# Pre and Post Processing for BEM 3D Reinforced Concrete Corrosion Simulation

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**Abstract.** Corrosion simulation of rebar in concrete structures using BEM 3D have been developed. However, pre processing procedure such as geometry development and meshing is still performed manually. In addition, the visualization of BEM simulation results is still illustrated using the simple chart and graph. Nowadays, many softwares have been developed under open source platform that can be used freely. There is open source softwares for CAE purposes such as Salome and VisIt. The aim of this study is to implement the open source software as pre- and post-processing for the developed BEM 3D code in order to simulate corrosion of reinforced concrete. Salome 2.3.9 is used for developing geometry and meshing the model. The visualization of the simulation results are conducted using VisIt 1.8. The study shows that the open source software i.e. Salome and VisIt, perform well as pre and post processing of developed code for simulating the corrosion of reinforced concrete. It shows that the meshing procedure and the interpretation of results become simpler and easier.

## Introduction

Corrosion analysis using Boundary Element Method (BEM) has been extensively studied by many researchers [1-2]. BEM 2D and 3D for corrosion analysis, i.e. computational and corrosion research group (CCRG)-BEM, have been developed by authors. This code can be used to analyze the corrosion of steel in concrete structures [3-4].

However, pre processing procedure such as geometry development and meshing process are still performed manually. Additionally, the visualization of simulation results is still illustrated by simple chart or graph. These cause the BEM codes are sensitive to human errors when we used for analyzing large and complex geometry. In addition, the geometry development and meshing becomes time consuming and less accurate.

Nowadays, many software applications have been developed under open source platform for various purposes. Some open source softwares are available freely for computer aided engineering (CAE) purposes such as Salome [5-6] and for visualization such as VisIt [7].

The aim of this study is to solve the above problems by implementing the open source as pre and post processing into the developed BEM codes for effective corrosion analysis of reinforced concrete.

## Modeling of Corrosion Problem

Concrete is referred to as homogeneous domain. There is no accumulation or loss of ions in the bulk of the domain. Thus, the potential field in the concrete domain (Ω) can be modeled mathematically by the Laplace's equation [1-4]:

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

Fig. 1 shows the basic equation and boundary conditions used in the study. The density of current across the boundaries, which will be denoted by *i*, is given by

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

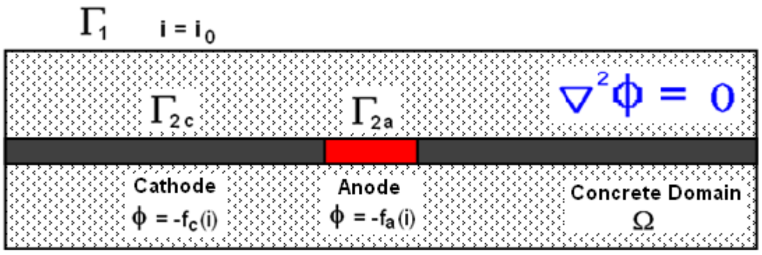


Fig. 1 Boundary conditions of reinforced concrete corrosion modeling.

The boundary conditions associated with Eq. 1 are written as:

$$i = i_o \quad \text{on } \Gamma_1 \tag{3}$$

$$\phi = -f_a(i) \quad \text{on } \Gamma_{2a} \tag{4}$$

$$\phi = -f_c(i) \quad \text{on } \Gamma_{2c} \tag{5}$$

where $\phi$ is potential at any point, *i* is current density, and $f_a(i)$ and $f_c(i)$ are the non-linear functions representing the experimentally determined polarization curves for corroded and non-corroded areas on the steel in concrete, respectively.

If the boundary conditions in Eq. 3 to 5 are known, boundary element method can be used to solve the Laplace's equation in Eq. 1. Hence, the potential, $\phi$ and current density, *i* on the whole domain can be determined.

## Open Source

All softwares that used in the study of corrosion are open source based software. Figure 2 shows the integration of the open source codes and developed boundary element corrosion code (CCRG-BEM). The operating system is PC-Linux-OS 2007. The geometry development and meshing process are conducted by applying the Salome 3.2.9. CCRG-BEM code is developed by using Fortran language and then compiled by using gFortran compiler. VisIt 1.8 is used for visualization the result.

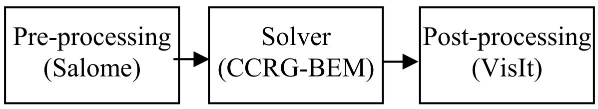


Fig. 2 Integration of open source and developed code.

**Salome.** Salome is an open source integration platform for Pre- and Post-Processing for numerical simulation. It is one of OPEN CASCADE project. Its development is a partnership of OPEN CASCADE with other software, industrial and research companies: CEA, EDF, EADS, Bureau Veritas, Principia, Cedrat, LIP6, and LEG [8].

Salome can be used to build model, perform meshing and post-process calculation results from external solver. Salome is indeed designed to be integrated with external solver. Salome supports 3D modeling using many tools available to enable user building even the complex models.

Salome features several types of mesh algorithms and mesh modification tools which can be used to build good geometry approximations. It can be used to perform line, surface and volume meshing. The meshes then can be modified through process such as cutting, removing, adding, merging, changing orientation, smoothing meshes or nodes, etc. It also supports reading and exporting of standard open source 3D model file format such as IGES.

In this study, Salome is used to build the geometry and mesh the surface of models. The geometric data produced is then used for the input of CCRG BEM Solver.

**VisIt.** VisIt is open source visualization software released by Lawrence Livermore National Laboratory under BSD licenses. It was developed by Department of Energy (DOE) Advanced Simulation and Computing Initiative (ASCI) to visualize results from tera-scale simulations. First version of VisIt was released in the fall of 2002. VisIt can handle data of the size in tera-scale but also suitable for small application in kilobytes range [9].

VisIt can be used to visualize data in various plot type with many plot modification tools. Among the plot types it supports is pseudo-color, vector plot, tensor, scatter plot and also curve and histogram. It can be used in many areas such as plotting earth terrain in GIS application, human brain from MRI data, heat transfer rate, molecule structure, fluid mechanics and stress simulation data, and many more. The plot can be modified to meet user need such as cutting part of plot, focusing plot to specific places, completing a half geometry plot which is usually used in axi-symmetric calculations and so forth.

In this study, VisIt is used to visualize BEM calculation results associated with each element in pseudo-color plot.

## Numerical Simulations

**Case I: Pre- and post-processing without using open source.** The two-dimensional galvanic corrosion model, given in Fig. 3a, was considered in Case I. Stainless steel, SUS304, was coupled with gray cast iron, FC20. The steel acts as cathode and the cast iron as anode. The galvanic couple (stainless steel–gray cast iron) was immersed in a 0.016% NaCl solution. The model was discretized manually as seen in Fig. 3b. The boundary conditions of cathode and anode were represented by polarization curves that given in Fig. 4.

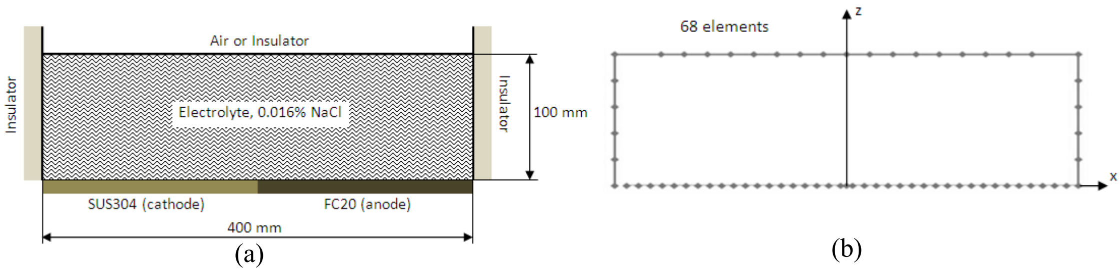


Fig. 3 Two-dimensional model of galvanic corrosion.

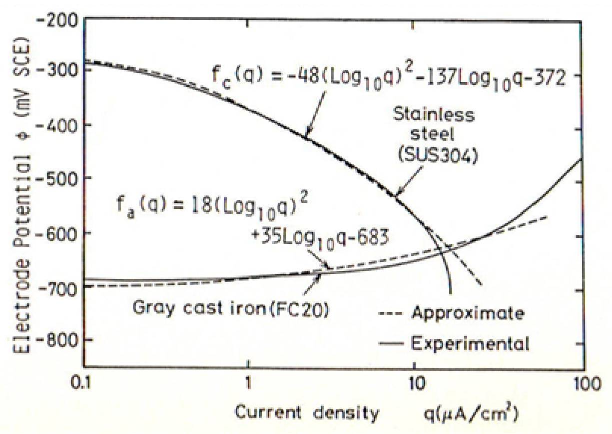


Fig. 4 Polarization curves of stainless steel (cathode) and gray cast iron (anode) [8].

The result obtained from CCRG-BEM code is given using the simple chart in Fig. 5. The figure shows that the potential difference between cathode and anode is decrease as the depth of electrolyte increasing.

From Case I, the meshing procedure that performed manually is already satisfied for two-dimensional case and simple geometry domain. However, the meshing procedure becomes difficult with increasing the complexity of the geometry and the number of element. In addition, it is not easy to visualize the results using common chart for such geometry.

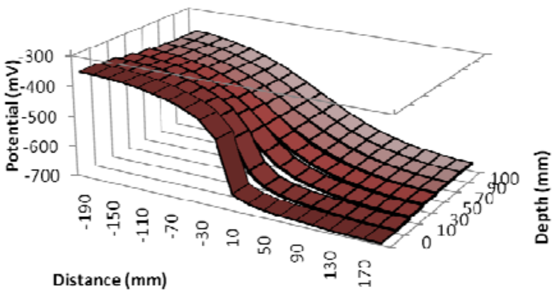


Fig. 5 Visualization of BEM result, i.e. potential distribution in the electrolyte.

**Case II: Pre- and post-processing using open source.** The reinforced concrete block with 28 cm x 28 cm x 100 cm dimension was considered as the model in Case II. Four steel, each 96 cm length and 1 cm diameter, were cast into concrete structure as shows in Fig. 6. The conductivity of concrete (κ) was 0.007 $\Omega^{-1}.m^{-1}$.

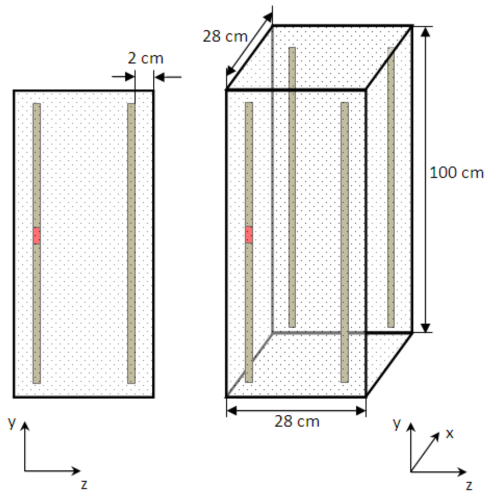


Fig. 6 Geometry of the reinforced concrete block.

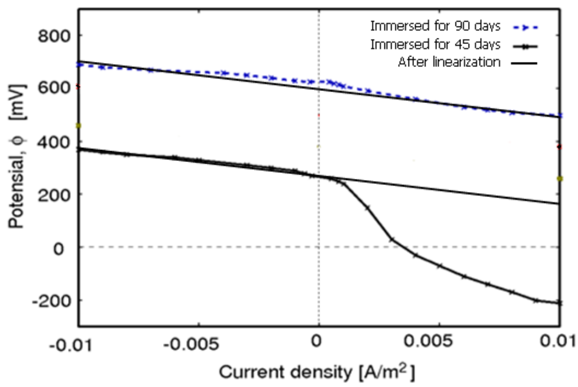


Fig. 7 Polarization curve for corroded and non-corroded areas of steels in concrete [9].

It was assumed that 4 cm corrosion size take place on the surface of steel as shown in the figure for first simulation. For second simulation, three reinforced steel were already corroded at the middle with each 4 cm corrosion size.

The corroded and non-corroded areas on the surface of steel were represented by each polarization curve in the CCRG-BEM code. The polarization curve of non-corroded and corroded areas were shown in Fig. 7, immersed for 45 days curve and immersed for 90 days curve respectively.

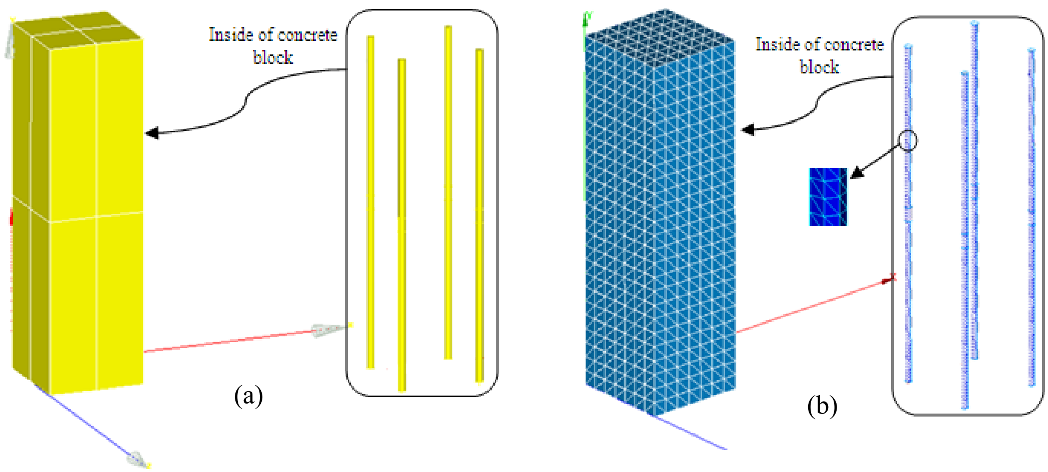


Fig. 8 Pre-processing using Salome: (a) Geometry development; (b) Meshing of concrete block and reinforced steels.

Fig. 8a shows the geometry model that developed using Salome software. The meshing result performed using Salome was given in Fig. 8b. Total elements for concrete block and four reinforced steel is 7060 elements and the shape of element using in this study was triangle element. Then, the mesh data i.e. node, element number and coordinate, imported into the CCRG-BEM code.

The simulation result of potential distribution on the surface of concrete and reinforced steel for first simulation is shown in Fig. 9 that visualizing by VisIt. It shows that the potential value above the corrosion site is higher than others. The maximum absolute potential is 474.2 mV for first simulation (Fig. 9a) and 475.6 mV for second simulation (Fig. 9b). The corrosion just affect the potential distribution on the plane nearby the corrosion area. Meanwhile, the potential distribution on other planes of concrete surface are almost constant.

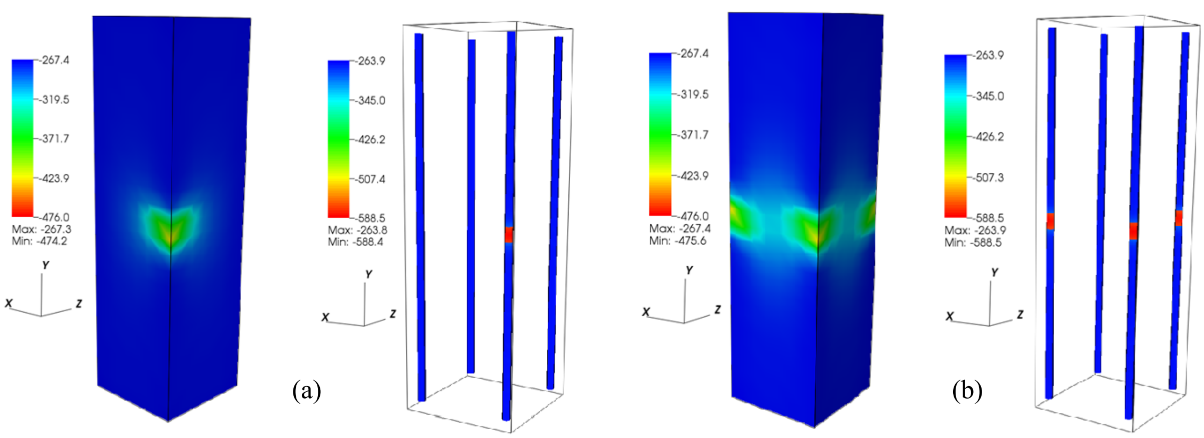


Fig.9 Post-processing using VisIt of potential distribution on concrete and steel surface: (a) First simulation; (b) Second simulation.

From Case II, the development of geometry and meshing procedure are not performed manually but using open source Salome. It is suitable for three-dimensional case and other sophisticated geometry. Also, by using open source Salome, meshing a large number of elements becomes easier. Furthermore, it shows that interpretation of the simulation result becomes much easier by using VisIt as visualization tools. Also, the results become attractive and eye-catching for the reader.

## Summary

The pre- and post-processing open source software was employed for corrosion analysis by combining with the developed CCRG-BEM code. The pre-processing, Salome software, was applied to develop a geometry model and meshing. The simulation results were visualized using the post-processing, VisIt software. The employment of pre- and post-processing software is very helpful for corrosion analysis in term of geometry model development, meshing and result visualization. Further works are needed to reduce the human effort for bridging the CCRG-BEM code and the pre- and post-processing software.

## Acknowledgement

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## References

[1] Aoki, S., Amaya, K. and Miyasaka, M.: *Boundary Element Analysis on Corrosion Problems*, Shokabo, Tokyo. (1998)

[2] Telles, J.C.F., Mansur, W.J., Wrobel, L.C. and Azevedo, J.P.S.: Boundary Elements for Cathodic Protection Problems, *Proceeding of Int. Conf. Boundary Element VII*, Editor: Brebbia, C.A. and Maier, G., Springer-Verlag, (1985), p. (1)73-(1)83

[3] Syarizal, F., Safuadi, Ridha, M. and Ariffin, A. K.: Corrosion Detection in Concrete Structure by Using 3D Boundary Element Inverse Analysis, *CD Proceeding of Indonesia's Anti-Corrosion Days 2008, INDOCOR,* 4 December 2008, Jakarta. Indonesia. (2008)

[4] Syarizal, F., Safuadi, A.K. Ariffin, M. Ridha, A.R. Daud and N.F.L. Ramli: Boundary Element Method: an Application to Evaluate the Potential on Reinforced Concrete, *Proceeding of Seminar on Engineering Mathematics, UKM*, 27-29 June 2008, Pahang, (2008), p. 64-69

[5] Bergeaud, V. and Tajchman, M. Application of the Salome Software Architecture tor Nuclear Reactor Research. SpringSim Vol. 1, ISBN 1-56555-313-6, p. 383-387

[6] Ribes, A. and Caremoli, C. Salome Platform Component Model for Numerical Simulation, 31st Annual International Computer Software and Applications Conference (COMPSAC 2007)-IEEE, Vol. 2, (2007), p. 553-564

[7] Brebia, C.A.: *The Boundary Element Technique in Engineering* (Newnes-Butterworths, London 1980)

[8] Information on http://www.salome-platform.org/about/history

[9] Information on https://wci.llnl.gov/codes/visit/about.html

[10] Aoki, S. and Kishimoto, K., in: *Topics in Boundary Element Research*, edited by Brebbia, C.A., Vol. 7, Springer-Verlag, (1990), p. 65-86

[11] Ridha, M., Amaya, K., and Aoki, S.: NACE, Corrosion, Vol. 61 No. 8, (2005), p.784-791