Study on the effect of mesh ratio to the potential distribution of RC cathodic protection using BEM

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Abstract. Researchers and engineers have used cathodic protection (CP) to prevent corrosion in reinforced concrete (RC). Boundary element method (BEM) is a promising numerical technique to evaluate the effectiveness of CP on RC structures. However, some parameters that might affect the system or the potential distribution, such as mesh ratio, still need to be studied further. This paper aims to study the effect of mesh ratio on the potential distribution of RC installed CP using BEM. Simple 3D beam model of RC was used for the case study. The mesh for the model was triangular element and six variations of the mesh ratio were selected for the study. The mesh ratio obtained from the comparison between the size of the concrete element and the anode or cathode element. Simulation results show that the distribution of potential for all mesh ratios is within the protection criteria (≤ -850 mV vs Cu/CuSO4). However, the difference between maximum and minimum potential value becomes smaller when the mesh ratio increased. Hence, it shows that the mesh ratio has an effect on the distribution of potential of RC installed CP. However, it is still tolerable since the potential within protection criteria.

1. Introduction
Corrosion is the phenomenon of metal degradation due to electrochemical reactions that occur on metals in corrosive environments [1]. Corrosion often occurs in reinforced concrete or commonly called RC. RC is a construction formed by cement, aggregates, water and reinforcing steel (rebar). Corrosion causes increased the volume of RC (in the form of corrosion products) which damages the structure. So that it can make a decrease in service life and cause early failure of RC [2, 3]. An example of structural damage of RC due to corrosion can be seen in Figure 1.

Cathodic protection (CP) is one of the methods that have been widely applied by researchers and engineer to prevent RC from corrosion. While, boundary element method (BEM) becomes a promising solution that has been popularly used by researchers to evaluate CP [3,4,5]. BEM has successfully performed in simulation of CP on a pier structure [4]. An example of a sacrificial anode cathodic protection (SACP) on RC can be seen in Figure 2. To increase the effectiveness of BEM in solving corrosion engineering problem, Fonza et al [6] have evaluated CP on RC by observing the effect of anode-cathode displacement and anode type to the system. However, some parameters that might affect the CP system or the potential distribution, such as mesh ratio, still need to be studied.

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Figure 1. Structural damage on RC [7].

Figure 2. The schematic of a SACP on RC [8].

2. The model of cathodic protection on RC

For this study, CP on RC model is a domain composed of reinforcing steel (rebar) and sacrificial anodes that electrically connected and the model is shown in Figure 3. The domain is assumed to be isolated which is having constant conductivity. Thus, the domain can be mathematically modelled with the Laplace equation as shown in equation (1) and relationship between \( i \) and \( \phi \) given in equation (2) [1-2].

\[
\nabla^2 \phi = \frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \phi}{\partial z^2} = 0 \quad \text{in } \Omega
\]

\[
i = -\kappa \frac{\partial \phi}{\partial n} \quad (A/m^2)
\]

Where \( \phi \) is the electrical potential, \( i \) is the current density on the RC domain, \( \kappa \) is the conductivity of the concrete and \( n \) is the normal vector. The boundary conditions for solving the Laplace equation of the domain are shown in equation (3-5) [6].

\[
i = i_0 = 0 \quad \Gamma_1 \quad (A/m^2)
\]

\[
i = 0 \quad \Gamma_2 \quad (A/m^2)
\]

\[
i = 0 \quad \Gamma_3 \quad (A/m^2)
\]
\begin{align}
\phi &= -f_c(i) \quad \Gamma_2 \quad \text{(V)} \quad (4) \\
\phi &= -f_a(i) \quad \Gamma_3 \quad \text{(V)} \quad (5)
\end{align}

By following the standard formulation of BEM, the matrix equation is obtained in order to solve the Laplace equation. The matrix equation is given in equation (6).

\[
\kappa \begin{bmatrix} \phi \\ -f_c(i) \\ -f_a(i) \end{bmatrix} - \begin{bmatrix} i_a \\ i_c \end{bmatrix} = 0 \quad (6)
\]

By knowing the boundary conditions in equation (3-5), equation (6) can be solved. The calculation results are in the form of electric potential values on the entire surface of the RC domain [2].

3. Case study

In this study, a 3D beam model was developed which refers to Doods et al [9]. The size of the concrete, the anode, and the reinforcing steel geometry were \((100 \times 100 \times 1000)\) mm, \((\Phi 25 \times 50)\) mm, and \((\Phi 6 \times 840)\) mm, respectively. The geometry and modelling of RC can be seen in Figure 4 and Figure 5.

![Figure 4. Reinforced concrete geometry.](image1)

![Figure 5. Reinforced concrete modelling.](image2)

| Mesh length | Anode/Cathode (mm) | Concrete (mm) | Mesh Ratio |
|-------------|---------------------|---------------|------------|
| Variation   |                     |               |            |
| 1           | 16                  | 50            | 3.1        |
| 2           | 14                  | 50            | 3.6        |
| 3           | 12                  | 50            | 4.2        |
| 4           | 10                  | 50            | 5          |
| 5           | 8                   | 50            | 6.3        |
| 6           | 6                   | 50            | 8.3        |

The mesh for the model was triangular element and there were six variations of the mesh ratio that used in the study which given in Table 1. The ratio is obtained by dividing between mesh length of concrete and anode/cathode. The displacement between cathode-anode was constant i.e. 20 mm for each variation. The anode used in the study was Zn and the reinforcing steel/cathode was mild steel.
The boundary condition for anode and cathode were obtained from reference [6]. The model of RC was developed using the Salome Mecca 8.3 software. Thus, the data of the model had been integrated into the BEM code.

4. Result and discussion
The potential distribution for the first variation (mesh ratio 3.1) is showed in Figure 6. From the simulation result, it can be seen that the potential value on anode is <-924 mV. This potential value of anode describe that the anode is in a corroded condition [10]. For the rebar, the potential value are within the range of -920.09 to -920.11 mV. These potential values show that rebar is protected from corrosion because the potential values fall within the standard of corrosion protection that published by National Association of Corrosion Engineers (NACE) [11]. Therefore, BEM has been successfully carried out a simulation of SACP in RC, and the result obtained is consistent with previous research [6]. The simulation is continued with variations 2, 3, 4 and 5. For these variations, the results are relatively the same as the previous one. The anodes are also in the corroded criteria, while the rebars are well protected from corrosion.

![Potential distribution for variation 1 (mesh ratio 3.1).](image1)

**Figure 6.** Potential distribution for variation 1 (mesh ratio 3.1).

![Potential distribution for variation 6 (mesh ratio 8.3).](image2)

**Figure 7.** Potential distribution for variation 6 (mesh ratio 8.3).

Then simulation was continued for the highest mesh ratio in this study i.e. 8.3. The potential distribution for the highest ratio can be seen in Figure 7. In general, it can be seen that there is no significant different with the previous results. The anode has a potential value <-924 mV that indicated
in a corroded state. While rebar has a potential value within -919.93 to -919.67 mV and it fulfilled the cathodic protection criteria. However, the effect of mesh ratio to the distribution of potential on the protected structure (rebar) can be seen by comparing the maximum and minimum potential value of each simulation.

The comparison of maximum and minimum potential values for all mesh ratio variations can be seen in Figure 8. It can be seen that the difference between maximum and minimum potential value becomes smaller when the mesh ratio increased. So that, the mesh ratio has an effect on the distribution of potential of RC installed CP. However, it is still tolerable since the potential within protection criteria.

Figure 8. The effect of mesh ratio to potential distribution.

5. Conclusion
In this study, BEM was used to study the effect of mesh ratio to the potential distribution on RC installed CP. From the simulation results, it is found that the mesh ratio has an effect on the distribution of potential of RC installed CP. However, the effect is not significant since the overall value of potential distribution still within protection criteria.

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