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Control of Corrosion on Underwater Piles

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Abstract

Corrosion and in particular corrosion of metal structures, is a problem that must regularly be addressed in a wide variety of areas, for example, in the automotive industry, metal parts are often plated or coated to protect them from road salt and moisture in hopes of increasing their longevity. Indeed, many traditional metal parts are currently being used with polymeric components, which are not only lighter but also more cost effective to produce. But these are generally impervious to electrochemical corrosion often experienced by metals. Even with the proper selection of base metals and well-designed systems or structures, there is no absolute way to eliminate all corrosion. Therefore, corrosion protection methods are used to additionally mitigate and control the effects of corrosion. Corrosion protection can be in a number of different forms/strategies with perhaps multiple methods applied in severe environments. Forms of corrosion protection include the use of inhibitors, surface treatments, coatings and sealants, cathodic protection and anodic protection.

Introduction:

Corrosion is the destruction of metals and alloys by the chemical reaction with the environment. During corrosion the metals are converted to metallic compounds at the surface and these compounds wears away as corrosion product [1-3]. Hence corrosion may be regarded as the reverse process of extraction of metals from ore. On steel piling in seawater, the more chemically active surface areas (anodes) are metallically coupled through the piling itself to the less chemically active surface areas (cathodes) resulting in a flow of electricity and corrosion of the anodic areas [4-6]. General surface roughening occurs when these local anodic and cathodic areas continually shift about randomly during the corrosion process. Sometimes these active local areas do not shift position end, therefore, the metal suffers localized attack and pitting occurs [7-9]. In general, the depth of pitting is related to the ratio of the anodic sites to the area of cathodic site in contact with the electrolyte (seawater). The smaller the anode area relative to the cathode area, the deeper the pitting [10-11]. Examination of corroded marine piles reveals several distinct areas of attack. It is convenient to divide these areas into five zones, each having a characteristic corrosion rate as shown in Fig 1.

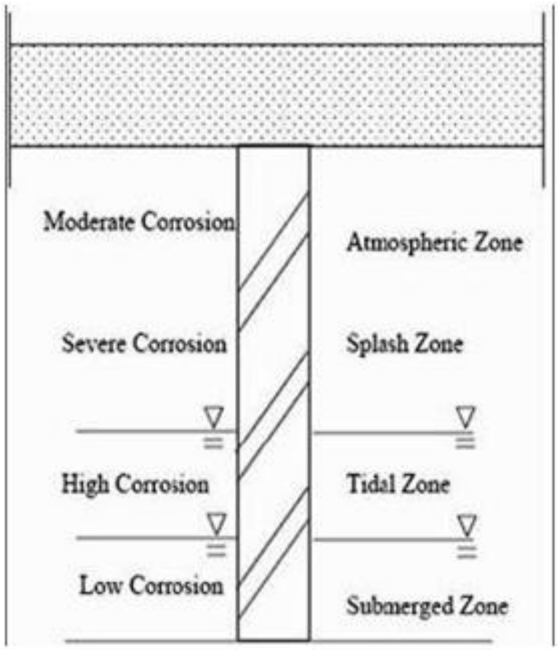

Fig 1 zone of corrosion of steel plates

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Corrosion Management

Before deciding on the methods for control of corrosion to be applied, conceptual and feasibility studies have been carried out. Typically, corrosion management can be divided into three major phases.

Phase 1 of the program is the programmatic assessment of the project. This phase is the planning stage for a corrosion management program to take place. It initiates the program to be implemented on structures that are found to be under the threat of corrosion. For the planning stage, three main requirements are sought, namely the strategy, budget and schedule needed to overcome the problem raised from corrosion of reinforcement. This is seen as an important part for an effective management program as feasibility studies are normally conducted to determine the serviceability of the structure after treatment [12].

Phase 2 of the program involves physical assessment and actual remediation. Inspections for severity of corrosion are conducted in this phase to determine what strategy or methods are most suitable to be applied. Development of corrosion control strategy would present more option to the management program. Remedial work would be carried out once the proper strategy has been recognized.

Phase 3 of the program mainly deals with future monitoring of the repaired structure. Currently and historically, most of the corrosion control programs are driven by response to incident or urgent need, rather than systematically identifying and managing the existing resources. This can be overcome by implementing internal or external monitoring system using current technology practiced in oil and gas industries is as shown in Fig. 2.

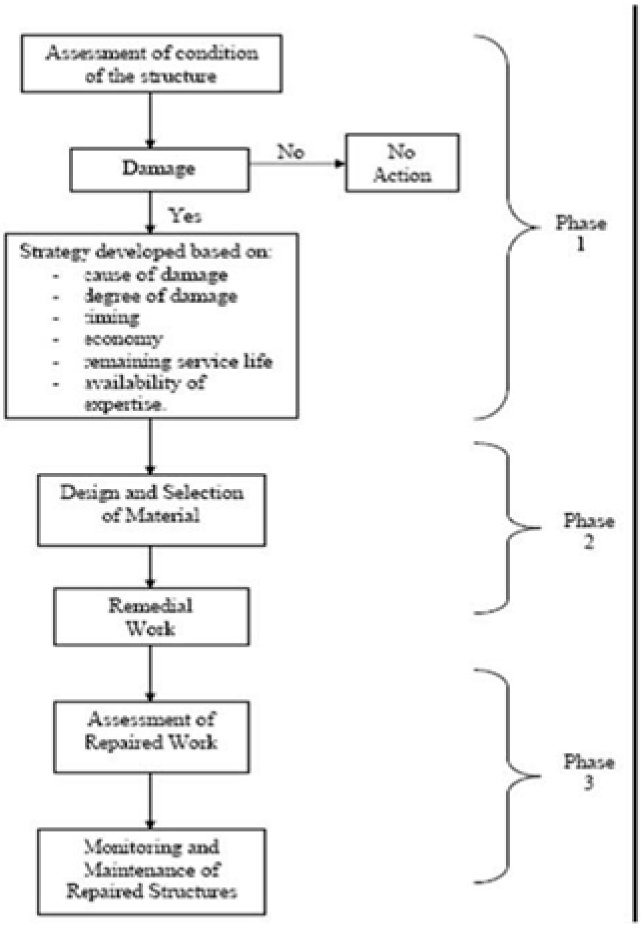

Fig.2 The overall flowchart for an effective corrosion management program

CORROSION PROTECTION METHODS

Protective Coating

In order to protect metals from corrosion, the contact between the metal and the corrosive environment is to be cut off. This is done by coating the surface of metals with a continuous nonporous material inert to the corrosive atmosphere.

Surface coatings are broadly classified into three:

a). Metallic coatings

b). Inorganic Coatings

c). Organic Coatings

Individual coatings are formulated to perform specific functions and must be selected to become components of a total system designed for optimum results considering the environment and service expectations.

The different types of coatings used for under water piles are:

Inorganic Zinc Silicates Primers

Steel structures that are permanently immersed in sea water, such as jackets in the area below the Splash Zone, are typically not coated for various reasons and protected solely by cathodic protection systems consisting of sacrificial anodes or impressed current arrays, which can be maintained as required by underwater contractors. Various anticorrosive pigmented primers are available, some that passivate the steel but the most effective are inorganic zinc silicate primers which essentially become anodic to the steel in a corrosion cycle. The primary advantage of this type of coating is that it will arrest rust creep, or undercutting of the coatings surrounding the damaged area, and confine corrosion to the point of the damage. These coatings also provide a high degree of resistance to heat and chemical spills.

High Build Epoxy Coatings

Epoxies are generally more abrasion and chemical resistant than primers and topcoats and in this case protect not only the substrate itself, but the zinc primer as well from all of these detrimental factors. However, one drawback with epoxy coatings is very poor resistance to ultra violet from sunlight and most will chalk and fade rapidly. This leads to an erosion of the coatings' film thickness, reducing the barrier protection of the system.

Aliphatic Polyurethane Topcoats

Polyurethane finish coats are generally acknowledged as providing optimum resistance to UV and high degrees of flexibility and chemical resistance. They also help to maintain a very high level of cosmetic gloss and colour retention and can be cleaned very easily, generally with low pH detergents and fresh water pressure washing. Although polyurethane finishes offer no real anticorrosive or barrier protection to the substrate they do provide a high level of protection to the integrity of the coatings system.

Zinc Rich Epoxy Primers

Zinc modified epoxy anticorrosives will provide a high level of service and are more tolerant to compromised surface preparation and ambient weather conditions provided the zinc loading of the formula is sufficient. Zinc rich epoxy is also most effective in maintaining damaged areas and breakdown of the coatings systems applied at new construction as it is compatible with alternate methods of surface preparation such as power tool cleaning and UHP Hydro Blasting.

Non-Skid Deck Coatings

Coatings specifically designed with anti-slip properties normally incorporate very course aggregates for an exaggerated profile. They are applied in very high film builds and normally without a zinc rich primer. When primers are required they are usually epoxy types.

Cathodic Protection

The preferred technique for mitigating marine corrosion, based on historical performance and measurable results, is cathodic protection (CP) - the practice of using electrochemical reactions to prevent the corrosion of steel structures. The reason for increased acceptance: cathodic protection prevents corrosion on underwater structures. In theory and practice, the implementation of a CP system is quite simple. Assuming you already have corroding steel in seawater, all you need is an anode, a power supply, and engineering talent. A protective circuit is accomplished between the anode, steel (cathode), power supply and electrolyte (seawater).

Suspension Anodes

Suspension Anode Delivery Systems allow for strategic placement of anodes in and around a marine facility, providing optimum distribution of current. Many suspended anode systems are also suitable for mounting on pilings, or other structural steel.

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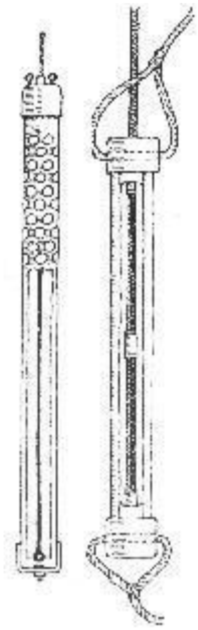

Fig 3 Suspension anode

Application Of FRP Composites

Fibre reinforced polymers (FRP) have long been used for the repair and retrofit of concrete structural elements. Their lightweight, high strength and resistance to chemicals offer obvious benefits. In fabric form, they provide unparallel flexibility. Moreover, as fibres can be oriented in any direction, their use can be optimized. This makes FRP particularly suited for emergency repairs where damage can be multi-directional and speed of strength restoration critically important.

Fig 4 Repair and retrofit of concrete structural elements using FRP composites

The emergence of new adhesives that allow FRP to be bonded to wet concrete surfaces makes it possible to economically conduct emergency repairs on sub-structure elements. Fig.3.6 shows impact damage that led to both cross-section loss and breakage of the spiral ties. Conventional repairs will require the cross-section to be enlarged to accommodate new ties. If instead, FRP were used it would only be necessary to re-form the cross-section and apply bidirectional layers that could restore lost tensile capacity while providing equivalent lateral support to the longitudinal steel. Moreover, the application of a protective UV (ultra-violet) coating on the wrap of the right colour will render the repaired pile indistinguishable from other undamaged piles. The aesthetics of FRP repair is one of its unheralded benefits.

Fig 5: Impact damage that led to both cross-section loss and breakage of the spiral ties

Preparatory work

All piles wrapped were 50.8 cm x 50.6 m (20 in. x 20 in.) reinforced concrete piles and wrapped over a depth of 1.5 m that extended all the way to the underside of the pile cap. The waters are approximately 4.88 m (16 ft) deep. This meant that ladders could no longer be used to apply the FRP in this situation. An innovative scaffolding system was designed and fabricated. It was lightweight, modular yet sufficiently rigid when assembled to support 4-6 people. The scaffolding was suspended from the pile cap and extended 2.74 m (9 ft) below.

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Its mesh flooring provided a secure platform around the pile that allowed the wrap to be carried out unimpeded in knee deep waters Fig. 2.7.

Fig 5: Mesh flooring around piles

Instrumentation

Unlike the Allen Creek Bridge where vandalism was a real concern, the piles of the Friendship Trails Bridge are located in deeper and more turbulent waters. Moreover, as the majority of the piles supporting this bridge had been repaired and some were instrumented, the element of novelty was absent making vandalism less likely.

In view of this, an instrumentation system developed by the Florida Department of Transportation was selected. This required both wiring and junction boxes. The scheme uses rebar probes Fig. 3.8 that are installed at different elevations close to the reinforcing steel. Changes in the direction of the corrosion current between these locations can indicate if the FRP is working as expected.

Reductions in the measured current compared to unwrapped controls were also expected to provide an index of the efficacy of the FRP wrap. The drawback with this system is that it takes time for the equilibrium state around the probe to be attained. Until this time, data may not be meaningful.

Fig. 6: Use of rebar probes in instrumentation

FRP wrapping

Two different FRP systems were used. One was the same pre-preg system with a water-activated resin used in the Allen Creek Bridge. The other was Fyfe's system that used resins that cure in water. The pre-preg system was used to wrap four piles – two using carbon and two using glass. The wet-layup system from Fyfe required on-site saturation of the fibres. Two piles were wrapped with fibreglass using this system. Of the two, one was an experimental FRP system that combined wrapping with a sacrificial cathodic protection system. Two other unwrapped piles in a similar initial state of disrepair were used as controls to evaluate the performance of the wrapped piles. Application was facilitated through the use of a scaffolding system mentioned earlier Fig. 2.7.

Fig. 7 Wrapping of FRP material around piles

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The pre-preg system was applied as in the Allen Creek Bridge and posed no problems. The Fyfe system was more challenging since the FRP material had to be saturated on-site. Access to foundations of an adjacent bridge provided a convenient staging post for the on-site impregnation Fig. 2.9. On an average the operation took 90 minutes to complete.

Fig.8. On-site saturation, Friendship Trails Bridge, Tampa

CONCLUSION

Though there is no absolute way to eliminate all corrosion on under water piles, there are some effective measures to control them. The cathodic protection is found to be quite simple to employ and mostly used in marine conditions. The protective coatings are used in vast and expensive structures. The FRP composites have many advantages over conventional methods such that they are light weight, possess high strength and chemical resistance and moreover have incomparable flexibility. Of the various ways of wrapping of FRP composites, transverse wrapping is found to be the easiest as otherwise, the longitudinal pieces are awkward to handle and difficult to position. Bi-directional material is the best option. Scaffolding measures during the application of materials ensures safety and simplifies installation. Out of the two system of FRP application, the pre-preg system is easier to use. On-site FRP saturation can be problematic. High winds and high tides should be avoided during the process.

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