

Sacrificial Cathodic Protection of Reinforced Concrete Elements— A State-of-the-Art Report

This NACE International technical committee report represents a consensus of those individual members who have reviewed this document, its scope, and provisions. Its acceptance does not in any respect preclude anyone from manufacturing, marketing, purchasing, or using products, processes, or procedures not included in this report. Nothing contained in this NACE report is to be construed as granting any right, by implication or otherwise, to manufacture, sell, or use in connection with any method, apparatus, or product covered by Letters Patent, or as indemnifying or protecting anyone against liability for infringement of Letters Patent. This report should in no way be interpreted as a restriction on the use of better procedures or materials not discussed herein. Neither is this report intended to apply in all cases relating to the subject. Unpredictable circumstances may negate the usefulness of this report in specific instances. NACE assumes no responsibility for the interpretation or use of this report by other parties.

Users of this NACE report are responsible for reviewing appropriate health, safety, environmental, and regulatory documents and for determining their applicability in relation to this report prior to its use. This NACE report may not necessarily address all potential health and safety problems, or environmental hazards associated with the use of materials, equipment, and/or operations detailed or referred to within this report. Users of this NACE report are also responsible for establishing appropriate health, safety, and environmental protection practices, in consultation with appropriate regulatory authorities if necessary, to achieve compliance with any existing applicable regulatory requirements prior to the use of this report.

CAUTIONARY NOTICE: The user is cautioned to obtain the latest edition of this report. NACE reports are subject to periodic review, and may be revised, or withdrawn at any time without prior notice. NACE reports are automatically withdrawn if more than 10 years old. Purchasers of NACE reports may receive current information on all NACE publications by contacting the NACE FirstService Department, 15835 Park Ten Place, Houston, TX 77084-5145 (tel: +1 281-228-6200, email: firstservice@nace.org).

ABSTRACT

This technical report presents state-of-the-art information on several commercially available galvanic cathodic protection/prevention systems for protecting atmospherically exposed reinforced concrete structures. The information contained in this report has been provided by key manufacturers of these systems and is intended as a technical resource for engineers responsible for the rehabilitation of reinforced concrete structures. It may also be useful to owners, contractors, and other practitioners related to the field of galvanic cathodic protection (CP). All information related to galvanic CP is intended for atmospherically exposed concrete structures and may not be applicable to concrete containing epoxy-coated reinforcing steel, galvanized, or other coated or nonferrous reinforcement.

KEYWORDS

Cathodic protection, galvanic, sacrificial anode, reinforced concrete, metallized coating, TG 557.

Foreword

The purpose of this technical committee report is to present state-of-the-art information on several commercially available galvanic cathodic protection/prevention systems for protecting atmospherically exposed reinforced concrete structures. A summary of these systems is presented in Appendix A. It is beyond the scope of this report to fully address all factors associated with design, criteria, implementation, quality control, cost, maintenance, and monitoring of these systems. The information contained in this report has been provided by key manufacturers of these systems and is intended as a technical resource for engineers responsible for the rehabilitation of reinforced concrete structures. It may also be useful to owners, contractors, and other practitioners related to the field of galvanic cathodic protection (CP). All information as it relates to galvanic CP is intended for atmospherically exposed concrete structures and may not be applicable to concrete containing epoxy-coated reinforcing steel, galvanized, or other coated or nonferrous reinforcement. Galvanic CP has also been successfully applied to buried or submerged reinforced concrete structures; however, this aspect is not addressed in this state-of-the-art report.

This NACE technical committee report was originally prepared in 2005 by Task Group (TG) 047 on Sacrificial Cathodic Protection of Reinforced Concrete Elements, which was administered by Specific Technology Group (STG) 01 on Reinforced Concrete and sponsored by STG 05 on Cathodic/Anodic Protection. It was revised in 2020 by TG 557 on Sacrificial Cathodic Protection of Reinforced Concrete Elements. TG 557 is administered by STG 01 and sponsored by STG 05. This report is issued by NACE International under the auspices of STG 01.

NACE technical committee reports are intended to convey technical information or state-of-the-art knowledge regarding corrosion. In many cases, they discuss specific applications of corrosion mitigation technology, whether considered successful or not. Statements used to convey this information are factual and are provided to the reader as input and guidance for consideration when applying this technology in the future. However, these statements are not intended to be recommendations for general application of this technology and must not be construed as such.

Sacrificial Cathodic Protection of Reinforced Concrete Elements— A State-of-the-Art Report

1.	Introduction	5
2.	Definitions	5
3.	General Principles of Cathodic Protection	6
4.	Sacrificial Anode Cathodic Protection	6
5.	Types of Galvanic (SACP) Systems.....	8
6.	Galvanic Corrosion Prevention for Concrete Repair	15
7.	Project Case Studies.....	16
	References.....	27
	Bibliography	27
	Appendix A: Current Galvanic Sacrificial Anode Systems.....	29

Tables and Figures

Figure 1: Thermal Spray Zinc on Concrete	9
Figure 2: Thermal Spray Zinc Layering	9
Figure 3: Temperature-Humidity Chamber Performance of Thermally Sprayed Zinc	10
Figure 4: Temperature-Humidity Chamber Performance of Thermally Sprayed Al-20Zn-0.2In	10
Table 1: Seasonal Effects on Current Density and Polarization (mV)	10
Figure 5: Zinc Mesh Attached to FRP Jacket.....	11
Figure 6: Finished Zinc Mesh Jacket with Junction Box	11
Figure 7: Alkali-Activated Distributed Zinc Anodes in Stay-In-Place Jacket.....	12
Figure 8: Corrosion Rate of Pure Zinc in Water as a Function of pH.....	12
Figure 9: Cast Zinc in Wicking Socks.....	13
Figure 10: Wicking Anodes Cast into Stay-In-Place PVC Jackets	13
Figure 11: Alkali-Activated Distributed Zinc Anodes with Concrete Overlays and Enlargements	13
Figure 12: Zinc Mesh Embedded into Activated Grout Binder Matrix	14
Figure 13: Zinc-Hydrogel Connection Drawing	14
Figure 14: Bulk Zinc Anodes for Bridge Pilings	15
Figure 15: Galvanic Anodes In Patch Repairs	15
Figure 16: Galvanic Anodes in Parent Concrete	15
Figure 17: Topcoat Application	16
Figure 18: Completed Al/Zn/In Metalizing	16
Figure 19: Current Density Measurements of Zinc Metalizing with Humectant in Monitored Zones at Conveyor Tower ...	17

Figure 20: Schematic and Installed Zinc Mesh with Stay-In-Place FRP Jacket and Bulk Anode	18
Table 2: Routine Monitoring of Zinc Mesh with Stay-In-Place FRP Jacket (2014 Site Visit).....	18
Figure 21: Alkali-Activated Distributed Zinc Anode Placement (Robert Moses Causeway).....	19
Figure 22: Alkali-Activated Distributed Zinc Anode in Stay-In-Place Jacket Installation	19
Figure 23: Niles Channel Bridge (Left) and Lake Worth Bridge (Right)	20
Figure 24: Alkali-Activated Distributed Zinc Anode in Stay-In-Place Modular PVC Jackets (Above Splash Zone)	20
Figure 25: FDOT Above-Water Alkali-Activated Distributed Zinc Anode in PVC Jackets (Lake Worth).....	21
Figure 26: Wicking Zinc Anode and Zinc Mesh Anode Installation and Monitoring (Siesta Key).....	21
Figure 27: Long-term Current Output vs. Time from Control Jackets (Red and Brown) and Wicking Anode Jackets (Green and Blue).....	22
Figure 28: Milling and Surface Preparation (North Otter Creek Bridge).....	22
Figure 29: Installation of Alkali-Activated, Distributed Galvanic Anodes and Carbon Fiber Grid Prior to Installation of Silica Fume Concrete Overlay	23
Table 3: Long Term Monitoring of Alkali-Activated Distributed Zinc Anode Overlay (North Otter Creek Bridge).....	23
Figure 30: Spalling and Damage at Harbour Lights Towers.....	24
Figure 31: Schematic of Grouted Zinc Mesh Overlay	24
Figure 32: Commissioning the Grouted Zinc Mesh System.....	25
Figure 33: The Completed Project	25
Table 4: Typical Monitoring Data for Grouted Zinc Mesh Overlay.....	25
Figure 34: Crack on the Soffit Slab	26
Figure 35: Beam Description.....	26
Figure 36: Soffit Slab Description.....	26
Figure 37: ZLA on Beam	26
Figure 38: ZLA on Slab Soffit	26
Table 5: Polarization Effect on the Beam	27
Table 6: Polarization Effect on the Soffit Slab	27
Table A1: Summary of Information on Sacrificial Anodes.....	29

Introduction

Over the past several decades, the corrosion of steel reinforcement embedded in concrete structures has received considerable worldwide attention. In theory, concrete and reinforcing steel are very compatible. They have similar coefficients of thermal expansion. Concrete, because of its highly alkaline nature, creates a protective environment for the steel. Studies have shown that corrosion activity and damage result when critical quantities of aggressive substances penetrate through the concrete pore structure by diffusion and other transport processes and reach the embedded steel reinforcement. When this happens, the naturally occurring passive film developed by highly alkaline concrete becomes contaminated with aggressive ions, eventually breaking down this protective layer. In regions of low electrical resistance, aggressive ions, mostly in the form of salts, attack the passive film and develop localized anodic sites (pits) on the surface of the steel. Immediately adjacent to these anodic sites are oxygen-rich regions that cathodically “fuel” the corrosion reaction. As corrosion proceeds, the lower pH in and around the anodic sites attacks the passive layer in greater proportions, facilitating corrosion propagation. These corrosion products occupy more volume than the reactant steel, so pressure builds until the tensile force required to confine the corrosion product exceeds the capacity of the concrete cover and the concrete cracks.

Several approaches have been used to rehabilitate concrete structures suffering from corrosion damage. The most widely used approach typically involves removing the damaged concrete in and around the affected area and replacing it to the original dimension. The principal intent of this remove-and-replace approach is to return the form and function of the structure. Although this strategy is widely used, it rarely incorporates the complete removal of contaminated areas that surround the damaged region, often resulting in a short-term solution. Modifications to this technique include expanding the area excavated to include sound but chloride-contaminated or carbonated concrete, expanding the repair to include areas where the steel-reinforcement potential is more negative than a defined threshold, or inclusion of discrete anodes in the repair.

The remove-and-replace approach is normally broken into two general categories. The first is patch repair, and the second is rehabilitation. Patch repair is a short-term solution that makes no attempt to extend the structure life, but merely restores concrete back to dimension. The rehabilitation technique attempts to return the distressed area to uniformity with the pre-existing conditions. The rehabilitation technique carries with it some expectation of an increase in service life. In some applications, a coating is applied to the reinforcing, galvanic anodes are tied to the reinforcing in the patch area, and/or a corrosion inhibitor is included either as an additive to the repair/replacement concrete mix or as a post treatment. The methods of concrete repair are much more involved than discussed in this report and are well integrated into most structure owner agencies and the civil engineering community. The reader should refer to American Concrete Institute⁽¹⁾ or International Concrete Repair Institute⁽²⁾ standards and guidelines for more detailed discussion of concrete repair practices.

Alternatively, cathodic protection (CP) applies electrochemistry to halt the corrosion process or reduce it to levels below engineering significance. Cathodic protection is an electrochemical technique used to reduce the corrosion of metallic materials. This is accomplished through the addition of sufficient cathodic current to the metal-electrolyte system to counteract the anodic current produced by the electrochemical corrosion reaction. Providing cathodic current increases the rate of the cathodic reaction (the formation of hydroxide [OH⁻] and possibly hydrogen [H₂]) on the metal being protected, while decreasing the rate of the anodic reaction (metal dissolution). If enough cathodic current is applied, the entire reinforcement network becomes the cathode and corrosion propagation is halted. The source of this cathodic current is immaterial to the protection process, and can come from impressed current, or galvanic sources.

Definitions

The definitions of many of the corrosion-related terms used in this report can be found in NACE/ASTM⁽³⁾ G193.¹ Other terms not included therein that have been used in this report are defined as follows:

Cathodic Prevention: The application of cathodic polarization to passive steel to prevent or delay a transition to the actively corroding condition.

Humectant: A substance that promotes retention of moisture.

Near-White Metal Appearance: A cleaned surface from which all oil, grease, dirt, mill scale, rust, corrosion products, oxides, paint or other foreign matter have been completely removed from the surface except light shadows.

⁽¹⁾ American Concrete Institute (ACI), 38800 Country Club Dr., Farmington Hills, MI 48331-3439.

⁽²⁾ International Concrete Repair Institute, Inc. (ICRI), 1000 Westgate Dr., Ste. 252, St. Paul, MN 55114.

⁽³⁾ ASTM International (ASTM), 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.