Influence of Seawater Composition on Corrosion Prevention System Parameters

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Abstract

Cathodic protection systems, such as those designed for ships, utilize material electrochemical properties t 0 minimize corrosion damage. The extent of material interaction in the corrosion process is partially dependent on the resitivity of the surrounding medium. A medium with low resititvity, such as seawater, provides a greater degree of electrical connectivity than a medium of higher resistivity. In computational modeling studies seawater is typically represented as a uniform continuum with a single set of material properties. In reality, the resistivity of seawater varies with the amount of salt content and temperature. Salt content may vary for many reasons, including an influx of fresh water or evaporation. In this work variations in corrosion protection provided by an impressed current cathodic protection system under moderate variations in seawater resistivity are examined.

1 Introduction

Impressed current cathodic protection (ICCP) systems are designed based on electrochemcial corrosion behavior of materials to minimize corrosion damage. In an ICCP system, an external source of electrons is provided to the metal/electrolyte combination to raise the potential of the metal to be protected to a level at which corrosion damage is minimized. Factors incorporated into the design of such systems are the geometry, the resitivity of the electrolyte, the location and polarization response of any exposed metal and the magnitude of the power source supplying the electrons. While computational modeling of ICCP systems is a relatively recent innovation, the use of shipboard ICCP systems is well established. Computational modeling is presented not only as tool for system design but as a method for examining performance and extending our understanding of the material-environment interactions of such systems.

2 Scope of Work

The operating parameters and performance of ICCP systems are dependent on the resitivity of the surrounding water. It is expected that in extreme cases, such as entering brackish or fresh water environments, the operating parameters of a ICCP system should be redefined for the new environment. It is also recognized that all factors of system performance, including anode placement, may be adversely affected by extreme changes in the resitivity of the surrounding water. In addtion to exterme changes due to changing locations, moderate variations in resitivity are known to occur in what would be considered ‘the open sea.’ The present analysis examines the effects of these types of moderate variations on system performance. The ICCP system modeled is a 7 anode/2 power zone system which exists for the U S Navy CG-66 destroyer. The range of resitivity chosen is 16.5 to 24.8 Ohm-cm. This range corresponds to variations which can be expected due to location, temperature or tidal effects. Static conditions are considered for a minimum paint damage configuration.

3 Seawater Composition and Variation

In computational models, seawater is defined as a continuum material with constant material properties. In reality seawater is a complex solution of many different dissolved minerals [1]. Even though it is a complex solution, single parameters are typically used to define seawater. One standard value defining seawater is the chlorinity, a measure of the amount of chlorine, bromine and iodine replaced by chlorine as measured in grams per kilogram of seawater. The higher the chlorinity, the higher the concentration of salts. Chlorinity can be directly related to resistivity, which is the material parameter of interest in the modeling of ICCP systems. This analysis will focus on observed changes in reistitivity resulting from variations in chlorinity and temperature. Measured values of resistivity range from 333.3 Ohm-cm for a chlorinity of 1 to 19.2 Ohms-cm for a chlorinity of 19 [1]. The later is an typical seawater value. Temperature changes result in a changes of resitivity from 19.2 Ohms-cm for 25°C to 30.3 Ohms-cm for 5°C [l].

A parameter study was defined to capture effects of variation in resistivity. Variations of + or - 20% resitivity from an average seawater value of 19.8 Ohm-cm were examined; the numeric range considered is 16.5 to 24.8 Ohms-cm. The higher values of resitivity represents both higher chlorinity regions and lower temperature regions. The lower resitivity values represents decreases due to mixing with minor amounts of fresh water and increases in temperatures.

4 Computational Modeling

The use of boundary element methods for modeling shipboard corrosion prevention systems is well established [2,3]. It can be readily shown that such systems meet the requirements for application of LaPlace s equation governing corrosion. The systems are surrounded by electroneutral electrolyte and have an absence of polarization concentration gradients and an absence of electron sources or sinks. Shipboard ICCP systems can be mathematically defined to meet these requirements. In this work a commercial boundary element code is used to determine the current requirements and potential contours of the ICCP system for the CG 66 destroyer for a range of seawater resitivity which includes an average seawater value.

The polarization responses for steel and nickel-aluminum-bronze (N-A-B) used in the analysis were obtained for natural seawater [4] The same values of polarization response are used for' all salinity conditions analyzed. This was considered acceptable because of the moderate nature of the range of salinity studied.

The boundary element model of the CG 66 system has been verified with experimental results for an average seawater resistivity [5,6]. The wetted surface of the ship hull is reproduced as a boundary element model. Symmetry of ship geometry and ICCP system allow for modeling of half of the hull. The boundary element model incorporates detailed geometric modeling of the hull, propellers and rudders including a three dimensional representation of the bilge keel. Propellers are modeled as solid disks. Impressed current anodes are represented by assigning potential values to selected elements which represent the anodes. The surface ship is enclosed in a large but finite seawater domain. The model consists of 1583 constant quadrilateral elements with quadraic geometric definitions. The boundary element mesh is shown in Figure 2 in the next section. The commercial boundary element code BEASY [7] is used for the anlayses.

Materials definitions are assigned to each element in the model; N-A-B for the propellers, perfectly insulated material for the painted surfaces and steel for exposed metal representing paint damage. Paint damage locations for minimum paint damage total 3% of the wetted surface area and include the entire rudder, propeller and support block locations used in dry-dock.

The ICCP system is evaluated at steady-state conditions. The values of anode strength for average seawater to maintain a target potential of -0.85 Volts Ag/AgCl. These voltage values are then maintained through variations in the seawater resistivity. This process eliminates the feedback adjustment of the system from the model. This allows a direct association of the change in resitivity with any observed performance changes. Analyses were completed for nine descrete resistivity values in the range from 16.5 to 24.8 Ohms-cm (Table 1).

5 Results

Potential profiles for a depth of 10 feet from the waterline are shown in Figure 1. This location is where in situ readings may be taken shipboard. There is a shift to higher potential values for lower values of resistivity. The potential profiles bracket the physical scale model experimental results. The potential profiles do not indicate that there are differences in protection levels.

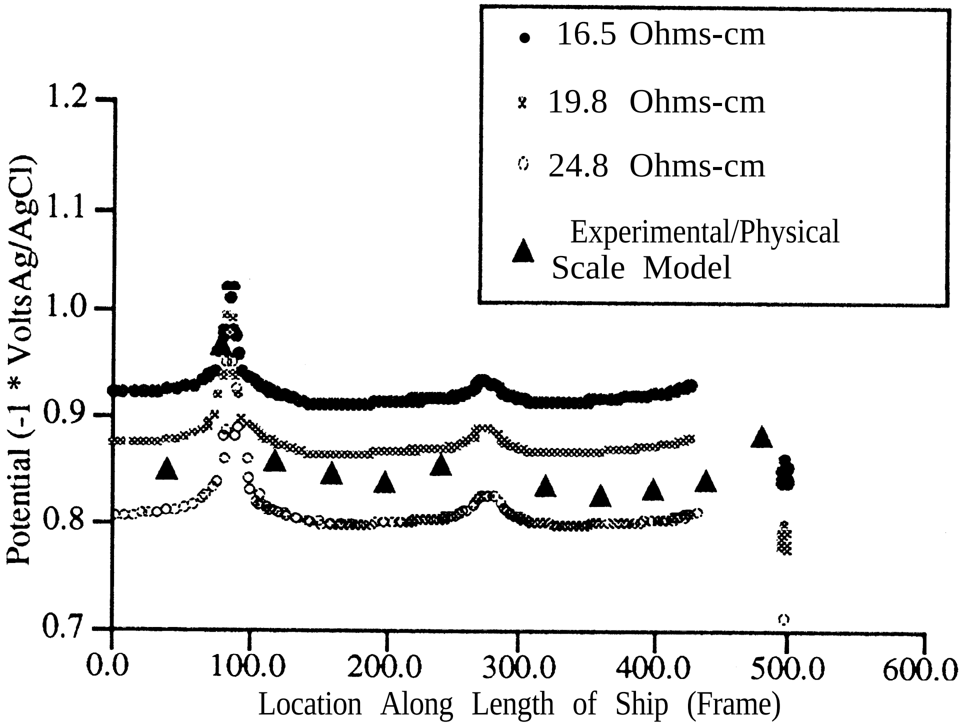

Figure 1 - Potential profiles 10 feet below waterline.

Computer generated potential contours, however, indicate signficant changes in protection levels (Figure 2). Shifts in protection levels for a large portion of the hull occur. Based on a comparison of Figures 1 and 2, it is easily seen that information not otherwise available can be obtained from the computer.

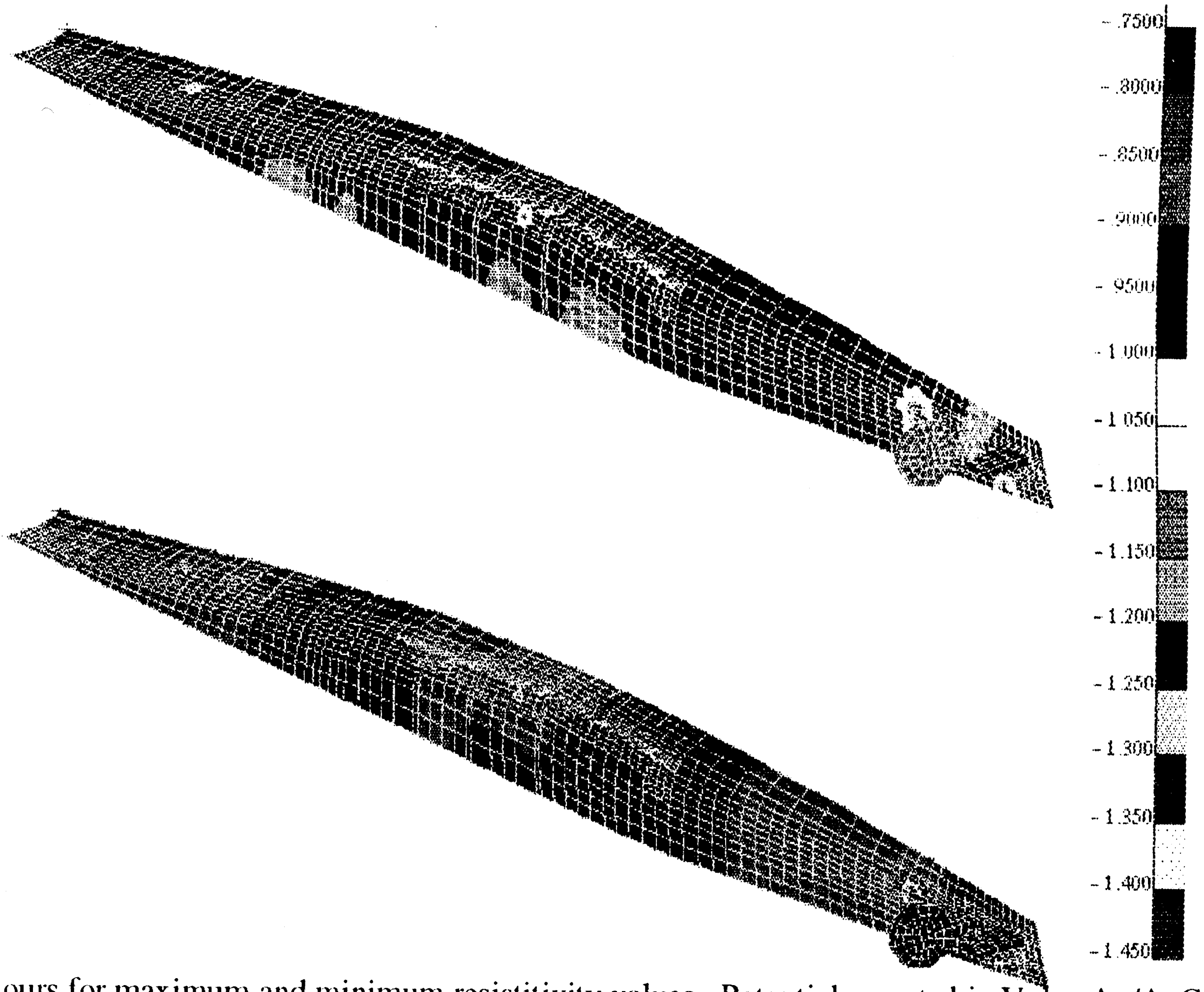

Figure 2. Potential contours for maximum and minimum resistitivity values. Potential reported in Volts, Ag/AgCl electrode

The total current required to maintain anode voltage levels at set values is determined by the analyses. Table 1 shows resulting draw of current for exposed steel areas. As expected, as the resistivity decrease, the current required to maintain anode voltage levels increases. With decreasing resisitivity the percentage of current which reaches the exposed steel area increases.

Table 1. Current Distribution for Minimum Damage Static Conditions.

Resistivity (Ohm-cm)	Current Draw (Amps)	Current to Steel (Amps)	% of Total Current
16.5	39.6	10.8	27.2
17.2	38.8	10.6	27.1
18.0	37.4	10.0	26.7
18.9	36.2	9.4	26.1
19.8	35.2	8.8	25.1
20.8	34.2	8.2	24.0
22.0	33.2	7.6	22.8
23.3	32.2	7.0	21.6
24.8	31.0	6.2	20.2

6 Summary

Computational modeling has been used to determine the effects of moderate changes in seawater resistivity. The range of resisitvity considered is representative of variation which may be seen in ship deployment. The range is moderate and does not considered extreme changes resulting from transition from sea to fresh water environments. Results demonstrate that even moderate changes have significant effects on system performance. It is observed potential profiles alone are inadequate to capture the changes in potential contours and the resulting variations in protection from corrosion delievered by the system due to moderate variations in resistivity. The limitations of system performance, while not observed from data corresponding to data obtainable from shipboard measurements, is clearly observed from computational results. Computational can be used to identify limitations in system performance which occur due to changes in environment. In many instances, computational modeling may be the only avenue to examine system performance variations with environemental changes. Computational modeling has provided additional insight and information for system design that would not be otherwise available.

7 References

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