NACE Standard RP0290-2000
Item No. 21043

Standard
Recommended Practice

Impressed Current Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures

Revised 2000-06-16
Approved April 1990
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ISBN 1-57590-103-X

Foreword

The purpose of this NACE standard recommended practice is to present guidelines for impressed current cathodic protection of reinforcing steel in atmospherically exposed concrete structures. These guidelines provide the design engineer with information to control corrosion of conventional reinforcing steel in portland cement concrete structures through the application of impressed current cathodic protection.

For more information on design, maintenance, and rehabilitation of reinforcing steel in concrete, refer to NACE Standard RP0187[1] and NACE Standard RP0390.[2] For a state-of-the-art overview regarding the use of reference electrodes for atmospherically exposed reinforced concrete structures, refer to NACE International Publication 11100.[3] For a state-of-the art overview on criteria for cathodic protection of prestressed concrete structures, refer to work in progress by Task Group T-11-1d.[4]

This standard was originally prepared in 1990 by NACE Task Group T-3K-2, a component of Unit Committee T-3K on Corrosion and Other Deterioration Phenomena Associated with Concrete. It was revised by Work Group T-11-1a (formerly T-3K-2) in 2000 and is published by NACE International under the auspices of Group Committee T-11 on Corrosion and Deterioration of the Infrastructure.

To provide for the necessary expertise on all aspects of the subject and to provide input from all interested parties, Task Group T-11-1 was composed of corrosion consultants, consulting engineers, architect-engineers, cathodic protection engineers, researchers, structure owners, and representatives from both industry and government.

In NACE standards, the terms *shall*, *must*, *should*, and *may* are used in accordance with the definitions of these terms in the *NACE Publications Style Manual*, 3rd ed., Paragraph 8.4.1.8. *Shall* and *must* are used to state mandatory requirements. *Should* is used to state that which is considered good and is recommended but is not absolutely mandatory. *May* is used to state that which is considered optional.

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Impressed Current Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures

Contents

Section 1: General

1.1 Background

1.1.1 Reinforcing steel is compatible with concrete because of similar coefficients of thermal expansion and because concrete normally provides the steel with excellent corrosion protection. The corrosion protection is the result of the highly alkaline portland cement that allows a stable, corrosion-mitigating passive oxide film to form and be maintained on the surface of the encased steel. If the film does not form, or is weakened or destroyed so that it does not protect the steel, corrosion can occur. The protective oxide film does not form or is destroyed if (1) excessive amounts of chloride or other aggressive ions are present, (2) alkalinity is lost by reaction with aggressive gases, or (3) the concrete does not fully encase the steel.

1.1.2 Corrosion occurs as a result of the formation of an electrochemical cell. An electrochemical cell consists of four components: an anode, where oxidation occurs; a cathode, where reduction occurs; a metallic path, where the electric current is electron flow; and an electrolyte (concrete), where the electric current is ion flow in an aqueous medium. The anodic and cathodic areas occur as a result of coupling dissimilar metals and/or exposure to differential environmental conditions. If any one of the four elements of the electrochemical cell is eliminated, corrosion can be prevented.

1.2 Cathodic Protection

1.2.1 The basic principles of corrosion can be used to understand the theory of cathodic protection. Cathodic protection is defined as a technique to reduce the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

1.2.2 Cathodic protection is a proven technique for controlling corrosion of steel in existing chloride-contaminated concrete structures. However, cathodic protection will neither replace lost steel nor return corroded reinforcement to its original section. There may be areas of the reinforced concrete structure that appear sound by traditional inspection techniques that are, in fact, corroding and experiencing corrosion-related tensile stress near the rupture levels. Such distressed areas may crack, spall, or delaminate subsequent to the application of cathodic protection.

NOTE: For further information, see a glossary of terms in Appendix A.

1.3 Scope and Limitations

1.3.1 The provisions of this standard should be applied under the direction of a registered Professional Engineer or a person certified by NACE International as a Corrosion Specialist or certified as a Cathodic Protection Specialist. The person's professional experience should include suitable experience in cathodic protection of reinforced concrete structures. Under certain circumstances, a cathodic protection system may either become a structural component or significantly affect the serviceability and structural performance of a reinforced concrete structure; therefore, review of such impact by the cathodic protection system should be made by a qualified registered Structural Engineer or the equivalent.

1.3.2 The guidelines presented here are limited to impressed current cathodic protection systems for new or existing atmospherically exposed reinforced concrete and are not applicable to prestressed concrete.

Section 2: Criteria

2.1 The criteria in this section serve as a guide for achieving cathodic protection and providing corrosion control for reinforcing steel embedded in atmospherically exposed concrete. Compliance with these criteria is dependent on analysis of representative data in each situation. These criteria are applicable only with impressed current systems. The number and locations of measurements made during data collection should be commensurate with the complexity of the structure being protected. Sampling plans should be in accordance with ASTM[(1)] E 105.[5] Sample size should be determined in accordance with ANSI[(2)]/ASQC[(3)] Z1.4,[6] with the unit of product typically being 0.836 m^2 (1.00 yd^2) of protected metal surface area. For structures in which cathodic protection systems are divided into discrete zones, testing inspection lots should be defined. Acceptable quality and confidence levels should also be defined. Potentials of reinforcing steel or other embedments measured against portable reference electrodes shall be obtained in accordance with the techniques described in ASTM C 876.[7]

[(1)] American Society for Testing and Materials (ASTM), 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.
[(2)] American National Standards Institute (ANSI), 11 W. 42nd St., New York, NY 10036.
[(3)] American Society for Quality (ASQ), 611 East Wisconsin Ave., Milwaukee, WI 53201-3005.

Sign conventions for potential and current density as well as conventions for graphical presentation of data should be in accordance with ASTM G 3.[8]

2.2 Situations in which physical conditions effectively preclude full implementation of sampling programs derived from ASTM E 105 and ANSI/ASQC Z1.4 may exist. Examples of these cases include asphalt or other nonconductive overlays, conductive asphalt cathodic protection systems, and situations in which access to the cathodically protected surface is difficult and limited. In these situations embedded reference electrodes should be installed. Additionally, "most anodic" sites may be constructed. Typically, this involves fully exposing a short length of existing reinforcement. The excavation is then patched with concrete containing an amount of chloride well above that found in existing conditions. Attention should be given to the location of "most anodic" sites to avoid making the sites exceptionally favorable cathodic protection current paths. A reference electrode may also be installed. It is important that the reinforcing steel adjacent to the embedded reference electrode be left in the original concrete. If this is not done, the measured potentials will not be representative of the reinforcing steel in undisturbed concrete. If "most anodic" sites are to be the basis for cathodic protection system performance judgment, the number of sites constructed should reflect the complexity of the structure.

2.3 NACE Work Group T-11-1a developed these criteria through empirical evaluation of data obtained from successfully operated impressed current cathodic protection systems. NOTE: Persons using this standard should review data made available after this standard's publication to determine whether more effective criteria have been established. It is not intended that persons responsible for corrosion control be limited to these criteria if it can be demonstrated by other means that corrosion control has been achieved. A combination of criteria may be used for a single structure.

2.3.1 100-mV Polarization Development/Decay

2.3.1.1 A minimum of 100 mV of polarization should be achieved at the most anodic location in each 50 m^2 (500 ft^2) area or zone, or at artificially constructed anodic sites, in accordance with Paragraphs 2.1 and 2.2, provided its corrosion potential or decayed off-potential is more negative than -200 mV_{cse} (versus a copper/copper sulfate reference electrode [CSE]). If the corrosion potential or decayed off-potential is less negative than -200 mV_{cse}, then the steel is passivated and no minimum polarization is required.

2.3.1.2 When the polarization decay method is used, the decay should be determined by interrupting the protective current and monitoring the reinforcement's potential measured relative to a stable reference electrode. When the current is interrupted an immediate voltage shift that is the result of eliminating the IR drop occurs. This shift should not be included in the polarization measurement. The potential of the steel immediately after the shift (instant-off potential measured between 0.1 and 1.0 second after interrupting the current flow) shall be used as the initial value from which to measure polarization. Figure 1 depicts a typical polarization decay curve. The polarization equals the instant-off potential subtracted from the reinforcement's final "depolarized potential."

2.3.1.3 Polarization development should be determined by measuring the potential immediately before applying current to the reinforcing steel and measuring the instant-off potential at intervals of time during the polarization of the steel reinforcement.

The polarization equals the initial reinforcement potential (static potential) before applying current subtracted from the reinforcement's "final instant-off potential." Figure 2 depicts a typical polarization development curve using "instant-off" values only.

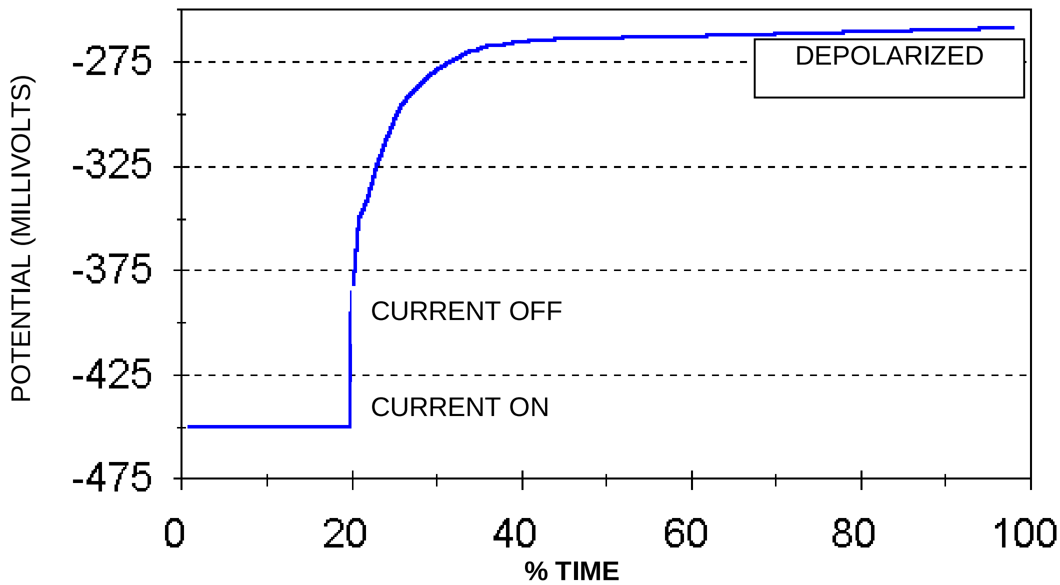

FIGURE 1—Typical Polarization Decay Curve

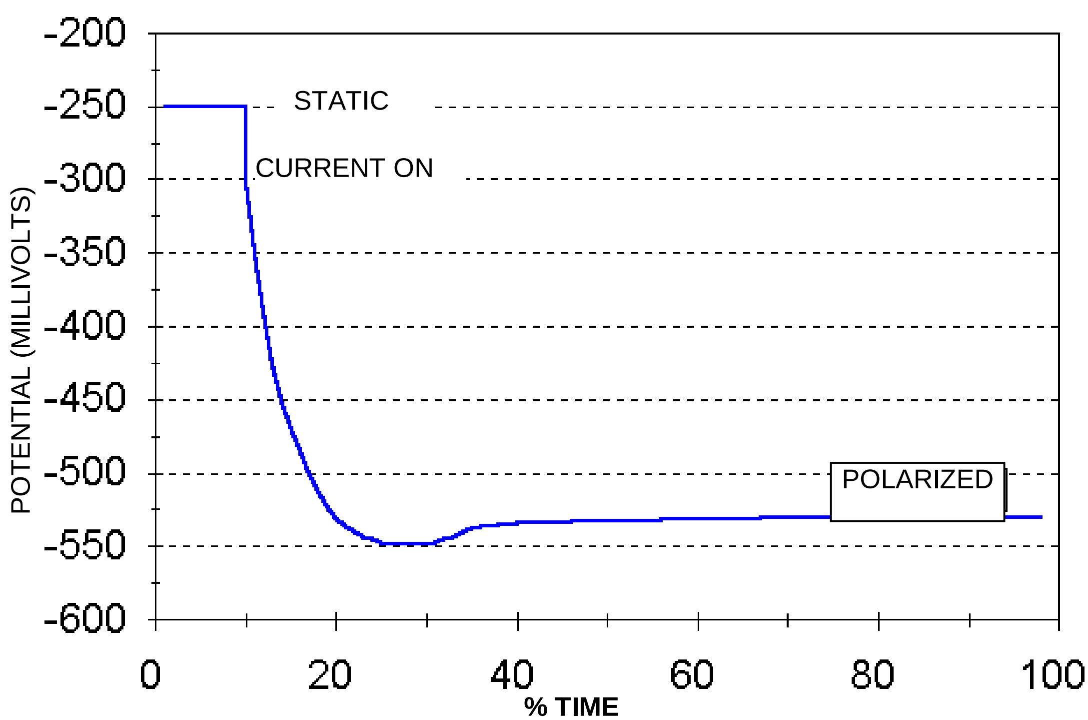

FIGURE 2—Typical Polarization Development Curve Showing "Instant-Off" Potentials Only

2.3.1.4 Changes in environmental conditions such as temperature and moisture can significantly change the native corrosion potential, decayed off-potential, and rate of decay being measured from one day to the next. Therefore, during the polarization measurement interval, the corrosion engineer shall monitor for the impact of these phenomena throughout the test period to ensure that these conditions have not affected the readings. The period for potential decay or polarization development is largely determined by oxygen availability at the reinforcement surface and is not a reflection of the efficiency of the cathodic protection system. Longer periods of decay or polarization development are required for less permeable, coated, or water-saturated concrete.

2.3.2 E-log I Test

2.3.2.1 An E-log I test is conducted by application of cathodic current to the steel, followed by measurement of the potential response of the steel. The results are analyzed graphically after plotting (E) versus the logarithm of the applied current (log I). The use of the E-log I test procedure is subject to the practitioner's interpretation of the data obtained. Consequently, this technique is more often used to determine the initial cathodic protection current requirement.

Section 3: Design of Impressed Current Cathodic Protection Systems

3.1 Introduction

3.1.1 This section provides guidelines for designing impressed current cathodic protection systems that will satisfy the criteria listed in Section 2 and that will exhibit maximum reliability over the intended operating life of the systems.

3.2 Impressed current cathodic protection systems

3.2.1 Impressed current cathodic protection systems consist of anodes and a source of direct current power.

3.2.2 The following types of impressed current cathodic protection system anodes are currently available:

3.2.2.1 Conductive overlays, which consist of conductive materials dispersed in a binder applied to the surface of the concrete structure.

3.2.2.2 Carbon-based conductive coatings applied to the concrete.

3.2.2.3 Thermally sprayed metallic coatings.

3.2.2.4 Conductive materials that are mechanically attached to the concrete structure surface and overlayed with a cementitious material.

3.2.3 Impressed current anodes can be materials such as platinum clad or electroplated on niobium or titanium, conductive polymers, carbon-based or metallic coatings, mixed-metal-oxide coated titanium, conductive grouts, and conductive asphaltic concrete.

3.3 Information useful for selecting and designing an impressed current cathodic protection system includes:

3.3.1 As-built drawings of the concrete structure

3.3.2 Condition survey (in accordance with ACI 201[9])

3.3.3 Potential survey (in accordance with ASTM C 876)

3.3.4 Chloride analysis of the concrete

3.3.5 Electrical continuity of the embedded metal

3.3.6 Repair and maintenance history

3.3.7 Concrete cover

3.3.8 AC power availability

3.3.9 Concrete resistivity data

NOTE: Some additional information useful for design is included in Appendix B.

3.4 Parameters for selection of the impressed current cathodic protection system

3.4.1 The cathodic protection system shall provide sufficient current to the structure to be protected and distribute this current so that the selected criterion for cathodic protection is attained.

3.4.2 The design life of the cathodic protection system must be commensurate with the required life of the protected concrete structure.

3.4.3 Electrochemical performance of the anodes

3.4.3.1 Anode materials have different rates of consumption when discharging a given current density from the anode surface in a specific environment. Therefore, for a given current density, the anode life depends on the electrochemical properties of the anode material, volume, surface area, and geometry.

3.4.3.2 The system shall be designed to limit the maximum sustained current density at the effective surface contact area between the anode and the concrete to levels below 108 mA/m^2 (10.0 mA/ft^2). Sustained operation at current densities above these levels may result in deterioration of the concrete at the anode-concrete interface.

3.4.3.3 The anode material selected should be resistant to the electrochemical reactions that occur at the anode-concrete interface.

3.4.3.4 Concrete drying effects can limit the ability of the anode to deliver adequate current at specified circuit voltage.

3.4.4 Structural considerations

3.4.4.1 The physical space available, access, maintenance of right-of-way, safety, and other construction and maintenance aspects should be considered. Overhead clearance and dead load constraints may preclude the use of overlay systems in some areas of concrete structures.

3.4.4.2 Future repairs to the concrete structure and future extensions to the cathodic protection system should be considered.

3.4.4.3 The physical properties of anode material selected must be compatible with the concrete structure.

3.4.4.4 Durability, shrinkage, ease of repair and, if relevant, skid resistance of wearing surfaces should be considered in the selection of anode systems.

3.4.4.5 The effect of construction and repair techniques that utilize insulating materials (e.g., epoxy injection), high temperature (e.g., asphaltic overlays), or impact loads should be considered in the selection of anode systems, instrument design, and wiring methods.

3.5 In the design of an impressed current cathodic protection system, the following items should be considered.

3.5.1 Materials and installation practices that conform to applicable codes and standards such as the National Electrical Code[10] issued by the NFPA,[(4)] those issued by OSHA,[(5)] NEMA,[(6)] NACE, ACI,[(7)] ASTM, and any other applicable codes or standards should be specified.

3.5.2 Detailed specifications should be given for all materials and installation practices to include transportation, storage, handling, and disposal that are to be incorporated in construction of the impressed current cathodic protection system. When performance specifications or requirements are used, specific evaluation procedures should be outlined or citations published, and recognized industry standards should be listed. Terminology should be clearly defined.

3.5.3 Voltage and current attenuation along the anode and its connecting wire in distributed anode impressed current systems should be evaluated. The design should optimize anode system length, anode spacing and size, and conductor size in order to achieve the criteria set forth in Section 2.

3.5.4 The proximity of anodes to other metallic embedments such as form ties, chairs, tie wire, embedment plates, and electrical conduit shall be determined. Minimum depth of cover over the reinforcement must be maintained in accordance with the manufacturer's recommendations. If the minimum cover cannot be maintained, insulating methods should be used to prevent deadshorts or near shorts in specific areas.

3.5.5 Rectifiers should be selected to provide adequate allowance for anticipated changes in current requirements and circuit resistance with time. Circuit resistance is related to the type of concrete used, internal moisture content, temperature, and chloride content with their respective fluctuations.

3.5.6 Components should be located where the possibility of damage is minimal.

3.5.7 System design shall provide safe step-and-touch potentials.

3.5.8 Suitable design drawings that clearly delineate the overall layout of the concrete structure to be protected should be prepared. The location of significant items of system hardware, corrosion control test stations, electrical bonds, electrical insulators, and adjacent metallic embedments should be shown.

3.5.9 Design or shop drawings, details, and schedules for each impressed current cathodic protection installation should be prepared to show quantities, detailed anode layout, relevant typical cross-sections, and location of the components within the protected concrete structure(s). Tolerances should be stated.

3.5.10 In areas where stray currents are suspected, appropriate tests should be conducted. Special considerations may be required to achieve the criteria set forth in Section 2 when stray currents are encountered.

3.5.11 Cathodic protection may not be appropriate to protect certain metal items mounted on, in, or adjacent to the protected concrete structure. Electrical isolation and avoiding stray current corrosion of such items should be addressed during the cathodic protection system design.

[(4)] National Fire Protection Association (NFPA), 1 Battermarch Park, Quincy, MA 02269-9101.
[(5)] Occupational Saftey and Health Administration (OSHA), 200 Constitution Ave NW, Washington, DC 20210.
[(6)] National Electrical Manufacturers Association (NEMA), 1300 N. 17th St. Ste. 1847, Rosslyn, VA 22209.
[(7)] American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333.

3.5.12 Redundancy of current output, circuitry, and monitoring components and the capacity to readily isolate sections of the impressed current cathodic protection system can be beneficial. These features can minimize the area affected by a malfunction or physical damage.

Section 4: Installation Practices

4.1 It is critical for the successful operation of the impressed current cathodic protection system that all materials and equipment be installed according to manufacturer's and design specifications. Installation procedures include intermediate testing, quality assurance of materials, and application restrictions. Materials and installation practices should conform to applicable codes and standards such as the National Electrical Code, those issued by OSHA, NEMA, NACE, ACI, ASTM, and any other applicable codes or standards.

4.2 Quality assurance of materials should be made by acceptance of manufacturer's certification, on-site test, or sample testing in a qualified independent laboratory. Quality assurance requirements should be clearly stated in the design specifications.

4.3 Ongoing inspection and testing shall be conducted throughout construction to ensure that design and manufacturer's specifications are met and recorded.

4.3.1 Electrical continuity or isolation requirements between reinforcing bars and other embedded metals must be verified.

4.3.2 Equipment used for installation shall be in accordance with manufacturer's specifications and any other conditions specified by the material's manufacturer or design specifications.

4.3.3 Pertinent storage and application restrictions should be given in the design specifications. Such restrictions include, but are not limited to, temperature, relative humidity, surface moisture content, and surface preparation.

Section 5: Energizing and System Adjustment

5.1 This section presents recommended procedures for the energizing and adjustment of an impressed current cathodic protection system.

5.2 Component Installation Inspection

5.2.1 Prior to energizing, the AC service to the cathodic protection system shall be inspected for compliance with the National Electrical Code and such local codes and ordinances that may be applicable or in force. It shall be verified that the AC service voltage, phase, and wiring size are compatible with the cathodic protection rectifier.

5.2.2 Prior to energizing, the rectifier shall be inspected. The integrity of all AC input and DC output connections shall be verified. All mechanical fasteners shall be inspected and tightened or replaced if appropriate.

5.2.3 The primary and, if appropriate, secondary anodes, including feed circuitry, shall be visually inspected for proper installation. It shall be established that no short circuits exist between any anode material and any metal embedments.

5.2.4 The electrical continuity between all the steel reinforcement and other metal embedments intended to be cathodically protected shall be tested at accessible locations.

5.2.5 Electrical isolation of metal mounted on, in, or adjacent to the protected concrete structure and not designed to be cathodically protected should be verified.

5.2.6 All reference and monitoring devices and attendant hardware shall be inspected for proper installation and operation in accordance with the manufacturer's instructions and design specifi-cations. The open-circuit potential of all permanent reference electrodes shall be measured against a closely placed, calibrated, stable portable reference electrode.

5.2.7 Additional cathodic protection equipment and associated components shall be inspected for proper installation and operation in accordance with the manufacturer's instructions and design specifi-cations.

5.3 System Energizing and Adjustment

5.3.1 After completion of the component installation inspection, the impressed current cathodic protection system shall be energized. Each rectifier shall be turned on and operated manually at not more than 20% of the full rated maximum design current output.

During this initial energizing period, all circuits shall be tested.

5.3.1.1 Proper circuit polarity shall be verified.

5.3.1.2 The rectifier shall be tested for proper operation. The accuracy of all rectifier meters shall be verified with a calibrated portable meter.

5.3.1.3 Proper cathodic protection current distribution through all anode feed circuits shall be determined. If panel boards for such testing were not included in the system design, clamp-on DC ammeters or other techniques should be used.

5.3.1.4 The anodes shall be inspected for proper operation. Areas of relatively high initial current discharge shall be investigated.

5.3.1.5 Reference electrodes and other monitoring devices shall be tested.

5.3.1.6 Additional equipment required by the cathodic protection system design shall be inspected for proper operation.

5.3.2 After completion of the initial energizing inspection, the impressed current cathodic protection system should be adjusted for current requirements in accordance with Section 2.

5.3.3 After adjustment, the cathodic protection system should be operated continuously for a period of at least one month before conducting acceptance testing to verify that the operational criterion selected in Section 2 is being met. Environmental or physical extremes can affect system performance and must be considered in acceptance testing.

5.3.4 Tests should be conducted to verify that electrically isolated metal is not adversely affected by stray current from the operation of the impressed current cathodic protection system.

Section 6: Operation and Maintenance of Impressed Current Cathodic Protection Systems

6.1 This section presents recommended procedures and practices for maintaining continuously effective and efficient operation of impressed current cathodic protection systems.

6.1.1 Electrical measurements and inspections are necessary to determine that, once achieved, protection according to the selected criterion is maintained and that each part of the impressed current cathodic protection system is operating properly. Conditions that affect protection are subject to change with time. Corresponding changes may be required in the cathodic protection system to maintain protection. Periodic measurements and inspections are necessary to detect changes in the cathodic protection system. Conditions in which operating experience indicates that testing and inspections need to be made more frequently than recommended herein can exist.

6.1.2 Adequate locations, number, and types of electrical measurements shall be used to determine the effectiveness of cathodic protection.

6.2 All cathodic protection systems should be inspected as part of a preventive maintenance program to minimize in-service failure. Inspections should include a check for electrical shorts, ground connections, meter accuracy, rectifier efficiency, and circuit resistance. Annual surveys should be conducted to verify that the cathodic protection system is meeting the protection criterion. The accuracy of permanent embedded reference electrodes should be evaluated during these surveys. The effectiveness of continuity bonds and isolation of cathodic protection circuits should be evaluated during the periodic surveys. These surveys should be conducted under the direction of persons described in Section 1 of this standard.

6.3 All sources of impressed current should be checked at intervals of one month or at such intervals as necessary to ensure effective operation of the system. Evidence of proper functioning can be normal current and voltage output, a signal indicating normal operation, or a satisfactory polarized potential state of the embedded steel.

6.4 The test equipment used for obtaining cathodic protection data should be of an appropriate type. Instruments and related equipment should be maintained in good operating condition and checked periodically for accuracy. A list of appropriate test equipment is provided in Appendix C.

6.5 Remedial measures should be taken where annual surveys and inspections indicate that protection is no longer effective. These measures may include the following:

6.5.1 Repair, replace, or adjust components of the cathodic protection system.

6.5.2 Provide supplementary cathodic protection where additional protection is necessary.

6.5.3 Repair, replace, or adjust continuity bonds and defective isolating devices.

6.6 An operations and maintenance manual that includes the following information should be provided.

6.6.1 Description of concrete structure and impressed current cathodic protection system.

6.6.2 As-built drawings of cathodic protection system.

6.6.3 Periodic inspection requirements.

6.6.4 System output parameters.

6.6.5 Rectifier maintenance requirements.

6.6.6 System physical maintenance requirements.

6.6.7 Spare parts list.

6.6.8 System reporting records.

6.6.9 Required test procedures.

6.7 A training program should be provided for the owner/operator and should include the necessary information and data required for system operation.

6.7.1 System operation training shall include the following:

6.7.1.1 Adjustment and operation of the rectifier and components.

6.7.1.2 Adjustment of other related components of the cathodic protection system.

6.7.1.3 Evaluation of electrical continuity bonds and effectiveness of electrical isolation.

6.7.1.4 Proper use of other associated components, including reference electrodes and test coupons.

6.7.1.5 Reinforcement and permanent reference electrode potential measurements.

6.7.1.6 Current and voltage measurements.

Section 7: Records

7.1 Records of the cathodic protection system shall be maintained. This provides reference to previously obtained data in the event that changes occur, troubleshooting is required, or modifications or additions are made to the system. These records should include all the physical, design, and test data accumulated on the installation.

7.2 The following information, if collected during the design survey, should be made an integral part of the record.

7.2.1 Results of chloride in concrete tests and other chemical and physical analyses.

7.2.2 Delamination survey data.

7.2.3 Depth-of-cover data.

7.2.4 Reinforcement and permanent reference electrode potential data.

7.2.5 Electrical continuity and electrical isolating data.

7.2.6 Current requirement data.

7.3 During installation of the impressed current cathodic protection system, certain tests should be performed to ensure a quality installation. The following data should be part of the records:

7.3.1 Electrical continuity verification.

7.3.2 Tests for electrical shorts.

7.3.3 Tests for electrical isolation.

7.4 The following additional information, if available, shall be included in the permanent records of the impressed current cathodic protection system:

7.4.1 Tests conducted to determine that all components are in working order prior to permanent energizing.

7.4.2 Reinforcement potential data at representative locations prior to energizing the system.

7.4.3 Reinforcement potential data at representative locations after energizing the system.

7.4.4 Criterion compliance data.

7.4.5 Final rectifier data including voltage and current outputs, mode of control including limits, rectifier serial number, and AC and DC capacity.

7.4.6 Current density and distribution data.

7.5 Detailed as-built drawings and data should be incorporated into the permanent records.

7.6 The operation and maintenance manual shall become a part of the permanent records for the system.

References

1. NACE Standard RP0187 (latest revision), "Design Considerations for Corrosion Control of Reinforcing Steel in Concrete" (Houston, TX: NACE).

2. NACE Standard RP0390 (latest revision), "Maintenance and Rehabilitation Considerations for Corrosion Control of Existing Steel Reinforced Concrete Structures" (Houston, TX: NACE).

3. NACE Publication 11100 (latest revision), "Use of Reference Electrodes for Atmospherically Exposed Reinforced Concrete Structures" (Houston, TX: NACE).

4. Work in Progress by NACE Task Group T-11-1d, "Criteria for Cathodic Protection of Prestressed Concrete Structures" (Houston, TX: NACE).

5. ASTM E 105 (latest revision), "Standard Practice for Probability Sampling of Materials" (West Conshohocken, PA: ASTM).

6. ANSI/ASQC Z1.4 (latest revision), "Sampling Procedures and Tables for Inspection by Attributes" (Milwaukee, WI: ASQC).

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Appendix A— Glossary of Terms

Attenuation: Electrical losses in a conductor caused by current flow in the conductor.

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

Depolarization: The removal of factors resisting the current in an electrochemical cell.

Design Specifications: A set of documents that, in aggregate, form the nucleus for well-founded, understandable, and equitable contract documents. These documents include written specifications and drawings.

Drying Effect: Migration of water molecules away from the anode as a result of current flow.

Electrical Continuity: A closed circuit (unbroken electrical path) between metal components under consideration.

Electrical Isolation: The condition of being electrically separated from other metallic structures or the environment.

Electrode Potential: The potential of an electrode in an electrolyte as measured against a reference electrode. (The electrode potential does not include any resistance losses in potential in either the electrolyte or the external circuit. It represents the reversible work to move a unit of charge from the electrode surface through the electrolyte to the reference electrode.)

Energizing: The process of initially applying power to turn on an impressed current cathodic protection system.

Immediate Voltage Shift: The difference between the potential value when the power source is on and the instant-off value. (This is also referred to as IR Drop.)

Instant Off Potential: The polarized potential of an electrode with respect to a reference electrode taken immediately after the impressed current flow is stopped (closely approximates the IR-free value when there was current flow).

Overlay: A layer of concrete or mortar placed over and usually bonded onto the worn or cracked surface of a concrete slab to restore or improve the function of the previous surface.

Polarization: The change from the open-circuit potential as a result of current across the electrode/electrolyte interface.

Polarization Decay: The decrease in electrode potential with time resulting from the interruption of applied current.

Potential Survey: Obtaining potentials with respect to a reference electrode at multiple locations on the surface of the concrete structure.

Prestressed Concrete: Concrete in which internal stresses of such magnitude and distribution are introduced that the tensile stresses resulting from the service loads are counteracted to a desired degree; in reinforced concrete the prestress is commonly introduced by tensioning the tendons.

Rectifier: An electrical device for converting alternating current to direct current.

Reference Electrode: An electrode whose open-circuit potential is constant under similar conditions of measurement, which is used for measuring the relative potentials of other electrodes.

Step-and-Touch Potentials: The electrical potential gradients that may exist between two points on the electrolyte surface equal to one pace (one meter) or between a grounded metallic object and a point on the electrolyte surface separated by the distance equal to a human's normal reach (one meter).

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

Appendix B—Additional Information Useful for Design

1. Site-related:

    a. Location
    b. Climate
    c. Exposure
    d. Use
    e. Access
    f. Environmental factors
    g. Chloride source
    h. Possible stray current sources

2. Structure-related:

    a. Use restrictions
    b. Design load
    c. Construction dates
    d. Repair details and history
    e. Concrete design properties
    f. Reinforcing details
    g. Other embedments
    h. Overlays, sealers, membranes
    i. Chloride test and chemical analysis
    j. Chloride source
    k. Potential survey
    l. Delamination survey
    m. Cover survey
    n. Continuity of embedded metal
    o. Existing cathodic protection
    p. Electrical isolation from foreign structures
    q. Location and details of joints
    r. Location and details of drains and scuppers and drainage conditions
    s. Location and details of railings
    t. Location of lighting, conduits, and pipes
    u. Prestressed elements
    v. Sulfates
    w. Carbon dioxide
    x. pH
    y. Resistivity

3. System-related:

    a. Circuit resistances
    b. Power supply rating and location
    c. Current distribution
    d. Anode current densities
    e. Instrumentation for monitoring
    f. Physical, electrical, and environmental protection of components
    g. Maintenance interval
    h. Materials
    i. Equipment

j. Electrode reactions
k. Protective current requirements to meet applicable criteria (see Section 2)
l. Electrical resistivity of the concrete
m. Electrical continuity
n. Electrical isolation
o. Stray currents
p. Other maintenance and operating data
q. Connections and splices
r. Step-and-touch potentials

Appendix C— Test Equipment

Equipment used for evaluating corrosion and corrosion control of reinforced concrete can include the following:

1. pH testing equipment
2. Resistivity meter—AC type
3. Sulfate and chloride test equipment
4. DC voltmeter with variable input impedance
5. Multimeter (AC-DC volts, ohms, amps, 10 megohm minimum)
6. Portable reference electrodes
7. DC source: generator/battery
8. Equipment for use during current requirement tests
9. Reinforcement depth-of-cover meter
10. Metal detector

ISBN 1-57590-103-X