# Cathodic Protection Simulation Using BEM for Pipe-Lines Structure with Ribbon Sacrificial Anode

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## Absract

In this paper, a boundary element formulation is developed and used for the analysis of cathodic protection systems of buried pipe-lines structures. It is very important to maintain the effectiveness of the cathodic protection system for the pipelines structure, which is to lengthen the lifetime of the system. However, nowadays the evaluation of the effectiveness of the system only could be done after the system applying in field. This study is conducted on 2D boundary element method to evaluate the effectiveness of the cathodic protection system for pipe-lines structure using ribbon sacrificial anode. Two factors i.e. the soil conductivity and the distance between pipe-lines and anode, are analyzed by using the proposed method. In this method, the potential in the domain was modeled by Laplace's equation. The anode and cathode areas were represented by polarization curves of different metals. Boundary element method was applied to solve the Laplace's equation to obtain any potential and current density in the whole surface of the pipe. The pipe and anode were modeled into 2D model. The numerical analysis result shows that the current density values on the surface of the pipe are subject to change when the factors were changed. Therefore, the effectiveness of the protection system can be evaluated before the system applied.

**Keywords: Cathodic protection, BEM, pipe-lines structure, ribbon sacrificial anode, polarization curve**

## 1. Introduction

Many studies have been conducted with the objective of understanding the corrosion mechanisms in soil, as well as the development of effective techniques for the protection of buried pipe-lines structures. Cathodic protection (CP) is a technique, which uses the electrochemical properties of the metal being protected.

In an CP system, the main variables that can be changed in order to modify the performance of the system are the soil conductivity, the displacement between pipe-lines and anode, and the material of anode. Up to now, only the currents of the anodes have been modified but obviously the locations of the anodes have a major influence on the performance of the CP system. For instance: an anode at the optimum position will require less current to protect the buried pipe-lines structures and therefore the signature will be reduced.

In many cases of corrosion, frequently due to economical reasons, the structures are protected by any protection system. One of the ways to reduce the corrosion cost is by implementing corrosion protection system such as cathodic protection. However, it is difficult to evaluate the effectiveness of cathodic protection system before the system applied. People only depend on the experience or trial-and-error. Hence, a method to evaluate the cathodic protection system before deployment becomes important.

The use of numerical method such as boundary element method (BEM) [3] becomes popular among researchers and corrosion engineer for modeling and solving various corrosion problems [4-7]. The mathematical model for the cathodic protection of tank bottoms using standard anode configuration was developed, which realistic polarization kinetics, non-uniform current distributions and non-uniform oxygen concentrations were taken account [8]. Some factors affecting cathodic protection interference was studied using BEASY software (BEM) in the reference [9].

In this paper, the influence of some factors such as the soil conductivity, the displacement between pipe-lines and anode, and the material of anode to the current distribution on the pipe surface that protected using cathodic protection with ribbon sacrificial anode are analyzed by applying the boundary element method (BEM).

## 2. Modeling of Corrosion

For numerical analysis or simulation purposes, suppose that the soil domain ($\Omega$) is ($\Gamma s$) limited as shown in Figure 2, the surface ribbon anode is ($\Gamma_{m1}$) and the surface of the pipe is ($\Gamma_{m2}$). The electrical conductivity ($\kappa$) is uniform in the whole soil domain and there is no accumulation or loss of ions in the bulk of the domain. Figure 3 gives the boundary condition of the model.

The potential field in the soil domain ($\Omega$) can be modeled mathematically by the Laplace's equation:

$$\nabla^2\phi = 0 \quad \text{in } \Omega \tag{1}$$

The density of current (i) across the boundary is given by

$$\mathrm{i} = -\kappa \frac{\partial \phi}{\partial \mathbf{n}} \tag{2}$$

where $\kappa$ is the electrical conductivity and $\partial/\partial$n is the outward normal derivative.

The associated boundary conditions to Equation (1) are given as followings:

$$\mathbf{i} = \mathbf{0} \quad \text{on } \Gamma_s \tag{3}$$

$$-\phi_{\mathbf{a}} = f_a(\mathrm{i}) \text{ on } \Gamma_{m1} \tag{4}$$

$$-\phi_{\mathbf{c}} = f_c(\mathrm{i}) \text{ on } \Gamma_{m2} \tag{5}$$

where $f_a$(i) and $f_c(i)$ are the non-linear functions representing the experimentally determined polarization curves for anode and cathode areas, respectively.

The minus signs on the right hand sides of Equation (4) and (5) are due to the fact that the potential in the electrolyte near the metal surface, $\phi$, is equal to minus value of potential difference between the metal and the reference electrode (E), such as saturated calomel electrode, SCE. It is noted that the potential $\phi$ is defined with referring to the metal and has the inverse sign of the employed usually in the corrosion science.

Since the knowledge of physical quantities on the metal surface is important, boundary element method is employed here. The standard boundary element procedures lead to:

$$\kappa\,[H]\begin{Bmatrix}\phi_s \\ -f(i_a) \\ -f(i_c)\end{Bmatrix} - [G]\begin{Bmatrix} i_o \\ i_a \\ i_c\end{Bmatrix} = 0 \tag{6}$$

where the detail expression of matrices [H] and [G] are given in references [10] and the subscripts s, a, c and m represent the quantities on $\Gamma_s$, $\Gamma_{m1}$ and $\Gamma_{m2,}$ respectively.

Boundary element method is used to solve the Laplace's equation in Equation (1) if the boundary conditions in Equations (3) to (5) are known. Hence, $\phi$ and i on the whole metal surface can be determined.

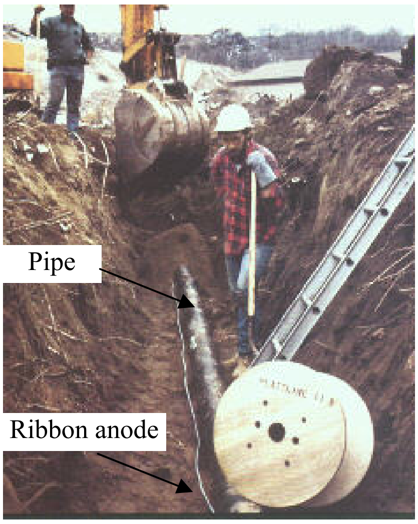


Figure 1. Cathodic protection system using ribbon sacrificial anode [11]

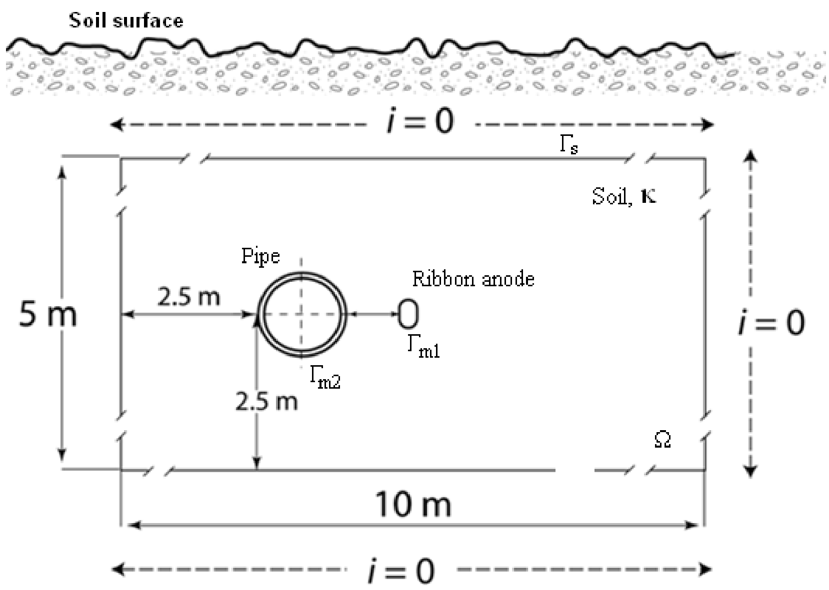


Figure 2. Cathodic protection with ribbon anode model in 2D

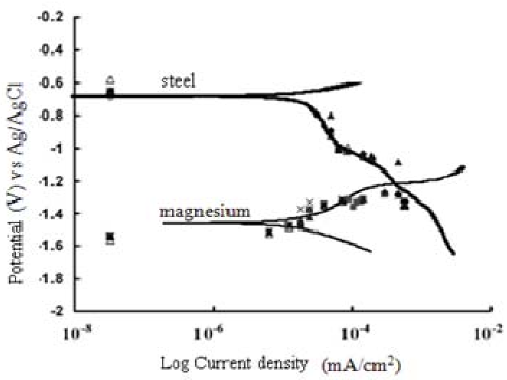


Figure 3. Polarization Curve of Steel and Magnesium vs Ag/AgCl [12]

Table 1. Polarization Curve Value of Steel and Magnesium vs Ag/AgCl [12]

| Materials | Potential (V) | Current density ($mA/cm^2$) |
|---|---|---|
| Steel | -0.648 | 0.000 |
| | -0.800 | 0.049 |
| | -0.998 | 0.065 |
| | -1.021 | 0.085 |
| | -1.039 | 0.146 |
| | -1.049 | 0.190 |
| | -1.086 | 0.459 |
| | -1.355 | 0.570 |
| Magnesium | -1.538 | 0.000 |
| | -1.510 | -0.006 |
| | -1.474 | -0.012 |
| | -1.465 | -0.018 |
| | -1.419 | -0.024 |
| | -1.345 | -0.038 |
| | -1.320 | -0.072 |
| | -1.310 | -0.145 |
| | -1.268 | -0.288 |

## 3. Example of Numerical Simulation and Conclution

In this study, cathodic protection using ribbon sacrificial anode that is already used extensively in the field was analyzed. Ribbon anode is deployed parallel along the pipe-line to maintain good current distribution on the pipe surface as seen in Figure 1. The good current density profile is the distribution which the profile almost similar for the whole surface of the pipe.

The analysis was limited only to simulate the influences of the soil conductivity, and displacement between pipe-lines and anode, to the current density and potential on pipe surface. The two-dimensional model of cathodic protection using ribbon sacrificial anode is given in Figure 2.

Some assumptions were made in developing the model for such case i.e. the cross-section shape of ribbon anode was simplified into circle shape, the experimental polarization curve for pipe and anode was taken from the reference (Figure 3 and Table 1) and the soil domain was presumed to be one single domain. All parameters used for simulation are given in Table 2.

The cross-section of the pipe is divided into four parts i.e. points A, B, C and D as shown in Figure 4. Point p and q are the nearest and the farthest part of the pipe to the anode respectively.

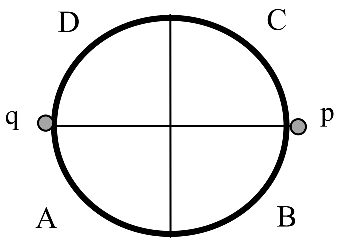


Figure 4. Cross-section of the pipe divided into four parts

**The influence of displacement of pipe-anode (r)**

The parameters set for this analysis are κ =698 μS/cm for the soil. Parameters used in the analysis are as given in Table 2.

Table 2. Parameters for numerical analysis

| | |
|---|---|
| Diameter of pipe, D | : 50 cm |
| Diameter of anode, d | : 1 cm |
| Soil | : κ = 200 μS/cm |
| | κ = 698 μS/cm |
| | κ = 1000 μS/cm |
| Pipe material | : mild steel |
| Anode | : magnesium |
| Displacement of pipe-anode, r | : 5 cm, 20 cm, 60 cm, 1 m, 1.5 m |

Figure 5a and 5b shows influence of displacement of pipe-anode to the current density on the pipe surface. With decreasing the displacement, the current density values of the nearest area (between points B and C) become higher. However, the current density of the farthest area (between points A and D) become lower for such condition. We can see that the higher displacement (r) gives good current density distribution. Nevertheless, the current density is lower by increasing the displacement (r).

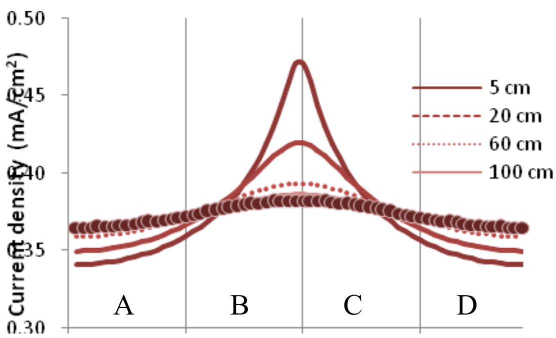


Figure 5a. The influence of pipe-anode displacement on current density

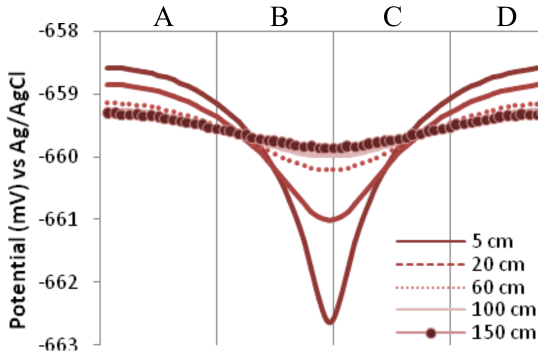


Figure 5b. The influence of pipe-anode displacement on potential

**The influence of soil conductivity (κ)**

The displacement of pipe-anode, r = 20 and 100 cm are used for this simulation. Others parameter are as shown in Table 2.

The influence of soil conductivity to the potential on the pipe surface is shown in Figure 6. It can be seen that the potential along the area between points B and C become higher when the conductivity of the soil is low. However, the potential of the farthest area (between points A and D) become lower for such condition. Meanwhile, the potential for higher conductivity has a fairly well distributed along the pipe section.

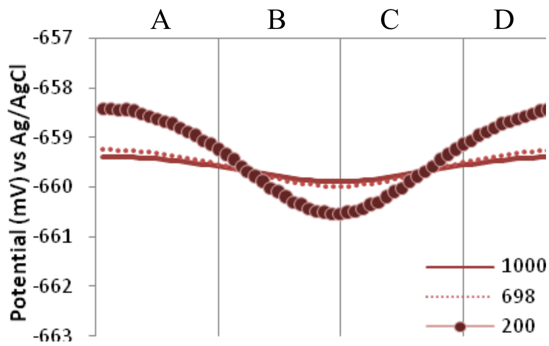


Figure 6a. The influence of soil conductivity (r =100 cm)

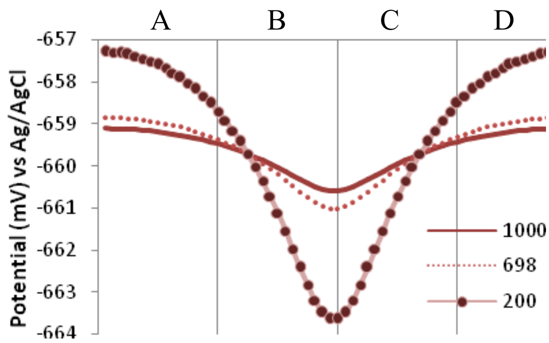


Figure 6b. The influence of soil conductivity (r = 20 cm)

## Conclusions

The influence of some factors to cathodic protection system with ribbon sacrificial anodes for pipe-line structure was evaluated by applying Boundary Element Method. The potential in the soil domain was modeled using the Laplace's equation. BEM was used to solve the Laplace's equation. Thus, the current density and potential on the whole pipe surface can be determined. The result of boundary element simulation using a 2D model shows that the current density and potential values on the surface of the pipe are subject to change when the factors such as the soil conductivity, and the displacement between pipe-lines and anode were changed. However, the method needs an improvement by combining with optimization method such as GA to obtain the optimum design of the protection system. Hence, prior to the implementation, the effectiveness of the protection system can be evaluated.


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