



Standard Recommended Practice

Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures

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Contents

Foreword	1
1. Introduction	1
2. Criteria	1
3. Design of Cathodic Protection Systems	3
4. Installation Practices	5
5. Energizing and System Adjustment	6
6. Operation and Maintenance of Cathodic Protection Systems	7
7. Records	8
Appendix A. General Records	8
Appendix B. Glossary of Terms	8
Appendix C. Some Additional Information Useful for Design	9
Appendix D. Test Equipment	10

Foreword

This NACE standard is a recommended practice prepared by NACE Task Group T-3K-2 of Unit Committee T-3K on Corrosion and Other Deterioration Phenomena Associated with Concrete. It is published by NACE under the auspices of Group Committee T-3 on Corrosion Science and Technology.

The purpose of this recommended practice is to present guidelines for cathodic protection of reinforcing steel in concrete structures. 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. These considerations include guidelines that will provide the design engineer with information to control corrosion of reinforcing steel in portland cement concrete structures through the application of cathodic protection.

Throughout this document, references are made to pertinent available standards. The citations refer to the latest edition of the document referenced, unless stated otherwise. Sources of these standards are given in Appendix A. Of particular interest are NACE Standard RP0187-87, "Design Considerations for Corrosion Control of Reinforcing Steel in Concrete Structures" and NACE Standard

RP0390-90 entitled, "Maintenance and Rehabilitation Considerations for Corrosion Control of Existing Steel Reinforced Concrete Structures."

The provisions of this recommended practice should be applied under the direction of a registered Professional Engineer or a person certificated by NACE as a Corrosion Specialist or certificated 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.

To provide for the necessary expertise on all aspects of the subject and to provide input from all interested parties, Task Group T-3K-2 is composed of corrosion consultants, consulting engineers, architect-engineers, cathodic protection engineers, researchers, structure owners and representatives from both industry and government.

Section 1: Introduction

1.1. General

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 will not form or will be destroyed if: (1) the concrete does not fully encase the steel, (2) alkalinity is lost by reaction with aggressive gases, or (3) excessive amounts of chloride or other aggressive ions are present. If one or more of these conditions exists, and moisture and air are in contact with the steel, corrosion can occur.

1.1.2 Corrosion occurs as a result of the formation of an electrochemical cell. An electrochemical cell is usually thought to consist of four components: an anode, where oxidation occurs; a cathode, where reduction occurs; a metallic path, where the electric current is electron flow; 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.

1.1.3 In the electrochemical cell, relative anodic and cathodic areas can be determined through voltage, or "potential" measurements. This is accomplished by measuring the potential (voltage) between a metal immersed or embedded in an electrolyte and a stable reference electrode. This technique may also be used to assess the effectiveness of cathodic protection.

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 the reduction of the corrosion rate by polarizing the potentials of the cathodes to that of the open circuit potential of the anodes (see Figure 1).

1.2.2 Cathodic protection is the only proven procedure currently available to control corrosion of steel in existing chloride-contaminated concrete structures. However, it should be understood that 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.

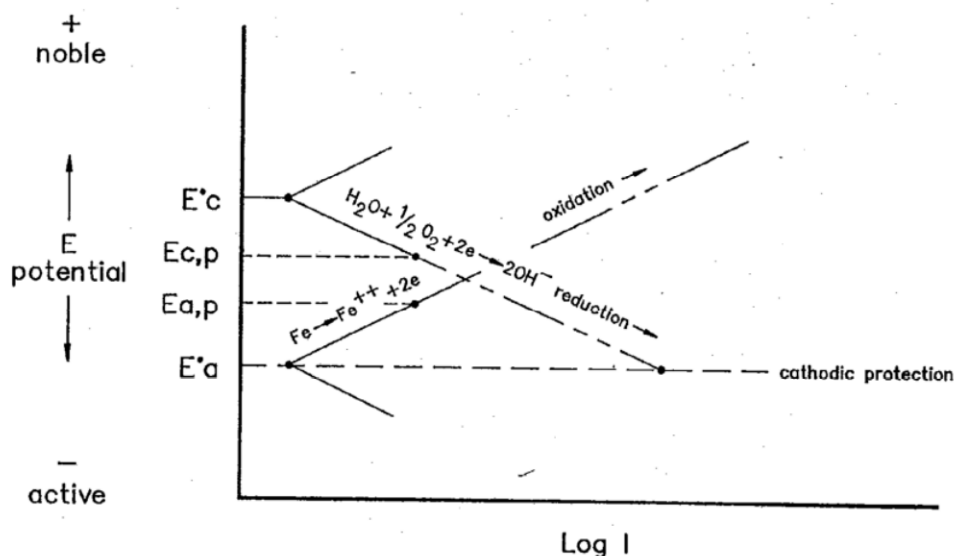
NOTE: For further information, see Appendix A and a glossary of terms in Appendix B.

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 distributed anode systems. The number and locations of measurements made during data collection should be commensurate with the complexity of the

structure under investigation. Sampling plans should be in accordance with ASTM⁽¹⁾ E105, "Recommended Practice for Probability Sampling of Materials." Sample size should be determined in

⁽¹⁾American Society for Testing and Materials (ASTM), Philadelphia, PA.



- $E'a$: EQUILIBRIUM OR "OPEN CIRCUIT" POTENTIAL OF ANODIC AREA
 $E'c$: EQUILIBRIUM OR "OPEN CIRCUIT" POTENTIAL OF CATHODIC AREA
 $E'a,p$: POLARIZED POTENTIAL OF ANODIC AREA (POTENTIAL AS OBSERVED ON REAL STRUCTURE)
 $E'c,p$: POLARIZED POTENTIAL OF CATHODIC AREA (POTENTIAL AS OBSERVED ON REAL STRUCTURE)

FIGURE 1 — Polarization Diagram

accordance with ANSI⁽²⁾/ASQC⁽³⁾ Z1.4, with the unit of product typically being 1 yd² (0.836 m²) of protected metal surface area. For complex structures or cathodic protection systems broken into discrete zones, it may be advantageous to define testing inspection lots. 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 C876, "Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete." Sign conventions for potential and current density as well as conventions for graphical presentation of data should be in accordance with ASTM G3, "Recommended Practice for Conventions Applicable to Electrochemical Measurements in Corrosion Testing."

2.2 Situations may exist where physical conditions effectively preclude full implementation of sampling programs derived from ASTM E105 and ANSI/ASQC Z1.4. Examples of these cases include asphalt or other non-conductive overlays, conductive asphalt cathodic protection systems and situations where access to the cathodically protected surface is difficult and limited. In these situations it may be desirable to install embedded reference electrodes. Additionally, it may be desirable to construct "most anodic" sites. Typically, this involves fully exposing a short length of existing reinforcement. The excavation is then patched with concrete containing chloride well in excess of 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. 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 Task Group T-3K-2 developed these criteria through empirical evaluation of data obtained from successfully operated

cathodic protection systems. NOTE: Persons using this standard should review data made available after this standard's publication to determine if more effective criteria have been established. NACE Task Group T-3K-2 will review new data relevant to this standard two years after its publication and possibly revise the criteria included herein at that time. 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 The reinforcing steel, and any other metal embedments to be protected, shall be polarized a minimum of 100 mV at anodic locations. When using the polarization decay method, the decay is 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 will occur. This voltage shift is the result of eliminating the IR drop and is not to be included in the polarization measurements. The potential of the steel immediately after that shift shall be used as the initial reading from where to measure polarization. Figure 2 depicts a typical polarization decay curve. The polarization equals the initial reinforcement potential after interrupting the current subtracted from the reinforcement's final potential.

2.3.1.2 Polarization development can be determined by measuring the IR drop free potential immediately after the current has been applied and comparing that potential to the IR drop free potential after current has been applied for a period of time. The polarization equals the initial reinforcement potential after current is applied subtracted from the reinforcement's final potential. Typically, the polarization criterion should be met within four hours.

⁽²⁾American National Standards Institute (ANSI), New York, NY.

⁽³⁾American Society for Quality Control (ASQC), Milwaukee, WI.

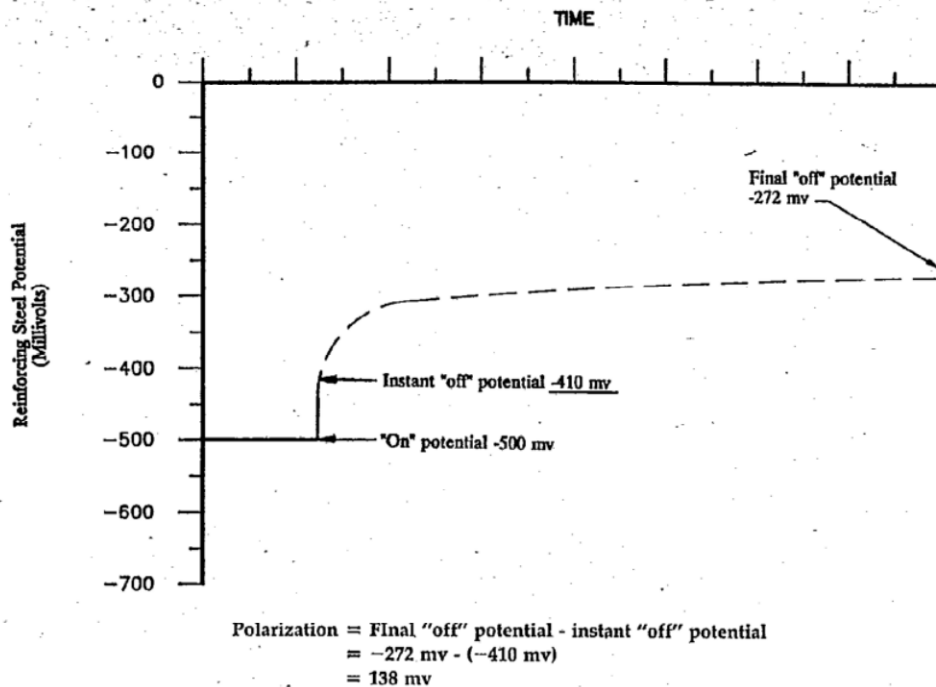


FIGURE 2 — 100 mv Polarization Decay

2.3.2 Statistical distribution analysis

2.3.2.1 After the completion of any concrete repairs, but before energizing the cathodic protection system, a survey of reinforcement potentials should be made of the concrete surface under consideration.

2.3.2.2 Potentials obtained should be analyzed to determine the arithmetic mean potential, the most electronegative (anodic) potential and the standard deviation.

2.3.2.3 Using this method for determining the effective output necessary for cathodic protection, sufficient current is applied to the area under consideration so that the most electronegative reinforcement potential is polarized to a more negative value by an amount that is numerically equal to or greater than the standard deviation of the reinforcement potentials found.

2.3.2.4 At any time, the structure can be resurveyed for the distribution of reinforcement potentials, providing the cathodic protection system has been turned off and complete depolarization has occurred.

2.3.2.5 Polarized reinforcement potentials, measured and recorded, shall be free of cathodic protection current IR drop. When multiple potentials are to be obtained, the

cathodic protection current should be interrupted only for that minimal period of time necessary to make a measurement.

2.3.3 The E log I analysis

2.3.3.1 The E log I test is performed by incrementally increasing the cathodic protection current from the installed system. At each interval, the IR drop free potential of the steel reinforcement is measured relative to a stable reference electrode. A plot of the steel reinforcement potential versus the logarithm of the current applied is called an E log I plot.

2.3.3.2 When performing the E log I test, the reference electrodes are placed at anodic locations.

2.3.3.3 Potential measurements recorded shall be free of cathodic protection current IR drop.

2.3.3.4 The current required for cathodic protection is the value determined to occur at the beginning of linear behavior of the plot (see Figure 3). It should be noted that this is a purely empirical approach that is not supported by the electrochemical theory of corrosion. Under certain conditions, including nature of the structure, exposure conditions, etc., the linear portion of the plot may be difficult to determine. In these cases, alternative criteria should be applied.

Section 3: Design of Cathodic Protection Systems

3.1 Introduction

3.1.1 The purpose of this section is to recommend procedures for designing impressed current cathodic protection systems

that will provide effective corrosion control by satisfying the criteria listed in Section 2 and that will exhibit maximum reliability over the intended operating life of the systems.

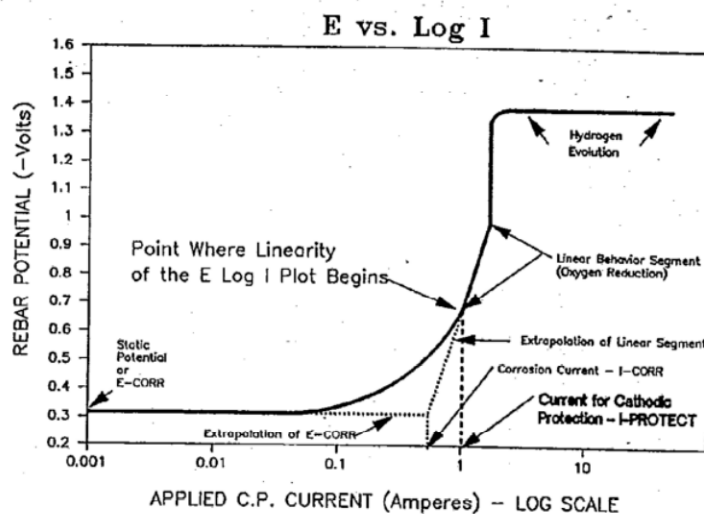


FIGURE 3 — E log I curve. Determination of current required by E log I analysis. Value is determined at the beginning of linear behavior of the plot.

3.2 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 anode systems are presently available:

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

3.2.2.2 Embedded anodes, which consist of conductive materials fully or partially embedded in the structure surface.

3.2.2.3 Conductive coatings applied by brush, roller or spray to the structure surfaces.

3.2.2.4 Surface mounted anodes, which are mechanically attached to the structure.

3.2.3 Impressed current anodes can be materials such as platinum, conductive polymers, conductive coatings, catalyzed titanium, conductive ceramics and conductive asphalt.

3.3 Information generally useful for selecting and designing a cathodic protection system includes:

- 3.3.1 As-built drawings
- 3.3.2 Structural survey
- 3.3.3 Delamination survey
- 3.3.4 Potential survey
- 3.3.5 Chloride content
- 3.3.6 Electrical continuity of the embedded metal
- 3.3.7 Repair and maintenance history
- 3.3.8 Concrete cover
- 3.3.9 Power availability

NOTE: Further information is included in Appendix C.

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 efficiently.

3.4.2 The cathodic protection system must provide a cost-effective design life commensurate with the required life of the protected 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 will depend 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 10.0 mA/ft² (108 mA/m²). Anodes may be designed for higher maximum current density if it can be demonstrated by independent laboratory and field testing that no significant deterioration of the concrete or the anode is likely to occur for the service life of the system. 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 resist the effects of the electrochemical reactions that occur at the anode-concrete interface.

3.4.3.4 Concrete drying effects and the electromigration of mobile ions can limit the ability of the anode to deliver current. Increasing the anode-concrete contact area can reduce these effects.