Corrosion Resistance of Reinforcement in Architectural Precast Concrete

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Presents the mechanism of corrosion of reinforcement and the conditions under which corrosion can occur in reinforced concrete. Chloride ingress and carbonation are discussed together with the importance of concrete cover and an impervious surface. Criteria for evaluating crack widths are given. Methods of protecting reinforcement, such as galvanized and epoxy-coated reinforcement, are discussed but not generally advocated. It is concluded that corrosion of reinforcement is usually not a problem in architectural precast concrete. High quality concrete with strengths between 5000 and 6000 psi (34.5 and 41.4 MPa) and a water-cement ratio of 0.40 or less is adequate in preventing corrosion.

Many years of experience have shown that reinforcement surrounded by concrete is protected from corrosion by the alkaline nature of the concrete, which renders the steel passive. This is particularly important in architectural precast concrete because buildings with such members need to retain their attractive appearance and durability over a long period of time (see Figs. 1a and 1b).

In an alkaline environment, a very thin protective layer of iron oxide (called the passivating layer) forms on the steel surface-to-concrete interface, which stops corrosion.[1] Passivity may be destroyed either by carbonation of the concrete, which reduces the alkalinity, or by the ingress of chlorides, which can cause localized disruption of the passive layer.

Depassivation, either locally or generally, is necessary but not sufficient cause for active corrosion induced damage to occur. The presence of moisture and oxygen are essential for corrosion to proceed at any significant rate. Because architectural precast members are vertical or inclined, the possibility of moisture retention or ponding on these elements is remote. Therefore, such members are not as susceptible to moisture penetration.

This paper presents the mechanism and conditions under which corrosion of reinforcement can occur, discusses chlorides and carbonation and methods of corrosion protection. The arti-

Fig. 1a. Aurora Municipal Justice Center, Aurora, Colorado [PCI Design Award Winner (1990)].

cle emphasizes that adequate concrete cover and high quality concrete is essential for producing long lasting architectural precast concrete.

CORROSION MECHANISM

To understand how subsurface corrosion of reinforcement can cause stains or cracking in concrete, a close look at the phenomenon of corrosion itself is required. Corrosion of steel is an electrochemical reaction. The preponderance of instances of electrochemical corrosion in concrete results because of the existence of differences in metals or non-uniformities of the steel (different steels, welds, active sites on the steel surface) or non-uniformities in the chemical or physical environment afforded by the surrounding concrete. These non-uniformities under certain specific conditions can produce significant electrical potential differences and resultant corrosion.

Differences in the structure or chemistry of the steel create a mosaic pattern of anodes and cathodes on the

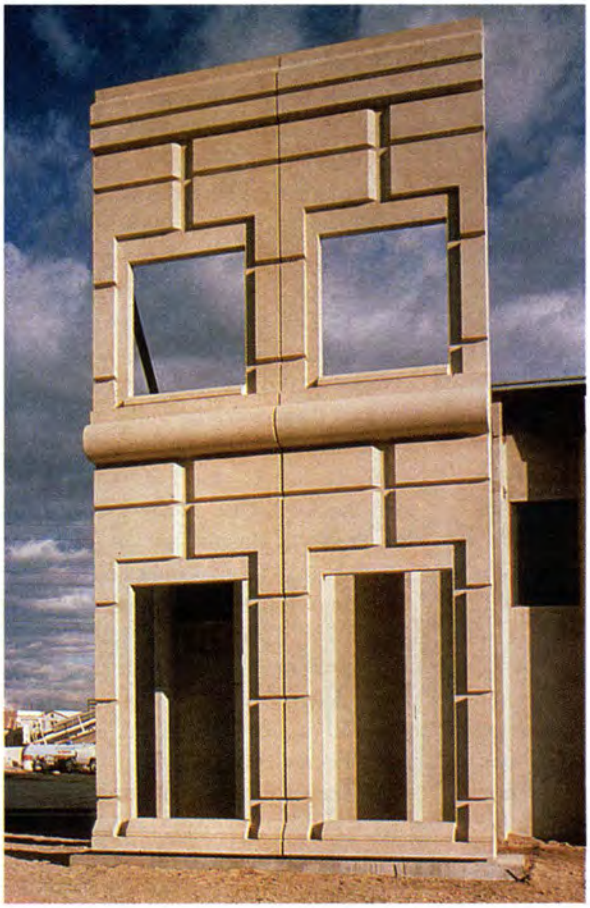

Fig. 1b. Closeup of architectural precast concrete panel (Aurora Municipal Justice Center). Architect/Structural Engineer: Skidmore, Owings & Merrill Precast Concrete Manufacturer: Rocky Mountain Prestress Inc.

steel containing stored electrochemical energy. Pore water in the concrete forms an electrolyte, which completes the electrical path between the anodes and cathodes. The anodic reaction occurs when iron atoms lose electrons. These then react to form rust. Electrons released by the iron move through the steel reinforcement to a location where oxygen reacts with the electrons and water to form hydroxide ions. The reaction, which uses the electrons, is known as the cathodic reaction.

The conditions that must be fulfilled if corrosion of steel is to be sustained are as follows:

- The availability of oxygen at the cathodic areas must be sufficient to sustain a reaction. If oxygen is limited, the current passing from the anodic area to the cathodic area will be low. It is not necessary that water be in contact with concrete for corrosion to occur. There is a threshold value of relative humidity (within the concrete) in the range of 70 to 85 percent relative humidity (RH) above which active corrosion can occur.
- The relative concentration of chloride ions to hydroxyl ions at the steel surface must be sufficient to break down the passivity.

Concentration cells due to differences in oxygen and chloride concentrations may occur at the surface of the steel and increase the probability of corrosion. Resulting potential differences of one-half volt may occur, which is enough to cause corrosion if the total resistance of the system is not sufficiently high. Factors related to the concrete that promote non-uniform concentration are cracks, voids, or variable density of the concrete. Lesser potential differences can be established by inclusions on the surface of the reinforcement.

Iron, as it corrodes and reacts with oxygen, expands up to four times its original volume. This expansion exerts a pressure on the concrete surrounding the reinforcement that can ultimately crack the surrounding concrete just as the expansion of freezing water will crack a pipe. The cracking may allow rust to "bleed" through and stain the concrete surface. As corrosion buildup continues, the resulting pressure causes spalling of the concrete. In most practical circumstances, this spalling occurs well before the reinforcement has become significantly weakened. Cracking and staining caused by the expansion of subsurface rust and bleeding through to the surface is a highly visible irritant to the building owner and public.

CHLORIDES

The most common cause of corrosion of reinforcing steel is the presence of chloride ions in the concrete. In general, precast concrete does not have a quantity of chloride ions that will cause corrosion. This is the case even in marine environments with salt spray, fog, or mist. The principal source of chloride in architectural concrete is that introduced into the concrete mix, intentionally or otherwise. The use of chloride containing materials in the concrete is strongly discouraged.

Architectural precast concrete is generally not exposed to deicing salts. According to Table 4.3.1 of the ACI Building Code (ACI 318-95),[1] the total mix water-soluble chloride ion content contributed from the water, aggregates, cementitious materials and admixtures should not exceed 0.06 percent chloride ions by weight of cement for prestressed concrete. The corresponding figure for reinforced concrete is 0.15 percent. Additionally, each admixture should not contribute more than 5 parts per million by weight of chloride ions to the total concrete ingredients.

When chloride ions reach the steel, some of them find naturally occurring imperfections in the passivating layer. At these points, the chloride reacts with the iron. One of the theories on the effect of chloride ions on steel corrosion is that the chloride and ferrous ions form soluble complexes, which move away from the steel and these complexes react with oxygen to form iron oxides (rust).[2] More chlorides move to the defects as the new rust compounds diffuse away from the steel. The original passivating layer is destroyed and a new layer cannot form. The corrosion process now continues unabated.

The threshold value of chloride concentration from externally applied sources below which corrosion does not occur is about 0.20 percent acid-soluble chloride ion content by weight of cement.[3] This is equivalent to about 0.025 to 0.040 percent by weight of concrete or 1.0 to 1.5 lbs per cu yd (0.593 to 0.890 kg/m^3) of concrete. It can take years or decades for this threshold amount of chloride to collect at the steel in uncracked concrete from externally applied salts. The time to corrosion depends on the concrete cover and the concrete permeability to chloride ions. Permeability is mainly affected by the water-cement ratio and concrete additives.

While chlorides are directly responsible for the initiation of corrosion, they play only an indirect role in determining the rate of corrosion after initiation. The primary rate controlling factors are the access of oxygen, the electrical conductivity and the relative humidity — all of which are interrelated — and temperature. Similarly, carbonation destroys the passive film but does not play a role in determining the rate of corrosion.

CONCRETE COVER

The two key factors influencing the likelihood of corrosion in precast/prestressed concrete members are the amount of cover for the reinforcement and the properties of the concrete immediately surrounding it, particularly the permeability of the concrete, and whether it is cracked or not. Ensuring proper cover is a frequently overlooked item in a durability protection program. Economical design against corrosion depends on understanding how these two factors influence corrosion.

Concrete cover refers to the minimum clear distance from the reinforcement to the face of the concrete. For exposed aggregate surfaces, the concrete cover to the surface of the steel should not be measured from the original surface. Instead, the depth of mortar removed between pieces of coarse aggregate (depth of reveal) should be subtracted to give a realistic measurement. Attention also must be given to scoring, false joints or rustications, and drips, as these factors also reduce the effective cover. The reduction in cover at these areas should not exceed one-third of the specified cover. The required minimum cover should be measured from the thinnest location to the reinforcement.

In order to provide corrosion protection to reinforcement, concrete cover should conform to ACI 318, Section 7.7, as listed in Table 1.[1]

Cover requirements over reinforcement should be increased to 1½ in. (38.1 mm) for non-galvanized reinforcement or be ¾ in. (19.1 mm) with galvanized or epoxy coated reinforcement when the precast concrete members are acid treated, exposed to a corrosive environment, or subjected to other severe exposure conditions. For all exposure conditions, the cover should be greater than 1½ times the nominal maximum aggregate size or equal to the specified concrete cover, whichever is larger.

Reinforcement should be placed within the allowable tolerances, but the concrete cover should be set so that the resulting concrete cover is never less than the specified value. Where possible, excess cover of ⅜ in. (9.5 mm), depending on the degree of complexity of the cage, should be specified because of the inaccuracy of locating reinforcing steel utilizing standard fabrication accessories and placing procedures.

In determining cover, consideration should be given to the following:

1. Structural or non-structural use of precast concrete members.

2. Maximum aggregate size (cover should always be greater than the nominal maximum aggregate size, particularly if a face mix is used).

3. Means of securing the reinforcement in a controlled position and maintaining this control during placement of concrete.

4. Accessibility for placement of concrete, and the proportioning of the concrete mix relative to the structural environment.

5. Type of finish treatment of the concrete surface.

6. Environment at the concrete surface: interior or exposed to weather, ocean atmosphere, or corrosive industrial fumes.

7. Fire resistance requirements.

Table 1. Minimum cover requirements for architectural precast and prestressed concrete.*,§

Conditions	Minimum cover
Exposed to earth or weather†	#11 and smaller – ¾ in.‡
Not exposed to earth or weather	#11 and smaller – ⅝ in.

Note: 1 in. = 25.4 mm.

* Manufactured under plant control conditions.

† Increase cover by 50 percent if tensile stress of prestressed members exceeds $6\sqrt{f'_c}$.

‡ Realistic only if maximum aggregate size ≤ ½ in. and reinforcing cage is not complex.

§ Cover requirements for #5 bars and smaller apply to prestressing steel.

Increased concrete cover increases the protection provided to the reinforcement, in part, because it acts as a diffusion barrier to the passage of water vapor and liquid. To provide too much cover is not beneficial, although Section 7.7 in ACI 318 does not specifically say so, and 2½ to 3 in. (63.5 to 76.2 mm) should be regarded as a maximum.[4] Concrete outside this limit lacks the restraint of the steel and is consequently liable to have wide cracks. In no case should the reinforcement be allowed to be beyond mid-depth of the precast element.

PERMEABILITY

The ability of high quality architectural precast concrete to resist the ingress of water, carbon dioxide, chloride, oxygen or other deleterious substances depends mostly on the permeabilities of the cement paste. Because the aggregate particles are surrounded by the hardened cement paste and most sound aggregates have low porosity, the permeability of concrete is principally a function of the permeability of the cement paste component of the concrete.

The water permeability of hardened cement paste is primarily a function of the original water-cement ratio and the length of the curing period (extent of hydration). Low permeability is obtained in a well-consolidated concrete having a low water-cement ratio, a characteristic of architectural precast concrete. A maximum water-cement ratio of 0.40 is recommended for corrosion protection of concrete exposed to deicing salts, brackish water, seawater, or spray from these sources. Fig. 2 shows the effect of water-cement ratio on the penetration

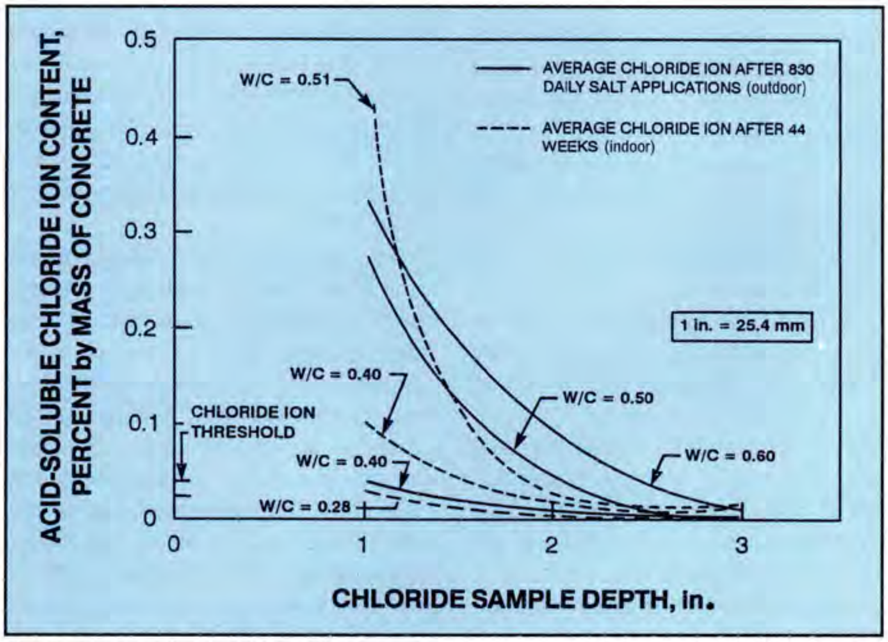

Fig. 2. Measured chloride profiles in moist-cured concrete from two FHWA investigations (Ref. 3).

of chlorides.[3] If the minimum concrete cover required by ACI 318, Section 7.7 is increased by 0.5 in. (12.7 mm), the water-cement ratio may be increased to 0.45 for normal weight concrete. Prior to specifying water-cement ratios less than 0.40, the designer/engineer should contact local precast concrete suppliers to determine their capabilities with the desired special facing aggregates.

Permeability can also be reduced by the use of clear penetrating concrete surface sealers, such as silane or siloxane, chemical products used to partially penetrate the concrete and prevent moisture or soluble chemicals from penetrating to reinforcement. However, prior to specifying sealers, designers should contact local precasters on the use of sealers to determine the effect on surface appearance and cost of the project.

CARBONATION

The reaction of carbon dioxide (CO_2) and sulphur dioxide with hydrated portland cement, called "carbonation," neutralizes the passivating oxide film on the steel developed by the alkaline conditions of hydrated cement paste. The pH of the pore water in concrete drops from 12.6-13.5 to about 8-9, at which level the passive film on steel is unstable. Thus, if the entire concrete cover to steel were carbonated, corrosion of steel would occur, provided oxygen and moisture necessary for the reactions of corrosion are present.

For this reason, it is important to know the depth of carbonation and specifically whether the carbonation "front" has reached the surface of the embedded steel. Because of the presence of coarse aggregate, the front does not advance as a perfectly straight line. It might also be noted that, if cracks are present, CO_2 can ingress through them so that the front advances locally from the penetrated cracks. Galvanized steel remains passivated to much lower levels of pH than does mild reinforcing steel.

Carbonation rates in typical precast concrete with water-cement ratios less than 0.40 are generally low, but are on the rise because of the increased concentration of the gases in industrial environments. Under natural conditions, the atmospheric concentration of CO_2 in air is about 0.03 percent; in American cities this is increased to ten times that value and in industrial sites can be as high as 100 times the normal levels.

Carbonation occurs progressively from the outside of concrete exposed to CO_2, but does so at a decreasing rate because CO_2 has to diffuse through the pore system, including the already carbonated surface zone of concrete. Carbonation does not occur in very dry concrete or concrete at 100 percent RH. Apparently, at 100 percent RH, the moisture blocks CO_2 from passing through the pores. The most aggressive environment for concrete neutralization is that of alternate dry and wet cycles (and, of course, high temperatures). Under constant conditions, the optimum condition for carbonation occurs at a RH of between 50 and 70 percent.

The very considerable influence of the moisture content of concrete upon carbonation means that even in a single building made of the same mix design, there may be a considerable variation in the depth of carbonation at a given age; the walls more exposed to rain will have a lower depth of carbonation; so will sloping surfaces which can be washed down by rain; the same applies to walls which can be thoroughly dried by the sun's rays. Normally, with good quality concrete, the effect of carbonation does not penetrate more than about $^1/_8$ to $^1/_4$ in. (3.2 to 6.4 mm), even when the concrete is exposed to the weather for 30 years.

The chloride content at the carbonation front reaches much higher levels than in uncarbonated concrete as chloride bound in the cement paste is released and is also much higher than the levels measured just below the concrete surface. This in itself would increase the risk of corrosion initiation when the carbonation front reaches the reinforcing steel. Added to this factor is the effect of the decrease in pH of the carbonated concrete. Note that the concentration of chlorides necessary to initiate corrosion (the threshold value) decreases with pH.

CRACK WIDTHS

Cast-in-place concrete structures are inherently prone to restrained volume change-induced cracking. This cracking is due to the normal restraint to movements created by complex shapes when integrally-cast slabs, beams, columns, walls, and footings attempt to be compatible in their contraction movements while undergoing early-age concrete volume changes caused by concrete temperature changes and drying shrinkage. Such natural restraint is difficult to eliminate. Therefore, cast-in-place concrete is designed with the assumption of a cracked section.

Precast concrete has less natural restraint problems because the individual members are not initially integral with the structure, particularly during the early-age time period when large concrete-related thermal and drying shrinkage effects are occurring. Architectural precast concrete is designed with the assumption of a crack free section.

As a result, precast concrete members and structures have less potential for cracking, particularly when prestressed. Therefore, the potential exposure of the reinforcement to oxygen and moisture (necessary for corrosion) is less with precast concrete. In addition, the denseness and impermeability of the precast concrete due to low water-cement ratios of plant cast concrete should be considered when evaluating the corrosion potential.

It should be recognized that a certain amount of cracking may occur without having any detrimental effect on the structural capacity of the member and it is impractical to impose specifications that prohibit cracking. However, in addition to being unsightly, cracks are potential locations of concrete deterioration and should be avoided if possible. Cracks need not lead to corrosion of reinforcement. This depends not only on the width of the crack and whether it reaches the reinforcing steel, but also on the presence of chlorides or low pH in combination with water.

When corrosion starts at a crack, the depassivated area near the crack becomes the anode of a corrosion cell, while portions of the bar still protected

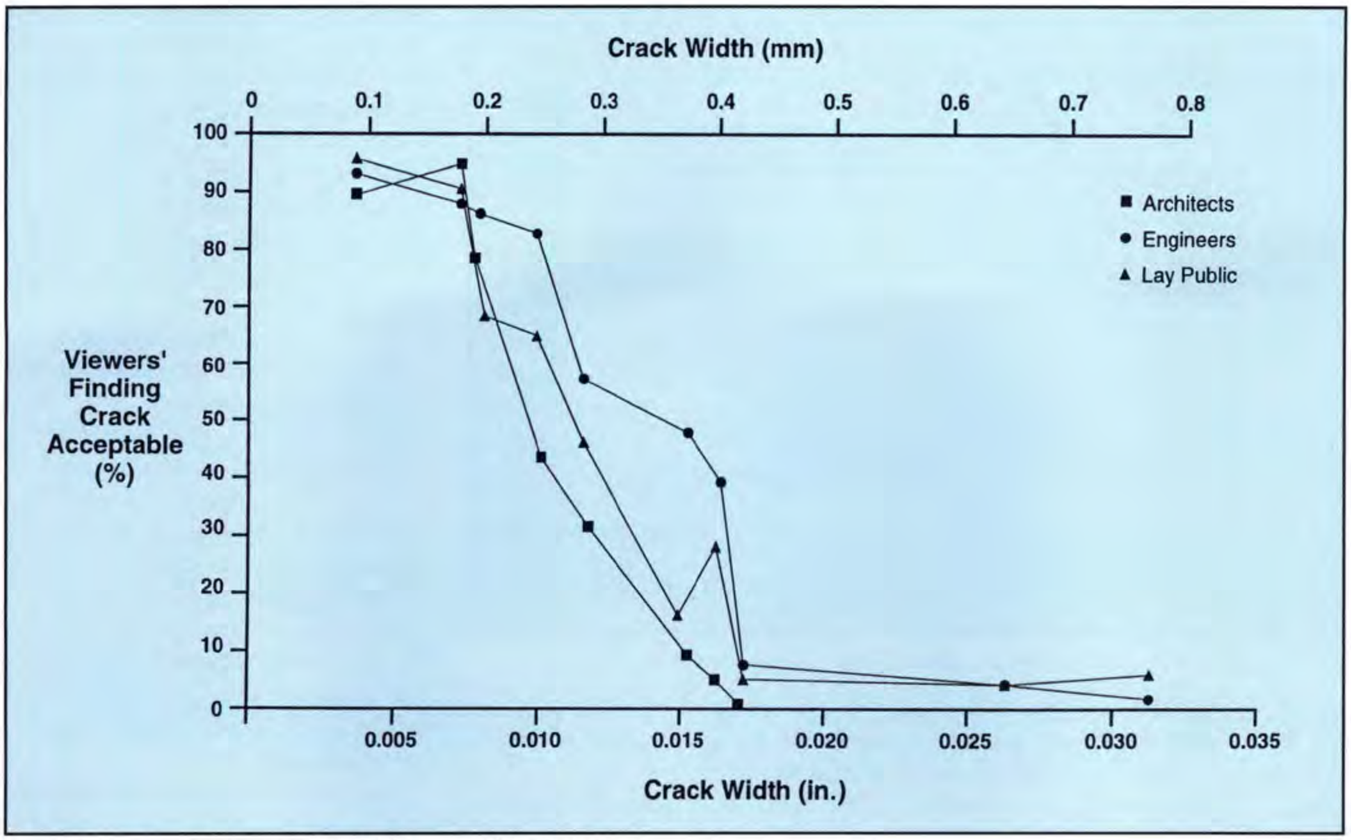

Fig. 3. Viewer reaction to cracks of different widths (Ref. 6).

by sound alkaline concrete become the cathode. At the anode, metal ions are released. At the cathode, oxygen combines with water to form hydroxyl ions which flow through the electrolyte to the anode where they combine with the metal ions to produce iron hydroxide. As a secondary reaction, this hydroxide combines with additional oxygen to form rust.

The rate at which corrosion will occur depends on the resistance of the path through the concrete between the anode and the cathode and the availability of oxygen at the cathode, which is situated on the bar surrounded by sound concrete, not at the crack. The rate of corrosion is thus dependent on the properties of the sound concrete. The crack plays no part in corrosion control; its function is simply to initiate the process by allowing the bar to become depassivated locally.[5]

The amount and location of reinforcing steel has a negligible effect on performance until a crack develops. As flexural tension increases above the modulus of rupture, hairline cracks will develop and extend a distance into the member. A sufficient amount of closely spaced reinforcement limits crack widths and the intrusion of corrosion initiators. Prestressing also may be used to limit crack width. If the crack width is narrow, not over 0.010 in. (0.25 mm), the structural adequacy of the casting will remain unimpaired and the crack will have little influence on the corrosion of the reinforcement.

Cracks transverse to the reinforcing steel usually do not cause continuing corrosion of the reinforcement if the concrete has low permeability. The corroded length of intercepted bars is likely to be no more than three bar diameters. This is due to the fact that the exposed portion of a bar at a crack acts as an anode. Cracks that follow the line of a reinforcing bar are much more damaging because the corroded length of the bar is much greater and the resistance of the concrete to spalling is reduced. Cracks up to 0.005 in. (0.13 mm) wide for surfaces exposed to the weather have no influence on the corrosion of reinforcement and should be acceptable from an aesthetic viewpoint (see Fig. 3).

Fig. 4 shows variations in crack width between the concrete surface and the bar surface obtained by injecting resin into cracks in a beam and then sawing up the beam after the resin has set.[7] For a given steel stress, the crack width at the bar surface remains constant while that at the surface varies more or less linearly with increase in cover. Thus, there is not a constant relationship between surface width and width near the bar; a direct relationship between the surface crack width and corrosion should not be expected to exist.

Crack width appears to have a significant effect on the amount of corrosion at a relatively early age, because the time to depassivation is dependent on the width of the crack. However, once corrosion has started, the rate of corrosion is independent of crack width. If the combination of density and cover thickness is adequate to restrict the flow of oxygen and moisture, then the corrosion process is self sealing. Crack widths should be controlled for appearance and watertightness.

CORROSION PROTECTION

High quality concrete provides adequate corrosion protection of reinforcement for most conditions. Even in moderate to severe aggressive envi-

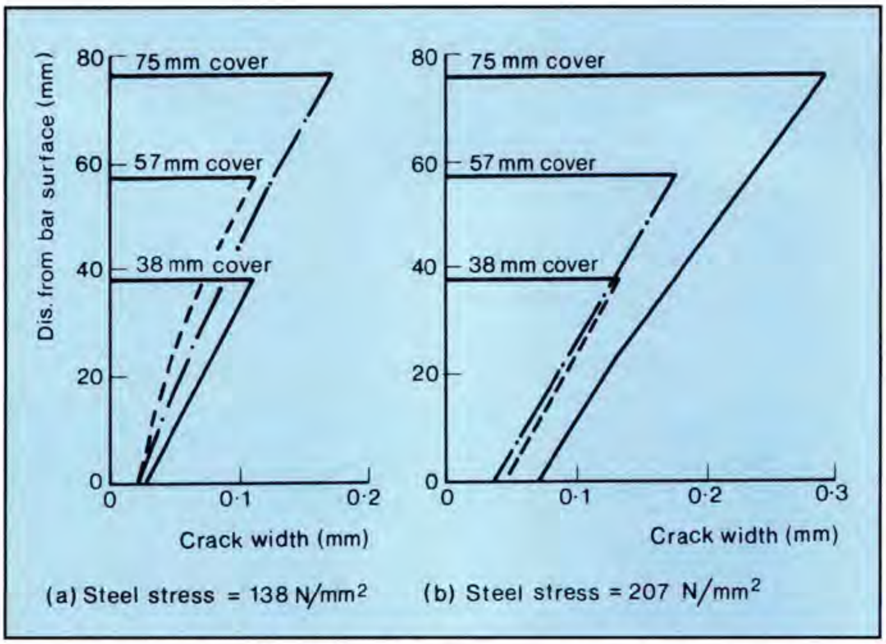

Fig. 4. Internal crack widths (Ref. 7). **Note:** 1 mm = 0.039 in.; 1 N/mm^2 = 145 psi.

ronments, precast concrete can provide adequate protection with proper attention to mix design, steel stress level and the extent of cracking under service loads, and the thickness of concrete cover. Only when these protection measures are not feasible is it necessary to consider special ways of protecting the reinforcement, such as galvanizing or epoxy coating. These methods are described below.

Galvanized Reinforcement

The term galvanized steel refers to the electrolytic method which bonds zinc to the steel surface. Zinc is a reactive metal that readily oxidizes in air to form a corrosion resistant film of zinc oxide. The zinc oxide layer is very thin, hard and tenacious and is the first step in the development of the protective corrosion product layer normally associated with the galvanized coating. When this surface has access to freely moving air in normal atmospheric exposure, the surface reacts with rainfall or dew to form zinc hydroxide.

During drying, the zinc hydroxide reacts with carbon dioxide in the atmosphere and is converted into a thin, compact and tightly adherent layer of basic zinc carbonate. This layer provides the barrier protection afforded by the galvanized coating. Because it is relatively insoluble, the basic zinc carbonate layer is weather resistant and, once formed, minimizes further corrosion.

Galvanized welded wire fabric is generally manufactured from galvanized wire and is a stock item in some sizes. There is no specific ASTM specification for galvanized welded wire fabric; however, ASTM A641/A641M is used for reference. The amount of zinc coating on wire fabric is rarely specified for galvanized wire fabric reinforcement. Galvanized wire can be produced with thicknesses of zinc coating ranging from 0.30 to 2.0 ounces per sq ft (107 and 610 g/m^2) for different grades and wire sizes. The cost premium is usually 15 to 20 percent over non-galvanized wire. Deformed wires are seldom galvanized.

Where galvanizing of reinforcing bars is desired, galvanizing in accordance with ASTM A767/A767M is usually performed after fabrication. The ASTM specification has two classes of zinc coating weights. Class II [2.0 ounces per sq ft (610 g/m^2)] is normally specified for precast concrete units.*

Some precast concrete manufacturers prefer to use galvanized reinforcement because staining caused by red rusting will be minimized during the prolonged storage, which is often required by the economics of bulk purchasing.

A galvanized coating is anodic to the base steel and provides cathodic protection to exposed steel such as cut edges or holes due to abrasion or impact. Galvanizing is "sacrificial" protection; therefore, in a corrosive environment, it too corrodes. The zinc oxide does not crack the concrete as quickly as iron oxidation products because it occupies about one-third less volume for a given weight and is loose and powdery.

The rate of pressure buildup is reduced by using a zinc sacrificial barrier, increasing the time before corrosion-related cracking occurs. Whether cracking of the concrete occurs subsequently or not depends on many factors such as the strength of concrete, amount of concrete cover, size of galvanized member, exposure conditions, and chemical composition of concrete. To what extent the base steel will be corroded is uncertain because galvanizing does furnish sacrificial protection to the steel.

Galvanized reinforcement is recommended when minimum cover requirements cannot be achieved, or when the concrete is exposed to a particularly severe environment. However, a detrimental chemical reaction can take place when the concrete is damp and chlorides are present. Therefore, the benefit obtained by galvanizing is questionable for members subjected to a marine atmosphere.

Epoxy Coated Reinforcement

Epoxy coated reinforcement has been widely used in aggressive environments since the early seventies. Epoxy coated reinforcing bars should conform to ASTM A775 and epoxy coated welded wire fabric should conform to ASTM A884. The effectiveness of epoxy coating to protect steel from corrosion in some cases has been well documented. However, this can only be achieved as long as the coating has minimal pinholes (holidays) and is not significantly damaged. The corrosion resistance is re-

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* ASTM A767/A767M states that "the galvanized coating shall be chromate treated. This is to preclude a reaction between the bars and fresh portland cement paste." The chromate solution has been designated a carcinogen (cancer causing) and the chromating treatment is under consideration for deletion. This can cause problems for the precaster by increasing reinforcement reflection and causing sticking of concrete to metal forms.

lated to holiday count (that is, any hole or defect in the coating that permits corrosion current to pass between the bare steel and liquids) and extent of damage.

In practice, there will be some pinholes in the coating when the epoxy coated reinforcement leaves the factory (ASTM requires not more than an average of one holiday per foot), and damage during transportation to the precast plant, placement of the reinforcement, and placing and vibrating the concrete. Such damage should be repaired, but locating all of the holidays is difficult and very time consuming. The after-production cut ends and damaged areas should be patched using the manufacturer's approved patch compound.

In addition, bent bars, although visually undamaged might have lower corrosion resistance than straight bars. The long-term durability of structures employing epoxy coated reinforcement will depend on the progress of corrosion at defects in the material. If the number of defects is limited and corrosion does not spread beneath the coating, then long-term performance should be possible. If good quality practices cannot be used, then the use of epoxy reinforcement should be limited.

Cracks in concrete members reinforced with epoxy coated reinforcement, if they occur, will tend to be larger than cracks of similar concrete members reinforced with mild reinforcing steel.

Epoxy coated reinforcement may add significantly to the cost of the precast concrete products because the cost of epoxy coated welded wire fabric is 2 to $2^1/_2$ times plain fabric, and depends on the size of the wires. The premium cost of epoxy coated reinforcing bars ranges from 15 to 25 percent more per pound (average added cost differential of $0.087 per pound) than plain bars.

The use of epoxy coated reinforcement in architectural precast panels has not been observed to produce significantly better performance, perhaps because of difficulties in achieving the ideal epoxy coating. The reduction of performance when exposed to heat or fire is a concern regarding the application of epoxy coating.

Epoxy coating has been employed where the projected loss of bond under high heat is not significant. Epoxy coated reinforcement is not necessary with the environmental conditions typically experienced by architectural precast concrete as long as adequate cover and a low water-cement ratio concrete are used.

CONCLUDING REMARKS

Corrosion of reinforcement is usually not a problem in architectural precast concrete. It should be recognized that galvanized or epoxy coated reinforcement cannot take the place of quality control in mix proportioning and steel placement. Experienced designers and precasters recognize that galvanized or epoxy coated reinforcement should not substitute for proper control of concrete mixtures.

Sound concrete having strengths of 5000 to 6000 psi (34.5 to 41.4 MPa) in 28 days with a water-cement ratio of 0.40 or less and proper cover [greater than $^3/_4$ in. (19.1 mm)] will typically provide all of the corrosion protection necessary for the reinforcing steel in architectural precast concrete.

There is no such material as "general concrete." Each project must be approached individually. Just as a concrete road differs from a concrete bridge, though both may be part of the same highway system, so, in architectural precast concrete, a wall or spandrel member differs from a precast paving slab. Each architectural member requires its own specific attention to detail with regards to its intended exposure conditions.

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