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State-of-the-Art Report: Criteria for Cathodic Protection of Prestressed Concrete Structures

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Foreword

This NACE International state-of-the-art report is intended for use by engineers when evaluating criteria whereby prestressed concrete structures and members can be protected from corrosion by means of cathodic protection (CP). Throughout this report, reference is made to pertinent available standards. Of particular relevance are NACE SP0187, SP0290, and SP0390.[1-3] Under certain circumstances, the CP system can either become a structural element or significantly affect the serviceability or structural performance of the prestressed concrete element. Therefore, a review of such impact from the CP system is typically made by a registered structural engineer.

This technical committee report was prepared in 2002 and revised in 2018 by Task Group (TG) 046,[(1)] "Cathodic Protection of Prestressed Concrete Elements." This TG is composed of corrosion researchers, corrosion engineers, corrosion consultants, architects, structure owners, and representatives of both industry and government. TG 046 is administered by Specific Technology Group (STG) 01, "Reinforced Concrete." It is also sponsored by STG 05, "Cathodic/Anodic Protection" and STG 41, "Electric Utility Generation, Transmission, and Distribution." This technical committee report is issued by NACE International under the auspices of STG 01.

Key words: Cathodic protection, prestressed concrete, reinforcing steel, TG 046

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Introduction

Types and Principles of Prestressed Concrete

Prestressed concrete has evolved during the past five-plus decades to the point that it is now widely employed for transportation structures, buildings, pipelines, and other applications because of its technical viability and economic competitiveness. While concrete per se normally exhibits acceptable compressive strength, it is relatively weak in tension. Therefore, embedded steel is added to accommodate tensile stresses. For structural applications, concrete is either reinforced or prestressed (or a combination of the two). For the former, bars are positioned in the formwork; and the concrete is poured and sets such that, neglecting dead weight and service loadings, no stresses are imparted by either component (steel or concrete) to the other. The principle of prestressed concrete is based on tensioning of the steel in such a manner that it ultimately places the concrete in a state of residual compression. Consequently, service tensile loadings on the concrete, up to a certain level, act to reduce this compression; and tensile stresses are either less than would otherwise be the case or are avoided altogether. A basic introductory discussion of the two types of prestressed concrete, pretensioned and post-tensioned, is provided in this *Introduction.* For more detailed information, a standard text in the field may be consulted.[4]

Types and properties of prestressing steel. Imposition of adequate residual compression to a concrete member via prestressing steel uses steel of high strength, because its cross-section is generally small compared with that of the concrete and the net force in each component (steel and concrete) balances. The specification for prestressing steel strand is provided by ASTM[(2)] A416.[5] Currently, most prestressing steel is in the form of spiral, seven-wire strand that is designated as either Grade 250 or Grade 270, in which the number refers to minimum ultimate strength in kilo pounds per square inch (ksi) units (1 ksi = 1,000 psi [6.895 MPa]). Historically, bar as well as strand has been employed. Prestressing for concrete pipe is in the form of wire and is addressed by ASTM A648.[6] In either case (strand or wire), strengthening is achieved by a carbon concentration near the eutectoid composition (0.77 w%) combined with cold drawing. Heat-treated (quenched and tempered) steel is not used because of its greater susceptibility to brittle fracture and environmental cracking. In the past, however, quenched and tempered material has been used in some countries. Otherwise, the above standards primarily address dimensions and strength, with the means by which the requisite strength is achieved being left to the producer. Steel composition is typically considered to be important, because this influences the strengthening that is derived from cold drawing. Either plain carbon or micro-alloyed steel, with small amounts of either chromium, vanadium, or chromium plus vanadium, is commonly employed.

Pretensioned concrete. Components in this class are normally produced in a prefabrication yard and then transported to the construction site. Consequently, there are practical limits on member size. Beams, columns, and pilings are examples of components that are routinely pretensioned. Fabrication involves placement and pretensioning of the tendons[(3)] in a form bed, pouring the concrete, allowing the concrete to set, and, finally, removing the applied tensioning force on the tendon. The tendency for the tendon within the hardened concrete to contract, once this force is removed, places the concrete in a state of residual compression.

Posttensioned concrete. Components in this class are normally produced in place at the job site (an exception to this, *segmental construction,* is described below). Slabs for buildings and decks for parking garages are examples in which posttensioning is commonly employed. For fabrication, tendons are contained in ducts that are, in turn, positioned in the pouring forms. Consequently, only the duct and not the tendon is in direct contact with and is bonded to the concrete. Once the concrete has achieved a prescribed strength, the tendons are tensioned and the loaded ends secured by collets in anchors. As is the case for pretensioning, compressive stresses are imparted to the concrete. In some cases grout slurry is then pumped into the duct pore space (bonded posttensioning), while no such measure is used in others (unbonded posttensioning). Tendons in unbonded posttensioned concrete are typically surface treated with grease that contains a corrosion inhibitor.

Reinforcing steel has invariably been present in addition to the prestressing strands within prestressed concrete members. This is done either to ensure integrity in areas of locally high stress or to provide strength in the transverse direction, or both.

Segmental construction is a special case of prestressed concrete in which individual pretensioned members are secured together into a larger assembly by posttensioning.

Corrosion of Prestressing Steel in Concrete

Corrosion mechanism. Typically, the cement paste in concrete and mortar is alkaline (pH~12.5 to 13.8), which facilitates formation and maintenance of a protective, passive film; and a low corrosion rate generally results. However, this protective film can be compromised by either carbonation or chlorides. Carbonation involves reaction of atmospheric carbon dioxide with hydroxides to form carbonates;

[(2)] ASTM International (ASTM), 100 Barr Harbor Drive, West Conshohocken, PA 19428.
[(3)] Tendons are high-strength steel strands, groups of strands, or bars that, when tensioned, impart a compressive stress to the structure or structural member.