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Stray-Current Corrosion in Reinforced and Prestressed Concrete Structures

ABSTRACT

This technical committee report reviews the corrosion of reinforcing and prestressing steel in concrete structures caused by stray currents. It provides information on the history of stray-current corrosion, the sources of stray currents, the mechanism of corrosion, the effects on structures, and detection and mitigation of stray-current-induced corrosion on steel in concrete. Also covered are measures taken during the design phase and modelling of the stray-current effects. The report is intended for use by designers of reinforced concrete structures, professionals dealing with electrochemical techniques (e.g., cathodic protection, realkalization, and electrochemical chloride removal), owners of structures with the potential for reinforcement corrosion caused by stray currents, owners of systems that could generate stray currents to concrete structures, and electrical engineers.

KEYWORDS

Stray current, AC, DC, corrosion, reinforcement, reinforced concrete, cathodic protection, TG 572.

Foreword

This technical committee report reviews the corrosion of reinforcing and prestressing steel in concrete structures caused by stray currents. It provides information on the history of stray-current corrosion, the sources of stray currents, the mechanism of corrosion, the effects on structures, and detection and mitigation of stray-current corrosion on steel in concrete. Measures taken during the design phase and modeling of the stray-current effects are also covered.

The report is intended for use by designers of reinforced concrete (RC) structures, professionals dealing with electrochemical techniques (e.g., cathodic protection [CP], realkalization, and electrochemical chloride extraction), owners of structures with the potential for reinforcement corrosion caused by stray currents, owners of systems that could generate stray currents to concrete structures, and electrical engineers.

Detailed information on the methodology and criteria for detection of stray currents and mitigation techniques are described in the related NACE SP21427.[1]

Even though much of the information is applicable to metallic structures, this report focuses only on reinforced and prestressed concrete structures.

The report makes reference to galvanic corrosion; however, corrosion because of galvanic coupling between reinforcing steel and other metals is not part of this report.

This report was originally prepared in 2010 by NACE Task Group (TG) 356, "Reinforced Concrete: Stray-Current-Induced Corrosion." It was reaffirmed (with editorial changes) in 2019 by TG 572, "Stray Current Corrosion in Reinforced and Prestressed Concrete Structures-SOA Report,"* which is administered by Specific Technology Group (STG) 01, "Reinforced Concrete," and sponsored by STG 05, "Cathodic/Anodic Protection." It 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.

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Introduction

State of Steel in Concrete

Steel reinforcing bars embedded in high-quality concrete without chloride contamination are in a passive condition with a negligible corrosion rate. The highly alkaline pore solution in portland cement pastes (pH is greater than 12.5)[2] allows a stable, protective oxide film to form on the surface of the encased steel. The protective oxide film on the steel surface is not formed or can be destroyed if (1) the cement paste is not in contact with the reinforcing steel, such as at voids and cracks; (2) alkalinity is lost by reaction with certain gases and liquids; or (3) excessive amounts of chloride or other aggressive ions are present in the vicinity of the steel. It has been shown[3] that chloride ion content as low as approximately 0.2 percent by mass of cement (or approximately 0.6 kg/m^3 [1 lb/yd^3] of concrete, depending on the cement content of the mix) at the steel depth can initiate the corrosion process. If any of these conditions occurs, and both sufficient moisture and oxygen are in contact with the steel, an electrochemical cell forms, resulting in corrosion.

Corrosion most commonly proceeds by the formation of an electrochemical cell. This electrochemical cell is composed of four elements: (1) an anode; (2) a cathode; (3) an electrical connection between the two (steel); and (4) an ionic connection provided by an electrolyte (concrete pore solution).[4,5] A current flows from the anodic area through the electrolyte to the cathodic area and then through the metal to complete the circuit. The anodic area, which has the most negative potential, is the area that becomes corroded through loss of metal ions to the electrolyte. The cathodic area (to which electrons flow) is protected from corrosion. If any one of the elements of the electrochemical cell is eliminated, corrosion can be prevented.

Dissimilar metal couples and externally applied electric currents can also initiate or accelerate corrosion by forcing the current flow, resulting in galvanic or electrolytic corrosion, respectively.

Galvanic corrosion occurs when the current is self-generated, such as when dissimilar metals are in contact (galvanic coupling), when variations in conditions take place on a single metal surface, or when differences exist within the electrolyte. The galvanic cell creates an electrical energy source similar to that of a battery cell, capable of supplying current flow from a more active metal (anode) to a more noble metal (cathode) using a common electrolyte. This may occur when steel reinforcement is bonded to a grounding system using bare copper components. The principles of galvanic coupling and corrosion are used for sacrificial anode CP of steel in concrete and are discussed in NACE Publication 01105.[6] Corrosion induced by galvanic coupling is outside the scope of this report.

Electrolytic corrosion takes place when electric current from an outside source leaves the metal through the electrolyte. In electrolytic corrosion, metal corrodes where the current leaves the metal (the metal is the anode) but no corrosion occurs where the current enters the metal (the metal is the cathode).[7,8] This mechanism is discussed in detail in *Principles of Stray-Current Corrosion* below.

Electrolytic corrosion can occur in concrete structures as a result of currents from external current sources leaving the reinforcing steel and is referred to as “stray-current” corrosion. Note that in the technical literature, the terms “electrolytic corrosion” or “electrolysis” were used in early studies of externally imposed current on metal structures (and reinforcing steel) on site and in laboratory examinations of the phenomenon. In recent literature, the term “stray current” has been used for on-site studies of current from outside sources into structures, and is also the term used in this report.

Stray Currents

Stray currents are defined as electrical currents flowing through electrical paths other than the intended paths. Stray currents can arise from railways, CP systems, high-voltage power lines, or other sources (such as welding equipment). Stray currents can deviate from their intended path because they find a lower resistance, parallel and alternative route to flow, for example, through metallic structures buried in the soil such as pipelines, tanks, and industrial and marine structures. Subway systems consist of many miles of steel-reinforced concrete tunnel networks. Modern subway systems are designed to restrict the generation of stray current through the use of isolated track fasteners. However, some traction current might inevitably stray into the concrete electrolyte from the running rails in the vicinity of the load (transit vehicle) and return to the running rails.

Stray currents can be a serious problem for the corrosion engineer, not only for the damage they can cause, but also for the difficulties encountered in the solution of the problem. Stray currents may be direct currents (DC) or alternating currents (AC), depending on the source.

Stray-current interference can result in localized corrosion of reinforcing bars where current leaves the steel and in hydrogen embrittlement of prestressing steel where current enters the steel if the potential is negative enough to generate hydrogen gas (see *Polarity of Steel* below). Reinforcing steel in concrete is susceptible to stray current because concrete is an electrolyte, thus a conductive medium, that supports the pickup onto and subsequent discharge of stray current from the embedded steel.