Retrofit Corrosion Control for Al-Zubare Harbor Marine Structures

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Abstract

Today's offshore and ocean going structures are fitted with systems which work to inhibit the rate at which the structure corrodes in the aggressive marine or soil environment. In Al-Zubare Harbor corrosion is also a significant problem, which is due in part to the marine environment and ignorance in corrosion control methodologies. Some costly examples which have recently occurred in Al-Zubare Harbor are excessive corrosion. These problems could have been avoided with selection of appropriate materials, better design, or utilization of corrosion control methodologies like cathodic protection. These retrofit cathodic protection (CP) systems are carefully designed to offer the structure a uniform protection over its surface with the most economical use of anodes. These operate by setting up an electrostatic field in the water surrounding the structure which causes a desired voltage and current density distribution over its surface area.

Keywords: Cathodic protection, Corrosion Control, Marine structures

1. Introduction

There is no undergraduate engineering course that is dedicated to corrosion fundamentals and corrosion control methodologies. Thus, UH-educated engineers are not trained to handle corrosion problem unless they receive additional education elsewhere. The impact on the local community has been greater losses due to corrosion and higher costs, resulting in unhappy citizens and sometimes lawsuits(Rui Miguel, 2004).

In recent years, an extensive amount of research work has been carried out in order to better understand and control several of the most important deteriorating mechanisms such as alkali aggregate reactions, freezing and thawing and corrosion of embedded steel. In particular, much work has been carried out on corrosion of embedded steel, which represents the greatest threat both to the safety and economy of the structures. Never before has so much basic information and knowledge about concrete durability been available. The great challenge to the professional society is, therefore, to utilize and transform more of this existing knowledge into good and appropriate engineering practice (Gjorv, O.E, 2002).

The main degradation process for durability of reinforced concrete structures in marine environment is, without any doubt, the corrosion of the concrete reinforcement. In this specific environment, the corrosion occurs almost entirely due to the presence of chlorides in the seawater. Therefore, the presence of chlorides in concrete is discussed further. The main mechanisms responsible for the transport of chlorides into the concrete are well known and extensive literature exists on this topic alone. Of more interest to the research is the effect of the concentration of chlorides in the concrete on the corrosion of the reinforcement and the binding of the chlorides by the concrete (Malhorta,V.M. 2000).

No single parameter controls the durability of concrete. Instead, there are a number of contributing factors which affect its durability. In practice, several degradation mechanisms can act simultaneously with possible synergistic effects. The schematic diagram below illustrates how different degradation mechanisms can act on concrete exposed to sea water. Improper procedures or carelessness during any phase of the construction operation results in concrete of inferior quality. Poor transportation, placing, finishing techniques, and inadequate curing conditions are a few examples (Malhorta,V.M. 2000).

Deterioration is any adverse change of normal, mechanical, physical, and chemical properties either in the surface or in the body of concrete, generally due to the disintegration of its components (Anonymous, 1987)(Masters. L. W. and Brandt, E., 1987)(Cady, P.D, 1990)(Higgins, D. D., 1981) The phenomenon which induces such distress may be associated with one of the phases (e.g. design, construction, or service).

In this Retrofit project for a new development. The projects will help imprint important concepts to the works by challenging them to apply fundamentals acquired in the class room to real problems in the laboratory or community**.**

2. Experimental Work

2.1 General Principles

The general principles of the methods are to make the concrete less permeable and protect the steel as shown in Fig1 and Fig 2. Examples of methods are:

• Cathodic protection of the reinforcement. A voltage is applied between the reinforcement and a conducting paint applied to the outer surface of the concrete.

• Sacrificial anodes. An electropositive metal or alloy, e.g. zinc, is embedded in the concrete and connected electrically to the reinforcement.

• Corrosion inhibitors. A chemical compound, e.g. $Ca(NO_2)_2$, is used in the concrete mix to stabilize and/or alter the oxide film on the steel. A division is made in three groups, depending on their primary action, [8]: (1) Anodic, (2) Cathodic (3) mixed.

• Coating of the steel or concrete surfaces. The surface of the steel is coated, with e.g. epoxy, to prevent corrosion from initiating. The surface of the concrete is painted to decrease the permeability of the concrete cover and also influence the moisture conditions in the concrete in a positive way.

• Alternative reinforcements (stainless steel, galvanized, epoxy coated, etc.) . These methods should be used with care since the result is, to a large extent, dependent on the way they are applied. If, for example, cathodic protection and/or sacrificial anodes are used, it is important that the reinforcement bars have electrical contact with one another; otherwise the protective effect will be partly lost. If the reinforcement is coated with e.g. epoxy, a crack in the coating may destroy its protective function, and even make the problem worse due to pitting effects.

2.2 Cathodic Protection Systems

The evolution of cathodic protection systems is well described elsewhere, in the references given as further reading in the Introduction [9, 10, 11, and 12]. Only a brief review will be given here. The major anode types (in no particular order) are:

• The expanded titanium mesh has a mixed (or rare) metal oxide coating to prevent chemical attack. The anode is fixed to the concrete surface and overlaid with a cementations coating.

• New variations of the anode in a ribbon form or a rod, drilled into the member which are becoming available, but are not described here as these systems are not surveyed in this work.

• The conductive cable anode is a copper conductor sheathed in conductive plastic, so that current "leaks" out uniformly along the length of the cable. The anode is wound back and forth across the concrete surface and overlaid with a cementitious coating. Although the primary commercial anode for several years, it is no longer available, except on

• The pancake anode system (usually of silicon iron), fixed to a deck surface, and overlaid with a conductive asphalt.

• The slotted system which uses a rigid conductive polymer, laid in slots cut on the bridge deck. A variation in this system is to mound the polymer on the deck and apply a cementitious overlay. Primary or additional conductors of carbon fiber and platinized niobium/copper are usually incorporated in the system as well.

• The conductive paint system, usually applied by brush or airless spray to substructure elements.

• The sprayed zinc system, either by arc or flame, which can be applied to substructure elements (and has also been applied to decks). This is normally an impressed current system, but experiments to use it as a sacrificial system are underway.

• Other experimental anodes which include the surface mounted strip (a system of conductive strips fixed to a substructure surface), conductive rubber mats clamped to a surface, and various configurations of zinc metal are used as a galvanic anode.

3. Results and Discussion

3.1 Corrosion Rate

The corrosion rate is dependent on if the reinforcement corrosion has been initiated by chloride ingress or carbonation. In extreme cases the corrosion rate can be (3- 5 mm/year) for corrosion initiated by chloride ingress and 0.05 mm/year for carbonation-initiated corrosion. There are several methods available to prevent corrosion and reduce the corrosion rate.

3.2 Rust, Spalls and Patches

The observation of rust staining was noted on some structures as shown in Fig 3. This can be due to "tramp" steel corroding, especially if it is in contact with the anode. Although unsightly, this is not a problem, although it can lead to small shallow surface spalls. Problems will arise if the steel creates a short circuit between anode and rebar (cathode). If this happens then the system will not function properly. Low resistance anodes like arc or flame sprayed zinc will show this problem readily. Other anodes with lower conductivity will hide the problem, which can be more serious.

Another cause of rust is the oxidation of iron containing aggregates. These are unsightly harmless. Accelerated anode consumption around patches was noted on some installations**.**

3.3 System Performance

An anode zone is an electrically continuous area of anode which is separately operated from adjacent zones, with the level of current and voltage set by separate testing. Of the 40 anode zones inspected, 18 (11.9%) had failed by the criteria used by the inspection team.

The 11.9% failure is in reasonable agreement with the overall figure from the questionnaire survey (10.1%). However, these sites were chosen

because, according to the questionnaire responses, they were supposed to be operating. Problems were found at the site with several systems thought to be performing correctly by the agency replying to the questionnaire. The percentage failures could therefore be considered to be additive, i.e., 22% failure rather than about 11% in each. The oldest systems investigated were 15 years old, the average age was 7.6 years. The major problems identified were as follows:

• Failure of conductive paint anodes under wetting (particularly in the splash zone of marine piles).

• Pop out of slot systems.

• Overlay delimitation on both decks and substructures, with both the conductive cable and the mesh anode.

The failure of rectifiers, meters, cables, housings, conduits and half cells is often easily remedied *w*ithout need for traffic control or major expense. It may require better scrutiny of equipment suppliers for design and durability to prevent it recurring or o**c**curring in the first place on new installations." Permanent" reference electrodes are normally expected to have a life time of up to 5 years in other application where freeze thaw, drying, rewetting **a**nd are not a problem as they are on a bridge.

3.4 Current and Voltage Levels

High resistance and under polarization of the systems may be due to poor design or anode problems. The system resistance (rectifier voltage/current), was generally less than I00 ohms on systems. Systems with high resistance included substructures that may stay dry for long periods.

The four hour decay criterion is frequently used for assessing adequate polarization of cathodically protected steel in concrete. It is popular because it does not require specialized equipment.

The reading is independent of the type or long term stability of the electrode used, and it is easily carried out and understood. However some electrodes display short term instability with age, which makes all criteria measurements erratic.

The logic of the four hour decay criterion is that it shows that the corrosion rate has slowed down. Plots of corrosion rate against polarized potential show that for steel in concrete there is roughly an order of magnitude reduction in corrosion rate with every (100 to 150mV) of polarization applied.

4. Conclusions

Agencies need to have the correct infrastructure to maintain and monitor systems. This will ensure that problems are identified and remedied quickly, and that the correct settings of current and voltage are maintained to that the steel is protected and the system is not overpowered unnecessarily. In some cases, the problem of maintenance expertise occurred when responsibility is passed down to district level. Some are districts able to maintain excellent standards, others are less able. A centralized system often provided more expertise and interest in maintaining the systems. Staffs need adequate training and proper direction on maintenance and trouble shooting. Most systems are performing well, although the level of maintenance is inadequate. Some systems have persistent problems due to poor performance of key components. A badly performing rectifier is more likely to lead to system failure than a damaged anode system. It is not clear whether the failure of permanent, embedded half cells are principally on older systems, or whether there is still poor embedded half cell performance with newer designs. A circuit resistance (rectifier applied voltage divided by the current) of more than 100 ohms usually shows that the system is no longer polarizing the steel adequately. The two major anode failures are conductive paints in splash and tidal areas on marine substructures, and pop out of slotted systems; Other failures are:

- deterioration of the conductive cable anode,
- deterioration of overlays on conductive cable and Ti mesh,
- a case of some debonding and high resistance of a sprayed zinc system.

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Table 1. A tabulation of problems

Rust or Spalls in the area	**7**
System Replaced after accidental removal	**3**
System found switched off	**2**
Rectifier Net Working	**6**
Rectifier Meter Not Working	**4**
Half Cells Not Working	**6**
Housings/Conduits failing	**2**
Cable Damage	**2**
Anode Damage Paint	**5**
Slot	**6**
Cond. Cable	**1**
Overlay damaged	**4**
Under polarized	**2**
High Resistance	**8**

Figure 1. View under of the harbor structure

Figure 2. Exposed reinforcement on beam 3

Figure 3. Rust stains on beam