Computer Simulation Of The Interference Between A Ship And Docks
Cathodic Protection Systems

E. Santana-Diaz, R. Adey

(1) Computational Mechanics BEASY, Ashurst Lodge, Southampton, Hampshire, SO40 7AA, UK
Tel: +44 2380 293223, Fax: +44 2380 292853, Email: r.adey@beasy.com, ernesto@wessex.ac.uk

Abstract

Paint and impressed current cathodic protection (ICCP) systems are used to control corrosion on many different types of structures. Since cathodic protection (CP) systems were first applied, engineers have used experience and intensive monitoring to optimise their design to prevent corrosion. Numerical methods and in particular Boundary Elements Methods (BEM) have been widely used in the cathodic protection field to simulate the performance of the CP system and to predict the associated electric and magnetic fields.

Special care must be taken when a new structure is commissioned as additional stray currents could alter the performance of exiting CP systems. In this work, the influence of the cathodic protection system of a ship on a dock is predicted using computer modelling. The damage that the cathodic protection system of the ship could cause to the structure is highlighted and possible mitigation measures assessed using the optimisation features of the modelling software.

The data requirements and practical application of computer modelling is discussed and other possible applications highlighted.

1 Introduction

Boundary Element Methods (BEM) have been used to simulate the behaviour of cathodic protection systems since the late 70’s [1]. As the name implies, the method requires elements to be created, but now only on the boundary (or surfaces) of the problem geometry.

The advantages of boundary elements for CP analysis are many, for instance:

- The meshes are now only on the surface, hence only (equivalently) two dimensional elements are required. Mesh generators can be used with confidence, and models can be constructed extremely quickly and inexpensively.
BE gives the solutions on the boundary and, only if required, at specified internal points. Since for CP analysis the solution is only required on the surfaces, it is far easier to analyse the results than for FE analysis which automatically gives results for all nodes (internal or boundary).

- BE methods are very effective and accurate for modelling infinite domains as is the case for CP analysis.

2 State of the art

Numerical methods have been widely used in the corrosion field since the early 80’s when IMI Marstons employed them to help model the performance of the impressed anodes to be used on the Conoco TLP platform for the North sea [2].

They have been successfully compared with physical scale modeling experimental results and data obtained from tests performed on full size ships [3]. Physical scale model testing provides the computer analyst with a well defined set of conditions to model.

DeGiorgi, Kee and Thomas studied a 3D model of a U S Navy CG class ship [4] using boundary elements (Figure 1, Figure 2).

![Figure 1 Schematic Diagram of a U S Navy CG class ship.](image)
Physical scale model experiment data was available for direct comparison with computational results. The potential profiles for reference cell readings of -0.85 Volts Ag/AgCl showed very good agreement between experimental and computational results. The total current requirements for static minimum damage conditions are:

<table>
<thead>
<tr>
<th></th>
<th>Experimental</th>
<th>Computational</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Amps for full ship</td>
<td>33.6</td>
<td>35.7</td>
</tr>
<tr>
<td>Amps to propellor</td>
<td>26.3</td>
<td>27.7</td>
</tr>
<tr>
<td>Amps to docking blocks</td>
<td>7.3</td>
<td>8.0</td>
</tr>
</tbody>
</table>

Table 1 Comparison between experimental and computational results for current requirements of a US Navy CG class ship.

The difference between experimental and computational results was 6% for total current values, 5% for Amps to the propeller and 10% for Amps to the docking blocks.

The potential profiles along the side of the hull at a depth of 3.05 m (10 ft.) are shown in Figure 3.

As can be seen, the potential profiles for reference cell readings of -0.85 Volts Ag/AgCl show very good agreement between experimental and computational results.
The conclusions were that the boundary element methods were a viable technique for determining marine corrosion parameters. Nevertheless, the analysis must be aware of the degree of accuracy which can be expected from a particular level of mesh refinement. Detailed refined meshes are required for detailed design. Of equal importance as the degree of mesh refinement is whether the polarisation response is appropriate. It is indispensable in order to obtain good agreement between the in-service conditions and the conditions under which polarisation responses are determined. Frequently, a simple laboratory test will not be representative of the actual in-service conditions. The electrical current demand should be measured for environmental conditions as similar as possible to actual service conditions. The electrolyte conductivity, time exposed to seawater for the formation of films and deposits, the use of natural seawater, and appropriate velocity conditions should be included in the experiments from which polarisation response is measured.

Gartland, Bjoernaas and Osvoll described in their paper published in the 1999 Corrosion Conference in San Antonio, where a special session was organised on computer modelling, what they had learnt about computing modelling in 15 years of work [5]. Gartland P.O, Bjoernass F., Osvoll H. Computer modelling of offshore CP systems for 15 years: What have we learnt?, Corrosion NACE Expo 99, San Antonio Texas. (1999). Some of the points highlighted were:

- **CP design is an area where experience is quite important**, and even if there are several guidelines available, these are not written to meet the new challenges. Computer modelling has no such limitations.
Computer modelling is very well suited for "what if-studies", where results can be obtained rather quickly compared to time-consuming experiments, or where full scale experiments cannot even be carried out.

The usefulness of CP modelling is perhaps most evident for problems related to uneven anode distribution or hybrid systems. CP design guidelines offer absolutely no means to create a safe CP design for a structure with uneven anode distribution. All equations and formulas used to calculate the required anode mass and anode size are based on the assumption that the anodes shall be distributed most evenly on the structure.

The influence of the boundary conditions depend very much on the problem. For a verification study of a structure covering the entire lifetime, the boundary conditions must be very accurately modelled, which includes the non-linearity and the time dependence.

Upgrading of CP systems for existing structures is an area where computer modelling has proven to be cost effective. In a study of the Ninian Northen it was concluded that a saving was in the order of £7.75m using CP Modelling technology combined with measurements of the current densities on the platform before retrofitting.

In general, boundary element methods are a viable technique for determining corrosion parameters and some of the main features are:

1. BEM is a very convenient basis for CP modelling since no volume elements, only surface elements have to be defined.
2. Realistic, time dependent boundary conditions are required for accurate modelling of the CP system performance over the entire lifetime.
3. New types of structures and new problems require that the modelling program is sufficiently flexible or can be modified with minimum effort.
4. Current distribution problems and problems related to uneven anode distribution in the design phase cannot be investigated by other means than a computer model.
5. Detailed refined meshes are required for detailed design.
6. Accurate polarisation curves are necessary to obtain good agreement between in-service conditions and the computer simulation.
7. The determination of the polarisation curves must include the environment conditions of the real structure.
Boundary elements have become a very useful tool not only in design of protection systems but also in interpretations of readings from subsea inspection of offshore structures. Successful applications include [6][7]:

- Analysis of electric field strength and current density readings to accurately estimate current output from sacrificial anodes and current consumption on exposed steel.
- Analysis of potential readings and attenuation curves at sacrificial anodes.
- Analysis of potential distributions at nodes and other complex and critical areas on the structures.
- Design analysis of impressed current anodes and hybrid systems to evaluate stray currents and interference effects.
- Design analysis of cathodic protection systems generally, to include buried and partially buried submarine pipelines.

3 Stray currents

Stray current corrosion can be caused by the systems used to protect ship hulls and buried structures, by the DC electrical systems used to power trolley cars, and by a number of other sources. Stray current corrosion is of immense economic importance, since it has led to such problems as rapid failure of buried natural gas pipelines and water mains, and costly repairs to ship structures and piers.

The interference case simulated in this paper is explained in detail by J. Trevelyan and H. P. Hack [9]. In the case of a ship’s impressed current cathodic protection system interacting with a steel sheet piling of a neighbouring pier. A ship impressed current cathodic protection system consists of a power supply with its negative terminal connected to the ship’s hull and its positive terminal connected to a special device called an anode. The power supply forces current out of the anode, through the seawater, and into the ship’s hull to complete the circuit. The action of the current causes a shift in electrochemical potential of the steel of the ship’s hull which slows or stops the normal tendency of steel to corrode in seawater. This technique is used to control corrosion on all large ships and most small ones. A variety of this technique is even used to protect outboard motors on small craft. On large ships, the current being delivered by the anodes is typically controlled by monitoring the amount of potential shift of the steel hull using special electrodes called reference cells. The current is usually adjusted to
give a fixed steel potential near the controlling reference cell. A ship may dock near a large metallic object such as the steel sheet piling on the pier to which the ship is tied. This creates the following situation, illustrated in Figure 4. Current flowing from the ship’s anode through the seawater to the ship hull encounters a resistance due to the resistivity of seawater. If the sheet piling is closer to the anode than sections of the ship hull, the current has an alternate path that it may follow. It can travel through a much shorter seawater path to the piling, through the low resistance steel of the piling until it gets close to the ship hull, then through another short seawater path between the piling and the hull to complete the circuit. At the point where the current enters the piling, the steel is protected from corrosion the same way as the ship hull is protected by the cathodic protection system. Where the current leaves the piling to enter the seawater, the opposite occurs. The corrosion of the steel piling in this area is dramatically increased. The magnitude of the resulting stray current corrosion depends on how much the cathodic protection current takes the alternate path through the piling.

**Figure 4 Stray current corrosion of the ICCP system of the ship to the dock.**
The behaviour of the cathodic protection system of a frigate in open sea and its influence, interference on a steel made dock, is shown in the next sections of this paper. In addition, a possible mitigation of the interference by placing a sacrificial cathodic protection system on the walls of the dock is also shown.

4 Frigate model, description

The dimensions of the frigate are:
- Waterline length: 34.0m.
- Draft: 2.3m.
- Waterline beam: 6.4m.

The frigate was considered fully coated apart from some specific damaged areas (Figure 5):
- Area at the stern of the frigate, nearby the propeller, area= 3.51m².
- Shaft of the propellers, area= 0.18m².
- Small area of the keel, area= 3.18m².
- Area at the bow, area= 11.56m².

Figure 5 Frigate and damage distribution.
The propeller was set made of Nickel-Aluminium-Bronze with an area of 1.84m$^2$.

The electrolyte considered was seawater with a resistivity of 20ohm cms [8], what implies a conductive of about 5S/m [8].

Two impressed anodes were placed at the starboard and port of the hull of the frigate. In addition, two reference cells of silver chloride (Ag/AgCl/seawater) were also placed at both sides of the hull (Figure 6). The criterion for protection was that the reference cells should be in -900mV to assure that the surrounded areas were protected.

Figure 6 Impressed anodes and reference electrodes distribution.

5 Analysis of the Frigate ICCP system on open sea

Initial the frigate was analysed considering an open sea environment where there were no interference with the environment. Thus, the normal behaviour of the ICCP (Impress current cathodic protection) system could be set.

The current of the impressed anodes were iteratively adjusted to satisfy the potential required at the reference electrodes (-900mV). This was achieved using the boundary elements software assisted by optimisation software [10-[14].

The final potential distribution on the hull of the ship is shown below (Figure 7). The area near the propeller is the anode more likely of suffering from corrosion since its potential is above the rest of the areas of the ship.
The current supplied by the anodes is shown in Table 2. The current supplied by both anodes is the same since the frigate is totally symmetric.

<table>
<thead>
<tr>
<th>Name</th>
<th>Current (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anode Port</td>
<td>-2160</td>
</tr>
</tbody>
</table>
Table 2 Current supplied by the impressed anodes.

<table>
<thead>
<tr>
<th>Anode Starboard</th>
<th>-2160</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>-4320</td>
</tr>
</tbody>
</table>

6 Analysis of the Frigate ICCP system berthed at a steel dock

The frigate is moved near a dock where it is berthed for simple maintenance. For the sake of simplicity, the dock is considered a plate made of steel of 15m height.

![Figure 9 Dock height.](image1)

The frigate was berthed at the port at about 1.75m from the dock. The frigate’s ICCP system was not switched off unless a diver needed to inspection the hull.

![Figure 10 Distance from the ship to the dock.](image2)

The potential distribution on the hull of the ship is shown in Figure 11. It can be observed that the potential distribution presents a slightly higher value than the values had when the ship was on open sea.
The current supplied by the anodes is shown in Table 3. The total current supplied by the anodes is about 4% larger than the value had when the frigate was on open sea Table 2.

<table>
<thead>
<tr>
<th>Name</th>
<th>Current (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anode Port</td>
<td>-2240</td>
</tr>
<tr>
<td>Anode Starboard</td>
<td>-2240</td>
</tr>
<tr>
<td>Total</td>
<td>-4480</td>
</tr>
</tbody>
</table>

Table 3 Current supplied by the impressed anodes.

Therefore, the dock must be influencing the measurements of the reference cells of the ship to make the ICCP system to generate more current to keep them at -900 mV.

A study of the dock shows that there are two clear areas with different potentials, one of the areas is acting anodically as the other is acting cathodically (Figure 12). In fact, the current the dock is receiving current from the impressed anodes of the frigate and the current returns to the frigate near the propeller, creating two areas with cathodic and anodic behaviour respectively, see Figure 14 and Figure 2.
Figure 12 Potential distribution on the dock.

Figure 13 Current distribution on the dock.
The current returning to the ship from the dock will provoke faster corrosion of this area of the dock and therefore a remedy to this situation must be considered.

7 A passive cathodic protection on the dock

In order to avoid the previous situation in which the dock was being corroded by the ICCP system of the frigate, a passive system (sacrificial anodes) of protection was designed which consisted of an array of 60 zinc anodes was placed on the wall of the dock. The dimensions of those anodes are shown in Figure 15.

The anodes were distributed on the wall of the dock as it is shown in the figure below.
When no ship is in the surroundings of the ship the dock presents a potential distribution as shown in the Figure 18.
When the frigate is berthed to the dock the potential distribution on the dock is almost the same than the one found when there is not ship in the surroundings of the dock.

In addition, the current supplied by anodes on the frigate is very similar to the current supplied when no anodes were placed on the dock. In contrast to the case with no sacrificial anodes, the dock is protected from corrosion and no anodic areas are found.

<table>
<thead>
<tr>
<th>Name</th>
<th>Current (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anode Port</td>
<td>-2.235</td>
</tr>
<tr>
<td>Anode Starboard</td>
<td>-2.235</td>
</tr>
<tr>
<td>Total</td>
<td>-4470</td>
</tr>
</tbody>
</table>

Table 4 Current supplied by the impressed anodes of the frigate in case of having a passive cathodic protection system on the dock.

The impressed anodes of the frigate still supply current to the dock and the current returns back to the frigate near the propeller position. However, the current is returns back from the sacrificial anodes causing a faster consumption of these anodes. Thus, it can be seen in the Figure 20, Figure 21, Figure 22, Figure 23 and Figure 24 that the current supplied by the sacrificial anodes of the dock near the impressed anodes supply less current to the dock when
the frigate is berthed than when there is no ship around. In contrast, the sacrificial anodes near the propeller supply more current (to the dock and to the frigate).

Figure 20 Current supplied by the anodes when there was and there was not ship berthed (1st row).

Figure 21 Current supplied by the anodes when there was and there was not ship berthed (2nd row).
Figure 22 Current supplied by the anodes when there was and there was not ship berthed (3rd row).

Figure 23 Current supplied by the anodes when there was and there was not ship berthed (4th row).
Figure 24 Current supplied by the anodes when there was and there was not ship berthed (5th row).

8 Conclusions

Quantitative data on the behaviour of the cathodic protection system of a frigate in open sea and its influence/interference on a steel dock has been shown by using computer simulation software. A possible mitigation of the interference by placing a sacrificial cathodic protection system on the walls of the dock was attempted with the results that still there were stray currents coming from the frigate into the dock and from the sacrificial anodes of the dock back to the frigate. Thus, the sacrificial anodes of the frigate placed near the propeller of the frigate will be consumed faster than the rest. In contrast, the sacrificial anodes placed near the impressed anodes of the frigate will last longer since the frigate is providing part of the current necessary to protect the dock. Anode consumption rates were predicted by the computer model under various possible scenarios.

The simulation has been carried out using boundary elements package software [1] and the assistance of an optimisation tool was essential to obtain a faster convergence of the problem.

It could be observed that 3D model enables the impact of small changes to the geometric design, coating condition, location of anodes etc to be assessed.

9 References


