Repair and Protection of Concrete Exposed to Seawater

By Ali Sohanghpurwala and William T. Scannell

Our love for the blue waters has, over the last several decades, supported a massive construction program along the U.S. coastline. Resorts, condominiums, bridges, jetties, and a host of other structures have all been constructed using reinforced concrete. During the boom times more emphasis was placed on efficient construction rather than on the long-term durability of structures. Also, the impact of the marine environment on reinforced concrete structures was not well understood. Concrete was believed to be the magic material that would last for generations without any maintenance. Even today, many people in the construction industry believe in the myth that concrete is forever, no matter what environment it is exposed to. However, the condition of many reinforced concrete structures exposed to the marine environment makes one wonder what happened to the magic of concrete.

We are not proposing that concrete is not durable—in fact it is still the most durable material known to mankind. The point is that there are certain environments that can compromise the durability of concrete and reduce its service life. In a marine environment corrosion of reinforcing steel is one of the most important and prevalent deterioration processes. Concrete under normal exposure conditions protects reinforcing steel against corrosion. This protective behavior of concrete is attributed to its high pH and the formation of a protective film on the surface of the embedded steel. However, the presence of chloride ions (salt) in sufficient quantities at the steel-concrete interface destroys the protective film and initiates corrosion on the steel surface. Chloride ions are obviously abundant in marine environments and can permeate through the concrete to the reinforcing steel surface. A reduction in the pH of the concrete by carbonation or any other process can also result in corrosion.

One of the Bryant Patton Bridges in Florida displays a reinforced concrete pile with significant corrosion induced damage.

Although carbonation can occur in marine structures, it has not been identified as the primary cause of reinforcing steel corrosion in North America.

Structures in marine environments can be divided into two categories of exposure; direct and indirect. The direct exposure category includes structures that are partially or fully submerged and the indirect category includes structures along the coast line which do not come in direct contact with seawater. Jetties, bridge substructure elements and retaining walls are examples of structures in the direct exposure category, whereas, multi-storied condominiums and other buildings on the coast are examples of structures in the indirect exposure category. Although the results of the corrosion process are similar for all reinforced concrete structures, the process by which corrosion occurs, the corrosion rate and appropriate repair and long-term protection schemes can be very different. This article focuses on semi-submerged structures in the direct exposure category. To the author's knowledge, most maritime repair work has occurred on semi-submerged pilings and, therefore, the majority of this article is dedicated to the repair and long term protection of pilings.

Semi-Submerged Structures

Partially submerged reinforced concrete structures typically show three distinct regions with varying corrosion conditions. The completely submerged section of the structure may have some corrosion induced damage, but this is generally inconsequential, as the steel in this situation corrodes at a very slow rate. Although chloride ion levels in submerged sections far exceed the threshold level required to initiate corrosion of reinforcing steel, the availability of oxygen

A severely deteriorated pile which had previously been repaired with a fiberglass jacket.

at the steel-concrete interface becomes the controlling factor. The diffusion of oxygen in fully saturated concrete is very slow and can only support very low corrosion rates.

The most important region of the partially submerged structure is the tidal and splash zone. On structures in Florida, for instance, this region is typically bounded by the low tide mark and approximately 5 to 7 feet (2 m) above the low tide level. Repeated wetting and drying of the concrete provides both a high concentration of chloride ions and sufficient quantities of oxygen. Also, the electrical conductivity of the concrete in this region is high. This situation may be made even worse by the development of corrosion macrocells between higher regions of the concrete element which are not undergoing corrosion, but where oxygen access is greater, and the highly chloride contaminated and corroding zone. Most of the corrosion induced damage occurs in the tidal and splash zones and extensive research into repair and long term protection technology for these zones has been conducted.

The region above the tidal and splash zone generally shows less corrosion damage. The primary difference in this region is the source of salt (airborne chlorides versus direct contact with salt water) and the concrete moisture content.

Improved materials and concrete designs are being applied in new construction. The simplest design change that has been incorporated is to increase the clear concrete cover over the reinforcing steel. Lower water/cement ratio and lower permeability conventional concretes are also being used, along with specialty concretes such as latex modified, fly ash and silica fume concrete. Other design changes include the use of special reinforcing steel, such as galvanized or epoxy coated rebars. The Federal Highway Administration encourages epoxy coated reinforcing steel in the construction of concrete bridge structures susceptible to corrosion induced damage. Although epoxy coated rebars have performed effectively in many environments, recent reports by the Florida Department of Transportation and recent research have questioned the ability of epoxy coated reinforcing steel to perform effectively in marine environments. Both users and researchers are very polarized on the issue of epoxy coated rebar performance and no consensus has been reached.

With regard to existing structures, it has been reported that externally visible signs of deterioration occur on bridge substructure elements within about 12 years of service in some marine environments. To ensure safe and continued operation of marine bridges, many different types of repairs have been tried. Initial attempts at developing a good long term protection system targeted conventional repair materials and technology. However, with the successful application of cathodic protection to bridge decks and many other reinforced concrete structures, the focus has now shifted to cathodic protection for marine substructures. However, all systems and materials should be considered for all projects.

Conventional Repair

Understandably, the first approach to repairing corrosion induced damage was to repair the deteriorated areas only. Many different materials and application techniques have been used. Initially, sand/cement mortars were used to repair spalled areas. Later shotcrete (guniting) became very popular as it offered a more convenient and economical means of applying repair material particularly on large repair projects. Although several problems with shotcreting were encountered, experience has shown that most of these can be avoided with proper selection of materials, good mix design and a well trained applicator.

With the advancement of materials technology, many specialty materials, such as latex modified concrete, polymer modified concrete and silica fume concrete, were introduced as repair materials. It was reasoned that the repaired areas would have enhanced resistance to corrosion due to the use of materials with lower permeability and electrical conductivity. Surface preparation techniques were also improved to produce a better bond between the repair material and the original concrete.

However, the removal of deteriorated concrete and repairing with cementitious materials by itself does not address the root cause of the corrosion problem—the presence of chloride ions, oxygen and moisture. High concentrations of chloride ions still exist in the remaining concrete, and in these areas the corrosion process is allowed to continue unabated. The repair material itself also proved to be a problem as corrosion cells were inadvertently created between steel embedded in chloride-free re-

Failure of a non-structural pile jacket.

pair material and steel embedded in chloride contaminated native concrete. This resulted in corrosion damage along the periphery of the patch and eventually complete failure of the surrounding material and the repair itself. Many in the industry refer to this phenomena as the "halo effect." Also, with time, chloride ions will permeate the new patch material. Although the amount of time required for diffusion of a sufficient amount of chloride ions is dependent on several factors, eventually the situation will come full circle.

The philosophy of a "cut and patch" repair is very similar to taking aspirin to cure a chronic migraine headache problem. The only benefit it provides is to temporarily cover up the symptoms of the process going on inside. It does not in any way retard or control the ongoing process. The cut and patch philosophy works only when all concrete which is contaminated with chloride ions (or carbonated) is removed and replaced and no further ingress of chloride ions (and no carbonation) is permitted to occur. Also, as explained above, the "cut and patch" process can actually accelerate corrosion in the surrounding chloride contaminated concrete. The procedure is particularly inappropriate on marine substructure elements which are heavily contaminated with chloride ions from all sides.

Epoxy injection of cracks on semi-submerged pilings has been attempted without any success to date.

Another kind of conventional repair involves the use of "jackets." There are two broad categories of jackets; structural and non-structural. Structural jackets are used to repair structural damage and non-structural jackets are typically used when dealing with corrosion induced damage. The discussions that follows pertain to non-structural jackets only. This type of repair has been used on bridge pilings and several different kinds of jackets have been used to date. Materials such as wood and fiberglass have been used to manufacture jackets and the filler material has varied from sand/cement mortars to synthetic polymers. It was believed that the jackets would provide protection against future corrosion damage. However, it turned out that jackets were powerless against corrosion for a number of reasons. First, capillary action allowed water from the submerged section of the pile to rise up the pile. Also, high levels of chloride ions remained in unrepaired areas. Although jackets could delay additional chlorides from entering the pile through the jacket surface, they did nothing to mitigate corrosion of the reinforcing steel. In fact, it has been shown that jackets accelerate the corrosion process in pilings since the concrete is never allowed to dry out and sufficient oxygen is always available in the jacketed area. Unfortunately, the only thing a jacket can do is keep corrosion induced damage out of site which, as discussed below, can prove to be more dangerous than ignoring the problem altogether.

The detrimental effects of pile jacketing for corrosion protection are exemplified by the Bryant Patton Bridges in Florida. A 1990 survey of the piles conducted by the Florida Department of Transportation showed that 50% of the piles that were found to be deficient had previously been repaired with fiberglass jackets. In some cases, construction defects were found in the jackets. A rehabilitation project was initiated in 1993 and jackets from numerous piles were removed. Almost all piles which had been jacketed showed significant corrosion induced damage. Due to the severity of the damage, the Florida Department of Transportation decided to install supplementary replacement piles (crutch bends) to each and every pile which had been jacketed.

Many owner agencies have been forced to repeatedly repair their marine structures when only conventional techniques were used. In the case of bridge structures, the problem is compounded in that some repair efforts, especially the installation of crutch bends, may involve a partial closure of the bridge. The resulting inconvenience to the traveling public and the economic impact on the local area can be immense.

Cathodic Protection

Cathodic protection is being increasingly used to provide long-term corrosion protection on existing semi-submerged concrete elements in marine environments. When dealing with cathodic protection systems, it is necessary to differentiate between conventionally reinforced and prestressed concrete elements as an entirely different set of problems are encountered in these cases. For gen-

The integral pile jacket system uses a fiberglass jacket supplied with the mesh anode.

A thin layer of zinc is applied directly to cleaned steel and adjacent concrete surfaces as part of the galvanic system.

This conductive rubber jacket system is protecting the tidal and splash zones of a bridge piling.

eral information on cathodic protection, please refer to the article entitled "Cathodic Protection as a Corrosion Control Alternative" in the July/August 1993 issue of *Concrete Repair Bulletin*.

Impressed current cathodic protection systems have been successfully used to protect conventionally reinforced concrete bridge decks and many other concrete structures. Galvanic cathodic protection is being increasingly considered for the protection of semi-submerged elements and this type of system is presently preferred on prestressed components to avoid problems associated with hydrogen embrittlement. Several galvanic systems have been installed on semi-submerged structures and are reportedly functioning satisfactorily.

Systems for bridge substructures fall into three general categories; surface applied, encapsulated and non-encapsulated systems. The surface applied and non-encapsulated categories include both impressed current and galvanic systems, whereas the systems in the encapsulated category are impressed current type systems only. Each of these categories is discussed below and some specific systems are mentioned. However, it should be noted that research on several other systems is underway.

The surface applied systems involve application of an anode material over the entire surface of the concrete. The most common surface applied anodes are conductive paint and thermally sprayed zinc. The conductive paint anode is applied by spray or roller and a decorative overcoat is then applied, if desired, for aesthetic purposes. Due to EPA regulations, most conductive paint systems are water based and cannot be used in the tidal and splash zones. The thermally sprayed zinc system can be installed as either an impressed current or galvanic system. In both cases, a thin layer of zinc is applied to the concrete surface using metallizing techniques. In the case of a galvanic system, the zinc may be applied directly to cleaned steel in areas where damaged concrete has been removed and to the adjacent concrete surfaces. If aesthetically acceptable, the areas where damaged concrete was removed may then be left unrepaired. The moisture content of the concrete during application of the zinc significantly impacts the bond between the zinc and concrete. Thus, thermally sprayed zinc systems are not presently applicable in the tidal zone and splash zones.

The encapsulated category includes two systems, both of which utilize a titanium anode mesh. The first system uses shotcrete to encapsulate the anode mesh. When this system is used special attention must be given to surface preparation and shotcrete application to prevent debonding of the shotcrete.

The second system is called an integral pile jacket system. This recently developed system utilizes a prefabricated fiberglass jacket which is supplied with the mesh anode already in place. The jacket system is mounted to the pile using compression bands and then the void between the jacket and the concrete surface is filled with a grout.

Presently, there are three non-encapsulated bridge piling systems. The impressed current system is called the conductive rubber jacket system. A corrugated conductive rubber material is attached to the concrete surface. Intimate contact is achieved by fiberglass panels and compression bands. This system can be designed to protect the tidal and splash zone on bridge pilings in a marine environment. Another system utilizes perforated zinc sheets to provide galvanic protection in the tidal and splash zone. Recycled wood/plastic panels with cut grooves on the contact face are used in lieu of fiberglass panels. Installation is very similar to the conductive rubber system except extensive electrical wiring and an external power source are not required. The final system, termed the bulk zinc anode system, utilizes a large zinc ingot which is submerged adjacent to a bridge piling in a marine environment. This system can provide galvanic protection in the tidal and splash zone. Research to determine whether this system can provide protection above the splash zone is continuing.

It should be noted that selection and design of cathodic protection systems for any given structure should be conducted with care. In addition, although structures in the indirect category have not been addressed in this article, it should be pointed out that conventional repair techniques and corrosion protection methods other than cathodic protection may be more appropriate and cost effective for these structures.

Ali Sohanghpurwala and William T. Scannell are principals of CONCORR, Inc., Ashburn, Virginia. They specialize in the evaluation, repair and protection of reinforced concrete structures. They are also researchers in the areas of reinforcing steel corrosion and corrosion protection technology including cathodic protection and epoxy coated reinforcing steel. They both received master's degrees in Ocean Engineering from Florida Atlantic University and have authored several technical publications on corrosion, structure evaluations and cathodic protection. They are members of, ICRI, the International Concrete Repair Institute, the National Association of Corrosion Engineers (NACE), and the American Concrete Institute (ACI). They serve on several technical committees for these organizations and the Transportation Research Board. They both are NACE certified corrosion specialists and cathodic protection specialists.

This article appeared in the
July/August 1994 issue of the
Concrete Repair Bulletin.

CONCORR Inc.
CONCRETE CORROSION SPECIALISTS
Headquarters
45710 Oakbrook Court
Suite 160
Sterling, VA 20166-7223
Tel: 571-434-1852
Fax: 571-434-1851
E-mail: inquiry@concorr.com

Web: www.concorr.com