

UNIFIED FACILITIES CRITERIA (UFC)

CATHODIC PROTECTION



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UNIFIED FACILITIES CRITERIA (UFC)

CATHODIC PROTECTION

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U.S. ARMY CORPS OF ENGINEERS

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER CENTER (Preparing Activity)

Record of Changes (changes are indicated by \1\ ... /1/)

Change No.	Date	Location

This UFC supersedes UFC 3-570-02A, dated March 2005 and 3-570-02N dated January 2004.

FOREWORD

The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with [USD \(AT&L\) Memorandum](#) dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of Forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the most stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

UFC are living documents and will be periodically reviewed, updated, and made available to users as part of the Services' responsibility for providing technical criteria for military construction. Headquarters, U.S. Army Corps of Engineers (HQUSACE), Naval Facilities Engineering Command (NAVFAC), and Air Force Civil Engineer Center (AFCEC) are responsible for administration of the UFC system. Defense agencies should contact the preparing service for document interpretation and improvements. Technical content of UFC is the responsibility of the cognizant DoD working group. Recommended changes with supporting rationale should be sent to the respective service proponent office by the following electronic form: [Criteria Change Request](#). The form is also accessible from the Internet sites listed below.

UFC are effective upon issuance and are distributed only in electronic media from the following source:

- Whole Building Design Guide web site <http://dod.wbdg.org/>.

Refer to UFC 1-200-01, *DoD Building Code (General Building Requirements)*, for implementation of new issuances on projects.

AUTHORIZED BY:



GEORGE O. LEA, P.E.
Chief, Military Engineering Branch
U.S. Army Corps of Engineers



JOSEPH E. GOTT, P.E.
Chief Engineer
Naval Facilities Engineering Command



EDWIN H. OSHIBA, SES, DAF
Deputy Director of Civil Engineers
DCS/Logistics, Engineering &
Force Protection



MICHAEL McANDREW
Director, Facilities Investment and Management
Office of the Deputy Under Secretary of Defense
(Installations and Environment)

UNIFIED FACILITIES CRITERIA (UFC) NEW SUMMARY SHEET

Document: UFC 3-570-01, *Cathodic Protection*

Superseding: UFC 3-570-02A, *Cathodic Protection*, March 2005
UFC 3-570-02N, *Electrical Engineering Cathodic Protection*, Jan 2004

Description: This UFC provides general design guidance for cathodic protection (CP) systems. This UFC applies to all Army, Navy, and Air Force service elements and contractors.

Reasons for Document:

- Update the format of the manual (more of a policy and guidance manual instead of a technical cookbook on design) and unify UFC 3-570-02A and UFC 3-570-02N.
- Incorporate policy, guidelines, and procedures previously identified in Engineering Technical Letters and Interim Technical Guidance Documents.
- Provide additional guidance to the Project Design Engineer (PDE) in managing CP design contracts and guidance on commissioning of CP systems.
- Incorporate information regarding new technologies and update obsolete technical information.

Impact:

- Clarifies policy where CP must be provided. Provides more guidance to the PDE managing a CP Architect-Engineer (A-E) design contract to help improve designs. Previously, the manual only described technical requirements for the actual designers. Helps ensure CP provided where necessary and properly designed to ensure economical long-term facility/structure life cycle cost.

Unification Issues

None identified to date.

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CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE.

This UFC provides policy and design requirements for cathodic protection (CP) systems. This document provides the minimum design requirements, and must be utilized in the development of plans, specifications, calculations, and Design/Build Request for Proposals (RFP).

UFC 3-501-01, *Electrical Engineering*, provides the governing criteria for electrical systems, explains the delineation between the different electrical-related UFCs, and refers to UFC 3-570-01 for Cathodic Protection requirements. Refer to UFC 3-501-01 for design analysis, calculation, and drawing requirements.

1-2 APPLICABILITY.

Compliance with this UFC is mandatory for Department of Defense (DoD) facilities located on or outside of DoD installations, whether acquired by appropriated or non-appropriated funds, or third party finance and constructed.

1-3 GENERAL BUILDING REQUIREMENTS.

UFC 1-200-01, *General Building Requirements*, provides applicability of model building codes and government-unique criteria for typical design disciplines and building systems, as well as for accessibility, antiterrorism, security, sustainability, and safety. Use this UFC in addition to UFC 1-200-01 and the UFCs and government criteria referenced therein.

1-4 REFERENCES.

Appendix A contains a list of references used in this document. The publication date of the code or standard is not included in this document. In general, the latest available issuance of the reference is used.

1-5 GLOSSARY.

Appendix C contains acronyms, abbreviations, and terms.

1-6 CYBERSECURITY.

All control systems (including systems separate from an energy management control system), remote monitoring units, and automated data collection units must be planned, designed, acquired, executed and maintained in accordance with UFC 4-010-06; and as required by individual Service Implementation Policy.

1-7 RECONCILIATION WITH OTHER UNIFIED FACILITIES CRITERIA.

The CP requirements and criteria in this document will be reconciled with CP requirements and criteria in other UFCs so that the required criteria is located in a single location; the other UFCs and criteria documents will refer to UFC 3-570-01. In the event there is a conflict between these criteria and other criteria in another document, these criteria govern. The documents listed in Table 1-1 are known to be affected by the requirements and criteria in this document.

Table 1-1. UFC Documents Requiring Reconciliation of CP System Requirements and Criteria

DOCUMENT	TITLE
UFC 3-230-01	Water Storage, Distribution and Transmission
UFC 3-460-01	Design: Petroleum Fuel Facilities
UFC 3-460-03	Operation and Maintenance: Maintenance of Petroleum Systems
UFC 3-570-06	Operation and Maintenance: Cathodic Protection Systems
UFC 4-150-07	Maintenance and Operation: Maintenance of Waterfront Facilities
UFC 4-151-10	General Criteria for Waterfront Construction
UFC 4-152-01	Design: Piers and Wharves

CHAPTER 2 CATHODIC PROTECTION SYSTEM PLANNING

2-1 INTRODUCTION.

In accordance with [DoD Instruction 5000.67](#), *Prevention and Mitigation of Corrosion on DoD Military Equipment and Infrastructure*, consider corrosion prevention and control (CPC) as an integral part of the design, construction, sustainment, restoration and maintenance of all DoD infrastructure. Utilize CP systems to reduce corrosion of buried or submerged metallic structures, thus reducing the probability of failure and concomitant environmental, operational, safety, and economic repercussions. Petroleum, oil and lubricant (POL) systems, waterfront structures, and utility systems have been found to be the most critical facilities in terms of a combination of risk from corrosion, the need for continuous direct support of base operations, and the life cycle cost effectiveness of utilizing appropriate corrosion control systems.

CPC requirements development, pre-design surveys, system designs, and acceptance surveys must be accomplished under the supervision of one of the following individuals:

- NACE International certified Corrosion Specialist or Cathodic Protection Specialist with a minimum of five years of experience in the applicable CP system being designed.
- Where the qualification requirements are more restrictive or more stringent than any one of the above requirements, an appropriately certified person as required by applicable state/local laws, regulations, or requirements (primarily for underground storage tanks).

2-2 STRUCTURES FOR WHICH CP IS MANDATORY.

Regardless of soil or water corrosiveness, provide both CP systems and protective coatings for the following buried or submerged metallic structures:

- Petroleum, Oil, and Lubricants (POL) pipelines
- Underground POL/gas storage tanks, piping, and ancillary items
- Underground hazardous substance storage tanks
- Oil/water separators and all associated metallic fittings in contact with soil
- Natural Gas and Propane Pipelines, including metallic components of non-metallic lines
- New waterfront structures
- Fire protection water storage tanks, piping or water lines, including metallic components of non-metallic lines (i.e., PIV's, fire hydrants, change of direction devices, valves, metallic sections under building slabs and elsewhere, etc.)
- Interior of all steel water distribution storage tanks, including the interior of elevated tank risers

- Metallic water distribution pipelines (including steel, ductile and cast iron pressurized piping) buried under concrete slabs (building foundations, runways, taxiways, parking aprons, wharf decks, and similar)
- Oxygen Pipelines
- Metallic components of force mains
- Sewage lift stations (all metallic components in contact with soil or liquids)
- Underground heat distribution and chilled water piping in metallic conduit
- Other facilities with hazardous products as identified by the major commands, major claimants, or other competent authorities

2-2.1 POL Facilities and Structures.

Provide CP systems along with other corrosion control measures such as protective coatings and materials selection for all POL liquid fuel pipelines and storage facilities following the provisions of [Code of Federal Regulations](#) (CFR) Title 49 Chapter 1, Part 195, Transportation of Liquids by Pipeline, and CFR Title 40 Chapter 1, Part 112, Oil Pollution Prevention. Overseas installations must comply with the requirements of the Host Nation standards, [DoD Overseas Environmental Baseline Guidance Document](#) (OEBGD), and related specific Area Governing Standards. Coordinate CP system design with other POL related requirements in UFC 3-460-01.

2-2.2 Underground Storage Tank System.

Provide CP systems along with other corrosion control measures such as protective coatings and materials selection for all steel underground storage tank (UST) systems in accordance with CFR Title 40 Part 280, Technical Standards and Corrective Action for Owners and Operators of Underground Storage Tanks. By definition, the underground storage tank system includes the storage tank and associated piping. In addition, comply with State and Local government laws that may dictate additional or more stringent requirements. Overseas installations must comply with the requirements of the Host Nation standards, [DoD OEBGD](#), and related specific Area Governing Standards. Ensure that UST CP systems are designed by a certified CP Specialist.

2-2.3 Natural Gas Pipe Lines.

Provide CP systems along with other corrosion control measures such as protective coatings and materials selection for all metallic natural gas pipelines in accordance with the provisions of CFR Title 49 Chapter 1, Part 192, Transportation of Natural and Other Gas by Pipeline.

2-2.4 Waterfront Structures.

Provide CP systems in conjunction with other protective measures such as proper material selection, protective coatings, and encasement, for the following submerged metallic waterfront structural systems:

- Steel sheet pile bulkheads along the waterfront or waterway
- Steel bearing piles for piers and wharves
- Steel fender piles for piers and wharves
- Submerged mooring components

Specify the proper type and size of galvanic or impressed current anodes to meet the desired CP system life. Do not specify magnesium anodes as the primary CP system for structures immersed in salt water.

2-2.5 Buried or Submerged Steel Utility Piping.

For all other steel utility piping, provide CP systems and bonded protective coatings on buried or submerged steel utility piping in which the electrolyte (soil or water) resistivity is less than 30,000 ohm-cm at the installation depth at any point along the piping installation.

2-2.6 Ductile or Cast Iron Utility Piping.

For all other ductile or cast iron utility piping and fittings, provide CP systems and protective coatings on buried or submerged new ductile or cast iron pipe in which the electrolyte resistivity is less than 30,000 ohm-cm at the installation depth at any point along the piping installation. Do not use unbonded protective coatings such as loose polyethylene wraps. Additionally, provide joint bonding for all ductile and cast iron installations. For non-metallic pipe with ductile or cast iron fittings, provide CP systems and protective coatings on buried or submerged new ductile or cast iron fittings in which the electrolyte resistivity is less than 30,000 ohm-cm.

2-2.7 Potable Water Storage Tanks.

Provide CP and protective coatings for the interior submerged surfaces of potable water storage tanks, including bolted panel tanks in accordance with National Sanitation Foundation (NSF) Standard 61. Include requirements in the contract specifying that the contractor is responsible for providing an interior coating system and ensuring that the coating system is compatible with an impressed current CP (ICCP) system, if specified, and NSF Standard 61. For bolted panel storage tanks, require the contractor to ensure all panels of a bolted panel storage tank are electrically continuous.

2-2.8 Fire Protection Water Storage Tanks.

Fire protection water storage tanks are mission critical facilities and must be properly protected against corrosion. Provide an ICCP system for the interior submerged surfaces of all fire protection water storage tanks, including bolted panel tanks. When the backfill beneath an on-grade tank is corrosive, provide an ICCP system for the exterior bottom of the on-grade tank. Include requirements in the contract specifying that the contractor is responsible for providing an interior coating system and ensuring that the coating system is compatible with the ICCP system. For bolted panel storage tanks, require the contractor to ensure all panels of a bolted panel storage tank are electrically continuous.

2-3 OTHER STRUCTURES FOR WHICH CATHODIC PROTECTION MUST BE EVALUATED.

Evaluate the economic feasibility of providing CP systems for the following buried or submerged systems:

- Gravity sewer lines
- Existing steel waterfront structures
- Reinforcing steel in concrete
- New or existing cast or ductile iron potable water lines (unless installed under a concrete slab) in soils with resistivity greater than 30,000 ohm-cm along its entire length
- Exterior bottom of on-grade steel water storage tanks
- Buried hydraulic elevator cylinders
- Other buried/submerged metallic structures not covered above

Installation of CP systems on these types of structures must be based on life-cycle economics. The overall corrosion protection system must include a combination of CP systems, protective coatings, proper material selection, encasement, or other methods. CP system requirements determined by non-DoD personnel (e.g., A/E's, private contractors, private consultants, etc.) must first be reviewed by a DoD qualified Corrosion Engineer or DoD NACE International certified cathodic protection specialist who subsequently recommends government approval prior to implementation,

2-4 PROTECTIVE COATINGS SPECIFIED IN CONJUNCTION WITH CATHODIC PROTECTION.

Protective coatings to be applied to a new metallic structure in conjunction with CP must have the minimum characteristics as described in NACE International SP0169 and the appropriate UFGS. Coordinate the coating type and requirements with the CP system being specified. Utilize the appropriate protective coating UFGS and supplement the UFGS requirements, as necessary, with the minimum coating characteristics indicated in NACE International SP0169, *Control of External Corrosion on Underground or*

Submerged Metallic Piping Systems. Do not delete the CP requirements simply because it is not compatible with a particular coating.

2-5 ISOLATION OF COPPER WATER PIPES FROM FERROUS PIPES.

Dielectrically isolate copper water service lines from ferrous pipe in accordance with the requirements in NACE International SP0286, *Electrical Isolation of Cathodically Protected Pipelines*, unless not economically practicable. Where not practicable, design the CP system to include protection of both the copper and ferrous piping.

2-6 CP PROJECT PLANNING.

2-6.1 General CP Requirements.

Include CP system requirements as a separate line item in project documentation for the construction of new or the repair/upgrade of existing metallic structures as required by paragraphs 2-1 and 2-2. Cathodic protection systems are often not included in a project design because they are not appropriately identified in the project planning documents. Addition of these requirements later in the process often results in funding problems and other delays. Coordinate CP system requirements with the appropriate service CP subject matter expert or Major Command Corrosion Engineer. Refer also to the best practices in Appendix B.

2-6.2 Environmental/Site Concerns.

Identify environmental and site concerns. Prepare proper environmental Categorical Exclusions (CATEX), or if necessary, Environmental Impact Assessments (EIA) documentation prior to project execution. Refer also to paragraph 3-3.5.

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CHAPTER 3 DESIGN REQUIREMENTS

3-1 INTRODUCTION.

This chapter identifies CP system technical design requirements and defines the data that must be developed to establish engineering design bases and to evaluate the proper type of CP system(s) to be provided.

3-2 APPLICABLE CODES AND REGULATIONS.

In addition to the policy in Chapter 2, ensure that the CP system design complies with the legal requirements in any of the applicable codes, regulations, and other documents:

- CFR Title 40 Chapter 1, Part 112, *Oil Pollution Prevention*
- CFR Title 40 Part 280, *Technical Standards and Corrective Action for Owners and Operators of Underground Storage Tanks*
- CFR Title 49, Chapter 1, Part 192, *Transportation of Natural and Other Gas by Pipeline*
- CFR Title 49, Chapter 1, Part 195, *Transportation of Liquids by Pipeline*
- Department of Defense, *Overseas Environmental Baseline Guidance Document* and the appropriate regional/country Final Governing Standards.
- State or locality laws and regulations with more stringent CP requirements than the Federal laws and regulations.

Design agents doing Air Force designs will also comply with the requirements in Air Force Instruction 32-1054, *Corrosion Control*.

3-3 SYSTEM DESIGN.

Design CP systems in accordance with the policy in Chapter 2, applicable codes and regulations in paragraph 3-2, and the requirements of this section. Refer also to the best practices and lessons learned in Appendix B.

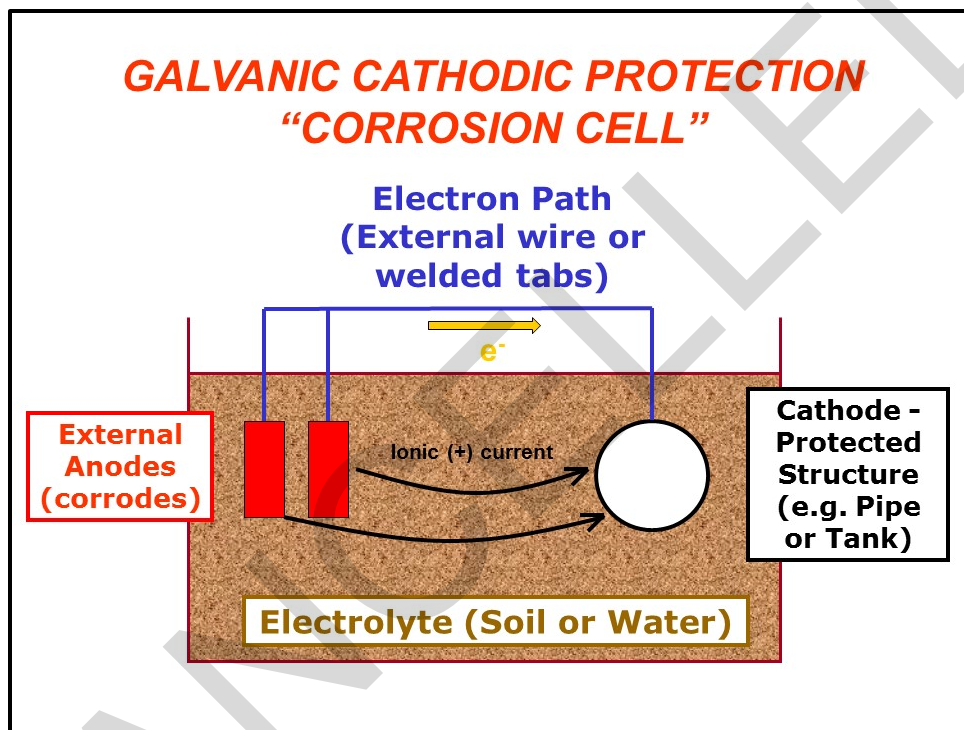
3-3.1 Two types of CP systems.

Select the CP system type, sacrificial anode (GCP) or ICCP, based on feasibility and cost. An economic analysis may be necessary to determine the system with the best life-cycle cost. In general, systems with small stable current requirements (0.5 Amp or less per 100 linear feet of structure) are more likely to be protected using sacrificial anode type systems. Those structures with larger current requirements (1 amp or more per 100 lineal feet of structure), or where the current requirements vary considerably with time, are more likely to require ICCP systems.

3-3.1.1 Galvanic (Sacrificial) Anode Systems.

A galvanic (sacrificial) anode CP system is essentially a controlled electrochemical cell. Figure 3-1 illustrates such a system. The structure becomes the cathode in the electrochemical cell, and corrosion that would have occurred on the structure being protected is mitigated due to the corrosion of the anode. The anode is consumed in the process but can usually be replaced when consumed. Anode life of 10 to 15 years is common, although lifetime can be limited by other factors such as mission requirements or mechanical damage.

Figure 3-1 Schematic Illustration of a GCP System

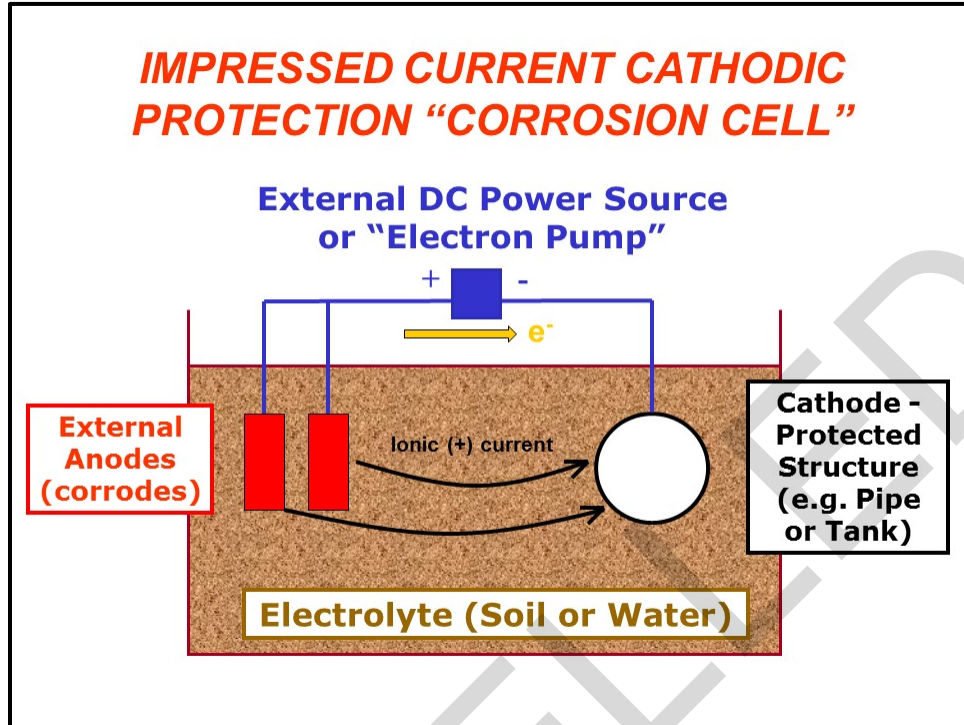


The structure and ancillary components intended for protection by sacrificial anodes must be electrically continuous. Conversely, other buried metals electrically continuous with the structure to be protected, but are not intended to be protected by the CP system, must be electrically isolated from the protected structure.

3-3.1.2 Impressed Current Systems.

Impressed current CP systems are also essentially controlled electrochemical cells. However, in the ICCP system, a supply of direct electrical current is used to develop the potential difference between the anode and the structure being protected as Figure 3-2 illustrates. The direct current source supplies current from the anode through the electrolyte to the surface of the structure being protected. Like sacrificial anodes, ICCP anodes are also consumed, although typically at a much lower consumption rate. Anode life of 20 to 25 years is common; although similar to GCP systems, lifetime can be limited by other factors such as mission requirements or mechanical damage.

Figure 3-2 Schematic Illustration of an ICCP System



As with GCP systems, the structure and ancillary components intended for protection by ICCP systems must be electrically continuous. Conversely, other buried metals electrically continuous with the structure to be protected, but are not intended to be protected by the CP system, must be electrically isolated from the protected structure.

3-3.2 Field Surveys and Tests.

Conduct a field survey to determine site conditions required to adequately design a CP system. Perform specific investigations and field tests at the proposed installation site(s) to evaluate as a minimum:

- Electrolyte corrosivity (resistivity, pH, etc.)
- CP system current requirements
- Suitable anode bed locations, including geological concerns
- Available electrical power
- Location of rectifiers
- Overall terrain around the structure (location of test stations)
- Easement issues for structures located off station
- Possible environmental concerns
- Constructability issues (physical and operational)

- Location of existing nearby CP systems and potential stray current concerns. Review of a published Base Corrosion Control Plan.
- Security restrictions that may impact cost
- Communication with local Corrosion Coordinating Committees for structures located off station

3-3.3 Availability of AC Power (ICCP Systems).

During the site survey, determine the availability of alternating current (AC) power at the site as the cost of installing new AC power service may be an important factor in determining whether a sacrificial or ICCP system is the more practical solution for the specific application. Where practicable, locate the ICCP rectifier nearby a building with available AC power and comply with applicable fire safety codes.

Design required electrical service in accordance with UFC 3-501-01. The electrical service design must be accomplished under the supervision of a registered professional electrical engineer.

3-3.4 Environmental/Site Concerns.

Consider the numerous environmental and safety concerns that may significantly impact the selection of CP system type, materials specified, system component installation procedures and controls, design document preparation, and the overall cost of the project. Consult with environmental and safety personnel during the early stages of design to identify the concerns and allow ample time for the designer to address these concerns. The following are some examples:

3-3.4.1 Hazardous Material.

Identify existing hazardous material at the proposed project site. These should be identified in the required environmental documents.

3-3.4.2 Archaeological/Historic Preservation Requirements.

Identify archaeological/historic preservation requirements and limitations at the proposed project site. This should also be identified in the required environmental documents.

3-3.4.3 Federal, State and Local Regulations.

Review and comply with Federal, state and local regulations that may affect the CP system installation. Some states have specific regulations regarding the design and installation of CP systems for underground storage tanks.

3-3.4.4 Mercury-Containing Anodes.

Avoid specifying mercury-containing aluminum alloy anodes. Consult with local/state regulators regarding concerns about the use of zinc anodes in certain situations.

3-3.4.5 Water Storage Tanks.

Specify anodes and other related components in water storage tanks that comply with National Sanitation Foundation/American National Standards Institute (NSF/ANSI) Standard 61.

3-3.4.6 Issues That May Impact Construction/Installation.

Address issues that may impact the construction/installation process, particularly, the drilling or excavation for installation of the anodes:

- Address requirements and specify procedures and controls when hazardous material is encountered.
- Address requirements and specify procedures and controls when drilling into the ground water table. Specify controls for preventing cross contamination of ground water aquifers.
- Specify construction site controls to prevent pollution of the environment.
- Specify safety requirements applicable to the site and specific installation.

Review the appropriate UFGS sections for environmental and safety requirements to ensure the applicable concerns are addressed. Provide design documents to the base/DoD installation environmental and safety personnel for review to ensure the requirements are properly addressed.

3-3.5 Electrical Continuity.

Determine locations and provide bonding to ensure electrical continuity of all buried metallic structures that are intended to be protected by the CP system. All electrically discontinuous section(s) of the structure(s) to be protected must be properly bonded into the system to ensure adequate protection. Common causes of electrical discontinuities include:

- Dresser couplings.
- Mechanical pipe section connections such as found in ductile iron pipe.
- Plastic valves and fittings.
- Non-metallic sections of pipeline (new, existing or future installation).
- Improper bonding (or lack of bonding) on joints, flanges or previously installed dielectric isolation unions or flanges.

If electrical discontinuities cause the pipeline system to be too fragmented, and continuity bonding is not feasible, consider providing multiple smaller separate CP systems for the electrically discontinuous sections of structure. Some isolated sections of pipelines may be small enough to use a GCP system, but the designer must consider possible interference problems on these sections.

3-3.5.1 Tracer Wires on Plastic Pipe.

When plastic pipe is used to replace or extend existing pipe, exothermically weld an insulated No. 8 American Wire Gage (AWG) copper wire to the existing steel pipe and run the wire along the full length of the plastic pipe for continuity and locator tracing purposes. As this may not always be technically feasible; alternatively, install tracer wires/tapes/devices directly above the plastic pipe at a depth that will be detectable by current detection equipment and technologies.

3-3.6 Identification of Other Structures in the Area.

Locate existing or planned buried or submerged structures. Determine if the other structures will impact or be impacted by the planned CP system. Identify the location of such structures in the design documents for interference testing during commissioning. Locate new CP anode beds to minimize the possibility of interference, while providing the best current distribution possible. Although resistivity is an important factor in anode bed location, the location of other structures in the area is just as important.

3-3.6.1 Pipeline Crossings.

For a new pipeline installation, require/specify a minimum clearance of twelve inches between all pipelines lines at crossings. If practicable, specify 24 inches of clearance. Indicate that direct contact between crossing or adjacent pipelines must be avoided. Also where practicable, specify installation of insulating mats between pipelines at crossings if substantial earth currents are detected in the area or if a newly coated line is crossing a poorly coated or uncoated line.

3-3.6.2 Cathodic Protection Interference.

Stray currents, also called interference, result from external electromotive forces and can greatly accelerate corrosion. Stray current corrosion can be caused by voltage gradients (current flow) resulting from DC transit systems, HVDC Transmission systems, DC welding, telluric earth currents, and CP systems. The amount of corrosion caused is directly proportional to the amount of DC current flowing in the electrolyte. Steel corrodes at a dissolution rate of about 20 pounds per ampere-year. CP systems can impress large amounts of current from their anodes, through the electrolyte, to the cathode. When a metallic structure not connected to or not intended to be protected by the CP system (referred to as the "foreign" structure) is immersed in the same electrolyte in the vicinity of the protected structure, it is subjected to stray current corrosion because of the electromotive force being applied through that electrolyte, and can undergo extremely severe corrosion without proper mitigation.

Provide test stations with provisions for bonding at all crossings for stray current interference testing and mitigation. Specify any additional appropriate methods and procedures to mitigate stray currents. Contact the users (owners, if not government owned) of the existing pipelines and inform them of the planned project. As any solutions to problems at pipeline crossings require cooperative efforts, effective coordination is essential. Identify coordination points of contact on the design drawings, particularly if non-government owned structures are impacted. For off base locations,

Corrosion Coordinating Committees have been established in many areas to facilitate coordination of such efforts.

3-3.7 Electrical Isolation.

Determine locations and provide electrical isolation from buried metallic structures that are not intended to be protected by the CP system. Electrical isolation is essential to minimizing current requirements for both GCP and ICCP systems and ensuring the intended structure can be adequately protected. Also provide insulating joints to isolate sections of structures so that each section can be protected separately when necessary (e.g. a pipeline with multiple road crossings). For POL pipelines, provide surge arrestors across the electrical isolation device per UFC 3-460-01.

3-3.8 Connecting Electrical Wires and Cables.

Specify proper selection of cable size and type of insulation for ampacity, mechanical strength and electrically safe, reliable system operation. Use only copper cables in any CP installation. The DC output connecting cables used between the various components of CP systems are vital to the proper performance of the system. Any break in the primary circuit will result in failure of the system. Breaks in the auxiliary connections such as those used to test the system will also result in difficulties in proper adjustment and inspection of the system. See also paragraphs 4-2.4 and 4-3.3.

3-3.9 Connections and Splices.

Wire splices and connections are a source of undesirable circuit resistance and are a weak point in the reliability of the system as they often fail due to either corrosion or mechanical damage. Wire splices are not permitted in the following situations:

- Submerged GCP and ICCP anode lead wires or anode header cables
- Buried individual GCP and ICCP anode lead wires. Provide anodes with lead wires of sufficient length to reach an anode junction box/test station
- Buried sections of anode header cables unless specific site conditions or mission requirements prohibit the installation of an anode junction box/test station
- Buried sections of structure lead wires/header cables in highly corrosive environments

Keep connections to an absolute minimum and specify types of connections that have low resistance, high reliability, and good resistance to corrosion. See also paragraph 4-4.2.

3-3.10 Hazards Associated with Cathodic Protection.

3-3.10.1 Explosive Hazard Concerns.

Design both ICCP and sacrificial anode CP systems to comply with the regulations governing the hazardous area where flammable liquids or explosive gasses may be present. Such areas include, but are not limited to:

- Fuel storage farms
- Fuel terminals and fueling areas
- Refineries
- Ammunition depots
- Manholes (sewer gas)

Cathodic protection rectifiers used in such applications must be special oil-immersed explosion-proof types, or must be located outside of the hazardous area. In addition, all connections must be made in explosion-proof housings, and electrical conduits entering the housings properly sealed.

3-3.10.2 Bonding for Electrical Safety.

Provide electrical bonding points to prevent static discharge as required for safety where ships, vehicles, or aircraft are fueled or loaded. Any voltage gradient in the soil can result in a potential difference between structures located at different points, resulting in dangerous arcing. Cathodic protection systems are one source of such voltage gradients. Normal electrical bonding methods used in such circumstances is sufficient to mitigate this hazard. Voltage gradients caused by CP systems can also cause arcing during pipeline repairs when the pipeline is severed. Specify that a temporary bond be provided across the area to be cut to prevent this hazard before cutting a pipeline.

3-3.10.3 Installation Work near High Voltage Power Lines.

Installation work around high voltage power lines constitute a safety hazard from either direct contact with the power lines or induced voltage from these power lines. If the potential for such occurrences exists at the project site, then include provisions in the design documents addressing these concerns during construction.

3-3.10.4 Induced Alternating Current Concerns.

Alternating current (AC) can be induced on underground or aboveground components of CP systems, as well as large structures being protected in the vicinity of AC electrical transmission lines. This is particularly true if the structure is well coated or isolated from the ground, and the probability and intensity of induced current increases the more the pipeline is oriented parallel to the AC transmission lines. Pipelines using the same right-of-way as the AC transmission lines are particularly susceptible to induced AC voltages. In addition to causing corrosion damage, these voltages can be dangerous to personnel who may come in contact with the structure or CP system.

Identify the location of the AC transmission lines during the design of CP systems and assess the effects of induced currents. Where practicable, avoid placement of CP system components and test stations in areas where induced currents may exist. Provide the appropriate combination of safety features to mitigate the effects of induced current for equipment that must be located within induced current areas and prevent electric shock to maintenance personnel such as.

- Electrical test stations and cabinets with a lockable dead front
- Gradient control mats around pipeline appurtenances engineered to provide safe (15 volts or less) touch-and-step voltages during both load and fault conditions
- Grounding systems for pipeline appurtenances and nearby independent isolated metallic structures
- Distributed galvanic anodes connected to the pipeline as part of the grounding system
- High resistivity crushed stone around pipeline appurtenances (use in conjunction with grounding/gradient control system)

Include induced current safety precautions and test procedures in the specifications for CP system commissioning field surveys or other electrical tests in the vicinity of AC transmission lines

3-3.10.5 CP Systems Near Communication Equipment.

Electrical filters are used to both increase the efficiency of the rectifier by reducing alternating current ripple and to reduce interference with communications equipment. Efficiency filters can increase the efficiency of single-phase bridge type rectifiers by 10 to 14 percent and their use must be based upon a first cost versus operating (power) cost basis. Efficiency filters are not commonly used with three-phase rectifiers as the alternating current ripple in these units is inherently lower.

Specify noise interference filters where operational requirements mandate their use. Verify requirements with the user during the design survey. Where necessary, retrofit noise interference filters into an existing rectifier when noise problems are encountered and are significantly affected by turning the unit on and off.

3-3.11 Special Requirements.

Identify any special requirements in the proposed CP system description such as the need for remote monitoring units, automated data collection units, unique structure or procedural features that may impact the CP system design, operation, or maintenance. Refer to paragraph 4-5 and the best practices in Appendix B. These special requirements will impact the construction cost.

All control systems, remote monitoring units, and automated data collection units must be planned, designed, acquired, executed and maintained in accordance with DoD

Instruction 8500.01 and DoD Instruction 8510.01, and as required by individual Service Implementation Policy.

3-3.12 Easement Issues.

Easements are usually not an issue since most projects are located on-installation where easements are not necessary. In the case of CP systems for distribution pipelines and other structures located off-installation, identify easement issues as early as possible during the design process if not already addressed during the planning stages. Obtaining easements can be a long legal process; therefore, should be identified as early as possible before the start of construction. Involve installation real estate personnel for assistance. Ensure easement issues are well documented and the documents kept on file in the event property owners contest the location of the CP equipment years after installation.

3-3.13 CP System Protection Criteria.

Design all CP systems to provide protective levels according to the requirements and criteria for adequate protection identified in the NACE International standards appropriate for the structure(s) being protected.

3-3.14 System Maintainability.

Identify operation and maintenance (O&M) requirements for the end users early on in the design process as end user O&M capabilities may impact the CP system design. Refer to UFC 3-570-06. The following paragraphs briefly summarize the general O&M requirements and design features that facilitate O&M:

3-3.14.1 GCP Systems.

Conduct structure-to electrolyte (S/E) potential tests semiannually (or at least annually as a minimum) to determine adequacy of the CP system. Read and record potential reading at all established test points. Inspect junction boxes and test boxes. Tighten wire connections and perform minor repairs as necessary. Test insulating joints annually.

3-3.14.2 ICCP Systems.

Inspect each rectifier monthly (bimonthly as a minimum), to ensure the system is operating. Read and record rectifier input and output voltage and current readings. Inspect, clean, and tighten output wire connections. Conduct structure-to electrolyte (S/E) potential tests quarterly (or at least annually as a minimum) to determine adequacy of the CP system. Read and record potential reading at all established test points. Adjust or repair rectifiers if test potentials indicate inadequate protection. Test insulating joints annually.

3-3.14.3 Design Requirements to Facilitate O&M.

Specify CP system features and configuration that will save time by making it easier for base facilities management personnel to operate, maintain, adequately test, and

troubleshoot the CP system, and ensure adequate CP is being provided to the intended structure throughout the life cycle of the system. The capability for maintaining the CP system at the installation may affect the decision on the type of CP system to be installed. Examples of features, configuration, and design considerations include but are not limited to:

- Location of CP equipment where they will be readily maintainable
- Provision of equipment cabinets suitable for the environment
- Provision of an adequate number of test stations in readily accessible areas. Where possible avoid test station installation in the middle of roads. Without sufficient test stations and test access, a system may be impossible to accurately evaluate for adequacy of protection
- Provision of test stations that preclude maintenance personnel from having to enter confined spaces
- Specification of time saving features such as remote monitoring and automated data collection units where feasible
- Identification of the location of all CP equipment and test points on the design drawings
- Specifications that include training of base maintenance personnel by the contractor and/or manufacturer
- Specifications that include provision of maintenance manuals to the base maintenance personnel by the contractor and/or manufacturer

Refer also to the best practices in Appendix B-8.

3-3.15 Design Submittals.

Project managers or Architects/Engineers-in-charge should contact the service CP system Technical Expert or Major Command Corrosion Engineer regarding the CP system design during the various project phases, and upon request, provide the design documents for review. Design submittals must include the following as a minimum:

3-3.15.1 Design Basis.

The Design Basis must include a narrative description of the proposed CP system and rationale for selecting the type of system, electrolyte (soil, water, etc.) corrosivity data, CP system current requirement test data (if applicable), and all design calculations. The design basis shall also address the anticipated CP system maintenance requirements for the installation.

3-3.15.2 Drawings.

Drawings must include CP system one line diagrams, locations of all CP equipment (anodes, rectifiers, test stations, etc.), stray current test points, installation details, dielectric insulating fittings, and electrical continuity bond connections.

3-3.15.3 Specifications.

Specifications must describe all CP system equipment and installation procedures; acceptance testing procedures including static (native) potentials, initial and final system potentials, and interference tests; special contractor qualifications; and applicable reference standards.

3-3.16 Design Build.

Design build contracts are generally based upon performance specifications. Successful application of CP for the system life will be significantly dependent upon the requirements detailed in the request for proposal (RFP). The contractor selected is responsible to design a CP system that will meet the RFP requirements. Requirements that are too general and are not explicit in performance will result in the installation of a minimum system that will not perform over the anticipated system life. Typically, the contractor's warranty is one-year, while the system design life is typically 15 - 25 years. Include the following CP system requirements in the RFP:

3-3.16.1 CP Requirements.

Include CP system requirements in the performance technical specifications. If necessary, mark-up guide specifications (UFGS) with prescriptive requirements where a particular system type or specific features are required based on experience

3-3.16.2 CP System Life.

Require a minimum CP system life of 15 - 20 years for GCP systems and 20 -25 years for ICCP systems, unless specific mission requirements or overarching project requirements dictate otherwise.

3-3.16.3 CP System Maintainability.

Require the contractor to address CP system maintainability. Many bases may have a limited ability to readily maintain the CP system.

3-3.16.4 CP System Commissioning.

Require the contractor to provide explicit CP system commissioning requirements. Require commissioning reports be sent to qualified base/installation government personnel for review.

3-3.16.5 CP System Warranty Testing.

Require the contractor to test and maintain the CP system(s) for first year. Include requirements for test data submission to the government.

3-4 DESIGN FOR CONSTRUCTABILITY.

Cathodic protection systems must be properly installed in order for effective protection to be achieved. Problems during construction and installation do occur, and many are due to unforeseen conditions. In some cases, these issues may already be known by installation personnel and it would be beneficial to identify these during the early stages of the design process.

3-4.1 Identification of Issues During Design Field Survey.

During the design field survey, identify and resolve issues that may impact the ability to construct the CP system. Evaluate the following as a minimum:

- Site conditions differing from those shown on installation development maps and as-built drawings. Specify CP system component locations to avoid interference from existing structures
- Site conditions may also be a significant factor in the determination of the type of system selected and the materials used for the components of the system
- Site conditions that may impact construction safety. Coordinate with the installation construction management office/safety officer for any site specific requirements
- Environmental/ archaeological concerns
 - Pollution prevention considerations
 - Preservation of historical structures or site conditions
 - Excavation, drilling and other permits
- Communication with installation personnel regarding
 - Operational requirements that may impact site access, materials of construction, installation or schedule.
 - Future construction at or nearby the project site that may affect the location of the CP system components
 - Security or operational requirements that may impact personnel/construction equipment access and construction schedule (e.g. inside of a shipyard controlled access area)
 - Easement issues if located off-base

The appropriate UFGS sections contain sections that generally address many of the above issues, and site conditions may require the designer to modify these sections for a particular site. Provide copies of the design submissions to installation personnel, including the local construction management office, to ensure that the requirements have been adequately addressed.

3-4.2 Prevention of Damage to Existing Structures/CP System Components.

Include requirements for the contractor to pay particular attention to maintaining the condition of the coating on the structure and maintaining the structural continuity and isolation required for proper CP system operation when working around existing structures. If the coating on a structure is damaged and not repaired, CP requirements will increase dramatically, and the new or existing CP system for the structure may not function properly. Damage to/removal of existing continuity bonds or dielectric isolating devices are common causes of inadequate protection or interference on nearby pipelines that can cause accelerated corrosion damage.

3-4.3 Commissioning.

Specify adequate commissioning procedures so that the system is energized and fully tested to ensure its proper operation before being accepted from the contractor. The cathodic protection UFGS listed below provide detailed commissioning and testing procedures that must be considered and tailored for the specific system being designed.

- UFGS 26 42 13.00 20, Cathodic Protection by Galvanic Anodes
- UFGS 26 42 14.00 10, Cathodic Protection System (Sacrificial Anode)
- UFGS 26 42 15.00 10, Cathodic Protection System (Steel Water Tanks)
- UFGS 26 42 17.00 10, Cathodic Protection System (Impressed Current)
- UFGS 26 42 19.00 20, Cathodic Protection by Impressed Current
- UFGS 26 42 22.00 20, Cathodic Protection System for Steel Water Tanks

Proper commissioning by qualified personnel ensures the system is properly operating from the onset and helps identify system deficiencies, both design and construction, that should be corrected before the system is accepted. A properly commissioned system will help simplify maintenance and operation, and commissioning test data can be used as a baseline for future operation and troubleshooting. See also Appendix B-11.

3-4.3.1 General Commissioning Requirements.

Require the CP systems to be tested and inspected by the Contractor's corrosion engineer/CP Specialist in the presence of the Contracting Officer's corrosion protection/CP engineer or approved representative. Also require the contractor to record test data, including date, time, and locations of testing and submit a report to the Contracting Officer. Specify that the contractor shall correct, at his expense, all deficiencies in the materials and installation observed by these tests and inspections, and must pay for retests made necessary by the corrections.

3-4.3.2 Required Tests.

Commissioning testing must include the following measurements as a minimum:

- Baseline Potential Tests

- Insulation Joint Testing
- Electrical Continuity Testing
- Rectifier System Testing (ICCP systems)
- Permanent Reference Electrode Calibration (if included in the design)
- Pipe Casing Testing (if applicable)
- Energized Potential Tests
- Interference Testing (If ICCP system is specified or exists nearby)

Refer to the detailed requirements and procedures in the UFGS identified in Paragraph 3-4.3.

3-4.3.3 Warranty Period Testing.

For most CP systems, specify the contractor also conduct periodic testing during warranty. Refer to the detailed requirements and procedures in the UFGS identified in Paragraph 3-4.3.

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CHAPTER 4 CATHODIC PROTECTION SYSTEM COMPONENTS

4-1 INTRODUCTION.

There are two main types of CP systems, GCP or ICCP, and they can be applied many different ways to cathodically protect different types of structures. There are many different types and sizes of anodes for either type of CP system that can be installed either horizontally or vertically. Since CP is applied to prevent corrosion of a wide variety of structures in a variety of environments, each situation will require special consideration. There are fundamental requirements that should be followed in each case, and the method of application of CP to a particular structure depends upon unique design factors.

4-2 GALVANIC ANODE SYSTEMS.

Specify GCP systems where economically practical unless specific site conditions or mission requirements require the use of an ICCP system. GCP systems generally require less maintenance efforts than ICCP systems; however, this may not be true for extensive piping systems with numerous distributed anode connection points. The design must consider the DoD installation's ability to maintain and operate the system specified.

Do not specify GCP systems where the electrolyte resistivity is more than 30,000 ohm-cm, on large/extensive bare or poorly coated storage tank and distribution pipeline structures, or on structures that cannot be practically electrically isolated from all other structures, unless specific site conditions or mission requirements prohibit the use of a GCP system. Do not specify GCP systems for the exterior bottoms of aboveground (on-grade) fuel storage tanks with a clean sand backfill and a secondary containment liner unless specific site conditions or mission requirements prohibit the use of an ICCP system.

4-2.1 Anodes.

Specify the type and size of GCP anode that will provide the optimum performance based upon site conditions, electrolyte characteristics, system life, and economic feasibility. The minimum GCP design life is 15 years unless mission or operational requirements dictate otherwise (e.g. a particular structure will be in service for less than 15 years). The design basis and calculations must provide clear rationale for the anode selection and must address:

- Anode life
- Anode current output
- Specific environmental conditions that may impact performance
- Material costs
- Installation costs

Specify the proper type and size of GCP anodes to meet the desired CP system life for structures immersed in seawater or brackish water. Do not specify magnesium anodes as the primary CP system for structures immersed in salt water.

4-2.1.1 Zinc Anodes.

Zinc anodes are most commonly used in immersion service either in fresh or salt water. They are also occasionally used in the protection of buried structures when soil or water resistivity is low and special circumstances are encountered. Do not use zinc anodes where the soil or water resistivity is greater than 2,000 ohm-cm. Ensure that the proper type of zinc anode is specified. Two zinc anode compositions are commonly available; a standard alloy formulated for use in fresh water and soil, and an alloy specially formulated for use in seawater.

In some fresh waters, the potential between steel and zinc can reverse at temperatures above 140 degrees F, in which case, the steel will act as anode and corrode to protect the zinc. Do not specify zinc anodes to protect steel in such cases (e.g. do not use zinc anodes to protect a steel hot water storage tank).

4-2.1.2 Magnesium Anodes.

Magnesium anodes are most commonly used in soils with higher resistivity and fresh or brackish water immersion service. Do not use magnesium anodes for waterfront structures immersed in sea water, as they do not have a favorable economic life in such environments. Also, do not use magnesium anodes in soil where the soil resistivity is less than 2,000 ohm-cm unless determined to be more feasible for the specific soil conditions. In such cases, ensure that sufficient anode quantities are provided to meet the desired design life.

Ensure that the proper type of magnesium anode is specified. Two compositions are commonly available; a standard alloy and a high-purity (high potential) alloy. Specifications should include provisions that prohibit contractors from inter-mixing the anode types, particularly if the high potential anode is specified.

4-2.1.3 Aluminum Anodes.

Specify aluminum anodes for structures immersed in salt water, brackish water or other low resistivity or high chloride aqueous environments such as sewage effluent unless specific conditions are more favorable to zinc anodes. Specify only the indium activated (Type III) aluminum anodes. Do not specify anodes containing mercury unless specific site conditions or mission requirements dictate their use.

Do not use aluminum anodes for GCP systems for the interiors of potable water tanks. They have been used in past installations in cold climates, but are no longer preferred.

4-2.2 Backfill.

Specify anodes pre-packaged by the manufacturer in backfill consisting of a mixture of hydrated gypsum, bentonite, and sodium sulfate for GCP anodes that will be installed in soil. Besides providing a uniform resistivity environment which reduces the self-

corrosion rate, the backfill is hygroscopic and will absorb moisture from the surrounding soil to lower the resistivity and improve the anode current output.

4-2.3 Connecting Wires.

For sacrificial anode CP systems, the electrical currents are usually quite low, and the size of the conductors is normally more a function of mechanical strength than of ampacity or resistance. In systems where sacrificial anodes are used in groups as remote anode beds, the currents can be larger and the voltage drop in the cable must be considered. Calculate the most economic wire size with No. 12 AWG or foreign equivalent being the minimum size wire that must be used.

4-2.3.1 Wire and Cable Insulation.

Specify high molecular weight polyethylene (HMWPE) insulated stranded copper cable for anode leads and structure leads, with the wire appropriately sized for current carrying capacity, mechanical strength, and total CP circuit resistance. Wire size must conform to the requirements in the National Electrical Code (NEC). For submerged applications or chemical environments, specify the appropriate insulation that best resists deterioration in that environment.

Test station wires carry only very small currents and insulation requirements are not critical, but should be selected to match the environment. Specify stranded copper wires, No. 12 gauge AWG with thermoplastic (THW), cross-linked polyethylene (RHW or USE), or HMWPE insulation for this application unless otherwise dictated by economics or site conditions.

4-3 IMPRESSED CURRENT SYSTEMS.

4-3.1 Anodes.

Specify the type and size of ICCP anode that will provide the optimum performance based upon site conditions, electrolyte characteristics, system life, and economic feasibility. The design basis and calculations must provide clear rationale for the anode selection. The minimum design life is 25 years unless mission or operational requirements dictate a shorter economic life.

4-3.2 Backfill.

Provide special carbon backfill, referred to in the industry as coke breeze, in the anode hole for soil applications. Some specific backfill requirements are as follows:

4-3.2.1 Backfill Specific Gravity.

Specify backfill with the appropriate specific gravity for the type of anode hole so that the particles will settle and compact themselves. Where applicable, include procedures for installing and tamping the backfill in lifts to avoid voids and bridging in the anode hole. Where tamping is not practicable, specify calcined petroleum coke backfill for its spherical shaped particles that can better settle into the hole and compact itself.

4-3.2.2 Backfill Particle Size.

Specify backfill with the appropriately sized particles for optimum contact between the anode and backfill for the type of installation being designed. At the same time, consider the permeability of the backfill to gases that will be generated to prevent gas blockage.

4-3.3 Anode/Structure Lead Wires and Header Cables.

For ICCP systems, select connecting cables and wires based upon consideration of the following factors:

- Current carrying capacity
- Voltage attenuation (IR drop)
- Mechanical strength
- Economics (first cost versus power costs)
- Dielectric strength of insulation
- Durability (abrasion & cut resistance) of insulation

4-3.3.1 ICCP Power Supply to Structure Cables.

Specify HMWPE insulated stranded copper cable, with the wire appropriately sized for current carrying capacity, mechanical strength, and total CP circuit resistance. Wire size must conform to the requirements in the NEC. For submerged applications or chemical environments, specify the appropriate insulation that best resists deterioration in that environment.

4-3.3.2 ICCP Power Supply to Anode Cables.

Wire size must conform to the requirements in the NEC. The insulation in these cables is critical. The connection between the CP power source and the anodes for ICCP systems, are typically buried or submerged, and are extremely susceptible to failure as they are operated at highly positive potentials. Any contact between the metallic conductors and the environment will result in rapid deterioration of the conductor and loss of continuity of the protective circuit. Specify HMWPE insulation, 0.110 inches thick, as a minimum, for these cables in most buried applications. Where exposure to chlorine will be encountered, such as in seawater or in deep well applications, specify chlorine resistant composite insulation consisting of an HMWPE outer jacket for abrasion resistance combined with an ethylene-chlorotrifluoroethylene copolymer inner jacket.

4-3.4 Deep Anode Bed Design.

A deep anode bed consists of one or more anodes installed vertically at a nominal depth of 15m (50 feet) or more below the earth's surface in a drilled hole for the purpose of supplying CP for an underground or submerged metallic structure. Refer to Figure 4-1. The deep anode bed design must consider several important factors essential to ensuring the proper installation and operation of the well. Refer to the best practices

and lessons learned in Appendix B-10.1.

4-3.4.1 Location of Anode Well.

Consider the following when selecting a location for a deep well anode bed:

4-3.4.1.1 Geological Considerations.

Consider subsurface stratigraphy, hydrology, and lithology. Avoid rock, as it is a generally high resistivity environment that could hamper installation and proper operation. In sand environments specify methods to keep hole open during drilling and anode installation. Select a location with consistent subsurface resistivity as much as practicable to help ensure a uniform current discharge from the anodes.

4-3.4.1.2 Ground Water Aquifers.

Consider the location of ground water aquifers. From a geological standpoint, indicate in the design documents if artesian well conditions will be encountered. Such conditions will hamper drilling and anode installation operations, and installation procedures must be specified to account for these conditions. From an environmental standpoint, consider installation methods that will prevent contamination of a water aquifer during installation and operation of the anode well. Refer also to paragraph 4-3.4.5.

4-3.4.1.3 Communication with the Community.

Communicate with both on base and off base community where applicable. Where the CP system is located off base, communicate with the local community in order to identify easement issues, coordinate with local planning for future developments that could result in future easement issues, and coordinate with owners of buried utility pipelines and other buried structures in the area.

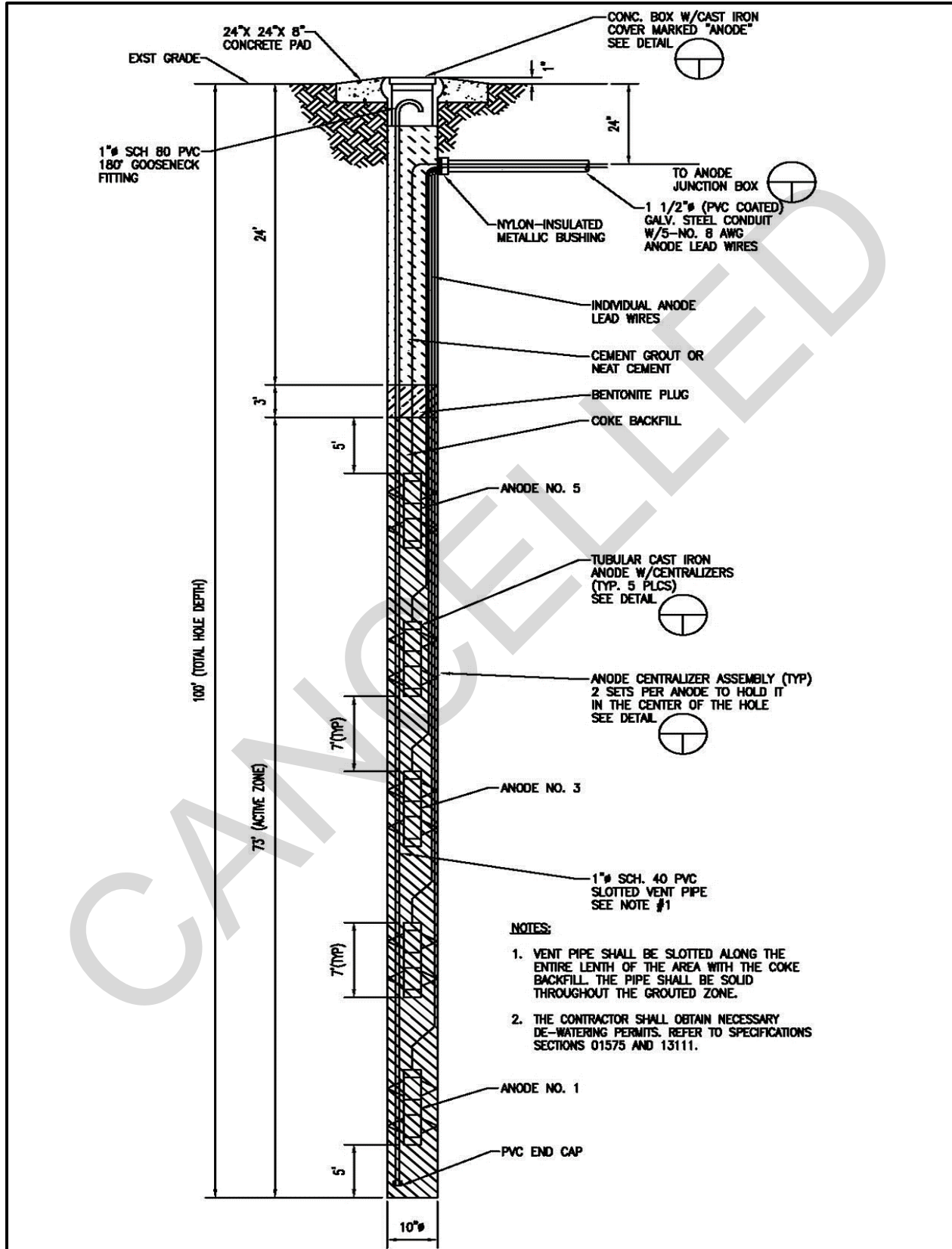
4-3.4.2 Anode Column.

Some anode column design requirements and considerations are as follows:

4-3.4.2.1 Anode Selection.

Select anode type for optimum performance and reduced difficulty of installation. Local subsurface conditions influence the selection of anode type, and anode selection affects the design for the column, i.e. quantity of anodes, depth and diameter of the column, and installation procedures.

Figure 4-1 Schematic of a typical deep well anode bed



4-3.4.2.2 Anode Centralizers.

Provide anode centralizers to help ensure the anodes are completely surrounded by backfill to lessen the chance of premature failure. Design/specify centralizers that do not significantly reduce total anode discharge area. Avoid the attachment of centralizers directly to anode surfaces that are subject to crevice corrosion such as mixed metal oxide or platinum coated titanium or niobium.

4-3.4.2.3 Anode Column Venting.

Provide vent pipes in the anode well to vent gases generated around the anode out of well to avoid gas blockage. Gas blockage can result in increased anode resistance and uneven current discharge from the anode surface resulting in premature failure. Specify vent pipes with holes or slots small enough to prevent the backfill from entering and clogging the vent pipe. Do not terminate the vent pipe inside of the anode junction box. The chlorine gas will cause corrosion of junction box hardware and detrimentally affect operation of the CP system. Also, do not terminate the vent in the anode well head box. The concentration of chlorine gas can result in corrosion of the well head box cover if it is made of steel or cast iron, and can degrade the insulation around the anode lead wires, and result in loss of the anode.

4-3.4.2.4 Anode Installation Procedure.

Follow the anode installation procedures as indicated in UFGS 26 42 17.00 10 and UFGS 26 42 19.00 20. In most cases specify that the contractor must not use the anode lead wire to lift, transport or install the anode. Handling the anode by using the lead wire can compromise integrity of wire and anode connection. Where the situation requires the use of the anode lead wire for anode installation, specify the appropriate pull out strength of the wire-to-anode connection and provide destructive test procedures to verify conformance with the specifications. Refer to UFGS 26 42 17.00 10 and UFGS 26 42 19.00 20.

4-3.4.3 Anode Column Backfill.

Provide a special carbon coke breeze backfill in the anode hole or column for all underground deep anode bed installations, except for open hole, replaceable anode deep wells. Consider open hole deep anode beds only where there is sufficient low resistivity groundwater to keep the anode well filled with water and provide the uniform environment for uniform distribution of current. Environmental concerns must be addressed. Anodes in open holes are more easily replaced in the event of failure. Specific backfill requirements are as follows:

4-3.4.3.1 Backfill Specific Gravity.

Since deep anodes are typically installed in the ground water table, specify backfill with high specific gravity so that the particles will settle and compact themselves since they cannot be tamped. Specify calcined petroleum coke backfill for its spherical shaped particles that can better settle into the deep column and compact itself without tamping.

4-3.4.3.2 Backfill Particle Size.

Specify backfill with small particles for optimum contact between the anode and backfill. Also consider the permeability of the backfill to prevent blockage of gases generated in the well.

4-3.4.3.3 Backfill Installation.

Backfill must be installed by pumping a slurry of the backfill into the hole from the bottom up to preclude voids or “bridging”. Do not use the vent pipe to install the backfill, as it will clog the vent pipe. Large particles specified to prevent gas blockage will be difficult to pump.

4-3.4.4 Anode Lead Wires.

Anode lead wires are a very important component of the anode installations, and many deep anode installations have failed because of improperly specified lead wires. Some considerations for anode lead wires for deep anode beds include:

4-3.4.4.1 Wire Insulation.

Specify HMWPE insulation. For chlorine ion environments, specify a dual insulation consisting of an inner ethylene-chlorotrifluoroethylene layer with an HMWPE outer layer for abrasion resistance.

4-3.4.4.2 Splices Not Allowed.

Provide individual anode lead wires to the anode junction box instead of splicing them to a single header cable from the rectifier. Specify that splices are not allowed in the anode lead wires. Splices are a point of premature failure of anode lead wires.

4-3.4.4.3 Damage Insulation Not Acceptable.

Specify that nicks or other damaged to the wire insulation are not acceptable. As with splices, and even more so with damaged wire insulation, nicks and damaged insulation are points of premature failure of anode lead wires.

4-3.4.5 Environmental Concerns.

Installation of a deep anode bed can impact the environment. Environmental concerns must be considered during the early design stages. Consult with base environmental personnel and ensure that they are afforded the opportunity to review the design. Failure to consider environmental concerns can result in:

- Delays in completing the final design if an environmental issue is identified too late in the design
- Delays in obtaining construction permits
- Work stoppage and costly construction delays if environmental issues must be settled after construction is awarded, with the potential for disapproval of work and cancellation of the installation

- Pollution of the environment and the resulting costly cleanups
- Fines for violating environmental regulations
- Other legal ramifications

4-3.5 Rectifiers and Other DC Power Supplies.

Any source of direct current of appropriate voltage and current can be used as a source of power for ICCP systems. Select the power supply based upon local conditions at the site and evaluation of economics, availability of AC power or fuel, and the availability of maintenance capability. Design drawings must identify the specific source of power and any necessary additional electrical equipment components required to provide power to the rectifiers.

4-3.5.1 Transformer-Rectifier.

Unless AC power is unavailable, specify a transformer-rectifier, or more simply, a rectifier. They are by far the most commonly used power supply type for ICCP systems, as they are readily available in a wide variety of types and capacities that are specifically designed and constructed for use in ICCP systems. The most commonly used type of rectifier has an adjustable step down transformer, rectifying units (stacks), meters, circuit breakers, lightning arresters, current measuring shunts, and transformer adjusting points (taps), all in one enclosure. Ensure rectifiers and associated wiring and conduit are installed according to applicable electrical and safety codes and guidance.

4-3.5.2 Solar Power-Rectifier.

Consider the use of storage batteries and solar panels (Figure 4-2) for ICCP power supplies at remote sites where electrical power is not available. Security must be considered with solar power systems to avoid theft and vandalism especially in off-base locations. Environmental and safety considerations must address procurement, maintenance and disposal of battery electrolytes.

Specify high efficiency (96-98%) controls that have flexibility to match the anode ground bed and its fluctuating conditions. In order to maintain constant CP levels, specify a control unit that has either constant potential (with reference to a permanent reference electrode) control or constant current output capability. Select the controller unit that minimizes the mismatch loss between the PV array and the storage batteries. Finally, consider providing a controller that has built-in current interruption capability so that IR free (more accurate) structure potentials of the pipelines can be measured. NAVFAC Engineering Service Center (ESC) Technical Report TR-2312-SHR *CPC Program Final Report Solar Powered Cathodic Protection System*, documents some of the key considerations and lessons learned when considering the use of solar power.

Figure 4-2 Small Solar Powered CP System. Solar Panels Shown in Picture on Left. Battery Bank and Control Center Shown on Right.



4-3.5.3 Other Power Supplies.

Consider usage of other types of power supplies such as engine or wind driven generators or thermoelectric generators in remote locations where electrical power is not available and solar power is not practicable. They must be justified by life-cycle economic analysis.

4-4 OTHER COMPONENTS.

4-4.1 Electrical Continuity and Isolation.

Electrical continuity or isolation requirements must be determined to design an effective CP system for the structure and ensure it will receive adequate CP as intended. For electrically discontinuous structures, provide continuity bonds (Figure 4-3) or provide independent CP systems for each electrically isolated section of the structure.

Conversely, provide electrical isolation if only a portion of a larger structure will be protected, or other buried metallic structures not intended to be protected are electrically continuous with the structure to be protected.

4-4.1.1 Electrical Bond Wires.

These wires carry more current than test wires, and may require mechanical strength. Specify No. 4 or 8 AWG stranded copper cable with HMWPE insulation for all bond wires unless a larger wire size is required for current carrying capacity.

Figure 4-3 Bond Wire Installed Between Two Electrically Isolated Pipe Sections



4-4.1.2 Electrical Isolation Joints (Insulating Fitting).

Provide dielectric insulation joints (flanges or unions) between sections of a structure to electrically isolate the structure into sections that can be protected by independent CP systems, or to separate sections that require CP from those that do not. Electrical isolation is provided to minimize current requirement for both GCP and ICCP systems by isolating structures that are not intended to be protected by the CP system. Insulating joints are sometimes used to isolate sections of structures so that each section can be protected separately when necessary.

Unless it is not feasible, install electrical isolation devices where the pipe emerges from the ground or in valve pits. Where the isolation joints absolutely must be buried, provide two-wire test stations to allow testing of the electrical isolation joint. Coordinate with the design team/users to ensure mechanical or structural features will not unintentionally bypass the electrical isolation. For example:

- Electrical grounding system connection points that result in the area grounding system (bare copper wire and ground rods) being connected to the CP system
- Tank gauging system or other electrical conduits that unintentionally bypass electrical isolation
- Pipe racks supporting the pipe to be protected as well as pipe not intended to be protected and/or electrical conduits connected to grounding systems

- Small diameter bypass pipelines that bypass the dielectric isolation gasket in the main larger diameter pipeline

Consider the need for surge and fault current protection at isolation devices. If an insulation flange is installed in a hazardous classified area per the NEC, provide a sealed, weatherproof surge arrester across each isolation device. The arrester must be the gapless, self-healing, solid state type (e.g., metal oxide varistor). Cable connections from arresters to isolating devices must be short, direct, and of a size suitable for short-term, high current loading.

4-4.1.2.1 Insulation Joints and Surge Arresters on POL Pipelines.

For POL pipelines, provide surge arrestors across all aboveground insulated flanges connected to below ground cathodically protected piping per UFC 3-460-01. Require surge arrestors to be designed for use with insulated flanges and for use in NEC Class I, Division 1 areas. Provide covers over flanges to preclude dirt from degrading surge arrestors.

4-4.1.2.2 Insulation Flanges and Surge Arresters on Fire Protection Pipelines.

Provide insulation flanges in fire protection risers or in other piping extending from below grade into the building. Install insulation flanges in fire riser piping or other piping, above the floor slab. Additionally, consider installation of AC/DC decoupling devices across the insulation flanges per the NEC. The NEC allows the underground piping extending into the building to be bonded into and used as part of the building grounding system, which can result in premature corrosion failure of the buried piping due to DC component currents discharging to ground via the buried piping.

4-4.2 Connections and Splices.

While connection of wires to the structure can be either by exothermic weld or mechanical connections, utilize exothermic welding (Figure 4-4) as much as practicable. Avoid mechanical connections as much as practicable (Figure 4-5), as corrosion of the mechanical connection tends to result in a high resistance connection over time that could prevent the CP system from properly operating. Insulate underground connections with either epoxy encapsulation or other type of mastic compatible with the pipeline coating. Above grade connections such as wires in test stations are usually mechanical connections. Specify that they be carefully taped in order to prevent corrosion due to the entry of moisture.

Include details on the design drawings showing a typical exothermic welding process and include notes describing the step by step procedure. The UFGS include sections detailing the requirements for exothermic welding. Ensure the project specifications include the applicable requirements including the requirements regarding safety.

Figure 4-4 Exothermic Weld of CP System Wiring to the Structure

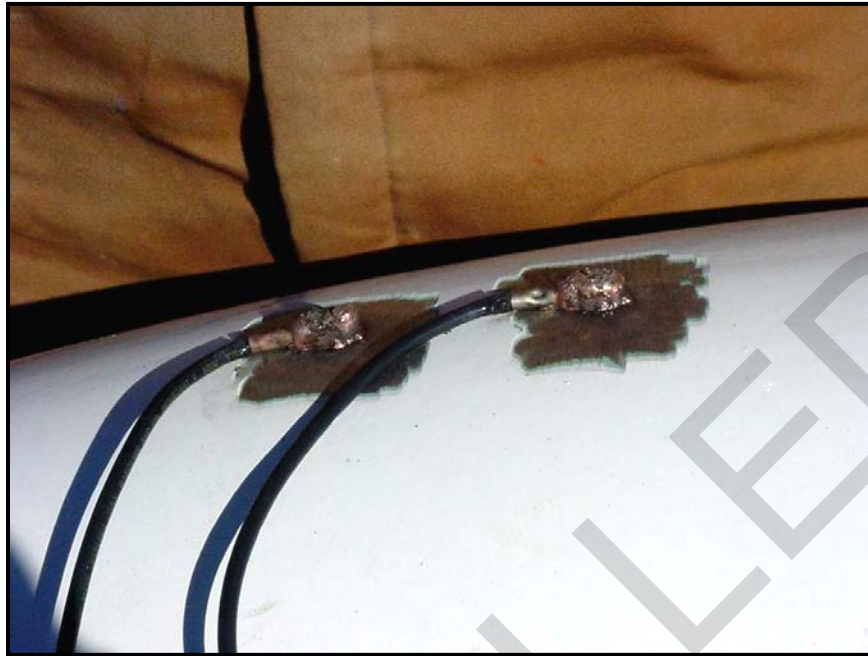


Figure 4-5 Mechanical Connection of Wiring to the Structure



4-4.2.1 GCP Systems.

The following connections are required for GCP anode systems and must be shown on the design drawings:

- Connection between anode(s) and structure through a test station
- Connection between cable and anode (must be factory made with wire connection attached to cast-in core)
- Necessary bonds and test wires

4-4.2.2 ICCP Systems.

The following connections are required for ICCP systems and must be shown on the design drawings:

- Connection between power source and structure
- Connection between anode bed(s) and power source (anode header cable)
- Connection between anode header cable and each anode
- Connection between cable and anode (must be factory made)
- Necessary bonds and test wires

Carefully insulate all connections, particularly in the anode to power supply portion of the circuit where any loss of insulation integrity will result in rapid system failure. All connections in the power source to anode bed portion of the circuit and all cable-to-cable connections must be insulated by encapsulation in epoxy using commercially available kits made expressly for this purpose.

The cable to structure connection is less critical and either epoxy encapsulation or insulation with mastic must be used on this connection.

4-4.3 Test Stations.

Provide a sufficient number of test stations to allow access to the structure for potential surveys to determine if adequate CP has been achieved. They are also necessary to perform recurring maintenance, troubleshooting and repair of the system during its life cycle.

4-4.3.1 Test Station Location and Function.

Accurately identify test station locations on the design and as built drawings. Include details of the schematic wiring of all test stations in the system design. Specify test stations manufactured specifically for the intended purpose. Provide flush mounted test stations in paved areas or other areas where damage by vehicles, etc. is anticipated. Provide above grade test stations where they are not subject to vehicle damage or are located in areas where flush mounted test stations can easily be covered over and lost.

Provide test stations on all foreign structures that cross the protected structure or are in the vicinity of the anode bed. Also provide test stations for all pipeline casings, underground dielectric insulation unions and flanges, and other components such as bonds. Provide test station markers for flush mount test stations on cross country pipelines to facilitate location of these test points.

4-4.3.2 Test Station Wiring.

All test stations must include at least two wires to each structure protected or impacted by the CP system. Provide non-corroding metal or plastic identification tags on all test wires to identify them and indicate the system component to which they are connected.

Since test stations are manufactured in many different types and configurations, ensure that they are adequately sized and configured for the number of test wires and intended purpose of the test station. Some small flush mount test stations are manufactured with five or more terminals on the terminal board, but when installed with thick polyethylene insulated wire, are difficult to open and close, often resulting in damage to the wiring terminals and measuring shunts. Provide test stations large enough to appropriately accommodate the wire quantity, size and insulation type and facilitate maintenance and testing.

4-4.4 Permanent Monitoring Electrodes and Probes.

For structures that will have limited access to the electrolyte after construction, provide permanent electrodes, probes or other means to allow structure-to-electrolyte testing and other means to demonstrate CP system effectiveness. Following are some examples:

- Exterior bottoms of on-grade fuel storage tanks with a secondary containment liner
- Water storage tank interior
- Rebar in a concrete structure
- Submerged waterfront structure

4-4.4.1 Permanent Reference Electrodes.

Provide the type of permanent reference electrode suitable for the electrolyte and specific environment conditions.

4-4.4.1.1 Seawater and Brackish Water.

Specify silver-silver chloride reference electrodes (SCE) for most sea water and brackish water environments. Do not specify copper-copper sulfate reference electrodes (CSE) in these environments.

4-4.4.1.2 Soil and Fresh Water.

Specify CSE or zinc reference electrodes (ZRE) for most soil and fresh water environments. Ensure that reference electrodes for use inside of potable water storage tanks are approved in accordance with NSF/ANSI Standard 61. For soil applications, specify reference electrodes that are prepackaged in backfill SCE by the manufacturer.

4-4.4.1.3 Concrete.

For reinforced concrete, specify SCE manufactured for use embedded in concrete.

4-4.4.1.4 Aboveground Storage Tanks.

Specify dual element CSE/ZRE for the exterior bottom of aboveground (on-grade) storage tanks.

4-4.4.1.5 Industrial Hot Water Tanks.

For industrial hot water tanks, refer to paragraph 4-5.6.2

4-4.4.2 Reference Electrodes with Coupons.

Provide reference electrodes with coupons where voltage drop (IR) free structure-to-electrolyte measurements are necessary and interruption of the CP current is not practicable. NAVFAC ESC Technical Report TR-3559-SHR *Corrosion Protection Utilizing IR Drop Free Sensors and Data Acquisition for Cross Country Pipelines*, includes lessons learned regarding the application of reference electrodes with coupons to monitor CP effectiveness on a buried pipeline.

4-4.4.3 Electrical Resistance Probes.

Provide electrical resistance (ER) probes where it is necessary to demonstrate a reduction of corrosion rate in addition to structure-to-electrolyte measurement to demonstrate CP system effectiveness. Ensure the design includes provisions for protecting the connection point of the lead wires to the probe body. Any corrosion in the connection will render the probes useless. Technical Report TR-NAVFAC EXWC CI-1301 *CPC Program Final Report Electrical Resistance Probe Corrosion Sensors for In Situ Assessment for Waterfront Structures*, documents some of the technical considerations and lessons learned when considering the use of ER probes in submerged waterfront structure applications.

4-5 SPECIAL TECHNOLOGICAL CONSIDERATIONS.

Refer to Appendix B-10 for best practices and lessons learned regarding the special considerations in this section.

4-5.1 Remote Monitoring.

For critical or remote locations, consider the use of remote monitoring equipment to monitor the CP system and the protected structure. Required periodic monitoring of ICCP rectifiers requires a crew to travel to the location to perform testing and can result

in up to 60 days between inspections. Remote monitoring systems help reduce testing costs and aid in collection and management of data for historical records.

Remote monitoring units commonly communicate by cell phone technology or satellite transmission technology. Technical Report TR-NAVFAC EXWC CI-1405 *CPC Program Final Report Satellite Based Remote Monitoring Systems for Cathodic Protection Systems in Remote Locations*, documents some of the key considerations and lessons learned when considering the use of satellite remote monitoring. Technical Report ERDC/CERL TR-07-25 *Remote Monitoring of Cathodic Protection and Cathodic Protection System Upgrades for Tanks and Pipelines at Fort Carson*, documents the use of and lessons learned regarding “drive-by” remote monitoring systems. Refer to paragraph 1.6 for cybersecurity requirements.

4-5.2 Pre-engineered CP for Underground Storage Tanks.

USTs and oil water separators that conform to the Steel Tank Institute STI-P3-90 include a pre-engineered sacrificial anode CP system that is one part of the overall pre-engineered external corrosion control system for the underground steel storage tank (Figure 4-6). The STI-P3® system combines three basic methods of underground corrosion control, all installed on the tanks during manufacture:

- Cathodic Protection
- Protective Coating
- Electrical Isolation of the tank from other underground metallic structures

Figure 4-6 STI-P3® Tank



***** CAUTION - RISK OF INADEQUATE CP *****

The CP system for an STI-P3® tank is intended only to protect the tank. Pipelines associated with the tank will not be protected. A separate CP system must be provided for the associated pipelines to comply with UST regulations. Also note that the integrity of the isolating bushings for an STI-P3® tank must be maintained. Loss of this electrical isolation can result in inadequate protection of the tank because of electrical shorts to other buried metallic structures in the vicinity.

Do not specify these types of pre-engineered CP systems where field survey conditions indicate they are not feasible. For new STI-P3® tanks specify provision of manufacturer provided PP4 CP testing equipment or provide separate appropriate test stations and wiring, to allow proper testing of the CP system.

4-5.3 Aboveground (on-grade) Storage Tanks.

Provide ICCP systems for the exterior bottoms of aboveground (on-grade) storage tanks with a secondary containment liner. Anodes must be installed in the backfill between the tank bottom and the containment liner. Do not specify GCP systems unless mission requirements preclude the use of ICCP systems. Provide a combination of permanent reference electrodes, corrosion probes, and reference electrode tubes to allow sufficient long-term testing and monitoring of the CP system effectiveness. Provide a separate CP system for buried distribution pipelines associated with the tank.

Provide a properly designed ICCP system for aboveground storage tank bottoms without secondary containment liners. With the many other systems incorporated into these storage facilities (e.g. tank gauging systems, fire protection systems, etc.), complete electrical isolation can be difficult to achieve. The tank may also be connected to a grounding system for safety, precluding the possibility of complete tank isolation. Provide CP for buried distribution pipelines associated with the tank. Consider electrical isolation issues, stray current interference issues, and life cycle costs to determine the need for a single integrated CP system for the tank and pipelines or separate CP systems for the tank and pipelines.

4-5.4 CP Systems for Reinforcing Steel in Concrete.

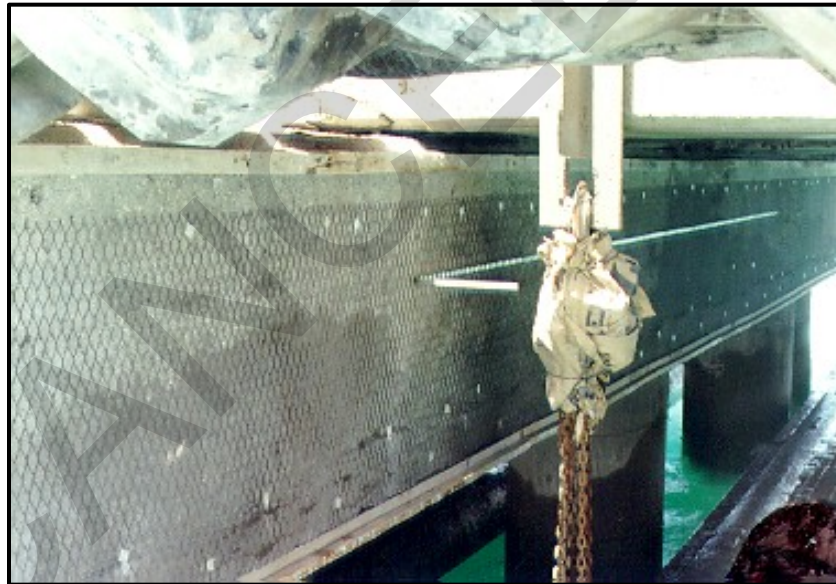
CP systems are not required for reinforcing steel (rebar) for new reinforced concrete structures. Instead, comply with the requirements of the appropriate UFC and UFGS documents that include concrete design considerations that enhance corrosion prevention and control of the rebar. However, for major concrete structure repair projects, provide CP for the rebar in concrete where economical over the life cycle of the structure. CP systems for rebar in concrete must be designed by a qualified person experienced in the design of CP systems for rebar in concrete. Provide permanent reference electrodes or corrosion probes to allow testing and monitoring of the CP system effectiveness.

4-5.4.1 ICCP Systems.

For corrosion protection of reinforced concrete structures requiring significant structural concrete repairs, consider one or a combination of the three different types of ICCP anode systems that is most appropriate for the type of concrete structure and repairs being accomplished.

- Titanium mesh system consisting of mixed metal oxide coatings on an expanded titanium mesh fastened to the concrete surface (Figure 4-7) and overlaid with a cementitious material, usually a Portland cement concrete mix. This type of system is commonly used on deck surfaces, piles or columns
- Titanium ribbon (mesh) slotted system consisting of mixed metal oxide coatings on either solid titanium ribbon strips or on expanded titanium mesh strips (ribbons). The ribbons are installed between the rebar and concrete substrate or in slots cut in the concrete surface and backfilled with a cementitious mix. This type of system is commonly used on deck surfaces

Figure 4-7 Titanium Mesh Anodes Fastened to a Concrete Beam



- Discrete anode system that typically consist of short strips of mixed metal oxide coated expanded titanium mesh, ceramic anodes, or platinized titanium wire typically installed in drilled holes and backfilled with cementitious grout. The length and spacing of the discrete anodes depends on the density of rebar and protection current requirements. These systems are most economical for beams, piles and columns

4-5.4.2 GCP Discrete Anode System.

When cracked and spalled concrete structures containing high chloride contamination are repaired by patching, consider installation of GCP discrete anode systems (DAS) in the vicinity of the patched area. The GCP discrete anodes are sacrificial zinc anodes in a special backfill (Figures 4-8 and 4-9). Unless a large area of concrete is removed during spall repairs, provide discrete anodes areas near the outer edges of the patch before applying the concrete patch. The type, length and spacing of the discrete anodes depend on the density of rebar and patch dimensions.

The intent of the DAS anodes installed along with patches is not to provide adequate CP to the entire structure, but to minimize the galvanic corrosion effects between the rebar surrounding the patched area and the rebar within the patched area. Technical Report TR-NAVFAC EXWC CI-1412 *CPC Program Final Report Alkali Activated Zinc Grouted Anode System for Concrete Reinforcing Steel*, includes details on design considerations for the application of DAS anodes in a waterfront structure.

Figure 4-8 Discrete Zinc Anode (Wrapped in Green Mesh) in Concrete Deck Repair. Device with Yellow Lead Wire is a Permanent Reference Electrode.



4-5.4.3 Pre-engineered CP for Pier Pilings.

Integrated concrete pile repair and corrosion protection systems (Figure 4-9 and 4-10) contain pre-engineered CP systems for the pile reinforcing steel. Consider these type of systems as a viable alternative for long-term repairs of waterfront structures with reinforced concrete piles containing high chloride contamination, and significant spalling/delamination of concrete due to corrosion of reinforcing steel. These systems can increase the service life of a pier patch repair up to 20 years in contrast to only six to seven years if pier pilings containing high chloride levels are only patched. For piles with only minimal damage, prepare a life cycle cost analysis to help determine the economic viability of this technology. NAVFAC ESC Technical Report TR-2292-SHR

CPC Program Final Report Integrated Concrete Pier Piling Repair and Corrosion Protection System, documents an innovative repair technique known as “Lifejacket” which integrates both concrete pile repair and a zinc mesh GCP system.

Figure 4-9 Discrete Zinc Anodes in Fiberglass Jacket for Pile Installation.



Figure 4-10 Photos Showing “Before” and “After” Installation of Integrated Pile Repair Systems



4-5.5 Water Storage Tanks.

Water storage tank CP systems must be designed by a qualified person experienced in the design of CP systems for water storage tanks to ensure its proper operation. Refer also to the best practices and lessons learned in Appendix B-10.4.

4-5.5.1 Interior of Potable Water Tanks.

Ensure that CP system materials are approved for use inside of potable water storage tanks in accordance with NSF/ANSI Standard 61. Coordinate CP system requirements with the interior protective coatings designer to eliminate conflicting requirements. Include requirements in the contract specifying that the contractor is responsible for providing an interior coating system and ensuring that the coating system is compatible with the ICCP system. For bolted panel storage tanks, require the contractor to ensure all panels of a bolted panel storage tank are electrically continuous.

4-5.5.2 CP for Interior of Water Tanks Subject to Icing Conditions.

There is a persistent problem at DoD installations with CP systems for water storage tanks located in areas with cold winters. Water tank interior CP system anodes are typically suspended from the roof of the tank with wires and cables such that they are submerged in the water. Such systems are often prematurely damaged or destroyed when surface ice forms in the tank in very cold environments. ICCP systems to protect the interior surfaces of water storage tanks in cold climates must be designed to prevent damage from ice. Specify a CP system consisting of mixed metal oxide wire anodes along with a flotation and support system that keeps the anodes submerged in water underneath surface ice, regardless of the water level, where they will no longer be subject to ice damage. Technical Report ERDC/CERL TR-07-22 *Demonstration of Ice-Free Cathodic Protection Systems for Water Storage Tanks at Fort Drum*, documents considerations for designing ICCP systems for water tanks subject to icing conditions. Refer to the material and installation requirements in UFGS 26 42 15.00 10.

4-5.5.3 Bolted or Riveted Water Storage Tanks with Interior Glass Lining.

Where a CP system is planned for a bolted or riveted steel water storage tank with an interior glass lining, include provisions to ensure electrical continuity between the riveted steel plates. The interior glass lining may electrically isolate adjacent plates. For other types of protective coatings, include requirements in the contract specifying that the contractor is responsible for providing an interior coating system and ensuring that the coating system is compatible with the CP system.

4-5.5.4 Monitoring Water Tank CP Effectiveness.

Provide a CP monitoring system that will allow monitoring of system effectiveness without having to physically climb the tank. Design the monitoring system such that test lead terminals are conveniently located in, or nearby the rectifier at ground level. Consider the use of remote monitoring systems.

4-5.6 Hot Water Storage Tanks.

Steel hot water storage tanks need protection against internal corrosion to prevent chronic leaking and premature failure. Corrosion caused leaks could cause extensive water damage to structures and mission critical electrical and mechanical equipment that may be co-located in rooms where the water storage tanks are located.

Furthermore, the resulting leaks will eventually cause an accumulation of moisture that will promote mold and bacteria growth. Technical Report ERDC/CERL TR-07-26 *Cathodic Protection of Hot Water Tanks at Fort Sill*, documents the economics of the application of CP systems for hot water storage tanks. Refer also to Appendix B-10.5.

4-5.6.1 Domestic Hot Water Heaters/Tanks.

Provide factory-equipped glass linings and sacrificial anodes for domestic and smaller hot water heaters/tanks (75 – 1000 GA capacity). The glass linings and sacrificial magnesium anodes are economical for corrosion protection due to the reduced maintenance and monitoring for these systems.

4-5.6.2 Industrial Hot Water Heaters/Tanks.

Provide ICCP systems that use mixed metal oxide titanium rod anodes for larger industrial hot water heaters/tanks where corrosion of the interior has historically been a problem. Provide a capillary pore tube measurement port or bridge that facilitates CP system testing with a reference electrode located outside the hot water tank with the tip held against the ionically conductive capillary tube (see Appendix B-10.5.2.1).

4-5.6.3 ICCP for Water Boxes in Power Plants.

Water boxes can contain a mixture of many different metallic materials. Some of the materials such as titanium, austenitic stainless steels, and super alloy stainless steels are more noble than the rest of the water box components. As a result, without CP, water box components can experience substantial galvanic corrosion. However, improperly designed ICCP systems for water boxes can result in metallurgical problems such as:

- Hydride formation in titanium tubes under excessive CP results in reduced ductility as the hydride forms.
- Generation of chlorine gas at the anodes under excessive CP resulting in pitting corrosion in the upper tubes of austenitic stainless steel tube bundles.
- Hydrogen embrittlement of stainless steel under excessive CP.

Cathodic protection systems must be carefully designed to operate within selected operating potentials, and be properly maintained within these potentials to prevent any metallurgical problems from occurring. Designs must be accomplished by personnel qualified and experienced in these types of systems.

APPENDIX A REFERENCES

AMERICAN SOCIETY FOR TESTING AND MATERIALS

ASTM G57-95a (latest edition): *Standard Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method*

CODE OF FEDERAL REGULATIONS

CFR Title 40 Chapter 1, Part 112, *Oil Pollution Prevention*, Washington DC

CFR Title 40 Part 280, *Technical Standards and Corrective Action for Owners and Operators of Underground Storage Tanks*

CFR Title 49, Chapter 1, Part 192, *Transportation of Natural and Other Gas by Pipeline*

CFR Title 49, Chapter 1, Part 195, *Transportation of Liquids by Pipeline*

DEPARTMENT OF DEFENSE REGULATIONS

Department of Defense, *Overseas Environmental Baseline Guidance Document*

Department of Defense Instruction 5000.67 *Prevention and Mitigation of Corrosion on DoD Military Equipment and Infrastructure*

DEPARTMENT OF THE AIR FORCE REGULATIONS

Department of the Air Force Instruction 32-1054, *Corrosion Control*

NATIONAL ASSOCIATION OF CORROSION ENGINEERS INTERNATIONAL

NACE International Standard Practice SP0100, *Cathodic Protection to Control of Concrete Pressure Pipelines and Mortar Coated Steel Pipelines for Water or Wastewater Service*

NACE International Standard Practice SP0169 (latest edition): *Control of External Corrosion on Underground or Submerged Metallic Piping Systems*

NACE International Recommended Practice RP0193 (latest edition): *External Cathodic Protection of On-Grade Carbon Steel Storage Tank Bottoms*

NACE International Standard Practice SP0196 (latest edition): *Galvanic Anode Cathodic Protection of Internal Submerged Surfaces of Steel Water Storage Tanks*

NACE International Standard Practice SP0285 (latest edition): *Corrosion Control of Underground Storage Tank Systems by Cathodic Protection*

NACE International Standard Practice SP0286 (latest edition): *Electrical Isolation of Cathodically Protected Pipelines*

NACE International Standard Practice SP0290 (latest edition): *Impressed Current Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures*

NACE International Standard Practice SP0388 (latest edition): *Impressed Current Cathodic Protection of Internal Submerged Surfaces of Carbon Steel Water Storage Tanks*

NACE International Test Method TM101 (latest edition): *Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Tank Systems*

NACE International Test Method TM0497 (latest edition): *Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems*

NACE International Standard Practice SP0572 (latest edition): *Design, Installation, Operation, and Maintenance of Impressed Current Deep Anode Beds*

NATIONAL FIRE PROTECTION ASSOCIATION

NFPA 70, *National Electrical Code*

NATIONAL SANITATION FOUNDATION

NSF/ANSI Standard 61, *Drinking Water System Components - Health Effects*

NAVAL FACILITIES ENGINEERING AND EXPEDITIONARY WARFARE CENTER,

NAVFAC ESC TR-2312-SHR, *CPC Program Final Report Solar Powered Cathodic Protection System*

NAVFAC ESC TR-3559-SHR, *Corrosion Protection Utilizing IR Drop Free Sensors and Data Acquisition for Cross Country Pipelines*

TR-NAVFAC EXWC CI-1301, *CPC Program Final Report Electrical Resistance Probe Corrosion Sensors for In Situ Assessment for Waterfront Structures*

TR-NAVFAC EXWC CI-1405, *CPC Program Final Report Satellite Based Remote Monitoring Systems for Cathodic Protection Systems in Remote Locations*

TR-NAVFAC EXWC CI-1412, *CPC Program Final Report Alkali Activated Zinc Grouted Anode System for Concrete Reinforcing Steel*

TR-2292-SHR, *CPC Program Final Report Integrated Concrete Pier Piling Repair and Corrosion Protection System*

TR-NAVFAC EXWC CI-1425, *Environmentally Friendly Cathodic Protection Anode Beds*

STEEL TANK INSTITUTE

Steel Tank Institute STI-P3-90, *Specification and Manual for External Corrosion Protection Underground Steel Storage Tanks*

UNIFIED FACILITIES CRITERIA

http://www.wbdg.org/ccb/browse_cat.php?o=29&c=4

UFC 1-200-01, *General Building Requirements*

UFC 3-460-01, *Design: Petroleum Fuel Facilities*

UFC 3-570-06, *Maintenance and Operation: Cathodic Protection Systems*

UNIFIED FACILITIES GUIDE SPECIFICATIONS

http://www.wbdg.org/ccb/browse_cat.php?o=29&c=4

UFGS 26 42 13.00 20 *Cathodic Protection by Galvanic Anodes*

UFGS 26 42 14.00 10 *Cathodic Protection System (Sacrificial Anode)*

UFGS 26 42 15.00 10 *Cathodic Protection System (Steel Water Tanks)*

UFGS 26 42 17.00 10 *Cathodic Protection System (Impressed Current)*

UFGS 26 42 19.00 20 *Cathodic Protection by Impressed Current*

UFGS 26 42 22.00 20 *Cathodic Protection System for Steel Water Tanks*

US ARMY CORPS OF ENGINEERS ENGINEERING RESEARCH AND DEVELOPMENT CENTER CONSTRUCTION ENGINEERING RESEARCH LABORATORY

ERDC/CERL TR-07-25 *Remote Monitoring of Cathodic Protection and Cathodic Protection System Upgrades for Tanks and Pipelines at Fort Carson*

ERDC/CERL TR-07-22 *Demonstration of Ice-Free Cathodic Protection Systems for Water Storage Tanks at Fort Drum*

ERDC/CERL TR-07-26 *Cathodic Protection of Hot Water Tanks at Fort Sill*

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APPENDIX B BEST PRACTICES

B-1 CATHODIC PROTECTION PLANNING.

Cathodic protection systems are often not included in a project design because they are not appropriately identified in the project planning documents. CP systems reduce corrosion of buried or submerged metallic structures, thus reducing the probability of failure and concomitant environmental, operational, safety, and economic repercussions. However, in many cases, CP requirements are not considered during the early planning or design of such systems. Also, repairs to existing structures without CP can easily result in accelerated corrosion of the repaired section. Finally, while CP does add additional costs initially, they will generally be the best economic alternative over the life cycle of the structure.

Identifying the CP requirements early on in the process enhances the chances of a successful design. CP requirements added to the scope during the later stages of the process are less likely to be adequately designed or implemented because of limited budgets (often resulting in mediocre design efforts and greater likelihood that the CP requirement will be eliminated), limited time schedules, and resistance from project design teams to further complicate and delay their design process at later stages.

B-1.1 Project Documentation.

The project documents indicate general intent and the final product may change based upon the designers analysis. Even if the designer later determines that a CP system is not required, or a type of CP system different from that identified in the project documents is required, as a minimum, the requirement has been considered. It is usually easier to modify or delete a requirement than it is to add the “new” requirement, particularly in the later design stages.

B-1.1.1 Cost Estimates.

Provide CP system cost estimate information as part of the project documentation. Detailed cost information sheets are most helpful, but if such information is not available, estimate CP system costs based on a percentage of the cost of the structure being repaired, replaced or constructed. Table B-1 provides general guidelines:

Table B-1. General CP System Cost Guidelines

PROJECT COST OR STRUCTURE REPAIR, REPLACEMENT, OR CONSTRUCTION COST	CP SYSTEM COST PERCENTAGE (%)
< \$500,000	15 – 20
\$500,000 - \$5,000,000	10 – 15
> \$5,000,000	5 - 10

B-1.1.2 Sketches and Drawings.

Provide proposed CP system sketches and drawings as part of the project documentation when such information is available. Such information may be available from base corrosion/CP surveys, early stage design drawings, previous CP system installation drawings, or facility condition assessment reports.

B-1.2 Corrosion Control/CP System Assistance.

Bases/Installations/Activities should seek assistance from the service CP subject matter experts, MAJCOM Corrosion Engineers, or service execution agents.

B-2 CP SYSTEM DESIGN CONTRACT PROCESS.

B-2.1 Project Documentation.

When properly planned, infrastructure project documentation should already identify general corrosion prevention/CP system requirements. If not, discuss these requirements with the user to ensure that they are included in the process from the onset of design. This will allow the user ample time to arrange for funding for the CP system design and construction if not already included. Addition of these requirements later in the process often results in funding problems and other delays.

B-2.2 Developing A-E Scope of Work.

Spend a conscientious effort in preparing the A-E scope of work. The scope of work describes the nature of the project and the results expected from the designer. In the design contracting world DoD will not get what is desired unless specified in the design.

B-2.2.1 References.

Reference the policy and requirements in Chapter 2. Reference any applicable codes, regulations, and other applicable UFC documents.

B-2.2.2 Designer Field Survey.

Include costs and effort for the A-E to conduct a field survey to determine site conditions required to adequately design a CP system. The A-E designer must conduct specific field tests at the proposed installation site(s) to evaluate as a minimum, the electrolyte corrosiveness (resistivity, pH, etc.) and CP system current requirements.

B-2.2.3 Typical Field Survey Time.

Typically, allot about two days on site for the designer to inspect the project site conditions, conduct field measurements, research as built drawings of existing structures and associated or nearby CP systems, meet with the installation user and engineering personnel, and determine CP system equipment locations. Additional field time may be necessary, for extensive or complex structures.

B-2.2.4 Electrolyte Environment Data Provided by the Government.

It is generally not recommended that the A-E be asked to design a CP system based on electrolyte information provided by the government. The designer must obtain such information during his own field survey. In isolated cases where a field survey cannot be conducted and an adequate amount of reliable historical information is available, it may be beneficial to ask the designer to base his design on the information provided by the government, however, this may release the A-E from liability if the system is inadequate.

B-2.3 What Information to Provide A-E.

A-E firms must be qualified to design the technical aspects of a project, and an integral part of a good design is the incorporation of user requirements. To aid with the preparation of good CP system designs, provide the designer with user preferences and operational requirements that will affect the design. These requirements can either be written into the design scope of work or discussed during a pre-design meeting.

B-2.3.1 Documents with Pertinent Structure Information.

Documents commonly provided by the government include:

- A copy of a published Base Corrosion Control Plan
- General layout of project site showing location of nearby CP systems
- Drawings of existing CP systems on the existing structure or nearby CP systems if the structure is or will be newly constructed. Also provide the latest Base CP System Assessment Survey and available CP system data if appropriate and requested
- Drawings of the facility for which CP is being designed
- Past historical work effort and manpower maintenance requirements for existing systems (if available)

B-2.3.2 Project Limitations and Constraints.

Information regarding user/Base operational requirements and restrictions should be made known to the designer that may impact the design and/or construction of the CP system.

- Access/Security policies and requirements
- Any special limitations on working hours
- Budget limitations for the project
- Anticipated timeframe for construction
- User Operations limitations that may affect construction schedule (e.g. operational schedules that may prohibit shutdown of the facility, access limitations on airfields or waterfront areas, restricted areas, etc.).

- Safety requirements (e.g. hot work permits)
- Environmental and historical preservation limitations

B-2.4 Deliverables – What to Expect from the A-E.

Assuming proper scope of work has been prepared, design submittals must include, as a minimum:

- Design Basis
- Drawings
- Specifications
- Cost Estimate

B-2.5 Common Problems/Lessons Learned with A-E Designs.

B-2.5.1 Ensure That the CP Design Engineer is Qualified.

CP systems must only be designed by a National Association of Corrosion Engineers (NACE) International Certified Cathodic Protection or Corrosion Specialist. In addition to the certification requirements, the CP design engineer should also have a minimum of five years of experience in the design and successful installation of the type of CP being proposed. Include these requirements in the contract statement of work. Refer to paragraph 3-3.2.

B-2.5.2 Vague Statement of Work (SOW).

Disagreement on design results sometimes occur because of a vague statement of work. Ensure that the scope of work explains the expected results. Ensure that all of the structures intended to be protected are identified. Identify specific system features that are desired. For example, if an ICCP system is desired, then clearly state this in the SOW. Consult with service CP subject matter experts for assistance.

B-2.5.3 Appropriate Level of Effort.

Ensure all levels of effort are identified when negotiating with the contractor. Appropriate design survey field time is a common level of effort causing disagreement. In most cases, CP systems cannot be accurately designed without allowing the designer field survey efforts.

B-2.5.4 Maintain Lines of Communication.

Maintain lines of communication between all interested parties. Operational requirements often change during the design and installation process, and the CP engineer, often a sub-contractor, is sometimes not notified of the change that can result in inadequate CP design (e.g. structure size increased, or additional buried structures added). Miscommunication between disciplines as to which drawings will show certain

details sometimes results in neither one doing it, or conflicts between different drawings or between drawings and specs which can lead to installation problems.

B-3 CP SYSTEM DESIGN DOCUMENTATION.

B-3.1 DESIGN BASIS.

The design basis must include a narrative description of the proposed CP system, field test data, design calculations, catalog cuts of proposed CP equipment, responses to review comments. The basis must address any environmental and historic preservation requirements and considerations that may impact project execution. Significant amounts of time are often required to comply with environmental and historical preservation requirements. Although the base or installation is typically responsible for processing the environmental requirements, the basis of design must identify these requirements to help ensure that they are addressed early on in the process and prevent delays in construction. Where the protected structure is located outside of the base, the contractor should identify potential easement issues and appropriate contacts for resolving these issues, as well as local Cathodic Protection Coordinating Committee contacts.

B-3.1.1 Narrative Description.

The narrative will help determine that the A-E designer understands the scope of work, the nature of the project, and the expected results. The narrative description must discuss the rationale for selecting the type of system, including the impact of seasonal variations on the CP system design, and include discussion of special requirements and limitations that may impact construction, operation and maintenance.

B-3.1.2 Field Test Data.

The basis of design must include all field test data taken preferably in tabular form including, but not limited to:

- All electrolyte (soil, water, etc.) corrosivity data as necessary (resistivity, pH, chloride content, sulfide/sulfate content, soil classification, and reviews of available soil borings)
- CP system current requirement test data (existing structures as applicable)
- Operational test data for existing or nearby CP systems
- Results of interference tests
- Historical information deemed important to the new CP system design

B-3.1.3 Design Calculations.

The basis for design must include all design calculations including, but not limited to:

- Calculation of surface area of the structure to be protected

- Determination of the CP current requirement. For existing structures, this should almost always be determined by on-site field current requirement tests
- Determination of type of system to be used based on existing variables and cost
- Determination of anode size and quantity
- Determination of CP system circuit resistance
- Determination of rectifier size
- A/C power calculations including short circuit analysis (ICCP systems only)
- Calculation of appropriate wire and conduit size
- Other related electrical calculations as necessary
- Attenuation calculations where appropriate

Section B-6 provides additional details regarding these calculations. [Technical Papers 16, *Impressed Current Anode Material Selection and Design Considerations*, and 17, *Galvanic \(Sacrificial\) Anode Material Selection, Design Considerations*](#), provide examples of typical design considerations, process and calculations for the project engineer as a guide to follow when reviewing A-E designs. Do not direct A-E designers to follow these examples, and do not cite these examples as standard DoD design procedures. Qualified designers should be able to design a CP system without having to reference these examples.

B-3.2 DESIGN DRAWINGS.

The CP system design drawings must include sufficient detail and clarity to ensure the system is properly constructed. The design drawings should include, but not be limited to:

- Plan view(s) indicating locations of all CP equipment (anodes, rectifiers, test stations, foreign pipeline crossings, stray current test points, dielectric insulating fittings, electrical continuity bond connections, etc.)
- Details of anodes indicating size and weight
- Installation details of the anodes. Where applicable provide notes indicating allowances, if any, for relocating anodes
- Details of the rectifier showing type (air, oil, explosion proof, automatic, multiple circuit, etc.), size and capacity
- Installation details of the rectifiers (pad, wall, pole, grounding, etc.)
- Details of test stations (type, size, terminal boards, quantity and type of shunts and other wire terminals, quantity and size of wires and conduits terminating in the test station)
- Details of anode junction boxes

- Locations and details of dielectric insulating fittings
- Locations and details of electrical continuity bond connections
- Exothermic weld details
- CP system electrical one line diagram(s)
- Electrical installation details such as cable/wire identification schemes and appropriate legends

Refer to Appendix D for examples of typical details.

B-3.2.1 Quantity and Size of Details.

The number of details shown on one sheet and the size of the details must be appropriately sized so that the details are clearly legible when reproduced at half size. Half size drawings with clearly legible details will also facilitate testing and maintenance by base personnel.

B-3.2.2 Notes.

Provide notes on the drawings to further describe and clarify important/critical items in the details, particularly for critical items. Even if critical items are already described in the specifications, it is still useful to have these also included as notes on the drawings. Contractor personnel usually have the drawings at the work site, while the specifications are usually in the office. It is easy to miss some critical installation items if the notes are not included on the drawings. The notes on the drawings will help preclude unnecessary rework and consternation from both the contractor and construction management personnel. Installation notes also help facilitate testing and maintenance by base personnel.

B-3.3 Specifications.

Boiler plate sections include general specifications. Technical sections include descriptions of all CP system equipment and installation procedures; acceptance testing procedures including static (native) potentials, initial and final system potentials, and interference tests; special contractor qualifications; and applicable reference standards. The UFGS include common, standard recommended clauses for:

- Appropriate references to standards and other governing documents
- Contactor qualifications – do not delete this section without approval
- Required submittals
- Specifications of all CP system equipment and materials
- Specifications describing installation procedures
- Specifications describing commissioning and testing procedures
- Maintenance instructions

Open brackets indicate choices where appropriate. The standard and non-optional clauses should generally not be edited without government review and approval. However, since many CP systems are somewhat unique and the UFGS cannot include accurate clauses for every situation encountered, the designer should add missing or delete non-applicable requirements as necessary. Pay attention to user notes in the guide specifications that provide background information on some of the options for standard phrases. When using SPECSINTACT, turn on the “display notes” before deciding to use or delete certain paragraphs.

B-3.3.1 Protective Coatings Specified in Conjunction with Cathodic Protection.

Protective coatings to be applied to a new metallic structure in conjunction with CP must have the minimum characteristics as described in NACE International SP0169 and the appropriate UFGS. Coordinate the coating type and requirements with the CP system being specified. Many of the coatings specified in recently revised UFGS are compatible with CP systems. Utilize the appropriate protective coating UFGS and supplement the UFGS requirements, as necessary, with the minimum coating characteristics indicated in NACE International SP0169. Do not delete the CP requirements simply because it is not compatible with a particular coating.

B-3.4 Common Problems/Lessons Learned with Design Documents.

B-3.4.1 Computer Aided Design.

The use of computers has greatly aided in the design of CP systems (e.g. drawing programs, word processors, and spreadsheets). Many designers use previously completed designs as templates for new designs, and in their haste, forget to change some of the parameters from the previous design. Review all design documents to ensure that the information is accurate.

B-3.4.2 Notes on Drawings for Important/Critical Items.

For important/critical installation process, provide notes on the drawings even if the process is already included in the specifications. Contractor personnel in the field often work off of the drawings and important processes can be missed. The notes on the drawings will help preclude unnecessary rework and consternation from both the contractor and construction management personnel.

B-3.4.3 Size of Details on the Drawings.

Avoid details on the drawings that are too small in size. Ensure details are sufficiently legible at half size drawing reduction. In order to minimize the number of sheets, smaller sized details are sometimes crammed in on a sheet. While they may appear sufficiently legible on full size prints or enlarged on a computer screen, the half size drawings may not be as legible. Contractor personnel in the field often have the half size drawings. Good contractor personnel will ask if something is illegible, while others will not and will interpret the drawings to their advantage.

B-3.4.4 Insufficient Environmental Considerations.

Ensure environmental personnel review the design during its early stages. They may identify unknown requirements that may increase the cost estimate significantly (archaeological, environmental controls, water management during drilling, hazardous waste disposal, and work in/adjacent to wetlands). It is better to delay the design completion date and identify additional funding early on, than to delay construction (change orders) and attempt to obtain additional funding which may not be available forcing reduction in scope or cancellation.

B-3.4.5 Electrical Review of CP Designs.

Review CP designs for conformance to the National Electrical Code (NEC). Many CP design engineers are unfamiliar with the NEC particularly with wire size and conduit. Also, the commonly specified electrical wire and cable for CP systems is the HMWPE type insulation. This insulation is thicker than normal and harder to pull through long conduit runs and bends even though the design conforms to code. It is sometimes necessary to specify a larger size conduit to improve constructability.

B-3.4.6 Design Build CP Designs.

Design build contracts are generally based upon performance specifications. Successful application of CP for the system life will be significantly dependent upon the requirements detailed in the request for proposal (RFP). The contractor selected is responsible to design a CP system that will meet the RFP requirements. The government will have to provide or assume certain conditions to make the project awardable such as soil resistivity, detailed description of structure to be protected and if possible the preferred type of CP system. Requirements that are too general and are not explicit in performance will result in the installation of a minimum system that will not perform over the anticipated system life. Typically, the contractor's warranty is usually one-year, while the system design life is typically 15 - 25 years. There are instances where a contractor has proposed/installed minimal systems "to save the government money", but those systems have not performed over the anticipated life. Evaluate Contractors technical proposal with the CP system requirements in mind. Discuss CP system requirements at the design/construction kick-off meeting and ensure the contractor implements them on the plans at each submittal stage.

B-3.4.7 As Built Drawings.

Require the contractor to maintain as-built drawings of the CP system and provide them to the Contracting Officer upon completion of the construction contract. Indicate on the drawings the location of all CP components, especially if installed differently from that indicated on the original design.

B-4 TYPES OF CP SYSTEMS.

There are two main types of CP systems, GCP or ICCP, and they can be applied many different ways to cathodically protect many types of structures. The anodes in either type of system can be either distributed or remote, and in an ICCP system the remote anodes can be shallow or deep. There are many different types and sizes of anodes for either type of CP system that can be installed either horizontally or vertically. Since CP is applied to the prevention of corrosion of a wide variety of structures in a variety of environments, each situation will require special consideration. There are fundamental procedures that should be followed in each case, and the method of application of CP to a particular structure depends upon unique design considerations. These considerations help determine alternatives and methods of protection to use in each specific case.

Two main design factors, which considered together can generally indicate the type of protection recommended; the resistivity of the earth and structure coating quality. For buried structures, poor or lack of protective coating and/or high earth resistivity can virtually eliminate the practical application of GCP systems in many specific applications.

B-4.1 GALVANIC CP SYSTEMS.

A GCP system, sometimes called sacrificial anode or “passive” system, is essentially a corrosion cell being utilized in a beneficial way. The structure to be protected is coupled with a more active metal when both are immersed in an electrolyte and connected with an external path as shown in Figure 3-1. In this case the entire surface of the metal being protected becomes the cathode, and the more active anode metal corrodes during the process and is sacrificed. The anode must be periodically replaced, but it is often much more economical to replace the anode than the protected structure.

B-4.1.1 Advantages and Limitations of Galvanic Systems.

Galvanic systems have several advantages over ICCP systems, but unfortunately also have several limitations. Table B-2 summarizes these advantages and limitations.

B-4.1.1.1 Main Advantages.

The main advantages include generally lower installation cost, less maintenance requirements, and unlikelihood of interference to other structures.

B-4.1.1.1 Limitations.

The main limitations stem from their set voltage. The low driving potential between the GCP anode and the structure (less than a volt) often cannot overcome high soil resistivity (ohms law) and/or provide sufficient current to protect a bare or poorly coated structure. Also, GCP systems require isolation, which sometimes is impractical or impossible to accomplish.

Table B-2. Advantages/Limitations of GCP Systems

ADVANTAGES	LIMITATIONS AND DISADVANTAGES
<ul style="list-style-type: none"> • No external power required • No regulation required • Easy to install • No or minimum of cathodic interference • Anodes can be readily added • Minimum of maintenance • Uniform current distribution • Installation can be inexpensive for new construction • Minimum right of way/easement costs • Efficient use of protective current 	<ul style="list-style-type: none"> • Limited driving potential • Lower/limited current output • Retrofit installation can be expensive • Poorly coated/bare structures require many anodes • Can be ineffective in high resistivity soils. • Inability to meet desired system life for certain anode types for structures immersed in seawater or brackish water.

The use of certain GCP anodes is also limited for use on some structures immersed in seawater or brackish water. Operational requirements may limit the size of anodes, and hence, the CP system life. Ensure that the proper type and size of GCP anodes are specified to meet the desired CP system life for structures immersed in seawater or brackish water.

B-4.1.2 Where Galvanic Systems Not Recommended.

Generally, GCP systems are not economical for structures in electrolytes with resistivity over 30,000 ohm-cm or on bare or poorly coated structures. They are also impractical on systems that cannot be isolated from all other structures.

Specify the proper type and size of GCP anodes (or ICCP system if appropriate) to meet the desired CP system life for structures immersed in seawater or brackish water. Do not specify magnesium anodes as the primary CP system for structures immersed in salt water.

B-4.1.3 Distributed Galvanic System Applications.

Most GCP systems are distributed anode systems. This means the anodes are distributed geometrically along or around the structure to be protected. Individual anodes are spaced with each anode protecting only a portion of the structure. Continuous “ribbon” anodes are also available and installed along the structure or installed with the structure in the same trench. The quantity, size, and spacing of the anodes as well as the distance of the anodes from the structure are determined by the anode output current and the structure current requirement.

B-4.1.3.1 When Distributed Anode System Cost Effective.

A distributed anode system is most cost effective when it is installed during construction of the structure. Generally, a distributed anode system requires a very good coating and isolation of the structure being protected.

B-4.1.3.2 Common Uses.

Common uses of distributed GCP anode systems include well coated, isolated pipelines or underground storage tanks in low soil resistivity when installed for new construction, for application on existing underground storage tanks under the same conditions, and on submerged waterfront structures.

B-4.1.3.3 Common Misapplications.

Common misapplications of distributed GCP anode systems include bare or poorly coated pipelines, tank bottoms or tanks; non-isolated structures; structures in high soil resistivity; or for application on existing distribution systems.

B-4.1.4 Galvanic (Sacrificial) Remote System Applications.

In limited circumstances, GCP systems can be installed in one or more remote locations to provide protection to an entire structure. Individual anodes would be located in the remote locations with the number, size, and spacing determined by the current requirement, individual current output and total current requirement.

B-4.1.4.1 When Remote Anode System Cost Effective.

Remote GCP systems can be very cost effective for new or existing structures that are small in size (surface area), are coated with an extremely good coating (99.7% efficiency), are electrical isolated from other buried metallic structures, and installed in very low resistivity soils, (typically under 3,000 ohm-cm).

B-4.1.4.2 Common Uses.

Common uses include extremely well coated, short isolated sections of pipelines or underground storage tanks in very low soil resistivity.

B-4.1.4.3 Common Misapplications.

Common misapplications include bare or poorly coated pipelines, tank bottoms or underground storage tanks; non-isolated structures; and structures in medium or high soil resistivity.

B-4.2 IMPRESSED CURRENT SYSTEMS.

An ICCP system, sometimes called a “rectifier” or “active” system, like a GCP system, is also essentially a corrosion cell with one main difference. Instead of relying on the natural “driving” potential between two metals, an external power source, usually a transformer-rectifier, provides the driving force. Figure 3-2 illustrates a simple ICCP system.

B-4.2.1 Advantages and Limitations of ICCP systems.

B-4.2.1.1 Main Advantages.

The driving potential of an ICCP system is only limited by the size of the rectifier and the circuit resistance. Most systems are designed to a maximum of 50 amps and can range to over 200 volts, although typical systems are usually under 100 volts and 30 amps. Nearly all ICCP systems have adjustable outputs, an advantage over GCP systems whose outputs are normally not adjustable. ICCP systems can overcome all the limitations of a GCP system; however they do have some limitations and disadvantages as well. Table B-3 summarizes these advantages and limitations.

Table B-3. Advantages/Limitations of ICCP Systems

ADVANTAGES	LIMITATIONS AND DISADVANTAGES
<ul style="list-style-type: none"> • Can be designed for wide range of voltage and current and structures with high current requirements • Variable voltage and current output • Applicable in high-resistivity environments and applications in water having low resistivity. • High ampere year output available from a single ground bed • Large areas can be protected by a single installation • Effective in protecting uncoated and poorly coated structures, although good coatings would significantly reduce costs. • Effective in protecting structures that cannot be economically electrically isolated from other buried metal structures • Can be easier to retrofit on existing large structures 	<ul style="list-style-type: none"> • Requires external power - monthly power costs • Subject to power failure and vandalism • Higher maintenance and operating cost than GCP systems. Requires more frequent periodic inspection and maintenance • Can cause cathodic interference problems • Overprotection can cause coating damage

B-4.2.1.1 Main Disadvantages.

With this increased voltage and current there is more concern over current distribution and interference to other structures. More care and testing are required for the design and installation. There is a recurring power cost and a much higher maintenance cost. This higher maintenance cost includes more rigorous testing and higher repair and troubleshooting requirements.

B-4.2.2 ICCP Anode Installation Methods for Buried Structures.

There are several common methods of installing ICCP anodes for buried structures.

B-4.2.2.1 Shallow Vertical Anode Placement.

This is the most common method of installing shallow anodes for both remote and distributed anodes. This generally results in lower anode to earth resistance than horizontally installed anodes, and results in more CP current for a given voltage. The top of the anode is normally buried as deep as or deeper than the structure.

B-4.2.2.2 Horizontal Anode Placement.

This method of installing shallow anodes for both remote and distributed anodes is sometimes required due to rock strata, other special ground conditions or space limitations which preclude the use of vertical anode placement. It is important for these anodes to be deeper than the structure. This method results in a higher anode to earth resistance than vertical anodes, and generally requires more anodes (shorter spacing).

B-4.2.2.2 Deep Anode Placement.

Deep anode beds are generally installed in single vertical columns much deeper than shallow vertical anodes. The top anode is normally installed more than 50 feet deep from the ground surface. In effect the anode bed is installed remotely from the structure by being installed deep in the ground.

B-4.2.3 ICCP Anode Installation Methods for Submerged Structures.

There are also several common methods of installing anodes for submerged structures.

B-4.2.3.1 Distributed Anodes.

The most common method of installing anodes for submerged structures is a distributed anode ICCP system in which the anodes are distributed geometrically over the entire structure submerged in the same electrolyte as the structure.

B-4.2.3.2 Land Based Anodes for Waterfront Structures.

Generally, CP system anodes must be installed in the same electrolyte as the protected structure in order for the CP system to properly operate and adequately protect the structure. For waterfront structures such as steel sheet pile bulkheads and steel pilings

for piers running parallel to the shoreline, land based deep well anode systems may be installed to protect the submerged portions of the structure.

B-4.2.4 Distributed Anode ICCP System Applications.

Distributed anode ICCP systems are systems for which the anodes are distributed geometrically over the entire structure. They are most cost effective when they are installed along with the installation of the structure. They do not require a good coating or isolation of the structure being protected, although either would reduce costs.

B-4.2.4.1 Advantages.

In addition to those listed in Table B-3, the advantages of distributed anode ICCP systems include:

- Low installation cost when installed with the structure
- Lesser probability of causing interference than remote anode bed ICCP systems.

B-4.2.4.2 Disadvantages.

In addition to those listed in Table B-3, the disadvantages of distributed anode ICCP systems include:

- Greater chance of premature failure
- Is not cost effective to install (exorbitant trenching, boring and excavation costs) on an extensive existing structure, such as a distribution system; and
- damage to anode cables by future excavations is a big problem with this type of system. Protection and maintainability of the extensive anode leads should be addressed by the design and the installation.

B-4.2.4.3 Common Uses.

Common uses of distributed anode ICCP systems include:

- Pipelines with limited easement or land space to install anodes,
- On-grade storage tank bottoms,
- Newly constructed underground storage tanks, and application of CP to existing underground storage tanks or aboveground storage tank bottoms.

This is the only type of ICCP system used for water tank interiors.

B-4.2.4.4 Common Misapplications.

Common misapplications of distributed anode systems include the failure to distribute the anodes over the entire structure, or distribution of the anodes at excessive intervals.

Either case will result in poor current distribution and lack of protection between or at a distance from the nearest anodes while overprotecting the structure near the anodes.

B-4.2.5 Remote Anode Bed ICCP System Applications.

Remote anode bed ICCP systems can be used regardless of structure coating quality, soil resistivity or current requirements. They do not require any coating on the structure, and may not require isolation of the structure being protected (although either would reduce costs). Therefore, this method can be used on many types of existing structures. Multiple remote systems are commonly used to protect very large or extensive structures, such as cross country pipelines and large distribution systems. Multiple remote systems are several remote systems, distributed and geometrically placed, to provide current to different areas of extensive structures.

B-4.2.5.1 Advantages.

In addition to those listed in Table B-3, the advantages of remote anode ICCP systems include:

- Longer runs of pipelines can be protected with a single system
- Improved chances in finding a good anode bed location

B-4.2.5.2 Disadvantages.

In addition to those listed in Table B-3, the disadvantages of remote anode ICCP systems include:

- Interference to other structures is of high concern and the mitigation of interference should be part of the design and installation
- Easement issues when located off base
- Damage to anode cables by future excavations

B-4.2.5.3 Common Uses.

Common uses of remote ICCP anode systems include:

- Long pipeline runs or extensive pipeline distribution systems (e.g. fuel and natural gas distribution systems)
- On-grade storage tank bottoms
- Fuel storage tank farms with multiple on-grade storage tanks
- Situations where distributed anodes or shallow anodes in closer proximity to the structure(s) is not possible (e.g. pipelines running under an airfield or waterway)

A deep anode bed installation, described in paragraph B-4.2.6, is considered a remote system.

B-4.2.5.4 Common Misapplication.

A common misapplication of remote anode systems is installation of the anodes too close to parts of the structures where they are not truly remote from the entire structure. Poor or uneven current distribution results from not being truly remote from the structure and can result in inadequate protection of remote areas of the structure, while overprotecting parts of the structure nearby the anodes.

B-4.2.6 Deep Anode Bed ICCP System Applications.

A deep anode bed system is considered a remote anode bed system; its remoteness from the structure attained by installing the anodes deep in the ground below the structure. The top-most anode of a deep anode bed is normally installed at least 50 feet deep. Multiple deep anode systems, geometrically located, are commonly designed to protect very large or extensive structures, such as cross country pipelines, large storage tank farms, large distribution systems, and sheet pile bulkheads. Each individual system is commonly limited to approximately 60 amps. By installing the anode deep in the ground, remote from a structure, high current levels can be evenly distributed over very large or extensive areas of a structure or distribution system.

B-4.2.6.1 Advantages of Deep Anode Bed Systems.

In addition to those listed in Table B-3, the advantages of deep anode bed systems include:

- Longer runs of pipelines or multiple structures electrically bonded together can be protected with a single system. Improved current distribution, since the deep well is generally remote from the structure(s)
- High current output, but with less chance of causing stray current interference on nearby foreign structures
- Improved chances in finding a good anode bed location
- Installation of the deep well anode system may be easier
- Minimized excavations, particularly in congested areas
- Less likelihood of damage to anode leads, especially when the rectifier is located adjacent to the top of the anode bed installation
- Fewer problems with easement issues for systems located off base. The system can often be installed within the structure easement
- Land and waterside of waterfront structures can be protected with landside installations
- Less affected by seasonal moisture variations

B-4.2.6.2 Disadvantages of Deep Anode Bed Systems.

In addition to those listed in Table B-3, the disadvantages of deep anode bed systems include

- Generally higher cost and greater difficulty for well drilling and environmental considerations (e.g. implementing measures during design and construction to satisfy local water authority concerns about water aquifer contamination)
- Designer must be familiar with the geological factors that will impact the installation
- Prediction of deep anode performance is more difficult and less exact than for shallow beds
- Higher chance of premature failure if not properly designed, installed, and maintained
- Compaction of anode backfill may be difficult to achieve
- Must vent chlorine and other gas generated in the anode well to ensure proper operation (usually accomplished by installation of a vent pipe in the anode well)
- Environmental considerations for preventing contamination of groundwater may complicate installation

B-4.2.6.3 Common Uses.

Common uses of ICCP deep anode systems include:

- Multiple underground structures with high current requirements
- Installation of a single landside ICCP system to protect both land and seaside of steel sheet pile bulkheads
- Long or extensive pipeline distribution systems, particularly where space availability and easement issues limit the installation of anode beds (e.g. fuel and utility distribution systems)
- Long or extensive pipeline distribution systems or other structures in congested areas where stray current interference on foreign structures must be minimized (e.g. fuel and utility distribution systems)
- Existing large on-grade storage tank bottoms
- Existing fuel storage tank farms with multiple on-grade storage tanks
- Structures buried deep in the earth such as missile silos and well casings
- Situations where distributed anodes or shallow anodes in closer proximity to the structure(s) are not possible (e.g. pipelines running under an airfield or waterway)

B-4.2.6.4 Common Misapplications.

Common misapplications of deep anode systems include:

- Installation of deep anodes without considering all of the geological and environmental factors that affect the installation and operation
- Installation of anodes too shallow in the ground where they are not truly remote from the entire structure. The top anode is normally installed at a minimum of 50 feet deep. Installing the anodes too shallow will result in poor current distribution and the lack of adequate protection to remote areas of the structure, while overprotecting nearby parts of the structure

B-5 GENERAL DESIGN PRINCIPLES.

B-5.1 DESIGN APPROACH.

There are several different approaches to designing a CP system. Each approach must consider the set of design parameters affecting the structure to be protected to help determine the type of system best suited for the specific case. These design parameters include (but are not limited to):

- Type and geometry of structure to be protected
- Electrolyte conditions (mainly resistivity, but also pH, chloride content, moisture content, and sulfide content)
- Cathodic protection current requirement
- Type and quality of the structure coating
- Presence of other structures in the area
- Presence of other CP systems in the area

The first consideration in the decision process is to establish if the structure to be protected is existing, new, or a new structure that will be connected to existing structures with existing CP systems. The next decision is to determine if a GCP or ICCP system should be specified based on the design parameters and economics. If a GCP system cannot be ruled out, a design for both GCP and ICCP must be accomplished, and a determination made by evaluating the installation and maintenance life cycle cost.

B-5.1.1 CP System Operation Dependent Upon Local Environment.

The actual functioning of any CP system is dependent upon the local environment at each point on the surface of the structure to be protected, condition of the structure, and the actual level of protective current supplied to each point of the structure. It is impractical to determine the exact environmental conditions at each point on the structure, and as the environmental conditions change due to changes in soil moisture and aeration. It is also difficult to predict the actual distribution of protective current on the structure in many cases due to differing environment; the presence of other metallic structures in the vicinity of the structure to be protected, both known and unknown; and limitations on the ability to place anodes at ideal locations due to property boundaries or other limitations. Thus, while a good approximation of the system requirements can be obtained through field surveys, and a good approximation of current distribution can be

made when allowances are made for differing environments and interfering structures, the installed system will, at a minimum, require initial adjustments to balance the system and periodic adjustments to maintain that balance. In some cases, particularly in the case of previously unknown interfering metallic structures in the vicinity of the structure being protected, modifications to the initially designed system may be required in order to achieve adequate protection. The design and operation of CP systems may be an iterative procedure.

B-5.2 DESIGN PARAMETERS AND CONSIDERATIONS.

B-5.2.1 Electrolyte Resistivity.

Electrolyte (soil, water, etc.) resistivity is one of the major parameters that affect CP system designs. The electrolyte resistivity must be measured during a field survey, and this parameter is used to determine anode to electrolyte resistance. The anode to electrolyte resistance is a major factor in selecting the type of CP system, the type of anodes, and the size and quantity of anodes, since the anode resistance often accounts for most of the CP system circuit resistance. High resistivity environments preclude the use of GCP systems, and the higher the resistivity, the greater the likelihood that an ICCP system will be required. Also, the higher the resistivity, the longer the anode must be, and the greater the quantity of anodes that will be required to reduce circuit resistance.

Seasonal variations at a particular location can result in significant fluctuations in soil resistivity due to changing moisture content and temperature. The designer must discuss the impact of the seasonal variations with local knowledgeable personnel as such resistivity variations will affect the CP systems design calculations, and in extreme situations, may dictate the type of CP system specified.

B-5.2.2 Cathodic Protection Current Requirement.

The current requirement is the amount of current that is required for adequate protection of the structure, and is used to help determine the type of system and the size and quantity of anodes. High current requirements increase the likelihood that ICCP systems will be required. For existing structures, the current requirement should be determined by field measurement, while for new structures, the current can be estimated using current densities appropriate for the environment.

B-5.2.3 New Construction or Existing Structure.

For existing structures, ICCP is usually more cost effective, unless the structure surface area is small and well coated. The electrolyte resistivity around existing structures and the current requirement for the structure must be measured during the design field survey. Without this resistivity and current requirement information, a CP system for the existing structure cannot be accurately designed.

B-5.2.3.1 New Construction.

For new construction, the type of coating on the structure can be specified and the electrolyte resistivity measured, but accurately designing CP can be challenging due to unknown conditions that can occur during installation. Current requirements cannot be accurately calculated for new construction which is not electrically isolated.

Also for new construction other factors such as other existing CP systems and locations of other structures become very important. If the design is for new construction which connects to existing utilities, the type of system should be the same. In some cases the existing utilities CP system can protect the new construction with no further CP design or installation.

B-5.2.3.2 Structures with Existing CP Systems.

This parameter can often help easily determine the type and design of the CP system. Replacing the existing system in kind is all that is needed if the existing system functioned properly. However, GCP systems at the end of their design life are sometimes more economically replaced by ICCP systems. Also, if the previous system did not function properly, the new system should be designed to overcome the problems encountered with the existing CP system.

B-5.3 GENERAL CATHODIC PROTECTION DESIGN PROCESS.

B-5.3.1 Field/Site Surveys.

The first and foremost step of a CP system design is the field/site survey. In most cases, conduct a field/site survey in order to establish the actual environmental conditions that will be encountered, determine user requirements, and identify constructability parameters. There are only a very few instances in which a CP system can be properly designed without a field survey; therefore, always allow the designer field survey efforts when planning a CP design effort. The level of effort will be dependent upon the size and complexity of the structure(s) to be protected and whether the structure is new or existing. For submerged systems, all that is generally required is a water analysis, current requirement test (if the structure is existing), identification of interfering structures, determination of AC power sources, or other special circumstances. For buried systems, more extensive information may be required.

B-5.3.2 Electrolyte Characteristics.

Electrolyte resistivity is the single most important characteristic used in the design of CP systems for buried structures. Protective current requirements, sacrificial anode outputs, and ICCP anode bed resistance are all dependent upon electrolyte resistivity.

Other electrolyte characteristics may have a significant impact on electrolyte corrosivity and CP current requirements. Sulfide, sulfate, chloride, pH, and other chemical constituents may affect the current requirements necessary for CP as well as the protection criteria for some materials. Unless experience in the area has shown

otherwise, analysis for sulfate, sulfide, and chloride content should be performed on electrolyte samples from the site.

B-5.3.2.1 Determining Electrolyte Resistivity of Soils In-Situ.

Most designers will measure soil resistivity in situ using the Wenner 4-electrode method as shown in Figures B-3 and B-4. In this method, a current is passed through two electrodes and a drop in potential through the soil due to the passage of the current is measured with a second pair of intermediary electrodes. All four electrodes are setup equidistant, and in a straight line. A specialized instrument is used to supply the current and measure the potential drop. In order to reduce the influence of any stray currents in the area and polarization at the electrodes, alternating current is used in the instrument. The soil resistivity is calculated from the indicated reading by using the following formula:

$$\rho = 191.5 \times a \times R$$

where

- ρ = Soil resistivity (ohm-cm)
- a = electrode spacing (feet)
- R = meter resistance reading (ohms)

In the Wenner 4-electrode method, the average resistivity of the soil between the two center electrodes to a depth equal to the electrode spacing is measured. If the electrode spacing is increased then the average soil resistivity to a greater depth is measured. If the average resistivity increases as the electrode spacing increases, there is a region of higher soil resistivity in the deeper soil layers. If the average soil resistivity decreases with depth, there is a region of lower soil resistivity in the deeper soil layers.

B-5.3.2.2 Determining Electrolyte Resistivity Using a Soil Box.

When it is impractical to make field measurements of soil resistivity, soil samples can be taken from an appropriate depth and the resistivity of the sample can be determined by the use of a soil box. The measurement made using the soil box is essentially an application of the 4-electrode method (Figure B-5). Metal contacts in each end of the box represent the two outer electrodes in the 4-pin method, and are used to pass current through the sample. Potential drop is measured across probes on the soil box inserted into the soil. The resistivity is calculated using constants furnished with the particular size of soil box being used. Due to the disturbance of the soil during sampling and possible drying out of the soil during shipment, this method of soil resistivity measurement is less accurate than actual field tests by the preferred Wenner 4-electrode method. To minimize drying out of samples they should be placed in soil sample jars and sealed prior to shipment.

Figure B-3 Wenner Four Electrode Method Schematic

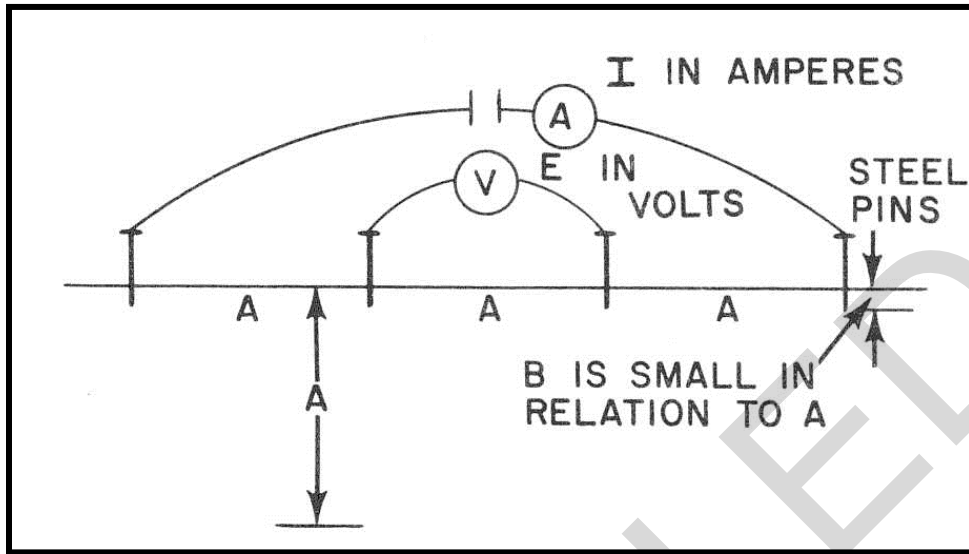
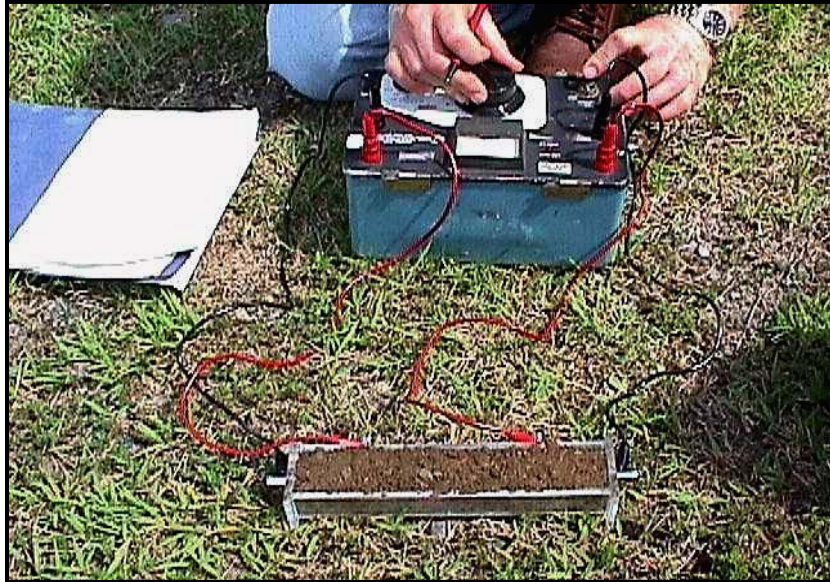


Figure B-4 Wenner Four Electrode Method for Measuring Soil Resistivity



Figure B-5 Measuring Soil Resistivity in a Soil Box



B-5.3.2.3 Water Analysis.

If the CP system is being installed inside of a water tank or other submerged structure, samples of water should be analyzed for pH, chloride, sulfate, and resistivity at a minimum. Other factors such as hardness may be pertinent to the specific circumstance. The resistivity of liquids can be measured using the Wenner 4-electrode method and a soil box or by using a conductivity meter which is specifically designed for the measurement of the conductivity of solutions. Conductivity is the inverse of resistivity.

$$\rho_w = \frac{1}{C}$$

where

ρ_w = water resistivity (ohm-cm)
 C = water conductivity (mhos or siemens)

B-5.3.3 Determine CP System Current Requirement.

B-5.3.3.1 Current Requirement Testing on Existing Structures.

The most desirable means of determining the amount of current required for protection of an existing structure is to measure the actual amount of current required to achieve protection through installation and operation of a temporary CP system. Perform measurements of the temporary CP currents supplied and the structure-to-electrolyte

potentials achieved on the structure to establish the current required to protect the structure.

If the temporary system cannot provide sufficient current to protect the entire structure, one method to determine the total amount of current required would be to protect a section of the structure, then multiply the result to estimate the amount of current to protect the entire structure. For example if 5 amps will protect one mile of pipeline, then 10 amps should protect 2 miles. A second method is extrapolation of the current and protection levels. For example, if 5 amps provide half the required current (half the required potential shift for protection) then linear extrapolation of the current versus potential line on a graph to the desired potential shift will yield the estimated required current to protect the structure.

Verify that the current requirement test results are reasonable by comparing them to a theoretical current requirement calculation as described in paragraph B-6.2. A large variation between the results of the field tests and theoretical calculations could be a result of:

- Incorrect assumptions about the existing protective coating condition.
- Electrical continuity with other structures in the vicinity (electrical isolation may be required).
- Unknown electrical isolation of portions of segments of the structure (electrical continuity bonding may be required).
- Specific electrolyte characteristics affecting the current requirement.

B-5.3.3.2 Current Requirement Calculations for New Structures.

For the design of CP systems to be installed in conjunction with the installation of a new structure, the estimated current requirements can be calculated as described in paragraph B-6.2.

B-5.3.4 Determine Coating Conductance.

In the design of CP systems the condition of protective coatings is an important factor. Protective coatings can both reduce corrosion of structures and reduce CP current requirements. For this reason, both coatings and CP should be applied synergistically on buried or submerged structures. For existing buried structures the condition of the coating can be determined by electrical field tests of the effective electrical resistance of the coating. The resistance measurements are then usually converted to conductivity per unit area, or conductance. Procedures for determining coating conductance are beyond the scope of this UFC.

B-5.3.5 Determine Electrical Continuity and Isolation.

B-5.3.5.1 Electrical Continuity Testing.

Continuity testing is important to determine if the structure being protected is electrically continuous. It is also used to determine which foreign structures are continuous to the

structure being protected. For purposes of a current requirement test, it is very important to know what structures are connected to the structure being tested for proper evaluation of the current requirement.

B-5.3.5.2 Electrical Isolation Joints (Insulating Fitting).

Determine locations where electrical isolation is necessary. Electrical isolation is necessary to minimize current requirement for both GCP and ICCP systems by isolating structures that are not intended to be protected by the CP system. Insulating joints are sometimes used to isolate sections of structures so that each section can be protected separately when necessary.

B-5.3.6 Locate Other Structures in the Area.

Buried or submerged structures other than the intended structure to be protected may impact or be impacted by the planned CP system, and the site survey should include the location of any such structures. Buried structures such as pipelines which have risers, valves, etc., in the area can be traced using electronic tracers. The presence of buried structures in the area that do not have any surface indications are difficult to locate, and the maintenance of accurate records showing all buried structures and utilities is extremely important.

B-5.3.7 Selection of GCP or ICCP Systems.

The decision between using sacrificial anode or ICCP systems is based upon two major factors, feasibility and cost. Often, a CP system using both methods is designed for a given structure and the systems are directly compared in order to select the most appropriate type of system. Economic analysis may be necessary to determine the least cost system. In general, systems with small stable current requirements (0.5 Amp or less per 100 lineal feet of structure) are more likely to be protected using sacrificial anode type systems and those structures with larger (1 Amp or more per 100 lineal feet of structure) or where the current requirements vary considerably with time are more likely to be protected using ICCP systems. ICCP systems are generally used where larger amounts of current than can be supplied by a sacrificial anode system are required.

B-5.3.8 Determine Availability of AC Power.

During the site survey, determine the availability of AC power at the site as the cost of installing new AC power service may be an important factor in determining whether a GCP or ICCP system is the more practical solution for the specific application.

B-6 TYPICAL DESIGN CALCULATIONS.

This section provides general information and practices about the CP system design calculation process. Technical Papers 16 and 17 provide additional considerations during the design process as well as simplified examples of CP system designs that the project engineer can use as guides for reviewing actual CP system designs.

B-6.1 Calculate Structure Surface Area to be Protected.

For new structures which will be protected by CP systems, field current requirement tests in most cases cannot be conducted and the current requirements will need to be calculated. The total bare surface area of the buried or submerged structure to be protected (e.g. the uncoated submerged areas of a water tank interior or the uncoated areas of a buried pipeline) must be calculated in order to calculate the current requirements. If the structure has/will have a protective coating, then the bare surface area of the structure to be cathodically protected can be significantly reduced dependent upon the protective coating efficiency. The current required to protect a well coated structure can be several orders of magnitude less than the current required to protect the same structure if it is uncoated. The reduced amount of current required for the protection of well coated structures reduces the cost of protection as well as reducing other problems such as interference with other structures.

B-6.2 Calculate Cathodic Protection Current Requirements.

For existing structures, current requirement tests should already have been conducted during the field survey. The designer should verify that the current requirement test results are reasonable by comparing them to theoretical current requirement calculations. For the design of CP systems to be installed in conjunction with the installation of a new structure, the estimated current requirements can be calculated by multiplying the required current density by the area of the structure to be protected using the equation.

$$I = A \times CD$$

where

A	=	Area of structure to be cathodically protected (ft ²)
I	=	Current required for cathodic protection (amperes)
CD	=	Current density (milliamperes/ft ²)

Table B-4 provides current density ranges for typical environments.

B-6.3 Determine CP System Circuit Resistance.

After the current requirement is determined, next determine the circuit resistance of the system. This requires calculation of the anode-to-electrolyte resistance, resistance of lead wires and the structure-to-electrolyte resistance.

Table B-4. Current Density Requirements for Cathodic Protection of Bare Steel

ENVIRONMENT	MILLIAMPERES (mA) PER SQUARE FOOT (mA/ft²)
Soil with resistivity <1,000 ohm-cm	6.0 - 25.0
Soil with resistivity 1,000 - 10,000 ohm-cm	3.0 - 6.0
Soil with resistivity 10,000 - 30,000 ohm-cm	2.0 - 3.0
Soil with resistivity >30,000 ohm-cm	1.0 - 2.0
Highly aggressive soil with anaerobic bacteria	15.0 - 40.0
Still fresh water	2.0 - 4.0
Moving fresh water	4.0 - 6.0
Turbulent fresh water	5.0 - 15.0
Hot fresh water	5.0 - 15.0
Still seawater	1.0 - 3.0
Moving seawater	3.0 - 25.0
Concrete	0.5 - 1.5

B-6.3.1 Structure to Electrolyte Resistance.

For some GCP systems, the structure-to-electrolyte resistance may be a factor, if the structure is very small or small with a good dielectric coating. In most ICCP systems, the major factor in the determination of the total circuit resistance is the anode-to-electrolyte resistance. If ICCP systems are used to protect very small or small well coated structures, the structure-to-electrolyte resistance could be a factor. Anode and structure leads are normally sized so that lead wire resistance is often negligible. Lead wire resistance may be significant if long runs of wire are required, or anode-to-electrolyte resistance is very low.

B-6.3.2 Calculate Anode to Electrolyte Resistance.

Also known as "ground bed resistance" or "anode bed resistance," this is often the parameter that most impacts the CP system circuit resistance. Anode-to-electrolyte resistance is dependent upon the electrolyte resistivity, but can be varied within limits by the use of different sizes or quantities of anodes.

Calculate anode-to-electrolyte resistance calculations from data on soil resistivity, anode type, size, shape, and configuration of multiple anode arrays. First, arbitrarily choose the type, size, and shape of the anode to be used. Next, calculate the resistance of a single anode. Then determine the effect of the use of multiple anodes. The process is iterative and several attempts may be necessary to determine the optimum anode system and corresponding anode-to-electrolyte resistance.

During actual operation, the environmental resistivity may not be uniform, or may undergo seasonal variations, and the calculation of anode-to-electrolyte resistivity is only an approximation of the actual resistance to be encountered. Therefore, the actual CP system operation results may be somewhat different than that calculated. Thus, after installation, the system may need to be adjusted periodically to provide the required protective current output.

B-6.3.2.1 Effect on System Design and Performance.

For ICCP systems the anode-to-electrolyte resistance is an important factor in the determination of the driving potential required to provide the current required for effective CP in ICCP systems. The lowest anode-to-electrolyte resistance commensurate with total system cost is desirable since it will reduce the power costs by lowering the output potential of the power supply. This lower power supply output potential also results in higher reliability for other system components, particularly the insulation on cables, splices, and connections. In general, anode bed resistances below 2 ohms are desirable and are rarely designed over 4 ohms.

B-6.3.2.2 Basic Equations.

The formulas developed by H. B. Dwight for a single cylindrical anode are commonly used as part of an iterative calculation process to determine the anode-to-electrolyte resistance. The formulae shown below are only some of several formulae used for CP design calculations and are provided for information only. Do not reference these formulae as DOD policy. Misapplication of these formulae by unqualified personnel can result in improperly operating CP systems. The formula for a vertically oriented anode is:

$$R_v = 0.0052 \rho/L \times [\ln (8L/d) - 1]$$

The formula for a horizontally oriented anode is:

$$R = 0.0052 \rho/L \times \ln\{[4L^2 + 4L(s^2 + L^2)^{1/2}] / ds\} + s/L - (s^2 + L^2)^{1/2} - 1$$

where

- R_v = electrolyte-to-anode resistance for a single vertical anode to a remote reference (ohms)
- R_h = electrolyte-to-anode resistance for a single horizontal anode to a remote reference (ohms)
- ρ = electrolyte resistivity (ohm-cm) at the location and depth of the anode
- L = anode length or backfill column length if backfill is used (feet)
- d = effective diameter of anode or backfill column (feet)
- s = twice depth of anode (feet)

B-6.3.2.3 Special Formulae for Water Tanks.

For water tanks where circular arrays of anodes are commonly used and where the structure surrounds the anodes and electrolyte, special formulae have been developed to calculate the anode-to-electrolyte resistance. For a single cylindrical anode, the formula developed by E. R. Shepard is commonly used:

$$R = 0.012 \rho_w \log (D/d)/L$$

where

R	=	anode-to-electrolyte resistance (ohms)
ρ_w	=	water resistivity (ohm-cm)
L	=	length of a single anode (feet) (backfill is not used)
D/d	=	ratio of anode diameter (d) to tank diameter (D) (same units for each)

The anodes are usually arranged in a circular array in the tank bowl. Determine the optimum diameter of this array by the following formula:

$$r = DN/[2(\pi + N)]$$

where

r	=	radius of anode array (feet)
D	=	tank diameter (feet)
N	=	number of anodes

B-6.3.3 Effect of Backfill.

Backfill is very important and is usually used to surround the anodes with a material of uniform resistivity to allow the anode to emit current evenly from its entire surface and reduce localized or uneven dissolution of the anode. In the case of ICCP anodes, backfill also reduces anode-to-electrolyte resistance; increases porosity around the anodes to insure that any gasses formed during operation will be properly vented; and reduces polarization effects. Under favorable circumstances, the anode-to-electrolyte resistance can be reduced to one-half through the use of backfill. In extremely low resistance environments most anodes can be used without backfill; however, except for anodes submerged in water, the use of backfill is highly recommended.

B-6.3.3.1 Backfill for GCP anodes.

For use in soil, the backfill must be used with GCP anodes in most cases and is highly desirable in most instances. The backfill typically consists of mixture of hydrated gypsum, bentonite, and sodium sulfate. Besides providing a uniform resistivity environment which reduces the self-corrosion rate, the backfill is hygroscopic and will absorb moisture from the surrounding soil to lower the resistivity and improve the anode current output.

B-6.3.3.2 Backfill for ICCP anodes.

For nearly all underground ICCP installations, provide a special carbon backfill, referred to in the industry as coke breeze, in the anode hole or column. Some of the reasons for using this special backfill include the following:

- Lower anode ground bed resistance, hence, resulting in lower rectifier design voltages and reduced probability of stray current interference.
- Improved current distribution along the anode since the backfill will provide a generally uniform environment. Helps avoid premature anode failure. Prolonged anode life since the carbon backfill is also consumed instead of anode. Stability of the anode hole or well. Permeable medium for migration of gases, thereby avoiding premature increase in anode bed resistance. When backfill is used with ICCP anodes, the effective diameter of the anode installation is the diameter of the backfill column rather than the diameter of the anode itself. This often results in a significant reduction in anode-to-electrolyte resistance which can be useful in reducing the number of anodes required, the required rectifier driving voltage, or both. Ensure that the appropriate type of backfill is specified and provided.

Backfill for ICCP anodes is carbonaceous material from several sources. It can be coke breeze (crushed coke), flake graphite, or round particle calcined petroleum coke. Specify calcined petroleum coke, or coke that has been heated to remove high resistivity petroleum by-products. The calcined petroleum coke has a lower total bulk resistivity and its more spherical particles aid in the compaction of the backfill. Experience has shown that round particle calcined petroleum coke has many advantages over coke breeze made from coal. Also, specify backfill that has a carbon content greater than 92%, preferably greater than 99%, for greater anode system life. Specify small diameter calcined petroleum coke for deep well anode installations. Because the material can be pumped and has good porosity and particle-to-particle contact, round particle petroleum coke backfill is the most desirable material and its higher cost will be justified for deep anode installations.

B-6.3.3.3 Anodes Prepackaged with Backfill.

In areas where the soil is extremely wet or loose, such as in a swampy area, it may not be possible to properly install or tamp the backfill material. Packaged anodes with the backfill contained in metal cylinders (cans) or cloth sacks surrounding the anodes may be useful in these circumstances. The packaged anodes will have a higher cost, but are generally easier to install than separate installation of anode and backfill. Besides the higher costs, packaged anodes also have the following additional disadvantages:

- High unit weight reduces ease of handling
- Possibility of voids developing in backfill during transportation and handling
- The critical anode cable and connection between the anode and cable are hidden and difficult to inspect

B-6.3.4 Calculate Operating Considerations.

For GCP systems, determine the circuit resistance which is the sum of the anode to electrolyte resistance, the structure to electrolyte resistance and the lead wires. The driving potential is set by the natural potential difference between the GCP anode and the polarized structure. The current can only be adjusted by adding additional anodes to increase current, or installing fewer anodes or a resistor with each anode to decrease current.

For ICCP systems, the driving potential is not set by the natural potential difference. System current is dependent upon the circuit resistance and the voltage of the power source. System current can be adjusted by changing the voltage applied to the system or by changing the circuit resistance. Circuit resistance is determined by selection of the anode size, number of anodes and anode spacing.

B-6.3.5 Determine the Number of Anodes Required.

The quantity of anodes required for the CP system is dependent upon the system current requirement and the maximum individual anode current output. The system current requirement is a function of the structure size, coating, and environment in which it is installed. The maximum individual anode current output is dependent upon anode type, anode size, and environment resistivity. For GCP anodes, anode life is determined by anode current, anode type, and anode efficiency. For ICCP anodes, anode life is a direct result of current and time. Each anode has a specific weight loss per ampere-year calculated from Faraday's Law or from manufacturer charts in anode life versus current discharge.

For GCP anodes such as zinc, magnesium and high purity magnesium, calculate the anode life based on anode type, anode efficiency, effective useful life factor and anode current. The anode efficiency is a percent of the anode discharge for CP compared to the anodes self-corrosion rate. Zinc is normally 90 percent, while magnesium and high potential magnesium is 50 percent. The effective useful life factor is the percentage of weight loss before anode failure. For most anodes, failure will occur after 80 percent of the weight is lost.

$$\text{Anode Life} = \frac{W * u * e}{I * S}$$

where

W = Total Anode Weight

u = Anode Effective Useful Life Factor

e	=	Anode Efficiency
I	=	Anode Current Output in Amperes
S	=	Anode Consumption Rate

In the case of ICCP bulk anodes such as High Silicon Chromium Bearing Cast Iron (HSCBCI), the manufacturer or distributor for the anode will provide the anode consumption rate. HSCBCI is usually 1 pound per amp year. The effective useful life factor is usually 80 percent. In systems with multiple anodes, use the maximum anode output to calculate life of the anode system (not the average anode output).

$$\text{Anode Life} = \frac{W * u}{I * S}$$

where

W	=	Total Anode Weight
u	=	Anode Effective Useful Life Factor
I	=	Anode Current Output in Amperes
S	=	Anode Consumption Rate

In the case of dimensionally stable ICCP anodes such as mixed metal oxide and platinized niobium, charts are available from the manufacturer or distributor for the specific anode, usually in years at specific current outputs.

B-6.3.6 Power Supply Requirements (ICCP Systems).

B-6.3.6.1 Determine Power Supply Requirements.

Calculate the power supply requirements, namely current and voltage, using Ohm's law and the required current for protection of the structure and the calculated or measured total circuit resistance. Include factors for anode back voltage and current losses due to unknown electrical shorts to other structures as necessary.

B-6.3.6.2 Select Power Supply Type.

Any source of direct current of appropriate voltage and current can be used as a source of power for ICCP systems. The selection of power supply depends upon local conditions at the site and should be evaluated based upon economics, availability of AC power or fuel, and the availability of maintenance.

B-6.3.6.3 Transformer-Rectifiers.

Transformer-rectifiers, or more simply, rectifiers, are by far the most commonly used power supply type for ICCP systems. They are available in a wide variety of types and capacities specifically designed and constructed for use in ICCP systems. The most commonly used type of rectifier has an adjustable step down transformer, rectifying units (stacks), meters, circuit breakers, lightning arresters, current measuring shunts, and transformer adjusting points (taps), all in one case.

The rectifier selected for a specific ICCP application must be matched to both the electrical requirements and the environmental conditions at the site. Rectifiers are available in many electrical types and specifically designed for use in ICCP systems in many environments. [Technical Paper 16](#) provides additional details about rectifier selection as well as simplified examples of CP system designs that the project engineer can use as guides for reviewing actual CP system designs.

B-6.3.6.4 Solar Power.

For solar powered systems, solar cells convert sunlight directly into direct current electricity. Consider using solar panels for CP power supplies at remote sites where neither electrical power nor fuel is available. In order to supply current continuously, solar cells are used in a system that both supplies power to the CP system and also recharges a set of batteries when sunlight is received (Figure 4-2). When sunlight is not being received, the batteries supply the required current.

Solar powered CP systems should use high efficiency (96-98%) controls that have flexibility to match the anode ground bed and its fluctuating conditions. The controller unit should also be selected to minimize the mismatch loss between the PV array and the storage batteries. Finally, consider providing a controller that has built-in current interruption capability so that IR free (more accurate) structure potentials of the pipelines can be measured.

B-6.3.6.5 Batteries.

When current requirements are low, storage batteries can be used to supply power for ICCP systems at remote sites. They must be periodically recharged and maintained. Again, environmental and safety considerations must include procurement, maintenance and disposal of battery electrolytes, usually acids.

B-6.3.6.6 Generators.

Engine or wind driven generators can also be used to supply direct current power for ICCP systems at sites where AC power is not available.

B-7 OTHER CP SYSTEM COMPONENT DESIGN CONSIDERATIONS.

In addition to calculation and selection of the anodes used and the source of power for cathodic protection, CP systems contain other important components. The entire system must be reliable in order to provide effective protection.

B-7.1 Connecting Wires.

The connecting cables used between the various components of CP systems are vital to the proper performance of the system. Any break in the primary circuit will result in failure of the system and will require repair to restore the flow of protective current. Breaks in the auxiliary connections such as those used to test the system will also result in difficulties in proper adjustment and inspection of the system. Proper selection of cable size, type of insulation and routing is necessary for proper and reliable system operation.

Use only copper cables in any CP installation. High connection resistances and difficulty in making welded connections associated with the use of aluminum wires precludes their use in cathodic protection.

B-7.1.1 Determination of Connecting Wire Size and Type.

For sacrificial anode CP systems, the electrical currents are usually low, and the size of the conductors is normally more a function of mechanical strength than of ampacity or resistance. In systems where sacrificial anodes are used in groups such as remote anode beds, the currents can be larger and the resistive drop in the cable must be considered. Calculate the most economic wire size, but do not use wire sizes smaller than No. 12 AWG or foreign equivalent.

For ICCP systems, connecting cables should be selected based upon consideration of the following factors:

- Current carrying capacity
- Voltage attenuation (IR drop)
- Mechanical strength
- Economics (first cost versus power costs)
- Dielectric strength of insulation
- Durability (abrasion & cut resistance) of insulation

B-7.1.2 Wire Insulation.

B-7.1.2.1 GCP Systems.

For GCP systems, the connecting wires are, themselves, cathodically protected, and insulation is not as critical as in portions of ICCP systems. Specify Type TW, Type RHW-USE or HMWPE insulation. Specify HMWPE, a heavier insulation, where mechanical strength is desired. For submerged applications or chemical environments, specify the appropriate insulation that best resists deterioration in that environment.

B-7.1.2.2 ICCP Systems.

For ICCP systems, the connection between the CP power source and the anodes are usually submerged or buried at least over part of their length. These cables are extremely susceptible to failure as they are operated at highly positive potentials. Refer to paragraph B-7.1.3.4

B-7.1.3 Recommended Cables for Specific Applications.

Because of similarities in required characteristics of the various connecting cables in many CP systems, the following paragraphs detail the established general specifications for cable sizes and types for many CP system requirements.

B-7.1.3.1 Test Wires.

Test station wires carry only very small currents and, as they are themselves cathodically protected, insulation requirements are not critical, but should be selected to match the environment. Specify solid copper wires, No. 12 gauge AWG, minimum, with type TW, RHW-USE or polyethylene insulation for this application unless otherwise dictated by economics or site conditions.

B-7.1.3.2 Bond Wires.

These wires carry more current than test wires, and may have a positive potential with respect to surrounding structures. Specify No. 4 or 8 AWG stranded copper cable with HMWPE insulation for all bond wires unless a larger wire size is required for current carrying capacity.

B-7.1.3.3 Power Supply to Structure Cables.

Specify HMWPE insulated stranded copper cable, with the wire appropriately sized for current carrying capacity, mechanical strength, and total CP circuit resistance. Wire size must conform to the requirements in the National Electrical Code. For submerged applications or chemical environments, specify the appropriate insulation that best resists deterioration in that environment.

B-7.1.3.4 Power Supply to Anode Cable.

The insulation in these cables is critical. The connections between the CP power source and the anodes for ICCP systems, are typically buried or submerged, and are extremely susceptible to failure as they are operated at highly positive potentials. Any contact between the metallic conductors and the environment will result in rapid deterioration of the conductor and loss of continuity of the protective circuit. Specify HMWPE insulation, 0.110 inches thick, as a minimum, on these cables for most buried applications. Where exposure to chlorine will be encountered, such as in seawater or in deep well applications, specify chlorine resistant composite insulation consisting of an HMWPE outer jacket for abrasion resistance combined with an ethylene-chlorotrifluoroethylene copolymer (ECTFE) inner jacket. For less critical applications such as test wires, and above ground wiring, specify thermoplastic insulation (Type TW), synthetic rubber (RHW USE), or HMWPE.

The minimum anode connection wire size is No. 8 AWG. The wire used to interconnect the anodes to the junction box or header cable, and to connect the anode bed with the power supply is commonly in the range of No. 2 AWG or larger. The actual wire size must conform to the requirements in the National Electrical Code (NEC).

B-7.1.4 Economic Wire Size.

For GCP systems, determine the most economic wire size when currents larger than one ampere flow in any portion of a sacrificial anode circuit. Compare the cost of additional anodes to overcome the resistive losses to the annual fixed costs for the cable size being analyzed.

For ICCP systems, select the size of the connection between the structure, anode bed and the power supply in ICCP systems to minimize overall cost. This can be determined by calculating the annual fixed cost of the selected wire and comparing them with the cost of power losses for the system. When the annual fixed cost and the cost associated with power losses are equal, their sum is minimal and the most economical selection of wire size is confirmed. If the power losses exceed the annual costs, a larger wire size is required. If the annual fixed costs exceed the power loss, then a selection of a smaller wire size would be appropriate. The formula for determining power loss costs is:

$$V = MK_m$$

where:

$$M = 0.0876 I^2 R$$

$$K_m = \frac{LP}{E}$$

and:

V	=	Annual cost of power losses (\$)
I	=	Current Flow (Amperes)
R	=	Resistance of 100 feet of cable
P	=	Power Cost (cents/KWH)
E	=	Power Source (Rectifier) Efficiency (%)
L	=	Length of Cable (feet)

The formula for determining the annual cost of fixed charges is:

$$F = E \times S \times L$$

where:

F	=	Annual Fixed Charges (\$/yr)
E	=	Estimated annual charges *
S	=	Initial Cable Cost (\$/ft)
L	=	Cable Length (ft)

* The estimated annual charges used will vary. They are the sum of depreciation, interest, taxes, insurance, operation and maintenance.

B-7.2 Connections and Splices.

Wire splices and connections are a source of undesirable circuit resistance and are a weak point in the reliability of the system as they often fail due to either corrosion or mechanical damage. Buried wire splices are not permitted in many situations. Refer to the appropriate UFGS. Keep wire splices and connections to an absolute minimum, and the type of connection used must have low resistance, high reliability, and good resistance to corrosion. While connection of wires to the structure can be either by exothermic weld or mechanical connections, specify exothermic welding (Figure 4-4) as much as practicable. Avoid mechanical connections as much as practicable (Figure 4-5), as corrosion of the mechanical connection tends to result in a high resistance connection over time that could prevent the CP system from properly operating. Insulate underground connections with either epoxy encapsulation or other type of mastic compatible with the pipeline coating. Above grade connections such as wiring in test stations are typically mechanical connections and must be carefully taped in order to prevent corrosion due to the entry of moisture.

Carefully evaluate the need for additional connections and splices. Specifically show the location of all necessary splices and connections on the design drawings. The designer of the system must determine the need for additional splices and connections. Do not leave this determination to the discretion of the installer.

B-7.2.1 GCP Systems.

The following connections are required for GCP anode systems and must be shown on the design drawings:

- Connection between anode(s) and structure through a test station.
- Connection between cable and anode (Must be factory made or connection is attached to cast-in core)
- Necessary bonds and test wires

B-7.2.2 ICCP Systems.

The following connections are required for ICCP systems:

- Connection between power source and structure
- Connection between anode bed(s) and power source (anode header cable)
- Connection between anode header cable and each anode
- Connection between cable and anode (must be factory made)
- Necessary bonds and test wires

Carefully insulate all connections, particularly in the anode to power supply portion of the circuit where any loss of insulation integrity will result in rapid system failure. All connections in the power source-to-anode bed portion of the circuit and all cable-to-cable

connections must be insulated by encapsulation in epoxy using commercially available kits made expressly for this purpose.

The cable to structure connection is less critical and either epoxy encapsulation or insulation with mastic must be used on this connection.

B-7.3 Bonds and Insulating Joints.

CP designs must include provision of electrical continuity bonds where necessary to ensure electrical continuity of all of the structures to be protected. Portions of metallic utility distribution pipeline systems are often replaced with non-metallic pipe sections, introducing electrical discontinuities into the pipeline system. Base utility distribution system plans are not always updated to reflect these replacements, and the designer should be allowed to conduct field current requirement and continuity tests to verify continuity if any doubt. If electrical discontinuities cause the pipeline system to be too fragmented, consider providing multiple smaller CP systems. Some isolated sections of pipelines may be small enough to use GCP anodes.

Use HMWPE insulated seven-strand copper cable, No. 8 AWG or larger cable for bonds between sections of the protected structure or between the protected structure and a foreign structure (Figure 4-3). Run all resistive bonds into a test station to allow for adjustment. Also run direct bonds into test stations if future adjustments or connections may be required. Make all bond-to-structure connections using exothermic weld connections, insulated by epoxy or mastic encapsulation.

B-7.4 Test Stations - Location and Function.

Include the location and wiring of all test stations in the system design. Color code all test wires, or identify them with non-corroding metal or plastic identification tags indicating the system component to which they are connected. Locate test stations either flush with the pavement or soil surface as shown in Figure B-6, or above grade as shown in Figure B-7. In either case, use test stations manufactured specifically for the intended purpose. Flush mounted test stations are preferred in paved areas or other areas where damage by vehicles, operational equipment, etc. is anticipated. Above grade test stations are preferable in unpaved areas and areas where flush mounted test stations can easily be covered over and lost. Provide test stations for all foreign structures that cross the protected structure or are in the vicinity of the anode bed. Provide test stations for all pipeline casings, underground dielectric insulation unions and flanges, at all foreign line crossings, and other components such as bonds to facilitate testing.

Balancing resistors are sometimes required when multiple anode beds are used with a single rectifier. Install these resistors in an above grade terminal box as shown in Figure B-8.

Figure B-6 Typical Ground Flush Mount Test Station



Figure B-7 Above Grade Test Stations. PVC Pipe Mount on the Left, Pole Mount in the Center, and Wall Mount on the Right.

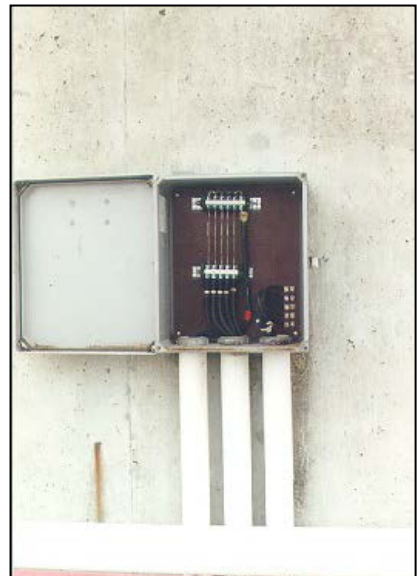


Figure B-8 Resistors in an Above Grade Terminal Box



B-7.4.1 GCP systems.

The most common type of test station used in GCP systems is the current-potential test station shown in Figures B-13 through B-11. In this test station, the anode lead wire is connected to the structure lead using a 0.01 ohm resistor (shunt) which is used to measure the current output by measuring the voltage drop across the shunt. The second structure lead is used to measure the structure potential using a non-current carrying connection thus eliminating any potential drop along the conductor. The second structure connection can also be used as a spare if the primary structure connection is damaged. Test stations for GCP systems can either be of the flush mounted or above grade type.

If flush mounted test stations are used, the soil exposed in the bottom of the test station can be used to measure the structure to electrolyte potential. Location of such test stations directly over the structure is advantageous as IR drops due to current flowing through the soil are minimized. Other test stations which are used in GCP systems are the potential test station, the soil contact test station, the line current (IR Drop) test station, the insulating joint test station, the casing insulation test station, and the bond test station.

Figure B-9 Flush Mounted Current-Potential Test Station



Figure B-10 Pipe Mounted Test Station. Figure on Right is a Close-Up of the Test Station “Head” or Terminal Board.

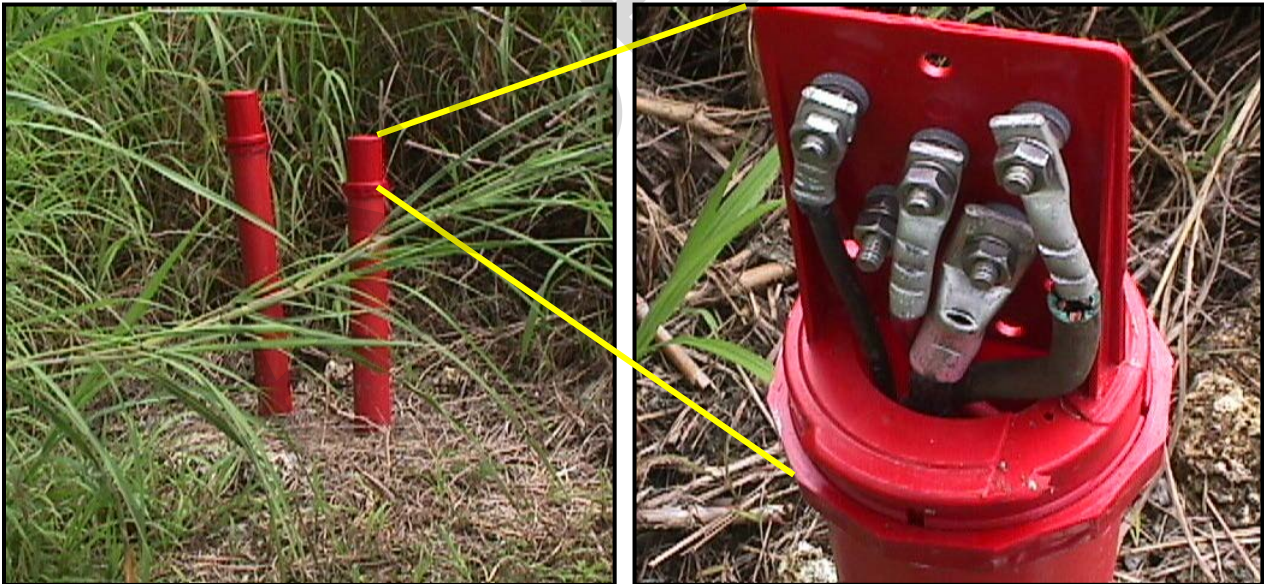
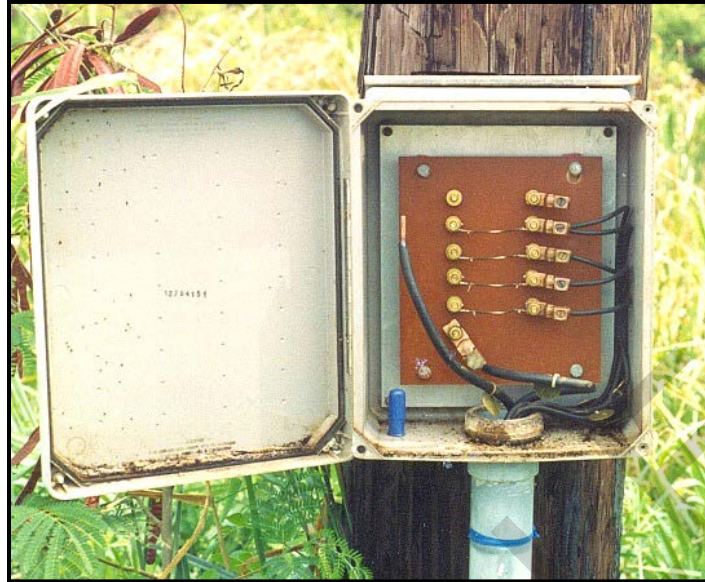


Figure B-11 Wall/Pole Mount Type Test Station.



B-7.4.2 ICCP systems.

There are five basic types of test stations used in ICCP systems:

- The potential test station (see Appendix D)
- The soil access test station (see Appendix D)
- The line current (IR Drop) test station
- The casing insulation test station
- The bond test station (see Appendix D)

Specify solid copper wires, No. 12 AWG, either TW or RHW-USE insulated. If future bonding across flanges or between structures may be required, connect HMWPE insulated stranded copper cables, No. 8 AWG or larger if required, to the structure(s) and run them into a test station for future use.

B-8 DESIGN PRACTICES THAT FACILITATE OPERATION AND MAINTENANCE.

Design of the system must include required items needed to conduct operations and maintenance on the system. Over the life cycle of the system, these items will save time by making it easier for personnel to perform the required testing, troubleshooting and repair of the system. Without sufficient test stations and test access, it may be impossible to accurately evaluate a CP system for adequacy of protection.

B-8.1 As Built Drawings.

Require accurate and detailed drawings of the installed system and the structure be provided upon project completion to allow base personnel to perform comprehensive evaluation, testing, troubleshooting or repair. The accurate location of all CP components, especially anodes and anode cables, can save days of effort by repair crews attempting to repair breaks in these cables. Structure leads, although less likely to fail, can be extremely difficult to locate and repair. Proper evaluation of CP systems requires accessing all test points on the structure and all CP components. As built drawings save a great deal of time when locating the test stations, finding the permanent reference cell locations, and other testing requirements, such as foreign line crossings, bonds, isolations and casings.

B-8.2 Locate Equipment Where Readily Maintainable.

Locate CP equipment where they would be readily maintainable. Locate rectifiers where they may be easily inspected and repaired. Rectifiers that are inaccessible are not likely to be properly maintained (Figure B-12). The rectifier in the picture on the left of Figure B-12 is easily accessed. The two rectifiers in the picture on the right are mounted over six feet high and will likely not be properly maintained. Provide test stations that are appropriate for the environment in which they are located. For example, do not specify flush mount test stations where there is a high probability that they will be covered by soil or vegetation. If flush mount test stations must be used in such areas, provide test station markers (Figure B-13). Provide insulating joints where they can be readily tested.

Figure B-12 Rectifiers Located for Ease of Maintenance. .



B-8.3 Test Stations.

Provide test stations to allow access to the structure for potential surveys to determine if adequate CP has been achieved. They are also necessary to perform recurring maintenance, troubleshooting and repair of the system during its life cycle. Installing a sufficient number of test stations to allow access to and testing of the structure at all locations is essential to maintaining the system. All test stations must include two wires to each structure protected or impacted by the CP system. This allows the maintenance crew to test the connection to the structure and allows for possible bonding or interference bonding. It is also important to have access to foreign lines to provide for interference testing and possible mitigation.

Provide test stations on all foreign lines that cross the protected structure or are in the vicinity of the anode bed. These test stations must be accurately shown on the as built drawings, especially if they are not located over the protected structure. Provide test stations for all pipeline casings, at all foreign line crossings, and for other components such as bonds. Provide test station markers (Figure B-13) for flush mount test stations on cross country pipelines to facilitate location of these test points.

Figure B-13 Test Station Marker for Flush Mount Test Station.



Since test stations are manufactured in many different types and configurations, ensure that they are adequately sized and configured for the number of test wires and intended purpose of the test station. Some small flush mount test stations are manufactured with five or more terminals on the terminal board, but when installed with thick HMWPE insulated wire, are difficult to open and close often resulting in damage to the wiring terminals and measuring shunts (Figure B-14). Provide test stations large enough to appropriately accommodate the wire quantity, size and insulation type and facilitate maintenance and testing.

Figure B-14 Small Flush Mounted Test Station with Too Many Large Sized Wires.



B-8.4 Markers and Labeling.

Clearly mark and label wires in all test stations and rectifiers. Wire colors, markings and test station labeling must be uniform and systematic. Rectifiers and test stations must be numbered and accurately included in the as built drawings. Rectifier anode and structure leads must be permanently marked; and very importantly, anode leads and structure leads must never be mixed up, as catastrophic results would ensue. Refer to paragraph B-9.1.4.

B-8.5 Test Access.

Provide soil access test stations to allow the reference electrode to contact the same electrolyte that is in contact with the protected structure (e.g. where a pipeline runs under an extensive paved area such as an airfield parking apron). Reference electrodes cannot “read” through non-electrolytes such as plastic, rubber, oil or asphalt. Reference electrodes also cannot accurately “read” through concrete, especially if it is reinforced concrete. Possible shorts of the reinforcing steel to the protected structure would cause the reference cell to “see” the rebar, instead of the protected structure. Therefore, provide sufficient soil access test stations to allow for accurate monitoring, evaluation, and troubleshooting of the CP system.

B-8.6 Permanent Reference Electrodes (PRCs).

Provide PRCs in locations to facilitate testing of the CP potentials on a structure where portable reference electrodes cannot access the electrolyte, or access would be difficult or dangerous. Provide PRCs at locations such as under storage tanks, between pipeline crossings, under pavement or concrete, inside of water tanks and elevated water towers, and along waterfront structures. PRCs also allow for reliable and

repeatable data and are often installed at specific points along the structure. Also install PRCs at critical points to allow them to be monitored remotely. When practical, install multiple PRCs in hard to reach areas, such as under the bottoms of on-grade storage tanks and inside elevated water tanks, to allow remote testing of the structure using the PRC. One PRC can be used to test the accuracy of another PRC. PRCs used to control automatic rectifiers are especially prone to failure and should have multiple back up PRCs installed to allow for testing of the PRCs and swapping of the control PRC if required.

B-8.7 Electrical Resistance Probes.

Where it is beneficial to also know actual cumulative corrosion rates in addition to CP system effectiveness, provide electrical resistance (ER) probe(s) in addition to PRCs. An ER probe monitoring system consists of an electrical resistance meter, usually with data logging functions, connected to a probe. This technique operates by measuring the change in electrical resistance of a metallic element immersed in a product media relative to a reference element sealed within the probe body. If the corrosion occurring in the vessel or structure under study is roughly uniform, a change in resistance is proportional to an increment of corrosion. Although universally applicable, the ER method is uniquely suited to corrosive environments having either poor or non-continuous electrolytes such as vapors, gases, soils, hydrocarbons, and non-aqueous liquids. ER probes are manufactured in various configurations, and Figure B-15 illustrates is an example of one type of ER probe.

Figure B-15 Example of an ER Probe



Metal loss from an ER probe is cumulative over time. The electrical resistance meter measures the resistance and an algorithm calculates the cumulative corrosion rate over the period of time since the initial measurement. After a probe is connected to a CP system, declining corrosion rates suggest that the CP system has mitigated corrosion of

the probes. The cumulative corrosion rates on a structure with an effective CP system would be expected to continue to decrease to negligible rates with time.

When used to monitor a structure under CP, the ER probe should be allowed to freely corrode for a short period of time before electrically connecting it to the cathodically protected structure. Over time, it will be necessary to temporarily disconnect the ER probe to make a measurement after which, the probe must be reconnected back to the cathodically protected structure. Since the system is measuring very small resistances, take the following measures to prevent premature failure of the ER probe system:

B-8.7.1 Probe Location.

Select and install probes in locations to preclude physical damage. On waterfront applications, avoid locations where floating debris and day to day operations can result in damage to the probes or connecting wires.

B-8.7.2 Prevent Water Intrusion.

For submerged applications, it is imperative to take every effort to prevent water intrusion into, and the subsequent corrosion of the connector between the probe and its lead wire. Encapsulate the probe connection to the lead wire (Figure B-16). For submerged applications, pre-assemble sections of conduits to be submerged before installation. This is also necessary to prevent water infiltration into probe-lead wire connection (Figure B-17).

B-8.7.3 Connection to CP System.

After allowing the probe to freely corrode for a short period of time, connect the probe to the cathodically protected structure as soon as practical after the CP system is energized. For probes to be installed in the vicinity of CP systems, particularly those operating at high CP system current levels, the potential for stray current effects and resulting pre-mature failure of the probe is high. Design a good connection means between the probe and the cathodically protected structure that will easily enable temporary disconnection to take measurements with the ER meter.

B-8.7.4 Backup PRC.

If a monitoring location is critical, provide a backup PRC adjacent to the probe in the event the probe fails and cannot be immediately replaced.

Figure B-16 Probe with Encapsulated Connector.



Figure B-17 Pre-Assembled Conduit System, Probe, and PRC for Submerged Use.



B-8.8 Coupon Test Station System.

Coupon test stations include a small sample of metal (coupon) made of similar material as the protected structure usually packaged with a PRC. The packaged coupon/PRC is typically installed adjacent to a buried or submerged structure with test wires running to a convenient measuring point (test station). Such devices allow for error free reading when the CP current to the structure cannot be easily interrupted.

Potential measurements of underground structures made with a PRC placed on the electrolyte surface or buried PRCs often contain an error known as voltage (IR) Drop error. IR Drop error results from the interaction of the CP current with the soil resistance. One way of accounting for this error is to momentarily interrupt the CP current and measure the potential immediately after interruption. This so-called “instant-off” potential can be substantially free of IR Drop error. Even in cases where current interruption is possible, there may be other sources of current at that location such as those from nearby CP systems, stray currents or telluric currents. Cathodic protection coupons, sometimes called instant off sensors, provide a means to make instant off potential measurements under those conditions.

Coupons are sometimes installed for structures protected by a GCP system with numerous distributed sacrificial anodes. It is nearly impossible to feasibly interrupt CP current on such systems and coupons provide a means to measure IR free potentials.

B-8.9 Anode Current Output.

Design systems with capability to monitor anode output currents. Provide readily accessible test stations with individual current measuring shunts to simplify measuring of individual anode current outputs to ensure that anodes are properly operating and are not being overdriven. Ensure terminals are prominently identified and wires are tagged. Figure B-18 illustrates an example anode junction box.

B-8.10 Electrical Isolation Testing.

Locate dielectric isolating flanges or unions where they may be readily inspected and tested. Preferably, locate these joints in valve pits, or located above grade.

Figure B-18 Anode Junction Box



B-8.11 Remote Monitoring.

For critical or remote locations, consider the use of remote monitoring equipment to monitor the CP system and the protected structure. A remote monitoring unit (RMU) can include components to monitor rectifier output, potential reference cells, interference test bonds, critical bonds, or foreign structure potentials. Remote monitoring can give an instant alarm if the system goes above or below set points. Monthly monitoring can result in up to 60 days between checks, and requires a crew to travel to the location and perform testing. Most RMUs are paid for by savings in these testing costs over a short period of time, when there are sufficient quantities of systems or distance between CP equipment locations. Remote monitoring systems also aid in collection and management of data for historical records.

B-8.11.1 Remote Monitoring Communication Methods.

Remote monitoring units commonly communicate by cell phone technology; telephone land lines; Supervisory, Control and Data Acquisition (SCADA) systems; or satellite transmission technology. Remote monitoring units, and automated data collection units must be planned, designed, acquired, executed and maintained in accordance with DoD Instruction 8500.01 and DoD Instruction 8510.01, and as required by individual Service Implementation Policy.

B-8.11.2 Remote Monitoring Selection Considerations

The following are some important considerations for selecting and installing a remote monitoring unit.

B-8.11.2.1 Rectifier Information.

Prior to selecting the RMU unit, collect adequate information about the rectifier and the location of the installation in order to obtain properly sized/configured RMU components.

- Rectifier maximum DC output voltage and current
- Availability of A/C power, including the operating A/C voltage, and means of running AC power cables to the unit
- RMU mounting location and method of mounting
- Need for one way or two-way communication
- Characteristics of the local operating environment

B-8.11.2.2 RMU Unit Type and Suitability.

Research the various units to determine which units would be most suitable for their intended application. Prior to selecting a satellite communication unit, ensure satellite coverage/location of satellites will allow sufficient communication signal strength where the RMUs will be installed. Install the antennas in a location that allows good communication.

B-8.11.2.3 RMU Power Source.

Ensure that the units selected have a reliable power source. Select units utilizing A/C power or solar power as the primary source and batteries serving as a back-up/secondary power source in the event the primary power source fails.

B-8.11.2.4 Surge Protection.

Provide units with proper surge protection and isolation if the locations of these units are subject to frequent AC power surges or lightning strikes during inclement weather.

B-8.12 GPS Synchronizable Interruption.

For long pipelines that may require close interval, instant off surveys, the installation of GPS synchronizable interrupters in all rectifiers can reduce costs of all future surveys. These are normally used for gas and fuel lines that are monitored in house. The interruption cycle start and stop times are set by computer, then the survey is completed during that time. All rectifiers are turned on and off at specific intervals for a specific time, synchronized together using GPS signals.

B-9 LESSONS LEARNED AND OTHER PRECAUTIONS FOR CP SYSTEM DESIGN.

B-9.1 Common Problems and Design Deficiencies.

B-9.1.1 Qualified Personnel.

Ensure new projects are designed, reviewed, monitored and inspected by qualified personnel. New systems that are not designed, installed, or tested properly result in inadequate corrosion control or even corrosion damage and significant loss in life cycle costs of government infrastructure and assets. Work accomplished by qualified personnel provides greater reliability of critical assets such as fuel systems, fire protection, gas and other infrastructure required for mission accomplishment, safety and environmental protection.

B-9.1.2 Improper Application of GCP Systems.

Table B-5 provides some commonly found problems with CP designs of GCP systems, particularly when unqualified personnel accomplish the design, that result in inadequate CP of the structure or other problems associated with cathodic protection.

B-9.1.3 Improper Structure Bonding/Electrical Discontinuities.

Application of ICCP to a pipeline distribution system with electrical discontinuities will result in unprotected areas and possible interference to the electrically discontinuous section(s) of the structure intended to be protected. All electrically discontinuous section(s) of the structure(s) to be protected must be properly bonded into the system to ensure adequate protection. Common causes of electrical discontinuities include

- Dresser couplings
- Mechanical pipe section connections such as found in ductile iron pipe
- Plastic valves and fittings
- Non-metallic sections of pipeline (new, existing or future installation)
- Improper bonding (or lack of bonding) on joints, flanges or previously installed dielectric isolation unions or flanges

Provide electrical continuity bonds where necessary to ensure electrical continuity of all of the structures to be protected.

Table B-5. Common Problems with GCP System Designs

PROBLEM	SOLUTION
Use of GCP system for bare or poorly coated structures, for example aboveground storage tank bottoms or pipeline distribution systems. In most cases, GCP system cannot economically protect bare or poorly coated structures.	<ul style="list-style-type: none"> • Use ICCP system. • Where applicable, isolate the structure into smaller sections for which GCP systems are feasible.
Use of GCP system in high soil resistivity, for example underground pipelines, underground storage tanks.	<ul style="list-style-type: none"> • Use ICCP system. • Where feasible, consider non-metallic materials for the structure.
Use of GCP system for isolated laterals to a main with ICCP system results in interference problems on the lateral.	<ul style="list-style-type: none"> • Consider using deep well anodes for the ICCP system. • Include provisions for proper bonding. • Consider ICCP system for entire structure.
Use of GCP system for improperly electrically isolated structures. Failure of existing dielectric unions or flanges and other shorts result in loss of protection to the entire structure. One electrical short can result in loss of protection to the entire structure.	<ul style="list-style-type: none"> • Properly electrically isolate the protected structure. • Install electrical isolation in readily maintainable location. • Consider if ICCP system feasible.
Excessive spacing of sacrificial anodes resulting in inadequate protection of the structure between successive anodes. This is often caused by improper design, over estimating the coating efficiency, or under estimating the soil resistivity or anode output (resistance to earth).	<ul style="list-style-type: none"> • Ensure qualified designer. • Do not guess the coating efficiency. Conduct field test. • Do not guess the soil resistivity. Conduct field test. • Do not guess on current requirement. Conduct field test. • Use correct parameters in calculations.

Portions of metallic utility distribution pipeline systems are often replaced with non-metallic pipe sections, introducing electrical discontinuities into the pipeline system. Base utility distribution system plans are not always updated to reflect these replacements; therefore, allow the designer to conduct field current requirement and continuity tests to verify continuity if any doubt. Where feasible, during installation of new non-metallic pipe, provide adequately sized tracer wire for the non-metallic pipe sections that can double as a bond wire. As this may not always be technically feasible; alternatively, install tracer wires/tapes/devices directly above the plastic pipe at a depth that will be detectable by current detection equipment and technologies. If electrical discontinuities cause the pipeline system to be too fragmented, consider providing multiple smaller CP systems. Some isolated sections of pipelines may be small enough to use GCP anodes, but the designer must consider possible interference problems on these sections.

B-9.1.4 Improper structure connection.

Improper connection of the structure to an ICCP system is another common problem. Examples of improper connection include:

B-9.1.4.1 Improper Connection to Conduit Pipe.

An ICCP system is improperly applied to a high temperature hot water distribution system with structure connections to the inner carrier pipelines instead of the outer conduit that results in interference and corrosion of the conduit. In this case, the CP was intended for the outer conduit, not the interior carrier pipe.

B-9.1.4.2 Improper Connection of Rectifier Lead Wires.

ICCP rectifier positive and negative lead wires (rectifier positive lead is improperly connected to the structure to be protected and the negative lead to the anode bed) that results in serious corrosion of the structure. This results in the structure protecting the anodes, and the structure suffering severe corrosion damage in a relatively short time. For proper CP system operation, ensure connection of the rectifier negative lead to the structure and the positive lead to the anode bed.

B-9.1.5 Improper Consideration of Permanent Reference Electrodes (PRCs).

PRCs do not last forever. PRCs used in water tanks and water towers, especially when used in conjunction with an automatic rectifier, often fail with time, resulting in excessive current (automatic rectifier increases its output in attempt to attain proper potential readings with the PRCs) that can cause cathodic disbondment of the coating.

PRCs used under on-grade storage tank bottoms fail because of one or more of the following causes:

- High resistivity of, plus a lack of moisture in the tank bedding material that causes excessive contact resistance and inability to obtain accurate potential readings

- Fuel contamination of the PRC again affecting the accuracy of the PRC or causing deterioration of the insulation of the connecting wires and eventual failure

The difficulty in replacing these PRCs often result in the PRCs not being replaced, leaving base personnel with little or no means to determine if the structure is adequately protected. In extreme cases, the anodes may also fail for the same reasons and with the loss of the PRCs it becomes impossible to determine if adequate protection is present. Alternative solutions for consideration include:

- Providing dual element (copper-copper sulfate/zinc) PRCs
- Providing a secondary means of measurement consisting of several perforated/slotted plastic pipes in the tank bedding installed radially to allow insertion of a portable reference electrode in the tube at any distance between the tank outer edge and the center

B-9.1.6 High Temperature Hot Water (HTHW) Systems.

HTHW distribution systems have many problems associated with electrical isolation reliability and failure of GCP systems; therefore, provide an ICCP system instead, capable of protecting the structure without requiring electrical isolation at numerous locations. Inadvertent failure to install a single insulator, thermal failure of a single installed insulator, or inadvertent removal of a single insulator during routine maintenance can render a GCP system to be ineffective. An ICCP system will generally have some spare capacity to adjust the output current in case of such an event. However, an ICCP system design may result in large current requirements, and to preclude interference, may require bonding or interference mitigation on other buried metal structures in the vicinity. Such an ICCP system should only be designed by a certified CP Specialist. Base the design on data taken during a design field survey that is representative of the entire system. Do not base the design of a CP system for a HTHW piping system upon a single soil resistivity measurement.

B-9.1.7 Aboveground (On-grade) Fuel Storage Tanks.

Provide ICCP systems for the exterior bottoms of aboveground storage tanks with a secondary containment liner. Anodes must be installed in the backfill between the tank bottom and the containment liner. Do not specify GCP systems unless mission requirements preclude the use of ICCP systems. Provide a combination of permanent reference electrodes, corrosion probes, and reference electrode tubes to allow sufficient long-term testing and monitoring of the CP system effectiveness. Provide a separate CP system for buried distribution pipelines associated with the tank.

Provide a properly designed ICCP system for aboveground storage tank bottoms without secondary containment liners. With the many other systems incorporated into these storage facilities, complete electrical isolation can be difficult to achieve. Automated tank gauging systems, product recovery systems, leak detection systems, electrical grounding systems, fire protection systems, bonding systems and other miscellaneous conduits and controls include components that will inadvertently bypass

installed electrical isolation devices. The tank may also be connected to a grounding system for safety, precluding the possibility of complete tank isolation. Provide CP for buried distribution pipelines associated with the tank. Consider electrical isolation issues, stray current interference issues, and life cycle costs to determine the need for a single integrated CP system for the tank and pipelines or separate systems for the tank and pipelines.

B-9.1.8 Excessive Cathodic Protection (Overprotection) Concerns.

Excessive CP (overprotection) is caused by application of excessive amounts of CP current and voltage. In addition to being wasteful of anode material or electrical power, excess potentials can cause disbondment of protective coatings; hydrogen embrittlement of certain types of steels, especially high strength steels; and corrosion damage of amphoteric metal structures made of aluminum and lead. Excessive CP current can also cause stray current (or interference) corrosion damage other metal structures in the vicinity.

B-9.1.8.1 Coating Disbondment.

Excess CP current results in protective potentials above established limits, and can result in the generation of hydrogen gas. Cathodic protection levels at potentials exceeding a polarized potential of -1.1 V with respect to a copper/copper sulfate reference electrode, result in the generation of excessive amounts of hydrogen gas on the surface of a protected metallic structure. When more gas is generated than can permeate the coating, bubbling or blistering of the protective coating occurs, causing disbonding of the coating from the structure surface. Electrolyte (water) can subsequently fill the space left between the coating and the metal, and as the coating is an electrical insulator, sufficient current for effective CP cannot flow to the affected area between the coating and the structure surface. Without CP, corrosion of the structure under the disbonded coating will occur.

Coating disbondment is a particular problem in water tanks in which the type of coating provided is especially prone to hydrogen disbondment and protective potentials exceed polarized potentials of -1.1 Volts DC. In soil environments where high quality coatings were provided, disbondment seldom occurs at potentials less negative than -1.1 Volts DC polarized potential (instant off).

B-9.1.8.1 Hydrogen Embrittlement.

The hydrogen produced when CP currents are excessive can also result in the reduction of the ductility of steel. This is particularly true for high strength steels (in excess of 130,000 pounds per square inch yield strength). This could lead to cracking from stress and loss of yield strength.

B-9.1.9 Stray Currents or Interference Concerns.

Stray currents, also called interference, result from external electromotive forces and can greatly accelerate corrosion. Stray current corrosion can be caused by voltage gradients (current flow) resulting from DC transit systems, HVDC Transmission

systems, DC welding, telluric earth currents, and CP systems. The amount of corrosion caused is directly proportional to the amount of DC current flowing in the electrolyte. Steel corrodes at a dissolution rate of about 20 pounds per ampere-year. CP systems can impress large amounts of current from their anodes, through the electrolyte, to the cathode.

When a metallic structure not connected to or intended to be protected by the CP system (referred to as the “foreign” structure) is immersed in the same electrolyte in the vicinity of the protected structure, it is subjected to stray current corrosion because of the electromotive force being applied through that electrolyte and can undergo extremely severe corrosion without proper mitigation.

B-9.1.9.1 Mechanism of Stray Current by CP Systems.

A CP system is a large corrosion cell, a result of an electro-chemical reaction that involves electrical current flow and chemical ion migration. The current flowing from the anodes of a CP system flows through an infinite number of paths in the electrolyte toward all parts of the intended protected structure. Since the CP system is an electrical circuit, all of the electrical current provided by the rectifier through the anodes and the electrolyte must eventually return to the rectifier. In doing so, the basic laws of electrical current flow prevail, and most of the current will flow through the path of least resistance. A “foreign” metallic structure in the vicinity of the protected structure may provide such a low resistance path back to the rectifier. Figure B-19 illustrates an example of interference on a pipeline in the vicinity of DC rail systems. Figure B-20 illustrates an example of interference on “foreign” pipelines in the vicinity of a CP system.

Where the current flows from the electrolyte onto the “foreign” structure, the current will collect and flow along the foreign structure until a low resistance path, commonly where the “foreign” and protected structures physically cross or are in close proximity, will allow the current to flow off of the foreign structure into the electrolyte towards and onto the protected structure to eventually return to the rectifier. At these points where the current flows off of the “foreign” structure (discharges) into the electrolyte, oxidation reactions (corrosion) occur. At metal dissolution rates of 20 pounds per ampere-year, significant interference concentrated at discharge points such as a coating holiday on the foreign structure could cause significant amounts of corrosion in a very short amount of time, in some cases, as quickly as several days.

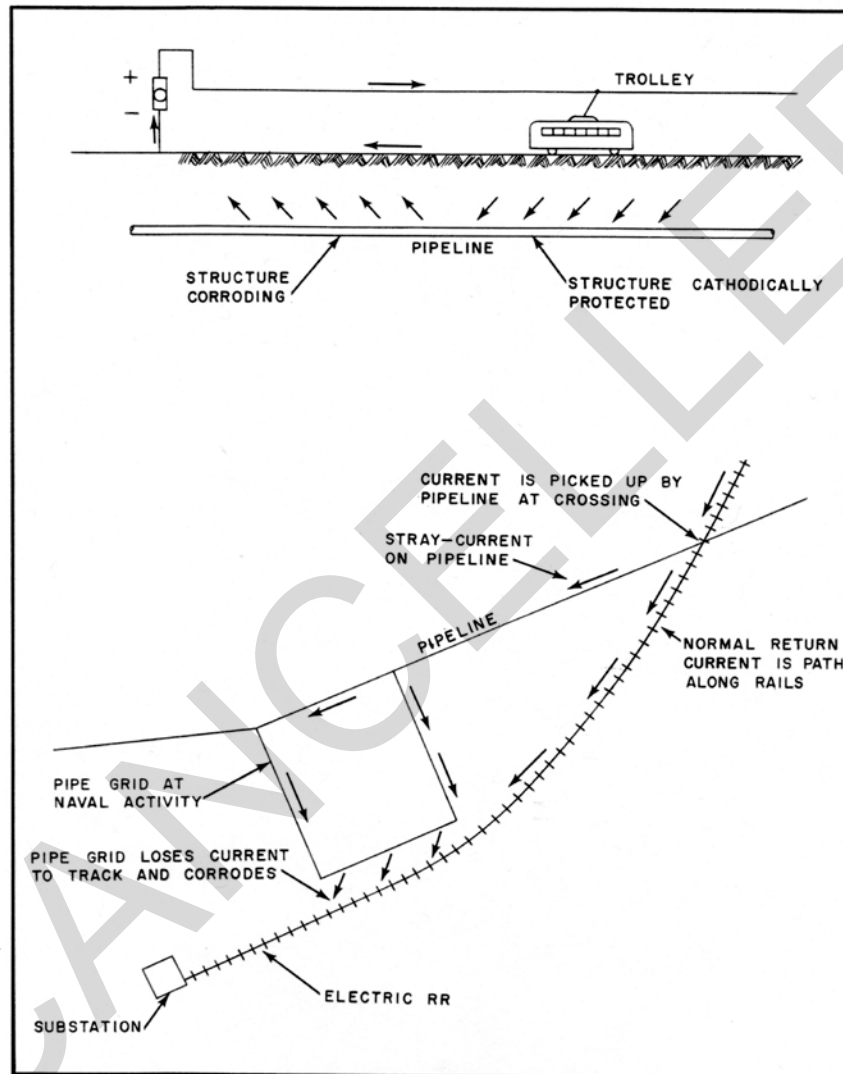
B-9.1.9.2 Impact of Stray Currents on the Protected Structure.

Although corrosion is not usually accelerated on the protected structure, cathodic interference can disturb the desired current distribution on the protected structure, and can reduce the amount of CP in some areas of the protected structure to inadequate levels.

B-9.1.9.3 Detecting Interference.

Cathodic protection interference problems are most commonly detected through the measurement of structure-to-electrolyte potentials. Where necessary, conduct stray current interference testing as part of the design field survey.

Figure B-19 Interference on Pipeline in Vicinity of a DC Powered Rail System.

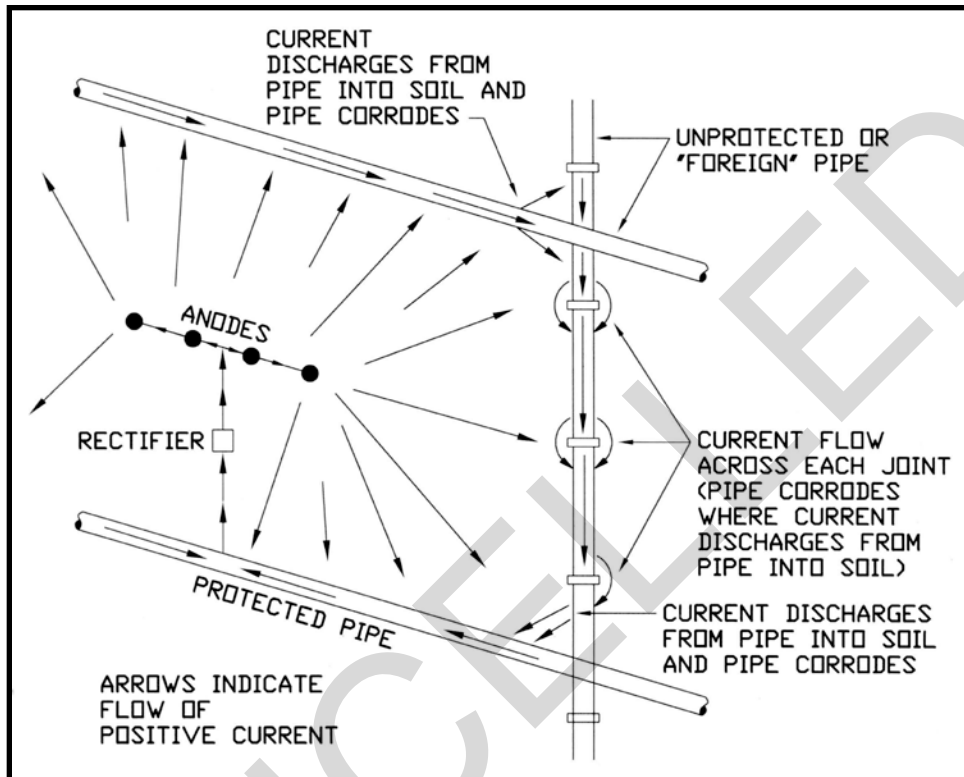


B-9.1.9.4 Mitigating Interference.

Include mitigation methods for interference detected during the design field survey tests or anticipated based on structure layout in the drawings and specifications. In other cases interference may not be detected until after the CP installation, during system commissioning, and the interference mitigation methods will need to be determined immediately after the commissioning. Interference can be mitigated by several methods, depending on the ownership of the foreign structure, the protective coatings

on each structure, and the surrounding soil conditions. If the foreign structure is owned by the same party, consider interference mitigation on the foreign structure as part of the CP system design.

Figure B-20 Interference on Foreign Pipelines in the Vicinity of a CP System.

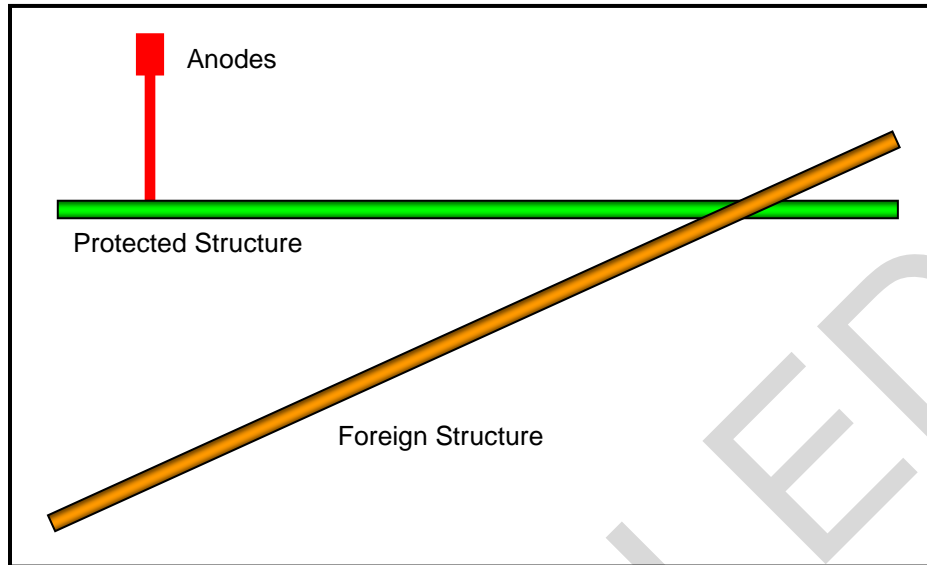


B-9.1.9.4.1 Anode Bed Location.

A significant factor in controlling interference is proper location of the anode bed. In general, the remote anode beds commonly used in ICCP systems cause more problems with interference than do sacrificial anode systems where the anode-to-structure distances are usually in the order of 10 feet or less and the driving potential is small (less than one volt). The influence on foreign structures is a primary consideration in the location of remote anode beds. Figure B-21 shows an example of an anode bed located to minimize interference on a foreign structure. Placing the anodes in between the two pipelines, nearby the crossing point or on the opposite side of the foreign pipeline would likely result in significant interference.

Deep anode beds generally have a significantly lower possibility of causing interference to foreign structures, as the foreign structures, in this case, usually do not provide lower resistant paths for the current from the anodes.

Figure B-21 Placing Anodes to Minimize Interference.



B-9.1.9.4.2 Direct Bonding.

Another technique for mitigating interference is to bond the foreign structure to the protected structure. The bonding can either be a direct low-resistance connection or a resistive bond. Bonding both structures together essentially provides CP to both structures. This can be accomplished to mitigate interference even if complete protection cannot be provided to the foreign structure. Direct bonding of a foreign structure to a protected structure will often require designing a larger capacity CP system than would be required just for the protected structure since the foreign structure can drain away substantial amounts of CP current intended for the protected structure.

Typically, provide the bond in a location where the structures physically cross or are in close proximity. Provide a test station at the direct bond location in order to verify the continuity of the bond, and to measure the current flowing through the bond. Specify insulated copper wire of appropriate size to properly carry the anticipated electrical bond current, and with a minimum wire size of No. 8 AWG for mechanical strength. Do not specify bare copper wire (e.g. grounding wires). Bare copper wire can drain away substantial amounts of CP current intended for the protected structure, and the insulated wire is necessary to minimize the amount of bare metal introduced to the CP system. Where interference testing cannot be conducted during the design survey, provide a bond station wherever pipelines cross and at other locations where interference is possible to allow for future bonding and testing. A bond test station must have two wires to each structure and room for possible installation of a resistor required in the future.

B-9.1.9.4.3 Resistance Bonding.

Direct bonding may not be desirable when the existing CP system cannot supply enough current to protect both the protected structure and bonded foreign structure (usually because of current distribution problems), or the foreign structure is not owned by the same installation as the protected structure. In the latter case, the structure owner supplying the CP current may desire to reduce the current provided to the foreign structure to just the minimum levels required to mitigate the interference. In either case, provide a resistive bond between the structures that can be adjusted to supply only the minimum amount of current to the foreign structure to bring its potential to its normal level prior to provision of the CP system for the protected structure.

Provide bond test stations where resistive bonds are used in order to facilitate testing of the corrective action and adjustment of the resistor, if required in the future. The resistor may either be a commercially supplied wire wound adjustable resistor of the proper resistance and current rating or may be fabricated from nickel-chromium alloy (nichrome) resistance wire cut to appropriate length in the field and wound into a coil. Adjustment of the resistor to correct the interference is determined by installing a temporary resistive bond and measuring the current through the resistor and the changes in potential achieved by the temporary bonding.

B-9.1.9.4.4 Use of Galvanic (Sacrificial) Anodes to Mitigate Interference.

Where the interference is localized, and the magnitude of the interference current is small, typically less than one ampere, sacrificial anode(s) on the foreign structure at the point of discharge may be an acceptable method to mitigate the interference. In order to determine the feasibility of using the sacrificial anode mitigation method, first measure the amount of bond current required to negate the interference. Next, calculate the ability of the GCP anodes to provide sufficient current based on the soil resistivity in the interference area. Size the GCP anode(s) to provide current in excess of the required bond current to control the interference. Provide test stations to monitor the potentials of both structures and GCP anode current outputs.

B-10 SPECIALIZED CP TECHNOLOGY AND CONSIDERATIONS.

B-10.1 Deep Anode Beds.

A deep anode bed according to the NACE International, is one or more anodes installed vertically at a nominal depth of 15m (50 ft) or more below the earth's surface in a drilled hole for the purpose of supplying CP for an underground or submerged metallic structure. Refer to Figure 4-1.

B-10.1.1 Advantages/Disadvantages of Deep Anode Bed Systems.

Paragraphs B.4.2.6.1 and B.4.2.6.2 describe the advantages and disadvantages of deep anode bed systems.

B-10.1.2 Deep Anode Bed Design.

Deep anode bed calculations are fairly simple and follow the process for calculating a shallow vertical anode bed, except that the anode well resistance would be calculated using the Dwight equation for a single anode, whose length is that of the entire active zone. However, equally important and more difficult to determine factors must be considered when designing a deep well anode system.

B-10.1.2.1 Location.

Determining a good location for the deep anode column is essential to help ensure the proper design, installation, and operation of the column. Paragraph 4.3.4.1 describes requirements to consider in locating a deep anode bed.

B-10.1.2.2 Anode Column.

Some anode column design requirements and considerations are as follows:

B-10.1.2.2.1 Anode Type.

Select anode type for optimum performance and reduced difficulty of installation. Local subsurface conditions influence the selection of anode type, and anode selection affects the design for the column, i.e. quantity of anodes, depth and diameter of the column, and installation procedures. [Technical Paper 16](#) provides information on the operational characteristics of different anodes in different environments.

B-10.1.2.2.2 Anode Centralizers.

Provide anode centralizers (Figure B-22) to help ensure the anodes are completely surrounded by backfill to lessen the chance of premature failure. Design/specify centralizers that do not significantly reduce total anode discharge area. Avoid the attachment of centralizers directly to anode surfaces that are subject to crevice corrosion such as mixed metal oxide or platinum coated titanium or niobium.

B-10.1.2.2.3 Anode Column Venting.

Provide vent pipes in the anode column to vent gases generated around the anode out of well to avoid gas blockage. Gas blockage can result in increased anode resistance and uneven current discharge from the anode surface resulting in premature failure. Specify vent pipes with holes or slots small enough to prevent the backfill from entering and clogging the vent pipe. Do not terminate the vent pipe inside of the anode junction box. Any chlorine gas generated will cause corrosion of the junction box hardware and detrimentally affect operation of the CP system. Terminate the vent pipes outside of the junction box as shown in Figure B-23 and seal the conduit to prevent gas from entering the junction box. Also, where practicable, do not terminate the vent in the anode well head box. The concentration of chlorine gas can result in corrosion of the well head box cover if it is made of steel or cast iron as shown in Figure B-24, and can degrade the insulation around the anode lead wires, and result in loss of the anode.

Figure B-22 Centralizers Installed on High Silicon Cast Iron Anodes



B-10.1.2.2.4 Anode Installation Procedure.

Follow the anode installation procedures as indicated in UFGS 26 42 17.00 10 and UFGS 26 42 19.00 20. In most cases specify that the contractor must not use the anode lead wire to lift, transport or install the anode. Handling the anode by using the lead wire can compromise integrity of wire and anode connection. Where the situation requires the use of the anode lead wire for anode installation, specify the appropriate pull out strength of the wire-to-anode connection to prevent damage to the connection, and provide destructive test procedures to verify conformance with the specifications. Refer to UFGS UFGS 26 42 17.00 10 and UFGS 26 42 19.00 20.

B-10.1.2.3 Anode Column Backfill.

Provide a special carbon backfill, referred to in the industry as coke breeze, in the anode hole or column for nearly all underground deep anode bed installations. Paragraph 4.3.4.3 describes requirements to consider for anode column backfill. Technical Report TR-NAVFAC EXWC CI-1425 *Environmentally Friendly Cathodic Protection Anode Beds*, describes a conductive concrete anode system that includes an impermeable backfill that can be considered as an option in deep anode bed CP systems where cross contamination of ground water aquifers is a concern or where artesian well conditions may complicate installation of the deep anode bed. Backfill is not required for open-hole, replaceable deep anode columns. Open-hole deep anode columns are considered where there is sufficient low resistivity groundwater to keep the anode well filled with water. In this case, the water provides the uniform environment for uniform distribution of current, with the advantage of more easily replaced anodes in the event of failure.

Figure B-23 Anode Column Vent Pipes Run Outside of Anode Junction Box.



Figure B-24 Severe Corrosion of Cast Iron Cover on the Anode Well Head Box Caused By Chlorine Gas Vented into the Box.



B-10.1.2.4 Anode Lead Wires.

Anode lead wires are very important components of the anode installations, and many deep anode installations have failed because of improperly specified lead wires. Some considerations for anode lead wires for deep anode beds include:

B-10.1.2.4.1 Wire Insulation.

Specify HMWPE insulation. For chlorine ion environments, specify a dual insulation consisting of an inner ethylene-chlorotrifluoroethylene layer with an HMWPE outer layer for abrasion resistance.

B-10.1.2.4.2 Splices Not Allowed.

Provide individual anode lead wires to the anode junction box instead of splicing them to a single header cable from the rectifier. Anode columns that traverse differing soil strata can result in uneven current distribution from the anodes (i.e. higher current output of individual anodes located in low resistivity strata) that can lead to premature failure of that anode. Loss of anodes can then result in overload of the remaining anodes that may then prematurely fail. This domino effect will eventually result in premature failure of the anode column. Specify that splices are not allowed in the anode lead wires. Splices are a point of premature failure of anode lead wires.

B-10.1.2.4.1 Damaged Wire Insulation Not Acceptable.

Specify that nicks or other damaged to the wire insulation are not acceptable. As with splices, and even more so with damaged wire insulation, nicks and damaged insulation are points of premature failure of anode lead wires.

B-10.1.2.5 Environmental Concerns.

Installation of a deep anode bed can impact the environment. Environmental concerns must be considered during the early design stages. Consult with base environmental personnel and ensure that they are afforded the opportunity to review the design. Failure to consider environmental concerns can result in:

- Delays in completing the final design if an environmental issue is identified too late in the design
- Delays in obtaining construction permits
- Work stoppage and costly construction delays if environmental issues must be settled after construction is awarded with the potential for disapproval of work and cancellation of the installation
- Pollution of the environment and the resulting costly cleanups
- Fines for violating environmental regulations
- Other legal ramifications

B-10.2 Pre-engineered Cathodic Protection for Underground Storage Tanks.

USTs and oil water separators that conform to the Steel Tank Institute STI-P3-90 standard include a pre-engineered sacrificial anode CP system that is one part of the overall pre-engineered external corrosion control system for the underground steel storage tank (Figure B-25). The STI-P3® system combines three basic methods of underground corrosion control, all installed on the tanks during manufacture:

- Cathodic protection
- Protective coating
- Electrical Isolation of the tank from other underground metallic structures

Do not specify these types of pre-engineered CP systems where field survey conditions indicate they are not feasible. For new STI-P3® tanks specify provision of manufacturer provided PP4 CP testing equipment or provide separate appropriate test stations and wiring, to allow proper testing of the CP system.

***** CAUTION - RISK OF INADEQUATE CP *****

The CP system for an STI-P3® tank is intended only to protect the tank. Pipelines associated with the tank will not be protected. A separate CP system must be provided for the associated pipelines to comply with UST regulations. Also note that the integrity of the isolating bushings for an STI-P3® tank must be maintained. Loss of this electrical isolation can result in inadequate protection of the tank because of electrical shorts to other buried metallic structures in the vicinity.

Figure B-25 STI-P3® Tank



B-10.2.1 Dielectric Coating.

Every STI-P3® underground storage tank is protected with one of the three generic types of coating that have been tested to STI requirements and then approved for adoption into the STI-P3® specification: coal tar epoxy, urethane, or isophthalic polyester resin. This first line of defense against corrosion completely covers the

external surface of the tank. A coating is applied to a blast-cleaned, prepared surface. If this coating is flawless, external corrosion cannot occur. Also, even if not perfect, the protective coating serves to reduce the amount of protective current needed for CP.

B-10.2.2 Cathodic Protection.

The only practical approach to a pre-engineered CP system for this application is using GCP anodes attached to the tank. GCP anodes develop their own protective current because of the natural potential difference between the anode metal and the metal being protected. This means that the anode system is self-activated after the tank is buried and will continue to provide corrosion control until the anode is consumed by corrosion.

Sacrificial GCP anodes made of either high-purity zinc or magnesium prevent corrosion of any exposed metallic surfaces, such as nicks or scratches in the coating that may occur during transportation or installation of the tank. Welded to the tank, these anodes control the direction of electrical current flow and will deteriorate in place of the steel. Based on the estimate of the average current produced by the anodes in a given soil, the estimated useful life of the anode system can be calculated. If the coating remains undamaged, the anodes will serve merely as back-up protection. Zinc anodes are provided where the soil resistivity is less than 2,000 ohm-cm. Otherwise magnesium anodes are provided.

B-10.2.3 Electrical Isolation.

All STI-P3® tanks must be electrically isolated from all other metallic underground structures that will be exposed to the backfill. This includes hold down straps installed to prevent the tank from floating out of the excavation during a high water table. Tank openings are electrically isolated by use of dielectric nylon bushings or flange isolators that will be compatible with stored product. By preventing contact between the tank and other nearby metal structures through the piping system, the chance of stray current corrosion is minimized, and the current demand that such contact would add is eliminated. This isolation, which defines the area to be protected by anodes, is intact when shipped from the factory.

B-10.2.4 Test Stations.

The STI-P3® design uniquely enables the testing of the tank's corrosion protection system. Varying federal and state regulations require that periodic CP tests be performed on single-wall STI-P3® tanks. For new STI-P3® tanks, specify provision of PP4 CP testing equipment or provide appropriate test stations and wiring, to allow proper testing of the CP system.

B-10.3 CP Systems for Reinforcing Steel in Concrete.

The chemical and alkaline nature of reinforced concrete normally results in the rebar developing a passive surface film that mitigates the effects of corrosion. Corrosion normally occurs around the tidal and splash zones due to the intrusion of oxygen, moisture, and chloride ions that will destroy the passive film. Most of the spalling and

crack damage is a result of corrosion of the steel reinforcing bar (rebar) due to the presence of chlorides in the concrete. The reinforcing steel corrosion products (rust) occupy a larger volume of space than the original bar, and will exert enough force on the concrete to cause structural cracks, delaminations, and spalling of the concrete structure. Structural engineers contracted to design the structural repairs frequently specify the industry state-of-the-practice repairs for damaged piles, typically, patching of spalled concrete and epoxy injection to repair cracks. Such repairs are expected to last for 20 – 25 years; however, repairs by patching do not stop the existing rebar corrosion process due to the continued presence of chlorides, and will often cause increased corrosion of the rebar just adjacent to the patched areas, resulting in larger spalled and cracked areas after only six to seven years.

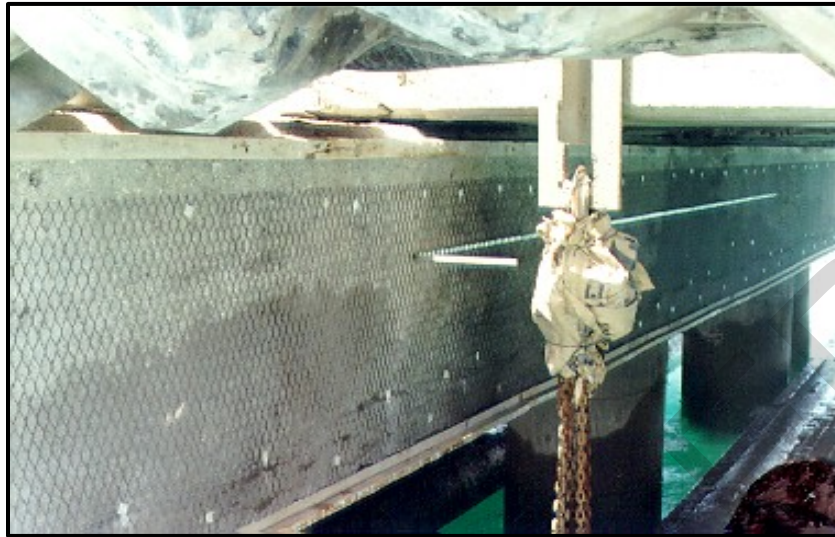
CP systems are generally not required for rebar for new reinforced concrete structures. Instead, comply with the requirements of the appropriate UFC and UFGS documents that include concrete design considerations that enhance corrosion prevention and control of the rebar. However, for major concrete structure repair projects, provide CP for the rebar in concrete where economical over the life cycle of the structure. CP systems for rebar in concrete must be designed by a qualified person experienced in the design of CP systems for rebar in concrete. Provide permanent reference electrodes or corrosion probes to allow testing and monitoring of the CP system effectiveness.

B-10.3.1 ICCP Systems.

For corrosion protection of reinforced concrete structures requiring significant structural concrete repairs, CP can be applied to protect the reinforcing steel from corrosion where economical. While several different types of ICCP anode systems are manufactured, consider one or a combination of the three different types of ICCP anode systems that is most appropriate for the type of concrete structure and repairs being accomplished.

- Titanium mesh system consisting of mixed metal oxide coatings on an expanded titanium mesh fastened to the concrete surface (Figure B-26), and overlaid with a cementitious material, usually a Portland cement concrete mix. This type of system is commonly used on deck surfaces, piles or columns
- Titanium ribbon (mesh) slotted system consisting of mixed metal oxide coatings on either solid titanium ribbon strips or on expanded titanium mesh ribbon strips. The ribbons are installed between the rebar and concrete substrate or in slots cut in the concrete surface, and backfilled with a cementitious mix. This type of system is commonly used on deck surfaces
- Discrete anode system that typically consist of short strips of mixed metal oxide coated expanded titanium mesh, ceramic anodes, or platinized titanium wire typically installed in drilled holes and backfilled with cementitious grout. The length and spacing of the discrete anodes depends on the density of rebar and protection current requirements. These systems are most economical for beams, piles and columns

Figure B-26 Titanium Mesh Anodes Fastened to a Concrete Beam



B-10.3.1 GCP Discrete Anode System (DAS).

When cracked and spalled concrete structures containing high chloride contamination are repaired by patching because of funding limitations, consider installation of GCP discrete anodes in the vicinity of the patched area. The GCP discrete anodes are sacrificial zinc anodes in a special backfill (Figure B-27 and B-28). Unless a large area of concrete is removed during spall repairs, provide discrete anodes areas near the outer edges of the patch before applying the concrete patch. The type, length and spacing of the discrete anodes depends on the density of rebar and patch dimensions. The intent of the DAS anodes installed along with patches is not to provide adequate CP to the entire structure, but to minimize the galvanic corrosion effects between the rebar surrounding the patched area and the rebar within the patched area.

B-10.3.2 Pre-engineered CP for Pier Pilings.

While GCP DAS can be provided for corrosion protection during the repair of reinforced concrete piles (Figure B-29), another alternative is an integrated concrete pile repair and corrosion protection system (Figure B-30) containing pre-engineered CP systems for the pile reinforcing steel. Refer to paragraph 4-5.4.3. Consider this type of system as a viable alternative for long-term repairs of waterfront structures with reinforced concrete piles containing high chloride contamination, and significant spalling/delamination of concrete due to corrosion of reinforcing steel. This system can increase the service life of a pier patch repair up to 20 years in contrast to only six to seven years if pier pilings containing high chloride levels are only patched. For piles with only minimal damage, prepare a life cycle cost analysis to help determine the economic viability of this technology.

Figure B-27 Discrete Zinc Anode (Wrapped in Green Mesh) in Concrete Deck Repair. Device with the Yellow Lead Wire is a Permanent Reference Electrode.



Figure B-28 Discrete Zinc Anodes in Fiberglass Jacket for Pile Installation.



Figure B-29 Photos Showing “Before” and “After” Installation of Integrated Pile Repair and CP Systems



B-10.3.2.1 System Description.

The integrated pile repair corrosion protection system is comprised of high purity expanded zinc mesh CP anode mounted into a durable, stay in place fiberglass form that positions the anode material the appropriate distance relative to the steel rebar in the piling. In addition, the form creates an essential annular space for filling with concrete material to complete/improve the structural repairs to the piling. A supplemental bulk anode is added to protect the submerged portion of the pile and minimize current demand on the lower portion of the anode mesh (see figure B-30).

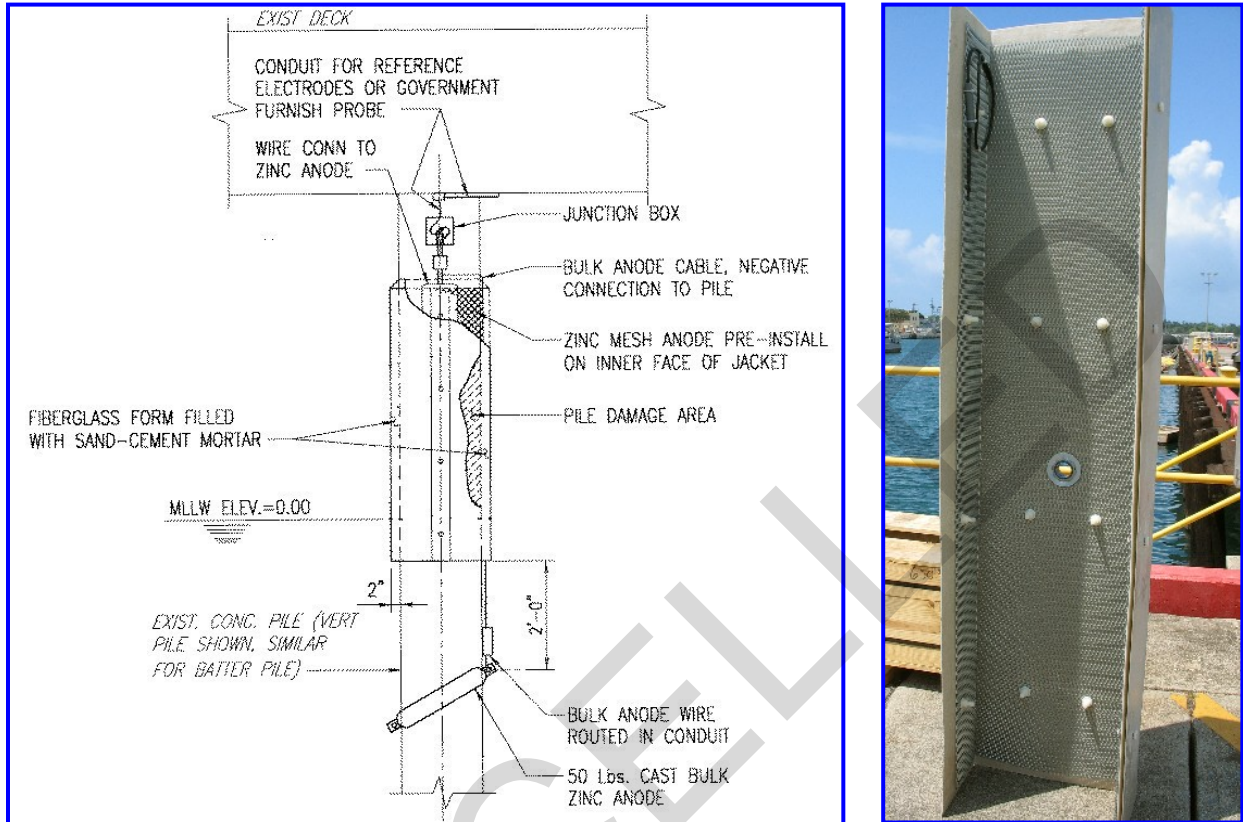
The system comes complete and ready to install with all components pre-positioned and fixed in place. The external jacket material is a durable fiberglass shell that is equipped with unique interlocking seams that literally snap together. Manufacturer's literature indicates that non-specialty contractors and supervised general laborers can do the job. Once installed, the system requires very little maintenance or monitoring, an expense that is often neglected with other ICCP systems that becomes a burden during the ICCP system life cycle. Based on results from a DOD demonstration project of this technology, the estimated average service life of the zinc CP system mesh is in excess of 25 years.

The system can be designed for a wide variety of pier piling structure configurations and can easily be integrated with the other pier piling repairs already being designed (removal of spalled concrete, replacement of badly corroded rebar sections, patching of spalled concrete areas, and repairs to small cracks in the concrete).

B-10.3.2.2 System Design.

Most Architect-Engineering (A-E) firms and even CP firms do not have experience with this technology. Close coordination between the design agent, the A-E designer, the product manufacturer, and service CP technical experts is necessary to ensure the system is properly designed, and adequate testing facilities are incorporated to permit monitoring of these systems.

Figure B-30 Typical Lifejacket Installation



B-10.3.2.2.1 Anticipated Concrete Repair Scope Creep.

From past experience in concrete waterfront repair projects, the scope of concrete repairs tends to increase over the design requirements as demolition of spalled concrete uncovers unseen damaged areas. Ideally, demolition of all spalled and cracked concrete should be completed prior to ordering jacket system materials to ensure proper jacket lengths and no negative impacts to the system installations. However, as the pile jacket systems may be a long lead time item, this plan would delay their installation and would also complicate installation as specific jackets would need to be matched to specific piles. It may be more reasonable and prudent to specify a jacket of length from two feet below the low water level to three or four feet above the high water level. Unforeseen additional damage found during demolition beyond the jacket length would be repaired in accordance with the appropriate typically prescribed repairs designed for concrete damage on piles without this system.

B-10.3.2.2.2 Pile Rebar Electrical Continuity.

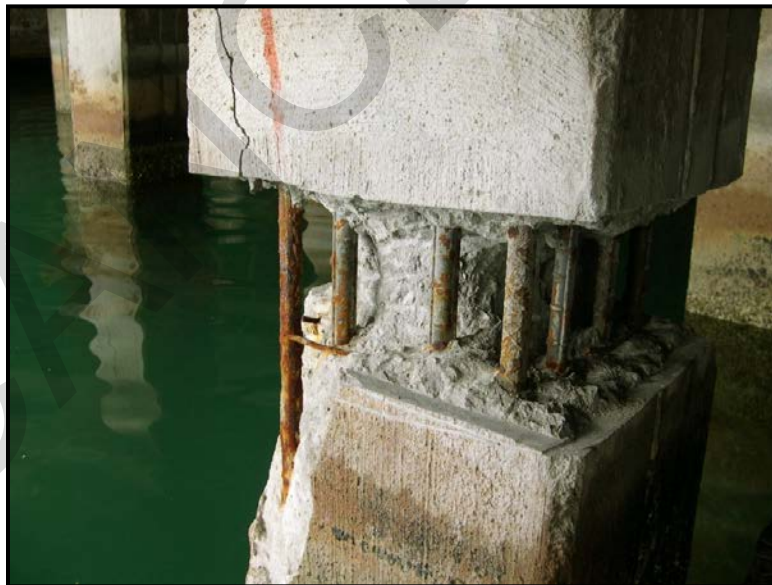
Electrical continuity among all of the reinforcing steel in the pile is necessary for proper operation and effectiveness of the CP system. The normal manufacturer's recommended procedure is for the contractor to drill several small holes in the concrete piles to locate rebars and permit testing to determine electrical continuity between the

rebars. Where not found electrically continuous, the contractor is required to install bond wires between such rebars to ensure electrical continuity. Since this process is essentially a trial and error process, it would require the contractor's corrosion technician to be on site for long amounts of time during this process, and the process may slow down the installation. If during a repair project, a large quantity of piles require repair, it may be more cost and time efficient for the contractor to demolish a band of concrete around the entire perimeter of the piles to expose all of the rebars in the piles (Figure B-31), and weld a continuous metal bar to each of the rebars in the pile to ensure their continuity. This will reduce the time needed for the contractor's corrosion engineer to conduct continuity testing, reduce the time for installation, and also ensure that the piles would not have to be reworked because of electrical discontinuities found during system commissioning.

B-10.3.2.2.3 System Installation.

Most contractors also do not have experience with this technology; therefore, specify requirements for project execution procedures for close coordination between the user, designer, contractor, and the product supplier/ manufacturer. Prior to commencement of construction, meet with the contractor to resolve issues that he may not understand or are not technically feasible in the design. Closely coordinate with the contractor to develop a system installation procedure as part of their quality control plan.

Figure B-31 Concrete Demolished Around Entire Pile to Permit Installation of a Bar Welded to Each Rebar to Establish Electrical Continuity.



B-10.3.2.2.5 Monitoring Test Stations.

A typical integrated concrete pile repair and corrosion protection system installation will come with a small test box mounted just above or on one of the jacket faces. Also consider the installation of several special monitoring test boxes along the pier or wharf

deck in various random areas throughout the structure to facilitate testing of these systems. The additional cost for these special test boxes will be offset by

- Eliminating the cost and time need to obtain and launch a boat to navigate to the piles during each round of testing. By having test boxes mounted on the deck of the pier, a significant amount of time is saved while conducting the tests. For example, a full round of tests for an averaged sized pier can be conducted on the pier deck in one to two hours versus the several hours to almost a day that would have been required using a boat
- Providing a stable surface on which to conduct the tests. Due to the constantly moving boat in the water, two people would be required during testing; one to hold the boat as steady as possible against the piles while the other conducts the test measurements. Only one person is required to conduct the tests at the deck mounted test boxes. Tide levels also impact testing procedures

B-10.4 Interior of Potable Water Tanks.

Water storage tank CP systems must be designed by a qualified person experienced in the design of CP systems for water storage tanks to ensure its proper operation. Ensure that CP system materials are approved for use inside of potable water storage tanks in accordance with NSF/ANSI Standard 61. Coordinate CP systems requirements with the interior protective coatings designer to eliminate conflicting requirements.

B-10.4.1 CP for Interior of Water Tanks Subject to Icing Conditions.

There is a persistent problem at DoD installations with CP systems for water storage tanks located in areas with cold winters. Water tank interior CP system anodes are typically suspended from the roof of the tank with wires and cables such that they are submerged in the water. Such systems are often prematurely damaged or destroyed when surface ice forms in the tank in very cold environments.

Older water tank CP systems used heavy silicon-iron or graphite anodes. Such systems were vulnerable to failure not only due to ice, but also due to the weight of the suspended anodes pulling on the wire and electrical connections. Ceramic-coated anodes have been used as a lightweight alternative to the silicon-iron and graphite anodes in recent years. These anodes are typically made by depositing mixed metal oxides (MMO) onto titanium substrates including rods, wire, and discs. The MMO-coated anode eliminates the problems caused by anode weight, but when they are suspended from the roof of the tank, the anodes, cables, and wiring are still susceptible to ice damage. ICCP systems to protect the interior surfaces of water storage tanks in cold climates must be designed to prevent damage from ice. Specify a CP system consisting of MMO wire anodes along with a flotation and support system that keeps the anodes submerged in water underneath surface ice, regardless of the water level, where they will no longer be subject to ice damage. Refer to material and installation details in UFGS 26 42 15.00 10.

B-10.4.1.2 System Design.

The design to prevent ice damage uses MMO-coated wire anodes along with a flotation and support system that keeps the anodes submerged in water underneath surface ice, regardless of the water level. Because the anodes and their supports are kept away from the ice, they will not be subject to ice damage. There are several design considerations for anode support systems developed by industry. One design example utilizes an octagonal-shaped buoy constructed on-site inside the tank from 4-inch diameter Schedule 40 PVC pressure pipe sections (Figure B-32). The sections cannot be pre-assembled because the finished buoy would be too large to insert through a tank hatch. The buoy is tethered with polyester ropes to the bottom of the riser in the center of the tank. This installation may not be practical during cold weather, as the PVC cement for joining pipes would not set properly in the cold weather conditions.

An alternative design for installation in cold weather, successfully demonstrated by the U.S. Army, consists of 4-inch diameter Schedule 40 PVC pressure pipes installed in a pattern of the “spokes” of an octagonal umbrella-like support structure (Figure B-33). These anode support arms are attached to the riser via hinged connectors. Polyester marine rope forms the outer hoop of the support structure, and the anode wire is wrapped around the rope. PVC legs at each corner of the octagon oriented downward from the plane of the hoop prevent contact between the anode and the tank walls. Four commercial fishing net floats are attached at the far end of each anode support arm to prevent the hoop from sinking. The positive lead wires (attached to the anode wire on two diametrically opposite sides and connections water-proofed) are also spirally wound around the buoy and terminated outside the tank through a tank-entrance pressure fitting. A lead wire from a copper/copper-sulfate reference electrode permanently mounted on the hoop leg is also terminated outside via this fitting. The negative lead wire is exothermically welded to the steel tank access tube ladder strut, coated with epoxy, and also terminated outside the tank through the pressure fitting. This system design does not require on-site assembly of PVC pipe sections, thus it is possible to install it during cold weather.

B-10.4.2 Bolted or Riveted Water Storage Tanks with Interior Glass Lining.

Where a CP system is planned for a bolted or riveted steel water storage tank with an interior glass lining, include provisions to ensure electrical continuity between the riveted steel plates. The interior glass lining may electrically isolate adjacent plates. For other types of protective coatings, include requirements in the contract specifying that the contractor is responsible for providing an interior coating system and ensuring that the coating system is compatible with the CP system.

Figure B-32 Octagonal Shaped Buoy Design.

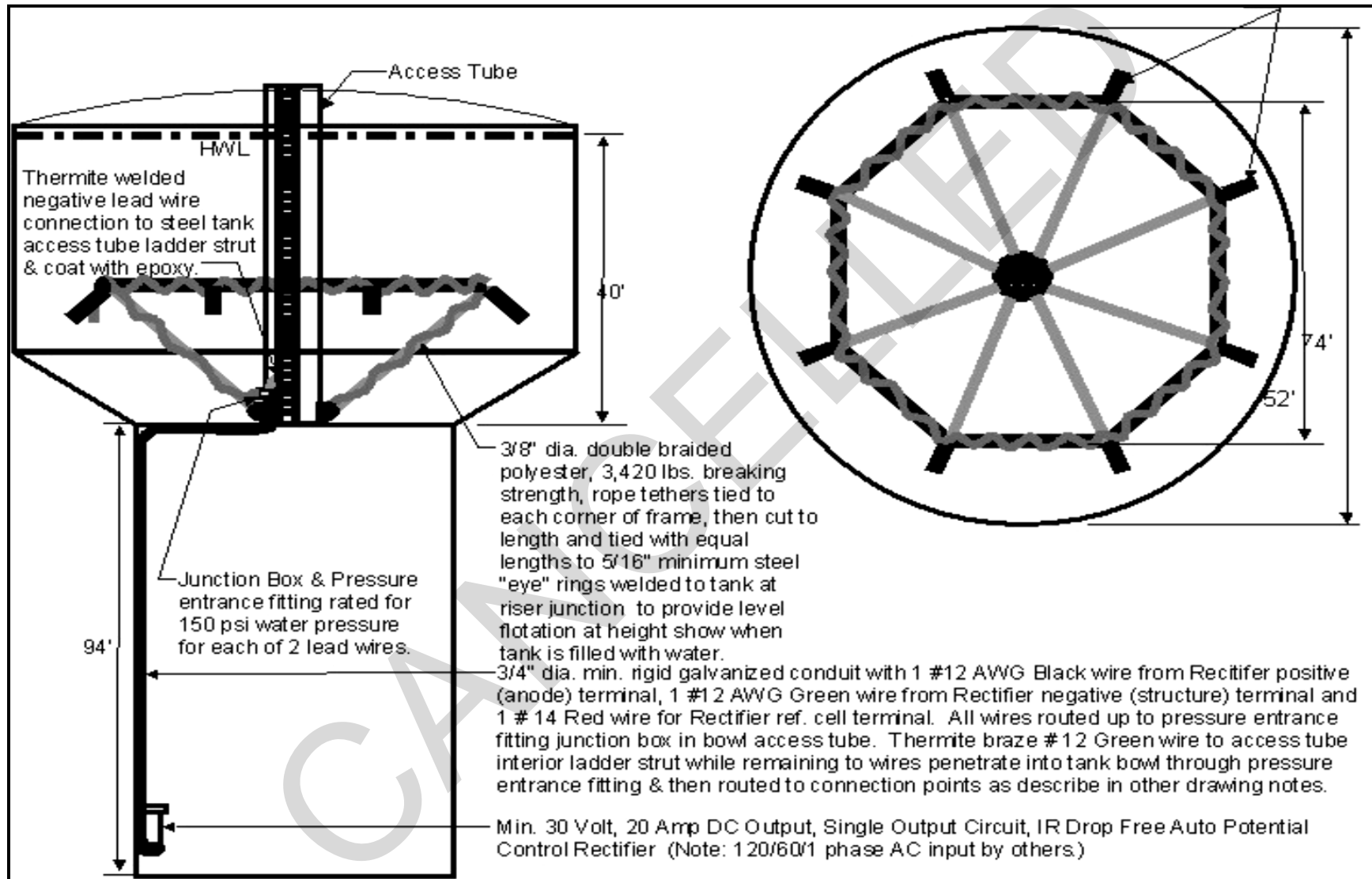
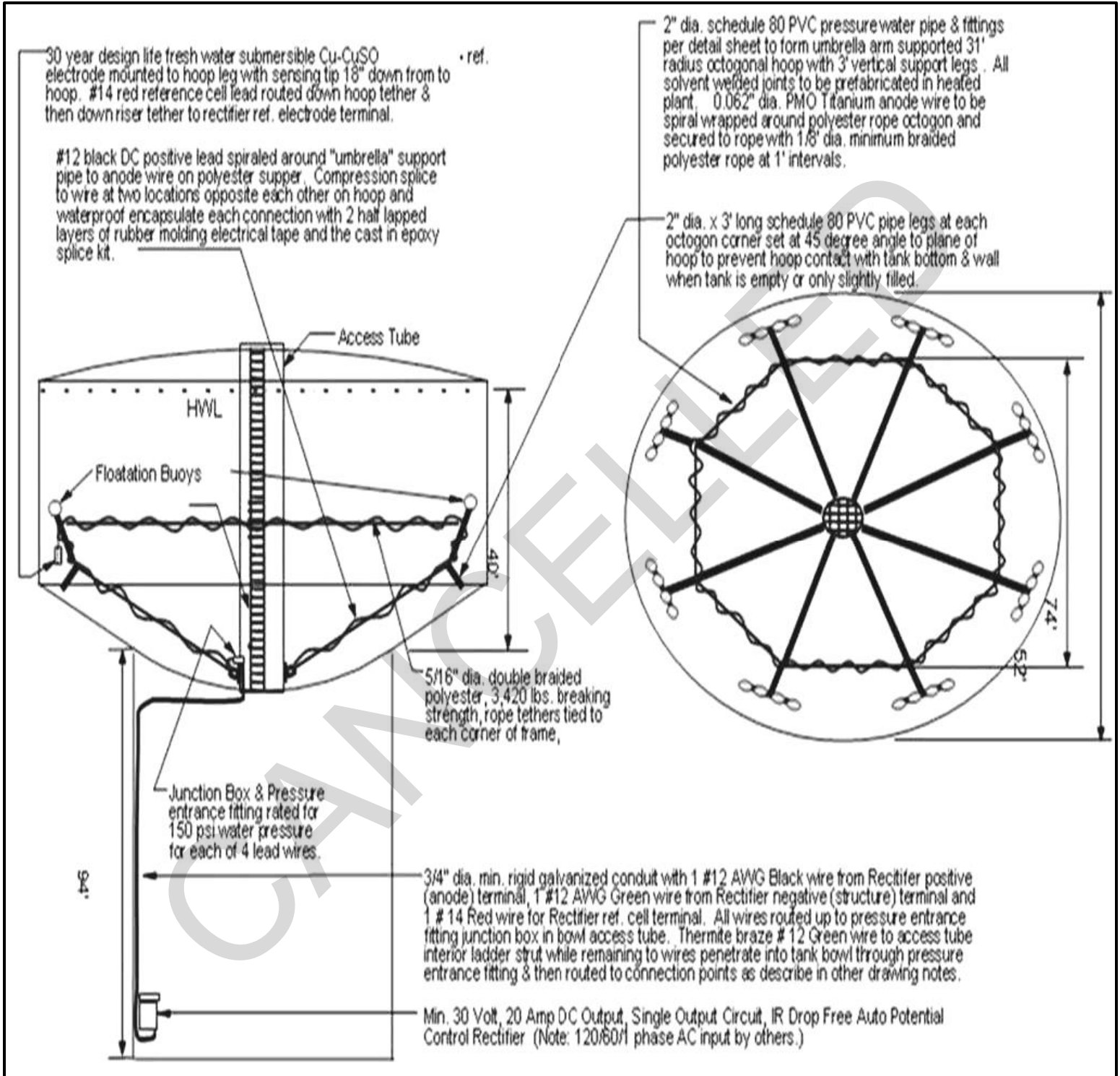


Figure B-33 Umbrella-like Anode Support Structure Design.



B-10.4.3 Monitoring Water Tank CP Effectiveness.

Provide a CP monitoring system that will allow monitoring of system effectiveness without having to physically climb the tank. Design the monitoring system such that test lead terminals are conveniently located in, or nearby the rectifier at ground level. Consider the use of remote monitoring systems.

B-10.5 Hot Water Storage Tanks.

Steel hot water storage tanks need protection against internal corrosion to prevent chronic leaking and premature failure. Corrosion caused leaks could cause extensive water damage to structures and mission critical electrical and mechanical equipment that may be co-located in the same rooms with the water storage tanks. Furthermore, the resulting leaks will eventually cause an accumulation of moisture that will promote mold and bacteria growth.

B-10.5.1 Domestic Hot Water Heaters/Tanks.

Provide factory-equipped glass linings and sacrificial anodes for domestic and smaller hot water heaters/tanks (75 – 1000 GA capacity). The glass linings and sacrificial magnesium anodes are economical for corrosion protection due to the reduced maintenance and monitoring for these systems.

B-10.5.2 Industrial Hot Water Heaters/Tanks.

Provide ICCP systems that use mixed metal oxide titanium rod anodes for larger industrial hot water heaters/tanks. Such systems have been successfully installed in Navy and Army installations. Figure B-34 illustrates a system installed in a vertical tank with a man-way access opening. In this example, a separate sacrificial anode is also installed to protect the man-way access cover since the sealing gasket prevented electrical continuity to the rest of the tank.

If an existing tank does not have a man-way access opening to permit work from the inside of each tank, utilize flexible and joinable mixed metal oxide coated anode rods, which can be bent and inserted into the tanks in 4-ft-long segments. This avoids having to break out any walls to provide clearance for their installation. Subsequent segments could be screw coupled to the first and subsequent segments as the assembly is pushed into the tank until the far end of the tank is reached (may require four or five segments). Insertion and penetration of the anode rod at each end of the tank can be made through a 1-in.-diameter “weld-o-let” fitting that is welded in place from the exterior on opposite ends of the tank (Figures B-35 and B-36). These provide threaded holes for high pressure stainless steel compression sealing elements minimizing the impact on the pressure vessel tank wall. The wire with black insulation in Figure B-36 is the positive lead wire from ICCP rectifier unit attached to the anode. The white insulation wire is rectifier system negative wire.

Figure B-34 CP System for a Vertical Hot Water Tank with a Man-Way Access Opening.



Figure B-35 CP System Rectifier and Anode Condulet Fitting on Side of Water Tank.



Figure B-36 Close up of Condulet Fitting Showing Anode Rod Extending Out of the Storage Tank.



B-10.5.2.1 Monitoring Water Tank CP Effectiveness.

Manufacturers of commonly used reference electrodes for CP system testing may not guarantee the accuracy of a permanently installed reference electrode in the high temperatures of a hot water storage tank. Instead, provide a capillary pore tube measurement port or bridge that facilitates taking these measurements with a reference electrode located outside the hot water tank with the tip held against the ionically conductive capillary tube (Figure B-37).

Figure B-37 Reference Electrode Placed in Contact with Moist Wadding Temporarily Placed Inside of the Capillary Tube Monitoring Port.



B-10.5.3 ICCP for Water Boxes in Power Plants.

Water boxes can contain a mixture of many different metallic materials. Some of the materials such as titanium, austenitic stainless steels, and super alloy stainless steels are more noble than the rest of the water box components. As a result, without CP, water box components can experience substantial galvanic corrosion. However, improperly designed ICCP systems for water boxes can result in metallurgical problems such as:

- Hydride formation in titanium tubes under excessive CP results in reduced ductility as the hydride forms
- Generation of chlorine gas at the anodes under excessive CP resulting in pitting corrosion in the upper tubes of austenitic stainless steel tube bundles
- Hydrogen embrittlement of stainless steel under excessive cathodic protection

Cathodic protection systems must be carefully designed to operate within selected operating potentials, and be properly maintained within these potentials to prevent any metallurgical problems from occurring. Designs must be accomplished by personnel qualified and experienced in these types of systems.

B-11 CP SYSTEM COMMISSIONING.

B-11.1 System Commissioning Procedures.

Proper commissioning of the new CP system plays an important role in the operation and maintenance of the CP system. Proper commissioning by qualified personnel helps ensure the system is properly operating from the onset and helps identify system deficiencies, both design and construction, that should be corrected before the system is accepted. A properly commissioned system will help simplify maintenance and operation, and commissioning test data can be used as a baseline for future operation and troubleshooting. Specify adequate commissioning procedures so that the system is energized and fully tested to ensure its proper operation before being accepted from the contractor. General commissioning procedures are detailed in the UFGS listed in paragraph 3-4.3, and the following are examples of requirements from these specifications that should be tailored towards the specific CP system being designed.

B-11.1.1 General.

Specify that the systems shall be tested and inspected by the Contractor's corrosion engineer in the presence of the Contracting Officer's corrosion protection engineer or an approved representative. Include requirements to record test data, including date, time, and locations of testing and submit required reports to the Contracting Officer. Require that the contractor shall correct, at his expense, all deficiencies in the materials and installation observed by these tests and inspections, and must pay for retests made necessary by the corrections.

B-11.1.2 Base Potential Tests.

Prior to energizing the CP system, require the contractor to measure the base (native) structure-to-electrolyte potentials of the structure. Require that the measurements be made at anode junction boxes, test stations and other locations suitable for test purposes (such as service risers or valves) at intervals along the structure with measurements at each end point and the midpoint as a minimum. Indicate that the locations of these measurements shall be identical to the locations specified for measuring energized structure-to-electrolyte potentials. For USTs, take a minimum of three measurements with the reference electrode located as follows:

- Directly over the longitudinal and transverse centerlines of the tank at intervals not exceeding the diameter of the tank and to a distance from the tank of two times the tank diameter.
- At points directly around the circumference of the tank.]

B-11.1.3 Permanent Reference Electrode (PRC) Calibration.

Specify that the contractor must verify calibration of the PRC by measuring the potential difference between the PRC and an independent (portable) calibrated reference electrode placed in the soil or water adjacent to or as close as practicable to the PRC. Potential differences between the two electrodes of the same generic type should not exceed 15 millivolts. Zinc PRCs should be within the range of -1000 to -1150 millivolts when calibrated with a CSE. Require that permanent reference electrodes not within these potential differences shall be removed from the construction site by the end of the day and replaced at the contractor's expense. The testing provision shall also apply to replacement reference electrodes as well.

B-11.1.4 Insulation Joint Testing.

Require the contractor to perform insulation integrity testing at each dielectric insulating joint or fitting before and after the CP system is energized. Before energizing, test using an insulation checker. After energizing, test the insulation by measuring the potential shift on both sides of the insulating joint. Indicate that this testing shall demonstrate that no metallic contact or short circuit exists between the two insulated sections of the pipe or structure. Require the contractor to report and repair defective insulating fittings at their expense.

B-11.1.5 Electrical Continuity Testing.

Require the contractor to conduct electrical continuity testing of the structures intended to be cathodically protected prior to backfilling of the structure.

B-11.1.6 Rectifier System Testing.

Upon completion of the installation, "Baseline Potential Tests", "Insulation Joint Tests", and "Electrical Continuity Tests", indicate that the contractor can energize and adjust each rectifier and conduct the following inspections and tests:

- Verify the correct AC power supply to the rectifier
- Inspect and record the rectifier DC output panel meters
- Verify the panel meter readings using portable, calibrated meters and shunts
- Adjust the rectifier output as required to attain effective cathodic protection levels
- Correct noted deficiencies

This testing shall demonstrate that the rectifier system is capable of functioning properly as required to provide effective cathodic protection.

B-11.1.7 Pipe Casing Testing.

Before final acceptance of the CP installation, require the contractor to test the electrical insulation of the carrier pipe from casings and correct any short circuits.

B-11.1.8 Energized Potential Tests.

With the entire CP system put into operation require the contractor to measure structure-to-electrolyte potentials along the structure using a portable reference electrode(s) appropriate for the electrolyte and a voltmeter having an input impedance of not less than 10 megohms. The locations of these measurements must be identical to the locations used for the base potential measurements.

B-11.1.9 Interference Testing.

Perform interference testing with respect to any crossing and nearby foreign pipelines in cooperation with the owner of the foreign pipelines. The testing shall verify that the subject CP system does not have a deleterious effect on the foreign pipelines, and vice versa. Prepare a full report of the tests, giving all details including remedial actions taken or recommendations to correct noted interference problems.

B-11.2 System Commissioning FAQs.

Refer to [Technical Paper 18, Frequently Asked Questions About Cathodic Protection System Equipment Commissioning and Testing](#), for additional information and FAQs regarding CP system commissioning.

APPENDIX C GLOSSARY

ACRONYMS

AC	Alternating Current
A-E or A/E	Architect-Engineer
AFCEC	Air Force Civil Engineer Center
ANSI	American National Standards Institute
AST	Aboveground (on-grade) storage tank
ASTM	American Society for Testing and Materials
AWG	American Wire Gage
CFR	Code of Federal Regulations
CP	Cathodic Protection
CPC	Corrosion Prevention and Control
CSE	Copper-copper sulfate (reference) electrode
DC	Direct Current
DoD	Department of Defense
EPA	Environmental Protection Agency
ER (probes)	Electrical Resistance (probes)
ERDC/CERL	Engineering Research and Development Center/Construction Engineering Research Laboratory
FGS	Final Governing Standards
GCP	Galvanic (Sacrificial) cathodic protection
HMWPE	High molecular weight polyethylene
HQUSACE	Headquarters, U.S. Army Corps of Engineers
ICCP	Impressed current cathodic protection
IR (Drop)	Voltage (drop)
OEBGD	Overseas Environmental Baseline Guidance Document

pH	A measure of hydrogen ion activity
POL	Petroleum, Oil and Lubricants
PRC	Permanent reference electrode
NACE	
International	National Association Corrosion Engineers International
NAVFAC	Naval Facilities Engineering Command (NAVFACENGCOM)
NAVFAC ESC	NAVFAC Engineering Service Center (now NAVFAC EXWC)
NAVFAC EXWC	NAVFAC Engineering and Expeditionary Warfare Center
NEC	National Electrical Code
NSF	National Sanitation Foundation
O&M	Operation and Maintenance
RFP	Request for Proposal
SCE	Silver-silver chloride (reference) electrode
S/E	Structure-to Electrolyte
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guides Specifications.
U.S.	United States
USACE	United States Army Corps of Engineers
UST	Underground Storage Tank
ZRE	Zinc reference electrode

DEFINITION OF TERMS

Amphoteric material: Material subject to attack by both acid and alkaline environments; include aluminum, zinc, and lead.

Anode: The electrode of an electrochemical cell at which oxidation occurs. (The anode is usually the electrode where corrosion occurs and metal ions enter the solution).

Bimetallic corrosion: (See galvanic corrosion).

Bond: See continuity bond.

Cathode: The electrode of an electrochemical cell at which reduction occurs.

Cathodic protection: A technique to prevent the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

Coating: A dielectric material applied to a structure to separate it from its environment.¹

Conductivity: The measurement of a material's ability to conduct electrical current.

Continuity bond: Metallic connection that provides electrical continuity.

Corrosion: The deterioration of a material or its properties due to a reaction of that material with its chemical environment.

Corrosion potential: The potential of a corroding metal surface relative to a reference electrode under specific conditions in an electrolyte.

Corrosion rate: The rate at which corrosion proceeds.¹

Crevice Corrosion: Localized corrosion resulting from a concentration cell formed between two metal surfaces or between a metal and non-metallic surface.

Current density: The current per unit area.

Electrical isolation: Condition of being electrically separated from other metallic structures or the environment.¹

Electrode: A conductor used to establish electrical contact with an electrolyte and through which current is transferred to or from an electrolyte.¹

Electrolyte: A chemical substance or mixture containing ions that migrate in an electric field. Examples are soil and seawater.

Fiber Reinforced Plastics (FRP): A broad group of composite materials composed of fibers embedded in a plastic resin matrix.

Foreign structure: Any structure that is not intended as a part of the system of interest.

Galvanic anode. A metal that, because of its relative position in the galvanic series, provides sacrificial protection to metal or metals that are more noble in the series, when coupled in an electrolyte. These anodes are the current source in one type of cathodic protection.¹

Galvanic cell: A corrosion cell in which anode and cathode are dissimilar conductors, producing corrosion because of their innate difference in potential.

Galvanic corrosion: Corrosion resulting from the coupling of dissimilar metals in an electrolyte.

Holiday: A discontinuity in a coating that exposes the metal surface to the environment.

Hydrogen embrittlement: The severe loss of ductility of a metal when hydrogen has been introduced into the metal structure.

Hydrogen overvoltage: Voltage characteristic for each metal-environmental combination above which hydrogen gas is liberated.

Impressed current: Direct current supplied by a power source external to the electrode system. For the purposes of this manual, direct current for cathodic protection.

Interference: Any electrical disturbance on a metallic structure as a result of stray current.

Interference bond: A metallic connection designed to control electrical current interchange between metallic systems.

IR drop: Voltage across a resistance according to Ohm's Law. ¹

pH: A measure of hydrogen ion activity defined by: $\text{pH} = \log_{10} (1/a\text{H}^+)$ where $a\text{H}^+$ = hydrogen ion activity = molal concentration of hydrogen ions multiplied by the mean ion activity coefficient (= 1 for simplified calculations).

Pipe-to-soil potential: The potential difference between the pipe metallic surface and electrolyte that is measured with reference to an electrode in contact with the electrolyte. See also structure-to-electrolyte potential.¹

Polarization: The deviation from the open circuit potential of an electrode resulting from the flow of current.

Reference electrode: A reversible electrode with a potential that may be considered constant under similar conditions of measurement.

Resistivity: The measurement of a material's ability to oppose the flow of electric current.

Rust: A reddish-brown corrosion product of iron that is primarily hydrated iron oxide.

Sacrificial anode: See galvanic anode.

Stray current: Current flowing through paths other than the intended circuit.

Stray current corrosion: Corrosion resulting from stray current flow through paths other than the intended circuit.

Structure-to-electrolyte potential (also structure-to-soil potential): The potential difference between a buried metallic structure surface and electrolyte that is measured with reference to an electrode in contact with the electrolyte. See also pipe-to-soil potential.

Structure-to-structure voltage (also structure-to-structure potential): Difference in voltage between metallic structures in a common electrolyte.

Surge arrestors: A protective device for limiting surge voltages by discharging or bypassing surge current, and it also prevents continued flow of follow current while remaining capable of repeating these functions. Designed primarily for connection between a conductor of an electrical system and ground to limit the magnitude of transient (surge) overvoltages on equipment. Also known as arrestor or arrester, surge arrester, lightning arrestor or arrester.

Uniform corrosion: Corrosion attack of a metal that is essentially the same at all exposed areas of its surface.

Voltage: An electromotive force, or a difference in electrode potentials expressed in volts.

APPENDIX D EXAMPLE CATHODIC PROTECTION DESIGN DETAILS

Figure D-1 Example GCP Anode Installation Detail

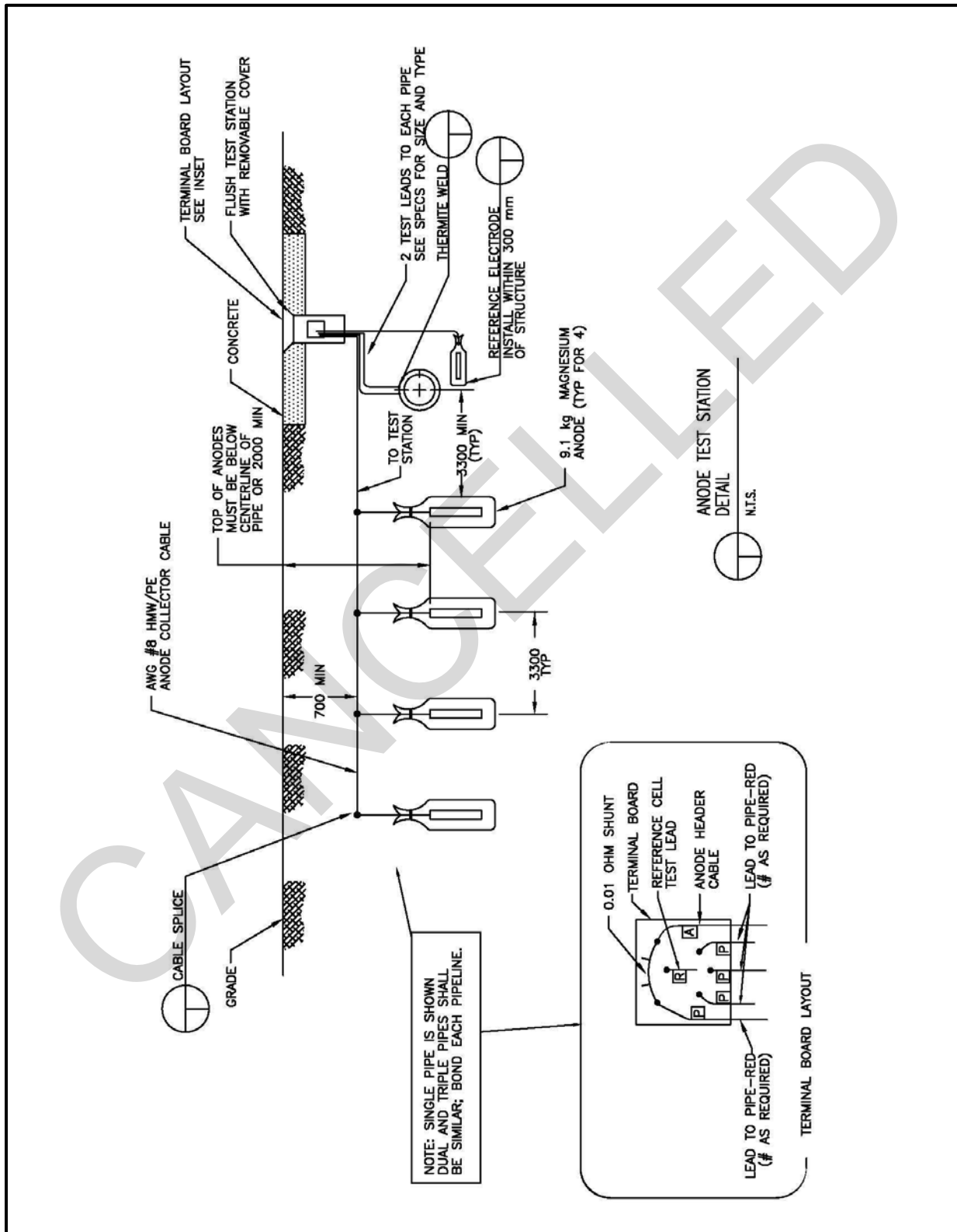


Figure D-2 Example ICCP Anode Installation Detail

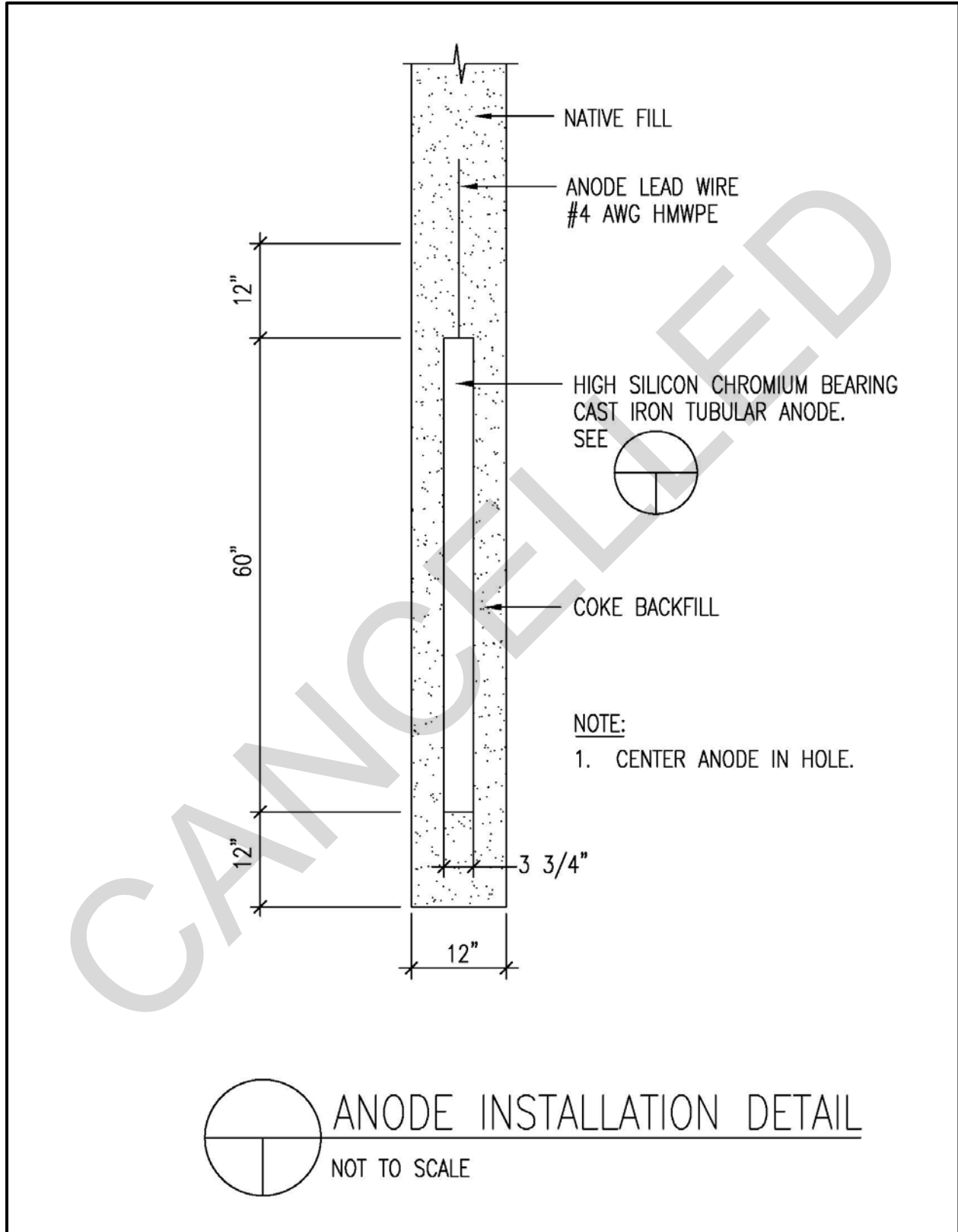


Figure D-3 Example Deep Anode Installation Detail

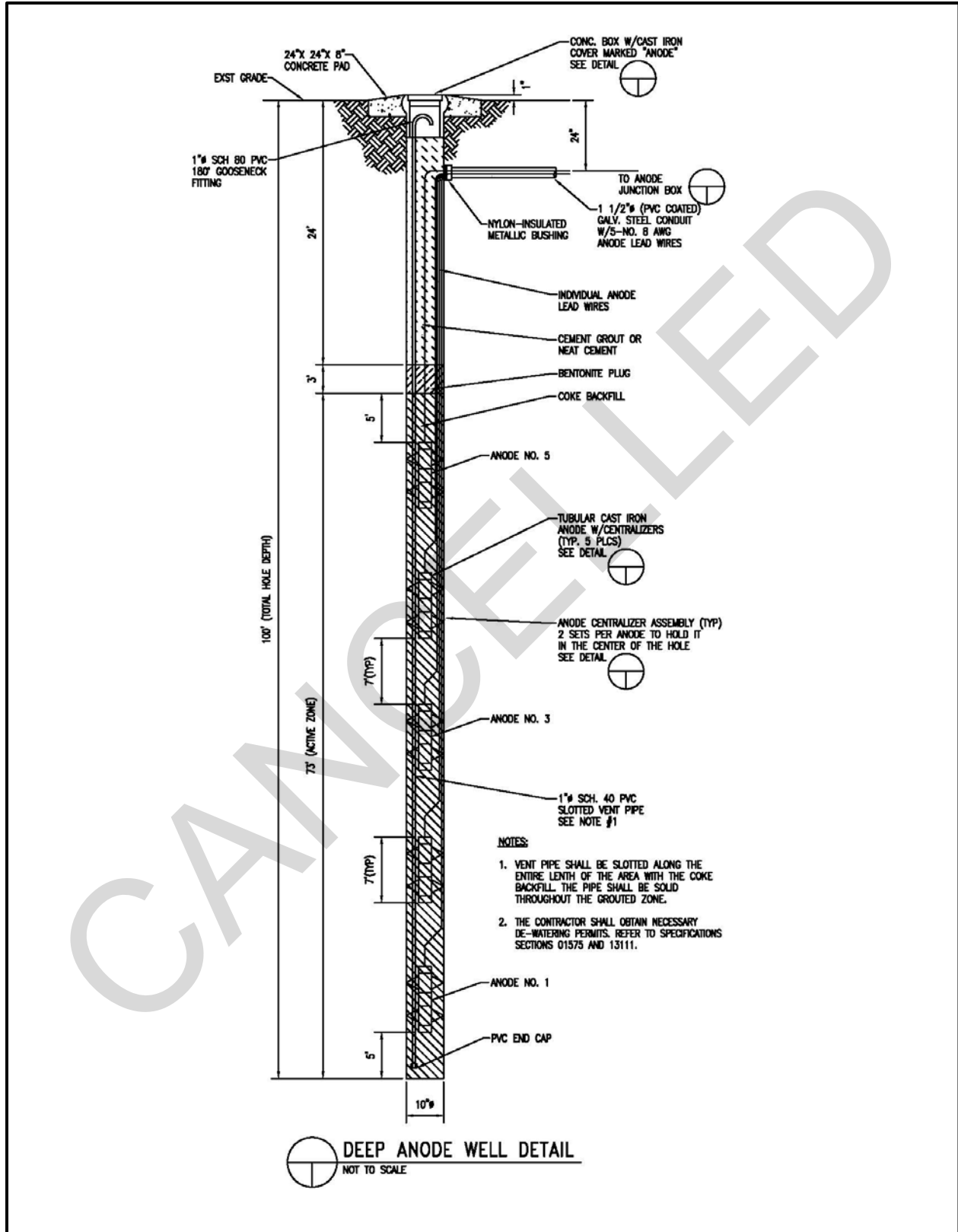


Figure D-4 Example GCP Anode Detail

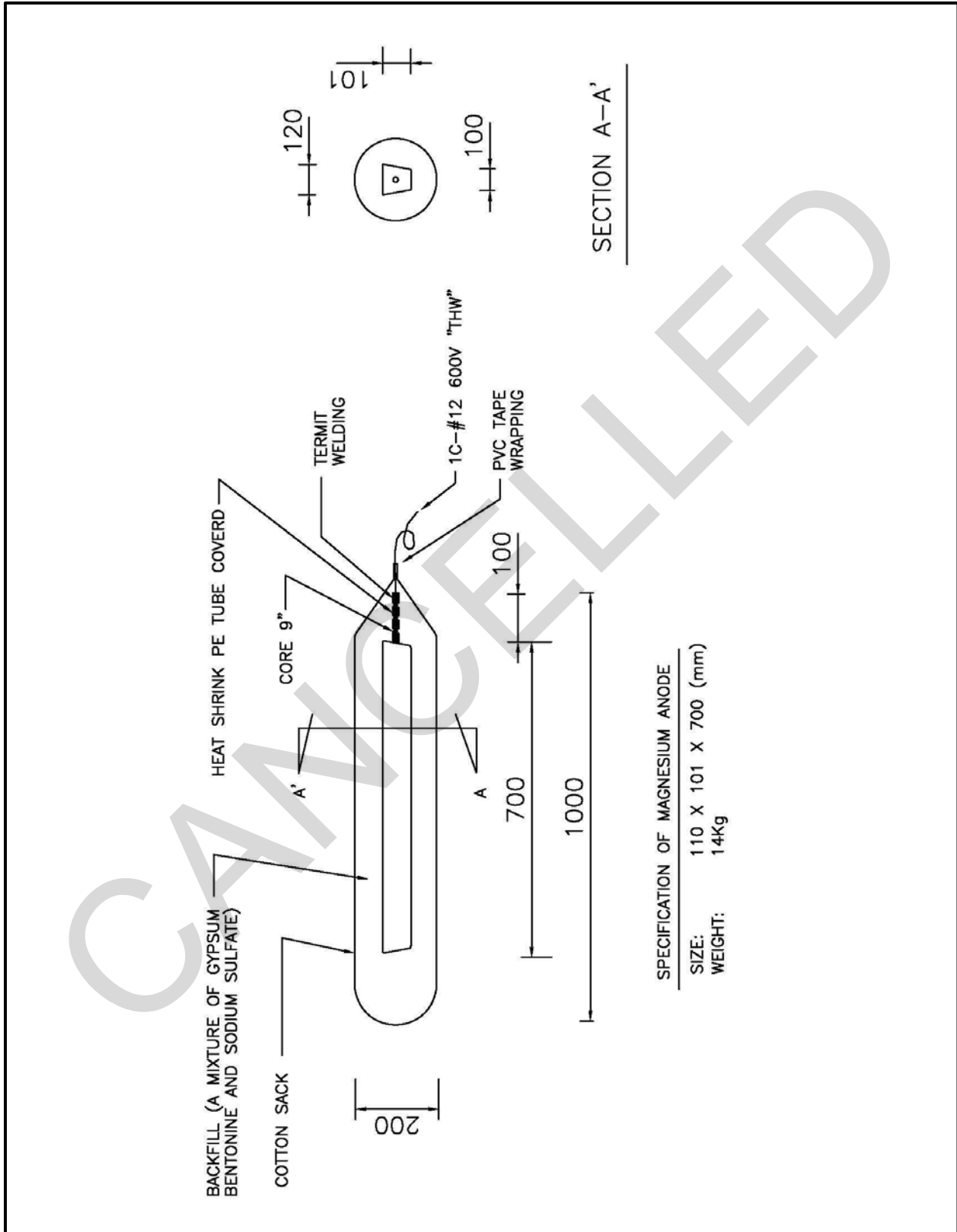


Figure D-5 Example Seawater GCP Anode Detail

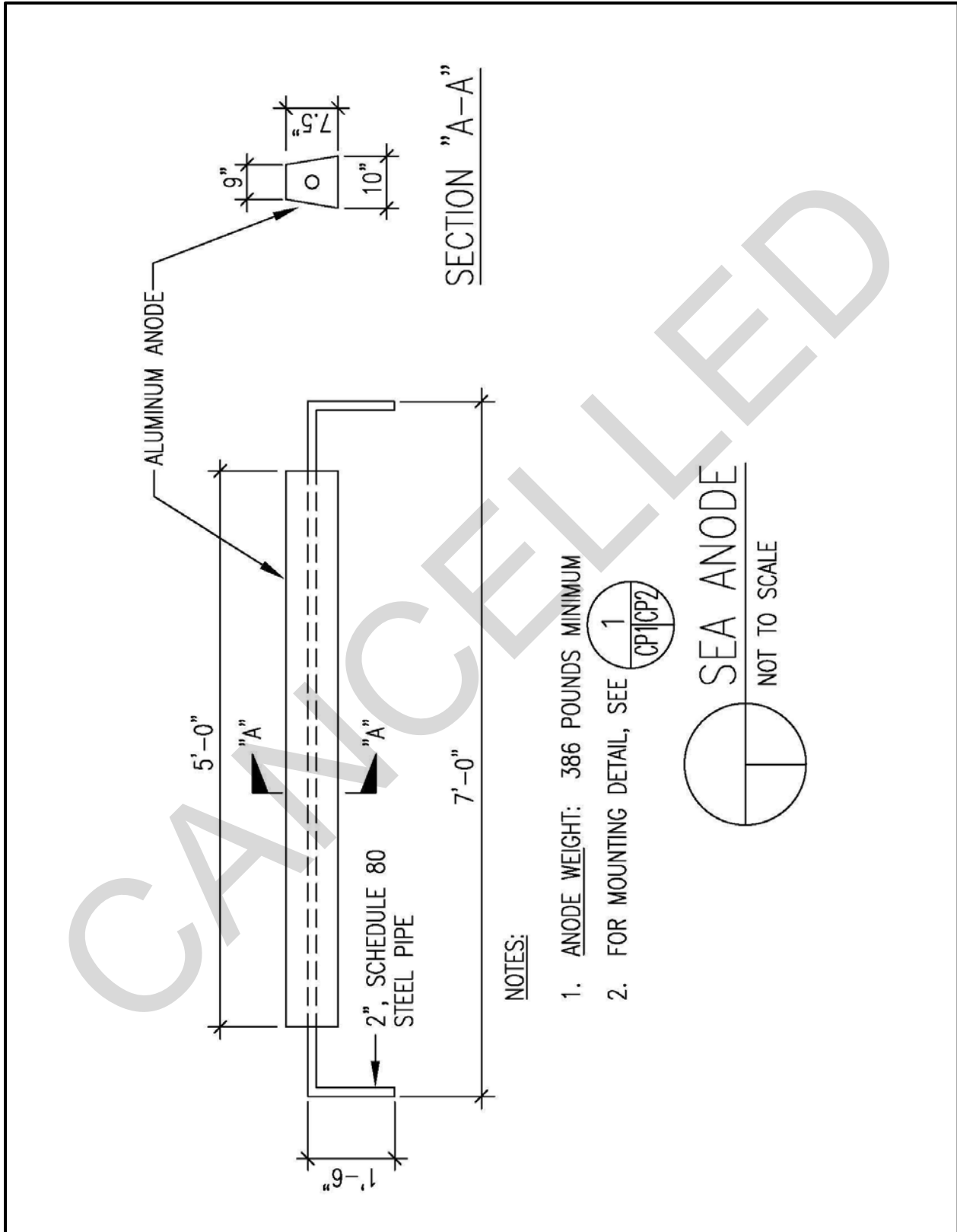


Figure D-6 Example ICCP Oil Cooled Rectifier Detail

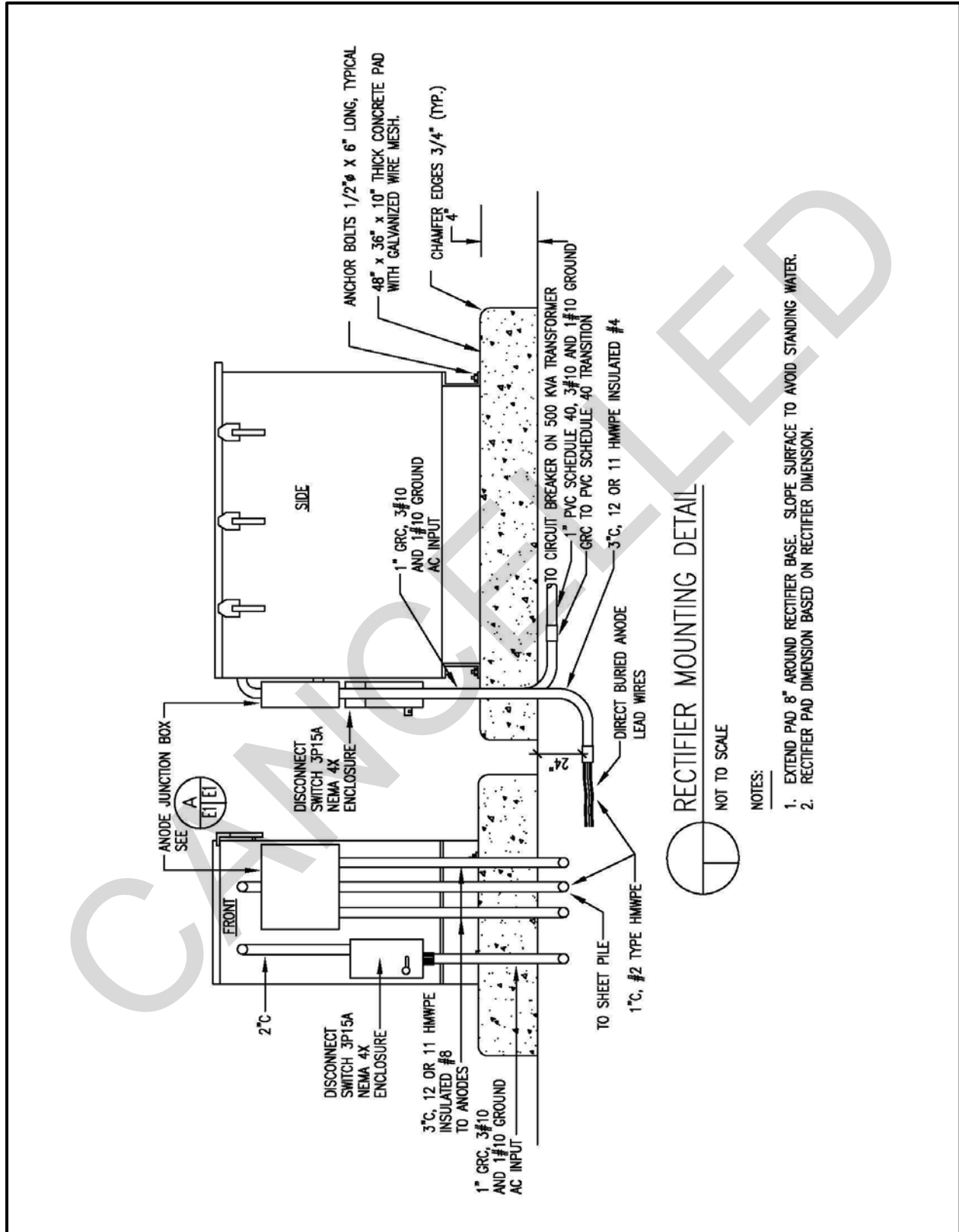


Figure D-7 Example Anode Junction Box Detail

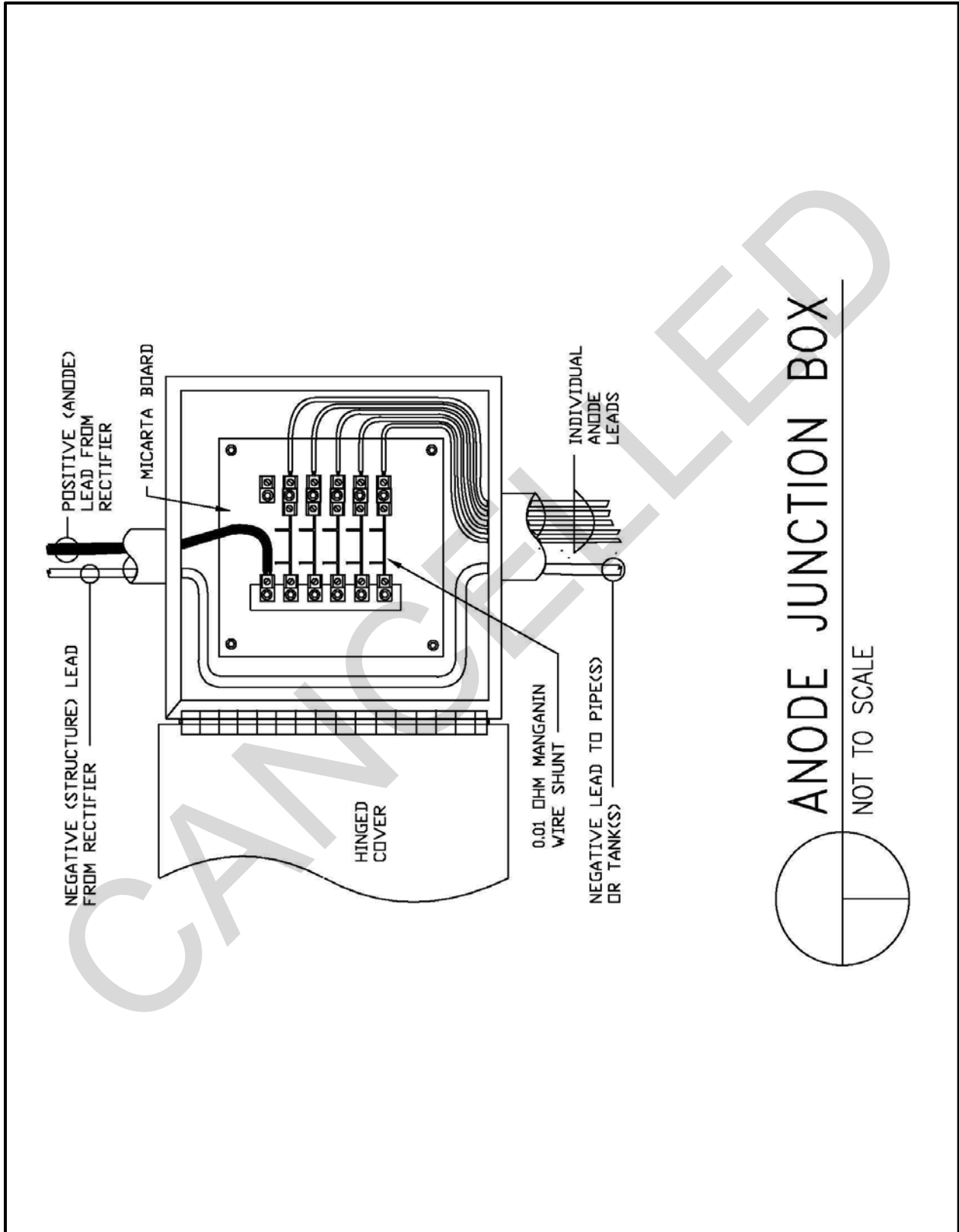


Figure D-8 Example Flush Mount Test Station Detail

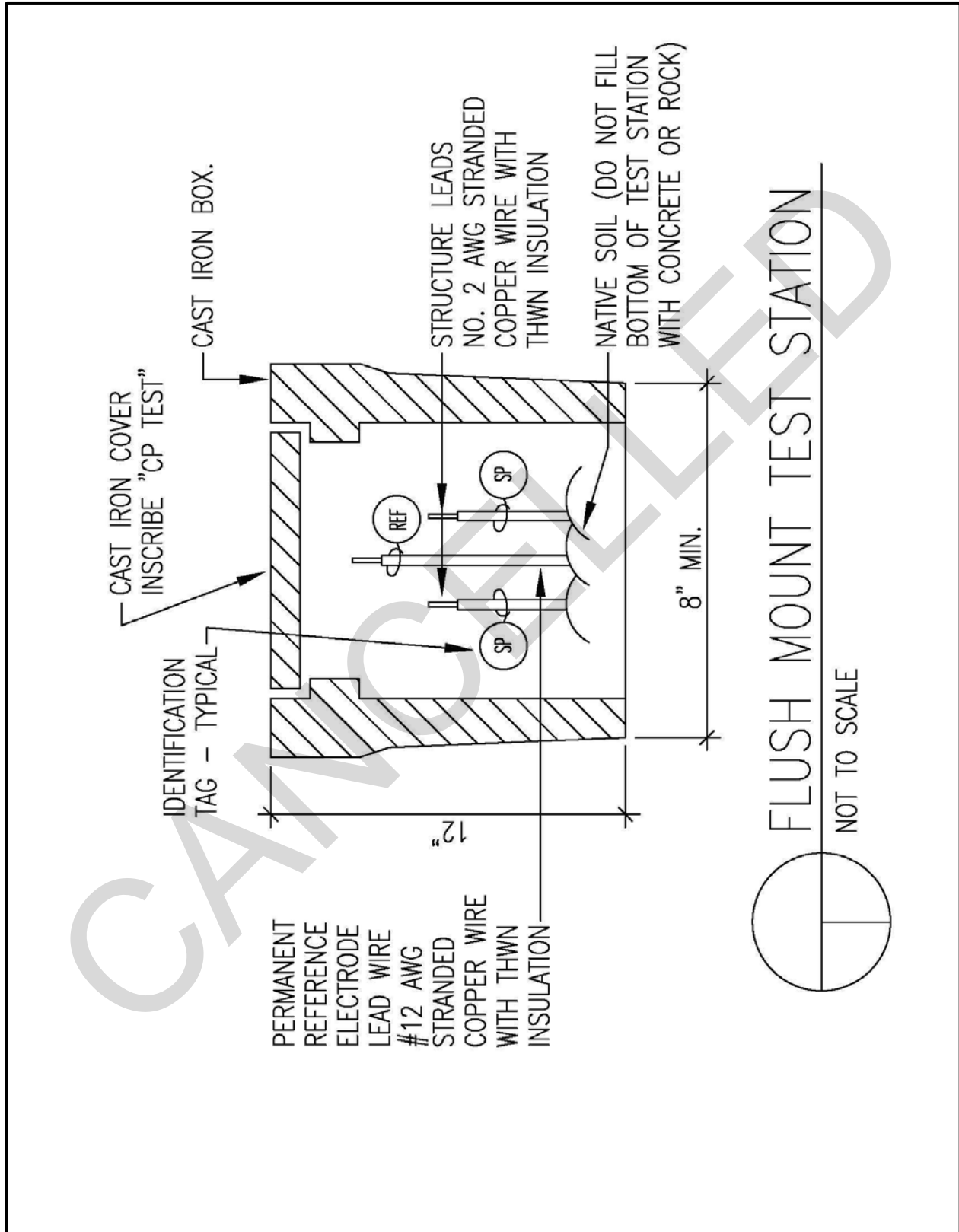


Figure D-9 Example Flush Mount Bond Test Station Detail

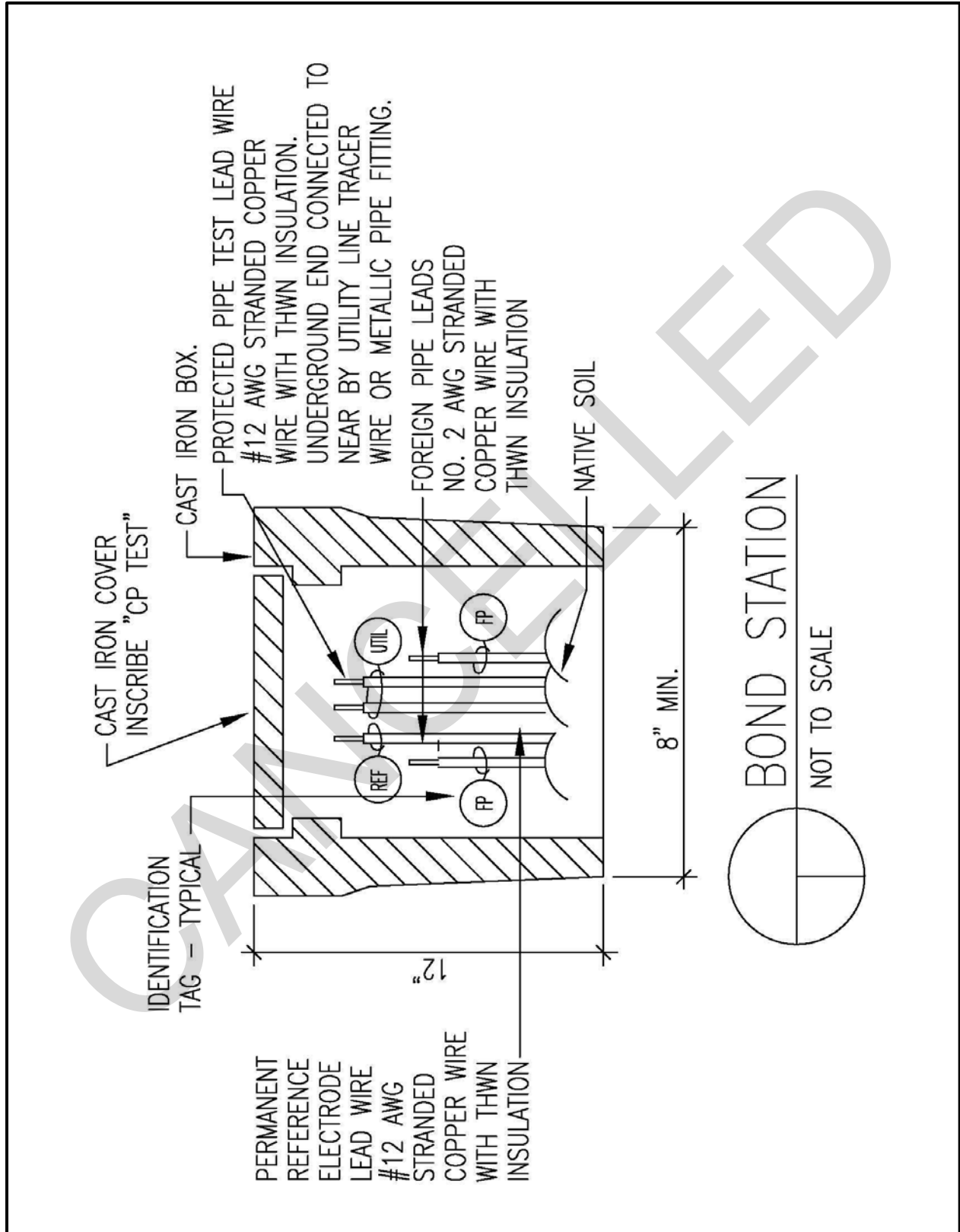


Figure D-10 Example Soil Access Test Station Detail

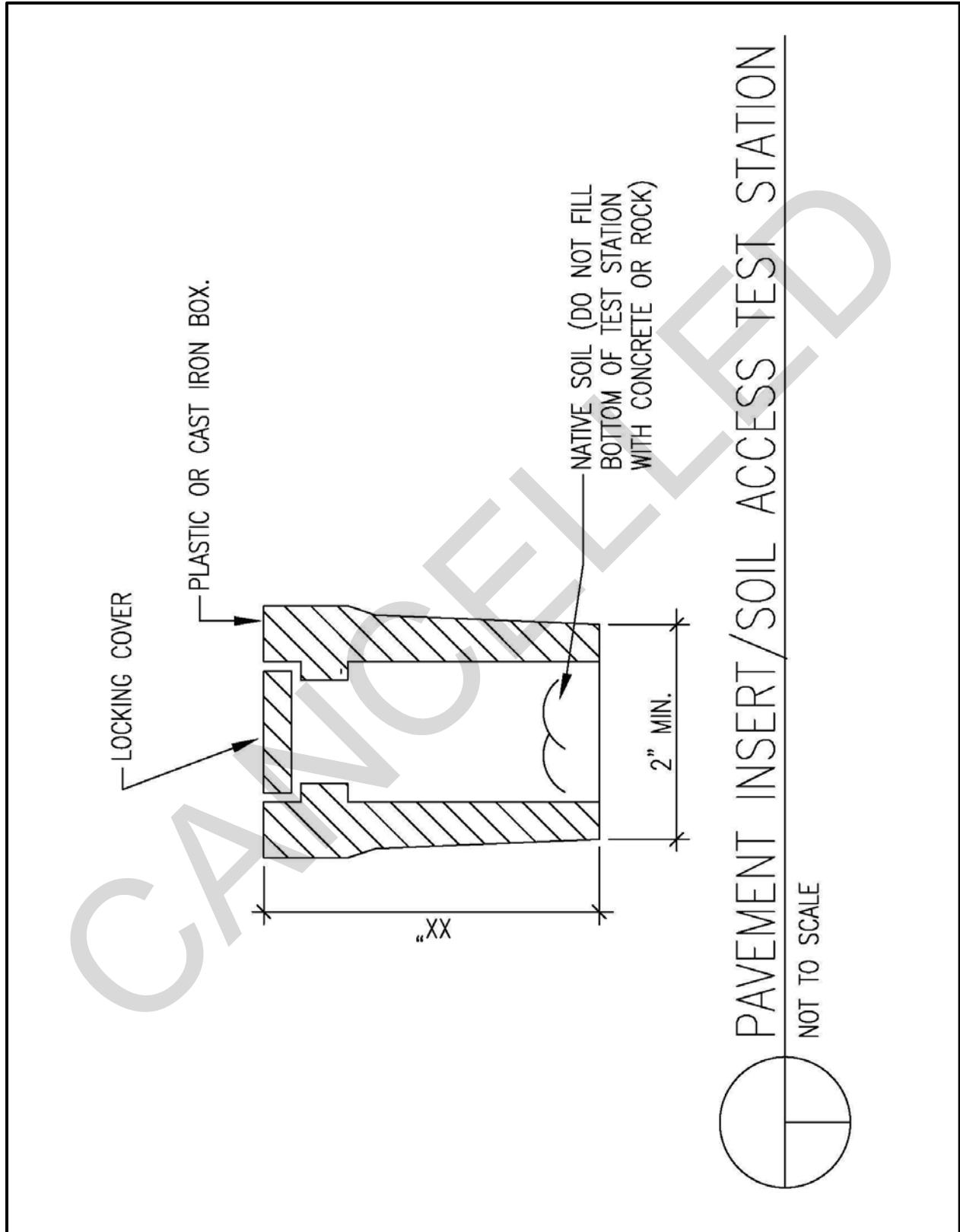


Figure D-11 Example Dielectric Insulation Flange Detail

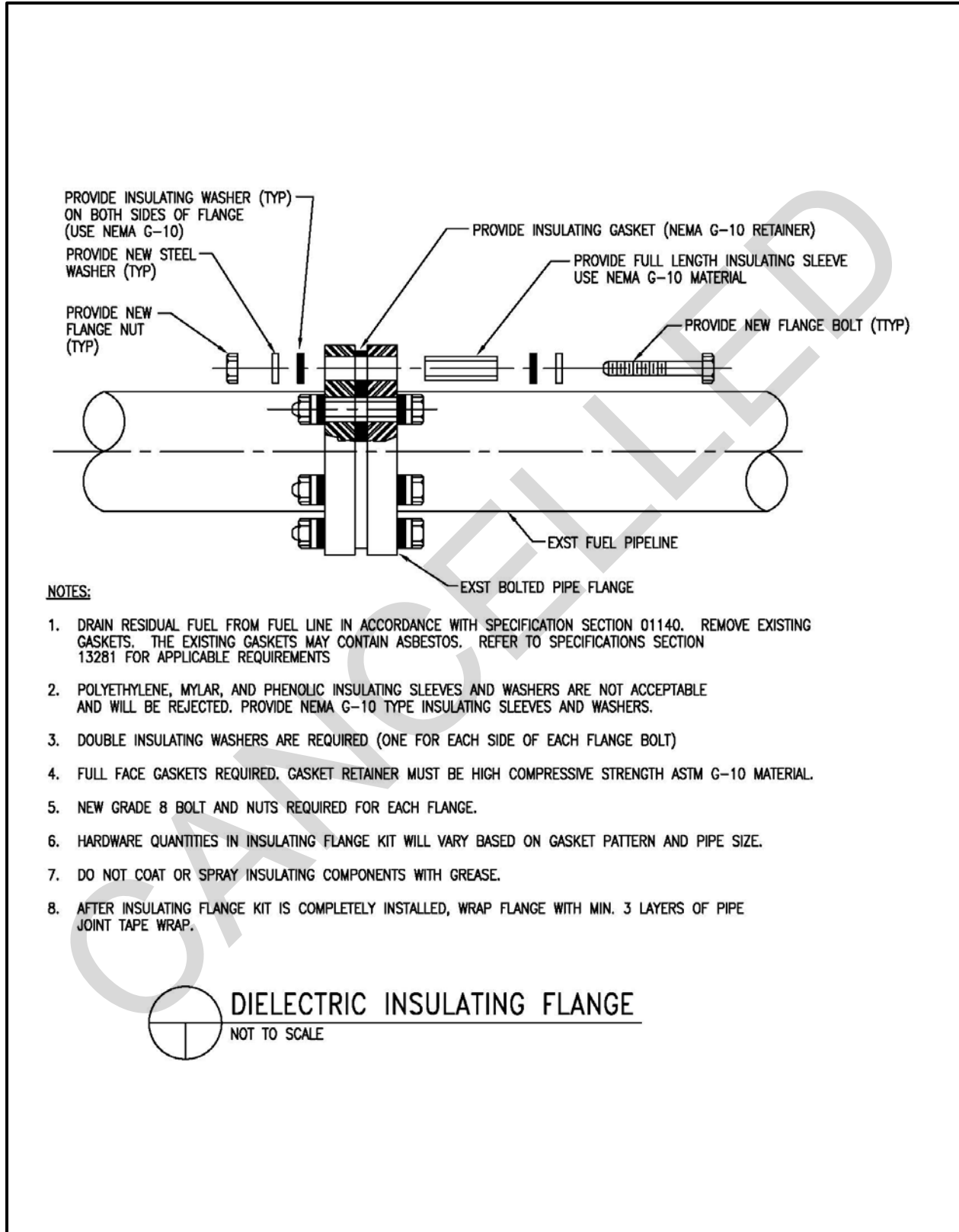


Figure D-12 Example Exothermic Weld Detail

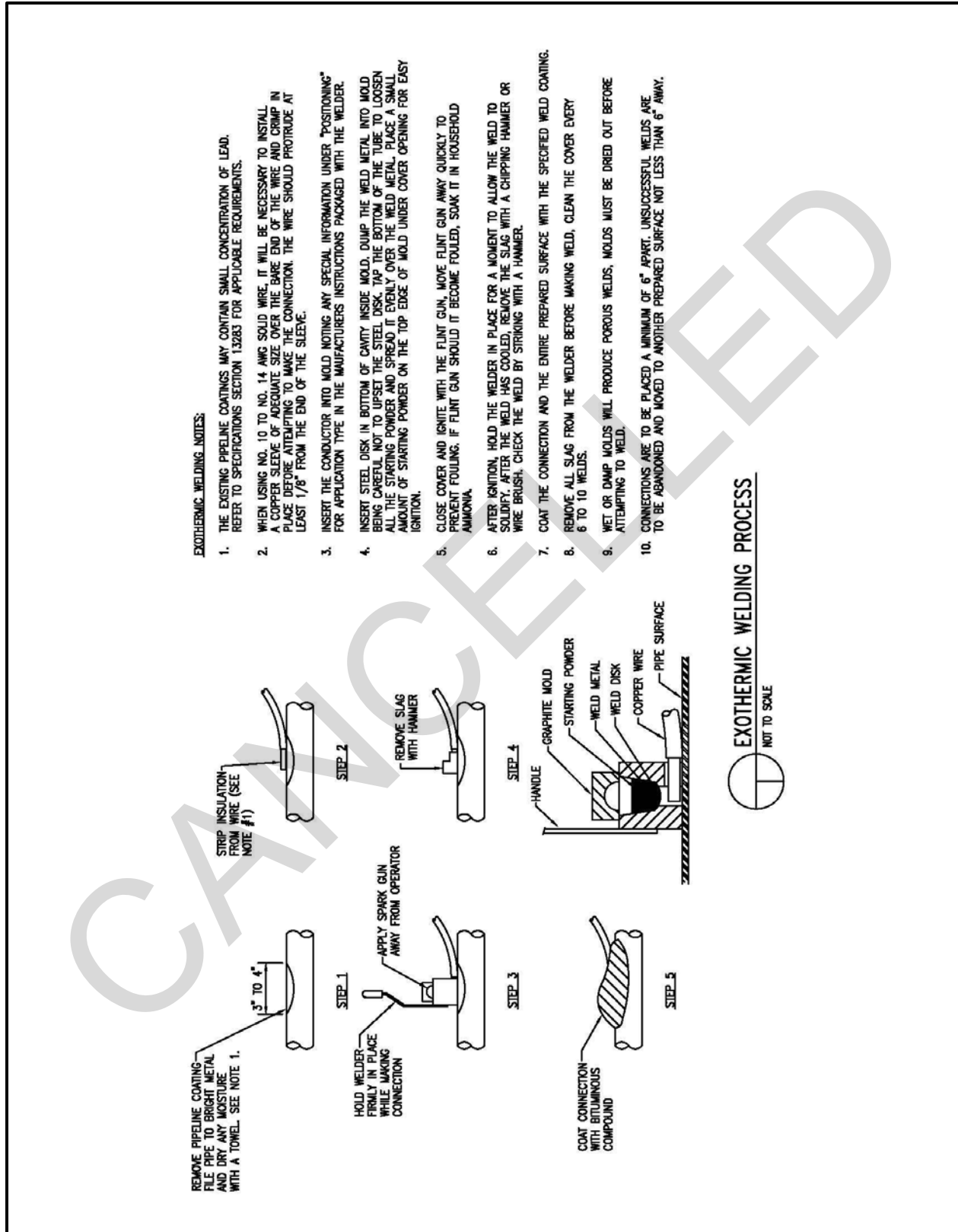


Figure D-13 Example Electrical One-Line Schematic Diagram

