Guide to Design and Construction Practices to Mitigate Corrosion of Reinforcement in Concrete Structures

Reported by ACI Committee 222

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Corrosion of metals in concrete is a significant problem throughout the world. In many instances, corrosion can be avoided if proper attention is given to detailing, concrete materials and mixture proportions, and construction practices. This guide contains information on aspects of each of these. In addition, the guide contains recommendations for protecting in-service structures exposed to corrosive conditions. The guide is intended for designers, materials suppliers, contractors, and all others engaged in concrete construction.

Keywords: admixtures; aggregates; aluminum; cathodic protection; cement; chlorides; consolidation; corrosion; curing; epoxy coating; high-range water-reducing admixtures; mixing; mixture proportioning; permeability; reinforcing steel; water-cementitious material ratio.

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FOREWORD

This guide represents a compendium of technology to combat the problems of corrosion and is arranged into four major chapters. Chapter 2 discusses design considerations pertinent to corrosion, including environmental factors, performance of structural types, and the influence of structural details. Chapter 3 addresses the effects of concrete materials and mixture proportions on susceptibility to corrosion, including cements, aggregates, water, reinforcing steels, admixtures, and other embedded materials. Chapter 4 examines corrosion as it is influenced by the changes that concrete undergoes as it is mixed, transported, placed, consolidated, and cured. Chapter 5 describes several procedures available for protecting in-place structures.

This guide will aid in the design and construction of corrosion-resistant reinforced concrete structures and assist those involved in ensuring that reinforced concrete continues to function as a reliable and durable construction material.

CHAPTER 1—INTRODUCTION

Corrosion of metals in concrete is a serious type of deterioration that affects concrete in service. Corrosion is seen in parking structures, marine structures, industrial plants, buildings, bridges, and pavements. The Federal Highway Administration published a report in 2001 that the estimated cost of corrosion of highway bridges was between $6.43 and $10.15 billion (FWHA-RD-01-097 2001). This problem drains resources in both the public and private sectors. Implementation of solutions is needed, both in the design of structures resistant to corrosion and the rehabilitation of structures suffering the effects of corrosion.

Concrete provides a highly alkaline environment, which results in the formation of a passivating film that protects the steel from corrosion. Corrosion of embedded metals in concrete can occur, however, if concrete quality and details such as concrete cover and crack control are not adequate; if the functional requirement of the structure is not as anticipated or is not adequately addressed in the design; if the environment is not as anticipated or changes during the service life of the structure; or a combination of thereof. For more details on the mechanism of corrosion of metals in concrete, refer to ACI 222R.

Once corrosion begins, it is aggravated by factors such as moisture and elevated ambient temperatures. Cracking, stray currents, and galvanic effects can also exacerbate corrosion. Other causes of corrosion include steel directly exposed to the corrosive elements due to incomplete placement or consolidation of concrete, and industrial or wastewater chemicals that attack the concrete and the reinforcing steel. Reinforced concrete structures should be designed either to avoid these factors when they are present or be protected from these factors when they cannot be avoided.

CHAPTER 2—DESIGN CONSIDERATIONS

2.1—Structural types and corrosion

Corrosion of steel in concrete was first observed in marine structures and chemical manufacturing plants (Biczok 1964; Evans 1960; Tremper et al. 1958). The design considerations relevant to corrosion protection depend on the type of structure and its environment and intended use. Certain minimum measures—for example, adequate concrete cover and concrete quality—should always be specified, even for structures such as concrete office buildings completely enclosed in a curtain wall with no exposed structural elements. Depending on the type of structure and its expected exposure, additional design considerations can be required to ensure satisfactory performance over the intended service life of the structure.

2.1.1 *Bridges*—The primary issues in designing the deck, substructure, and superstructure of a concrete bridge for increased corrosion resistance are knowing the potential for chloride ion exposure while in service and the degree of protection required. In theory, the design considerations for a bridge located in a semi-arid region of the U.S., such as parts of Arizona, should be different from a bridge located in either Illinois or on the coast of Florida. ACI 318, ACI 345R, and AASHTO HB-17 recognize this and contain additional requirements for concrete structures exposed to different levels of chloride ions in service.

There are differences in interpretation when applying these provisions for corrosion protection of bridge structures. For exposure to deicing chemicals, the top mat of reinforcement is more susceptible to chloride-induced corrosion than the bottom mat and, therefore, acts as the anode with the bottom mat acting as the cathode in macrocell corrosion. AASHTO HB-17 recognizes this and requires greater concrete cover for the top mat of reinforcement. This basic premise of chloride-ion exposure is reversed for a bridge located in a warm climatic area over saltwater where the underside of the bridge deck can be more vulnerable to chloride-ion ingress. Consequently, the concrete cover should be increased for the bottom mat of deck reinforcement in this type of application.

So much has been written about the bridge deck problem since the early 1970s that corrosion protection of a bridge superstructure and substructure has sometimes been overlooked. Leakage of chloride-contaminated water through expansion and construction joints and cracks onto the superstructure,