CORROSION SCIENCE AND TECHNOLOGY, Vol.31, No.2(2002), pp.162~165

BEM Analysis for Cathodic Protection Design of Pier

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Over the last years it has been recognized that traditional CP design procedures are not always adequate for complex structures. As a result numerical techniques for use on computers have been developed. The application of such numerical computer simulations based on BEASY-CP for analysis of cathodic protection is described.

The benefits of a software solution for CP system design are as follows. First is less reliance on empirical and semi-empirical methods. Second is efficient and cost-effective CP system design. Third is evaluation of design alternatives using what-if scenarios. Fourth is reduction in the need for costly field verifications testing and data interpretation. So computer modeling can be a useful resource for developing cost-effective design and remedial solutions to a wide variety of corrosion problems.

In this paper, we analysis the current density of anode surface and the potential distribution in the electrolyte. Therefore we seek to maximize the anode life and the safety of metal structures, pier.

Keywords : *CP design, numerical computer simulations, BEASY-CP, spline interpolation algorithms, pier*

1. Introduction

In recent years there has been a growing interest in the prediction of the behaviour of engineering problems involving galvanic effects. This class of problem includes galvanic corrosion, cathodic protection methods and the inverse problem of electrodeposition commonly used in manufacturing.

In the late 70's boundary element method(BEM) became available in the prediction. 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 BEM for CP design are many folds: First the meshes are now only on the surface, hence only two dimensional elements are required. Mesh generators can be used with confidence, and models can be constructed extremely quickly and inexpensively. Second BEM gives the solutions on the boundary and, only if required, at specified internal points. Since for CP design the solution is only required on the surfaces, it is far easier to analyze the results than for FEM analysis which automatically gives results for all nodes. Third BEM is very effective and accurate for modeling infinite domains as is the case for CP analysis.[1)]

In this paper, we analysis the sacrificial anode system of the pier with a length of 100 meters. The design parameter of the optimum anode system, such as anode locations is proposed based on the detailed analysis of the pier. The optimum anode location could be determined by performing a number of computer simulations with different anode locations using spline interpolation algorithms. This would provide a cost effective design approach and reduce the reliance on labor-intensive field testing.

2. Mathematical aspects

A brief description will be given here. The potential field throughout the electrolyte may be mathematically modeled by Laplace's equation (1) under boundary conditions (2) through (5):

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

$$\phi = \phi_0 \qquad \text{on } \Gamma_1 \tag{2}$$

$$i\left(\kappa\frac{\partial\phi}{\partial n}\right) = i_0 \qquad \text{on } \Gamma_2 \tag{3}$$

$$\phi = -f_a(i) \qquad \text{on } \Gamma_a \tag{4}$$

$$\phi = -f_c(i) \qquad \text{on } \Gamma_c \tag{5}$$

where ϕ is the potential, i the current density across

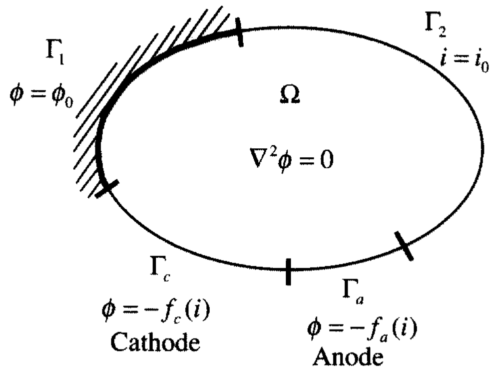

Fig. 1. Basic equation and boundary conditions

the boundary, κ the conductivity of the electrolyte, and $\partial/\partial n$ the outward normal derivative. The entire surface of the electrolyte domain (Ω) is indicated by $\Gamma_1+\Gamma_2+\Gamma_a+\Gamma_c(=\Gamma)$ (Figure 1). The given values of the potential and current density are respectively indicated by ϕ_0 and i_0, while $f_a(i)$and $f_c(i)$ are non-linear functions that respectively indicate the experimentally determined polarization curves for the anode(Γ_a) and cathode(Γ_c). Here, the relationship between the above mentioned potential ϕ and the electrode potential E is followed by equation.[6]

$$\phi = -E \tag{6}$$

Let P and Q be two points inside or on the surface of Ω, and let ϕ^* be the known fundamental solution with singularity at Q. Taking $\phi^* \times \nabla^2\phi$ to be integrated over Ω with Q located on Γ and applying two successive integrations by parts yields;

$$\kappa c\phi = \int_{\Gamma}(i\phi^* - \phi i^*)d\Gamma \tag{7}$$

where $i^* = \kappa\partial\phi^*/\partial n$, and c is the known constant resulting from the Cauchy principal value of the surface integral. Surface Γ is discretized into boundary elements and values of ϕ and i are approximated in terms of interpolation functions and nodal values.

By adopting the standard procedure of BEM, the following simultaneous algebraic equations are obtained:

$$[A]\begin{Bmatrix} x_j \\ i_j \end{Bmatrix} = [B]\begin{Bmatrix} b_j \\ f_j(i_j) \end{Bmatrix} \tag{8}$$

where x_j values (j =1, 2, . . . , p) are the unknown values of ϕ or i on $\Gamma_1+\Gamma_2$, and b_j (j =1, 2, . . . , p) the given values on $\Gamma_1+\Gamma_2$. The functions f_j (i_j) (j =1, 2, . . . , s) are the nonlinear functions representing the polarization curves. $[A]$ and $[B]$ are matrices geometrically determined on boundary Γ. The numbers of elements on $\Gamma_1+\Gamma_2$ and $\Gamma_a+\Gamma_c$ are respectively indicated by p and s. The above nonlinear equations are solved by using the Newton-Raphson iterative method.[2]

3. BEASY-CP software for CP design

The corrosion process creates a distribution of electrical potential and current on the surface of a metal structure. Analysis of corrosion systems must take into account a complicated interaction of mathematical, geometrical, and electrochemical factors. Given the mathematical nature of the solution to this problem, a numerical technique generally is required. Recent software developments in the area of corrosion analysis have made the simulation of complicated corrosion processes and parametric approaches to CP system design possible.[3]

The BEASY-CP software was developed to allow corrosion engineers to perform more sophisticated studies of corrosion behavior. This software uses the boundary element method(BEM) to solve the governing equations for the potential distribution in a corrosive medium. The BEM has particular advantages for simi-infinite or infinite field problems such as corrosion because only the surface of the structure in contact with the electrolyte needs to be defined in the computer model, not the entire electrolyte. The benefits of a software solution for CP system design include:

① Less reliance on empirical and simi-empirical methods.
② Efficient and cost-effective CP system design.
③ Evaluation of design alternatives using what-if scenarios.
④ Reduction in the need for costly field verifications testing and data interpretation.

3.1 Creating the computer model

The key task for the user of any computer simulation tool is to define a computer model to realistically represent the problem. In the case of corrosion the information required can be divided into three categories:

- Geometry (i.e., position of pier, anodes and other important structures).
- Electrochemical behavior of the metallic surfaces (i.e., polarization, coating performance, and anode characteristics).
- Characterization of the electrolyte (i.e., resistivity properties).

The geometry and material properties of the metallic surfaces are defined using quadrilateral and triangular shaped boundary elements. Special "tube" elements have

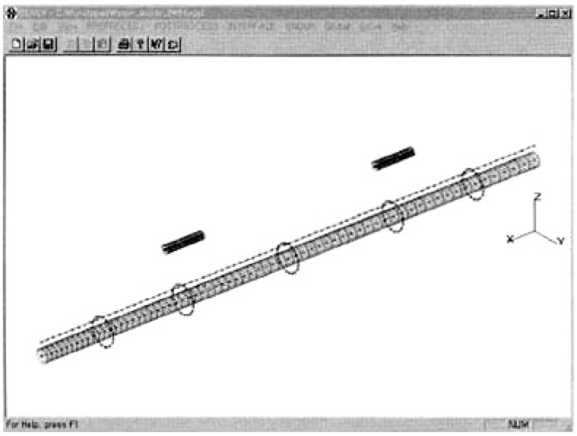

Fig. 2. The computer model is created by BEASY-CP software

been developed to simplify this process. These elements often are used to model sacrificial rod anodes or other cylindrical components such as pipelines, pier, and tubular structural framework. The computer model is created by BEASY-CP software as shown in Figure 2.

4. The optimization design for pier

The design of the corrosion protection system of the pier using a sacrificial anode system is a crucial process towards the minimization of electrochemical corrosion on the exterior of the pier.

To protect the pier from galvanic corrosion the CP system generates electrical potential levels on the pier, which inhibit corrosion. The optimum system design goals are to achieve an uniform distributed electrical potential on the pier and to ensure that the protection potential is within the specified margin so as to avoid under or overprotection. Therefore a numerical method which predicts the electrical potential and anode current with high accuracy and reliability is required. The boundary element method is a proficient numerical method that satisfies these requirements for cathodic protection system design of the pier.

An optimum design is achieved by moving the location of the anodes and using the computer model to predict the resulting protection levels on the structure. The design optimization process therefore consists of a series of calculations of the potential profiles on the pier and components with alternative anode designs. The boundary element software BEASY-CP is used to investigate the pier's sacrificial anode system performance.

The pier with a length of 100 meters is investigated. The geometry of interest in the boundary element model is the wetted surfaces. The sacrificial anode system consists of 2 zinc anodes. Zn anodes are attached to the

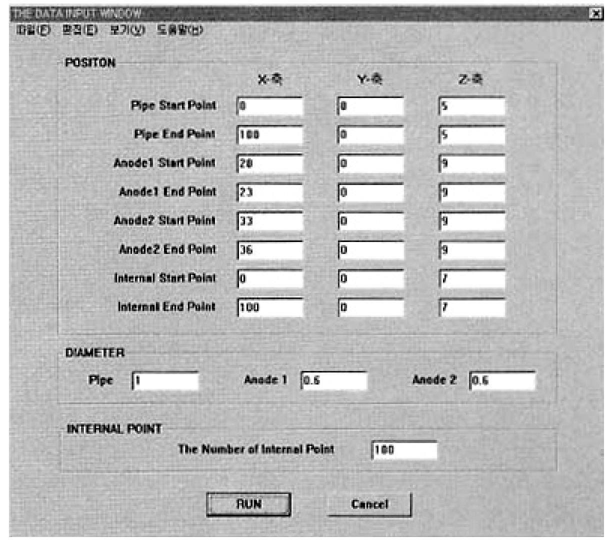

Fig. 3. GUI windows for the optimal design of sacrificial anode system

outer surface of the pier. The pier is made of steel and is surrounded with infinitive seawater and the boundary of solution domain is assumed to be far away from the regions of interest. The seawater is defined with a constant conductivity of 4.348[s/m] in the computer model. The object of the analysis is a steel horizontal pier with 1,000 mm diameter as shown in Figure 3. Polarization curves for steel and zinc is achieved from BEASY user guide.[4)]

4.1 Spline interpolation algorithms

We use spline interpolation algorithms for finding the optimal location of anodes. Splines are drafting aids used to draw smooth curves through a set of points. Weights

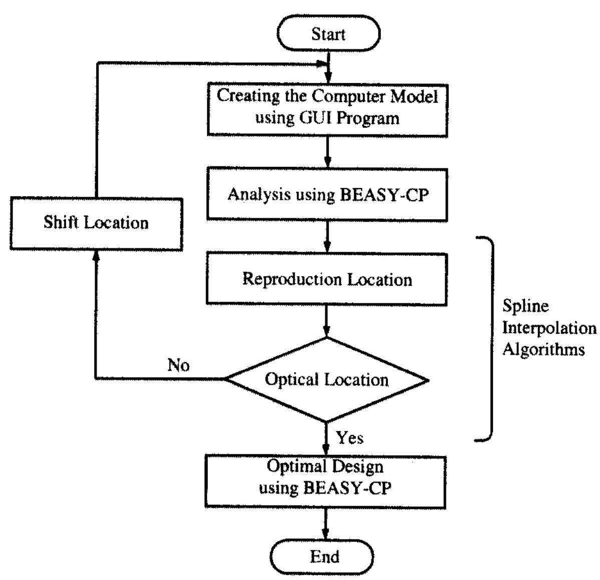

Fig. 4. The flow chart of the optimal design using spline interpolation algorithms

are attached at the points to be connected and a flexible strip is shaped around the weights.[5)]

A polynomial fitted to many data points could exhibit erratic behavior. But splines are smooth and continuous across the interval. The optimal design using spline interpolation algorithms is done by the flow chart as shown in Figure 4.

5. Results and discussion

5.1 Optimal location of anodes

The required potential level on the pier surface is obtained through and iterative process of adjusting the anode currents. The criteria of adequate potential level for the protection on the pier was set up in the range from -0.4 V to -0.3 V on the wetted pier surface.

If the z-axis of anodes is 9 which is just start point, the potential of internal points profile is between -324.57 V and -476.12 V. After applying spline interpolation algorithms, we can find the optimal z-axis value of anodes, 9.9072. The potential level on the profile is between -321.99 V and -399.99 V.

6. Conclusions

We analysis the sacrificial anode system of the pier with a length of 100 meters using BEASY-CP. The design parameter of the optimum anode system, such as anode locations is proposed based on the detailed analysis of the pier. The optimum anode location could be determined by performing a number of computer simulations with different anode locations using spline interpolation algorithms.

From now on we have to consider more the design parameter, such as anode numbers and system performance can be improved accordingly.

References

1. C. A. Brebbia, in *Topics in Boundary Element Research Vol. 7 Electrical Engineering Applications*, Springer-Verlag Berlin, Heidelberg, 34 (1990).
2. M. Miyasaka, H. Takayama, K. Amaya, and S. Aoki, in *Combined BEM Analysis of 3D and Axisymmetric Regions for Cathodic Protection Design of Seawater Pump*, 1998 by NACE International, 689/2 (1998).
3. R. A. Adey, M. Rudas, and T. J. Curtin, in *Corrosion Simulation Software Predicts Interaction of Underground Electric Fields*, Materials Performance, Jan. 28 (2000).
4. BEASY USER GUIDE Volume 2, *Corrosion and CP Guide*, Computational Mechanics BEASY, 42 (1998).
5. Hemuth Spath, *Two Dimensional Spline Interpolation Algorithms*, A K Peters Ltd., (1995).