

Standard Practice

Sacrificial Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures

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Foreword

This NACE International standard practice presents guidelines for sacrificial (galvanic) cathodic protection (SACP) of reinforcing steel in atmospherically exposed concrete elements or structures. These guidelines target owners, engineers, architects and contractors, and those concerned with mitigation of reinforced concrete corrosion through the application of SACP systems.

The information in this standard, as it relates to SACP systems, is intended for atmospherically exposed concrete structures and is not applicable to concrete with nonferrous reinforcement, epoxy-coated, galvanized, or other types of coated reinforcement. SACP has been successfully applied to buried and submerged reinforced concrete structures; however, these applications are not addressed in this standard.

TG 047 is comprised of corrosion consultants, consulting architects and engineers, material manufacturers and suppliers, cathodic protection engineers, metallurgical engineers, researchers, structure owners, contractors, and representatives from both industry and government.

For more information on the various SACP systems that are commercially available, refer to NACE Publication 01105.¹

This standard was prepared in 2016 by Task Group (TG) 047 “Reinforced Concrete: Sacrificial Cathodic Protection of Reinforced Concrete Elements.” TG 047 is administered by Specific Technology Group (STG) 01, “Reinforced Concrete;” and is sponsored by STG 05, “Cathodic/Anodic Protection.” This standard is issued by NACE under the auspices of STG 01.

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*. The terms *shall* and *must* are used to state a requirement, and are considered mandatory. The term *should* is used to state something good and is recommended, but is not considered mandatory. The term *may* is used to state something considered optional.

**NACE International
Standard Practice**

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Section 1: General

1.1 Background

1.1.1 The corrosion reaction between a metal and its environment is an electrochemical cell. An electrochemical cell consists of four components: an anode, where oxidation occurs; a cathode, where reduction occurs; a metallic path, where current flows; and an electrolyte (concrete), where ion transfer occurs in a shared environment. If any one of the four elements of the electrochemical cell is eliminated, corrosion cannot occur. The anodic and cathodic areas can occur, for example, as a result of exposure to differential environmental conditions or coupling dissimilar metals.

1.1.2 Reinforcing steel is compatible with concrete because of their similar coefficients of thermal expansion and because concrete generally provides the steel with corrosion protection. Corrosion protection is the result of the highly alkaline portland cement that allows a stable, passivating film to form on the surface of the reinforcing steel. This film naturally protects the steel until the film is affected. Mechanisms that affect the protective film and lead to corrosion include carbonation and other mechanisms that reduce the pH of the concrete and contamination of the concrete by chlorides, and other halides and chemicals that are corrosive to reinforcing steels. Carbonation results from atmospheric carbon dioxide diffusing through concrete and decreasing the alkalinity of concrete. Chloride contamination also affects the passive film. Chlorides can be cast in concrete or penetrate concrete from external sources such as seawater, deicing salts, or other chemicals.

1.2 Sacrificial Cathodic Protection (SACP)

1.2.1 The basic principles of corrosion can be used to understand the theory of SACP. SACP is defined as a technique to mitigate corrosion of a metal by making it the cathode in a corrosion cell via the introduction of a metal that is more electrochemically active in that environment than the metal to be protected.

1.3 Scope and Limitations

1.3.1 The provisions of this standard shall be applied under the direction of a registered professional engineer, or a person certified by NACE as a corrosion specialist or cathodic protection specialist. The professional's qualifications 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 should be made by a structural engineer.

1.3.2 The guidelines presented here are limited to SACP on existing atmospherically exposed concrete structures. This standard applies to both conventionally reinforced concrete and prestressed reinforced concrete.

1.3.3 SACP systems require monitoring provisions to determine the performance and to comply with this standard. SACP systems used without monitoring systems or methods to measure their performance do not comply with this standard practice as their performance cannot be verified.

1.3.4 Cathodic protection is a proven technique for controlling corrosion of steel in existing structures for certain applications. However, cathodic protection neither replaces lost steel nor returns corroded reinforcement to its original diameter. Although a reinforced concrete element may appear sound by traditional inspection techniques after a SACP system is installed, it could be experiencing corrosion-related tensile stress near ruptures in localized areas. This may lead to movements, deflection, cracking, delaminations or spalls that can appear several years subsequent to the installation of the SACP system.

1.3.5 Sacrificial anode systems have inherent limited current output characteristics and electrochemical characteristics. Accordingly, sacrificial cathodic protection systems may not always be the best system for all combinations of structure, environment, distress, and design life.

NOTE: For further information, refer to the glossary of terms in Appendix A (nonmandatory).

Section 2: Design of Sacrificial Cathodic Protection Systems

2.1 Introduction

2.1.1 This section provides guidelines for designing SACP systems for their intended service life.

2.2 Anode selection

2.2.1 SACP systems consist of sacrificial anodes and a connection between the anode and the reinforcing steel.

2.2.2 The following types of sacrificial anodes are currently available:

2.2.2.1 Embedded discrete anodes

2.2.2.2 Surface-applied anodes

2.2.2.3 Surface-mounted anodes

Refer to NACE Publication 01105¹ for system type and descriptions.

2.3 The design current density range to achieve cathodic protection is normally between 2 and 11 mA/m² (0.2 and 1 mA per ft²) of steel. This current density range should be used to determine the required anode mass unless data is available to justify an alternative value.

2.4 Information useful for selecting and designing SACP system includes:

2.4.1 As-built drawings of the concrete structure

2.4.2 Condition survey (in accordance with NACE SP0308² and ACI⁽¹⁾ 201.1R-08.³

2.4.3 Corrosion potential survey in accordance with NACE SP0308 and ASTM⁽²⁾ C876⁴

2.4.4 Chloride analysis of the concrete

2.4.5 Electrical continuity of the embedded metal

2.4.6 Repair and maintenance history (in accordance with NACE SP0390⁵)

2.4.7 Concrete cover (in accordance with NACE SP0308)

⁽¹⁾ American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333-9094.

⁽²⁾ ASTM International (ASTM), 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

2.4.8 Concrete resistivity data (in accordance with NACE SP0308)

2.5 Parameters for selection of the SACP system

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

2.5.2 The design life of the cathodic protection system must be considered in relation to the remaining service life of the protected concrete structure.

2.5.3 Electrochemical performance of the anodes

2.5.3.1 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 as well as physical properties of the anode such as volume, surface area, and geometry.

2.5.3.2 Concrete drying effects can limit the delivery of adequate current levels. A humectant may be used for certain types of anode to enhance the delivery of current under these circumstances.

2.5.3.3 Chemically enhanced mortars have been developed to encapsulate certain types of anode. The mortars are intended to enhance current delivery.

2.5.4 Structural Considerations

2.5.4.1 Access, maintenance of the right-of-way, ease of repair, and skid resistance (for traffic surfaces) should be considered during the selection of anode systems. Overhead clearance and dead load constraints may preclude the use of overlay systems for some structural elements.

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

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

2.5.4.4 The effect of construction and repair techniques that use high-resistivity materials (e.g., epoxy injection), high temperatures (e.g., asphaltic overlays), or impact loads should be considered during the selection of anode systems, instrument design, and wiring methods.

2.6 In the design of SACP systems, the following items should be considered:

2.6.1 Detailed specifications should be given for all materials and installation practices and shall include transportation, storage, handling, and disposal requirements for all materials that are to be incorporated in the installation of the SACP system. When performance specifications or requirements are used, specific evaluation procedures should be cited, and recognized industry standards should be listed. Terminology should be clearly defined.

2.6.2 Suitable design drawings that delineate the overall layout of the concrete to be protected should be prepared. The location of significant items of system hardware including but not limited to test stations, electrical bonds, electrical insulators, and adjacent metallic embedments should be shown.

2.6.3 The design should optimize anode layout and installation to achieve the criteria set forth in Section 3.

2.6.4 The proximity of anodes to 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 or engineer's design recommendations.

2.6.5 The components of the SACP should be located to minimize the possibility of damage or vandalism.

2.6.6 Design or shop drawings, details, and schedules for each SACP installation should be prepared to show quantities, detailed anode layout, relevant typical cross-sections, and location of the components within the protected concrete elements or structure. See Appendix B (nonmandatory) for additional information.

Section 3: Criteria

3.1 The criteria in this section serve as a guide for achieving cathodic protection and providing corrosion control of reinforcing steel embedded in atmospherically exposed concrete. Compliance with these criteria to assess performance of a cathodic protection system should be evaluated on a case-by-case basis.

3.2 Monitoring points should be in accordance with ASTM E105.⁶ Sample size should be determined in accordance with ANSI⁽³⁾ Z1.4⁷ with the unit of product typically being 1.0 m² (1.00 yd²) of protected metal surface area. Situations in which physical conditions effectively preclude full implementation of sampling programs derived from ASTM E105 and ANSI Z1.4 may exist. Examples of these cases include asphalt or other nonconductive overlays, and situations in which access to the cathodically protected surface is difficult and limited. 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.

3.3 Sacrificial anodes are directly electrically connected to the reinforcing steel. Therefore, measurements should be taken where testing can be conducted. The number and location of these test areas should be representative and consistent with the characteristics of the structure.

3.4 Measurement of potentials is essential to determine compliance with criteria for cathodic protection. Measurements obtained using a reference electrode shall be obtained using techniques described in ASTM C876. Potentials of reinforcing steel or other embedded metals can be measured using an external/portable or internal/embedded reference electrode.

3.5 The following criteria were developed through empirical evaluation of data obtained from successfully operated impressed current cathodic protection systems. Those using this standard should review data made available after this standard's publication to determine whether more effective criteria have been established

3.5.1 -720 mV CSE Criteria

3.5.1.1 If the potential of the steel in wet saturated concrete is more negative than -720 mV versus a copper/copper sulfate reference electrode (CSE) with the sacrificial anode disconnected, then the steel is considered not to be corroding. Care must be exercised that the sacrificial anode is not shorted with the steel thereby giving misleadingly negative potentials.

3.5.2 100 mV Polarization Development/Decay

3.5.2.1 A minimum of 100 mV of polarization should be achieved at the most anodic location in each 50 m² (500 ft²) area, or at artificially constructed anodic sites, provided its corrosion potential or decayed off-potential is more negative than -200 mV 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.

⁽³⁾ American National Standards Institute (ANSI), 25 West 43rd St., 4th Floor, New York, NY 10036.

3.5.2.2 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 occurs that is the result of eliminating the IR drop. 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 decay equals the instant-off potential subtracted from the reinforcement's final "depolarized potential."

3.5.2.3 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.

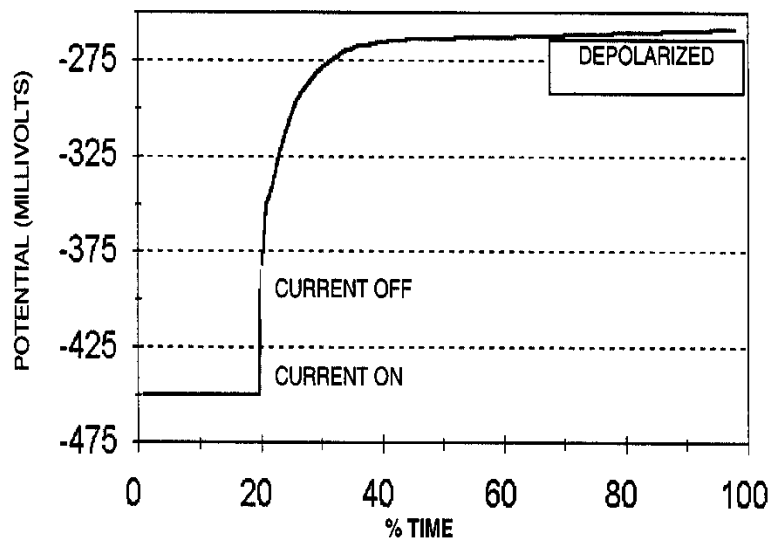


FIGURE 1: Typical Polarization Decay Curve

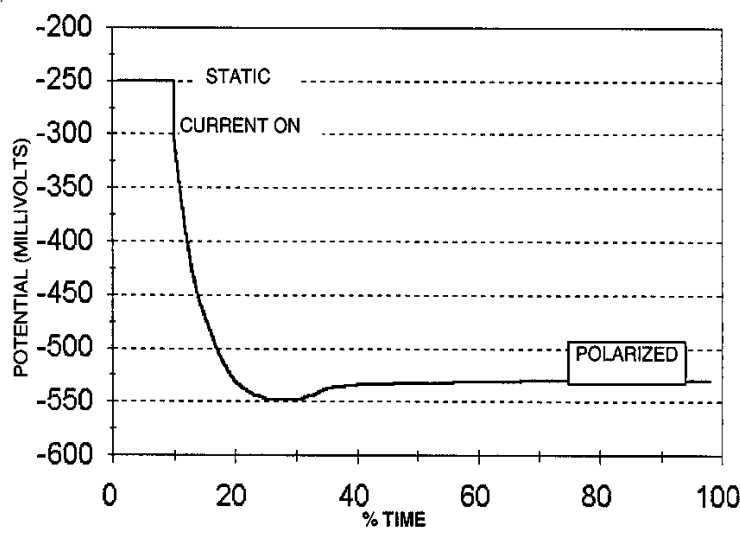


FIGURE 2: Typical Polarization Development Curve Showing "Instant-Off" Potentials Only

3.5.2.4 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, their impact shall be monitored throughout the test period. The period for potential decay or polarization development is largely determined by oxygen availability at the reinforcement surface and is not necessarily indicative of the performance of the SACP system. Longer periods of decay or polarization development are required for less permeable, coated, or water-saturated elements.

3.5.3 The most negative polarized potentials for susceptible prestressing steel should not be more negative than $-1,000$ mV CSE.

3.6 As SACP cannot be adjusted, it is imperative that sufficient anode material is installed to provide the desired service life extension.

3.7 In the event that the criteria are not met (i.e., there is insufficient current output at measured location) then notification must be provided to the owner stating that insufficient levels of protection are being provided.

3.8 If the interpretation of the performance assessment data indicates that criteria for protection are achieved, no further action is required. If they are not achieved and it is not possible to increase current to the steel, a further assessment of the corrosion risk shall be made. If deemed necessary, the SACP anode can be supplemented to mitigate this risk.

3.9 Where SACP anode installations are designed for an anode life in excess of five years, the performance of the system should be checked by potential and current measurement at regular intervals. Where junction boxes or similar devices are provided, current should be measured in addition to potential to confirm that the anodes are providing acceptable levels of protection. A record of the current output also enables an estimate to be made of the anode consumption. This is, however, impossible where anodes are permanently connected to the surface of the metal.

Section 4: Installation

4.1 General requirements

4.1.1 The performance of the SACP system can be detrimentally affected by defects in the installation. Materials and installation practices should conform to applicable codes and standards such as those issued by Occupational Safety & Health Administration⁽⁴⁾ (OSHA), NACE, ACI, ASTM, and any other applicable codes or standards. In addition, the installation of the SACP system should be carried out in a manner that minimizes impact to the environment.

4.2 Materials and Equipment

4.2.1 The manufacturer shall provide certificates of alloy composition for each batch or production run for the anodes delivered onsite for installation. Independent sample testing, if required, should be conducted by an accredited laboratory at the sampling rates established in the project specifications.

4.2.2 Specialty installation equipment, such as thermal spray equipment for application of metalized anodes, shall be as specified in the design documents. The equipment shall be certified by the original manufacturer as fit for the intended use. In addition, unless specifically excluded from the project specifications, all equipment and parts shall be commercially available.

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

4.2.4 Quality control testing equipment should be as specified in the project specifications. The equipment should be within calibration dates. Calibration certificates should be maintained by the installing contractor and/or quality control inspector for review as needed.

4.3 Concrete Repairs

4.3.1 Repair methods and materials can affect the operation and performance of cathodic protection systems. In particular, the resistivity of the repair materials can interfere with current output from the sacrificial anodes and current delivery to the reinforcing steel.

4.3.2 Concrete surface repairs in areas to receive cathodic protection should be performed with a repair mortar that is compatible with the SACP system.

4.3.3 Concrete surface repairs should be conducted in accordance with the project specifications as well as International Concrete Repair Institute⁽⁵⁾ (ICRI) and ACI applicable guidelines or standards.

4.3.4 The repair concrete material shall be allowed to cure for a minimum of 48 hours before applying metalized zinc anodes. For applications using aluminum alloy anodes the concrete must be cured until the pH stabilizes before applying the anode to achieve satisfactory bond strength.

4.3.5 Point anodes should be fully encapsulated by the cementitious repair material.

⁽⁴⁾ Occupational Safety & Health Administration (OSHA), U.S. Dept. of Labor, 200 Constitution Ave NW, Washington, DC 20210.

⁽⁵⁾ International Concrete Repair Institute (ICRI) 10600 West Higgins Road, Suite 607, Rosemont, IL 60018.

4.4 Electrical continuity testing and correction

4.4.1 Proper operation and performance of cathodic protection systems depends on electrical continuity of the reinforcing steel bars and other embedded metals. Electrical continuity testing, corrections and intended exclusions of foreign metals should be carried out in accordance with the project specifications.

4.4.2 Testing methodology should be as described in the project specifications. Electrical continuity should be, as a minimum, confirmed by testing the exposed reinforcement within open repair cavities. Project specifications may require additional openings deliberately made to test reinforcement for electrical continuity.

4.4.3 Electrical continuity corrections should be carried out in accordance with project specifications. Welded or other connections achieved by heat should be avoided on prestressing steel.

4.4.4 The design may call for specific embedded metals to be excluded from cathodic protection. The contractor shall test to confirm lack of electrical continuity using specified or approved methods. If electrical continuity needs to be corrected, it should be accomplished in accordance with project specifications. Locations should be recorded for future reference.

4.5 Anode and Ground Connections

4.5.1 SACP systems can have the anode permanently connected to the steel reinforcing or they can be connected via a test station. A structure connection facilitates monitoring of the system performance.

4.5.2 Connections to the steel should follow procedures established in the project specifications. The connections should be made on clean steel to minimize contact resistance. Connections should be coated with a nonconductive and moisture resistant protective material if specified.

4.5.3 Care should be used before and after concrete placement to avoid damage to the connection. The electrical continuity between the ground wire and the reinforcing steel should be verified.

4.6 Quality Control

4.6.1 The methods and frequency for quality control during installation should be detailed in the project specifications.

4.6.2 The designated quality control inspector should be qualified by training and experience. The inspector should be familiar with installation procedures, testing methods, and project reporting requirements.

4.7 Commissioning

4.7.1 The project specifications should detail a procedure for energizing or connecting the SACP system, recording the start-up data, and producing a report.

4.7.2 The startup of the SACP system should be conducted by a qualified and experienced cathodic protection specialist, with documented experience with similar SACP systems.

Section 5: Operation and Maintenance of Sacrificial Cathodic Protection Systems

5.1 General

5.1.1 SACP systems require limited ongoing testing and maintenance because of their inherent simplicity and since current adjustments may not be possible. The system's performance should be monitored to determine its service life and to plan maintenance and repair activities. Monitoring may include:

- (a) Visual Survey
- (b) Current Measurements
- (c) Potential Measurements

5.2 Visual Survey

5.2.1 If the anode material is accessible, a visual survey of the anode material is useful to assess its level of consumption, deficiencies in installation, etc.

5.2.1.1 Visual surveys can be useful to identify areas on the protected element or structure with visual evidence of corrosion-induced deterioration in the form of cracks, delaminations and spalls.

5.2.1.2 It is important to match the extent and degree of detail of the survey to the condition of the structure and its importance. Similarly, qualifications and experience of the individual carrying out the survey should be appropriate to the complexity of the survey. See Appendix C (nonmandatory) for additional information.

5.2.2 Anodes should be examined with respect to their condition. Although the inspection may be conducted by qualified technicians or engineers in training, rating of condition or performance should be performed by a qualified corrosion specialist, professional engineer, or structural engineer, as appropriate.

5.3 Current Measurements

5.3.1 In order to obtain current measurements for a SACP system, an electrical connection between anode and steel is made external to the concrete. Wires from both anode and steel may be routed to a junction box to facilitate testing. Current may be measured by placing a digital ammeter between wire leads, or by measuring the voltage across a calibrated shunt/resistor installed between anode and steel, using a digital voltmeter. If an installed shunt/resistor is used, its resistance shall not be greater than 10% of the measured alternating current (AC) resistance between anode and steel. However, higher resistance shunts may be used to deliberately limit current outputs.

5.3.2 If the anode is surface applied, such as with metallized anodes, it may be possible to isolate a section of anode of a defined area. The isolated section of anode may be connected to the surrounding anode through an on/off switch. Current density on the isolated section can be accurately determined by measuring the current flow between the isolated anode and the structure. The isolated anode section should not be less than 0.1 m² (1 ft²). The location and number of isolated sections shall be determined by the exposure, total surface area, and other relevant factors.

5.3.3 Current flow from the steel may be determined by installation of reinforcing steel probes. Probes should be of the same type of steel, and should be installed with concrete cover typical of the structure reinforcement. Each probe should have a wire connected to one end of the probe, and routed outside the concrete to facilitate measurement. Often, chlorides are added to the cementitious repair material that encapsulates the probe.

5.4 Potential Measurements

5.4.1 System performance may also be determined by measurement of steel potential, or polarization development/decay. Potential measurements are more difficult to carry out and interpret than current measurements, but can also be more informative. Measurement of steel potential requires the use of an accurate, stable reference electrode, or reference half-cell, as described in NACE Publication 11100.⁸

5.4.1.1 Reference electrodes may be embedded in the concrete adjacent to a steel reinforcing bar or other steel element to be measured. The reference electrode lead wire should be routed to a junction box to facilitate measurement and monitoring of potential versus the embedded steel. Embedded reference

electrodes are particularly useful for remote monitoring, or for protected elements that are difficult to access. Embedded reference electrodes must be selected, tested, installed, and applied in accordance with NACE Publication 11100.

5.4.1.2 Hand-held portable reference electrodes may also be used to measure the potential of embedded steel where access to the structure is relatively easy. When measuring steel potential beneath a surface-applied sacrificial anode, it is common practice to cut a hole in the anode to gain access to the concrete surface. Such practice can lead to substantial error, especially if the concrete surface is wetted, as is common practice when using a portable reference electrode on a concrete surface, the measurement can be significantly affected by the proximity of the anode. Junction potential, carbonation, or surface contaminants can also corrupt measurements taken from the concrete surface. In such cases, use a potential well or electrolytic bridge to more accurately measure the true potential of the embedded steel.

5.4.1.3 If the polarization development or decay has become insufficient, an indication of the cause can be obtained from a current measurement.

Section 6: Records

6.1 Test Data

6.1.1 Records of the SACP system shall be maintained. This provides reference to previously obtained data in the event that troubleshooting or modifications are required. See Appendix D (nonmandatory) for additional information.

6.2 Condition Assessment of the Structure

6.2.1 The following test data and information obtained as part of the condition assessment of the structure before the SACP system installation should be made an integral part of the record.

6.2.1.1 Visual and delamination survey data

6.2.1.2 Depth-of-cover data

6.2.1.3 Electrical potential of the steel reinforcement (native)

6.2.1.4 Electrical continuity tests of the reinforcing steel

6.2.1.5 Results of chloride in concrete tests and other chemical and physical analysis

6.3 Installation Data

6.3.1 During the installation of the SACP system, certain tests should be performed that are part of quality control. The following data should be part of the records:

6.3.1.1 Electrical continuity verification

6.3.1.2 Structure connection continuity verification

6.3.1.3 Possible electrical shorts that could complicate post-installation testing

6.3.1.4 Date of installation and type of SACP system installed. The contractor should record the date and type of system installed on the structure using a permanent marker.

6.4 Energizing and Monitoring Data

6.4.1 The following information should also be obtained initially when energizing and subsequently when the SACP systems is monitored.

- 6.4.1.1 Electrical continuity between the system negative leads
- 6.4.1.2 AC resistance between the anode and system negative (if specified)
- 6.4.1.3 Static steel potential in proximity to the anode
- 6.4.1.4 Initial current and current after the system has been energized a minimum of four hours
- 6.4.1.5 “Instant-off” and “off” potentials when conducting a polarization decay test

References

1. NACE Publication 01105, “Sacrificial Cathodic Protection of Reinforced Concrete Elements—A State-of-the-Art Report” (Houston, TX: NACE, 2005).
2. NACE SP0308 (latest version), “Inspection Methods for Corrosion Evaluation of Conventionally Reinforced Concrete Structures” (Houston, TX: NACE, 2005).
3. ACI 201.1R (latest version), “Guide for Conducting a Visual Inspection of Concrete in Service” (Farmington Hills, MI: American Concrete Institute).
4. ASTM C876 (latest version), “Standard Test Method for Corrosion Potentials of Uncoated Reinforcing Steel in Concrete” (West Conshohocken, PA: ASTM).
5. NACE SP0390 (formerly RP0390) (latest version), “Maintenance and Rehabilitation Considerations for Corrosion Control of Atmospherically Exposed Existing Steel-Reinforced Concrete Structures” (Houston, TX: NACE).
6. ASTM E105 (latest version), “Standard Practice for Probability Sampling of Materials” (West Conshohocken, PA: ASTM).
7. ANSI Z1.4 (latest version), “Sampling Procedures and Tables for Inspection by Attributes” (New York, NY: ANSI).
8. NACE Publication 11100, “Use of Reference Electrodes for Atmospherically Exposed Reinforced Concrete Structures” (Houston, TX: NACE, 2000).

Appendix A Glossary of Terms (Nonmandatory)

This appendix is intended to provide supplementary information only, although it may contain mandatory or recommending language in specifications or procedures that are included as examples of those that have been used successfully. Nothing in this appendix shall be construed as a requirement or recommendation with regard to any future application of this technology.

Cathodic Protection: A technique to reduce the corrosion rate of a metal surface by making that surface the cathode of 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: the voltage across a resistance when current is applied in accordance with Ohm's law.

Instant-off Potential: The polarized half-cell potential of an electrode taken immediately after the cathodic protection current is stopped, which closely approximates the potential without IR drop (i.e., the polarized potential) when the current was on.

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 corrosion potential as a result of current flow 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.

Reference Electrode: An electrode having a stable and reproducible potential, which is used in the measurement of other electrode potentials.

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

Appendix B Additional Information Useful for Design (Nonmandatory)

This appendix is intended to provide supplementary information only, although it may contain mandatory or recommending language in specifications or procedures that are included as examples of those that have been used successfully. Nothing in this appendix shall be construed as a requirement or recommendation with regard to any future application of this technology.

The following additional information may be useful for design

1. Site-related information:

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

2. Structure-related information:

- (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) Concrete chloride testing 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) Testing or sulfate exposure
- (w) Extent of carbonation
- (x) Concrete pH
- (y) Concrete resistivity

3. System-related information:

- (a) Current distribution
- (b) Anode current densities
- (c) Instrumentation for monitoring
- (d) Physical and environmental protection of components
- (e) Maintenance interval
- (f) Materials
- (g) Equipment
- (h) Protective current requirements to meet applicable criteria (see Section 2)
- (i) Electrical resistivity of the concrete
- (j) Electrical continuity
- (k) Electrical isolation
- (l) Stray currents
- (m) Other maintenance and operating data
- (n) Connections and splices

Appendix C
Survey Equipment
(Nonmandatory)

This appendix is intended to provide supplementary information only, although it may contain mandatory or recommending language in specifications or procedures that are included as examples of those that have been used successfully. Nothing in this appendix shall be construed as a requirement or recommendation with regard to any future application of this technology.

The following documents may be useful for completing the survey and recording the results:

- 1. Standard inspection form
- 2. Site plan
- 3. Field book

Additionally, the basic equipment listed below may also be useful during the survey:

- 1. Camera: digital, 35 mm, video, or any combination of these
- 2. Chalk or spray paint for marking the structure
- 3. Measuring tapes, 3 m (10 ft) and 30 m (100 ft)
- 4. Light chipping hammer
- 5. Pocketknife
- 6. Flashlights or auxiliary lighting equipment
- 7. Binoculars
- 8. Mirrors
- 9. Safety equipment (e.g., hard hat, reflective vest, eye and ear protection)

**Appendix D
Test Equipment
(Nonmandatory)**

This appendix is intended to provide supplementary information only, although it may contain mandatory or recommending language in specifications or procedures that are included as examples of those that have been used successfully. Nothing in this appendix shall be construed as a requirement or recommendation with regard to any future application of this technology.

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

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

