



Standard Recommended Practice

Maintenance and Rehabilitation Considerations for Corrosion Control of Atmospherically Exposed Existing Steel-Reinforced Concrete Structures

This NACE International standard 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, whether he or she has adopted the standard or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not in conformance with this standard. Nothing contained in this NACE International standard 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 standard represents minimum requirements and should in no way be interpreted as a restriction on the use of better procedures or materials. Neither is this standard intended to apply in all cases relating to the subject. Unpredictable circumstances may negate the usefulness of this standard in specific instances. NACE International assumes no responsibility for the interpretation or use of this standard by other parties and accepts responsibility for only those official NACE International interpretations issued by NACE International in accordance with its governing procedures and policies which preclude the issuance of interpretations by individual volunteers.

Users of this NACE International standard are responsible for reviewing appropriate health, safety, environmental, and regulatory documents and for determining their applicability in relation to this standard prior to its use. This NACE International standard 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 standard. Users of this NACE International standard 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 standard.

CAUTIONARY NOTICE: NACE International standards are subject to periodic review, and may be revised or withdrawn at any time without prior notice. NACE International requires that action be taken to reaffirm, revise, or withdraw this standard no later than five years from the date of initial publication. The user is cautioned to obtain the latest edition. Purchasers of NACE International standards may receive current information on all standards and other NACE International publications by contacting the NACE International FirstService Department, 1440 South Creek Drive, Houston, Texas 77084-4906 (telephone +1 281/228-6200).

Reaffirmed 2006-03-14

Revised 1998-06-26

Approved 1990-04-12

NACE International

1440 South Creek Drive

Houston, Texas 77084-4906

+1 281/228-6200

ISBN 1-57590-059-9

©2006, NACE International

Foreword

Corrosion of reinforcing steel in concrete is a serious problem in certain environments throughout the world. This corrosion is directly attributable to the presence of significant amounts of chloride or other aggressive substances at the steel surface. Parking structures, bridges and roadways, buildings, sanitary and water facilities, marine structures, concrete pipe, storage facilities, and other reinforced concrete structures are being damaged by corrosion.

Corrosion of the reinforcing steel can weaken or destroy a structure. Corrosion of the reinforcing steel in concrete and the resulting cracking and spalling of concrete costs billions of dollars each year. These losses can be reduced if proper corrosion control factors are considered during rehabilitation and maintenance repair of reinforced concrete structures.

Reinforcing steel is compatible with concrete, not only because of similar thermal expansion characteristics, but also because the highly alkaline portland cement allows a stable, protective oxide film to form 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 does not form or is destroyed if (1) the concrete does not fully encase the steel; (2) alkalinity is lost by reaction with certain gases and liquids; or (3) excessive amounts of chloride or other aggressive ions are present. It has been shown that chloride ion content as low as approximately 0.2 percent by weight 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 one or more of these conditions are present, and moisture and oxygen are available to the embedded reinforcing steel, corrosion can occur.

Corrosion occurs as a result of the formation of an electrochemical cell. This cell is composed of four elements: (1) an anode; (2) a cathode; (3) an electrical connection between the two; and (4) an ionic connection provided by an electrolyte (concrete). Direct current (DC) caused by electrochemical potential differences, such as between different metals or the same metal in different environments, flows from the anodic area to the cathodic area through the electrolyte. Corrosion occurs at the anode, where the current leaves the metal. If any one of the elements of the electrochemical cell is eliminated, corrosion can be prevented. Dissimilar metal couples and stray DC can initiate and accelerate corrosion.

The corrosion product of steel occupies several times the volume of the base metal. The expansive pressure exerts a significant tensile force on the surrounding concrete. The resulting cracks propagate either to the surface or to nearby reinforcing steel, resulting in a delamination. Steel sectional losses, which may or may not have structural significance, can generate cracking of the concrete. Bond forces and corrosion both put concrete in tension and are additive. Relatively small amounts of metal loss at the surface of the reinforcing steel can be sufficient to crack the concrete cover and result in the loss of bond and anchorage. Other problems resulting from delamination and spalling include danger from falling concrete, increased corrosion, loss of fireproofing, and safety considerations.

The purpose of this standard is to give maintenance personnel, engineers, and facility owners the necessary considerations for corrosion control of existing atmospherically exposed steel-reinforced concrete structures. These considerations include guidelines to control corrosion of reinforced steel in portland cement concrete structures. This standard does not cover pretensioned and posttensioned reinforced concrete.

The provisions of this standard should be applied under the direction of a registered Professional Engineer or a person certified by NACE International as a Corrosion Specialist or Cathodic Protection Specialist. His or her professional experience should include suitable experience in corrosion control of reinforced concrete structures.

This NACE standard was originally prepared in 1990 by NACE Task Group T-3K-5, a component of Unit Committee T-3K on Corrosion and Other Deterioration Phenomena Associated with Concrete. To provide the necessary expertise on all aspects of the subject and to gain input from all interested parties, Task Group T-3K-5 was composed of corrosion consultants, consulting

engineers, architect-engineers, cathodic protection engineers, researchers, structure owners, and representatives from industry and government. Unit Committee T-3K became Group Committee T-11 on Corrosion and Deterioration of the Infrastructure and later Specific Technology Group (STG) 01 on Reinforced Concrete. This standard was revised by Task Group T-11-4a in 1998 and reaffirmed by STG 01 in 2006. It is published by NACE under the auspices of STG 01.

In NACE standards, the terms *shall*, *must*, *should*, and *may* are used in accordance with the definitions of these terms in the *NACE Publications Style Manual*, 4th ed., Paragraph 7.4.1.9. *Shall* and *must* are used to state mandatory requirements. The term *should* is used to state something considered good and is recommended but is not mandatory. The term *may* is used to state something considered optional.

**NACE International
Standard
Recommended Practice**

**Maintenance and Rehabilitation Considerations for
Corrosion Control of Atmospherically Exposed Existing
Steel-Reinforced Concrete Structures**

Contents

1. General	1
2. Definitions	1
3. Periodic Inspection and Routine Maintenance.....	1
4. Assessment of Reinforced Concrete Structures.....	4
5. Corrosion Control Techniques and Repair Strategy	5
References.....	8
Bibliography	8
Figure 1: Repair or Rehabilitation Strategy Flow Chart.....	3

Section 1: General

1.1 This standard presents corrosion control guidelines that are applicable to existing atmospherically exposed structures made of conventionally reinforced concrete. These guidelines may be used to develop specifications involving repair and rehabilitation of steel-reinforced concrete structures. These guidelines should be used primarily when repair or rehabilitation is being implemented because of deterioration resulting from the corrosion of steel reinforcement.

1.2 This standard describes various approaches that may be taken with respect to corrosion control of existing

structures. The flow chart in Figure 1 delineates the repair or rehabilitation strategy covered in this standard. Because of the complexity of corrosion problems on individual structures, advice from a Professional Engineer or a Corrosion Specialist, whose professional qualifications include suitable experience in corrosion control of reinforced concrete structures, should be sought before proceeding with repair and rehabilitation programs.

1.3 This standard does not cover pretensioned and posttensioned reinforced concrete.

Section 2: Definitions

Anode: The electrode of an electrochemical cell at which oxidation occurs. Electrons flow away from the anode in the external circuit. Corrosion usually occurs and metal ions enter the solution at the anode.

Cathode: The electrode of an electrochemical cell at which reduction is the principal reaction. Electrons flow toward the cathode in the external circuit.

Cathodic Protection: A technique to reduce the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

Corrosion Specialist: A person certified by NACE International through verification of experience and examinations that demonstrate an advanced understanding of corrosion theory and mechanisms, corrosion monitoring and control, management, and professional conduct as well as a high level of knowledge and ability in the area of specialization.

Delamination: A separation of the concrete (usually in layers) from the reinforcing steel at the interface, usually as a result of corrosion.

Dissimilar Metals: Different metals that could form an anode-cathode relationship in an electrolyte when connected by a metallic path.

Electrochemical Cell: A system consisting of an anode and a cathode immersed in an electrolyte so as to create an electrical circuit. The anode and cathode may be different metals or dissimilar areas on the same metal surface.

Electrolyte: A chemical substance containing ions that migrate in an electric field. For the purposes of this standard, electrolyte refers to the concrete, including moisture and other chemicals contained therein.

Spalling: The spontaneous chipping, fragmentation, or separation of a surface or surface coating.

Stray Current: Current through paths other than the intended circuit.

Section 3: Periodic Inspection and Routine Maintenance

3.1 Periodic routine visual inspections of the structure should be carried out to note areas of distress. These inspections should include the following:

3.1.1 Visual Inspections

3.1.1.1 Cracks—Cracking of the concrete that appears to be coincident with reinforcement locations should be recorded. These cracks

should be distinguished from structural and shrinkage cracks.

3.1.1.2 Spalls—Corrosion-related and all other spalls should be noted.

3.1.1.3 Rust stains—Corrosion products seen on the concrete surface may indicate corrosion of steel embedded in the concrete.

RP0390-2006

3.1.1.4 Drainage—Ponded contaminants can accelerate local corrosion of reinforced concrete structures.

3.1.1.5 Waterproofing systems should be inspected for deterioration as follows:

3.1.1.5.1 Sealants—Areas of disbonding, cracking, crazing, or loss of elasticity should be noted.

3.1.1.5.2 Sealers—Whether or not water beads on the surface when wetted should be noted (some penetrating sealers may not produce beading; core specimens must be obtained to assess these sealers).

3.1.1.5.3 Membranes—Areas of cracking and disbondment in the wearing surface should be noted.

3.1.1.6 Leaks—Leaks may be indicative of localized areas of contamination. Areas of efflorescence or staining at soffit cracks or at expansion joints should be noted.

3.1.2 Frequency

3.1.2.1 The frequency of inspection depends on exposure to contaminants, environment, geographic location, conditions of use, age, and other factors.

3.1.2.2 The frequency of inspection may be regulated by codes or local entities.

3.2 Depending on the structure, routine maintenance may include, as examples, the following activities:

3.2.1 Cleaning of scuppers and drains to minimize water ponding and reduce ingress of water and chlorides and other contaminants that initiate corrosion.

3.2.2 Maintenance of existing protection systems.

3.2.3 Regular cleaning and washing of the structure to remove built-up contaminants.

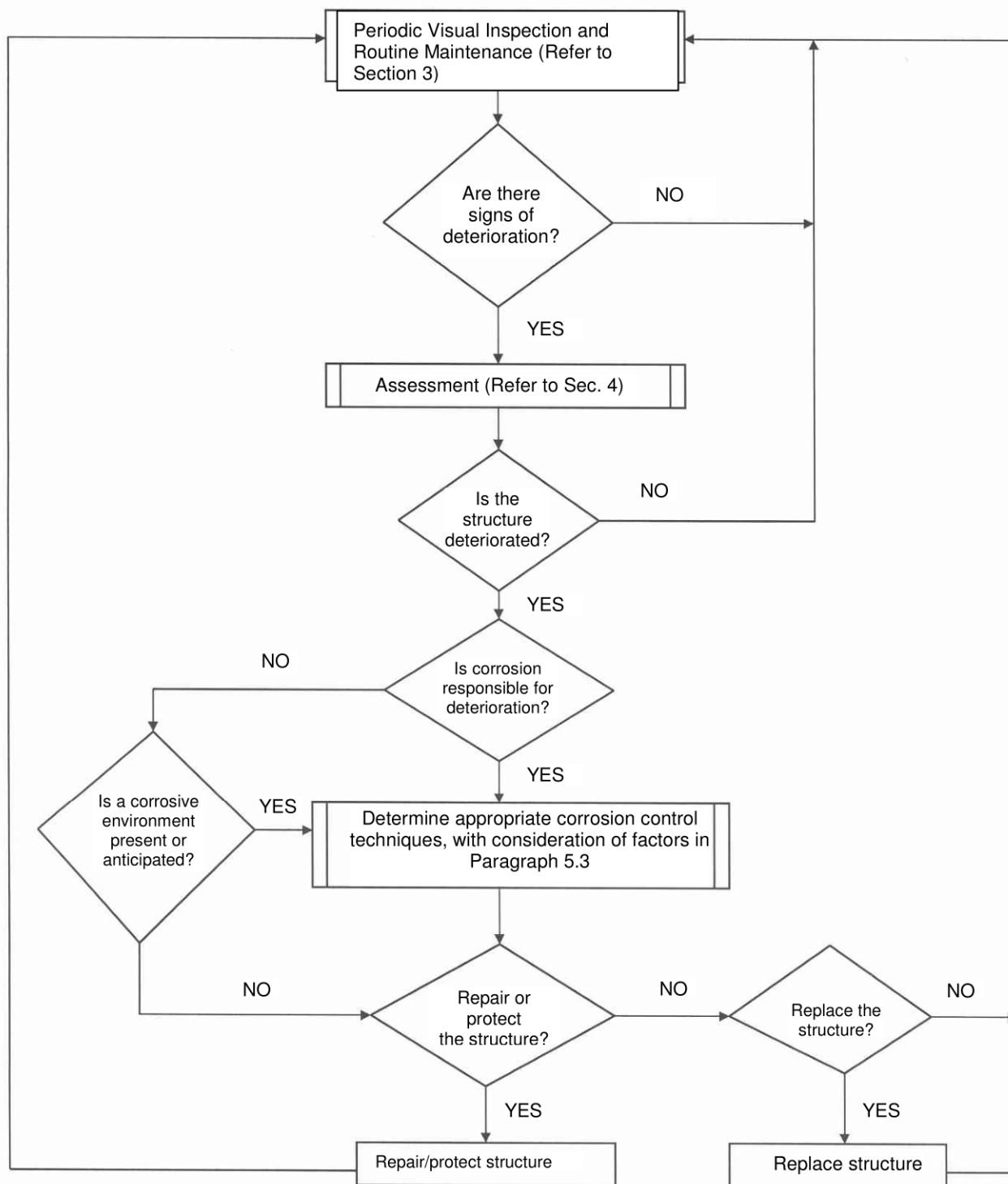


FIGURE 1
Repair or Rehabilitation Strategy Flow Chart

Section 4: Assessment of Reinforced Concrete Structures

4.1 General

4.1.1 When the periodic visual inspection and routine maintenance procedures identify a possible corrosion-related deterioration mechanism, a more detailed assessment shall be considered. The purpose of this detailed assessment is to define the nature of the environment surrounding the structure, to document the physical condition of the structure, and to define the extent and nature of corrosion occurring on the structure. Such a survey shall include at least the following items:

4.2 Site survey

4.2.1 In evaluating the condition of a reinforced concrete structure, a study of the site and its environment can provide useful data that will assist in analyzing the corrosion problem. The following items shall be evaluated:

4.2.1.1 General and local atmospheric influences—air pollution, carbonation, airborne chlorides, and other contaminants.

4.2.1.2 Climate—temperature, relative humidity, freeze/thaw and wet/dry cycles, etc.

4.2.1.3 Soil—characteristics.

4.2.1.4 Water—characteristics.

4.2.1.5 Deicing materials and procedures.

4.2.1.6 Stray electrical currents.

4.2.1.7 Exposure to corrosive materials, environments, or processes.

4.2.2 Tests of soil and water may include testing of pH, resistivity, chlorides, sulfates, sulfides, and bacteria.

4.3 Structure Survey

4.3.1 To determine the extent of concrete deterioration and corrosion, it is necessary to survey the structure. Such a survey shall be directed toward the following:

4.3.1.1 Evaluating the existing physical condition of the structure.

4.3.1.2 Evaluating the existing electrochemical conditions affecting corroding metallic embedments.

4.3.1.3 Exposure of embedments for purposes of visual examination.

4.3.1.4 Determining factors responsible for observed corrosion.

4.3.2 Historical review

4.3.2.1 An historical review can supplement subsequent field survey investigations. The following items shall be considered:

4.3.2.1.1 Age.

4.3.2.1.2 Review of “as-built” and record drawings.

4.3.2.1.3 Structure’s use and corrosion history.

4.3.2.1.4 Review of previous structure repair or rehabilitation.

4.3.2.1.5 Corrosion history of nearby or similarly used structures.

4.3.2.1.6 Effectiveness of corrosion protection methods.

4.3.2.1.7 Discussions with operators about present structure conditions and problems, corrosion evaluations, and control history.

4.3.3 Physical condition

4.3.3.1 Quality of concrete can be assessed by:

4.3.3.1.1 Cores for measuring compressive strength.

4.3.3.1.2 Projectile penetration.

4.3.3.1.3 Petrographic examinations.

4.3.3.1.4 Pulse velocity.

4.3.3.1.5 Rebound hammer.

4.3.3.1.6 Air content measurements.

4.3.3.1.7 Cement content measurements.

4.3.3.1.8 Permeability measurements.

4.3.3.2 Spalls and delamination can be assessed by:

- 4.3.3.2.1 Visual examination.
- 4.3.3.2.2 Hammer sounding, chain drag mapping, and other acoustic testing.
- 4.3.3.2.3 Infrared mapping.
- 4.3.3.2.4 Radar mapping.
- 4.3.3.2.5 Core sampling.
- 4.3.3.3 Cracking can be assessed by:
 - 4.3.3.3.1 Crack mapping.
 - 4.3.3.3.2 Crack width measurements.
 - 4.3.3.3.3 Crack movement monitoring.
- 4.3.3.4 Structural capacity can be assessed by:
 - 4.3.3.4.1 Load testing.
 - 4.3.3.4.2 Modal analysis.
 - 4.3.3.4.3 Structural calculations.
- 4.3.4 Corrosion
 - 4.3.4.1 Corrosion activity of reinforcing steel and other metallic embedments can be assessed by:
 - 4.3.4.1.1 Potential mapping.
 - 4.3.4.1.2 Corrosion rate measurement.
 - 4.3.4.1.3 Metal section loss.
 - 4.3.4.2 Factors that can affect corrosion of steel and other metallic embedments include the following:
 - 4.3.4.2.1 Depth of concrete cover.
 - 4.3.4.2.2 Concentrations of aggressive ions (such as chloride) at varying depths.
 - 4.3.4.2.3 Concrete resistivity.
 - 4.3.4.2.4 Concrete moisture.
 - 4.3.4.2.5 Concrete permeability.
 - 4.3.4.2.6 Concrete pH.
 - 4.3.4.2.7 Depth of carbonation of the concrete.
 - 4.3.4.2.8 Temperature.

Section 5: Corrosion Control Techniques and Repair Strategy

5.1 This section describes the more common techniques for controlling corrosion in reinforced concrete. The descriptions of techniques in this section are not meant to be exhaustive, all-inclusive, or necessarily appropriate for a particular structure, but are intended only to make the reader of this standard generally aware of some of the methods that can be considered. The objective of corrosion control techniques is to diminish the effect of existing and future corrosion cells. This can only be accomplished by altering one of the four components of the corrosion cell. Combinations of techniques in this section may be required or desired in a particular instance. Other techniques not included in this section might be appropriate for specific situations. The benefits of corrosion control techniques in this section may not be gained unless special care is taken in selecting and implementing the chosen technique. Benefits and detriments in this section refer only to the effects on corrosion; the techniques might have other benefits and detriments. When time and structure conditions permit, trial installations of possible corrosion control techniques for a specific structure should be done, and tests should be performed to evaluate the effectiveness and appropriateness of the method.

5.2 The techniques are divided into two classes, which are designated Class 1 and Class 2 for the purposes of this

standard. Class 1 techniques attempt to decrease the corrosiveness of the contaminated concrete environment by decreasing the rates of moisture, oxygen, and contaminant ingress; Class 2 techniques attempt to alter the environment around the reinforcement more directly either by replacing the electrolyte, removing the chloride contaminants, or by making the reinforcement the cathode in the corrosion cell. Use of any of these techniques may not achieve the desired effect, or the effect might take several years to achieve.

5.2.1 Class 1 techniques primarily include surface treatments to prevent or retard the intrusion of corrosive contaminants, moisture, and oxygen. Techniques in this class are generally more appropriate for structures that are not contaminated, or for structures that are only mildly contaminated. They can also be appropriate for severely contaminated structures if the only feasible strategy is to attempt to extend the life of the structure a few years. The effect on corrosion from the application of techniques in this class can take several months or more to become noticeable. Refer to Paragraph 5.4 for further details.

5.2.2 Class 2 techniques include a technique to remove and replace the contaminated concrete

physically, a technique to remove existing chlorides, and a technique to make the reinforcement cathodic regardless of the degree of contamination. Techniques in this class are generally more appropriate for severely contaminated structures, but some of these techniques can be appropriate for mildly contaminated structures. The effect on corrosion from the application of some techniques in this class can be more immediate than the techniques in Paragraph 5.2.1. Refer to Paragraph 5.5 for further details.

5.3 Corrosion control techniques should be selected for the ability to achieve the desired effect. Factors that may influence the general selection follow. Other influencing factors, specific to a particular technique, can be found with the description of the technique.

5.3.1 User safety.

5.3.2 Structure condition and safety.

5.3.3 Structure age and desired life.

5.3.4 Structure necessity.

5.3.5 Structure replacement cost.

5.3.6 The benefits of structure life extension.

5.3.7 Structure climatic environment.

5.3.8 Structure contaminant environment.

5.3.8.1 The magnitude of contamination at the time of the corrosion survey and the likelihood and expected magnitude of future contamination.

5.3.9 The effect on the physical characteristics of the structure (reduction of overhead clearance, added dead load, surface skid resistance, etc.).

5.3.10 The degree of disruption of the facility during application of the chosen technique.

5.3.11 Choosing techniques that do not preclude the future application of more rigorous corrosion control methods.

5.3.12 Other tangible and intangible factors that can apply in a particular instance.

5.3.13 Another consideration that can apply in some instances is the possibility of altering the source of the contamination. This can be done by eliminating or reducing the level of the contaminant, reducing its application rate, or substituting another material. This can provide an additional benefit that can be incorporated with other techniques.

5.4 Class 1 techniques, primarily surface treatments, are usually applied to the structural surface that is most exposed to the source of the contaminant. Generally,

surface delaminations and spalls must be repaired if techniques in this class are chosen.

5.4.1 Surface treatments generally include proprietary products and materials commonly referred to as sealers, coatings, barriers, membranes, linings, and overlays. This category also includes polymer impregnation and chloride neutralizers. Other products and materials that are not listed might perform a similar function.

5.4.2 Possible corrosion-reducing benefits of surface treatments include:

5.4.2.1 Reduction of the rate of intrusion of contaminants, oxygen, and moisture.

5.4.2.2 Drying of the concrete due to a reduction in the rate of intrusion of water or other liquids, or due to a reduction in the rate of intrusion of water vapor or other materials in a vapor phase.

5.4.3 Possible detrimental effects of surface treatments include:

5.4.3.1 Entrapment of moisture in liquid or vapor form.

5.4.3.2 Increased concentrations of contaminants at the reinforcement due to diffusion.

5.4.4 Selection of techniques in this class should include consideration of the following characteristics:

5.4.4.1 Ability to resist the penetration of the subject contaminants.

5.4.4.2 Ability to resist the passage of water, and generally allow water vapor transmission.

5.4.4.3 Durability and longevity.

5.4.4.4 Compatibility with previously or subsequently applied materials.

5.4.4.5 Performance record on similar structures.

5.5 When Class 2 techniques are used, in all cases the alteration of the surface of the reinforcement to a more passive state is desired.

5.5.1 Physical removal of contaminants involves removal and replacement of concrete. The contaminated concrete should be removed to a depth of several centimeters (inches). This usually extends to a level below that of the existing reinforcement. The concrete should be replaced with a similar concrete, a more impervious concrete, or another material. Concrete that contains inhibitors can also be used to neutralize future contamination as it occurs. Physical removal of all contaminated concrete has considerable

structural consequences and should be evaluated by a professional structural engineer.

5.5.1.1 Possible beneficial effects of physical removal and replacement include:

5.5.1.1.1 Complete removal of contaminants in the concrete removal area.

5.5.1.1.2 Restoration of the reinforcement to a passive state within the removal area.

5.5.1.1.3 Restoration of the concrete surface.

5.5.1.1.4 The possibility of improving surface drainage.

5.5.1.2 Possible detrimental effects of physical removal and replacement include:

5.5.1.2.1 Creation of corrosion cells between reinforcement in new concrete and reinforcement in partially contaminated concrete.

5.5.1.2.2 Physical damage to the structure during the restoration process.

5.5.2 Electrochemical removal of chlorides involves temporarily installing specific materials and equipment that are designed to force the migration of chloride ions from the concrete. The process is designed to achieve results over a relatively short time. The process of electrochemical removal includes covering the subject surfaces of the structure with an ionically conductive material. This material serves as an anolyte and contains an anode for the removal process. A DC power source must be connected between the anode and cathode (structure reinforcement). Specific current and voltage settings must be established for the desired effect. When the desired degree of chloride removal is achieved, the materials and equipment should be removed from the structure. Electrochemical removal is less destructive than physical removal but surface spalls and delaminations must still be repaired. The results of electrochemical removal can be variable because of time limitations, inconsistent concrete conductivity, and reinforcement discontinuities.

5.5.2.1 Possible beneficial effects of electrochemical removal include:

5.5.2.1.1 Removal of a large amount of the chlorides from around the reinforcement.

5.5.2.1.2 Restoration of the reinforcement to a more passive state.

5.5.2.2 Possible detrimental effects of electrochemical removal include:

5.5.2.2.1 Hydrogen embrittlement of high-strength reinforcing steel.

5.5.2.2.2 Promotion or acceleration of alkali/silica reaction in concrete that contains reactive aggregates.

5.5.2.2.3 Creation of corrosion macrocells between reinforcement that experienced a greater effect from the process and reinforcement that experienced a lesser effect from the process.

5.5.3 Cathodic protection (CP) involves permanently installing specific materials and equipment that are designed to provide a continuous DC to the reinforcement surface and thereby obtain a minimum level of cathodic polarization. (CP in this section is the impressed current type. Galvanic anode CP may be appropriate for certain structures.) The process is designed to achieve results over a somewhat longer time than electrochemical removal. However, the effect is continuously maintained as long as the equipment and materials remain functional. The process includes installing a material intended to act as an anode. The anode may be applied to or be embedded in the concrete. The structure's concrete serves as the primary electrolyte. A DC power source must be connected between the anode and cathode (structure reinforcement). Specific current and voltage settings must be established for the desired effect. CP is less destructive than physical removal but surface spalls and delaminations must still be repaired. The results of CP can be variable because of inconsistent concrete conductivity and reinforcement discontinuities. The physical configuration of the structure can also produce variable results because adequate CP current might not reach remote reinforcement without the risk of overprotecting nearby reinforcement. The application of CP to reinforced concrete structures should be prepared in accordance with NACE Standards RP0187¹ and RP0290.²

5.5.3.1 Possible beneficial effects of CP include:

5.5.3.1.1 Restoration to a passive or near-passive state of the reinforcement that receives adequate protective current.

5.5.3.2 Possible detrimental effects of CP include:

5.5.3.2.1 Stray current corrosion on unbonded embedded metallic components.

5.5.3.2.2 Promotion or acceleration of alkali/silica reaction at very high protective current densities in concrete that contains reactive aggregates.

5.5.4 Selection of techniques in this class should include consideration of the following characteristics and effects:

5.5.4.1 Durability and longevity.

5.5.4.3 Performance record on similar structures.

5.5.4.2 Compatibility with previously or subsequently applied materials.

References

1. NACE Standard RP0187 (latest revision), "Design Considerations for Corrosion Control of Reinforcing Steel in Concrete" (Houston, TX: NACE).

2. NACE Standard RP0290 (latest revision), "Impressed Current Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures" (Houston, TX: NACE).

Bibliography

1995 *Conference on Corrosion and Infrastructure—Extended Abstracts*. Proceedings of the 1995 Symposium held in Baltimore, MD, 1995. Houston, TX: NACE, 1995.

ACI 201 (latest revision). "Guide to Durable Concrete." Detroit, MI. American Concrete Institute (ACI).⁽¹⁾

ACI 222 (latest revision). "Design and Construction Practices to Mitigate Corrosion of Reinforcement in Concrete Structures." Detroit, MI: ACI.

ASTM C876 (latest revision). "Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete." West Conshohocken, PA: ASTM International.⁽²⁾

Corrosion of Steel Reinforcement in the Built Environment: Bridges, Buildings, Industrial Plants, Jetties, and Pipelines. (Technical papers presented at NACE Annual Conferences from 2000 through 2003 on various aspects of corrosion of steel reinforcing in concrete. Compiled by John P. Broomfield.) Houston, TX: NACE, 2004.

Crane, A.P., ed. *Corrosion of Reinforcement in Concrete Construction*. Chichester, England: Ellis Horwood Ltd., 1983.

Escalante, E.S., and A. Ito. *A Bibliography on the Corrosion and Protection of Steel in Concrete*. Special Publication 550. Gaithersburg, MD: National Institute of Science and Technology, August 1977.

ICRI Guideline 03733 (latest revision), "Guideline for Selecting and Specifying Concrete Repair Materials" (Des Plaines, IL: International Concrete Repair Institute [ICRI]).⁽³⁾

Slater, J. "Corrosion of Metals in Association with Concrete." STP-818. West Conshohocken, PA: ASTM, 1984.

Solving Rebar Corrosion Problems in Concrete. Proceedings of the 1982 Seminar on Solving Rebar Corrosion Problems in Concrete, held in Chicago, IL, 1982. Houston, TX: NACE, 1983.

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

⁽²⁾ ASTM International (ASTM), 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

⁽³⁾ International Concrete Repair Institute (ICRI), 3166 S. River Rd., Ste. 132, Des Plaines, IL 60018.