10-5 PROTECTION OF REINFORCEMENT AGAINST CORROSION DUE TO CHLORIDES, ACIDS AND SULFATES

General

Corrosion of steel reinforcement in concrete reduces the service life of a structure, as well as causes a reduction in its structural capacity. The factors that affect the rate of corrosion of reinforcement in concrete include the following:

a) Presence of harmful chemicals (such as chlorides, acids, and sulfates), as well as the concentration of these chemicals.

b) Availability of moisture and oxygen.

c) Concrete density and permeability.

d) Thickness of concrete cover.

While the rate of corrosion of reinforcing bars can be reduced by providing proper concrete cover, additional measures are needed to ensure adequate and efficient protection in harsh environments. Such measures include the use of corrosion resistant concrete (CRC) and the use of corrosion-resistant reinforcement such as epoxy-coated reinforcement (ECR).

Caltrans' Amendment to Section 5.12.3 of the AASHTO LRFD Specifications gives guidance to the Design Engineer in determining minimum required concrete cover to reinforcement to prevent corrosion. This section also offers guidance on other corrosion mitigation measures. Prior to using Table 5.12.3-1, the Design Engineer should have the following information concerning the bridge site:

i) Chloride content, acidity (pH value) and sulfate content of the surface water, ground water, and/or soil.

ii) Mean lower low water (MLLW) level and mean higher high water (MHHW) level.

The above information is obtained from the foundation report and the log of test borings (LOTB) report. In addition, the distance from marine or brackish surface water to the bridge site should be furnished to the Design Engineer.

Caltrans' Amendment to Section 5.12.3 has been developed for a 75-year design life of a bridge structure. However, it should be noted that the service life of a bridge deck is generally less than 75 years and is dependent on many factors such as magnitude and frequency of loading, environmental effects, and maintenance. Therefore, the minimum cover requirements for the deck, as well as for the barrier rails, have been established considering that their service life may be less than 75 years.

The Design Engineer should contact the Corrosion Technology Branch (CTB) in the Materials Engineering and Testing Services subdivision to determine the minimum concrete cover if the specified design life of a structure exceeds 75 years or if the conditions encountered at the bridge site are not addressed in the Specifications.

High Performance Concrete (HPC)

HPC is concrete that meets special requirements of performance and uniformity that cannot be achieved routinely using conventional constituents and normal practice. For example, HPC may be obtained by adding chemical admixtures, supplementary cementitious materials (SCMs), and/or by varying the water-to-cementitious material ratio. Generally, this type of concrete is developed with specific characteristics and for specific applications. Examples of specific requirements include reducing permeability, increasing density, increasing durability, improving ease in placement, and higher early strength (Concrete International, February 1999). FHWA has also proposed a more explicit definition for HPC based on performance criteria and testing requirements (Concrete International, February 1996).

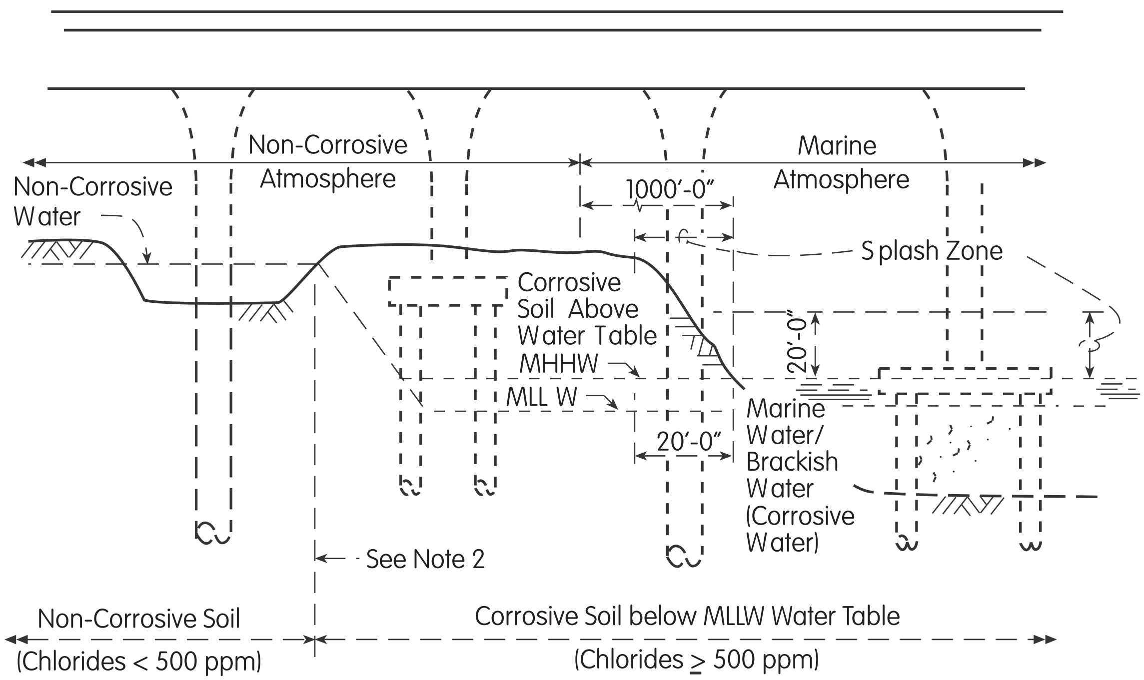
In Caltrans, CRC is a specific class of HPC. The mix-design requirements in CRC help to minimize the impact of a corrosive environment on structural concrete. The Design Engineer should contact the CTB to establish performance requirements for corrosion mitigation. Next, these requirements should be communicated to the Specifications Engineer through a "*Memo to Specifications Engineer/Estimator*" and incorporated into the Construction Specifications.

Corrosion Protection from Chlorides

Corrosion Zones

Table 5.12.3-1 identifies the following exposure conditions: non-corrosive atmosphere, soil, and water; marine atmosphere; corrosive soil above and below the Mean Lower Low Water (MLLW); corrosive water below the MLLW; corrosive splash zone (see MTD 10-6) and exposure to deicing salt, snow run-off and snow blower spray (Climate Area III or freeze-thaw zone - *Memo to Designers 8-2*). In addition, Caltrans' Amendment to Section 5.12.3 defines "Marine Atmosphere," "Tidal Water," and "Splash Zone." Corrosion of reinforcement in concrete may occur within any of these zones. In general, the rate of corrosion is highest within the splash zone where chlorides and oxygen are readily available. While corrosion of reinforcement in concrete which is immersed in tidal water is less severe than that in the splash zone, significant corrosion can still occur at large cracks in concrete when sufficient oxygen is available.

Figure 10-5(1) illustrates the different corrosion zones that are likely to be encountered in bridge design. Site specific information, when available, should be used to determine the range over which corrosive atmosphere adversely affects structures at a project site.



Notes:

1. The figure shows limits of corrosive and non-corrosive conditions in the atmosphere, soil, and water. Table 5.12.3-1 (Caltrans Amendments to LRFD Specifications) specifies actions required to protect reinforcement under these varying conditions.

2. The boundary between corrosive and non-corrosive soil conditions is to be determined by soil investigations at the site. Sulfate and pH assesments also may be required.

3. For additional information, refer to Caltrans Amendments to LRFD Specifications (Section 5.12.3)

Figure 10-5 (1): Corrosive Environment Diagram

Corrosion Control

Section 5.12.3 and the Table 5.12.3-1 provide information on methods to control rebar corrosion in concrete due to chlorides. Recent advances in concrete and corrosion technology, such as the use of ECR and CRC, have been utilized in developing these specifications as summarized below.

Epoxy Coated Reinforcement

The use of ECR slows the onset of corrosion and allows for reduced cover. There are two types of ECR that can be used in corrosive environments namely, the post-fabricated ECR (typically green in color) and the pre-fabricated ECR (purple or gray in color).

In post-fabricated ECR, the epoxy coating is flexible. Therefore, the rebar may be fabricated (bent to required shape) after the coating is applied. On the other hand, pre-fabricated ECR has a less flexible coating system, and the reinforcement is fabricated before the coating is applied. However, the coating used on pre-fabricated ECR provides a better adhesion and abrasion resistance as well as a more efficient protection against corrosion. Therefore, pre-fabricated ECR is generally specified for use in structural components that are within the salt-water splash zone and in barrier railing within 1000 ft from tidal water (see MTD 10-6).

Post-fabricated ECR should be used in Climate Area III (freeze-thaw zone) where required, and as specified in Table 5.12.3-1. However, if design considerations (e.g., the need to reduce concrete cover) necessitate the use of pre-fabricated ECR in areas other than those specified in Table 5.12.3-1, then the Design Engineer should obtain prior approval from the Deputy Chief, Division of Engineering Services, Structure Design.

ECR, where required, should be shown on Plans.

Supplementary Cementitious Materials (SCMs)

SCMs (such as fly-ash, silica fume, slag etc) are required when concrete is exposed to corrosive conditions. Addition of SCMs reduces the permeability of concrete to chloride ions. SCMs may slow the rate of strength gain in concrete, but do not adversely affect the long-term concrete strength.

The details relating to the use of several kinds of SCMs for developing CRC mixes are provided in the Construction Specifications.

Water-to-Cementitious Material Ratio

A low water-to-cementitious material ratio leads to a denser concrete. Table 5.12.3-1 specifies an upper limit of 0.40 for this ratio in corrosion zones.

Additional Corrosion Mitigation Techniques

In addition to the options discussed in the preceding paragraphs, protective measures such as the use of chemical admixtures, surface coatings, special curing techniques, protective overlays and cathodic protection, may be considered to improve the corrosion resistance properties of concrete and bridge components. Contact the CTB to determine the suitability of such options.

Effects of CRC and ECR on Concrete Cover

The minimum cover requirements in Table 5.12.3-1 are based on the following guidelines:

a) Where post-fabricated ECR is specified, the minimum cover is reduced by 0.5 inches (from cover that is provided for uncoated reinforcement).

b) Where pre-fabricated ECR is specified, the minimum cover is reduced by 1.0 inch (from cover that is provided for uncoated reinforcement).

c) When concrete having a combination of 5% SCM conforming to ASTM C1240 (eg. silica fume) and 20% SCM conforming to ASTM C618 Type F or N (eg. fly ash) is specified, the cover is 1.0 inch smaller than the cover provided when concrete contains 25% by mass of an SCM conforming to ASTM C618 Type F or N only.

The Design Engineer should contact the CTB to determine the effect on concrete cover when other SCMs are used.

In general, the Design Engineer should ensure that the same combinations of CRC are used for any portion of a bridge that is constructed in the same concrete placement. For example, the same type of CRC should be specified for the stem and soffit of a box girder, while a different type of CRC may be specified for the deck. The Design Engineer should provide all necessary information needed for CRC to the Specifications Engineer through a "*Memo to Specifications Engineer/Estimator.*"

Concrete Piles in Corrosive Environments

In corrosive environments, piles should be designed in accordance with Caltrans' Amendment to Section 5.12.3. Where the chloride concentration exceeds 10,000 ppm or when clear concrete cover exceeds 2.0 inches, standard pile details may not be adequate and site specific pile design may be required.

Corrosion Protection from Acids and Sulfates

Sections 5.12.4 and 5.12.5 of Caltrans Amendments to LRFD Specifications provide guidance on protection against acids and sulfates. Acids and sulfates have a detrimental effect on concrete and can adversely affect the performance and/or service life of a structure. The acidity of soil/water is determined by its pH value. If the bridge site data / foundation report indicates that the pH value of the soil/water is between 3 and 5.5 or that its sulfate concentration is between 2000 ppm and 15,000 ppm, then CRC will be required. This information should be conveyed to the Specifications Engineer.

When the pH of soil/water at the bridge location is less than 3.0 or when the sulfate content exceeds 15,000 ppm, contact the Corrosion Technology Branch.

References:

AASHTO LRFD Specifications and Caltrans Amendments to AASHTO Specifications, MTD 3-1, MTD 8-2 and MTD 10-6.

Original signed by Kevin Thompson

Kevin Thompson
Deputy Chief,
Division of Engineering Services
Structure Design