SPECIFICATION FOR

CATHODIC PROTECTION OF REINFORCED CONCRETE STRUCTURES USING VENTED INTERNAL DISCRETE ANODES

SECTION 13110 – Cathodic Protection

1.0 DESCRIPTION

This item involves the installation of an impressed current cathodic protection system for reinforced concrete structures. The purpose of the cathodic protection system is to protect the steel embedded in the concrete from corroding by passing a small DC current from the anode to the steel.

The cathodic protection system consists of an anode system, rectifier, DC wiring, conduit, and all associated electrical connections. In addition, the Contractor shall be responsible for furnishing a complete AC electric service at the location shown on the plans or as ordered by the Engineer and in accordance with the following:

- Secondary service is to be a single phase, 120/240 volts, 60 cycles.
- Transformer as required to be supplied and installed by the power company.
- Trenching and conduit for service entrance by Contractor, conductors by the power company.
- The Contractor is to arrange for and pay for all charges associated with the electric service.
- Electric service shall be metered or unmetered, as approved by the power company.

The cost of furnishing electrical service to the service cabinet including the cost of conduit and conductors are to be paid for under other items. The service cabinet and foundation, conduit and wiring from the service cabinet to the cathodic protection system are to be included in this item.

2.0 DESIGN REQUIREMENTS

The design of the cathodic protection system and the installation schedule shall reflect the staging for the construction sequences as shown on the plans and as specified herein.

The structure shall be subdivided into separately controlled cathodic protection zones as shown on the plans. The maximum zone size shall not exceed 6,500 ft^2 (600 m^2).

The design current density shall not be less than 1.8 mA/ft^2 (20 mA/m^2) of reinforcing steel surface. Both top and bottom mats of steel shall be taken into account.

Maximum allowable design current density for the Discrete Anodes shall be 83 mA/ft^2 (900 mA/m^2).

In order to assure uniform current distribution, the anode voltage drop shall not exceed 300 mV from the power feed point to the furthest point from the power feed.

The power wiring shall be sized according to the National Electric Code. The power cable for the anode and the power cable for the system ground shall be taken into consideration.

Each anode zone on the structure shall have at least two system negative connections. Any embedded steel besides the reinforcing steel (i.e., scuppers, conduit, piping, support bolts, etc.) must be made continuous with, or completely isolated from the cathodic protection system as determined by the Engineer.

At least two current distributors and two current feed points shall be provided for each zone.

Each zone shall contain as a minimum, one reference electrode and associated ground wire to monitor the potential of the reinforcing steel. The reference cell wiring shall terminate at the rectifier.

Contractor shall submit shop drawings and catalogue cuts of the materials to be utilized for approval prior to starting work.

3.0 MATERIALS AND EQUIPMENT

3.1 Discrete Anode System

The Discrete Anode System shall be installed in the sections of the structure as determined on the plans. For these areas a vented discrete anode system shall be used to eliminate the possibility of building up pressure and causing damage to the concrete. The Discrete Anode System shall consist of conductive ceramic with a dedicated venting system, current distributors, and grout. The specifications for each of these components is given below:

<u>Discrete Anodes</u>: The specified Discrete Anode System shall consist of Discrete Anodes fabricated from conductive ceramic tubes. The tubes shall be hollow, composed of titanium sub-oxide and shall have sufficient porosity to allow gases generated at the anode / filler interface to freely pass to the center of the anode and be vented to the exterior. Each discrete anode shall be supplied with its own dedicated venting system. Discrete anodes of sufficient surface area shall be supplied to meet the design requirements. The Discrete Anodes shall be provided with a factory installed titanium current feed wire of sufficient length and diameter. The current feed wire and connection method shall be compatible with the Discrete Anodes and shall have a proven field track record. Discrete Anodes shall be provided with sealed ends to prevent the center of the anodes from becoming filled with grout during the installation process. Each anode shall be supplied with anode centering devices to ensure the thickness of grout around each anode is uniform and the current to the surrounding reinforcing steel is uniformly distributed. The Discrete Anodes shall be Ebonex® Discrete Anodes or approved equal. Alternative materials may be permitted subject to the approval of the Engineer and provided that the alternative anode system can fully meet the following criteria;

Internal Discrete Anode System shall;

1. provide sufficient current to adequately protect the steel as per the current density requirements to the steel,
2. provide field proven ventilation of anodic gases,
3. demonstrate a minimum anode life expectancy of 25 years at the full design anode current density of 900mA/m^2 of anode surface area,

4. demonstrate at least five years of satisfactory operation in one or more similar applications, and
5. provide a positive system of locating and positioning the anodes to be installed in the structure ensuring a high confidence of zero short circuits and uniform current distribution.

Discrete Anode Grout: The specified Discrete Anode Grout shall be a Portland Cement based grout used to embed and surround the individual discrete anodes within the drilled holes. The Discrete Anode Grout shall be Ebofix Grout or approved equal. Alternative materials may be permitted subject to the approval of the Engineer and provided that the alternative grout can fully meet the following criteria;

Discrete Anode Grout shall;

1. be Portland Cement based and shall have physical and mechanical properties similar to and compatible with the existing, surrounding concrete,
2. have a high pH (pH >11) and provide a significant reservoir of alkali to absorb or resist acid generation at the anode,
3. have a high bulk density (Specific Gravity > 1.3) to absorb or resist acid generation at the anode,
4. be electrically resistive (Resistivity > 50,000 ohm·cm) to improve the uniformity of the anode to reinforcing steel current distribution, and
5. contain no carbonaceous or other oxidizable materials.

Current Distributor: The current distributor shall be solid Grade 1, uncoated titanium bar or wire. The current distributor shall be provided in rolls. The current distributor shall be of sufficient cross section area to meet the design requirements.

3.2 Rectifier (Power Supply)

The power supply shall be a tap-switch rectifier, capable of manual voltage control, with a filtered DC output. The rectifier shall be a silicon diode type. Cooling shall be by natural air convection. Operating ambient temperature shall range from –40 to +45° C.

The power supply shall have a non-conductive front panel with a digital panel meter for monitoring the rectifier DC voltage and current output for each zone. The power supply shall have an individual circuit for each anode zone and one spare circuit. Binding posts shall be provided for termination of the reference electrode wiring from each zone.

Variation in the AC input from 5% below to 10% above rated line values shall not damage any components nor alter the rated DC output. The DC output shall be regulated to within 3% of the setting. The rectifier shall have a fuse in each positive output and a quick acting magnetic breaker rated at 120% of the circuit capacity placed in one leg of the AC secondary of each circuit. Three spare fuses of the same rating shall be provided with the rectifier, which shall be secured inside the enclosure.

DC shunts shall be provided for each circuit. The shunts shall be mounted on the front panel, and have uninsulated ring tongue terminals, positioned for each connection of test equipment, fastened to the calibrated test points. The unit shall be furnished with upgraded lightning protection on both the AC and DC sides.

The rectifier cabinet shall be rated at NEMA type 3R, and constructed from 14 Ga. mill galvanized steel. The enclosure shall be finished in 3-5 mils fusion bonded polyester paint. The color shall be white. The housing door shall be lockable and shall have a bronze padlock and three keys.

AC input for each rectifier shall be 120/240 Volts, 60 Hertz, single phase. A separate breaker, of proper rating, shall be provided for each unit.

3.3 Reference Electrodes

Reference electrodes shall be silver/silver chloride (Ag/AgCl) and suitable for installation in reinforced concrete structures. Each electrode shall have a No. 10 AWG copper conductor with HMWPE insulation attached to the electrode at the factory. The ground wire shall also be No. 10 AWG HMWPE.

3.4 Electrical

The junction boxes shall be molded PVC and suitably weatherproofed for outdoor installation. The minimum size shall be 6 inches (152 mm) x 6" (152 mm) x 4 inches (102 mm). Anchors shall be encased in a nonmetallic expansion shield approved by the Engineer. Weep holes shall be provided at all low points in the conduit run including junction boxes.

The conduit for the DC circuitry shall be PVC Schedule 40. The conduit shall be sized in accordance with the latest revision of the National Electrical Code (NEC) for wire fill. Exposed conduit shall be mounted securely by suitable nonmetallic hangers or straps with the maximum spacing of supports not greater than indicated by Article 347(8) of NEC. Expansion joints shall be installed in accordance with the manufacturer's recommendations for temperature change of 73° C. Weep holes shall be provided in the at all low points in the conduit run. Anchors shall be encased in a nonmetallic expansion shield approved by the Engineer.

3.5 Wiring

Power wiring, which will be encased in the concrete overlay, shall be No. 10 AWG with HMW/PE insulation. Power wiring in the conduit run shall be at least No. 10 AWG with THHN insulation. Reference electrode wiring in conduit shall be No. 18 AWG shielded twisted pair with PVC outer jacket.

3.6 Connections

The system negative and electrical continuity bonding connections to the reinforcing steel shall be made by thermite welding, pin brazing, or resistance spot welding as approved by the Engineer. No mechanical connections will be accepted. All thermite weld connections shall be coated with a non-conductive epoxy.

The system negative connections and reference electrode wire connections in the junction boxes shall require the use of a mechanical crimp connection, which is subsequently sealed from the environment with a suitable insulating material. The system positive connections shall require the use of a crimp connection, which is subsequently sealed from the environment by a suitable insulating material. The mechanical and crimp connections shall be Llsco Part No. CT-8 or equivalent. The insulating material shall be Hysol Epoxi-Patch, 3M Scotch EZ Seal 2200 Alpha FIT-700 heat shrink, or equivalent.

4.0 CONSTRUCTION METHODS

The Contractor shall install a complete electrical service with associated equipment and terminations, as indicated on the plans or as directed. The Utility Company shall be given adequate advance notice for service. The date the service is energized shall be recorded for billing purposes.

4.1 Discrete Anode System

The discrete anodes shall be installed in pre-drilled holes no closer than 20 inches (500 mm) apart unless otherwise approved by the Engineer. The holes shall have a diameter of 4 to 8 mm larger than the nominal diameter of the anodes. The holes and anodes shall be located to minimize the proximity of the anodes to the steel reinforcement. The holes and anodes are to be sized and located to provide an even current distribution to the steel in the local vicinity of the anode. Each hole shall be tested for electrical shorts or the presence of near shorts. The method of testing shall be approved by the Engineer and shall meet the anode manufacturer's guidelines. The anodes shall be installed in accordance with the manufacturer's recommendations.

A general procedure for installing the anode system is given below:

Delaminated and spalled concrete shall be repaired by removing unsound concrete and fully exposing the bars in accordance with the concrete repair specifications. Concrete patching materials to be used on this project shall have a resistivity value less than 50,000 ohm·cm.

The proposed location of the drilled holes shall be marked on the concrete surface. The location of the top layer of reinforcing steel shall be confirmed using a Fisher M-100 metal locator or Kolectric Micro Covermeter and the location of any of the holes which conflict with the steel are to be adjusted as required to avoid the reinforcing steel. Spacing between the anodes must stay within the design requirements.

The holes shall be drilled using the proper diameter and to the required depth to facilitate installation of the discrete anodes. Each of the holes shall be tested for the presence of electrical shorts or near shorts using a resistance meter configured for use in drilled holes. Holes having insufficient concrete cover shall be insulated or re-drilled.

The bottom of the drilled holes shall be filled with Discrete Anode Grout and the Discrete Anode shall be inserted such that it is fully encapsulated in the grout with the ventilation tube and titanium current feed wire extending from the top of the hole.

The holes shall be connected by a groove, which is to be cut into the concrete surface. The groove shall be nominally ¼ inch wide by ½ inch deep (12mm by 25mm). Before cutting slots, all areas of the structure in which the cover is less than 1 inch (25 mm) shall be identified and the bars located accurately. The titanium current feed wire or bar and the ventilation tube shall run within this slot.

The current feed wires for each individual Discrete Anode shall be connected to the current feed wire or bar within the slot prior to installation of the grout. Similarly, the ventilation tube within the slot shall be connected to each individual anode prior to installation of the grout. The end of the ventilation tubes shall vent to the air beyond the substrate surface.

Prior to backfilling with grout, the contractor shall perform a crack investigation survey on the structure. In areas where cracks pass through the slots, the contractor shall place backer rod, 3 inches. (76 mm) on both sides of cracks. After grouting, the backer rod shall be removed, and the area filled with non-conductive polymer concrete or epoxy, so that the anode ribbon is encapsulated.

The titanium current distribution ribbon or wire shall be installed in the slots so that it lays within the slot, and is tensioned slightly and secured. Current feed wires from each individual anode shall be connected to the current distributor, as recommended by the anode manufacturer.

All titanium-to-titanium connections shall be metallurgical bonds made by resistance welding with equipment supplied by the anode manufacturer and used in accordance with the manufacturer's instructions, or proprietary titanium crimp connectors with a documented history of field performance may be used. Prior to commencing welding, the equipment settings shall be tested by welding current distributor test strips and anode test strips, to ensure that a satisfactory weld will be obtained.

The slots shall be grouted with a standard cementitious mortar such as Sika Repair 222, or approved equal. The contractor shall follow the manufacturer's guidelines regarding storage, mixing, proportioning and placement. The slots shall be thoroughly cleaned after saw cutting, and kept clean, so they are free of all foreign material throughout the subsequent placement of the anode ribbon in the slots and the backfilling of the slots with the cementitious grout. No standing water shall be allowed in the slots prior to placing the grout. The contractor shall submit a written plan for approval, which outlines the procedures for control and disposal of slurry, water and debris from the saw cutting operation.

Placing and finishing equipment shall include hand tools for placement and brushing-in freshly mixed mortar for distributing it to the approximate level of the original concrete surface. The concrete substrate in the slots shall be thoroughly saturated with water prior to mortar placement. All excess water shall be removed from the slots using compressed air if necessary.

4.2 System Negative Connections

The reinforcing steel shall be connected to the cathodic protection system by thermite welding a No. 10 AWG wire with HMWPE insulation to the rebar. Approximately ½ inch (13 mm) of insulation shall be removed from the end of the wire. The steel surface shall be wire brushed to remove any material, which could interfere with a good bond. The batting is placed over the cleared area and the sleeved wire located in the hollow. The mold is placed over the hollow such that ⅛ inch of the wire is exposed. The thermite charge is loaded and ignited. The thermite charge used shall be an Erico CA-25 or equivalent. All thermite weld connections shall be coated with a 100% solids non-conductive epoxy.

4.3 Reference Electrodes

Reference electrodes shall be installed in areas of sound concrete having high half cell potential readings (i.e. >-350 mV CSE) in accordance with ASTM C876, or at alternate locations as approved by the Engineer. Prior to excavating, the Contractor shall locate the reinforcing steel patterns in the area of the excavation using a pachometer or other similar rebar locator. Contractor shall cut a slot, about 3 inches (76 mm) wide x 7 inches (178 mm) long, between the reinforcing steel bars for placement of the reference electrode. The depth of the slot shall be such that the reference electrode is situated at the same depth as the reinforcing steel. Care shall be taken not to expose the reinforcing steel in the reference electrode excavation.

The reference electrode shall be placed in the prepared excavation and the lead wire routed through a slot and/or access hole to the appropriate junction box. The slot shall be a minimum of ½ inch (13 mm) wide x ½ inch (15 mm) deep. Any excess cable shall be cut once it has been properly routed to the junction box. An identification tag shall be affixed to the end of the cable indicating the reference electrode location and number.

A ground wire shall be connected to the reinforcing steel using the thermite weld procedure, or other approved method. The ground wire connection point shall be coated with a 100% solids epoxy. One ground wire shall be provided for each reference electrode. The ground wire connection shall be at least 20 inches (0.5 m) from the reference electrode excavation.

The reference electrode excavation, ground wire excavation and lead wire slot shall be patched with Sika Repair 222, standard Portland Cement grout or concrete. Just prior to backfilling, the cap shall be removed and discarded. Care shall be taken to fully encapsulate the reference electrode with backfill material. The backfill material shall completely fill the slots and excavations with no voids. All slots and excavations shall be visibly free of dirt, grease, oil, asphalt, and other foreign material prior to placing the backfill material. The Portland Cement grout or concrete shall not contain any purposely-added salt, admixtures such as fly ash, latex or silica fume, or any other material, which could significantly increase the backfill resistivity.

4.4 Rectifier (Power Supply)

The Power Supply shall be located as required by the Engineer. Grounding rods and cable shall be sized and installed such that the power supply to the ground resistance is less than 25 ohms. Tests shall be conducted to verify this resistance criterion.

5.0 TESTING REQUIREMENTS

The installation of a cathodic protection system requires that some specialized tests be performed. The activity chart below outlines the tests required, the phase of construction during which these tests normally takes place, the responsible party for each test, and the approval required before further activity can occur.

Required Testing	Phase
Steel Continuity	1
Depth of Cover Survey	1
Anode/Steel Isolation	2,3
Initial Energization	3

Legend

1	Before anode installation
2	After anode installation
3	After discrete anode grout has cured

5.1 Steel Continuity

The purpose of the steel continuity check is to ensure that all of the embedded steel is continuous. If the embedded steel is discontinuous, it will not receive cathodic protection current. The reinforcing steel shall be checked for electrical continuity at a minimum 5 locations per 1,000 ft^2 (93 m^2) and between all exposed rebars during the delamination repair stage, scuppers, expansion joints and other metallic members by using the DC millivolt technique. Testing shall be conducted during the delamination repair stage, so as to alleviate unwanted excavation. Test equipment for this procedure consists of a standard digital DC voltmeter, test leads and wire reel. The millivolt drop between the steel is measured. Readings greater than 1.0 mV indicate electrical discontinuity.

All reinforcing steel which is found to be discontinuous must be electrically bonded to the continuous steel with one No. 10 AWG wire with HMWPE insulation using thermite welding or by resistance spot welding a 1/16 inch (1.5 mm) diameter steel wire to the steel.

5.2 Anode-Steel Isolation Check

After each section of anodes has been installed, a check shall be made to ensure that the anodes are discontinuous from the steel so that the cathodic protection system will function as intended. Isolation checks shall be conducted prior to, during and after installation.

Isolation testing shall be conducted using a DC and an AC resistance meter. Prior to taking the readings, the steel must be cleaned to a bright metal condition at each test location. The connection to the anode may be made at any convenient location. The results of this testing will be dependent on the size of the zone as well as other variables. The readings shall be approved by the Cathodic Protection System Technical Representative before proceeding with the concrete placement. Alternately, a DC voltmeter can be used. If the voltage drops to zero immediately, then a short has occurred.

Should the anode and steel be continuous, the location of the short must be found and corrected. The Engineer shall approve the repair technique selected.

5.3 Energization Test

The acceptance testing is done to assure that the steel is adequately protected. Cathodic protection functions by forcing sufficient current to the steel to change the surface condition of the steel such that it no longer corrodes. This surface condition corresponds to a change in the electrical potential of the steel.

The potential of the steel is monitored by using the embedded reference electrodes. The criterion for adequate current shall be a depolarization of at least 100 mV. This test shall be made by measuring the steel potential immediately after the current is turned off and monitoring the change in the potential with time. If the depolarization is less than 100 mV, then the voltage setting on the power supply must be increased. The Cathodic Protection System Technical Representative shall conduct these tests. The results of the depolarization testing shall be submitted in writing.

6.0 DOCUMENTATION AND TRAINING

An operating and maintenance manual shall be submitted for the entire system. The manual shall document the results of all tests performed on the project and shall include "as-built" drawings. Three manuals shall be provided. The Cathodic Protection System Technical Representative shall provide training to the owner's personnel regarding the operation and maintenance of the system.

7.0 METHOD OF MEASUREMENT

This work will not be measured for payment but will be paid for on a lump sum basis.

8.0 BASIS OF PAYMENT

Payment for this work will be at the contract lump sum price for "Cathodic Protection," and shall include all materials, equipment, tools and labor incidental to the completion of this item.