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USACE / NAVFAC / AFCEC **UFGS-26 42 19.00 10 (November 2024)**

Preparing Activity: USACE **Superseding**
UFGS-26 42 19.10 (November 2008)

UNIFIED FACILITIES GUIDE SPECIFICATIONS

References are in agreement with UMRL dated July 2025
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DIVISION 26 - ELECTRICAL

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CATHODIC PROTECTION SYSTEMS (IMPRESSED CURRENT) FOR CIVIL WORKS STRUCTURES

11/24

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SECTION 26 42 19.00 10

CATHODIC PROTECTION SYSTEMS (IMPRESSED CURRENT) FOR CIVIL WORKS STRUCTURES
11/24

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NOTE: This guide specification is tailored for impressed current cathodic protection (ICCP) systems for use in submerged environments (water). This specification can be utilized for civil works structures such as lock miter gates, tainter gates, sector gates, and sheet pile walls.

Adhere to UFC 1-300-02 **Unified Facilities Guide Specifications (UFGS) Format Standard when editing this guide specification or preparing new project specification sections. Edit this guide specification for project specific requirements by adding, deleting, or revising text. For bracketed items, choose applicable item(s) or insert appropriate information.**

Remove information and requirements not required in respective project, whether or not brackets are present.

Comments, suggestions and recommended changes for this guide specification are welcome and should be submitted as a Criteria Change Request (CCR)**.**
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PART 1 GENERAL

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NOTE: The intent of this guide specification to require the Contractor to design, provide, test and place into service the complete cathodic protection system for submerged civil works structures. Cathodic Protection must be provided for all portions of the structures submerged at normal water levels. A complete system must consist of all equipment, wiring, and wiring devices necessary to produce a continuous flow of direct current from the anodes in the water electrolyte to the gate surfaces to protect the surfaces of the metal structures

adequately and efficiently against corrosion where the surfaces are in contact with the water. The metallic surfaces of the gates need only be protected to normal water levels. This is in addition to the protective coating on the gates.

This guide specification includes the technical requirements for the types of equipment normally provided in a cathodic protection system. The system must be designed by a qualified engineering firm hired by the Government. The engineering firm must provide the design services of a Corrosion Expert(s) to design, supervise, and inspect system installation and test, energize, and adjust the completed system installation. The Corrosion Expert is a person, who by reason of thorough knowledge of the physical sciences and the principles of engineering and mathematics, acquired by professional education and related practical experience, is qualified to engage in the practice of corrosion control of Lock & Dam Miter and Tainter Gates and other submerged metallic appurtenances. Such person(s) must be accredited or certified by NACE International (formerly the National Association of Corrosion Engineers) as a Corrosion or Cathodic Protection (CP) Specialist or be a register professional engineer who has certification or licensing that includes education and experience in corrosion control of Lock & Dam Miter and Tainter Gates and other submerged metallic appurtenances. The names and qualifications of the Corrosion Expert(s) must be certified and submitted in writing to the Contracting Officer prior to the start of the cathodic protection system design.

The Contractor will provide detailed design calculations, bill of materials lists and drawings of the cathodic protection system. The drawings will detail the system installation including arrangement and locations of all anodes, terminal boxes, conduit routing and test facilities to be installed for corrosion control on the submerged surfaces of the gates. The Contractor provided materials list, design calculations and drawings must be approved by the Contracting Officer prior to purchasing, delivering, or installing any of the cathodic protection system. These specifications together with the approved materials list, design calculations and drawings provide the minimum requirements of this contract. The cathodic protection system will be provided complete and in operating condition as further defined later in this specification.

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1.1 REFERENCES

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NOTE: This paragraph is used to list the

publications cited in the text of the guide specification. The publications are referred to in the text by basic designation only and listed in this paragraph by organization, designation, date, and title.

Use the Reference Wizard's Check Reference feature when you add a Reference Identifier (RID) outside of the Section's Reference Article to automatically place the reference in the Reference Article. Also use the Reference Wizard's Check Reference feature to update the issue dates.

References not used in the text will automatically be deleted from this section of the project specification when you choose to reconcile references in the publish print process.
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The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)

ANSI C39.1	(1981; R 1992) Requirements for Electrical Analog Indicating Instruments

ASTM INTERNATIONAL (ASTM)

ASTM A518/A518M	(1999; R 2022) Standard Specification for Corrosion-Resistant High-Silicon Iron Castings
ASTM D789	(2015) Determination of Relative Viscosity and Moisture Content of Polyamide (PA)
ASTM D1248	(2016) Standard Specification for Polyethylene Plastics Extrusion Materials for Wire and Cable

NACE INTERNATIONAL (NACE)

NACE SP0169	(2024) Control of External Corrosion on Underground or Submerged Metallic Piping Systems

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION (NEMA)

ANSI C80.1	(2020) American National Standard for Electrical Rigid Steel Conduit (ERSC)
NEMA 250	(2020) Enclosures for Electrical Equipment (1000 Volts Maximum)
NEMA FB 1	(2014) Standard for Fittings, Cast Metal Boxes, and Conduit Bodies for Conduit, Electrical Metallic Tubing, and Cable

NEMA FU 1	(2012) Low Voltage Cartridge Fuses
NEMA ST 1	(1988; R 1994; R 1997) Specialty Transformers (Except General Purpose Type)
NEMA ST 20	(2014) Dry-Type Transformers for General Applications
NEMA TC 2	(2020) Standard for Electrical Polyvinyl Chloride (PVC) Conduit

NATIONAL FIRE PROTECTION ASSOCIATION (NFPA)

NFPA 70	(2023; ERTA 1 2024; TIA 24-1; TIA 25-2) National Electrical Code

U.S. ARMY CORPS OF ENGINEERS (USACE)

CERL Tech Rep FM-95/05	(1994) Field Evaluation of Cathodic Protection Systems Using Ceramic-Coated Anodes for Lock and Dam Gates
EM 1110-2-2704	(2021) Engineering and Design -- Cathodic Protection Systems (CPS) for Civil Works (CW) Structures

UL SOLUTIONS (UL)

UL 489	(2025) UL Standard for Safety Molded-Case Circuit Breakers, Molded-Case Switches and Circuit-Breaker Enclosures

1.2 DEFINITIONS

It is convenient to classify corrosion by the forms in which it manifests itself, the basis for this classification being the appearance of the corroded metal. Each form can be identified by visual observation, although, in some cases, magnification is required. Valuable information for the solution of a corrosion problem can often be obtained through careful observation of the corroded test specimens or failed equipment. Examination before cleaning is particularly desirable. Cathodic Protection is a method used to control corrosion.

1.2.1 Cathodic Protection

Cathodic Protection (CP) is an electrochemical (half electrical and half chemical) method used to control corrosion of buried or submerged metallic structures. It prevents corrosion by making the protected structure a cathode by installing a more anodic metal (sacrificial or galvanic) anode or a metallic (Impressed Current) anode connected to a Direct Current (DC) power source. When the proper amount of current is applied to the structure, it becomes a cathode. Since all corrosion occurs at the anode, the structure no longer corrodes. The electrons move in the metallic path (electrical). Reduction (chemical) reactions occur at the surface of the cathode resulting in a hydrogen coating and more alkaline environment.

Oxidation (chemical) reactions occur at the surface of the anode resulting in corrosion and a more acidic environment. After a CP system is installed and adjusted to provide adequate protection, the hydrogen coats the defects in the coating and polarizes in the negative direction (to a copper/copper sulfate reference electrode). Over time the current and potentials remain relatively stable.

1.2.2 Corrosion

It is convenient to classify corrosion by the forms in which it manifests itself, the basis for this classification being the appearance of the corroded metal. Each form can be identified by visual observation, although, in some cases, magnification is required. Valuable information for the solution of a corrosion problem can often be obtained through careful observation of the corroded test specimens or failed equipment. Examination before cleaning is particularly desirable. Some of the eight forms of corrosion are unique, but all of them are interrelated.

The eight forms of corrosion are: (1) Uniform Attack, (2) Galvanic or Two-Metal Corrosion, (3) Crevice Corrosion, (4) Pitting Corrosion, (5) Intergranular Corrosion, (6) Selective Leaching, (7) Erosion Corrosion, and (8) Stress Corrosion Cracking. This listing is arbitrary but covers practically all corrosion failures and problems. The forms are not listed in any order of importance. Below, the eight forms of corrosion are discussed in terms of their characteristics, mechanisms, and preventive measures. Hydrogen damage, although not a form of corrosion, often occurs indirectly because of corrosive attack and is, therefore, included in this discussion.

1.2.3 Alternating Current (AC) Corrosion

AC corrosion occurs when there is a source of AC current, typically from a high-voltage overhead AC (OHAC) powerline, when there is a low soil resistivity (typically less than 5,000 ohm-cm) and there is a very small coating holiday. The AC corrosion pits typically have a tubercle of corrosion product at the pit. AC interference study modeling software can determine the mitigation solution to solve this problem. Typically, AC Corrosion mitigation is done in conjunction with high AC potentials and fault current mitigation.

1.2.4 AC Interference

AC interference occurs when a pipeline parallels a high-voltage overhead AC (OHAC) powerline. An interference study is required when this situation occurs as AC interference can cause high AC potentials along the pipeline (safety), can cause a fault condition between the pipeline and powerline, and could cause AC corrosion to occur. The pipeline coating when exposed can have blisters/bubbles caused by the excessive AC. The interference study will use modeling software to determine what combination of interference may be occurring (if any) and provide the mitigation solution to solve the problem.

1.2.5 Uniform Attack

Uniform attack is the most common form of corrosion. It is normally characterized by a chemical or electrochemical reaction that proceeds uniformly over the entire exposed surface or over a large area. The metal becomes thinner and eventually fails. For example, a piece of steel or zinc immersed in dilute sulfuric acid normally dissolves at a uniform rate over its entire surface. A sheet iron roof shows essentially the same degree of rusting over its entire outside surface.

Uniform attack, or general overall corrosion, represents the greatest destruction of metal on a tonnage basis. This form of corrosion, however, is not of great concern from a technical standpoint, because the life of equipment can be accurately estimated based on comparatively simple tests. Merely immersing specimens in the fluid involved is often sufficient. Uniform attack can be prevented or reduced by (1) materials, such as coatings, that reduce contact between metal and electrolytes, (2) inhibitors, or (3) cathodic protection.

1.2.6 Galvanic or Two-Metal Corrosion

A potential difference usually exists between two dissimilar metals when they are immersed in a corrosive or conductive solution. If these metals are placed in contact (or otherwise electrically connected), this potential difference produces electron flow between them. Corrosion of the less corrosion-resistant metal is usually increased, and attack of the more resistant material is decreased, compared to the behavior of these metals when they are not in contact. The less resistant metal becomes anodic, and the more resistant metal becomes cathodic. Usually, the cathode or cathodic metal corrodes very little or not at all in this type of couple. Because of the electric currents and dissimilar-metals involved, this form of corrosion is called galvanic, bi-metallic or two-metal, corrosion.
Galvanic corrosion is restricted to electrochemical corrosion caused by dissimilar-metal effects. It is electrochemical corrosion, but this document must restrict the term galvanic to dissimilar-metal effects for purposes of clarity.

1.2.7 Crevice Corrosion

Intense localized corrosion frequently occurs within crevices and other shielded areas on metal surfaces exposed to corrosives. This type of attack is usually associated with small volumes of stagnant solution caused by holes, gasket surfaces, lap joints, surface deposits, and crevices under bolt and rivet heads. As a result, this form of corrosion is called crevice corrosion or, sometimes, deposit or gasket corrosion.

1.2.8 Pitting Corrosion

Pitting is a form of extremely localized attack that results in holes in the metal. These holes may be small or large in diameter, but in most cases, they are relatively small. Pits are sometimes isolated or so close together that they look like a rough surface. Generally, a pit may be described as a cavity or hole with the surface diameter about the same as or less than the depth. Pitting is one of the most destructive and insidious forms of corrosion. It causes equipment to fail because of perforation with only a small percent weight loss of the entire structure. It is often difficult to detect pits because of their small size and because the pits are often covered with corrosion products. In addition, it is difficult to measure quantitatively and compare the extent of pitting because of the varying depths and numbers of pits that may occur under identical conditions. Pitting is also difficult to predict by laboratory tests. Sometimes the pits require a long time (several months or a year) to show up in actual service. Pitting is particularly vicious because it is a localized and intense form of corrosion, and failures often occur with extreme suddenness.

1.2.9 Intergranular Corrosion

Grain boundary effects are of little or no consequence in most applications or uses of metals. If a metal corrodes, uniform attack results since grain boundaries are usually only slightly more reactive than the matrix.
However, under certain conditions, grain interfaces are very reactive and intergranular corrosion results. Localized attack at and adjacent to grain boundaries, with relatively little corrosion of the grains, is intergranular corrosion. The alloy disintegrates (grains fall out) or loses its strength. Intergranular corrosion can be caused by impurities at the grain boundaries, enrichment of one of the alloying elements, or depletion of one of these elements in the grain-boundary areas. Small amounts of iron in aluminum, wherein the solubility of iron is low, have been shown to segregate in the grain boundaries and cause intergranular corrosion. It has been shown that, based on surface tension considerations, the zinc content of a brass is higher at the grain boundaries. Depletion of chromium in the grain-boundary regions results in intergranular corrosion of stainless steels.

1.2.10 Selective Leaching

Selective leaching is the removal of one element from a solid alloy by corrosion processes. The most common example is the selective removal of zinc in brass alloys (dezincification). Similar processes occur in other alloy systems in which aluminum, iron, cobalt, chromium, and other elements are removed. Selective leaching is the general term to describe these processes, and its use precludes the creation of terms such as de-aluminumification, de-cobaltification. Parting is a metallurgical term that is sometimes applied, but selective leaching is preferred.

1.2.11 Erosion Control

Erosion corrosion is the acceleration or increase in rate of deterioration or attack on a metal because of relative movement between a corrosive fluid and the metal surface. Generally, this movement is quite rapid, and mechanical wear effects or abrasion are involved. Metal is removed from the surface as dissolved ions, or it forms solid corrosion products, which are mechanically swept from the metal surface. Sometimes, movement of the environment decreases corrosion, particularly when localized attack occurs under stagnant conditions; this is not erosion corrosion because deterioration is not increased. Erosion corrosion is characterized in appearance by grooves, gullies, waves, rounded holes, and valleys and usually exhibits a directional pattern. In many cases, failures because of erosion corrosion occur in a relatively short time, and they are unexpected largely because evaluation corrosion tests were run under static conditions or because the erosion effects were not considered.

1.2.12 Stress-Corrosion Cracking

Stress-corrosion cracking refers to cracking caused by the simultaneous presence of tensile stress and a specific corrosive medium. Many investigators have classified all cracking failures occurring in corrosive media as stress-corrosion cracking, including failures due to hydrogen embrittlement. However, these two types of cracking failures respond differently to environmental variables. To illustrate, CP is an effective method for preventing stress-corrosion cracking; however, hydrogen-embrittlement may be caused when excessive current is applied, especially on stainless steel. Hence, the importance of considering stress-corrosion cracking and hydrogen embrittlement as separate phenomena is obvious. During stress-corrosion cracking, the metal or alloy is virtually unaffected over most of its surface, while fine cracks progress through it. This cracking phenomenon has serious consequences, since it can occur at stresses within the range of typical design stress.

1.2.13 Exothermic Welding

Exothermic welding is used in CP to connect a copper wire to a metallic structure, usually steel or cast-iron. It is a pyrotechnic composition of copper oxide, aluminum powder and magnesium powder. The magnesium powder is ignited with a spark gun or electronic ignition equipment. The aluminum powder serves as fuel, and melts the copper oxide, which bonds the wire to the structure. Although not explosive, it can create brief bursts of heat and high temperature in a small area.

1.2.14 Error-Free

Potential measurement error due to a voltage drop caused by current flowing through a resistor (the electrolyte) between the reference electrode and the protected structure.

1.3 SUBMITTALS

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NOTE: Review Submittal Description (SD) definitions in Section 01 33 00 SUBMITTAL PROCEDURES and edit the following list, and corresponding submittal items in the text, to reflect only the submittals required for the project. The Guide Specification technical editors have classified those items that require Government approval, due to their complexity or criticality, with a "G." Generally, other submittal items can be reviewed by the Contractor's Quality Control System. Only add a "G" to an item, if the submittal is sufficiently important or complex in context of the project.

For Army projects, fill in the empty brackets following the "G" classification, with a code of up to three characters to indicate the approving authority. Codes for Army projects using the Resident Management System (RMS) are: "AE" for Architect-Engineer; "DO" for District Office (Engineering Division or other organization in the District Office); "AO" for Area Office; "RO" for Resident Office; and "PO" for Project Office. Codes following the "G" typically are not used for Navy and Air Force projects.

The "S" classification indicates submittals required as proof of compliance for sustainability Guiding Principles Validation or Third Party Certification and as described in Section 01 33 00 SUBMITTAL PROCEDURES.

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Government approval is required for submittals with a "G" or "S" classification. Submittals not having a "G" or "S" classification are for

Contractor Quality Control approval. Submittals not having a "G" or "S" classification are for information only. When used, a code following the "G" classification identifies the office that will review the submittal for the Government. Submit the following in accordance with Section 01 33 00 SUBMITTAL PROCEDURES:

SD-02 Shop Drawings

Detailed Drawings; G, [_____]

Contractor's Modifications; G, [_____]

SD-03 Product Data

Materials and Equipment; G, [_____]

Protective Angle Irons; G, [_____]

SD-05 Design Data

Calculations; G, [_____]

SD-06 Test Reports

Factory Test Data

Tests and Measurements; G, [_____]

SD-07 Certificates

Qualifications; G, [_____]

SD-10 Operation and Maintenance Data

Cathodic Protection System; G, [_____]

Training; G, [_____]

SD-11 Closeout Submittals

Initial Cathodic Protection System Field Testing; G, [_____]

Final Cathodic Protection System Field Test Report; G, [_____]

One Year Warranty Period Cathodic Protection System Field Test Report; G, [_____]

1.4 MATERIAL AND EQUIPMENT MANUFACTURER DATA

DATE	ISSUE NO.	REQUEST DATE	REQUESTED BY	REQUEST REF. NO.
MANUFACTURER NAME				

DATE	ISSUE NO.	REQUEST DATE	REQUESTED BY	REQUEST REF. NO.
DESCRIPTION OF EQUIPMENT				

1.5 MAINTENANCE MATERIAL SUBMITTALS

1.5.1 Spare Parts

After approval of shop drawings, including spare parts for any modifications or changes made from original submittal, provide spare parts data for each different item of materials and equipment specified. The data must include a complete list of parts, special tools, and supplies, with current unit prices and source of supply.

1.5.2 Extra Materials

a. Provide spare rod, sausage, and button-type anodes (the type used in the original installation) to the Contracting Officer with a minimum of five of each type of installation component required for the original installation of the sausage and button anodes. Provide sufficient neoprene gaskets, mounting hardware, and epoxy cement for installation of the silicon button anodes. Supply a minimum of two of each type of anode rod or string assemblies each for the upstream and downstream gates (anode assembly complete with factory attached 100 ft anode lead cable and a minimum of five disk or button anodes with 100 ft of factory attached cable). Supply cement, epoxy, polychloroprene gaskets, and any other material needed for installation in sufficient quantity to install these spare components.

b. Provide a complete set of special tools, provided in a steel or plastic toolbox, for use in installing all types of anodes used in the installation. Tools used in making the original installation, provided they are in good working condition, will be acceptable. Ensure one tool is a torque wrench device capable of 40 psi.

1.6 QUALITY CONTROL

1.6.1 Regulatory Requirements

Obtain the services of a corrosion expert to supervise, inspect, and test the installation and performance of the CP system. The term "corrosion expert" refers to a person, who by thorough knowledge of the physical sciences and the principles of engineering and mathematics, acquired by professional education and related practical experience, is qualified to engage in the practice of corrosion control of submerged metallic structures of the type under this contract.

1.6.2 Qualifications

The corrosion expert must be accredited or certified by Association for Materials Protection and Performance (AMPP) as a CP-4 Cathodic Protection Specialist, be a AMPP certified Corrosion Specialist, or a registered professional engineer who has certification or licensing that includes education and experience in CP of the type of CP system being installed. The corrosion expert must have not less than [three] [five] [____] years of experience in the type of CP for submerged metallic structures under this contract. Submit evidence of qualifications of the corrosion expert including their name and qualifications certified in writing to the Contracting Officer prior to the start of construction. Certification must be submitted giving the name of the firm, the number of years of experience, and a list of not less than five of the firm's installations, three or more years old, that have been tested and found satisfactory.

1.6.3 Services of Corrosion Expert

Conduct a pre-installation meeting with the Contractor's project superintendent and Contracting Officer's Representative at the project site office. Hold this meeting after all pre-construction submittals have been made and approved by the Contracting Officer prior to the start of any work on this project. Include discussions of Safety, Communication and Work Plans, as well as any other issues which arise from the submittal review.

Once the submittals are approved and the materials delivered, verify all materials meet submittal requirements, ensure the contractor understands installation practices and that the contractor is capable and qualified to complete the installation. The "corrosion expert" will be available (but not necessarily be onsite the entire time) during the installation of the CP system to answer questions, approve any changes or additions required during construction, or to provide recommendations as required.

Upon completion of the installation, the "corrosion expert" will inspect, energize, and commission the CP system to ensure it has been installed properly and meets adequate CP criteria. Perform training and demonstrations to applicable personnel on proper testing and maintenance techniques of the installed CP systems. Perform additional interim inspections as required in paragraph ONE-YEAR-WARRANTY-PERIOD-TESTING, to ensure the system's continued conformance with the criteria outlined in this specification.

1.7 DELIVERY, STORAGE, AND HANDLING

Storage area for corrosion material will be designated by the Contracting Officer. If materials are not stored in a building, tarps or similar protection must be used to protect material from inclement weather. Repackaged equipment and materials that are damaged due to improper handling or exposure to rain for return.

1.8 PROJECT/SITE CONDITIONS

The cathodic protection system design is based on a water resistivity of [_____], a total area, in square meters feet, of [_____], a minimum coating efficiency of 50 percent, a minimum current density requirement for effective cathodic protection of [_____] amperes/bare square meter foot of submerged steel and a 20-year life expectancy.

PART 2 PRODUCTS

2.1 SYSTEM DESCRIPTION

2.1.1 Design Requirements

Provide a complete cathodic protection system for the structure(s) consisting of all equipment, wiring, and wiring devices necessary to produce a continuous flow of direct current from the anodes in the water electrolyte to the structure surfaces to, adequately and efficiently, protect the surfaces of the metal structures against corrosion where the surfaces are in contact with the water. This system is in addition to the protective coating on the structures. The system must meet the performance requirements in paragraph DESIGN REQUIREMENTS and the testing requirements in paragraph FIELD QUALITY CONTROL.

a. Submit [six] [_____] copies of detailed drawings consisting of a complete list of equipment and material, manufacturer's descriptive and technical literature, catalog cuts, results of system design calculations including water-resistivity, installation instructions and certified test data showing location of anodes and stating the maximum recommended anode current output density. Include in the detail drawings complete wiring and schematic diagrams, anode mounting details, reference cell mounting details (if applicable), terminal cabinets, conduit routing, and any other details required to demonstrate that the system has been coordinated and will function properly as a unit. Provide [one] [_____] electronic [digital] [PDF] [_____] copy and digital photos of the completed installation.

b. The Contractor's provided equipment and materials list, design calculations, and drawings are subject to approval by the Contracting Officer prior to purchasing, delivering, or installing any of the cathodic protection system. These specifications together with the approved materials list, design calculations and drawings provide the minimum requirements of this contract.

2.1.2 Performance Requirements

Test and adjust the system such that the cathodic protection system is providing corrosion control for the submerged surfaces of the structure(s) in accordance with one of the two criterion in the following paragraphs taken from Section 6 of NACE SP0169

2.1.2.1 First Criterion

A negative (cathodic) voltage of at least a minus 850 millivolts "instant-off" potential, as measured with respect to a calibrated, saturated copper-copper sulfate reference electrode (CSE) over 90 percent of each structure face, and at least minus 800 millivolts "instant-off" at all other locations. [Apply the second criterion below for areas within 2 ft of the sill, quoin, and miter of each gate (refer to Paragraph 1.3.3.2 of NACE SP0169).]Achieve the above criteria without the "instant-off" potential exceeding minus 1100 millivolts at any location. Determine this voltage with the cathodic protection system in operation. Make correction for IR drop using "instant-off" potential measurements (interrupt all operating cathodic protection systems simultaneously). If digital meters are used to obtain these measurements, interpret the second reading displayed on the digital voltmeter after interruption of the rectifier current as the "instant-off" reading.

2.1.2.2 Second Criterion

The second criterion is a minimum cathodic polarization voltage decay of 100 millivolts provided that a potential of at least minus 750 millivolts "instant-off" potential as measured with respect to a calibrated, saturated copper-copper sulfate reference electrode (CSE) is also obtained. [Make polarization shift measurements within 1 ft of the sill plate at the quoin, at 2 ft intervals along the gate bottom, and at the miter on each gate leaf face.] This criterion cannot be used until the criterion in paragraph 1.3.3.1 of NACE SP0169 for the remaining structure submerged surfaces has been maintained for a minimum period of one week. Measure "instant-off" potential between the structure surface and a saturated copper-copper sulfate reference cell immersed in the electrolyte directly adjacent to the structure. Determine this polarization voltage shift by interrupting the protective current and measuring the polarization decay thereafter. When the protective current is initially interrupted, an immediate voltage shift will occur. Record and use the second voltage reading observed after the immediate voltage shift as the base reading from which to measure polarization decay. Then take readings each 10 minutes thereafter and record the voltage readings and time intervals. The total time for achieving this decay is 4 hours or less.

2.1.3 Contractor's Modifications

Do not modify the design of the cathodic protection system as specified and shown on the Contractor's approved drawings except with the express written approval of the Contracting Officer. Fully describe and identify proposed modifications or changes as a "MODIFICATION" or "CHANGE" and submit to the Contracting Officer for approval within 15 days after the need for such modification or change is determined.

a. Submit [six] [_____] copies of detailed drawings showing proposed modifications in location, scope of performance indicating any variations from, additions to, or clarifications of contract drawings. Show proposed changes in anode arrangement, anode size and number, anode materials and layout details, conduit size, wire size, mounting details, wiring diagram, and any other pertinent information for proper installation and performance of the system. Include in the detail drawings complete wiring and schematic diagrams, anode mounting details, reference cell mounting details (if applicable), terminal cabinets, conduit routing, and any other details required to demonstrate that the system has been coordinated and will function properly as a unit. Provide [one] [_____] electronic [digital] [PDF] [_____] copy and digital photos of the completed installation.

b. The modified cathodic protection system must be in accordance with the performance requirements in paragraph PERFORMANCE REQUIREMENTS and the testing requirements in paragraph FIELD QUALITY CONTROL.

2.2 MATERIALS AND EQUIPMENT

Ensure all cathodic protection system materials and equipment provided is designed for a minimum 20-year service life when operating at the system maximum rated output. Use components that are based on the Contractor's Cathodic Protection System Specialist's design which is in accordance with these specifications. Submit a complete list in triplicate of materials and equipment to be incorporated in the work, within [30] [45] [90] [_____] days after date of receipt of notice to proceed, and before commencement of installation of any materials or equipment. Include cuts, diagrams, and such other descriptive data as may be required by the Contracting Officer. Partial lists submitted from time to time will not be considered. Submit, as a minimum, the following:

a. Water resistivity as measured on site.

b. As a minimum, provide complete system design calculations as provided in Appendix "K" of CERL Tech Rep FM-95/05 including calculations for total current required for each structure side, each anode circuit resistance, rectifier current and voltage output requirements and life of each anode type and location within the system.

c. Complete list of materials for all cathodic protection system components including all replaceable components in the rectifier units, terminal boxes and anodes materials with mounting equipment including part numbers and source name, address and phone number for each component.

d. Conductor types and sizes including copper grade, number of strands, insulation, and resistance for each wire type and size to be used.

e. Anodes, layout of anodes, and detailed description of anode installation procedure.

f. Layout of rectifiers and anode terminal boxes, rectifier and terminal box details including method of control including wiring diagram and schematic, output measurement means, cabinet materials and construction, ammeters and voltmeters, shunt resistors, variable resistors, and AC & DC lightning and surge protection.

g. All connections, supports, and seals for conductors, conduit, and plastic and steel protector pipes, pipe caps, angle iron, [_____].

h. All watertight connections and connection protection means.

i. Resistor and anode terminal cabinet details and mounting locations. Show identified connections and conductors in the terminal cabinet on a drawing.

j. Certified experience and qualification data of installing firm, as specified in paragraph QUALIFICATIONS.

2.3 CABLES AND CONDUITS

2.3.1 Direct Current Cables

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NOTE: Low-density, high-molecular-weight, polyethylene (HMWPE) insulation conforming to ASTM D1248, Type I, Class C, Grade 5, Grades E-5 and J-1, should be specified for all exposed cable or cable to be installed in conjunction with rod or string

anode protective conduit. High-density polyethylene is not recommended because it is subject to stress cracking. Polyvinyl chloride (PVC) insulation is not recommended because it is a relatively soft and easily damaged insulation and does not have the required tight fit on the wire, which can provide a path for moisture ingress and corrosion attack on the wire.

****

2.3.1.1   Anode Lead Cables

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NOTE: Select first paragraph for use with High Silicon Cast Iron anodes.

Select second paragraph for use with EMMO anodes. Select the first bracket when removable underwater connectors are needed for installation. This would apply for extended cable lengths exceeding 150 feet. Select the second bracket for permanently connected cables from the manufacturer. This is the preferred option due to reliability.

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[Provide direct current cable from the terminal cabinet to each anode disk, ribbon, button, or rod assembly consisting of 7-strand No. 8 AWG stranded copper wire with type CP high molecular weight polyethylene insulation (HMWPE), 7/64 inch thick, 600-volt rating, in accordance with ASTM D1248, Type I, Class C, Grades E-5 and J-1. Each anode lead must be continuous without splices from its point of connection in the terminal cabinet to the anode disk, ribbon, button, or rod assembly. Assemble cable-to-anode connection by the manufacturer and the seal area with a waterproof epoxy.
Ensure cable-to-anode contact resistance is 0.003 ohm maximum. Also assemble HSCI string anode assemblies (assembled in link sausage manner to the anode cable lead) by the manufacturer. Ensure conductor for the HSCI sausage strings only are 7-strand, No. 4 AWG copper wire with CP high molecular weight polyethylene insulation (HMWPE), 7/64 inch thick, 600-volt rating, in accordance with ASTM D1248, Type I, Class C, Grades E-5 and J-1, and do not cut or splice within the anode or assembly and route without splicing to the anode terminal box. The cable HMWPE insulation does not adhere well to some epoxies, rough in the sealant area prior to application of the sealant to the anode connections. Mark anode leads, terminal board connections, and corresponding jumpers on the front of the terminal board with the anode number, as specified.]

[Provide direct current cable from the rectifier cabinet to each EMMO strip, disk, rod or wire anode consisting of [27 strand T/C, minimum size No. 10 AWG, copper wire with 45 mil wall flame-retardant, low smoke irradiated cross linked polyolefin (XLPO) insulation, and 2 kV rating.] [27 strand, minimum size No. 10 AWG, copper wire with 15 mil wall, 2 kV rating, Diesel Locomotive Cable with Ethylene Propylene Diene Monomer Rubber (EPDM) insulation, Chlorinated Polyethylene (CPE) jacket rated for continuous wet/dry exposure and resists oils, acids, alkali's, heat, and flame.] Each anode lead must be continuous without splices from its point of connection in the rectifier cabinet to each EMMO strip, disk, rod or wire anode. All Cable-to-connector and Cable-to-anode connections must be made by the manufacturer in the factory.]

2.3.1.2 Rectifier and Terminal Cabinets Connection Cables

Provide soft drawn copper conductors and have the number of conductors as shown on the drawings. Cables connecting the terminal cabinet to the ac power outlet and cables between the ac power outlet and the rectifier dc terminals must be No. 10 AWG insulated copper wire with a neoprene jacket. Provide cables between the resistor and anode terminal cabinets consisting of 7-strand No. 8 AWG stranded copper wire with type CP HMWPE, 7/64 inch thick, 600-volt rating, in accordance with ASTM D1248, Type I, Class C, Grades E-5 and J-1. Include one conductor for each dc plus circuit and one conductor for each negative connection. Make each cable continuous without splices from its point of connection in one terminal cabinet to its point of connection in the other terminal cabinet.

2.3.2 Cable in Conduit

Provide cables that meet or exceed the requirements specified above. Make flexible cable connections between the ac power outlet and the ac input terminals of the rectifier with minimum No. 10 AWG copper conductors in flexible portable power cables, UL type SO.

2.3.3 Nonmetallic Conduit

Nonmetallic conduit must be type 80, extra heavy-wall, PVC, rigid-plastic conduit. Provide conduit conforming to the requirements of NEMA TC 2. PVC conduit utilized as rod or string anode protective pipe is the only PVC conduit allowed by these specifications. Design the plastic pipe such that its inside diameter (I.D.) is at least 2 inch greater than the anode outside diameter (O.D.). Provide perforated pipe on the side opposite the angle iron protective channel except for the area within 2 inches of the pipe couplings at each girder web which must not be perforated. The total open area provided by these perforations must be at least equal to the surface area of the anode material contained within the PVC pipe.

2.3.4 Rigid Metal Conduit

Provide rigid metal conduit conforming to the requirements of ANSI C80.1, and of the size indicated on the drawings. Galvanize conduit both inside and outside using the hot-dip method.

2.3.5 Conduit Fittings and Outlets

Provide conduit fittings and outlets for rigid metal conduit conforming to the requirements of NEMA FB 1.

2.4 IMPRESSED CURRENT ANODES AND MATERIALS

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NOTE: NOTE: For details on various types of anodes, anode designs and typical anode configurations for preparation of project drawings, refer to EM 1110-2-2704 and CERL Tech Rep FM-95/05.

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2.4.1 Ceramic Precious Metal Oxide Coated Anodes

Provide ceramic precious metal oxide coated anodes conforming to the following requirements:

2.4.1.1 Conductive Precious Metal Oxide Ceramic Coating

Use electrically conductive ceramic coating that contains a mixture consisting primarily of iridium, tantalum, and titanium oxides. Although the exact composition of the conducting layer can vary, the average composition must generally be a 50/50 atomic percent mixture of iridium and titanium oxides with small amounts of tantalum. Use coating resistivity certified by the manufacturer to have an electrical resistivity of less than 0.002 ohm-centimeters, a bond strength to the substrate metal greater than 50 MPa, and a current capacity of 100 DC amperes per square meter of anode surface area when operated in an oxygen-generating electrolyte at 65.5 degrees C 150 degrees F for 20 years.

2.4.1.2 Anode Substrate Material

Fabricate anode substrate from high purity alloy titanium.

2.4.2 Hi-Silicon Cast-Iron Anodes

Provide hi-silicon cast-iron anodes conforming to the following requirements:

2.4.2.1 Chemical Composition (Nominal)

ELEMENT	PERCENT BY WEIGHT
Silicon	14.20 - 14.75
Manganese	1.50 Max
Carbon	0.75 - 1.15
Chromium	3.25 - 5.00
Iron	Balance

2.4.2.2 Electrical Resistivity

Electrical Resistivity must be 72 micro-ohm-centimeter at -7 degrees C 20 degrees F maximum.

2.4.2.3 Physical Properties (Nominal)

PROPERTY	VALUE
Tensile Strength	1.05 kg/m^2 15,000 psi
Compressive Strength	7.04 kg/m^2 100,000 psi
Brinnell Hardness	520
Density	7.0 g/cm^3 0.253 lb/cu in.

PROPERTY	VALUE
Melting Point	1,260 deg C2,300 deg F
Coefficient of Expansion Between 0 deg C and 100 deg C 32 deg F and 212 deg F	0.00000733 cb/deg C0.00000289 in/deg F

2.4.3 Ceramic Coated Titanium Anodes (Disk Type)

2.4.3.1 General

Ceramic coated titanium disk anodes must be conductive ceramic coated titanium disks similar to that shown in Figure 2, "Typical Ceramic Coated Flat Disk Anode" of CERL Tech Rep FM-95/05, November, 1994. Provide anodes conforming to the requirements in paragraph SYSTEM DESCRIPTION, that are suitable for cathodic protection use, highly resistant to corrosion, and with good electrical properties. Ensure anodes disk is at least 127 mm 5 inch diameter factory mounted in a 305 mm 12 inch diameter FRP reinforced Polyurethane protective shield to prevent shorting of the anode to the skin plate and over voltage damage to the adjacent coating. Provide it with an integral titanium mounting rod with gold plated connector socket. Provide each disk anode with a gold plated connector plug and PVC cable connector that is assembled by the manufacturer. Submit certified Factory Test Data on anode connections showing anode-to-contact resistance. Provide a measured resistance of less than 0.003 ohm (or redo the connection). Provide a certified report on these factory tests within two weeks after fabrication by the manufacturer.

2.4.3.2 Impact Protection for Disk Anode Cables

Weld a 152.4 mm 6 inch diameter by 203.2 mm 8 inch long steel schedule-40 pipe with threaded pipe cap to the structure in back of each disk anode. Drill a hole in the side of this pipe and weld a thread-o-let fitting to the 152.4 mm 6 inch diameter pipe at this point to receive the anode lead wire and conduit routed to the anode terminal box at the top of the structure. The pipe and conduit are provided for impact protection of the anode cables and the anode bolt. Galvanize and paint the pipes with 0.1778 mm 7 mil of paint.

2.4.3.3 Number of Ceramic Coated Titanium Disk Anodes

Provide the actual number of ceramic coated titanium disk anodes in accordance with the corrosion engineer's approved design calculations based on the system circuit resistance, current requirements ,current distribution and anode life, in accordance with EM 1110-2-2704 and Appendix "A" in CERL Tech Rep FM-95/05, "Detailed Cathodic Protection Design Procedures for Pike Island Auxiliary Lock" as long as the minimum number of button anodes provided must equal or exceed one each for every 18.58 square meters 200 square feet of submerged steel surface area (for some typical anode configurations, refer to Figures 4, 5, 6, 7, C3, and F2 in CERL Tech Rep FM-95/05). The minimum number of anodes and an indication of their mounting locations should be shown in the design drawings.

2.4.4 Hi-Silicon Cast Iron Button Anodes

2.4.4.1 General

Provide high-silicon cast iron anodes conforming to ASTM A518/A518M.

2.4.4.2 High-Silicon, Cast-Iron Anodes (Button Type)

Provide high-silicon, cast-iron "button-type" anodes consisting of an alloy of silicon, carbon, manganese, and iron. Ensure anodes are similar in all respect to the Button anode design shown in Figure 1, "HSCBCI "Sausage" and "Button" Anode Designs of CERL Tech Rep FM-95/05. Ensure anodes conform to the requirements in paragraph IMPACT PROTECTION FOR RODS AND SAUSAGE-STRING ANODES and are suitable for cathodic protection use, are highly resistant to corrosion, and have good electrical properties. Provide anodes button castings with a nominal weight of 8.16 kg 18 lb and a size of 152.4 mm 6 inch diameter by 76.2 mm 3 inch deep and provide with a 19.05 mm 3/4 inch diameter by 50.8 mm 2 inch deep conical terminal connection cavity in the back of the anode and 25.4 by 50.8 mm 1 by 2 inch stepped mounting hole provision through the center of the anode as shown in above referenced Figure 1. Install a polychloroprene or neoprene gasket material behind the button anode no less than 3.175 mm 1/8 inch thick by 203.2 mm 8 inch diameter. Use gasket adhesive consisting of 100 percent silicone waterproof caulking material similar to GE 100 percent Silicone Caulk suitable for continuous immersion service. Mold or fabricate plastic seal plugs from an approved polystyrene. Fabricate flanged sleeve from nascent oxygen and chlorine resistant rigid plastic material. Button anodes and assemble cable by the manufacturer.

2.4.4.3 Anodes Number

Provide the actual number high-silicon, cast-iron "button-type" anodes in accordance with the corrosion engineer's approved design calculations based on the system circuit resistance, current requirements, current distribution and anode life, in accordance with EM 1110-2-2704 and Appendix "A" in CERL Tech Rep FM-95/05, "Detailed Cathodic Protection Design Procedures for Pike Island Auxiliary Lock" as long as the minimum number of button anodes provided equals or exceeds one each for every 18.58 square meters 200 square feet of submerged steel surface area (for some typical anode configurations, refer to Figures 4, 5, 6, 7, C3, and F2 in CERL Tech Rep FM-95/05. The minimum number of anodes and an indication of their mounting locations should be shown in the design drawings.

2.4.4.4 Assembly

The manufacturer is responsible for assembling the conductor to the anode after the conductor has been tinned. Make connections with caulked tellurium lead, and then sealed with epoxy around the connection. Cover all tinned wire completely by lead. Reference Figure 1, "HSCBCI "Sausage" and "Button" Anode Designs of CERL Tech Rep FM-95/05 for mounting component details.

2.4.4.5 Impact Protection for Button Anode Cables

Weld a 152.4 mm 6 inch diameter by 203.2 8 inch long steel schedule-40 pipe with threaded pipe cap to the structure in back of each button anode. Drill a hole in the side of this pipe and weld a thread-o-let fitting to the 152.4 mm 6 inch diameter pipe at this point to receive the anode lead wire and conduit routed to the anode terminal box at the top of the structure. The pipe and conduit are provided for impact protection of the anode cables and the anode bolt. Galvanize pipes and paint with 0.1778 mm 7 mil of paint.

2.4.5 Ceramic Coated Titanium Segmented Rod Anodes

a. Provide conductive ceramic coated titanium rods similar to that shown in Figure 3, "Typical Ceramic Coated Flat Disk Anode" of CERL Tech Rep FM-95/05. Provide anodes conforming to the requirements in paragraph SYSTEM DESCRIPTION, that are suitable for cathodic protection use, highly resistant to corrosion, and with good electrical properties. Each anode rod must be solid titanium and at least 3.175 mm 1/8 inch diameter by 1.2192 m 48 inch long with integral factory fabricated 12.7 mm 1/2 inch diameter ceramic coated titanium screw couplings at each end. Provide one anode for each assembled length with a screw coupled sealed PVC cable connector which is assembled by the manufacturer. Provide each such connector/cable assembly with sufficient lead length so that no splices are necessary between the anode/cable connector and the anode terminal box.

b. Provide the actual number of segmented rod assemblies and the number of strings per chamber in accordance with the corrosion engineer's approved design calculations based on the current required for protection in accordance with EM 1110-2-2704 and Appendix "A" in CERL Tech Rep FM-95/05, "Detailed Cathodic Protection Design Procedures for Pike Island Auxiliary Lock" as long as the number of segmented rod anode assemblies provided equals or exceeds 305 mm 1 linear foot of 3.175 mm 1/8 inch diameter (minimum) ceramic coated titanium rod material for each 9.29 square meters 100 square feet of submerged steel surface area and at least one full height assembly in each chamber (for some typical anode configurations, refer to Figures 4, 5, 6, 7, C3, and F2 in CERL Tech Rep FM-95/05). Extend each assembly at least 152.4 mm 6 inch above the normal highest water line to within 152.4 - 304.8 mm 6 - 12 inch of the bottom most girder plate.

2.4.6 Hi-Silicon Cast Iron Sausage Anode Strings

a. Provide high-silicon, cast-iron anodes consisting of an alloy of silicon, carbon, manganese, and iron conforming to ASTM A518/A518M. Ensure anodes are similar in all respect to the "Sausage" anode design shown in Figure 1, "HSCBCI "Sausage" and "Button" Anode Designs of CERL Tech Rep FM-95/05. Provide anodes that are suitable for cathodic protection use, are highly resistant to corrosion, and with good electrical properties. Provide "Sausage" anode castings with a nominal weight of 2.95 kg 6-1/2 lb each and with an irregular surface terminal connection cavity in the center interior of the tubular shaped anode as in CERL Tech Rep FM-95/05. Provide anodes that are 52.39 mm 2-3/16 inches in diameter by 305 mm 12 inch long, designed for tandem mounting in "link-sausage" manner on the anode lead cable. Connect cable and anodes all in a manner similar to the "Sausage" anode design shown in the above referenced Figure 1. Provide anode strings assembled by the manufacturer and do not splice the anode lead cable in the anode. Assemble anode by removing insulation from the anode cable and connecting the anode to the cable inside the anode.

b. Provide the actual number and spacing of the individual "sausage" segments and the number of strings per chamber in accordance with the corrosion engineer's approved design calculations based on the current required for protection in accordance with EM 1110-2-2704 and Appendix

"A" in CERL Tech Rep FM-95/05, "Detailed Cathodic Protection Design Procedures for Pike Island Auxiliary Lock" as long as the number of "sausage" anodes provided equals or exceeds one each for every 18.59 square meters 200 square feet of submerged steel surface area and at least one string in each chamber (for some typical anode configurations, refer to Figures 4, 5, 6, 7, C3, and F2 in CERL Tech Rep FM-95/05). Extend each assembly from 152.4 mm 6 inch above the normal highest water line to within 152.4 - 304.8 mm 6 - 12 inches of the bottom most girder plate.

2.4.7 Enhanced Mixed Metal Oxide (EMMO) Strip Anodes

a. The EMMO anodes are the newest generation of MMO anodes and far exceed the limitations of the MMO anodes. The EMMO anodes were originally designed for the interior of a USACE hydropower turbine unit and have proven very successful in this application. Since then, the EMMO anode has been utilized on other structures in USACE.

b. EMMO anodes possess excellent abrasion resistance and dimensional stability from the ceramic plasma spray processing technology and inherent inertness from the active catalyst, Iridium. The EMMO dielectric anode shield can be molded in different shapes, configurations, and to the curvature (radius) of the structure to be mounted to.

c. EMMO strip anodes must be made of Iridium/Tantalum based mixed metal oxide, catalyst arc-plasma spray EMMO ceramic anode coating. The EMMO coating must have a coating tensile bond strength >40 MPa per ASTM 633 and an average thickness of at least 900 micro inches (min: 500 micro-inch, max:1500 micro-inch). The anodes are to have a minimum current rating of 20 years at 8 Amperes in seawater, a maximum voltage rating of 92 Volts, and a minimum current density of 13,574 mA/square-foot. Contruct the anode shield out of dielectric PVC and have a minimum thru wall capacity of 1 inch with at least 6 recessed holes to mount the anode housing to the structure using welded studs. The PVC housing are to have a nominal tensile strength of at least 10,000 psi and be molded to the curvature (radius) of the structure for which the anodes will be installed on. Determine the size and quantity in the CPS design.

2.5 IMPACT PROTECTION FOR RODS AND SAUSAGE-STRING ANODES

2.5.1 PVC Pipe and Metal Couplings

Install PVC pipe, to be used for protection of the rod and sausage-string anodes, through each girder web in the center of each chamber which has an inside diameter (I.D.) that is at least 38.1 mm 1-1/2 inch greater than the anode outside diameter (O.D.). Provide pipe that is Schedule 80 PVC minimum and perforate on the side opposite the angle iron except for the area within 50.8 mm2 inch of the pipe couplings at each girder web. Ensure total open area provided by these perforations is at least equal to the surface area of the anode material contained within the PVC pipe. Install metal couplings through the girder webs on the compartment side of the structure (and where compartments are used on the skin plate side), where the PVC pipe penetrates the web. The steel coupling selected should have an I.D. that will allow the plastic pipe and its associated couplings to pass through the coupling. Align these steel couplings vertically for each anode string to serve as vertical troughs for the plastic pipes. Solvent weld full sections of the plastic pipe together end to end. Drill holes in the plastic pipe as shown on the drawings. Prepare steel coupling, angle iron, channel iron and all areas affected by the welding for painting and coat with the same paint system as the adjacent structure surfaces, in accordance with Section 09 97 02 PAINTING: HYDRAULIC STRUCTURES.

2.5.2 Protective Angle Irons

Submit anode disk, button, strip, rod and string details including ice and debris damage protection means for each anode type and alternative location.

2.5.2.1 PVC Piping

The protective PVC piping is subject to damage from floating ice and/or driftwood. Therefore, install protective angle irons in front of the protective PVC pipe. Ensure these angle iron sections are at least 6.35 mm 1/4 inch thick with angle legs whose height equals to at least 75 percent but no more than 100 percent of the plastic pipe coupling outside diameter. Weld this angle iron to each girder passage pipe coupling from the top of the highest girder to the bottom most girder plate. At each girder, which is penetrated by the PVC pipe, also weld the angle irons to the girder to reduce stress concentrations in the girder web caused by this penetration. Install entire assembly, consisting of the perforated PVC pipe containing the sausage anodes and the angle irons, as shown on the drawings. When plastic pipes only are used for sausage anode protection, ensure the girder penetration is the same, but install the angle iron in the impact area only.

2.5.2.2 Painting

Prepare steel couplings, angle iron, and channel iron for painting and coat with the same paint system as the adjacent structure surfaces, in accordance with Section 09 97 02 PAINTING: HYDRAULIC STRUCTURES. Each component must have the same minimum mil thickness (where 1 mil = 0.0254 mm 0.001 inch) of paint after couplings, angle irons, and channels are welded to the structure. Clean welded area to bare metal and paint in this same manner. Use paint that is the same type used on the structure.

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NOTE: Select first set of brackets for RECTIFIERS AND AUXILIARY EQUIPMENT for standard analog system. Select second set of brackets for RECTIFIERS AND AUXILIARY EQUIPMENT for digitally controlled system.

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[2.6 RECTIFIERS AND AUXILIARY EQUIPMENT - STANDARD ANALOG SYSTEM

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NOTE: Air-cooled rectifiers are used for most applications. Oil immersion cooled units are normally used in highly corrosion atmospheres.

The rectifier cabinet may be located in the control house to avoid problems caused by moisture, insects,

dust, vandalism, etc., when these are a factor. When outside placement of the rectifier is indicated, the rectifier must be securely mounted or fastened to the structure (see Alternate 2 below). When high-water flooding is likely, the rectifier should be mounted on wheels for easy removal (see Alternate 1 below). It is left to the designer to provide detailed drawings for either type rectifier installation. Adequate drainage must be provided in all terminal cabinets since flooding will in most cases cause sand and water to accumulate in the terminal cabinet. Eventually, this will cause the appearance that anodes are failing when, in fact, contacts in the terminal cabinets, or rectifier contacts, are causing failure and outages to the cathodic protection systems. Alternatively, watertight sealed terminal cabinets can be used. The rectifier cabinet referenced in these documents is for the air-cooled type transformer and rectifier unit. If the designer selects the oil-immersed type unit, then the specifications will have to be revised accordingly.
****

2.6.1 System Description

Provide a rectifier unit for [each upstream and downstream face of each gate leaf] [each of the four gate leaves of the lock][ ]. Provide cathodic protection system power circuit consisting of a step-down transformer with secondary taps for output adjustment, primary circuit breaker, rectifier transformer, rectifier, secondary fuses, and rectifier terminal panel. Locate rectifier units [in the control houses] [outside at the specified locations]. Design units [for removal during periods when flood waters overtop the lock wall] [to be free-standing].

2.6.2 Cabinets

Provide rectifier cabinet to house the rectifier transformer, rectifier stacks, circuit breaker, terminals, and the control and instrument panel. In installations requiring the use of a step-down transformer, design the cabinet such that the rectifier equipment specified above can be installed in the lower section of the cabinet with the step-down transformer in the upper portion. Provide [convection air cooled] [oil immersed cooled] cabinets constructed of 1.894 mm 14-gauge minimum sheet stainless steel, ASTM grade [304][316]. Design the cabinets for use outdoors; NEMA 250, enclosure 3R, and use appropriate structural shapes in the construction of the cabinet to provide rigidity and to prevent bending or flexing of the cabinet while being transported. Provide louvers for air-cooled units in the hinged doors and on the sides of the cabinets for ventilation. Cover all ventilation openings with ASTM grade [304][316] stainless steel insect screen arranged so as to be easily replaceable. Hinge all doors using post hinges designed to allow easy removal of all doors for unit servicing and provide with a hasp and lock for padlocking. Use locks that are keyed alike such that all cabinets can be opened with one key. Provide the keys and turn them over to the Contracting Officer.

2.6.3 Wheeled Rectifier Cabinets (Alternate 1)

Mount rectifier cabinet on wheels and provide with handles for moving during floods. Ensure wheels, axles, and bearings have sufficient capacity to support a weight of at least three times the weight of the complete rectifier. Weld studs for the clamps to be used for securing the rectifier to the pipe rail, as shown on the drawings, to a reinforced back section of the cabinet at the factory before finishing. All components must be ASTM grade [304][316] SS or equal.

2.6.4 Stationary Cabinets (Alternate 2)

Mount rectifier cabinet on structures as shown on the drawings. Accomplish welding of ASTM grade 304 SS or equal clamps, brackets, or cabinet-back reinforcement at the factory before finishing.

2.6.5 Circuit Breakers

Install a 120/240-volt, [10] [_____] ampere-interrupting-capacity, double-pole, molded-case circuit breaker conforming to UL 489 in the primary circuit of the rectifier transformer and disconnect both conductors. Provide breaker with instantaneous and inverse time trips. Provide [10] [_____] ampere cartridge-type fuses conforming to NEMA FU 1 with suitable fuse holders in each leg of the dc circuit.

2.6.6 Step-down Transformers

Provide step-down transformers of the two-winding, insulating dry type conforming to NEMA ST 20 rated for 480-120/240 volts, single-phase, 60-Hertz. Provide transformers with 2 to 5 percent full capacity primary taps below rated voltage. Ensure transformers rated for no less than a temperature rise of 80 degrees C 176 degrees F above a 40 degrees C 104 degrees F ambient and provide with Class B or H insulation.

2.6.7 Rectifier Transformers

Provide two-winding, [convection air-cooled] [oil immersed cooled] rectifier transformer, with a primary operating voltage of 120/240 volts, single phase, and conforming to the requirements of NEMA ST 1. Provide transformer secondary with five "coarse" and five "fine" taps on each dc circuit, to permit variations of the dc output voltage in 25 uniform increments of the rated output voltage, from zero to a maximum rated voltage of [_____] volts. Adjust voltage steps by rotating solid brass tap bars. Identify each control by suitable permanent, engraved marking such as "coarse" or "fine" with an arrow to indicate the type and direction of adjustment. Mark individual steps of adjustment with numbers in consecutive order for fine control and with letters in alphabetical order for coarse control. Mount all primary alternating current terminals behind the panel. Dip coils of all transformers manufactured for cathodic protection use in preheated varnish and bake dry for maximum moisture and corrosion resistance.

2.6.8 Rectifiers

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NOTE: Silicon rectifier stacks are usually recommended for the rectifier and these specifications reflect their use; however, the designer has the option to select either selenium or silicon stacks. When the specification writer selects selenium, the specifications should be revised accordingly. The advantages and

disadvantages for the two types of rectifier stacks are as follows:

Silicon stacks (diodes): These stacks are more economical in higher voltage output circuits and in higher current circuits.

Advantages:

a. Cost-effective in high current ratings.
b. More efficient in higher voltage ratings.
c. Replacement cells are easily stocked.
d. Higher efficiency

Disadvantages:

a. Must be surge protected with selenium.
b. Cannot withstand extreme surges.

Selenium stacks (cells): These stacks may be more economical in lower voltage output circuits where current requirements are lower.

Advantages:

a. Can withstand surges caused by lightning much better than silicon without additional protecting devices.
b. Are cost-effective in lower voltage and lower current ratings.
c. Can withstand severe short-term overloads

Disadvantages:

a. Expensive in high voltage and high current ratings.
b. Cannot be easily replaced
c. May be difficult to obtain.
d. Replacement stacks can be expensive to stock.
e. Relatively low efficiency

Recent studies by the US Army Corps of Engineers indicate that remote monitor of these systems can greatly improve the reliability of effective monitor and maintenance of these systems and eliminate the need for meters in the units:

"Demonstration of Remote Monitoring Technology for Cathodic Protection Systems" FEAP-TR 97/76 (April 1997),
http://owww.cecer.army.mil/TechReports/Vancatho/Vancatho.pdf

"Demonstration of Remote Monitoring Technology for Cathodic Protection Systems: Phase II" FEAP-TR 98/82 (May 1998),
http://owww.cecer.army.mil/techreports/van_cpr2/van_cpr2.flm.post.pdf

"Remote Monitoring Equipment for Cathodic Protection Systems" FEAP User Guide 97/75 (April 1997),

http://owww.cecer.army.mil/TechReports/Vancprem/Vancprem.pdf

"User Guide for Remote Monitoring Equipment for Cathodic Protection Systems: Phase II" FEAP User Guide 98/77 (May 1998), http://owww.cecer.army.mil/techreports/VANFUG2.CPR/vanfug2.cpr.post.pdf

The designer should investigate the cost, reliability and availability of these remote monitoring systems.
****

Provide [air-cooled] [oil-immersed] units, consisting of silicon stacks to provide full-wave, bridge-type rectification, within the manufacturer's ratings. The rectifier must be suitable for operation over an ambient temperature range of -18 to 49 degrees C 0 to 120 degrees F. Use output ratings as designed by the Corrosion Expert and for continuous duty operation.

2.6.9 Ammeter and Voltmeter

Provide a dc ammeter and voltmeter of the semi flush, 89 mm 3-1/2 inch round or rectangular panel board type, conforming to the applicable requirements of ANSI C39.1, in each dc circuit, or as otherwise indicated on the drawings. Provide sealed, taught band type instruments with a guaranteed accuracy of 1 percent of full-scale deflection, zero adjustment, and a minimum scale length of 61 mm 2.4 inch. Indicate full load reading by means of a red mark on the meter scale and incorporate at least 80 percent of the meter scale length. Provide each meter with a momentary contact switch, either integral with the meter or separately mounted, for momentary reading. A single meter having dual scales may be provided in lieu of separate meters, provided that the scales are distinct and easily read, and that a switch is provided to select the desired function and to prevent simultaneously energizing more than one function.

2.6.10 Current Monitoring Shunt

Provide a separate current monitoring shunt resistor on the rectifier unit face plate to facilitate using an external digital milli-voltmeter to confirm the current output displayed by the unit ammeter. This shunt resistor must have a calibrated accuracy of plus or minus 1 percent and a 1 ampere/millivolt drop rating.

2.6.11 Ammeter and Voltmeter Switches

Use switches for switching the meters in and out of the dc circuit that are lever action sealed toggle, quick make-or-break type switches. Ensure switches are [[single-pole] [double-throw]] [[double-pole] [double-throw]] and wired not to interrupt the output circuit.

2.6.12 Control and Instrument Panel

Provide dead-front type control and instrument panel and install in the rectifier cabinet. Make primary connection by means of a panel-mounted terminal block with screw connection protected by a removable metal or molded plastic cover. Terminate incoming power lines in such a manner as to prevent accidental contact by personnel using the rectifier.

2.6.12.1   Tap Bars

Permanently identify tap bars serving the rectifier transformer secondary adjustment by means of engraving on the non-metallic control panel face plate denoted "coarse" and "fine" and identify the individual tap positions by letters, such as "A," "B," "C," and numerals, such as "1," "2," "3," respectively.

2.6.12.2   DC Output Terminals

Identify rectifier dc output terminals by means of engraving on the non-metallic control panel face plate indicating polarity of the terminal and point of connection to the system, i.e., "+ANODES" and "-STRUCTURE."

2.6.12.3   Components Identification

Identify all other components on the rectifier panel face plate by means of engraving on the non-metallic control panel face plate.

2.6.13   Anode Cable Leads

Identify anode cable leads at the resistor and anode terminal cabinet by means of plastic sleeves or tags showing the anode lead number as indicated on the drawings. Ensure they are of sufficient length so that splicing between the anode and the anode terminal box is not necessary. No splices of the anode lead wires will be permitted between the anode and the anode terminal box.

2.6.14   Surge Arresters

Provide MOV surge arresters for all AC and DC power circuits. In addition, for AC voltages above 120-volt, use a single pole valve-type surge arrester for each input line. Locate it ahead of the ac breaker feeding the rectifier transformer. Use surge arresters rated for continuous load currents up to [10] [_____] amps minimum and limit the voltage to 200 volts peak. The response clamping activation time is 5 nanoseconds maximum.

2.6.15   Wiring Diagram

Encase s complete wiring diagram of the rectifier unit showing both the ac supply and the dc outputs to the resistor and anode terminal cabinets in clear rigid plastic and mount on the inside of the rectifier cabinet door. Show and label all components.

][2.7   RECTIFIERS AND AUXILIARY EQUIPMENT - DIGITALLY CONTROLLED SYSTEM

2.7.1   System Description

Provide a rectifier unit for [each upstream and downstream face of each gate leaf] [each of the four gate leaves of the lock] [   ]. Locate rectifier units [in the control houses] [outside at the specified locations]. Design units [for removal during periods when flood waters overtop the lock wall] [to be free-standing].

2.7.2   Rectifier Description

Each rectifier must be a minimum four (4) mode automatic rectifier with full feedback control and consist of a minimum of four independent channels (isolated circuits) with a controller that monitors the output voltage and current of each circuit. The rectifier controller also must obtain feedback from permanently installed dual reference electrodes and adjust the rectifier according to presets selected in the controller.

2.7.3 Operating Modes

The rectifier must have multiple operating modes which can be set independently for each circuit, including "automatic constant current", "constant voltage", "constant potential", and "I/R Free". An adjustable DC output interrupter for IR free manual testing must be integral to the rectifier.

2.7.4 Operation Characteristics

The rectifier must receive and display the polarization status of each dual reference electrode, regulate the current within predetermined windows of operation via set points and limits, and record and store the data at preset intervals.

2.7.5 User Interface Display, Connectivity, and Download Capabilities

The controller must allow for all set points and parameters to be defined by the operator through a color, touch screen panel with NEMA 4X rating. The rectifier must utilize industry standard connectivity and connectors that allow for remote control monitoring, optional rectifier remote control, and long-term data storage modules. The rectifier controller must allow downloading of the cathodic protection performance data over time and graphically represent a combination of rectifier voltage and current; anode voltage and current; on potentials; instant off potentials; native potentials; etc. The graphical representation of the anode voltage and current over time is critical for detecting coating degradation over time.

2.7.6 Rectifier Power Requirements

Rectifier power requirements must be rated for DC output per CPS design calculations and AC input per facility voltage/phase availability. Rating of rectifier cabinet must be a minimum NEMA 3R cabinet.

]2.8 RESISTOR AND ANODE TERMINAL CABINETS

Provide terminal cabinets for each rectifier output circuit. Provide NEMA type 4X cabinets consisting of weather-resistant construction. Construct cabinets of ASTM grade [304][316] stainless steel. Provide cabinets of ample size to accommodate all anode and power input lead wires and [_____] standard brass or copper heavy duty screw terminals to facilitate individual connection of each anode assembly lead wire through a 0.01 ohm type RS shunt resistor to a common copper bus bar. Mount all terminals, bus bars, shunts, and other DC conducting components to an extra strong, non-metallic panel. Identify all conductors in the cabinet by means of plastic or metal tags or plastic sleeves to indicate the anode number. Identify each terminal with permanent engraved identification of the anode number, or other corresponding conductor numbers, or function. [Mount cabinets securely on the top of the corresponding gate in the manner proposed by the Contractor and approved by the Contracting Officer.]Provide a removable, hinged front door facing a direction after installation that is easily accessible.

2.8.1 Resistor and Anode Terinal Cabinet Wiring Diagram

Provide a complete wiring diagram showing the anode numbers in the terminal cabinets and a complete wiring diagram of the entire cathodic protection system. Identify each conductor and each termination.

2.9 PERMANENT DUAL REFERENCE ELECTRODES

Reference electrodes specifically designed for the applicable flow rates and long-term stability requirements are to be employed to monitor the effectiveness of the ICCP System. Each reference electrode housing must contain dual electrodes for redundancy and incorporate stability filters as required. The reference electrode must be constructed of dielectric PVC and have a minimum thru wall capacity of 1 inch capacity with at least four (4) recessed holes to mount the reference electrode housing to the structure with welded studs. The PVC housing must have a nominal tensile strength of at least 10,000 psi. If applicable and required, the PVC housing must be molded to the curvature (radius) of the structure for which the dual reference electrodes will be installed on. Feedback from these electrodes to the rectifier controller will regulate the current for optimal control. Combinations of copper/copper-sulfate and zinc reference electrodes must be considered in brackish water or when salinity of water changes frequently.

2.9.1 Impact Protection for Permanent Dual Reference Electrodes

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NOTE: In areas with the problem of floating ice and/or driftwood, consideration should be given to the use of the more flexible ceramic coated titanium rod installed in PVC schedule 80 pipes with holes drilled in the pipe. These anodes should be used on the compartment side of the gate leaf, which is usually downstream. Alternatively, in areas subject to substantial floating ice and/or excessive driftwood, either Ceramic Coated Disk Anodes or High Silicon, Cast-Iron Button anodes may be used exclusively on both sides of the gate although this is usually a more expensive option.

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Weld a 6 inch diameter by 8 inch long minimum steel schedule-40 pipe with threaded pipe cap to the structure in back of each reference electrode housing. Drill a hole in the side of this pipe and weld a thread-o-let fitting to the 6 inch diameter pipe at this point to receive the connection wire and conduit routed to the terminal box at the top of the structure. The pipe and conduit are provided for impact protection of the anode cables and the. Paint the 6 inch diameter pipe at the same time as the structure (after all welding) with the same application standards and coating system that is applied to the structure surface.

2.10 MARKINGS

2.10.1 Manufacturer's Nameplate

Provide on each item of equipment a nameplate bearing the manufacturer's name, address, model number, and serial number securely affixed in a conspicuous place; the nameplate of the distributing agent will not be acceptable.

2.10.2 Rectifier Cabinets

Identify rectifier cabinets by means of suitable stainless steel plates attached to the outside of the rectifier cabinet by means of bolts or screws.

PART 3 EXECUTION

3.1 EXAMINATION

Visit the premises and thoroughly become familiar with all details of the work and working conditions, verify existing conditions in the field, note the exact locations for materials and equipment to be installed on the structures for cathodic protection, and advise the Contracting Officer of any discrepancies before performing any work.

3.2 INSTALLATION

Provide all materials, equipment, and labor necessary to provide a complete and workable cathodic protection system conforming to the drawings and specifications. Provide all electrical work and materials conforming to NFPA 70 and requirements specified herein. Provide 150 mm 6 inchdiameter Schedule 40 steel pipe. Provide fittings for rigid metal conduit conforming to NEMA FB 1. Use straight conduit; no kinks or bends will be permitted. Ensure conduit is RGS except the 152.4 mm 6 inch pipe required for protecting the HSCI button anodes and PVC schedule-80 perforated protective pipe used to protect the ceramic rod and HSCI sausage string anodes.

3.3 WIRING INSTALLATION

3.3.1 Rectifier in Control Room

Install cables, of the type specified in paragraph DIRECT CURRENT CABLES, between the rectifier cabinet located in the control room and the dc receptacle located adjacent to each structure. Install this cable in conduit conforming to the requirements of paragraph CONDUIT AND FITTINGS.

3.3.2 Rectifier on the Structure

Run Type SO cable exposed from the ac receptacle on the lock wall to the rectifier cabinet and from this cabinet to the dc receptacle. Also run Type SO cable exposed from the dc receptacle to the watertight bushing on the structure. Provide watertight insulating bushings with a cable seal fitting that makes a watertight conduit connection and a watertight seal between the cable jacket or insulation and the fitting. At all locations at which a conduit penetrates a watertight member, install a watertight packing gland constructed as shown on the drawings.

3.3.3 Wiring on the Structure

Provide all dc circuit wiring and anode lead wiring on the structures in rigid galvanized steel conduit, except sausage anode strings which must be shown on the drawings and as specified. [Where possible, install conduit on the gate structure in the recesses of the gate and flush with the wall skin plate to reduce the probability of physical damage from floating debris.]Provide each anode with sufficient lead length, without splice, to reach the terminal cabinets located on the top of each structure. Provide watertight insulating bushings with a cable seal fitting to seal between the cable jacket or insulation and the fitting. At all locations at which a conduit penetrates a watertight member, provide a watertight packing gland constructed as shown on the drawings. Prior to installation perform continuity testing utilizing a high impedance meter between the anode material surface and the anode lead wire end (that will be terminated at rectifier location), and insulation testing utilizing a Megger insulation tester. Replace all anodes and/or lead wires, including spares, that are found to be faulty or do not meet manufacturer suggested test results. After the cathodic protection system is installed, but prior to rewatering, the same two tests must be utilized to confirm that anodes and lead wires meet manufacturer suggested test results.

3.3.4   Conductor Identification

Provide conductor identification within each enclosure where tap, splice, or termination is made. For conductors No. 6 AWG and smaller diameter, provide color coding by factory-applied, color-impregnated insulation. For conductors No. 4 AWG and larger diameter, provide color coding by plastic-coated, self-sticking markers; colored nylon cable ties and plates; or heat shrink-type sleeves.

3.4   ROD AND SAUSAGE ANODE INSTALLATION

3.4.1   Metal Pipe Couplings for PVC Pipee

Weld metal pipe couplings (guides for PVC pipe used with sausage anodes) permanently on the structure. Do not use rod or Sausage-type anodes without these PVC pipe guides. Install PVC schedule-80 pipe (with holes) containing the sausage anode strings through the couplings with the holes oriented away from the protective steel angle channel (toward the back of the chambers). Use anode rod or string assembliescapable of being withdrawn at any time for inspection and repair. Install metal pipe couplings used for PVC pipe guides plumb, with an alignment tolerance of plus or minus 6.35 mm 1/4 inch over the entire height of the structure. When in place, weld the metal pipe couplings to the girder. Position protective angle irons at the previously specified locations to protect the PVC pipe and anode strings contained therein, exposing as much anode surface area as possible.

3.4.2   Assembly of Titanium Rod Anode

Sequentially assemble ceramic coated titanium rod anode as it is lowered into the PVC pipe by screw coupling each to the next anode element. Tighten coupling to a torque equal to that specified by the anode manufacture. Attach factory fabricated anode-to-cable connector to topmost element in a similar manner. The HSCI sausage anode assemblies are lowered into place inside the plastic pipe. Take care in handling these HSCI anode strings since the material is very brittle and subject to cracking if dropped or bounced against a hard surface. If any single anode element in the HSCI "sausage" string is cracked, replace the entire string with a new string. Do not install cracked anodes in the system. Install anode centering devices on each rod or string anode element to assure that the anode in maintained in a centered position within the pipe in a manner so that no portion of the anode is closer than 12.7 mm 1/2 inch of the pipe interior surface. Ensure each anode lead is continuous without splices from its point of connection to the anode to the terminal cabinet on the structure. Mark anode leads with anode string or anode number at the point of connection to the terminal box. Coil a minimum of 152.4 mm 6 inch of excess cable in the anode terminal box before cutting and connection the cable to the corresponding anode terminal in the terminal box. Coat this connection with a suitable oxidation preventing electrical contact paste.

3.4.3   Suspension of Anode Rod or String Assemblies

Provide support for each anode rod or string in a manner to permit easy raising, lowering, removal and/or reinstallation of the anode strings in the anode guides.   Suspend anode assemblies from anode connecting cables using "Kellum" or equal grips to provide uniform and non-deforming gripping of the wire insulation.

3.5   DISK AND BUTTON ANODE INSTALLATION

3.5.1   General

Install the Disk or Button-type anodes at the locations shown on the approved Contractor's corrosion engineer design drawings.

3.5.2   Impact Protection Pipes Installation

Install impact protection pipes for the disk or button anode connection cables prior to installation of the anodes. Fully seal weld a 152.4 mm 6 inch diameter by 203.2 mm 8 inch long galvanized steel schedule-40 pipe with threaded pipe cap to the structure in back of each button anode. Drill a hole in the side of this pipe and weld a thread-o-let fitting to the 152.4 mm 6 inch diameter pipe at this point to receive the anode lead wire and conduit routed to the anode terminal box at the top of the structure. The pipe and conduit provide impact protection of the anode cables and the anode support means. Prepare pipes for painting and coat with the same paint system as adjacent structure surfaces, in accordance with Section 09 97 02 PAINTING: HYDRAULIC STRUCTURES.

3.5.3   Disk Anode Installation

Deleiver the disk anode as a complete assembly by the manufacturer. Drill a 28.58 mm 1-1/8 inch diameter hole through the skin plate at each disk anode location shown on the approved system design drawings. Remove the FRP nut and washer from the disk support shaft. Apply 100 percent silicone waterproof caulk to the skin plate side of the anode composite shield in sufficient quantity to completely seal the shield at its outer perimeter and adjacent to the shaft where it passes through the skin plate. Then insert the disk through the structure and hold firmly in place while the washer and nut are placed on the support shaft from the opposite side of the structure and tighten using an automatic torque wrench set to 33.9 N-m 25 ft-lb of torque. Then attach cable connector to the integral threaded socket on the end of the anode support shaft and tighten to the torque specified by the manufacturer. Route this cable through the pipe protecting thread-o-let fitting and then via conduit to the anode terminal box. Ensure each disk anode lead is continuous without splices from its point of connection to the anode to the terminal cabinet on the structure. Mark anode leads with anode string or anode number at the point of connection to the terminal box. Coil a minimum of 152.4 mm 6 inch of excess cable in the anode terminal box before cutting and connection of the cable to the corresponding anode terminal in the terminal box. Coat this connection with a suitable oxidation preventing electrical contact paste.

3.5.4 Button Anode Installation

a. Provide polychloroprene or neoprene gasket material that is no less than 3 mm 1/8 inch in thickness and provide a minimum of 500,000 ohms of resistance between the button anode and the structure. Provide plastic plugs, molded or fabricated from an approved polystyrene to fit securely in the anode opening, in accordance with the approved submittal drawings. After assembly, insulate the anode support bolt completely on the button side of the structure by forcing epoxy cement through a passage provided for that purpose, around the insulating sleeve, into the bolt-head cavity, and out the vent hole in the plastic plug. Place the plastic plug in the bolt-head cavity such that the vent hole is at the highest point.

b. Provide epoxy cement of an approved type, with a suitable dielectric strength, that is water-resistant, and does not generate enough heat to damage or react with the plastic plug, the insulating bushings, or the gaskets. The epoxy must provide a minimum electrical resistance of 10 megohms between the anode and the structure.

c. Fabricate flanged sleeves from nylon conforming to the requirements of ASTM D789, or a similar approved rigid plastic material. It must be of proper size and length so that it will penetrate the skin plate enough to provide electrical isolation between the anode and skin plate. The sleeve must enter the skin plate at least 1.59 mm 3/16 inch. Refer to CERL Tech Rep FM-95/05 - Figure 1, "HSCBCI "Sausage" and "Button" Anode Designs for mounting component details.

d. Also isolate the bolt from the anode and skin plate. Use a metal washer behind the skin plate to connect the bolt to the structure so that the bolt will receive cathodic protection and not corrode. Apply the epoxy cement (resin) to provide a watertight seal in all areas of the bolt and anode bolt cavity. This will isolate the anode from the structure.

e. Sandblast the surfaces of the structure to be covered by the polychloroprene or neoprene gasket and the anode to clean metal to provide a bonding surface for the epoxy cement. The metal washer must not exceed the flange diameter of the nylon sleeve and the nylon flanges must be at least 3 mm 1/8 inch in diameter smaller than the diameter of the button anode hole bolt-head cavity. Provide anchoring bolt with slots that are large enough and adequate to transfer epoxy. Machine bolts and drill holes to transfer epoxy. Use bolt of sufficient length to allow threads to be visible past the nut. Consider structural thickness. Attach neoprene gasket to the structure and the anode using an approved cement to make a watertight seal. Use bolt to torque the anode to a watertight seal on the structure. Do not over-torque bolt, causing the metal anode to contact the structure or the polychloroprene gasket to turn out from the skin plate. Do not handle or carry anodes by the conductor. Ensure each anode lead is continuous without splices from its point of connection to the anode to the terminal cabinet on the structure. Mark anode leads with anode string or anode number at the point of connection to the terminal box. Coil a minimum of 152.4 mm 6 inch of excess cable in the anode terminal box before cutting and connection of the cable to the corresponding anode terminal in the terminal box. Coat this connection with a suitable oxidation preventing electrical contact paste.

3.6 RECTIFIER CABINET INSTALLATION

Secure wheeled rectifier cabinets, when provided, to the lock wall pipe rails using the clamp provided as a part of the rectifier. Secure stationary rectifier cabinets to the structures as shown on the approved submittal drawings.

3.7 RESISTOR AND ANODE TERMINAL CABINETS INSTALLATION

Install resistor and anode terminal cabinets at locations convenient for maintenance and testing purposes and to provide ready access to the terminals therein. Securely mount the cabinets to the structure with welded angle iron supports holding the cabinet in place.

3.8 REPAIR OF EXISTING WORK

Carefully lay work out in advance, and where cutting, channeling, chasing, or drilling of the structure or girder web, or other surfaces is necessary for the proper installation, support, or anchorage of the cabinets, conduit, raceways, or other electrical work, peerform this work carefully, and repair any damage to the structure or equipment by skilled mechanics of the trades involved, at no additional cost to the Government.

3.9 FIELD QUALITY CONTROL

3.9.1 Tests and Measurements

3.9.1.1 Insulation Testing

After installation of the button anode on the structure, but prior to connection to the rectifier and submergence, make an insulation test to demonstrate that no metallic contact or short circuit exists between the anode and the structure. Make these tests using a Megger apparatus or other device specifically designed for this purpose. Replace insulation found to be shorted. Ensure each button anode has a minimum resistance of 500,000 ohms isolation from the structure. If the button anode fails to indicate 500,000 ohms isolation, make the necessary corrections and/or modifications to the anode installation to achieve the minimum reading.

3.9.1.2 System Component Circuit Resistance Measurements

Within 1 week following the filling of the lock, measure and record the resistance of each anode, reference electrode, system ground, and reference ground using four separate test lead wires and a Nilsson Model 400 AC impedance meter or other similar AC impedance instrument acceptable to the Contracting Officer. Make the measurement by disconnecting the component lead at the appropriate terminal in the terminal box and connecting two of the four AC impedance test leads individually to the lead wire. Connect the other two AC impedance test leads individually to the structure component to which the component is mounted or connected. Should the resistance between the lead wire and the structure (immerse anode and reference elements in water) be less than 50 percent or more than 200 percent of the calculated (expected) resistance, make the necessary corrections and/or modifications necessary to achieve the anticipated value(s).

3.9.1.3 Structure-to-Reference Cell Potential Measurements

Following completion of the installation of the cathodic protection system and prior to placing the impressed current cathodic protection system in operation, make structure-to-reference cell potential measurements. Use testing equipment consisting of a calibrated copper-copper sulfate reference electrode with waterproof connector to insulated test lead wire suitable for immersion testing and of suitable length so that no splices are necessary in the test lead wire and a high-resistance digital voltmeter, Fluke Models 865 or 867 or equal. The copper-copper sulfate reference electrodes must contain a saturated reagent copper sulfate in distilled water. Prior to first system energization, record native "OFF" potential measurement using the same meter and calibrated reference electrode to be used during system energization and adjustment. Measure and record these native "OFF" potentials at all the specified locations.

3.9.2 Initial Cathodic Protection System Field Testing

Initial field testing must be completed by the contractor upon completion of construction. Field testing must be witnessed by the Contracting Officer or the Contracting Officer's Representative, Technical Expert and Project Manager or their designated representative. Advise the Contracting Officer or Contracting Officer's Representative [5] [_____] days prior to performing each field test. Field testing must include native and protected potentials, anode current and rectifier testing.

The contractor must submit an initial field test report of the CP system. All system component circuit resistances, structure-to-electrolyte measurements, including native potentials, protected potentials, anode current testing, rectifier testing, and other required testing must be recorded on applicable forms. Identification of test locations in reference to anode locations will coordinate with the as built drawings and be provided on system drawings included in the report. The contractor must locate, correct, and report to the Contracting Officer or the Contracting Officer's Representative, Technical Expert and Project Manager any unusual data, problems, or short circuits encountered during the checkout of the installed CP system.

3.9.2.1 Rectifier Adjustments

Accomplish rectifier adjustment as follows:

a. Adjust the output of the rectifier so that the structure-to-water potential measured using a reference cell indicates that the negative potential has stabilized and is at least minus 850 millivolts and not more than 1200 millivolts. Make these measurements with current applied. Make corrections for IR drop. Accomplish this by adjusting the rectifier to obtain the aforementioned "instant-off" potentials. Make this IR drop correction by interrupting the current output of the rectifier either manually or automatically using a 90 percent minimum "ON" and 10 percent maximum "OFF". If more than one rectifier is energized at the same time, interrupt all such rectifiers simultaneously. The "OFF" time must not exceed 1 second. During this "OFF" period, use the Fluke 865/867 meter to automatically read the minimum DC voltage that is the polarized protective potential on the structure.

b. Perform a complete structure-to-water potential survey structure face.

3.9.2.2 Locations of Structure-to-Reference Cell

Locate the reference cell in the water, 0.5 to 3 inches from the structure. Connect reference cell with a waterproof screw coupled connector to a conductor on a reel. Lower cell to depths in the water as indicated below. Connect reference cell conductor to the positive terminal of the digital voltmeter. Connect a second conductor from the structure (rectifier structure terminal) to the voltmeter negative terminal. Repeat and record measurement procedure for each measurement location. Make measurements every 3 ft vertically (minimum) from normal water elevation to the bottom of the structure. Make these same measurements at a minimum of five locations across the width of the submerged structure. [In addition, make one set of measurements at the quoin end and one at the miter end on both sides of the structure.]

3.9.2.3 Polarization Decay

a. Polarization decay measurements are only necessary if the structure fails to meet the above criteria of providing negative protection potential of at least minus 850 millivolts.

b. Measure a minimum negative (cathodic) polarization voltage shift of 100 millivolts between the structure surface and the reference electrode cell contacting the electrolyte. This polarization voltage shift is to be determined by interrupting the protective current and measuring the polarization decay. When the current is initially interrupted, an immediate voltage shift will occur. Use the second voltage reading displayed after the immediate shift as the base reading from which to measure polarization decay. Make polarization measurements at minimum 10-minute intervals for a maximum of 4 hours. This measurement

c. Location of the structure with respect to the reference cell for polarization decay measurements must be 1 ft from the bottomand at 2 ft intervals along the bottom of the structure. Make measurements on all surfaces contacting the electrolyte.

3.9.3 Government Review of Initial Field Testing

The government corrosion [engineer] [program manager] must review the contractor's initial field-testing report. The contractor must correct, at the contractor's expense, material and installation deficiencies not to be in conformance with the plans and specifications. The contractor will pay for all retesting necessary by the correction of deficiencies.

3.9.4 Final Acceptance Field Testing

Conduct final field testing of the CP system utilizing the same procedures specified under, "Initial Cathodic Protection Field Testing". The contractor will inspect, test, and adjust the CP system after one year of operation to ensure its continued conformance with the criteria outlined below. The performance period for these tests will commence upon preliminary acceptance for the CP system by the Contracting Officer or the Contracting Officer's Representative, Technical Expert and Project Manager. Copies of the Final Cathodic Protection System Field Test Report, certified by the contractor's corrosion engineer must be submitted to the Contracting Officer or the Contracting Officer's Representative, Technical Expert and Project Manager and the geographic EFD corrosion [engineer] [program manager] for approval, and as an attachment to the Operation and

Maintenance Manual in accordance with Section 01 78 23 OPERATION AND MAINTENANCE DATA. The government corrosion [engineer] [program manager] must review the contractor's final field testing report.

[3.9.5 One-Year-Warranty-Period-Testing

The contractor must inspect, test, and adjust the CP system [quarterly] [semi-annually] [_____] for one year, [4] [2] [_____] interim inspections total, to ensure its continued conformance with the criteria outlined below. The performance period for these tests will commence upon the completion of all CP work, including changes required to correct deficiencies identified during initial testing, and preliminary acceptance of the CP system by the Contracting Officer or the Contracting Officer's Representative, Technical Expert and Project Manager. Copies of the One Year Warranty Period Cathodic Protection System Field Test Report, including field data, and certified by the contractor's corrosion engineer must be submitted to the Contracting Officer or Contracting Officer's Representative, the activity, and the geographic EFD corrosion [engineer] [program manager] [Contracting Officer] [Contracting Officer's Representative] [Technical Expert] [Project Manager].

]3.10 CLOSEOUT SUBMITTALS

Submit Weekly, Monthly and Annual Test Procedure to be part of the operations and maintenance instruction manual. This test plan must conform to all applicable AMPP recommended practices.

3.10.1 Operating Instructions

Provide the Contracting Officer six (6) complete copies of operating instructions detailing the step-by-step procedures required for system start-up and adjustment of the rectifier to achieve the criteria of protection. Include native system and component test data (data before system energization), test set up, test equipment diagrams showing voltmeter and reference cell connections, test locations, and a description of the procedure for measuring "on" and "off" potentials. Provide detailed steps that show use of the equipment used in the training course and cover test and measurement of the cathodic protection systems for each structure. Submit the Operation and Maintenance manual to the Contracting Officer for approval 30 days prior to the training course. Include the manufacturer's name, model number, service manual, parts list, and a brief description of all equipment and its basic operating features.

3.10.2 Maintenance Instructions

Provide the Contracting Officer six (6) complete copies of maintenance instructions listing routine maintenance procedures, possible breakdowns and repairs, and trouble-shooting guides. Include diagrams for the system as installed, instructions in making structure-to-reference electrode measurements, and frequency of monitoring.

3.11 TRAINING

3.11.1 Government Personnel Training

Provide training for [_____] Government Personnel at a time designated by the the Contracting Officer. The training must be provided by a technician regularly employed or authorized by the manufacturer of the CP system for instructing government personnel in the proper operation, maintenance, safety, and emergency procedures of the CP system. The period of instruction must be not less than [eight] [_____] hour[s] and not more than [two] [_____] 8-hour working day[s]. Conduct the training at the jobsite or at another location mutually satisfactory to the government and the contractor. The field instructions will cover all the items contained in the Operation and Maintenance Manual and include demonstrations of the procedure for measuring the minus 850 millivolts "off" potentials and AMPP protection criteria of a minimum negative (cathodic) polarization voltage shift of 100 millivolts. Provide a digital voltmeter (Fluke 865 or similar and approved equal) and an insulated cable (minimum 100 ft length) on a reel with a saturated copper-copper sulfate reference cell attached by a factory assembled waterproof connector for these demonstrations. This equipment will become the property of the Government and turn over to the Contracting Officer upon completion of the training.

-- End of Section --