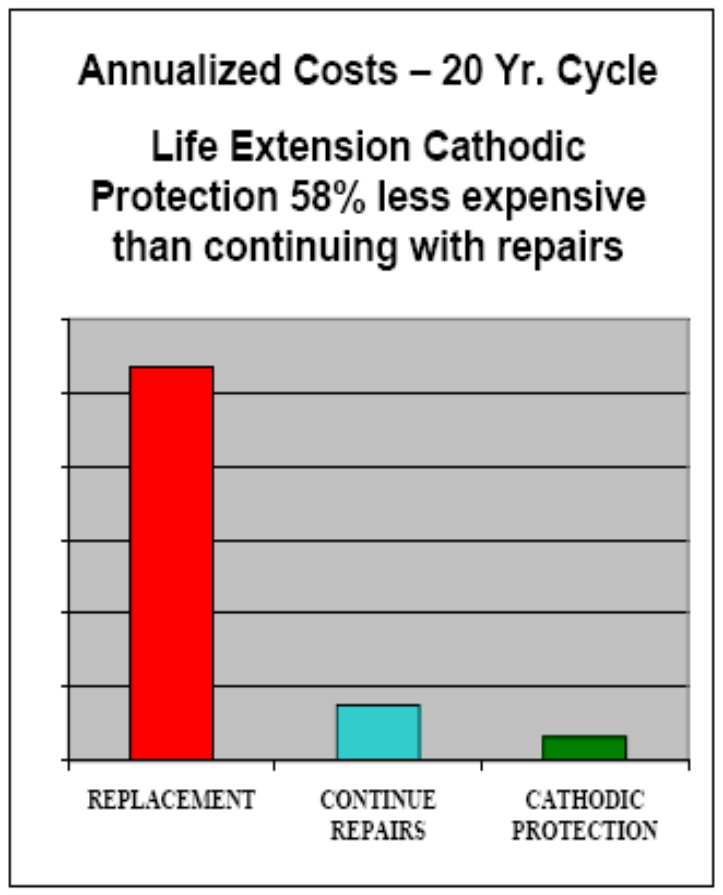
Corrosion Management Programs

Economic Benefits



The most effective corrosion protection system for submerged structures involves a good bonded coating and cathodic protection.

- **Coatings are the primary corrosion protection for gates, but today's epoxy coating systems do not last as long as the vinyl systems used in the past**
- **The costs for coating repairs or full recoating are constantly increasing**
- **Cathodic protection will help extend the life of the coating and maximize time between recoats**
- **The right corrosion mitigation system is a small up-front investment that will reduce long-term O&M costs on submerged structures (gates) and extend their useful lifetime.**

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Protected vs. Unprotected

Yellowtail Dam Spillway Radial Gates, April 1994

- ICCP system using surface mounted mixed-metal oxide anodes
- Upstream side was recoated in ~1984- one of the first applications of epoxy based coating system; CP applied at that time
- Photos 10 years after application. Gates have still not required recoating now 30 years later.

CP System Components

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Anodes

Magnesium Anodes

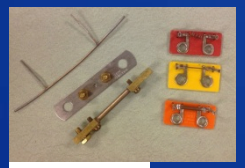
Mixed Metal Oxide Anode

Platinized wire anode in slotted PVC tube for submersion

- Mg- GA, fresh water, lightweight
- Zn- GA, fresh or brackish water
- MMO- IC, all waters, often used as low profile disk anodes on gates
- PT- IC, all waters, high current density
- Also- Aluminum, Graphite, High-Si Cast Iron

Zinc Anodes

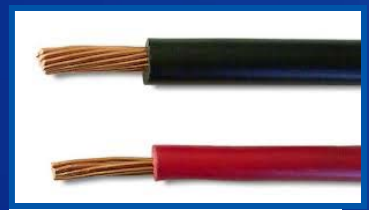
Components



Shunt

Busbar

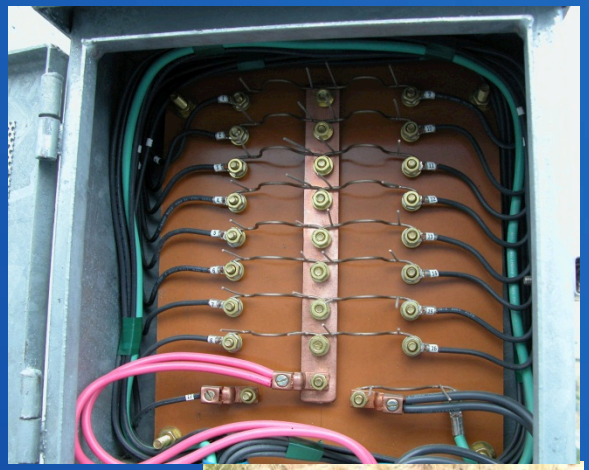
Conduit and Mounting Hardware

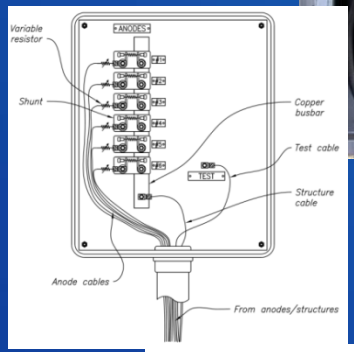


HMWPE Cu Cable

Variable Resistor

Dielectric Shield Material and Coating Repair





Junction Box

Rectifier

Typical CP System Design for Gates- New and Retrofit

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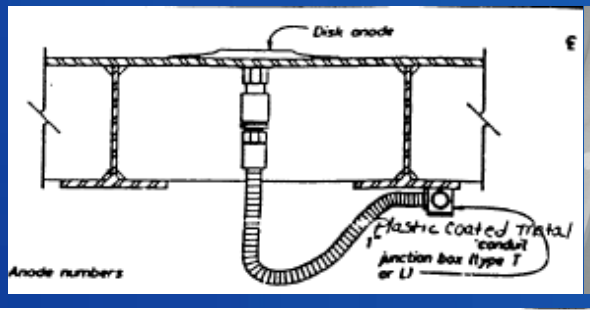
General Design Considerations

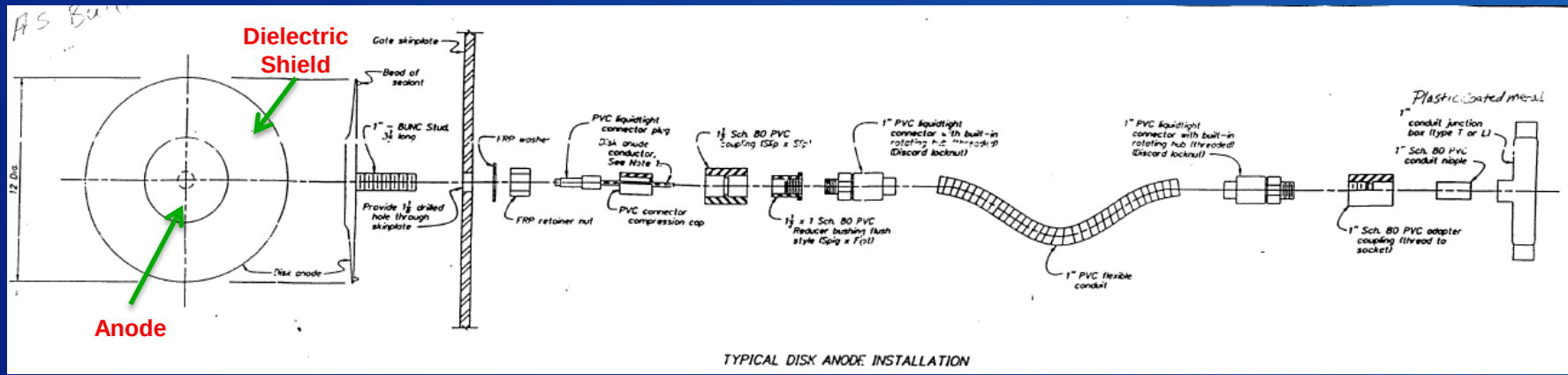
- Cathodic Protection systems are designed for a minimum 20 year service life
- Take into consideration ease of maintenance and replacement of anodes- for example we try to use GACP where possible
- Try to provide uniformity of design across a site with multiple gates

- Factors affecting design:
  - Size of structure- anodes must distribute current to entire submerged portion
  - Material, geometry, and weight of anode
  - Geometry of gate and guide structure- for example, some gates have minimal clearance between gate and guide and would do better with ribbon anodes or other low-profile designs
  - Design of gate- structural components can produce shielding of current, cellular designs will require drain holes
  - Operation of gate- what is the variation in water level, storage plan, anticipated availability for inspections and maintenance

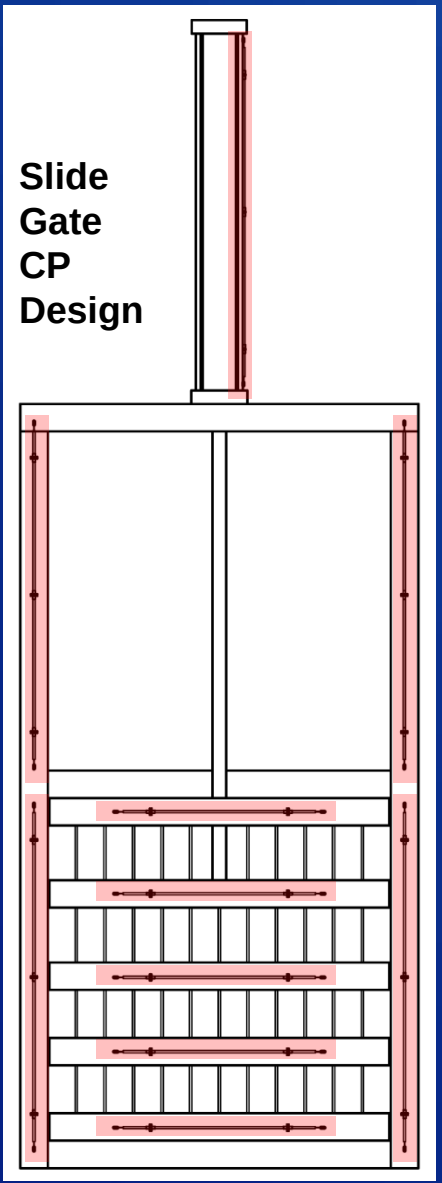
Flush Mounted Anodes

- ICCP only
- Low profile anode mounting
- Require drilling through gate
- Will have cables and attachments on back side running to junction box/rectifier
- Must have good seal between anode and gate skin plate to prevent leakage of water/crevice corrosion
- As with all ICCP systems, anode will not visibly deplete, but performance will diminish over time and must be monitored

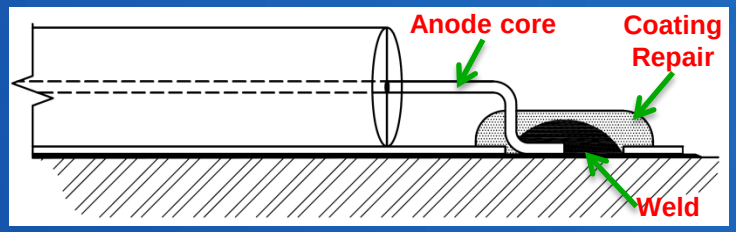


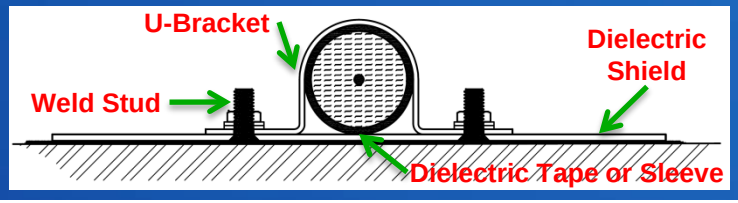


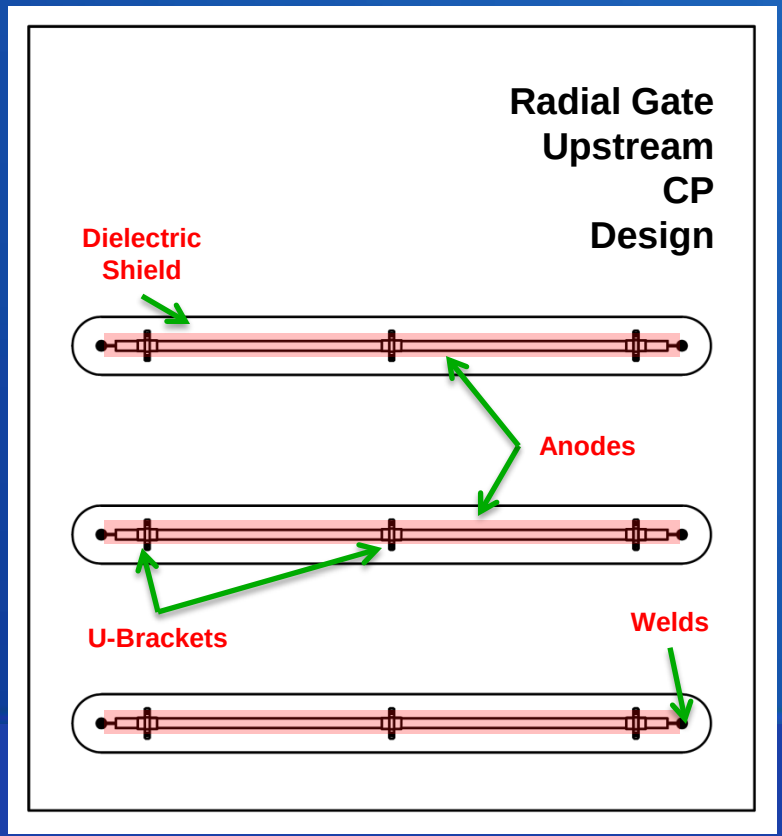
Surface Mounted



- GACP only
- Dielectric shield needed for Mg anodes- not for Zn
- Tape wrap at bracket to prevent anode consumption and mechanical instability
- Ensure good metallurgical/mechanical bond of core to gate
- Larger profile of anodes means tight tolerances should be considered for each site, as well as occurrences of turbulence and debris
- Profile of gate (curvature) and variable water level dictate horizontal vs vertical orientation of anode

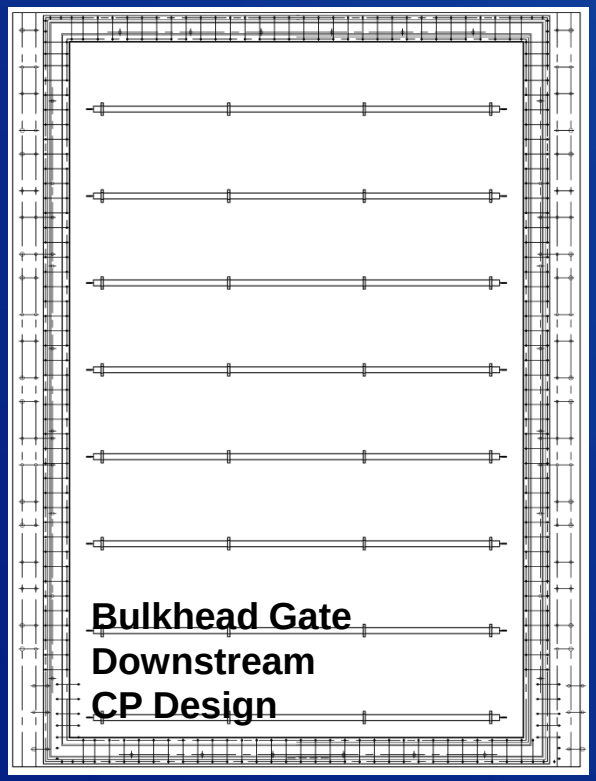


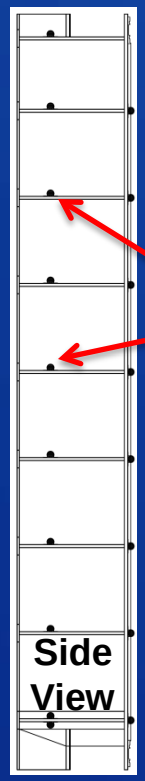




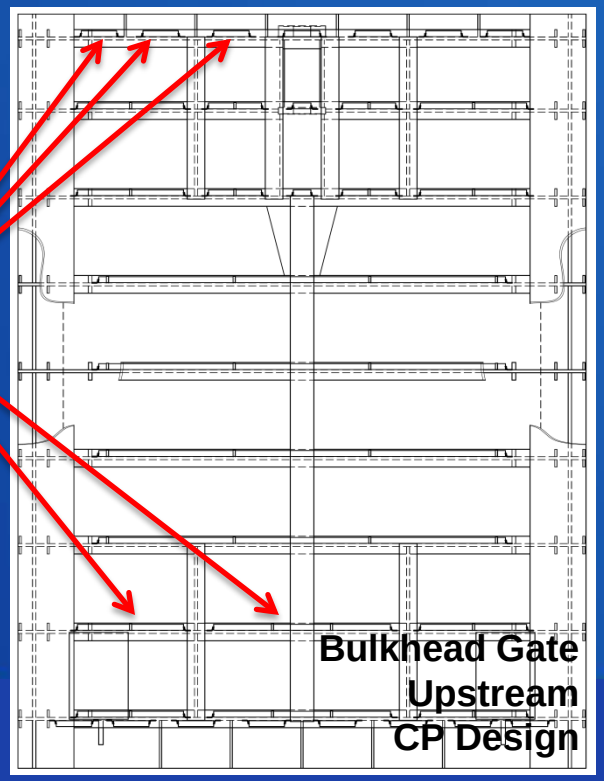
Compartment Mounted

- Current Shielding- in complex gate structure, each compartment needs an anode, support beams can shield current and limit protection
- Need to know operation conditions- eg low clearance for pocket-style guides, etc.
- DRAIN HOLES!! Avoid standing water when gate is in storage- anodes will be out of water and cannot protect structure





Anodes in each compartment



Other Types of Anode Attachment


Tracy Fish Collection Facility, March 2004

ICCP Hanging Anodes, Remote, Vertical

GACP, Direct Mounted Stub-type


Laguna Inlet Gates, November 2013

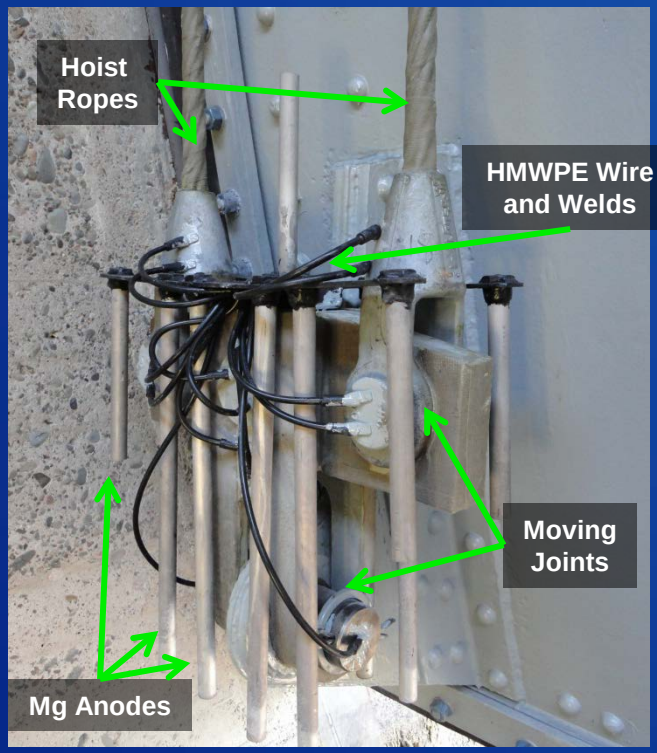

Delta-Mendota Canal, February 2013

GACP, Hull Mounted

GACP Surface Mounted, Offset, Vertical

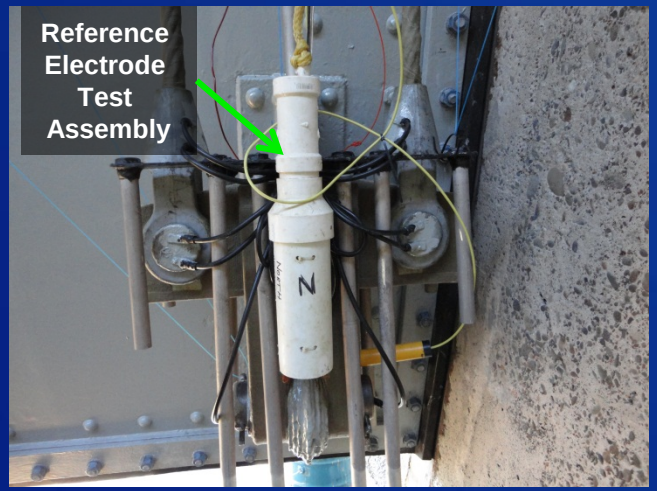

Angostura Dam Radial Gates, May 2011

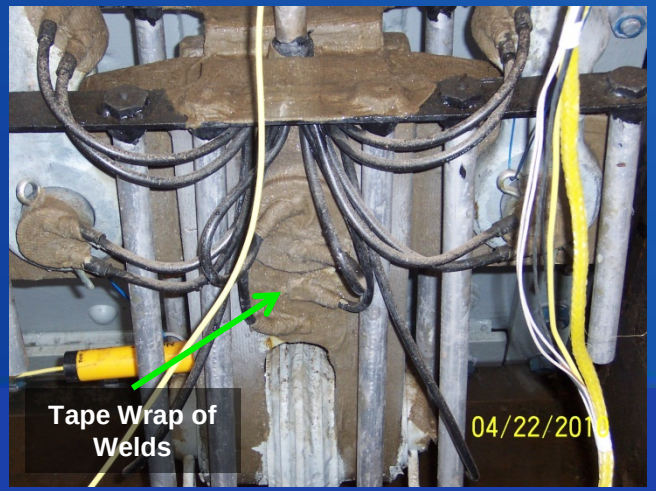
Hot Spot Repair



Nimbus Dam Radial Gates

- Hoist rope assemblies had galvanized steel, stainless steel, and mild steel in contact
- Moving joints stripped coating and exposed bare metal
- Anodes were attached to each assembly to protect hot spot from corrosion
- Dielectric tape was applied to coating repairs over welds to prevent cathodic disbondment





Guidelines and Specifications

- **Reclamation Corrosion staff follows the guidelines and criteria in NACE Standard SP0169 "Control of External Corrosion on Underground or Submerged Metallic Piping Systems"**

- **Other References:**
  - **Your USBR-TSC-MERL Corrosion Team**
  - **Cathodic Protection Survey Procedures, 2nd ed., NACE International, 2012**
  - **NACE RP0285 "Corrosion Control of Underground Storage Tank Systems by Cathodic Protection"**
  - **NACE SP0388 "Impressed Current Cathodic Protection of Internal Submerged Surfaces of Steel Water Storage Tanks"**
  - **NACE RP0196 "Galvanic Anode Cathodic Protection of Internal Submerged Surfaces of Steel Water Storage Tanks"**

Installation Overview

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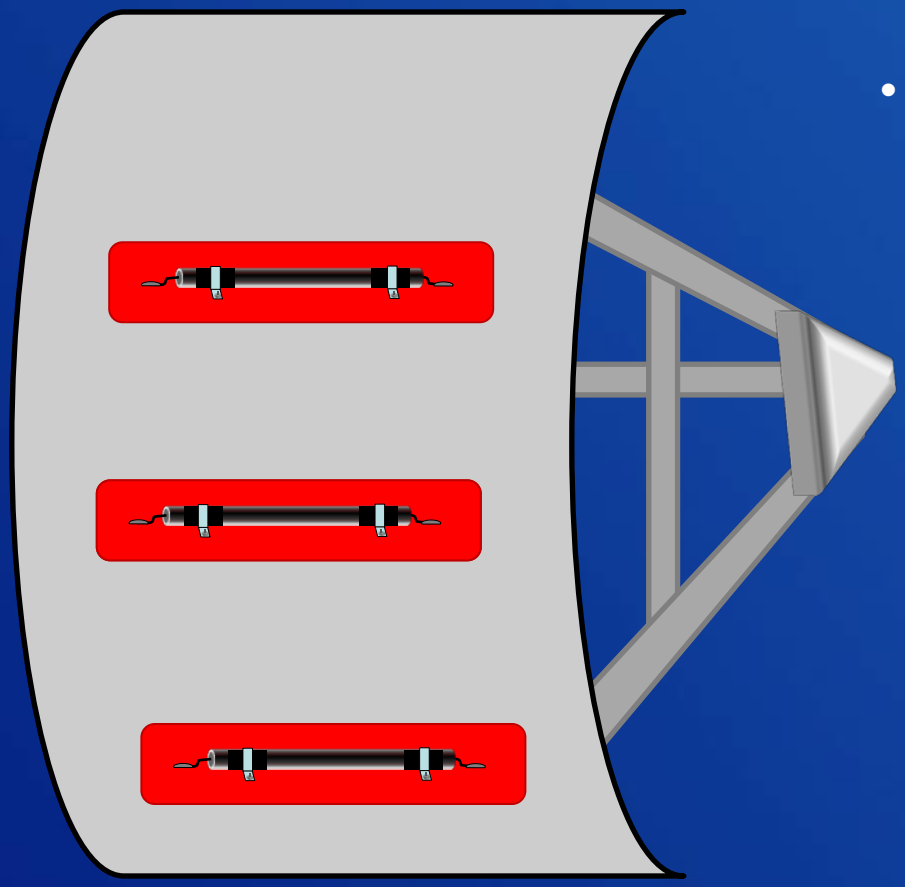
Installation Steps



- Step 1: Dielectric Shield Material (Mg anodes and ICCP systems)
  - Mark anode locations
  - Prepare surface for coating- could mean completely removing coating or roughening existing coating
  - Apply dielectric shield material (ex. capastic coating/ bituminous coating)
    - a high strength, high dielectric strength, high build epoxy
    - minimum thickness 75 mils
  - Apply top-coat, if required
  - NOTE- shield material is often built in to ICCP flush-mounted anodes
  - NOTE- Zinc anodes do not require dielectric shield due to lower output

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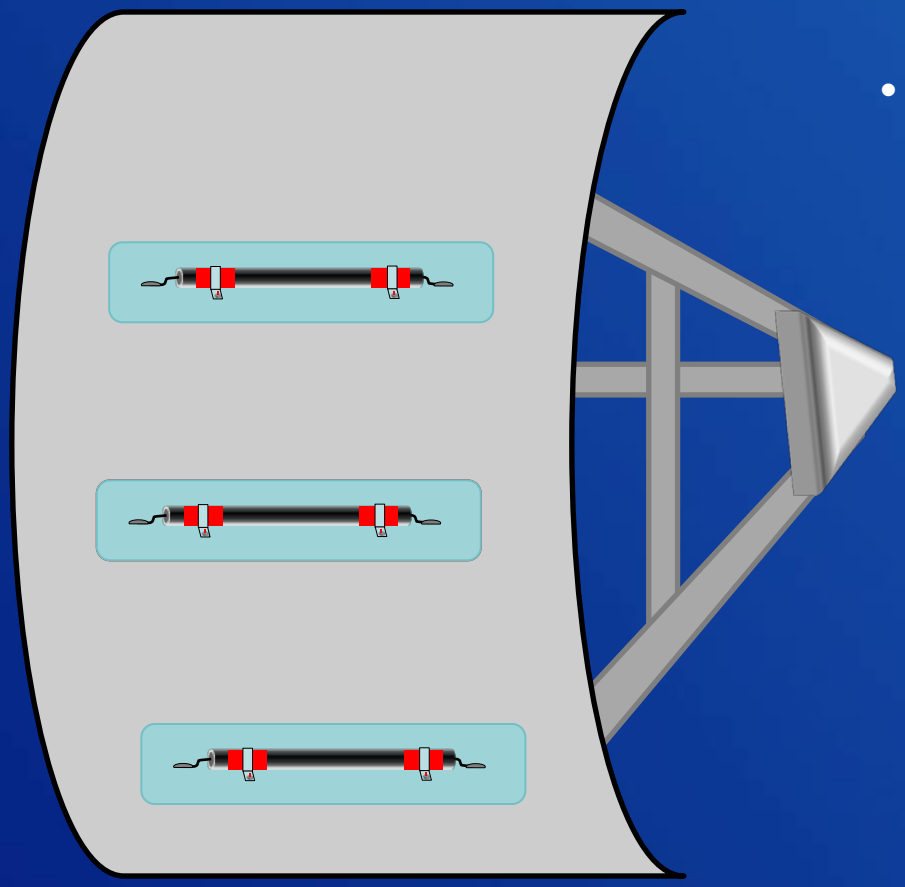
Installation Steps



- **Step 2: Prepare to Mount Anodes**
  - Remove coating beneath bracket weld studs and anode core weld
  - Weld bracket studs to skin plate
  - Repair weld area with bituminous coating
  - Apply dielectric tape wrap or sleeve to area of anode beneath bracket

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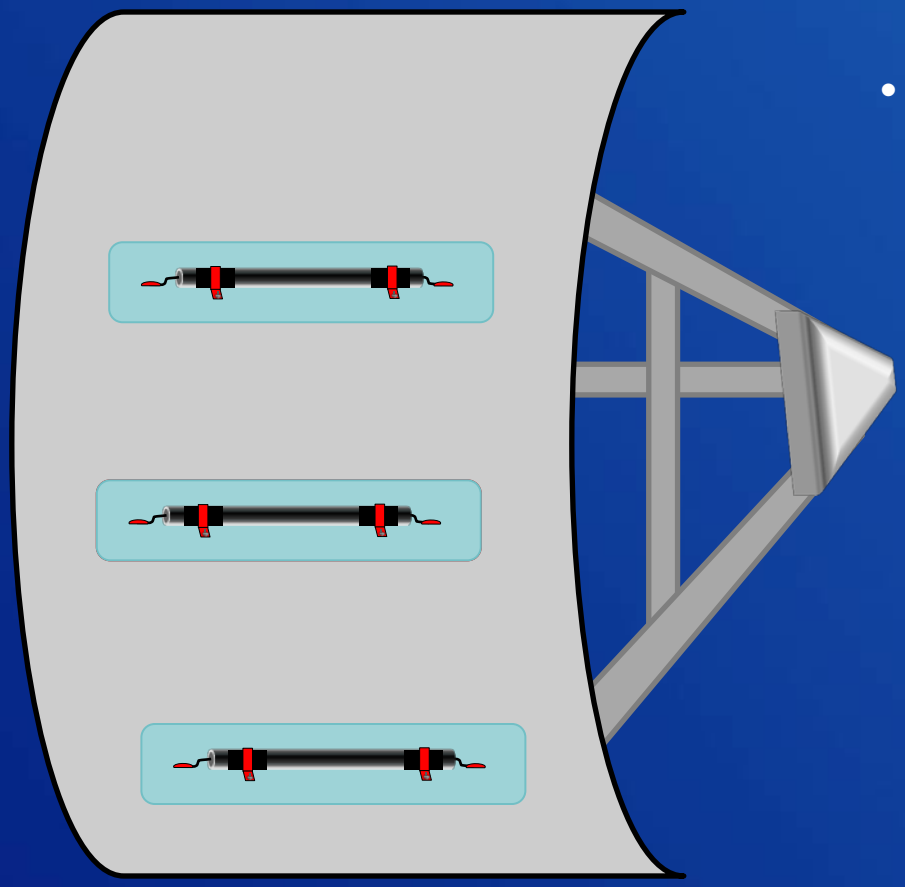
Installation Steps



- **Step 3: Mount Anodes**
  - Exothermically weld each end of anode core material or each mounting tab to skin plate
  - Secure U-brackets over anode
  - Test electrical continuity between gate and anode
  - Cover welds and exposed skin plate with bituminous coating, ~20 mils

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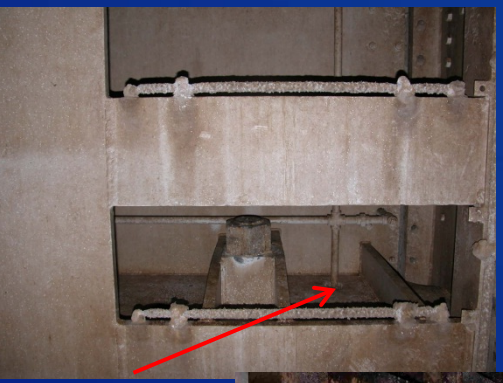
Things to Avoid

Palo Verde Diversion Dam Radial Gates, 2013



Fort Randall Dam Emergency Gate, 2005

With Drain Holes

No Drain Holes, Neglected CP

Seminoe Dam Bulkhead Gates, 2012

Testing and Inspection Guidelines

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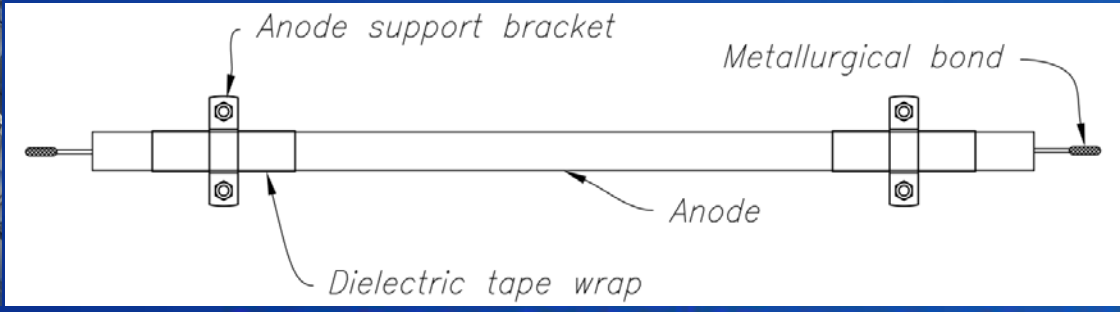
Testing Submerged CP Systems

- **Structures with a submerged GACP system should be inspected whenever structure is removed for maintenance**
  - **What is the condition of the coating?**
  - **What is condition of anodes?**
  - **Are brackets still providing sufficient mechanical support?**
  - **Are metallurgical bonds still intact?**
  - **Is cable between structure and anode still electrically connected?**

New Mg Anode

Old Mg Anodes

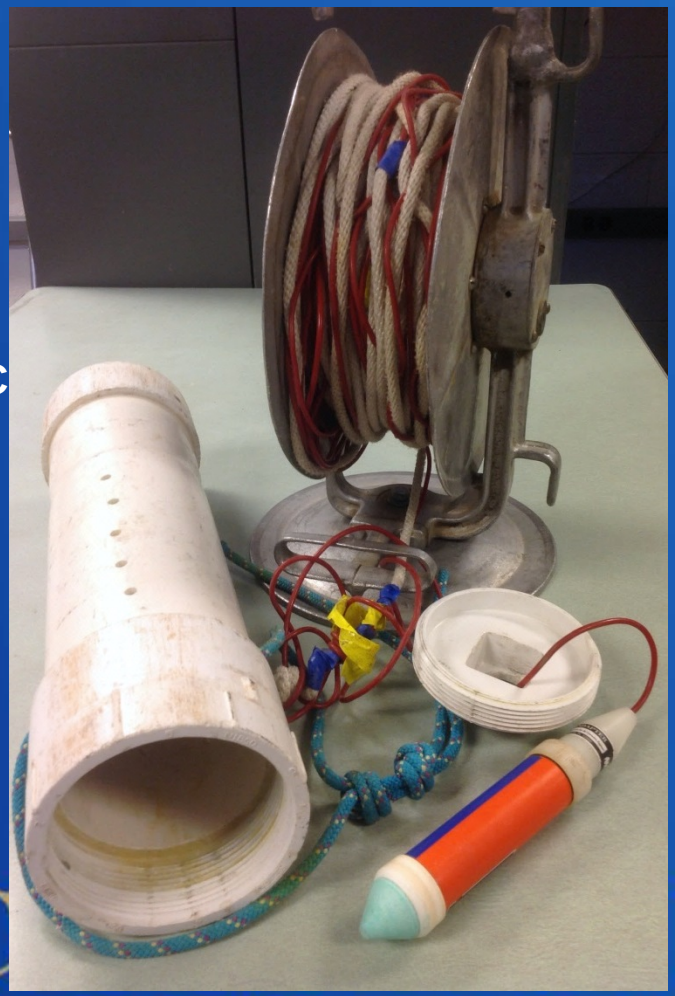


Testing Submerged CP Systems

On a submerged ICCP system

- Perform same inspections as for galvanic system
- Check rectifier
- Test current at each anode in junction box and balance output using variable resistor
- Test V_{OFF} of structure
  - Install current interrupter
  - Reference electrode goes in water, close to structure
  - May use weighted submersible container or rigid PVC pipe to hold reference electrode securely, prevent loss of electrode, and position electrode at test depth


Gallegos Pumping Plant, NIIP, 2004



Record Keeping

- **Testing Records should include:**
  - **General:**
    - **Tester's Name**
    - **Date and Time of Test**
    - **Location of Test Site (GPS)**
  - **Measurement Data:**
    - **Type of Measurement (V_{ON}, V_{OFF})**
    - **Value/Polarity (+/-)/Units (V, mV, mA, A, etc)**
    - **Type of reference electrode (CSE)**
  - **Other Useful Information:**
    - **Drawings, photos, maps of site**
    - **Sketches or photos of rectifier/JB/TS**
    - **General inspection description**
    - **Description of problems or troubleshooting work**
  - **Test rectifiers monthly, rest of system should be checked annually**

*** Good historical record keeping is the best way to determine health of a CP system.**

Research Project: MICA and Corrosion Database

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USACE/USBR Collaborations

- **Database of Corrosion Mitigation Installations aims to:**
  - **Catalogue types of protected structures and their locations**
  - **Document corrosion mitigation successes and failures**
  - **Share information between organizations**

- **Corrosion Detection and Monitoring Systems (USACE project)**
  - **Using FEA to improve efficiency of CP systems**
  - **Developing novel sensor for monitoring CP system and coating condition**
  - **Reclamation conducting inquiry to O&M corrosion-related issues- report at end of FY14**
  - **USBR seeking site for pilot test of USACE monitoring system**

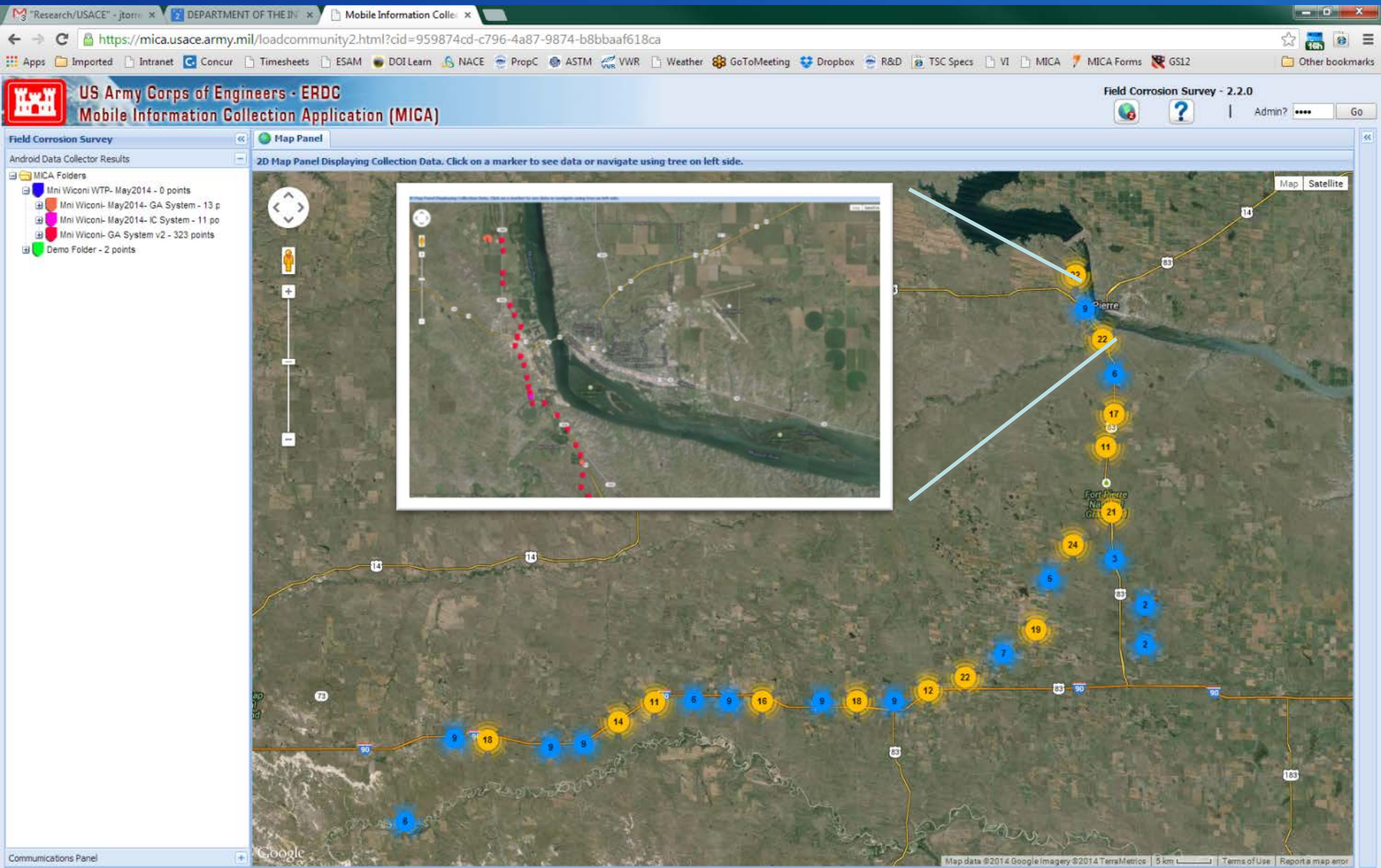
Use of Tablets for Field Work

- USBR working with USACE to employ MICA
- MICA- Mobile Information Collection Application
  - With one device collect:
    - GPS location
    - Photos, Video, Sketches
    - Field or Inspection Data
  - Eliminates paper forms and enables real-time updating

- Pilot Test for CP System Testing:
  - Mni Wiconi WTP, Pierre, SD
  - IC and GA system on >100 miles of pipe

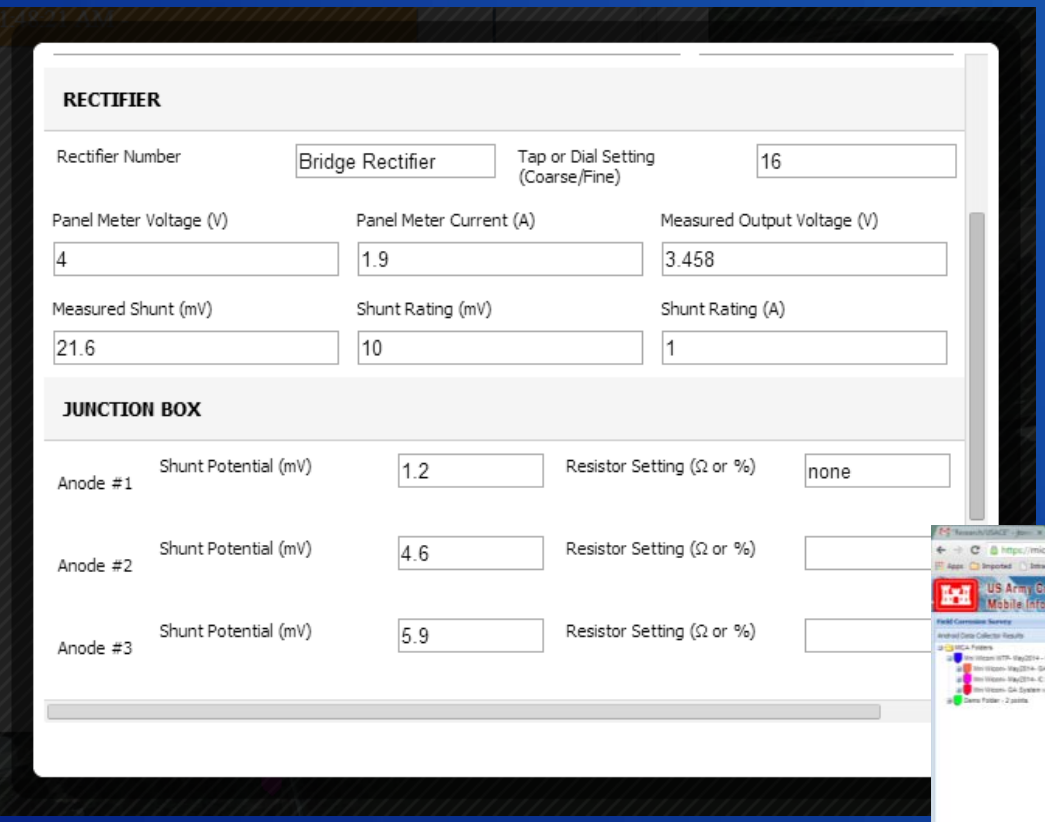
- FY15 Tasks:
  - Expand MICA use to other departments across Reclamation
  - Develop database for long-term storage and analysis of data
    - Likely using USBR GIS Tessel site and DoD-based SDSFIE (with Steve Jalbert from PN)

Use of Tablets for Field Work



Use of Tablets for Field Work

Form for Rectifier Testing



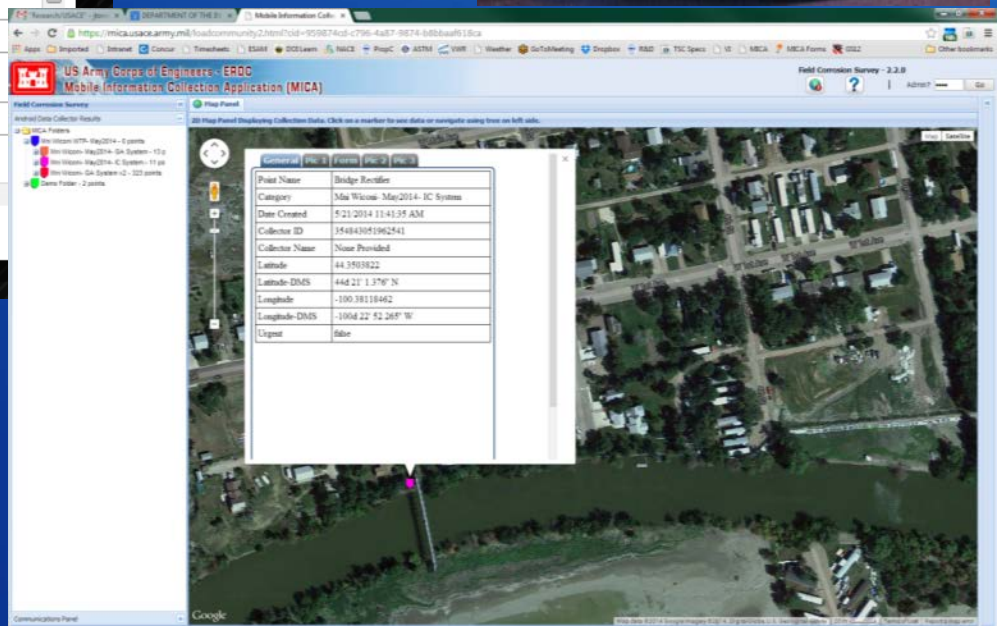
RECTIFIER

Rectifier Number	Bridge Rectifier	Tap or Dial Setting (Coarse/Fine)	16
Panel Meter Voltage (V)	4	Panel Meter Current (A)	1.9
Measured Output Voltage (V)	3.458	Measured Shunt (mV)	21.6
Shunt Rating (mV)	10	Shunt Rating (A)	1

JUNCTION BOX

Anode #1	Shunt Potential (mV)	1.2	Resistor Setting (Ω or %)	none
Anode #2	Shunt Potential (mV)	4.6	Resistor Setting (Ω or %)	
Anode #3	Shunt Potential (mV)	5.9	Resistor Setting (Ω or %)	

MICA available on tablet and smartphone devices



Web-based Interface for Data Viewing

Upcoming Events

- **Coatings and Corrosion School**
  - October 2014 in Denver
  - Registration should be open in August
  - Contact Allen Skaja for more info

- **Next Corrosion Webinar:**
  - Tentative: February 2015
  - Topic: Coatings Field Inspection
  - What do you want to hear about? Please suggest topics for future webinars!

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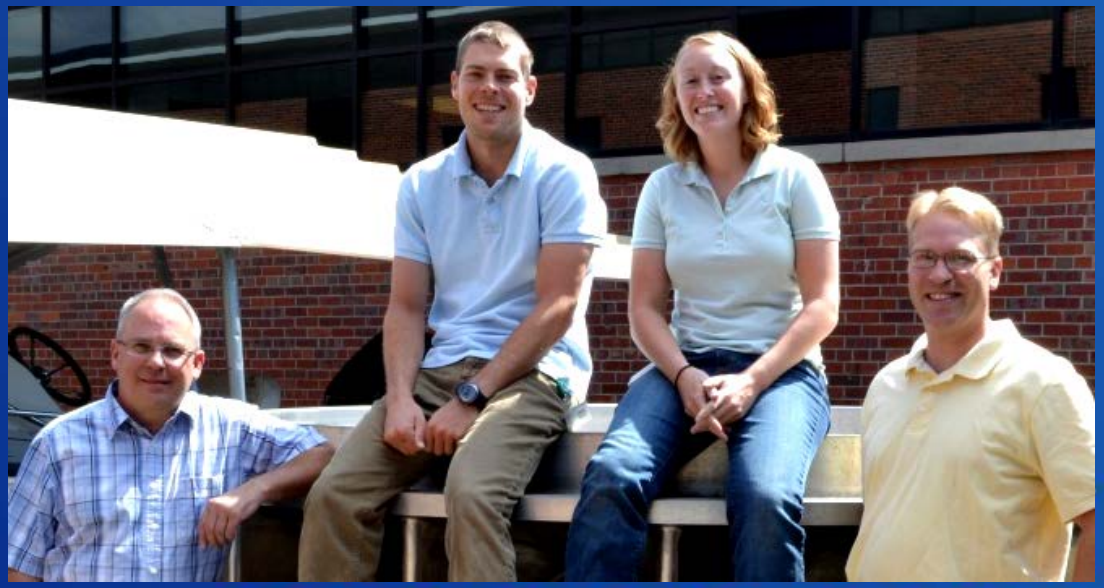

Questions? Comments?

De Sitter's "Law of Fives"

$1 spent in getting the structure designed and built correctly
is as effective as spending
$5 when the structure has been constructed but corrosion has yet to start,
$25 when corrosion has started at some points, and
$125 when corrosion has become widespread.

Thank you to everyone who provided photos and information for this webinar!

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