A Study of Electrical Resistance Tomography on Inhomogeneous System

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***Abstract*—This study is conducted to investigate inhomogeneous in Electrical Resistance Tomography system using COMSOL Multiphysics finite element software. An inhomogeneous system is represented with the concrete-steel medium. Three type of cases which are varies the dimension of steel, varies a number of steel phantom in concrete, and different location of steel in concrete are the subject in this study. Each case uses results from adjacent and opposite current driven method for comparison. As a result, extension in steel dimension could benefit the ERT system to obtain a good measurement. Also, as a number of steel placed in concrete medium increases, the potential difference will drop when compared with homogenous. It is demonstrated that as a phantom is placed close to the source or measuring electrode area, it could show changes in potential difference reading. In conjunction with that, that area indirectly becomes more sensitive and feedback.**

***Index Terms*— Concrete; ERT; Potential Difference; Steel.**

I. INTRODUCTION

Electrical Resistance Tomography (ERT) is commonly applied in imaging, monitoring and inspection in numerous fields in chemical, non-destructive testing, geology, oil and gas and medicals [1]–[3]. ERT is a high speed, non-hazard, non-invasiveness, and low-cost system. Additionally, ERT is a type of soft field process tomography method and the working principle is excitation of current or voltage that will create a sensing field and potential difference or current will be obtained through an electrode array on the boundary of a medium. As the conductivity distribution changes, indirectly the sensing field will demonstrate changes as well and result in the changes of electric potential distribution. The distribution holds the sensing field conductivity data which could be utilized in the later process.

Generally, ERT systems are applied on monitoring multiphase flow in the liquid phase where it is more conducting compared with gas and solid medium [4], [5]. ERT is one of non-destructive technique and non-invasive method to obtain information about concrete without destroying or changing the physical state [6]. Hence, the purpose of this study is conducted in order to investigate the behavior of inhomogeneous medium such as concrete-steel medium by performing simulation using COMSOL Multiphysics finite element software. This study will demonstrate the behavior of concrete with embedded steel in it under several circumstances such as varies the dimension of steel, varies a number of steel phantom in concrete, and different location of steel in concrete.

II. ERT MODELLING

A forward model presenting the dependence of the electrode potentials at the boundary to the conductivity distribution inside the medium and the current excitation at the boundaries is necessary. Complete Electrode Model (CEM) is considered the most accurate forward problem of ERT that involved the contact impedance between the electrodes and the medium. The CEM comprises the partial differential equation as presented in Equation (1) and boundary conditions as presented in Equations (2)-(4). Equation (1) is derived from Maxwell equations for electromagnetism for a linear isotropic media under quasi-static assumption [7].

$$\nabla \cdot (\sigma \nabla u) = 0 \tag{1}$$

$$u + Z_l \sigma \frac{\partial u}{\partial n} = V_l \tag{2}$$

$$\sigma \frac{\partial u}{\partial n} = 0 \tag{3}$$

$$\int_{e_l} \sigma \frac{\partial u}{\partial n} dS = I_l \tag{4}$$

$$\sum_{l=1}^{L} I_l = 0 \tag{5}$$

$$\sum_{l=1}^{L} V_l = 0 \tag{6}$$

where:
$\sigma =$ Conductivity
$u =$ Electric potential
$Z_l =$ Contact impedance
$n =$ Outward unit normal
$V_l =$ Electrode potential
$I_l =$ Total current through the electrode
$e_l =$ lth electrode

$\sigma \frac{\partial u}{\partial n}$ = Current density through the boundary

A. Excitation Method

In this study, two current driven methods are considered such as adjacent and opposite current driven method. The adjacent method which is known as the neighboring method is used in the simulation. Current is applied through the adjacent electrodes and the potential difference is measured from all other adjacent electrodes pairs without including one or both the current electrodes as shown in Figure 1. As current is injected on electrode 1 (E1) and electrode 2 (E2) and potential differences V1, V2, V3 . . . V13 are measured. The potential difference is not measured between pairs E16 and E1, E1 and E2, and E2 and E3. Hence the current projection provides 13 potential differences.

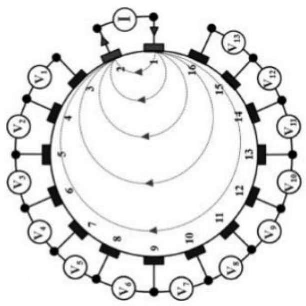


Figure 1: Adjacent current driven method [8]

On the other hand, opposite method as shown in Figure 2 which is also known as polar drive method is operated by applying current into the electrodes where the source electrode are face opposite each other while the remaining electrodes will be used for potential differences measurement. For the first projection, current is excited into electrode 1(E1) and electrode 9 (E9) and electrode 2 is set as voltage reference electrode while the potential difference is measured by pairing electrode 2 and 3 (E2-E3). The rest of potential differences are measured by pairing E2-E4, E2-E5 … E2-E16. Measurement will not be made on source electrodes such as E1 and E9. Therefore each projection, only 13 potential differences are recorded.

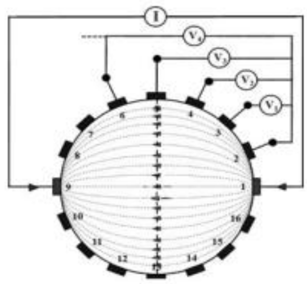


Figure 2: Opposite current driven method [8]

B. Simulation Procedure

In this study, COMSOL Multiphysics is used as finite element model software to simulate two-dimension inhomogeneous medium. The parameters are as listed in Table 1, and the modeling approach utilized in this study are as follow [9]:

1. Under AC/DC module, the Electric Current (EC) module is selected.
2. A geometry model of ERT system is drawn based on desired parameters.
3. Each geometry domain is assigned according to the particular material.
4. Next, the measuring electrodes and injection electrodes are set up at the electrical properties section. The injection electrodes are injected with 1mA at E1E2 while the rest are connected as measuring electrodes.
5. The extra fine mesh is produced.
6. The voltage and electric field are computed under post-processing stage.

Table 1
Simulation Modelling Parameters

No.	Parameter	Dimension
1	Electrode Thickness	1mm
2	Electrode Width	13mm
3	Concrete Diameter	50mm
4	Electrical Permittivity, ε_r	4.5 (Concrete) 1 (Copper) 1(Steel)
5	Electrical Conductivity, σ (S/m)	0.02 (Concrete) 5.998e7 (Copper) 4.032e6 (Steel)

III. Simulation Results and Discussion

When a constant current is injected into the medium, the current lines called current fluxes will be produced within the medium and the current is conducted through the medium. If the medium is homogeneous, the current flux lines will be symmetric for a circular medium as shown in Figure 3.

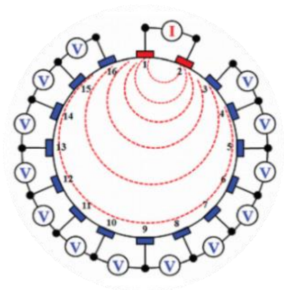


Figure 3: Homogenous medium current flux [10]

On the contrary, the inhomogeneous medium will interfere the current flux as shown in Figure 4.

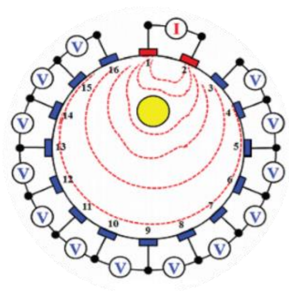


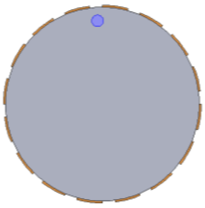
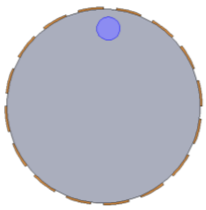
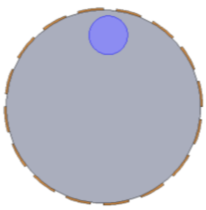
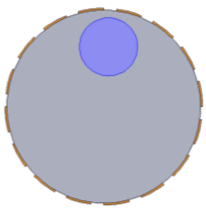
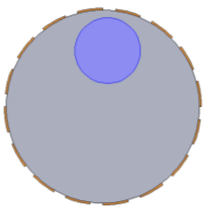
Figure 4: Inhomogeneous medium current flux [10]

The current flux will develop the voltages at each point of the medium, the data of the potential distribution within the medium depends on the current flux data. Likewise, the voltages developed at the medium periphery will also depend on the data of the current flux. Therefore, the voltage developed at the periphery for a homogeneous medium will be different from the periphery voltages for a medium with inhomogeneity. Assessment of varies dimension varies a number of steel and different location of steel in concrete are conducted and simulated result is demonstrated in the following section.

A. Single Steel Phantom with Varies Dimension in Concrete

In this section, the investigation on varies dimension of steel which is located next to the current injection source is performed and the simulation model is shown in Table 2. Obviously, the larger dimension in the steel could lead to good potential difference measurement deviation. A range of steel size diameter from 6mm up to 34mm is randomly picked for the simulation. It is clearly shown in the graphs at Figures 5 and 6 that the extension in the steel dimension affects the potential difference. Additionally, a small increment in the dimension of steel demonstrates relatively insignificant deviations for both adjacent and opposite method.

Table 2
Simulation Model with Varies of Steel Dimension

Steel Diameter (mm)	Simulation Model
6	
12	
20	
30	
34	

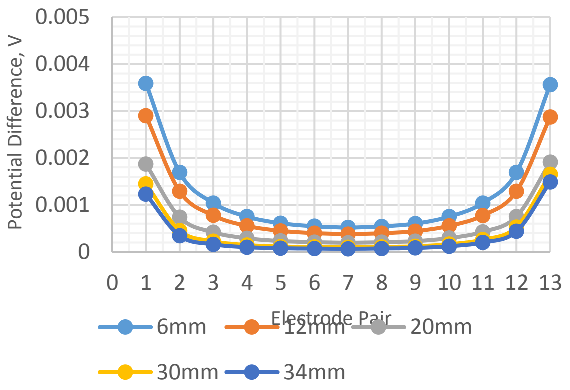


Figure 5: Potential difference distribution of varies steel dimension for an adjacent current driven method

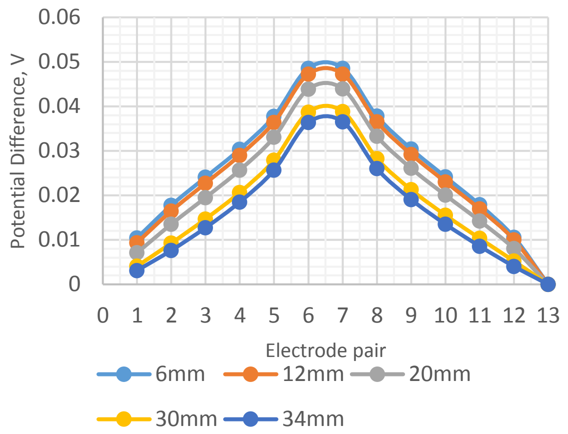


Figure 6: Potential difference distribution of varies steel dimension for opposite current driven method

B. Varies Number of Steel Phantom in Concrete

In this section, the investigation on the alterations surface electric potential and the electric field of the homogenous and inhomogeneous concrete medium are carried out on both adjacent and opposite method. The comparisons are made for a homogenous medium with the placement of two and four steel in the concrete in which all the steels are 20mm diameter. The simulation results are illustrated in Tables 3 and 4. As observed in the Tables 3 and 4, the changes in the surface electric potential and electric field are clearly demonstrated when the steels are located on the homogenous medium. Likewise, the potential differences are plunged as more steels located on the homogenous medium as shown in Figures 7 and 8.

Table 3
Surface Electric Potential and Electric Field from COMSOL for Adjacent Current Driven Method

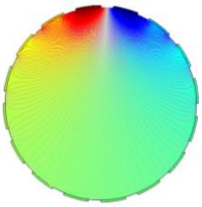
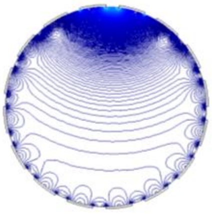
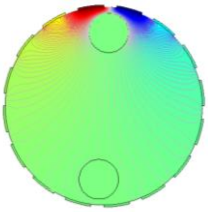
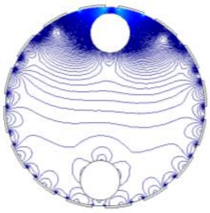
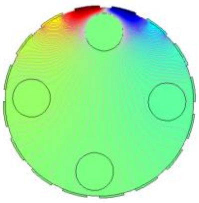
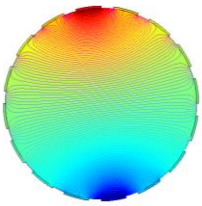
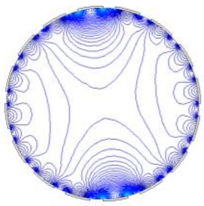
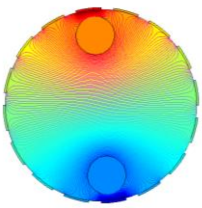
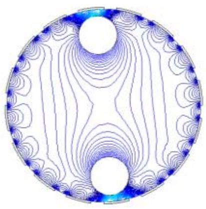
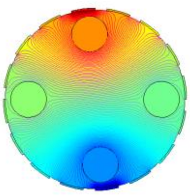
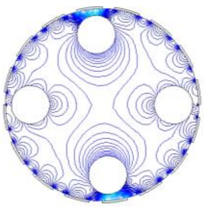
Number of Steel	Surface Electric Potential	Electric Field
Non		
2		
4		

Table 4
Surface Electric Potential and Electric Field from COMSOL for Opposite Current Driven Method

Number of Steel	Surface Electric Potential	Electric Field
Non		
2		
4		

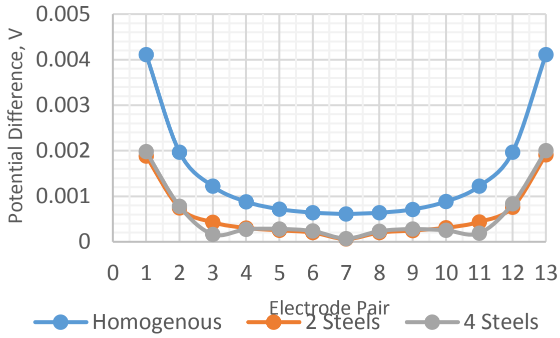


Figure 7: Potential difference distribution of steel number for adjacent method

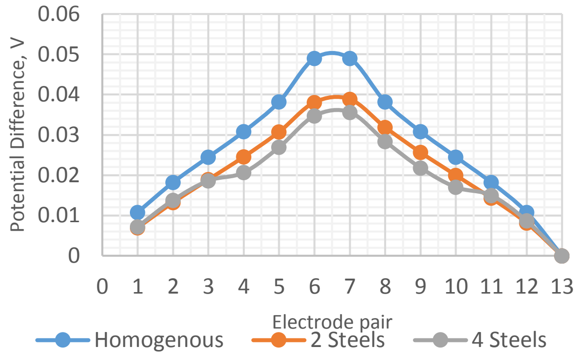
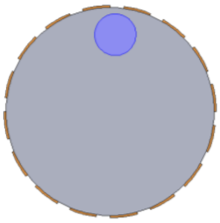
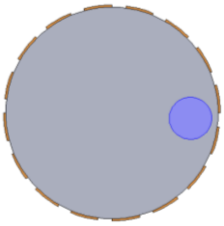
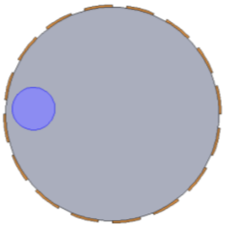
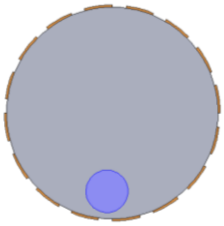


Figure 8: Potential difference distribution of steel number for opposite current driven method

C. Different Location of Steel in Concrete

Table 5 demonstrates four different location of 20mm diameter steel in the concrete medium. The potential difference for both adjacent and opposite method are recorded and plotted as illustrated in Figures 9 and 10. The potential difference reading of steel located close to the source is the lowest among others potential difference reading for other location. In the meanwhile, the potential difference measured from electrode pair 3 as steel placed on right and electrode pair 11 as steel placed on left are dropped. This phenomena occurs because the steel is located near to the measuring electrodes, the voltage will drop as well. In the nutshell, the electrode turn out to be sensitive at the area where the steel is placed close to the source electrode and measuring electrode due to large reflection of voltage signal before it could propagate and sensed by measuring electrodes.

Table 5
Simulation Model of Different Location of 10mm Diameter Steel Placement

Location	Simulation Model
Close to source	
Right	
Left	
Away from source	

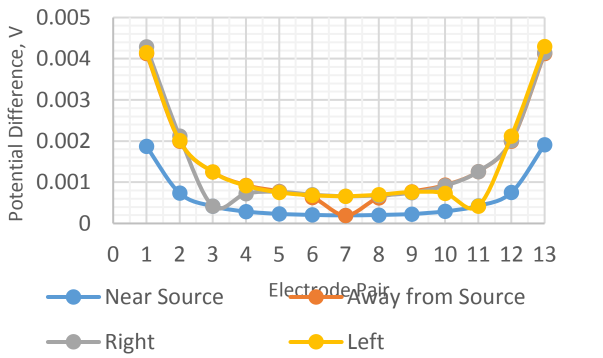


Figure 9: Potential difference distribution of the different location of steel for an adjacent method

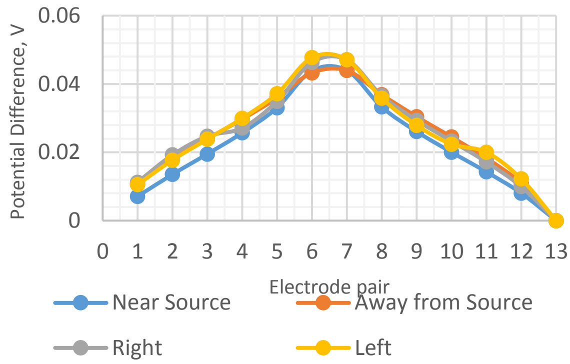


Figure 10: Potential difference distribution of the different location of steel for opposite method

IV. Conclusion

As a conclusion, a simulation study of non-homogenous ERT system within the concrete has been studied and examined. When the dimension of steel is amplified, ERT system could obtain good measurement because it enables the system to differentiate the steel with different sizes easily in the image reconstruction later due to the huge differences of the measurement value. Furthermore, as a number of steel placed in concrete medium increases, the potential difference will drop when compared with homogenous. From the thorough examination, it is demonstrated that as a phantom is placed close to the source or measuring electrode region, it could produce a deviation in potential difference reading. In conjunction with that, that region indirectly becomes more sensitive and better reaction. For varies, a number of steel phantom in the concrete study and different location of steel in the concrete study clearly prove that the placement of phantom near to the source or measuring electrode will lower the potential difference reading. This study can be utilized as a reference for future comparison with real data from ERT system.

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