

# RECLAMATION

*Managing Water in the West*

## **Canal Operation and Maintenance: Coatings and Cathodic Protection**



U.S. Department of the Interior  
Bureau of Reclamation  
Office of Policy  
Technical Service Center  
Denver, Colorado

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## **Mission Statements**

The Department of the Interior conserves and manages the Nation's natural resources and cultural heritage for the benefit and enjoyment of the American people, provides scientific and other information about natural resources and natural hazards to address societal challenges and create opportunities for the American people, and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities to help them prosper.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

## **Acknowledgements**

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## **Disclaimer**

Reclamation developed this manual to provide basic guidance to help canal operators promote safe and effective operations and maintenance for canal systems. This information complements—and does not replace—experience and sound judgment. This is general information useful for typical canal systems. As each canal system has unique designs and features, these general guidelines cannot substitute for facility or operating-specific guidance and specifications. Every operating entity is different, and this advice and strategies may not be suitable for all situations.

Portions of this manual make recommendations for actions to mitigate corrosion issues using materials selection, coatings, and cathodic protection. These recommendations were made using the best information available at the time of preparation of this guidance.

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## Acronyms and Abbreviations

|             |  |
|-------------|--|
| ACME        | anode, cathode, metallic pathway, electrolyte                      |
| CFRP        | carbon fiber reinforced polymers                                   |
| CP          | cathodic protection  |
| CSE         | copper/copper sulphate (Cu/CuSO <sub>4</sub> ) reference electrode |
| DC          | direct current   |
| EPA         | U.S. Environmental Protection Agency                               |
| FRP         | fiber reinforced polymer   |
| GACP        | galvanic anode cathodic protection                                 |
| GFRP        | glass fiber reinforced polymer                                     |
| HDPE        | high density polyethylene  |
| HMWPE       | high molecular weight polyethylene                                 |
| ICCP        | impressed current cathodic protection                              |
| IR          | current-resistance   |
| JHA         | Job Hazard Analysis  |
| MMO         | mixed-metal oxide  |
| NIOSH       | National Institute for Occupational Safety and Health              |
| O&M         | operation and maintenance  |
| OSHA        | Occupational Safety and Health Administration                      |
| PCB         | polychlorinated biphenyls  |
| ppm         | part per million   |
| ppb         | part per billion   |
| PVC         | polyvinyl chloride   |
| Reclamation | Bureau of Reclamation  |
| RCRA        | Resource Conservation and Recovery Act                             |
| RO&M        | Review of Operations and Maintenance                               |
| SDS         | safety data sheet  |
| SOP         | Standard Operating Procedures                                      |
| TSC         | Technical Service Center   |
| UV          | ultra-violet   |
| VCSE        | measurements using a saturated CSE                                 |
| VOC         | volatile organic compounds   |



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# 1. Purpose and Scope of Guidance

This manual is designed to help operating entities better understand the impacts that corrosion can have on water conveyance systems and structures. This volume describes how to protect infrastructure with coatings and cathodic protection (CP). Preventing infrastructure corrosion requires the right type of protection used the right way. While it is important to consult the experts for particular situations, a general understanding of protective coatings and cathodic protection will help in planning actions to prevent and address corrosion.

Other manuals in the Bureau of Reclamation (Reclamation) Canal Operation and Maintenance series discuss vegetation, animals, concrete, embankments, and mechanical maintenance. The Canal Operators Manual provides an overview of these topics as well as canal operations. Get these manuals at <https://www.usbr.gov/assetmanagement/OMG.html>.



Reclamation staff are available to provide advice and technical support on Reclamation-owned canals. Contact Reclamation and consider additional engineering support before making modifications to infrastructure. If you determine work outlined in this manual requires more expertise than your staff can provide, please contact Reclamation for technical support (see [www.usbr.gov/main/offices.html](http://www.usbr.gov/main/offices.html)).

## 2. Introduction to Corrosion

### 2.1. What is Corrosion?

Corrosion is the deterioration of a material due to its reaction with the environment it is exposed to. The corrosion process for iron-based materials (such as steel) is more commonly referred to as rusting. Although corrosion can affect any engineering material, this manual focuses primarily on the corrosion mechanisms and ways to prevent metal corrosion.

#### 2.1.1. Corrosion Cell

For corrosion to occur, certain conditions and elements are required to form a corrosion cell. A useful acronym for this corrosion cell is ACME:

- A is the **anode**. The anode is the less noble metal in the cell (less resistant to corrosion) and is the component that corrodes.
- C is the **cathode**. The cathode is the more noble metal in the cell (more resistant to corrosion) and does not corrode.

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- M is the **metallic pathway**. The metallic pathway which connects the anode to the cathode to allow electrons to flow from one to the other.
- E is the **electrolyte**. The electrolyte (typically water or soil) is the pathway for the ionic charges to complete the cell.

All four components are required for corrosion to occur. If one of these elements is removed, then the corrosion process is mitigated. Figure 1 shows a schematic of a basic corrosion cell indicating the flow of current through the metallic conductor and the electrolyte. The anodes and cathodes of a corrosion cell can occur on the same metallic surface as shown in Figure 2 which describes a corrosion cell with all four components and shows the chemical reactions that occur at the various sites.

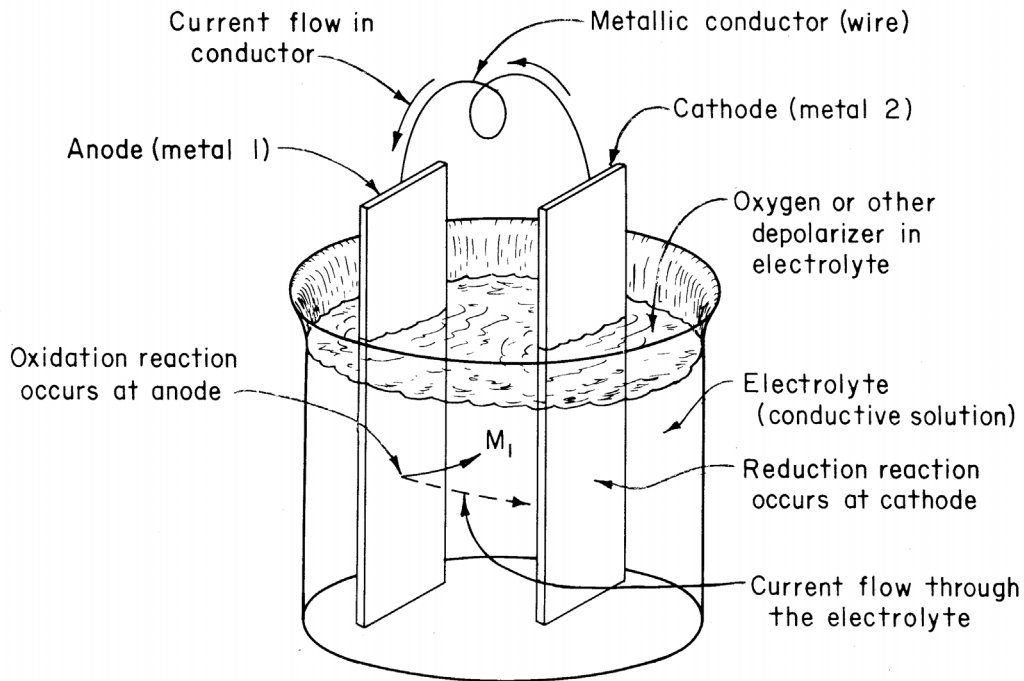


Figure 1. Corrosion cell showing the four components: anode, cathode, metallic connection, and electrolyte.

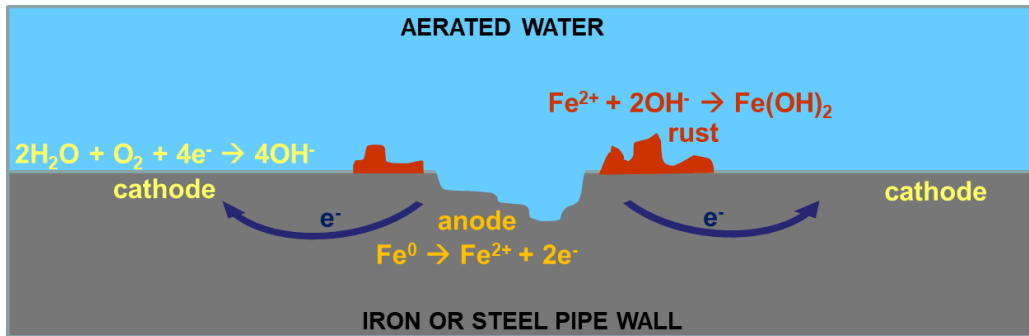


Figure 2. Description of a corrosion cell. The schematic shows the four elements of the corrosion cell and that anodes and cathodes can occur on the same metallic surface.

Corrosion rates are determined by many different variables, but are generally affected by oxygen, pH, temperature, salts, humidity/ immersion, and pollutants/ acids. Corrosive environments are usually defined by the electrolyte present in the corrosion cell.

### 2.1.2. Forms of Corrosion

There are many forms of corrosion, as shown in Figure 3. This manual will only focus on the typical forms observed on canal infrastructure: uniform corrosion, galvanic corrosion, crevice corrosion, pitting, corrosion in reinforced concrete, and erosion corrosion.

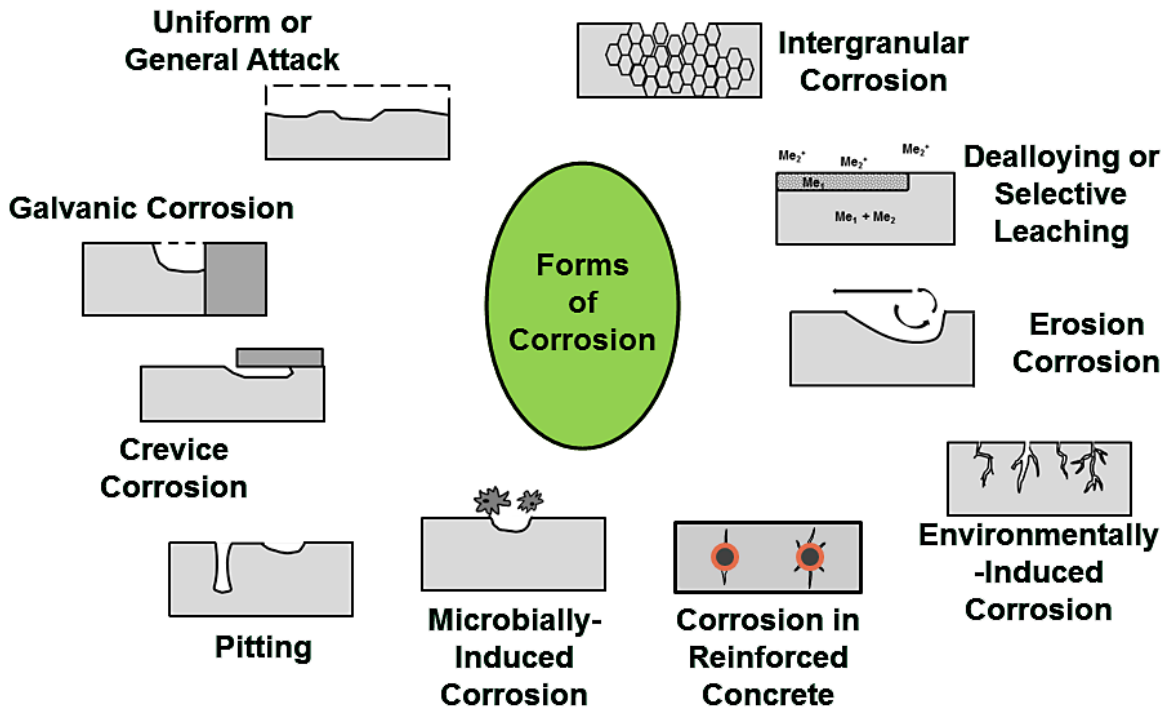


Figure 3. Forms of corrosion.

### 2.1.2.1. Uniform Corrosion

Uniform or general corrosion is an even surface rusting of the entire surface which results in general thinning or loss of metal thickness. Structural failure from uniform corrosion can take a significant amount of time and can be prevented easily by using cathodic protection, coatings, and specifying a corrosion allowance in the design. An example of uniform corrosion is shown in Figure 4.



Figure 4. Example of uniform corrosion (rust along the floor and walls) of a steel spillway.

### 2.1.2.2. Galvanic Corrosion

Galvanic corrosion is the result of two different metals, such as stainless steel and mild steel (Figure 5), in physical contact with each other—creating what is known as a galvanic couple. Table 1 is an example of some common materials in neutral soil or water, known as a galvanic series. This table shows the typical potentials of metals in neutral soils and water compared to a copper/copper sulphate (Cu/CuSO<sub>4</sub>) (CSE) reference electrode. The electric potential difference between the metals is often referred to as the “driving” force causing corrosion. The greater the electric potential difference between the two metals in contact with each other, the larger the driving force and thus the higher the corrosion rate or potential for corrosion will be.



Figure 5. Galvanic corrosion of mild steel anchor bolts in contact with stainless steel guides. Regardless of the grout provided, the effect of the galvanic couple is causing corrosion of the anchor bolts.

Table 1. Galvanic Series

| <p>Less likely to corrode</p> <p>↑</p> <p>Cathodic (more noble)</p> <p>Anodic (less noble)</p> <p>↓</p> <p>More likely to corrode</p> | Material          | Potential ( $V_{CSE}$ ) (approximate) |
|---|-------------------|---------------------------------------|
|   | Graphite (Carbon) | +0.3                                  |
|   | Stainless Steel   | -0.2                                  |
|   | Copper            | -0.2                                  |
|   | Steel in Concrete | -0.2 to -0.5                          |
|   | Cast Iron         | -0.5                                  |
|   | Mild Steel        | -0.5 to -0.8                          |
|   | Aluminum          | -0.8 to -1.05                         |
|   | Zinc              | -1.1                                  |
|   | Magnesium         | -1.45 to -1.75                        |

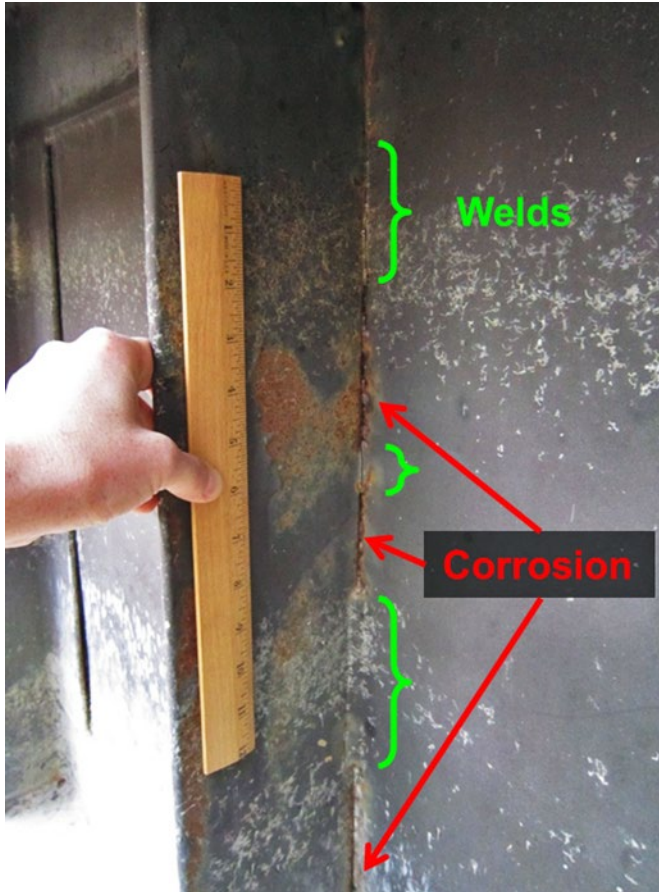
Potential measurements are in volts versus a saturated copper/copper sulfate reference electrode

### 2.1.2.3. Crevice Corrosion

Crevice corrosion occurs in the crevices or gaps where electrolyte has limited access. These locations do not require full immersion in the electrolyte and can include gaps, the areas under gaskets or seals, cracks, bolted connections, rivets, and seams.



Skip welds are one major problem location, as seen in the example in Figure 6. The open crevice between the welds exhibits corrosion and may lead to severe corrosion issues over time, such as thinning wall thickness and potential weld failure. Figure 7 shows a stiffener inside a radial gate. The two plates constructing the stiffener were not sealed with caulking or welding. Over time, the severity of the corrosion inside the crevice resulted in exfoliation of the metal structure.



**Figure 6. Crevice corrosion due to skip welds on a radial gate stiffener. Water entered the space between the metal plates, resulting in corrosion.**





**Figure 7. Interior stiffener inside radial gate compartment. Corrosion occurred between the two plates, causing extreme crevice corrosion and eventual exfoliation of the steel stiffeners.**

#### **2.1.2.4. Pitting Corrosion**

Pitting is a form of localized corrosion identified by holes or craters in a metal surface. The depth of a pit is typically greater than its diameter and can result in penetration through the entire metal thickness. Pitting corrosion can affect several different metals, including stainless steels. Figure 8 shows the pits which occurred on aluminum due to the chemistry change caused by invasive mussels. Pitting and surface corrosion of the metal strips in a concrete box canal, as shown in Figure 9, resulted in increased seepage and may lead to catastrophic failure if not remedied.





**Figure 8. Pitting corrosion on an aluminum gate due to environmental changes from invasive mussels.**



**Figure 9. Pitting and surface corrosion of a metal strip between concrete box canal sections. Corrosion has led to increased seepage from the canal.**



### 2.1.2.5. Corrosion in Reinforced Concrete

The corrosion of steel in concrete typically occurs due to the porosity and cracking of the concrete which allows chemical species, such as chlorides, to pass through and attack the steel. This causes the steel to corrode creating an extreme pressure inside the space around the steel. The corrosion products from the rebar are expansive and can occupy a volume between 6 and 10 times greater than the original steel resulting in cracking and spalling of the concrete. Figure 10 shows spalling of the concrete due to the corrosion of the reinforcing steel. Figure 11 shows how the cracks in the concrete form parallel to the corroding reinforcing steel.



**Figure 10.** Corrosion of steel reinforcement in concrete, which led to spalling and further corrosion of the reinforcement.



**Figure 11.** Cracking of the concrete occurs parallel to the corroding steel reinforcement.

### 2.1.2.6. Erosion Corrosion

Erosion corrosion is defined by the combination of mechanical damage and corrosion. Abrasion due to fast-flowing water, bubbles, cavitation, sediment, etc. removes the protective coating and any protective oxide layer (passive oxide layers such as corrosion products) in addition to mechanical damage to the structure. Without the protective coating and oxide, which is continuously being removed, corrosion will occur, and this constant erosion process will have a constant or increasing corrosion rate. The bottom of a gate is a location where this is likely to occur.

## 2.2. Why Control Corrosion?

Mitigating corrosion is important from both an operational and cost standpoint. Corrosion can shorten structure life, increase out-of-service time for equipment or a system, and increase maintenance requirements. Corrosion damage can be very costly but taking measures to prevent or reduce the risk of failure due to corrosion may save a significant amount of money and time. These savings can be used for other maintenance or system needs.

Figure 12 shows an example of what can occur if corrosion mitigation is not adequately performed.



**Figure 12. Damage to a radial gate caused by corrosion leading to uncontrolled leakage.**

### 3. Corrosion Mitigation Methods

The most effective corrosion mitigation system is to use a combination of protective coatings and cathodic protection. Protective coatings are the primary defense against corrosion. Cathodic protection works with coatings to provide protection at defects in the coating.

For new or replaced structures or equipment, materials selection is important for limiting or eliminating corrosion. Stainless steel, composites, or plastics can be used as non-corroding materials in certain environments. It is not always possible to change the materials being used for the structures—but should be considered.

#### 3.1. Protective Coatings

Coatings protect metal from the environment and are the primary methods for corrosion protection. These coatings are designed for specific service environments to protect the underlying metal. Protective coatings typically consist of three components: binder (resin/polymer), pigment, and solvent. In some instances, coatings may leave some components out. For example, a coating comprised of 100% solids materials does not have a solvent. The three generic types of coating materials for protecting metals are:

- **Inhibitive.** Lead and chromate primers were inhibitors, and coatings containing these pigments provided corrosion protection by passivating the steel surface preventing oxidation. Examples used today include zinc phosphate pigments.
- **Barrier.** Barrier coatings rely on the coating to form a barrier between the electrolyte and the metal. Examples used today include epoxy, polyurethane, moisture cured urethane, vinyl, vinyl ester, alkyd, polysiloxane, and silicone.
- **Sacrificial.** Sacrificial coatings use pigments or metals that are less noble than the steel substrate such as zinc, or aluminum and sacrifice themselves to protect steel. Examples used today include zinc rich primers (organic and inorganic), galvanizing coatings, and metallizing coatings.

Note that, many of the original coatings applied to structures are no longer available. Lead and chromate-based paints and coal tar enamel are no longer used due to the environmental and health toxicity concerns. Vinyl coatings have been restricted due to changes in the U.S. Environmental Protection Agency's (EPA) volatile organic compounds (VOC) limits set in the 1990s, but they can still be used if the structure is in impacted immersion service.

In general, most coatings today will not be able to provide a service life as long as the original coatings did. It is important to recognize this and to develop and follow a maintenance plan to conduct spot repairs frequently. Cathodic protection should be used to help extend the service life whenever it is feasible, practical, and cost effective. Note that CP is typically not an effective solution for corrosion mitigation in locations such as the interior surface of a siphon or other pipeline due to the high flowrates. Evaluating the need for CP on structures should be performed on a case by case basis.

### 3.1.1. Selecting Coatings

Coatings selection should be determined by the exposure conditions and environmental conditions during application. Selecting the best protective coating can be complicated because each manufacturer has a variety of products to select from. For areas with limited access, a product that can be brushed or rolled is preferred over products that are applied by conventional spray or airless spray equipment. Pipelines and flat surfaces can use faster setting materials but require using plural component equipment. Advances in robotics technologies for pipe lining replacement have allowed for extremely fast turnaround for projects and a 100,000 square foot job can be completed in 90 days.

General rankings for product selection are:

For atmospheric exposure:

Good – alkyd/ silicone alkyd, and waterborne acrylics

Best – zinc rich primer/ epoxy intermediate/ polyurethane or polysiloxane topcoat, and galvanizing/ metallizing

For water immersion:

Good – MC urethanes, epoxy, 100% solids epoxy, vinyl ester, coal tar epoxy, and polysiloxane

Best – vinyl (for impacted immersion only)

For buried exposure:

Good – extruded polyethylene, fusion bonded epoxy, and tape with rock shield

Best – AWWA C222 Polyurethane

Invasive Mussel Control:

Best – Silicone foul release coating system



Service life is directly related to the level of surface preparation, proper coating selection, and correct application techniques. Work with a coatings specialist from Reclamation's Technical Service Center (TSC) for proper selection and application guidance. See <https://www.usbr.gov/tsc/>.

### 3.1.2. Protecting Difficult-to-Protect Areas

Non-continuous surfaces such as crevices, riveted construction, back-to-back plates, bolted connections, or skip welds are problem areas and are normally the first areas to experience coating degradation. Most coatings available today are highly crosslinked and crack with any movement. Flexible caulking is used to aid in corrosion protection of these features—but this caulking may also require frequent maintenance.

## 4. Maintenance and Coating Repair

### 4.1. Safety and Health

Most original coatings contain hazardous materials, such as asbestos, polychlorinated biphenyls (PCB), poly aromatic hydrocarbons (coal tar) and the eight heavy metals listed under the Resource Conservation and Recovery Act (RCRA) (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver).

Test old coatings for hazardous materials prior to disturbing them or doing any maintenance work. Always follow the Reclamation Safety and Health Standards manual, Occupational Safety and Health Administration (OSHA), and EPA regulations. Respirators with air purifying particulate cartridges may be enough when cleaning power tools or hand tools. Tyvek suits help prevent clothing contamination and prevent skin contact. Good hygiene should be used to prevent accidental ingestion or inhalation of dust. Solvents should not be used to clean hands upon accidental contact with skin; always use soap and water. For abrasive blast cleaning, follow the OSHA regulations on using an air-supplied blasting helmet and an appropriate suit. Use proper containment and adequate air flow when working with hazardous materials.



If you are unfamiliar with hazardous materials characterization, handling and/or disposal, get help from a Reclamation TSC hazardous materials expert or similar professional.

See [Reclamation Safety and Health Standards](#).

### 4.2. Safety Plan

Develop a safety plan before doing any inspection, maintenance, or repair. The many safety hazards in coatings work include exposure to chemicals, flammable materials, confined spaces, and fall protection. Having a well-thought-out plan may save your life.



### **4.3. Surface Preparation**

Follow the coating manufacturer's surface preparation requirements at a minimum. Coating service life is directly related to the degree of surface preparation, so meet or exceed the surface cleanliness requirements. Surface preparation is typically the most labor-intensive activity in coatings maintenance taking two-thirds to three-quarters of the time for the entire project.

These surface preparation methods are considered suitable for spot repairs:

- Abrasive blast cleaning brush-off blast (SSPC-SP7/ NACE 4)
- Power tool cleaning using a bristle blaster, angle grinder, needle gun, or wire wheel (SSPC-SP3 or SSPC-SP11)
- Hand tool cleaning using sand paper, nonwoven pad, paint scraper, or wire brush (SSPC-SP2)
- Chemical strippers

For complete removal and recoat projects, follow the paint manufacturers' recommendations for the degree of surface preparation. Typical requirements are abrasive blast cleaning to SSPC-SP10 or SSPC-SP5, near white and white metal blast, respectively.

### **4.4. Coating Repair Materials**

Materials which are compatible with the existing coating should be selected for spot repairs; this requires knowledge of the existing coating. If the existing coating is unknown, use a surface tolerant epoxy or moisture cured urethane as the primer coat. This should provide the best adhesion as you feather the edges around the repair areas.

For full recoat jobs, use the best coatings designed for that particular service environment. Consult with coating manufacturers, coating specialists, and/or consultants to find the best products.



## 5. Condition Assessment and Project Planning

The primary goal of a condition assessment is to manage the corrosion protection of a given asset. Assessing the condition of any coating is challenging and subjective. Figure 13 is a flowchart showing a typical sequence of condition assessments and steps in project planning. In general, to assess a facility:

- Begin with a general assessment of the condition of the entire structure.
- After the overall condition has been assessed, a project engineer or supervisor can narrow the maintenance options.
- If repairs are necessary, a detailed inspection should follow to identify damaged coating locations, sizes, and quantities.
- Analyze the data to determine the degree of repairs required. This is usually defined as:
  - *Recoat*: Surface preparation and recoat the entire structure.
  - *Zone repairs*: Surface preparation and recoat of large areas of the structure.
  - *Spot repairs*: Surface preparation and recoat small damaged areas of the structure.
- Evaluate available funds and, if needed, conduct an economic analysis.

Considering all of these factors ensures a technically and financially sound maintenance decision.



If you have questions or seek additional guidance in determining feasible coating maintenance options or evaluating those options, get help from a Reclamation TSC expert or similar professional.

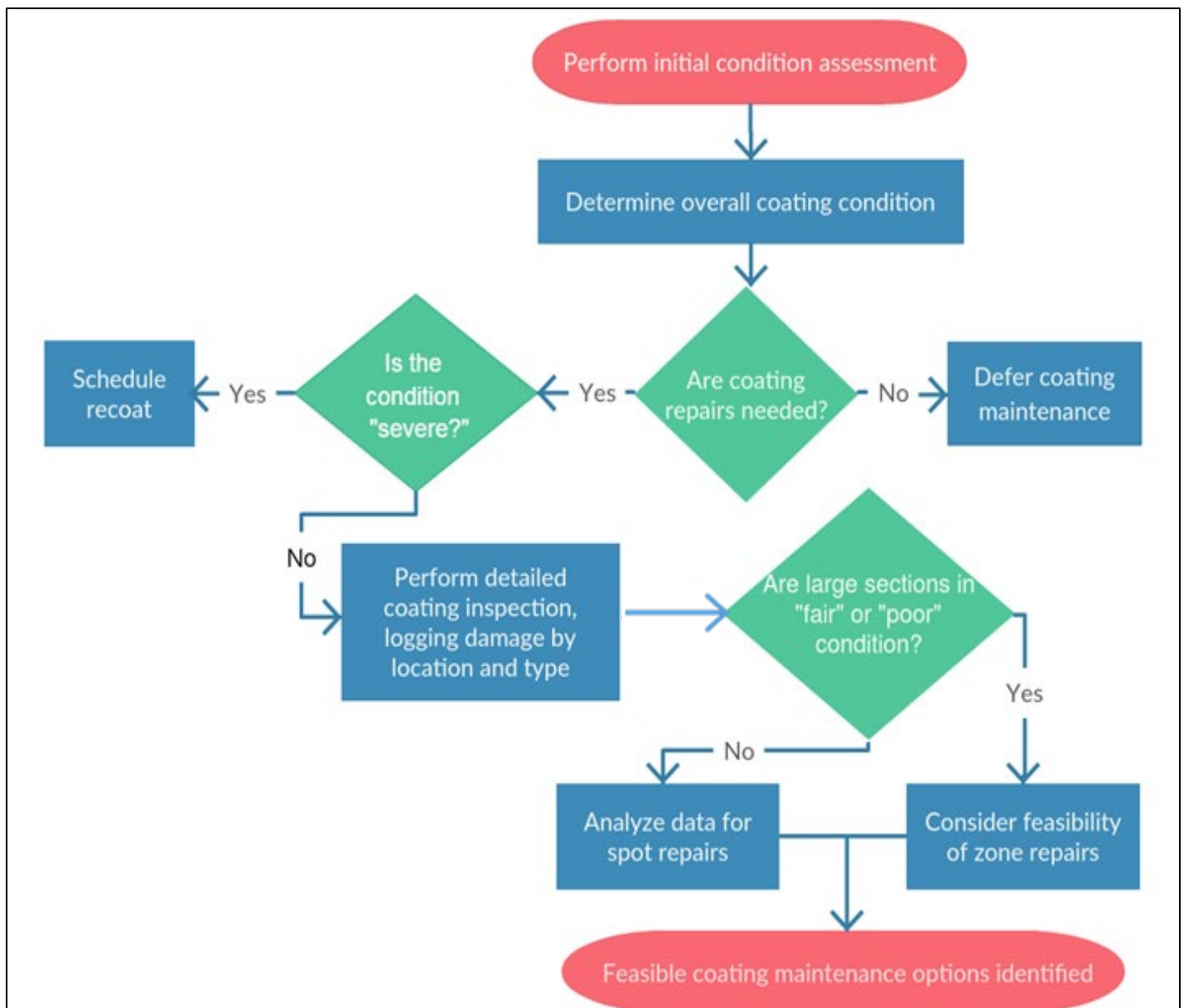


Figure 13. Flowchart for assessing and determining coating repair options.

## 5.1. General Assessment

An inspector should use Table 2 to rank the structure's general condition. These rankings are generic and subjective to the inspector's opinion of the overall condition, but they can be used to generalize the condition of the entire structure. This ranking includes a rough estimate of the total percentage of all coating damages (that is degradation, visible corrosion, and physical damage). In some instances, the structure can be split into different areas if the condition is severely damaged in one area, but good in another area. This is common when structures are subjected to multiple exposure conditions (for example, radial gates experience fluctuating immersion service).

**Table 2. General Inspection Ranking of Coating Conditions**

| <b>Ranking</b> | <b>Description</b>   | <b>Approximate Damage*<br/>(per 1,000 square feet<br/>and as percentage)</b> |
|----------------|--|--|
| Excellent      | Coating is in nearly perfect “as-applied” condition. Coating has limited visible damage.   | < 1 square feet<br>(< 0.1%)  |
| Great          | Coating has small damaged areas in a few locations. Coating could have some early stages of degradation with surface microcracking but no visible corrosion.           | 1-5 square feet<br>(0.1-0.5%)  |
| Good           | Coating has small damaged areas occurring in several localized areas. Coating could have some early stages of degradation with microcracking but no visible corrosion. | 6-10 square feet<br>(0.6-1.0%)   |
| Fair           | Coating has small to medium sized damaged areas appearing in several locations or larger damaged areas in a few locations.   | 11-50 square feet<br>(1.1-5.0%)  |
| Poor           | Coating has many small to medium sized damaged areas appearing in many locations, larger damaged areas in a several locations, or a single very large damaged area.    | 51-100 square feet<br>(5.1-10.0%)  |
| Severe         | Coating has extensive small to medium sized damaged areas that appear widespread throughout the inspection area or many large damaged areas                            | > 100 square feet<br>(> 10.0%)   |

\* The approximate damage provides a measure of the average density observed throughout the structure.  
Damage" includes defects, breaks, blisters, macro cracking, micro cracking, delamination, corrosion, pinholes, etc.

## **5.2. Detailed Assessment**

Detailed assessments are comprehensive analyses that provide a greater level of detail, including quantity, size, and location of damage in an inspection log. Labeling the condition of the coating is not as important at this level of assessment inspection because the goal is to identify all locations to be repaired. An inspector should break the structure down into smaller pieces (that is, identify a damage location within the structure). Table 3 shows an example of an inspection log broken down into pipe segments. Breaking the structure down into shorter sections simplifies the inspection—making it easier to document the location and extent of damage within each section. Individual corrosion spots can also be documented by estimating the specific location using station numbers, distances, or features of the structure. Labeling the type of damage at each location (such as blisters, cracks, spalls, uniform corrosion, or pits) makes it easier to identify later and determine if any new damage has occurred.

**Table 3. Sample Inspection Log in Pipe Segments**

| Pipe Segment<br>(20 feet/<br>segment) | Damage by clock position |                         |                            |                            | Surface Area/<br>Segment<br>(ft <sup>2</sup> ) | Notes  |
|---------------------------------------|--------------------------|-------------------------|----------------------------|----------------------------|--|--|
|                                       | Crown Area<br>(10-2)     | Invert Area<br>(4-8)    | Left Spring-line<br>(8-10) | Right Spring-line<br>(2-4) |  |  |
| 1                                     | —                        | 4 square feet           | 3: 0.5-inch diameter spots | 3: 3-inch diameter spots   | 10   | Segment contains the siphon breaker and temporary dike. There are anchors at 4, 6, and 8 o'clock.  |
| 2                                     | 30 square-feet           | —                       | 3: 1-inch diameter spots   | 4: 3-inch diameter spots   | 37   | Rust in cracks on the pipe crown across a 6-foot-wide swath in last 5-foot length of the pipe segment; 30 square-foot zone repair plus seven spot repairs. |
| 3                                     | 120 square feet          | —                       | —                          | —                          | 120  | Rust in cracks on the pipe crown across a 6-foot-wide swath over the length of the pipe segment.   |
| 4                                     | —                        | 1: 3-inch diameter spot | —                          | —                          | 1  | Coating is in excellent condition.   |

### **5.3. Data Analysis and Quantifying Surface Area**

After all the damaged areas for the entire structure have been documented, thoroughly analyze the data. Common practices include:

- Consider grouping damages that are close to each other into one spot repair area, rather than multiple repair areas.
- Determine damage boundaries (where to draw the lines of the repair area).
- Determine if the surrounding coating is in serviceable condition and capable of interfacing with the repair areas without further degradation.
- Make a list of priority areas, in case there is not enough time and budget to conduct all repair areas.

Typically, most contracts have a minimum of one square feet of area as a pay item. For spot repair areas that are less than one square foot, the contractor receives payment for one square foot. The contractor will measure the amount of coating removed—not just the size of the damaged area. This is important to remember when quantifying the total amount of surface area that requires repair.

The detailed condition assessment only represents the condition at the moment it is inspected. The coating will always continue to degrade, so it is best to slightly overestimate the repairs because it may take several years before a contractor can begin work onsite.

### 5.4. Economics of Maintenance Decisions

In most cases, a coating must be replaced several times during the operational lifetime of a facility. As a result, additional assessments of the annualized lifecycle costs may help to determine the appropriate maintenance activity. The annualized cost is the actual “direct” cost of the coating on a “per year” basis, and an economist can help ensure that the analysis properly accounts for the time value of money. Direct costs are costs associated directly with the project. Most people think contract costs are the only direct costs; however, there are other direct costs associated with the project. For example, acquisitions costs, facility costs, and construction support costs can also be associated with supporting the contractor.

Indirect costs are costs that cannot be readily assessed or realized. For instance, lost revenues for hydroelectric power generation or water delivery lost during maintenance outages are indirect costs. While these costs are not incorporated into the economic analysis or a cost-benefit analysis, these costs should still be considered in planning.

In general, the longer a coating can be kept in service before replacement, the longer the service life and the lower the annualized cost will be. Performing periodic maintenance activities, like spot repairs, can effectively reduce the annualized cost. This is most often true when the damaged areas represent a low percentage of the total coated structure. Adding cathodic protection is another alternative for corrosion protection of aging infrastructure to extend the service life.

Consider other site-specific variables that have economic impacts for facilities. A few example questions include:

- Are the available maintenance opportunities constrained by very short outage periods?
- Is the next outage opportunity for coating maintenance years or decades from now?
- Is the coating maintenance budget available, or are there severe funding constraints or limitations?
- Is the access to the structure and grade of slope within it going to impact work production rates?

- Is the work going to be scheduled for winter months, and will the structure have proper environmental conditions for coating application?

These questions can help determine the best approaches for a facility's specific circumstances. For example, conducting spot repairs may result in shorter down times that may justify higher costs if the outage period is the priority.



If you have an unfamiliar condition assessment or project planning, get help from a Reclamation TSC expert or similar professional.

## 6. Infrastructure Material Selection

Proper selection of materials can also reduce the risk of corrosion. For example, galvanic corrosion can be limited by eliminating situations of dissimilar metals in direct contact with each other when possible. When materials must be in direct contact with one another, choosing materials with similar potentials on the galvanic series will reduce the driving force for corrosion. Metallic and non-metallic materials which are more resistant to corrosion can also be substituted for conventional structure materials.

### 6.1. Corrosion Resistant Metals

Mild steel is susceptible to corrosion in most environments. Galvanizing can protect mild steel, but only in atmospheric conditions. Galvanized steel is not recommended in submerged or buried environments. Stainless steels are more noble (more corrosion resistant) than mild steel; however, the cost of the material can often deter its use. While stainless steels are more resistant to many corrosion mechanisms, not all stainless steels alloys are impervious to corrosion mechanisms such as crevice corrosion and pitting corrosion.

### 6.2. Non-Metallic Materials

Non-metallic materials such as plastics and composites can often be used as substitute materials for metals, including:

- Polyvinyl chloride (PVC)
- High density polyethylene (HDPE)
- Fiber reinforced polymer (FRP) composites:
  - Beams (Figure 14)
  - Pipe
  - Gratings (Figure 15)
  - Handrails (Figure 16)
  - Stoplogs (Figure 17)
  - Small gates (Figure 18)



**Figure 14. An FRP structural beam is lighter than a steel beam (Strongwell Corporation, all rights reserved).**



**Figure 15. FRP gratings on a fish rail structure.**



**Figure 16. FRP handrails on a bridge (Strongwell Corporation, 2015, all rights reserved).**



**Figure 17. FRP stoplogs. (Plasti-Fab, nd, all rights reserved).**



**Figure 18. FRP slide or sluice gate. (Plasti-Fab, nd., all rights reserved.)**

Non-metallic materials are often easier to transport, install, and maintain than many of their metal counterparts. The handrail shown in Figure 16 does not require welding or coating and can be easily assembled and installed without the use of heavy equipment or a large number of personnel.

Ultra-violet (UV) light inhibitors can be added to the resin and coatings for outdoor exposure conditions. Carbon fiber reinforced polymers (CFRP) have been used by both Reclamation and other water entities for lining damaged siphon pipe, such as prestressed concrete cylinder pipe. See Reclamation, 2019, PCCP: Condition Assessment, Repair, and Replacement Strategies for more information on prestressed concrete cylinder pipe.



### 6.3. Fiber Reinforced Polymer Repair Method

Where corrosion or other damage is found along the inside of reinforced concrete, prestressed concrete cylinder pipe, or steel pipe or siphon, glass fiber reinforced polymer (GFRP) and CFRP in-place lining are cost-effective repair solutions. GFRP and CFRP can also be used to wrap the outside of an exposed pipe or siphon. It is important that the first layer of the FRP repair for steel pipe be GFRP. The method requires no excavation and only needs a short downtime.

CFRP is a common repair method for prestressed concrete pipe. CFRP system design accounts for internal pressure and backpressures and can accommodate a variety of joint and leading-edge details as necessary to function as originally intended. FRP materials have also been used in reinforcing bridges and decks. Figure 19 shows a completed CFRP section inside a reinforced concrete siphon pipe.



**Figure 19. Completed CFRP lined 25-foot section of a 14-foot 8-inch diameter cast-in-place reinforced concrete pipe.**

CFRP rehabilitation can begin soon after repairs to the underlying concrete are completed. The short installation period reduces the costs due to the outage. Return to service is usually about 3 days after installation completion for the polymer to cure. This does not include time required for any needed concrete repairs. All the epoxies are mixed outside the pipe or other confined space and are 100% solids, so they contain no solvents or volatile organic compounds.

## 7. Cathodic Protection

### 7.1. What is Cathodic Protection?

Cathodic protection is a method used for controlling or mitigating the corrosion of a metallic structure by turning the structure into a cathode. This can be accomplished either passively or actively; passively by connecting the metal structure to another metal that corrodes rather than the structure (galvanic anodes), or actively by applying direct current to an anode connected to a structure (impressed current). Both methods cause the structure to become cathodic and mitigate corrosion.

Figure 20 and Figure 21 show how the surface of a structure has both anodic and cathodic sites causing corrosion. Figure 21 also shows how adding a coating can reduce the number of these sites by providing a barrier from the electrolyte. Corrosion will only occur at defects where the coating is absent (holidays), damaged (scratches and abrasions), or degraded. Holidays are holes in the coating which occur during application.

In the following figures, the more positive voltages represent the cathodic areas on the metal surface, while the more negative voltages represent the anodic areas. Whether a site acts as a cathode or an anode depends on the potential of the area next to it. For example, the second area from the right in Figure 20 is a cathodic site (-0.6 V) compared to the anodic site (-0.7 V) to the right but is anodic compared to the cathodic site (-0.5 V) to the left. Figure 22 and Figure 23 show how adding an external anode supplies the necessary current to change the potentials of the cathodic sites to those of the anodic site and thus mitigate corrosion. Figure 23 shows how the current is only changing the potentials at the bare sites.

*The best protection system uses both protective coatings and cathodic protection to achieve the desired design and operation life of a structure.*

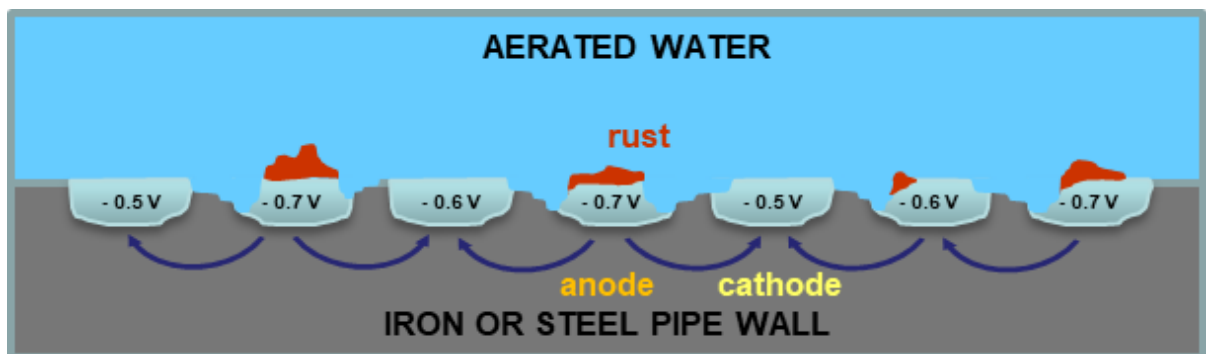


Figure 20. The schematic shows corrosion (rust) at the anodic sites on the steel surface and how there are both anodic and cathodic areas over the surface of a metallic structure. The values represent examples of differences in potential.

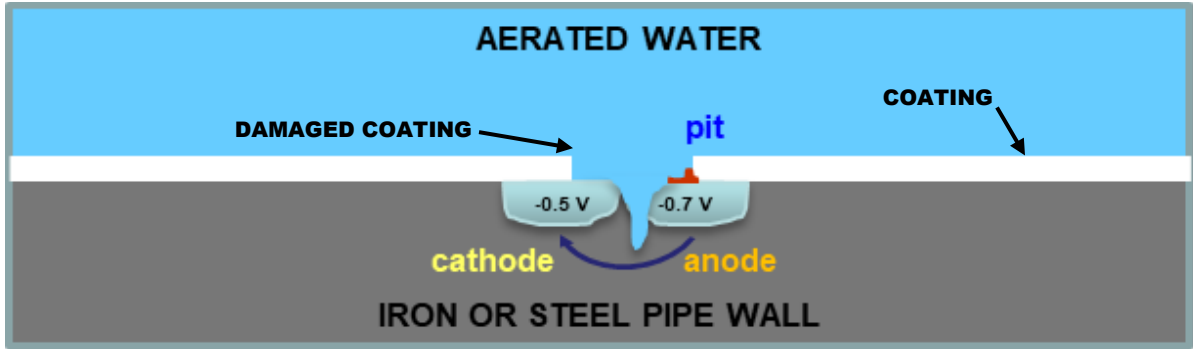


Figure 21. The schematic shows how applying a coating can reduce the area of anodic and cathodic sites and provides an example of a holiday. The coating acts as a barrier by mitigating the exposure of the structure to the electrolyte. Corrosion will occur in areas of coating damage and holidays in the coatings.

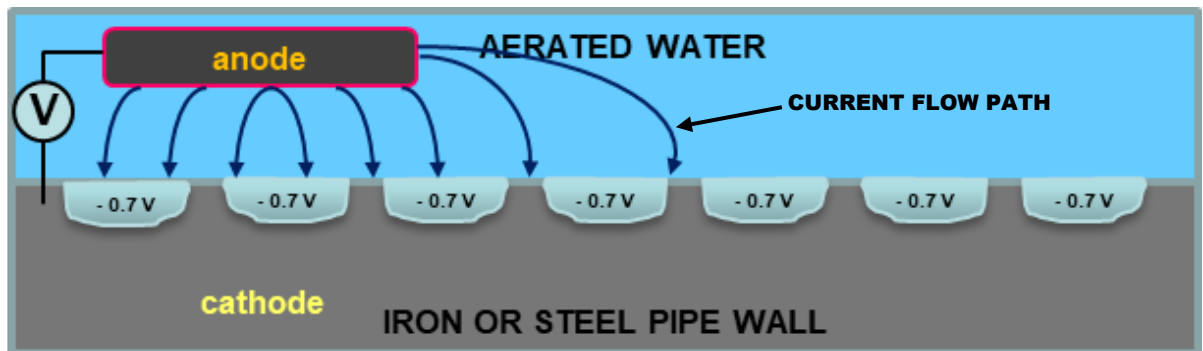


Figure 22. The schematic shows that adding an external anode to the circuit (ACME) supplies the current necessary to change the potentials of the cathodic sites to the same potential as the anodic sites, reducing the rate of corrosion.

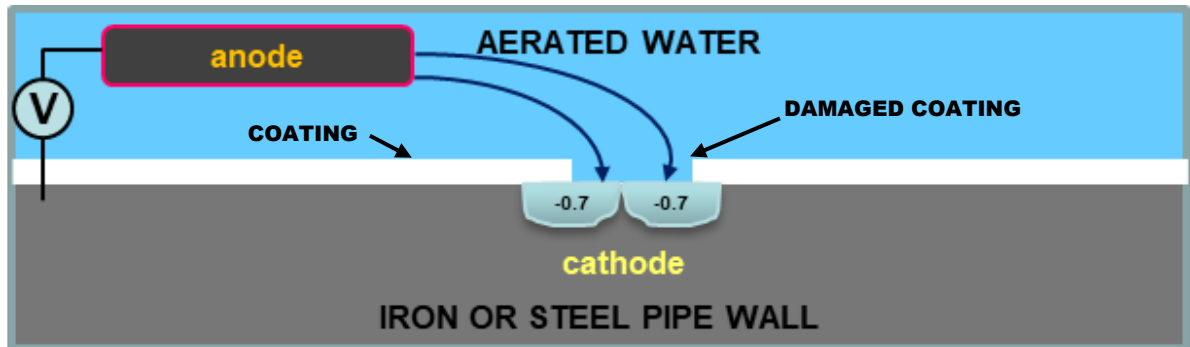


Figure 23. The schematic shows the optimal corrosion protection system, protective coatings with cathodic protection.

### **7.1.1. When to Use Cathodic Protection**

Not all structures require cathodic protection, and cathodic protection cannot be installed in every situation. CP is required when a structure is susceptible to deterioration to the environmental conditions, such as immersion and burial. While some waters and soils are less likely to cause corrosion, many of these environments are more aggressive—and therefore there is a higher probability that corrosion will occur. For new structures, samples are collected and chemically analyzed for elements such as chlorides, in addition to measuring the conductivity and performing soil resistivity surveys to aid in determining the need for cathodic protection. For existing immersed structures, it is recommended to add CP when corrosion such as galvanic, pitting, and uniform corrosion is observed. Buried structures cannot be visually inspected and, therefore, it is recommended that CP be added to the structure if feasible. Corrosion experts should be consulted to determine if there is a need for additional corrosion mitigation measures and if it is feasible to add CP to a structure.

### **7.1.2. Galvanic Anode Cathodic Protection**

Galvanic anode cathodic protection (GACP) systems, often referred to as sacrificial or “passive” systems, use material selection and galvanic corrosion in a beneficial manner. The natural voltage difference between the anode (typically magnesium or zinc) and the cathode (structure) is used as the direct current (DC) source to cathodically protect the structure. The sacrificial anode preferentially corrodes—rather than the structure turning the structure into the cathode and preventing corrosion.

The anode is connected to the structure through a test station or is directly welded or bolted to the structure (Figure 25). The method of connection depends on the operation and maintenance of the structure. Anodes for buried metalwork are typically connected through test stations while anodes for gates and other submerged structures are often directly attached to the surface by welding or bolting, as shown in Figure 26.

Improper design, installation, and operation of a GACP system can be detrimental to the structure. Therefore, CP experts should always be consulted when dealing with this type of system.

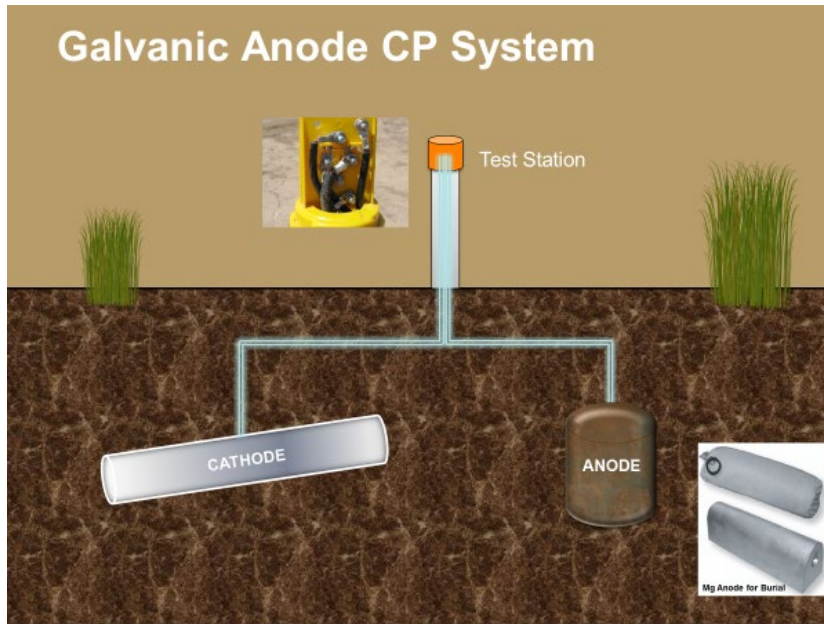


Figure 24. Schematic of a buried galvanic anode cathodic protection system using a test station to connect the anode to the structure.

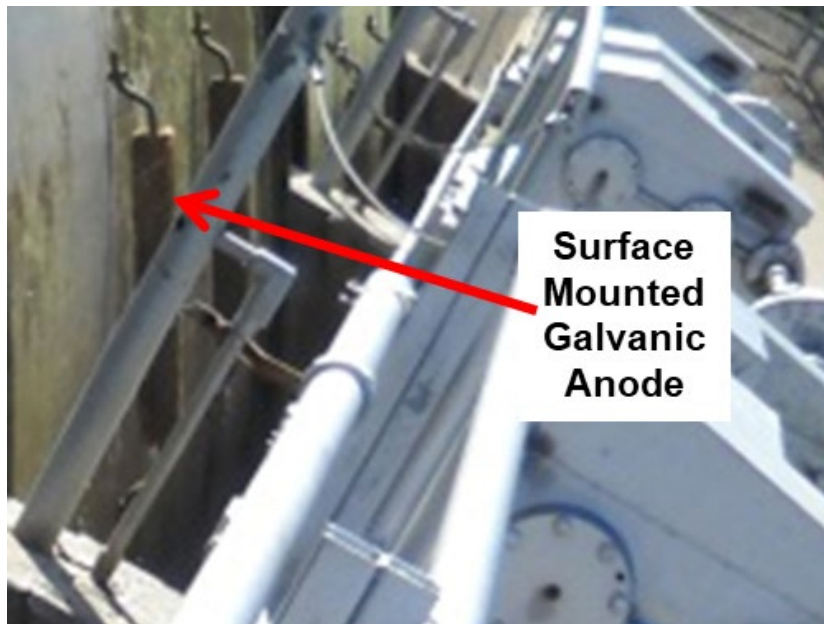


Figure 25. Galvanic anodes bolted directly to the skin plate of the gate.

### 7.1.3. Impressed Current Cathodic Protection

Impressed current cathodic protection (ICCP) systems, often referred to as “active” systems, require an external power source to generate a potential difference between the anodes and structure—enabling a large amount of current to discharge from the anodes through the electrolyte and onto the structure being protected. To minimize auto-corrosion of the anodes and achieve a longer life of the CP system, the anodes typically used for impressed current systems (e.g., high silicon cast iron, graphite, and mixed-metal oxide) are more noble on the galvanic

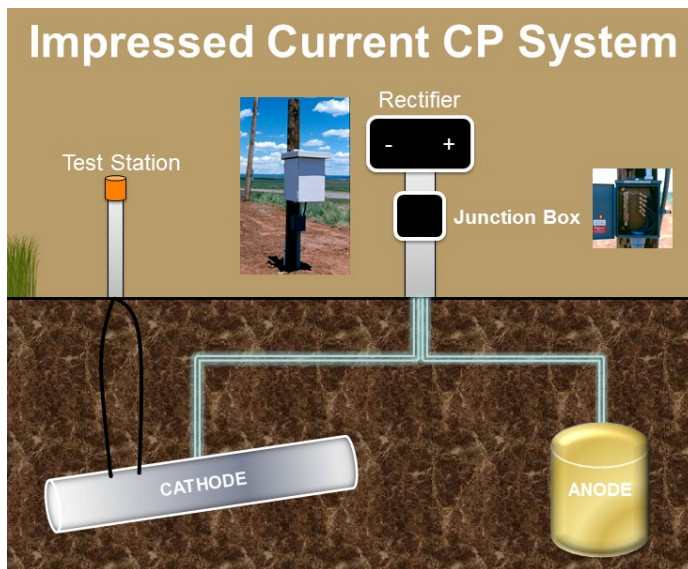
series than the structure. For the current to flow in the correct direction and protect the structure, the negative pole of the rectifier is connected to the structure being protected and the positive pole is connected to the anodes.



Improper design, installation, and operation of an ICCP system can be detrimental to the structure. Structures can be severely damaged if the connections are switched as the current would flow in the opposite direction—causing the structure to become the anode.

***Always consult CP experts when dealing with this type of system.***

Figure 26 shows a schematic of an ICCP system installed on a buried structure. Figure 27 shows a photo of an ICCP system where the anodes are installed (hanging) in front of the gates to protect the submerged portions of the gates. Figure 28 shows a photo of an ICCP system where the anodes are flush mounted on the gate surface. Test stations are used for buried ICCP systems to make an electrical connection for testing purposes.



**Figure 26. Schematic of a buried impressed cathodic protection system.**



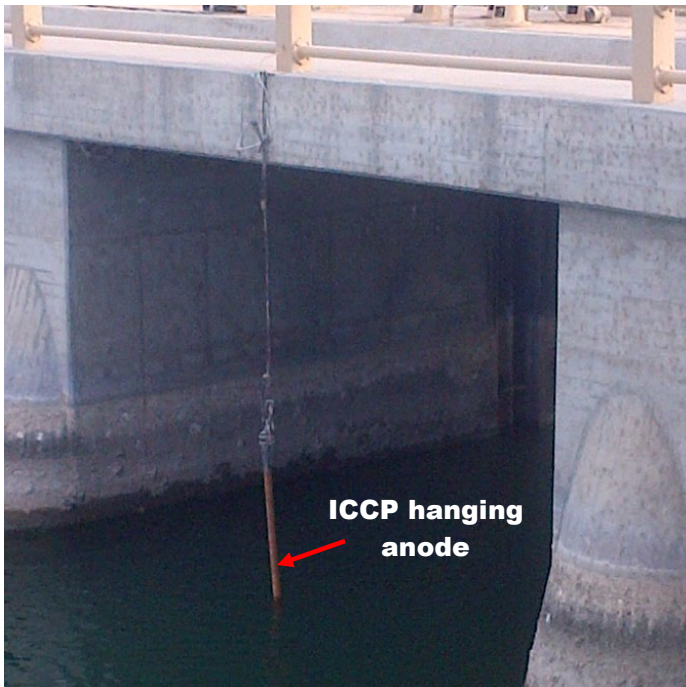


Figure 27. Remote impressed current anodes hanging in front of a gate.



Figure 28. Surface mounted mixed-metal oxide (MMO) disk anode with a dielectric shield for impressed current CP for a radial gate.

## 7.2. Cathodic Protection System Components

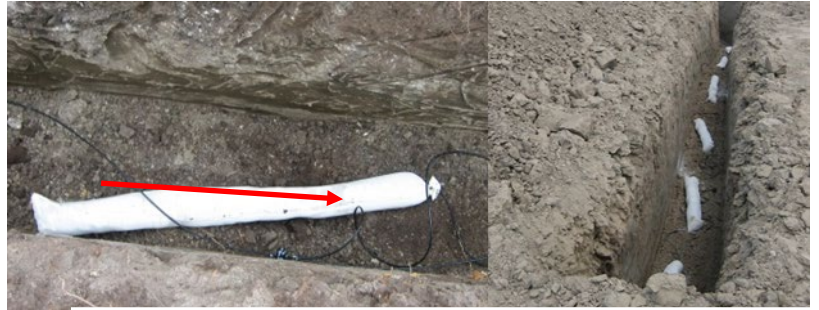
### 7.2.1.1. Cable

The cable used for the CP systems should be stranded copper cable with 0.1-inch thick, high molecular weight polyethylene (HMWPE) insulation.

### 7.2.1.2. Anodes

#### *(A) Galvanic Anodes (GACP)*

The typical anode used for buried service is a bagged magnesium anode such as the one shown in Figure 29. Bagged zinc anodes can also be used in certain situations. The chemical backfill inside the cloth bag keeps the anode active.



**Figure 29. Magnesium galvanic anodes in cloth bags with chemical backfill for buried use.**



Typical galvanic anodes for submersion service are magnesium (freshwater) and zinc (freshwater and brackish water). The magnesium hull mount anode shown in Figure 30 has a plastisol coating to avoid over-polarization, which could damage the coating.

**Figure 30. Magnesium galvanic hull mount anode with plastisol coating for submerged use.**

#### *(B) Impressed Current Anodes (ICCP)*

Impressed current anodes used for protecting buried structures are typically graphite, high silicon cast iron, and mixed-metal oxide (MMO) canisters as shown in Figure 31.

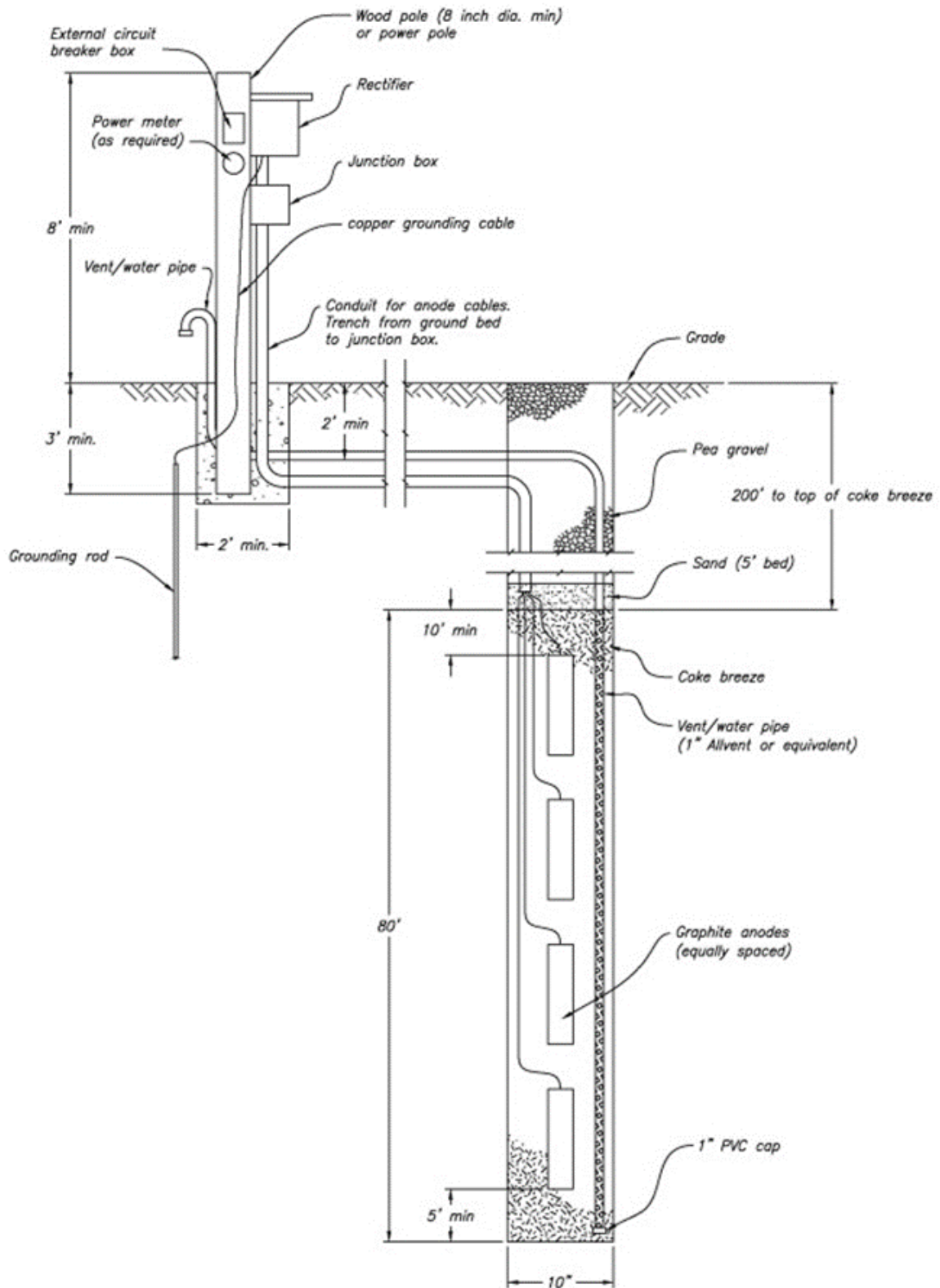


**Figure 31. Impressed current anodes used in anode beds for buried service. From left to right, the photos show example graphite, high-silicon cast iron, and MMO canister type anodes, respectively.**

The schematic shown in Figure 32 is an example of a deep well anode bed used in for long lengths of pipe as well as for areas with limited rights-of-way.



## Canal Operation and Maintenance: Coatings and Cathodic Protection



**Figure 32. Elevation view of a deep well anode bed for an impressed current cathodic protection system.**

High-silicon cast iron anodes can also be used in submerged conditions in addition to the mixed-metal oxide and platinum anodes shown in Figure 33.



**Figure 33. Impressed current anodes for submerged service. The photo on the left is a flush mounted MMO disk anode and the photo on the right a platinum/niobium wire anode in a slotted tube.**

### 7.2.1.3. Test Stations

Test stations are used as a connection to the buried structure to test the effectiveness of both GACP and ICCP systems. In addition to testing the effectiveness of a CP system, they are also used for monitoring the condition of structures without CP, determining CP interference issues at foreign line crossings, and measuring the effectiveness of isolation flanges and casing isolation. Test stations come in many different styles but serve the same purpose.

The plastic test station in Figure 34 is called a Big Fink. There are also cast aluminum test stations (Figure 35). The galvanic anodes are connected through a calibrate resistor or shunt to the structure inside the test station (Figure 36). The GACP test stations also include calibrated resistors (shunts) to measure the current output of the anode(s).



**Figure 34. Big Fink style corrosion monitoring test station (left) and isolation test station (right).**

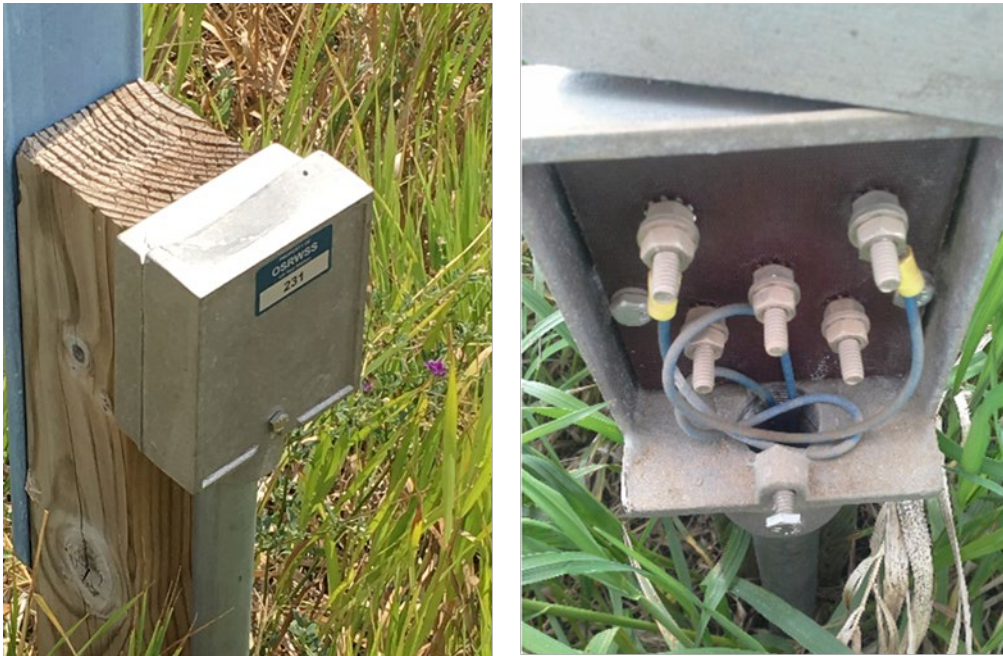


Figure 35. Cast aluminum style corrosion monitoring test station.

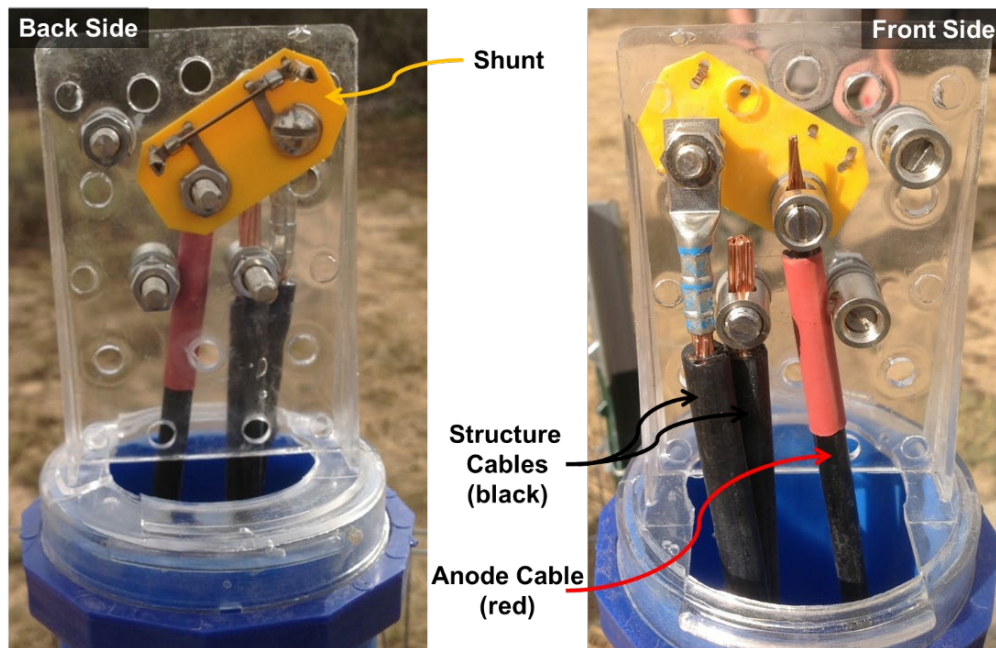


Figure 36. Big Fink style galvanic anode cathodic protection test station.

#### 7.2.1.4. Junction Boxes

Junction boxes are used for both GACP and ICCP systems. Like the test station, a junction box has shunts (Figure 37) to measure the current output of the anodes. Some junction boxes also have variable resistors (Figure 37) so the operator can adjust the output of the anodes and balance this output to use the anode bed more effectively and evenly. An ICCP anode junction box is shown in Figure 38 with all the components labeled.





Figure 37. Two anode junction boxes. Both have shunts; however, the one on the left also includes variable resistors.

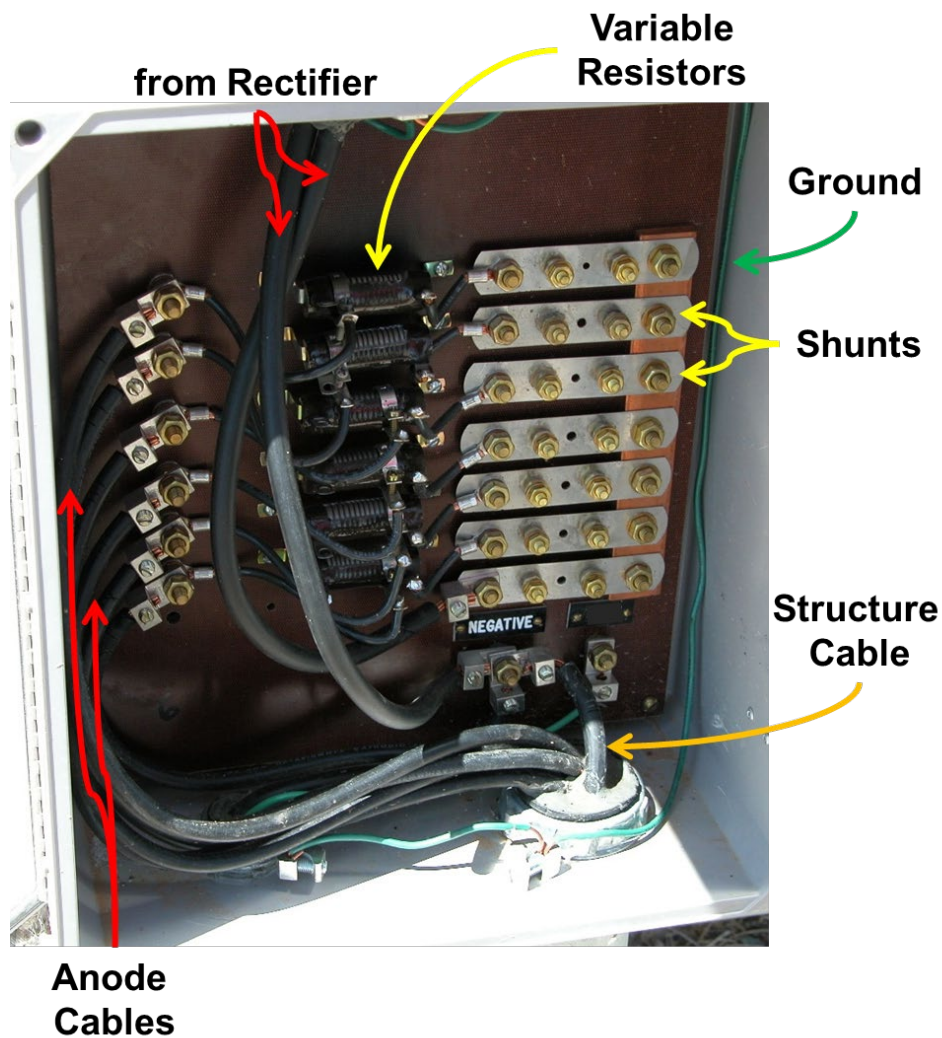


Figure 38. ICCP anode junction box with the critical components labeled, including shunts and variable resistors.

### 7.2.1.5. Rectifiers

Rectifiers are exclusively used for ICCP systems. They rectify the AC current input into a DC current output to supply the required current to the anode bed. An example of a rectifier can be seen in Figure 39. Figure 40 shows the components of a rectifier, including: taps for adjusting the output, breakers, shunt, meters, and positive and negative terminals.



Figure 39. Rectifier for ICCP system on buried pipeline. The photo on the left shows the front panel of a rectifier. The photo on the right is a photo of the rectifier cabinet.

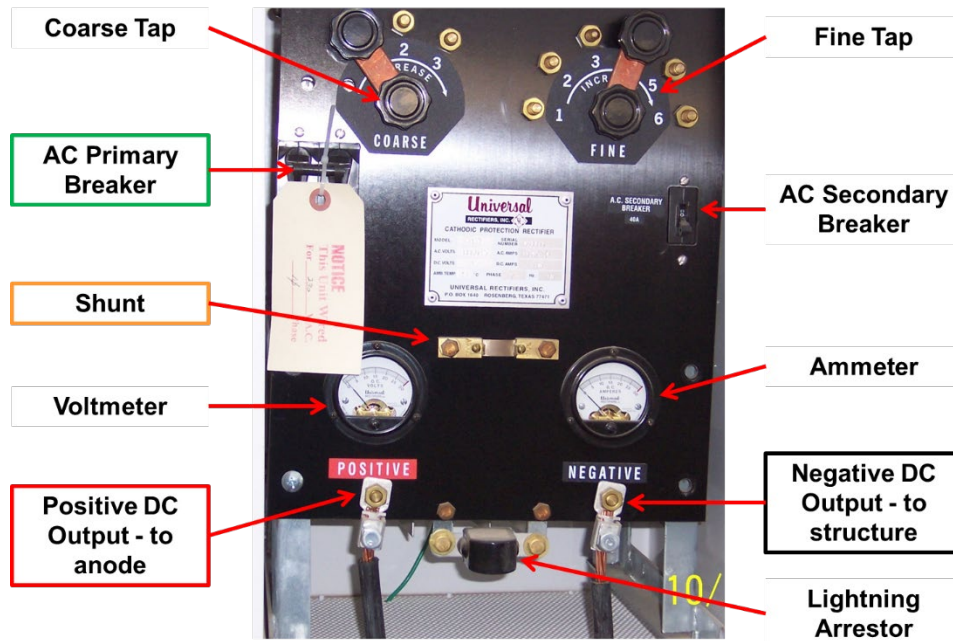


Figure 40. Rectifier front panel with all the components labeled, including the taps for adjusting the rectifier, breakers, meters, shunts, and the positive and negative terminals.



Contact Reclamation to work with corrosion and cathodic protection experts in the Technical Service Center. See:

Reclamation 2012. Technical Memorandum No. MERL-2012-40. [\*Guidelines for Field Installation of Corrosion Monitoring and Cathodic Protection Systems\*](#) has more information on the components and installation of cathodic protection systems

Reclamation 2013. [\*Corrosion and Cathodic Protection\*](#). Facilities Instructions, Standards, and Techniques (FIST) Volume 4-5.



Get a corrosion professional experienced in cathodic protection involved before attempting even simple installations. Such personnel include Cathodic Protection Technologists and Specialists certified by NACE International and are available at Reclamation's Technical Service Center.

NACE International is recognized worldwide as a premier professional society and standards setting organization concerned with corrosion control.

## 7.3. Cathodic Protection System Operation and Maintenance

### 7.3.1. Routine Inspections (Every 2 Months)

Inspections and testing of the CP systems should be performed by operations and maintenance (O&M) personnel every 2 months. During these inspections watch for and report problems such as:

- **Fencing and lockouts.** Check for any broken fences or locks to ensure that the test station remains secure against vandals, animals, or insects.
- **Missing test stations.** Find out where test stations should be and check them when you are out in the field. Look for other clues to missing stations, such as increased spacing between existing test stations or wires sticking out of the ground.
- **Power surges or disconnections.** Power disruptions from lightning, vandalism, or siphoning can damage rectifiers and test stations.
- **Insect, rodent, or water damage.** Insects and rodents can get into rectifier cabinets and cause damage and corrosion of components.
- **Vandalism or theft.** Report and plan to replace damaged components.



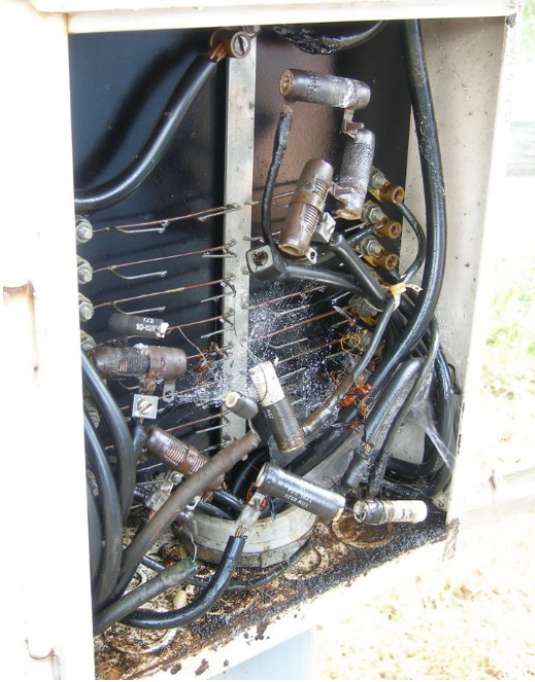
### 7.3.2. Maintenance to Prevent Damage

Where possible, prevent damage. Spending a little now can save a lot of time, hassle, and money later:

- Install screens (allows for heat dissipation and keeps out rodents and insects (Figure 41))
- Ensure cabinets are sealed and locked
- Erect barriers to deter damage
- Install lightning arrestors in rectifiers (prevents major damage to a rectifier when they are struck by lightning such as what happened to the anode junction box (Figure 42))



Figure 41. Junction boxes discovered containing a nest of grass and a wasp nest.



**Figure 42. Junction box with scorch marks on the door and cables with melted insulation and broken resistors.**

Protecting CP components from damage and performing the required repairs and replacement is paramount to an effectively operating CP system and protecting your structure. Keep test stations well maintained. Clear excess vegetation to ensure visibility (Figure 43) and discourage vandalism or theft (Figure 44) to prevent undermining the CP system on the structure.



**Figure 43. There is a test station somewhere in that growth.**





**Figure 44. Vandalism of junction box—shot, knocked down, and copper cable removed for salvage.**

When conducting maintenance activities such as clearing or burning, make sure that any test stations are protected and well away from any activity which could damage them (Figure 45). Maps or plans can prevent accidental burnings.



**Figure 45. O&M personnel burned debris collected from the canal next to a test station and melted it, so the test station had to be replaced.**



**Figure 46. Test station damaged during the removal of vegetation.**



### 7.3.3. Inspection of Submerged GACP Systems

Cathodic protection anodes will not last forever. Anodes are designed to be consumed and require periodic replacement to continue to mitigate corrosion of a structure. Thus, routine checks are required to ensure that the anodes are still working. Document and keep track of when the anodes were installed and when they need to be replaced to forecast future needs (Figure 47 and Figure 48). Check for corrosion around anodes and loss of mass of anodes to determine replacement needs. If the anodes are not replaced when they are expended, the result can be significant as shown in Figure 49.



Figure 47. Nearly new hull anode is shown on the left while a depleted anode is on the right. Note the lack of corrosion around the anode on the right.

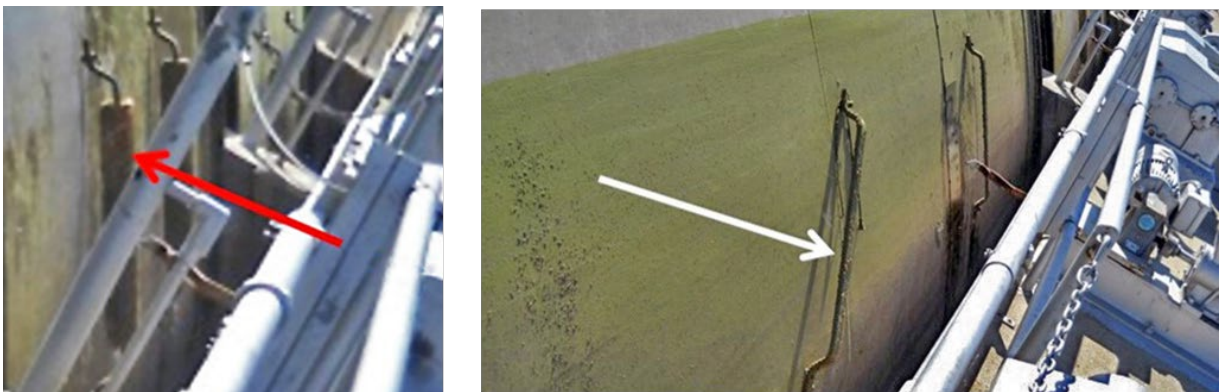


Figure 48. Nearly new rod anode is shown on the left while a depleted anode is on the right. Note the lack of corrosion around the anode on the right.



**Figure 49. Galvanic anodes were not replaced after they were expended—resulting in extensive corrosion damage.**

Documentation and personnel may not know where all the anodes are located, so inspections are key to system performance. Anodes have a non-sacrificial galvanized steel core. Significant or complete exposure of this core is a good indication that it is time to replace the anode. Inspect all metallic structures for steel rods, straps, or other unknown metalwork to ensure it is not a core wire for a CP system. Do not remove random wires connected to the structure or anodes! Photograph and note the location to help determine if this is an old anode that needs to be replaced.

A simple test is needed to confirm if a sacrificial anode or impressed current system is providing the proper level of protection. No less than every two months operations and maintenance (O&M) personnel shall inspect the rectifiers on ICCP systems to determine if they are still operating and note any damaged GACP, ICCP, and any corrosion monitoring test stations for repair and/or replacement. Additional test procedures are provided in Section 7.4.



***Improper maintenance and operation of CP systems, especially ICCP systems, can result in the corrosion of the structure and result in potential catastrophic failure.***

Trained O&M personnel or other certified professionals should test all CP systems and adjust all system adjustments annually.

## 7.4. Cathodic Protection System Testing

Structure-to-electrolyte surveys are annual measurements performed at test stations using a voltmeter and reference electrode to determine the effectiveness of a cathodic protection system. Close-interval surveys involve measuring the structure-to-electrolyte measurement every 3 to 5 feet along a pipeline.

Periodically inspecting and testing of the CP systems every 2 months can be performed in conjunction with any other required inspections. Coordinate with Reclamation staff and perform all testing in accordance with the standard operating procedures (SOP) for every specific CP system. Table 4 shows an example of inspection type and frequency for GACP and ICCP systems.

**Table 4. Examples of Inspection and Testing Frequency for GACP and ICCP Systems.**

| Corrosion inspection frequency               | Structure-to-electrolyte survey | Close-interval survey*   | Test station integrity and inspect rectifiers for ICCP systems | CP system data analysis by CP expert |
|--|---------------------------------|--|--|--------------------------------------|
| Annually dependent on access and maintenance | Annually                        | Every 5 years; when leaks occur or when system has been off for an extended amount of time | 2-month intervals  | Every 3-5 years                      |

\* Not required for GACP systems on plastic pipe with metallic fittings.

### 7.4.1. Safety

Safety issues involved with cathodic protection systems include, but are not limited to:

**Environmental issues** including heat, cold, rain, and lightning:



Do not test electrical equipment when it is raining.

**Insects and other pests** including snakes, wasps, and spiders:



Watch where you step.

Open junction boxes, test stations, and rectifiers with care.

**Rectifiers** have safety concerns from both alternating current (AC) and direct current (DC) voltages:



Approach a rectifier carefully.

Check for grounding using an AC voltmeter or AC voltage proximity detector: Do not grab the latch or handle on the rectifier without checking for an AC short. If necessary, touch the cabinet with the back of your hand. If the casing is shorted and you touch it with the back of your hand, you can remove your hand. However, if you grab it and your hand closes, you cannot let go, potentially resulting in serious injury.

All work performed inside the rectifier, other than testing with a voltmeter, should be done with the power off to the unit itself and the external circuit breaker.

If possible, only work with one hand in the rectifier cabinet at a time to avoid creating a circuit through your body.



Shock hazards and shorting are possible within the impressed current anode junction boxes if the box is too small for easy access to all of the cables and resistors. The physiological effects of 60-hertz AC are shown in Table 5. Additional safety considerations should be taken even when dealing with small currents.

**Table 5. Physiological Effects of 60-Hertz AC**

| Current (mA) | Physiological Effect                         |
|--------------|--|
| < 1          | No sensation                                 |
| 1 to 8       | Threshold of perception (no pain)            |
| 8 to 15      | Painful (no loss of muscular control)        |
| 15 to 20     | Painful (cannot let go)                      |
| 20 to 50     | Painful (breathing difficulties)             |
| 50 to 100    | Ventricular fibrillation possible            |
| 100 to 200   | Fibrillation certain (defibrillation needed) |
| > 200        | Severe burns                                 |

### 7.4.2. Test Equipment

The primary equipment, other than tools, required to perform most system measurements are a voltmeter and CSE. Annual measurements performed on ICCP systems also require a current interrupter.

#### 7.4.2.1. Portable Voltmeter

High impedance digital multimeter such as a Fluke Model 27 (Figure 50a), manufactured by Fluke Corporation, 6920 Seaway Boulevard, Everett, Washington, 98203 or equal with the following essential characteristics:

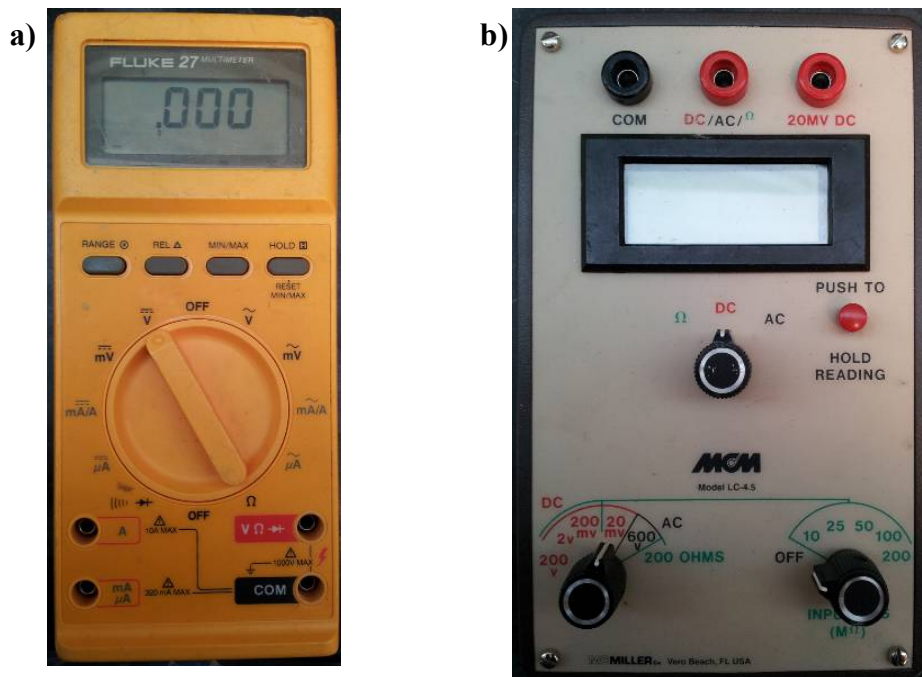


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- i. Minimum input impedance of 10 megohms
- ii. Capable of measuring DC voltages between  $\pm 0.1$  millivolts (mV) to  $\pm 1,000$  volts

Selectable input resistance digital multimeter such as an MCM LC-4 (Figure 50b), manufactured by M.C. Miller Co., Inc., 11640 U.S. Highway 1, Sebastian, Florida, 32958; or equal, having the following essential characteristics:

- i. Selectable input resistance 0 - 200 ohms (0.1-ohm resolution)
- ii. Selectable DC voltage range 0 - 200 volts (0.01-mV resolution)



**Figure 50. Multimeters for measuring potentials associated with CP systems: (a) Fluke 27 digital multimeter, and (b) MC Miller LC-4 variable resistance input digital multimeter.**

### 7.4.2.2. Portable Reference Electrode

Reference electrodes are used as a baseline potential against which the potential of a structure can be measured. They are used during annual testing for determining if a structure is adequately protected. CSE reference electrodes are standard for performing annual testing of the CP systems. An example of a reference is shown in Figure 51.

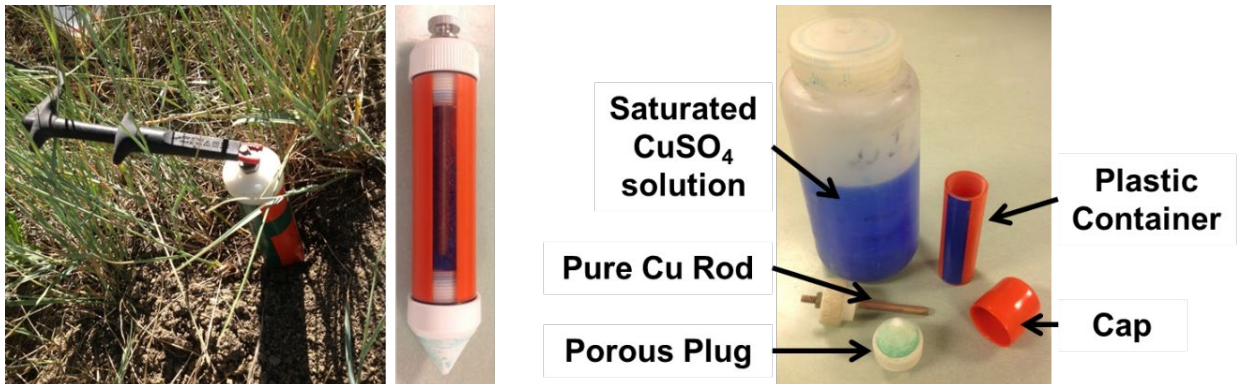


Figure 51. CSE portable reference electrode for performing structure-to-electrolyte potential measurements.

#### 7.4.2.3. Current Interrupter

Current interrupters (Figure 52) are inserted into the rectifier circuit to automatically switch the current on and off at a set interval. This is required to determine the polarized potential of the structure and determine if the structure is adequately protected.



Figure 52. Current interrupter: used to automatically switch the current on and off at set intervals. Used to measure the polarized or “instant-off” potential.

#### 7.4.3. Test Procedure

Inspect test stations, junction boxes, and rectifiers per SOP for exterior damage and be careful when opening them watching for rodents, wasps, spiders, and snakes. The canal should be watered up to perform any measurements on a gate or other submerged metalwork; however, since only the exterior of buried pipelines and siphons are protected with CP they can be tested any time. TSC personnel are available for training staff and testing of CP systems.



#### 7.4.3.1. Periodic Testing

The following inspection and tests should be performed every 2 months on the GACP and ICCP systems.

##### *(A) GACP Systems*

Ensure that damaged test stations are repaired, and the cable labeled anode is reattached to the structure cable through the calibrated resistor (shunt). Anodes shall be visually inspected when the gate and anodes are not submerged to determine the effectiveness and condition of the anodes.

##### *(B) ICCP Systems*

Check that the power is on and the cable connection to rectifier is done according to the following and as shown in Figure 40:

1. Structure cable must be connected to the **NEGATIVE DC** output terminal.
2. Anode cable must be connected to the **POSITIVE DC** output terminal.

Record the rectifier output in volts and amperes using a portable voltmeter:

1. **Volts:** Measure the DC voltage across the negative and positive terminals as shown in Figure 52.
2. **Amperes:** Measure the DC millivolts across the shunt and record the shunt rating using the shunt circled in Figure 53.
3. Record the tap settings.

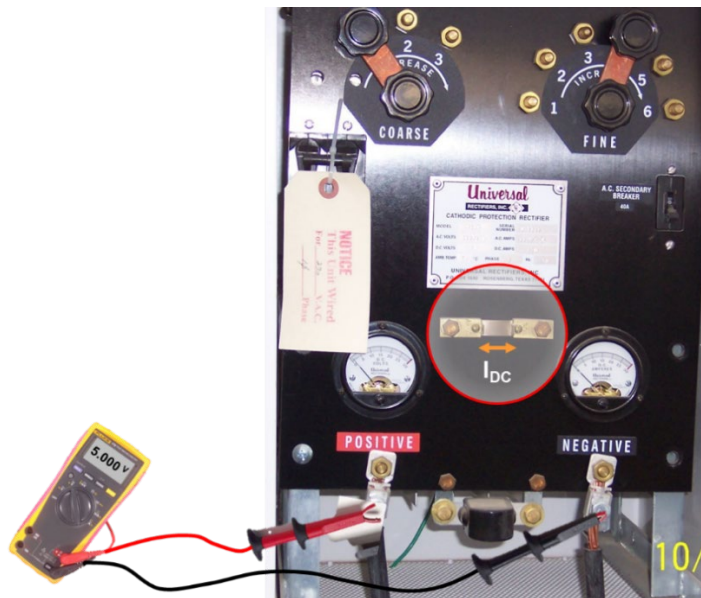


Figure 53. Example of how to perform test measurements on a rectifier.

#### 7.4.3.2. Annual Testing

In addition to the periodic testing, annual testing should also include the following measurements:

1. **Anode current output**
2. **Structure-to-electrolyte potential** (also referred to as structure-to-soil, pipe-to-soil, fitting-to-soil, and structure-to-water potential). This measures the potential of the structure in the electrolyte as compared to the potential of a reference electrode in contact with the same electrolyte.
  - (a) *Uncorrected structure-to-electrolyte potential*: The structure-to-electrolyte potential determined with the cathodic protection system energized and cathodic protection current flowing. This potential is sometimes called the protective potential and may contain significant IR or potential drop error.
  - (b) *Polarized structure-to-electrolyte potential*: The structure-to-electrolyte potential determined after the cathodic protection system has been energized, but immediately after the cathodic protection current is interrupted. This potential is also referred to as “instant off” structure-to-electrolyte potential.
  - (c) *Polarization*: The change from the static or native potential as a result of current flow across the electrode/electrolyte interface. Polarization is also considered the difference between polarized and native potentials.

The anode current output is measured using a voltmeter in the  $mV_{DC}$  setting and measuring the voltage across the shunts in the test stations, junction boxes, and rectifier. The current output is determined by using the equation  $V=IR$  where  $V$  is the voltage measured,  $I$  is the current, and  $R$  is the resistance of the shunt.

The structure-to-electrolyte measurements are performed by using the  $V_{DC}$  setting on the voltmeter and attaching the positive lead to the structure and the negative lead to the reference electrode. Place the reference electrode in the water or on the soil and measure and record the voltage to determine the uncorrected structure-to-electrolyte potential. To measure the polarized or “instant-off” structure-to-electrolyte potential the current must be briefly interrupted. For an ICCP system, the current at the rectifier is interrupted using a current interrupter and the polarized potential is measured. For GACP systems, this test must be performed manually by disconnecting the structure cable from the anode.

The polarized structure-to-electrolyte potentials can only be measured on GACP systems where the anode is not directly connected to the structure. Instead, the anode is connected through a test station.

### 7.4.3.3. Test Results Interpretation

CP protection criteria is listed in Table 6 and is in accordance with NACE International SP0169 and Reclamation standards. Cathodic protection systems which do not meet these criteria must be adjusted or replaced. Consult with a cathodic protection expert before performing all adjustments, repairs, and replacements of the cathodic protection system.

**Table 6. Cathodic Protection Criteria for Structure-to-Electrolyte Readings**

| Polarized potential                     | Minimum polarization   | Maximum polarized potential                    |
|---|--|--|
| -850 mV <sub>CSE</sub> or more negative | 100 mV polarization shift, 100 mV more negative than native potential* | Not more negative than -1100 mV <sub>CSE</sub> |

\* Native potential is the potential of the structure prior to the cathodic protection system being energized.

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