Buried Man-made Structure Imaging using 2-D Resistivity Inversion

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Abstract. This study is carried out with the objective to determine the suitable resistivity inversion method for buried man-made structure (bunker). This study was carried out with two stages. The first stage is suitable array determination using 2-D computerized modeling method. One suitable array is used for the infield resistivity survey to determine the dimension and location of the target. The 2-D resistivity inversion results showed that robust inversion method is suitable to resolve the top and bottom part of the buried bunker as target. In addition, the dimension of the buried bunker is successfully determined with height of 7 m and length of 20 m. The location of this target is located at -10 m until 10 m of the infield resistivity survey line. The 2-D resistivity inversion results obtained in this study showed that the parameters selection is important in order to give the optimum results. These parameters are array type, survey geometry and inversion method used in data processing.

1. Introduction
The Earth’s subsurface imaging especially related to environmental and engineering works is a challenging work. This is because researcher need to image the Earth’s subsurface with some noises which capable to affect the data acquisition. These noises can be came from internal (equipment’s sensitivity) and external (surrounding such as electric cable, etc.). Many researchers have used many kind of technical approaches to study the Earth’s subsurface directly and indirectly. Many effort have been put in to study the Earth’s subsurface because the Earth’s subsurface can be change due to their physical characteristics [1]. These physical characteristics can be related to water content, void, saturation degree, etc. In addition, these physical characteristics will affect the Earth’s subsurface condition and deformation. Landslide as an example occurred when there is overload of water content in soils at the slopy area. The water content as external caused the structure of soils to lose their strength and moved downward due to gravitational force. Therefore the slope condition (soil) is become more unstable especially during heavy rain as a physical factor [2]. Soil properties is one of concern matter related to Earth’s subsurface imaging. Researchers have been used many type of methods to study the soil properties. These include fiber materials [3], analytical models [4] and resonance methods [5]. The information about the soil properties is important because it is related to economic and construction purposes. The Earth’s subsurface imaging have been carried out by many...
researchers. The information and parameters related to the subsurface condition can be determined using various technical methods. The subsurface imaging algorithm is developed and tested using electromagnetic induction of broadband by [6] and the subsurface imaging of geophysical have been used for ecological purpose [7]. In addition, many researchers have used single and multiplication of geophysical methods for high resolution subsurface imaging. Integrating seismic reflection (SRfl) and ground penetrating radar (GPR) is successfully imaged the saturated zone with high resolution [8]. Combination of SRfl and GPR were capable to image the water table [9]. Electrical resistivity tomography (ERT) is successfully image the suspected interest for environmental and engineering studies [10]. This study was carried out with main objective to determine the suitable resistivity inversion method for buried bunker determination.

2. Study area
The study site is located in Penang Island, Malaysia. Penang Island is one of the historical area located at the northern part of Malaysia. The geology of Penang Island is granitic rock which can be divided into two types, namely Bukit Bendera type and Sungai Ara type. These two types were grouped based on mineralogy, age differences and lastly rocks texture [11].

![Geological map of Penang Island](image.png)

**Figure 1.** Geological map of Penang Island with study area is marked with red triangle.
3. Methodology

The first stage of this study is 2-D computerized modeling method. This approach has been carried out using RES2DMOD software to image a target with specific resistivity values. The target is rectangular in shape with dimension of 1.95 m in height and 8 m in length. The target is set with resistivity value of 100 ohm.m and the surrounding with resistivity value of 1000 ohm.m respectively (Figure 2). The reason the model is designed with target resistivity value of 100 ohm.m is that the target will give low resistivity value compared to surrounding due to corrosion process on its structure [12].

![Figure 2. 2-D computerized model with a rectangular shape as the target.](image)

The second stage in this study is infield study which is based on the 2-D computerized model results using four different type of arrays namely Dipole-Dipole (D-D), Pole-Dipole (P-D), Wenner-Alpha (W-A) and lastly Wenner-Schlumberger (W-S). The suitable array is selected for this infield electrical resistivity survey.

The electrical resistivity survey was carried out at the study area with minimum electrode spacing of 1.5 m. The equipment used were a unit of SAS4000 with a unit of Electrode-Selector 10-64, two resistivity cables, 41 number of stainless-steel electrodes, 42 set of jumpers and a battery pack (12 Volt) as electrical source to the resistivity equipment. In this study, the apparent resistivity data is collected from the infield survey and the conversion of the data was carried out using SAS4000 utilities program after the survey is completed. Then, the data set is filtered and processed using the RES2DINV program. The data filtering process was carried in order to exterminate bad datum points. In data processing, two types of inversion methods were used to get the optimum resistivity model. The motivation for this was, there is wide model range that might rise to the same calculated value of apparent resistivity. To slim down the range of possible models, several assumptions are made which concerning to the actual Earth’s subsurface nature that can be assimilated into subroutine of inversion. Two inversion methods used in this study namely smoothness-constrained inversion and robust inversion (also known as blocky inversion). The smoothness-constrained inversion is a conventional method and it normally gives resistivity model results where the Earth’s subsurface is exhibited as a smooth manner of variation. These two inversion methods were used and comparison was made for their suitability in providing reliable inversion of resistivity model results.
4. Results and Discussions
The 2-D computerized model results were divided into two parts. The first part is based on smoothness-constraint inversion method and the second part is based on robust inversion method. The electrical resistivity from 2-D computerized modeling results showed that only three arrays (D-D, P-D and W-S) capable to image the location of target (rectangular) using smoothness-constrained inversion method. Only W-A array unsuccessful to image the target with right resistivity value and the shape of target unresolved with good compared to others arrays (Figure 3). The electrical resistivity from 2-D computerized model shows that all four arrays (D-D, P-D, W-A and W-S) capable to image the location of target (rectangular) using robust inversion method (Figure 4).

Based on the 2-D computerized modeling approach, P-D array is chosen due to the depth of penetration and data coverage. In addition, this array provide sufficient total number of data points to provide better information about the subsurface structure. Only one array is chosen for the infield resistivity survey due to time and cost constraint. In the infield resistivity survey, the buried bunker is chosen as the target. The study area is located in USM main campus, Penang Malaysia. In order to get at reliable inversion results of the target, model refine method is used in 2-D resistivity inversion method. This approach will set the width of model cells to become as the same as the electrode spacing. This approach is suitable and important for P-D array which have high sensitivity near to the surface variations. In general, using a refinement model where the width of cells is half the unit electrode spacing will gives the optimum inversion results. Figure 5a shows the 2-D resistivity inversion model of P-D array using smoothness-constrained inversion method. Meanwhile Figure 4b shows the 2-D resistivity inversion model of P-D array using robust inversion method. The results showed that both smoothness-constrained inversion and robust inversion methods are capable to resolve the top part of the buried bunker with good at depth of -2 m. However, only robust inversion method is capable to resolve the bottom part of the bunker with good at depth of -9 m. The result provided by smoothness-constrained inversion method showed the bottom of buried bunker in curvy pattern and it gives indication that smoothness-constrained inversion method is not suitable to image drastic change in electrical resistivity properties. In general, the dimension of the buried bunker can be determined from resistivity inversion models. The dimension of the target is height of 7 m and length of 20 m. The location of the buried bunker is at distance -10 m until 10 m of the infield resistivity survey line. The location and dimension of the buried man-made structure is indicated with a rectangular shape as shown in Figure 5. The buried bunker gives low resistivity with value of less than 70 ohm.m compared to surrounding. The buried bunker is made of concrete and the corrosion process on its structure have occurred. Therefore, it will give low resistivity value in the inversion modeling results [12]. The low resistivity value on the target is due to increase in both water content and porosity [12,13]. Therefore, the rate of corrosion increase [14].
Figure 3. 2-D computerized model using smoothness-constrained inversion method.
Figure 4. 2-D computerized model using robust inversion method.
Figure 5. The infield resistivity survey results using model refinement method (unit electrode spacing of 0.75 m). (a) Smoothness-constrained inversion method. (b) Robust inversion method.

5. Conclusion
Based on the results in this study, the conclusion can be made that the study objective is successfully achieved. The 2-D resistivity inversion results showed that robust inversion method is suitable to resolve the top and bottom part of the buried bunker as target. In addition, the dimension of the buried bunker is successfully determined with height of 7 m and length of 20 m. The location of this target is located at -10 m until 10 m of the infield resistivity survey line. In general, this geophysical method is a suitable method to image the Earth’s subsurface. The results in this study showed that the parameters selection is important in order to give the optimum resistivity results. These parameters are array type, survey geometry and inversion method used in data processing.

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