Active Cathodic Protection and its application at Water Parks

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ACTIVE CATHODIC PROTECTION IS A METHOD OF PROTECTING a structural or otherwise valuable piece of base metal, usually iron/steel, from corrosion using an impressed current. This paper will first discuss briefly why steel corrodes especially at water parks, then the principle behind Active Cathodic Protection and its limitations, and move on to guidelines for installing an Active Cathodic system at a water park.

THE CHEMISTRY OF CORROSION

When a metal corrodes, chemically speaking, it is being oxidized. From the last chemistry class we attended, whenever that was, we may recall that OI L RIG, Oxidation Is Loss (of electrons) and Reduction Is Gain (of electrons). For our purposes rust is always formed in contact with water or moist air. The mechanism usually begins this way: some H+ cations, always present even in distilled water, at the steel surface, 'ask' the iron atoms below if they can 'borrow' some electrons, and when they do, the following reactions occur:

F e ‡ Fe2+ + 2e-

2H+ + 2e- ‡H2 (gas)

These reactions are much more likely in acid-water solution because acids by definition have more than the usual amount of H+ floating around. Another thing which will increase the rate of corrosion is the presence of chloride ions, which will bind very well to the Fe2+. Common forms of rust are FeO, Fe2O3, or Fe(OH)x. All forms of rust are bad for the structure and none revert back to being structural steel; they all flake off – some even dissolve. They are, however, unavoidable whenever steel is in water or moist air. The only thing to be controlled is the rate of corrosion, the rate of loss of structural steel.

Pool water will corrode steel at a faster rate than water in general. At waterparks, both Sodium Hypochlorite and Hydrochloric acid are added to the water. Sodium Hypochlorite kills microorganisms and Hydrochloric acid balances the pH of the water, but both of these chemicals eat away at steel. One path towards reducing the rate of corrosion would be to add other chemicals to the water which will somehow protect the steel, and while methods have been proposed,[1] they will not be approved in the short term. Reducing the concentration of the chemicals being used of course would present safety concerns. All of this is mentioned to say that if there were a way to make the pool water at water parks more inert, this would by far be the best way to preserve their steel structures. Other methods, including painting and cathodic protection are likely to be more costly and require more analysis and monitoring.

[1] US Patent 4992209. Nitrite is a well-established corrosion inhibitor for iron; the problem is that it is not compatible with hypochlorite. Claim of the patent is a new solute which remains an effective disinfectant in the presence of nitrite. Nitrite can be harmful to humans, but so of course can hypochlorite. More investigation needed.

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CATHODIC PROTECTION

Cathodic Protection takes on two forms: active cathodic protection and passive protection. In the case of a submergedor buried steel structure or pipe, passive protection is as simple as placing a piece of Zinc, Aluminum, or Magnesium near the structure and connecting them via a wire. This extra piece of metal is called a sacrificial anode. The hydrogen ions in the corrosive environment will preferentially attack the more active metal until it is gone. As the anode is attacked, electrons also flow from it to the steel, protecting it. Hot-Dip galvanizing or Zinc Plating are two other passive cathodic protection strategies which work in the open air as well as the buried/submerged case. The word anode means 'electron donor' and the process of degradation in the anode supplies extra electrons to the steel structure, protecting it. The steel structure then is called a cathode, or 'electron acceptor'.

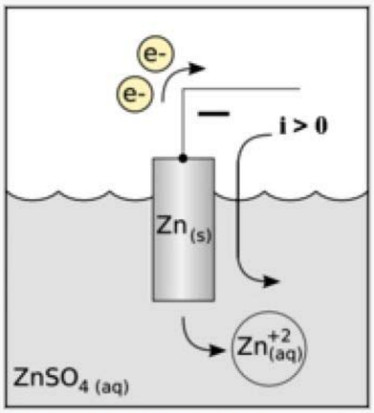

Diagram of a zinc anode in a galvanic cell.

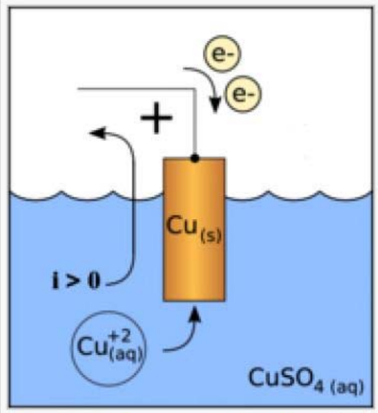

Diagram of a copper cathode in a galvanic cell.

Images free thanks to Wikipedia. In both cases, only the part of the metal in the ion-carrying media (water, soil, or concrete) participates in the reaction. Here, the copper attacks the zinc. Refer to a galvanic series to predict the direction of reactions involving other metals.

Active cathodic protection, on the other hand, is a different animal. The first thing to know about active cathodic protection is that steel may only be protected by it if the steel is 1) submerged or filled with water, 2) buried or 3) encased in concrete. It does not work through the air, even moist or misty air. The principle behind active protection is that you allow the iron atoms at the surface to interact with and give electrons to the hydrogen ions in the surrounding water/soil/concrete. However, as soon as those electrons leave the iron atom at the surface, the strategy is to supply that atom with another electron from one of its neighboring iron atoms, away from the surface. All that is needed to achieve this is a small amount of current. Just like in passive cathodic protection, an anode is needed to complete the circuit. Anode placement and selection are both tricky. The following images were borrowed from Principles and Prevention of Corrosion by Denny A. Jones, Macmillan Publishing, ©1992, illustrate active cathodic protection (Figure 1) along with a 'good' anode design (Figure 3) and a 'bad' anode design which causes stray current (Figure 2).

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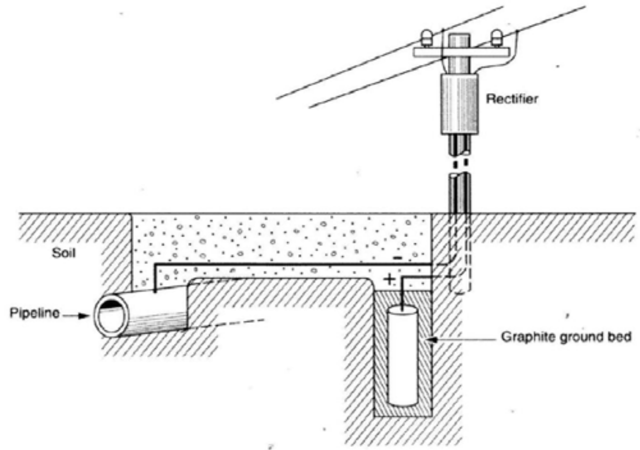

FIGURE 1 - Cathodic protection by impressed current. *(From H. H. Uhlig and R. W. Revie,* Corrosion and Corrosion Control, *Wiley, New York p. 217, 1985. Reprinted by permission, John Wiley & Sons.)*

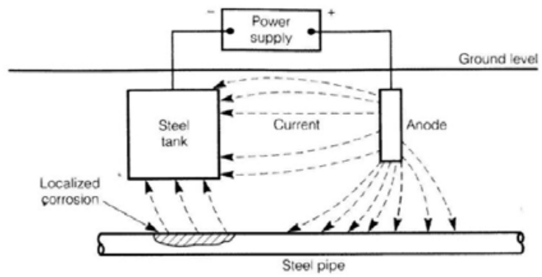

FIGURE 2 - Stray currents resulting from cathodic protection. *(From M. G. Fontana,* Corrosion Engineering, *McGraw-Hill, New York, p. 299, 1986. Reprinted by permission, McGraw-Hill Book Company.)*

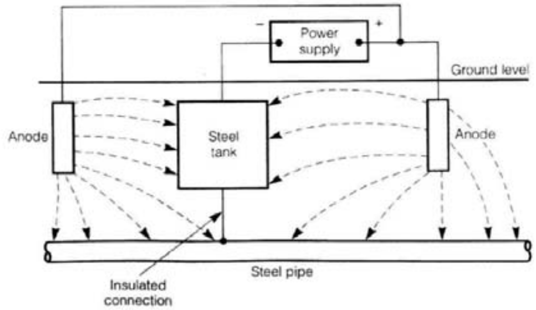

FIGURE 3 - Prevention of stray-current corrosion by proper design. *(From M. G. Fontana,* Corrosion Engineering, *McGraw-Hill, New York, p. 299, 1986. Reprinted by permission, McGraw-Hill Book Company.)*

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Cathodic protection of any kind is not usually necessary in reinforced concrete. While the concrete cures it is very alkaline and it will create layer of hydroxides on the surface of the steel. When locked into the cured concrete, the hydroxides are an effective corrosion barrier (Iron Hydroxide is not soluble in water). However, if there are chlorides in the environment, whether from sea water, road salt, or a swimming pool, these chloride ions will be absorbed by the concrete and convert the Iron Hydroxide layer around the rebar into Iron Chloride, which is not only soluble in water, it tends to crystallize around water molecules. This means that it will expand as it contacts water. This expansion can cause local stresses in the concrete great enough to break chunks off down to the rebar, and these breaks are known a spalling. If there is spalling in a reinforced concrete structure, active cathodic protection should be considered. Active protection will not only protect the steel from further damage, it will draw the chloride ions away from the steel as it works.

Forming the Cathode and Anode to protect the rebar of a reinforced concrete structure, you will first have to expose their ends at some point. If there is already spalling, your choice of where to remove concrete is that much easier. You will next want to check if the rebar and other steel elements are in contact with each other. It may be profitable to expose some rebar on opposite sides of the structure and check using an electrical probe. Most of the time there will be good electrical contact between all pieces of steel. In other cases the rebar will be in two distinct layers and you will have to expose some rebar in each. Drawings of the original structure will be helpful. You want to make sure all of the reinforcing steel is participating as the cathode, even if it means exposing the end of every single piece of rebar to make the connections one by one.

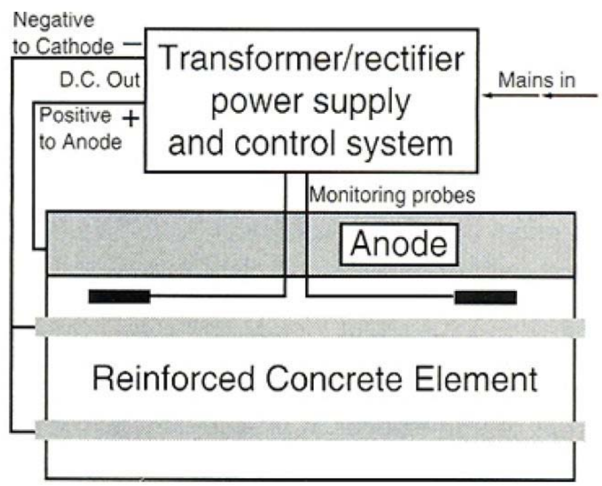

Figure 4 – Showing a continuous anode applied to surface and two layers of protected rebar. Optional monitoring probes shown. Taken from "The Repair of Reinforced Concrete," John Broomfield, writing for The Building Conservation Directory, 1996. http://www.buildingconservation.com/articles/concrete/concrete.htm

The next step is to select and install the anode. In nearly every case, the best course of action is to purchase a "mesh" anode made of titanium , secure it to the outside of the existing structure, and pour a new, thin layer of concrete on top. The manufacturer of the anode mesh will know the most about the proper type and thickness of concrete to use. It is also recommended to either install a monitoring device or leave a stub of the anode outside of the concrete for voltage measurements. A mesh is not the only way to go, of course, and anodes can also be placed at strategic locations by boring into the concrete between rebar. The best anodes are generally noble metals and have a high surface area compared to their volume. Active protection anodes can be made of more noble metals which will last longer, perhaps longer than the structure itself. These metals resolve the electrochemical charge by forming hydrogen ions at their surface rather than what follows are two tables comparing various types of active and passive anodes, listing their advantages and disadvantages when used with concrete.

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	Impressed Current System	Sacrificial (Galvanic) System
Merits	• longer anode life • current can be controlled • extensive track record	• inherently simple • no monitoring & maintenance • no requirement for electrical isolation • risk of hydrogen embrittlement on high strength steel is minimal • saw cutting & concrete encapsulation for anodes is not required
Demerits	• requires monitoring and maintenance • electrical isolation required between anode and steel • conduit & wiring required • detailed monitoring & control for prestressed concrete	• shorter anode life • anode current delivery is dependent on anode chemistry and surrounding environment • current cannot be adjusted or controlled

Table I. Comparison of CP Systems

	Surface Applied	**Encapsulated**	**Immersed**
Impressed Current	• conductive coating • arc sprayed zinc • thermally sprayed titanium	• titanium anode mesh encapsulation • titanium ribbon mesh slotted system • discrete anode system • titanium anode mesh integral pile jacket	• cast iron or MMO titanium anodes
Sacrificial (Galvanic)	• arc sprayed zinc • arc sprayed Al-Zn-In • zinc adhesive anode	• zinc mesh integral pile jacket	• cast zinc or aluminum anodes

Table II. Anode Types by Category

Tables I and II taken from Using Cathodic Protection to Control Corrosion of Reinforced Concrete Structures in Marine Environments by Steven F. Daily, Corrpro Companies, Inc. http://corrpro.com/pdf/cp-49.pdf. See also http://corrpro.com/pdf/cp-48.pdf

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SUPPLYING THE VOLTAGE OR CURRENT

As implied by Figure 4, an active control system may be necessary for optimum performance of the Cathodic Protection system. At the very least, an adjustable DC power supply is needed with enough current capacity to supply up to 2 mA / ft2 of protected concrete surface. The DC voltage supplied should be controllable and is unlikely to be greater than 12 V. The normal control strategy is to control the voltage only. This strategy is believed to be appropriate for concrete and other structures that are under attack at a steady rate. The other strategy is to control the current, and this strategy may be more appropriate for a tank that sometimes holds a corrosive and other times does not. With current control, the nominal value for supply current is determined by calculations after looking up values on tables and considering the surface area and type of surface. It is a complex process. With voltage control, the nominal value is determined by comparison to a reference electrode, as shown in Figure 5. These electrodes should be available from the same supplier as the mesh. Looking at Figure 5, if a Copper/Copper Sulfate electrode is used, the voltage measured between the copper rod and the exposed rebar should be less than -0.85V (that is, more negative). This is a conservative requirement which some criticize as overprotective.

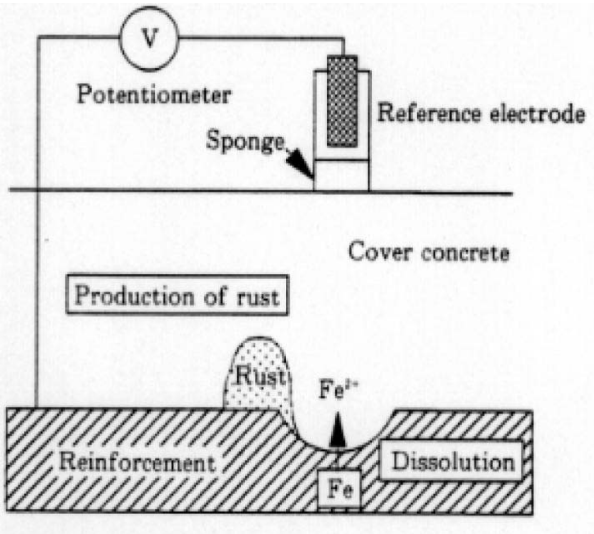

Figure 5 – Typical use of reference electrode.
Voltage is measured at 'V'. Source unknown.

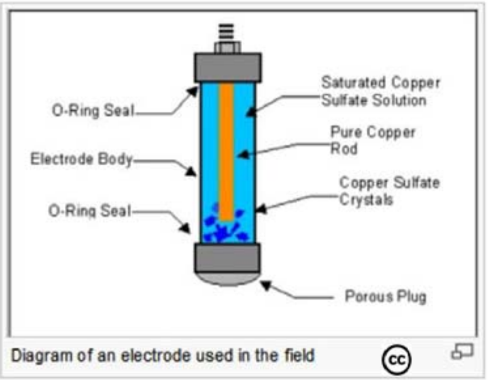

Figure 6 – Diagram of Copper-Copper Sulfate Electrode, Wikipedia.

http://en.wikipedia.org/wiki/File:CopperSulphateElectrode.png

SUMMARY

Cathodic protection is often a worthwhile investment for waterparks and other marine environments which will pay for itself in a short period of time if properly and designed and implemented.

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