Physical Modelling on Detecting Buried Object Using Electrical Resistivity Imaging (ERI)

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Abstract. This study focused on the evaluation of electrical resistivity method (ERM) for buried object detection and its relationship due to the different stiffness of material. In the past, the conventional method to detect the buried structure was face some limitation due to the time and cost. For example, previous approach related to the trial and error excavation has always expose to some risky outcome due to the uncertainties of the buried object location. Hence, this study introduced an alternative technique with particular reference to resistivity method to detect and evaluate the buried object with different strength of stiffness. The experiment was performed based on field miniature model (small scale study) using soil trial embankment made by lateritic soil and various concrete cube strengths (grade 20, 25 and 30) representing buried object with different conditions. 2D electrical resistivity test (electrical resistivity imaging) was perform using ABEM Terrameter SAS4000 during the data acquisition while the raw data was process using RES2DINV software. It was found that the electrical resistivity method was able to detect the buried concrete structures targeted based on the contrast of the electrical resistivity image produced. Moreover, three different strength of concrete cube were able to be differentiated based on the electrical resistivity values (ERV) obtained. This study found that the ERV of concrete cube for grade 20, 25 and 30 were 170 Ωm, 227 Ωm and 503 Ωm, respectively. Hence, this study shows that the ERV has a strong relationship with different stiffness of material thus applicable to be a useful alternative tool in underground structure detection.

Keywords: Geophysics, electrical resistivity, buried object detection.

1. Introduction

In the past, previous technique of bury object detection related to drilling and excavation suffer from several limitation due to the time and cost efficiency. Excavation machine which commonly heavy and bulky may not able to be operated in all site condition. For example, conventional method may suffer from difficulty relative to site workability especially when working at challenging and problematic site such as soft ground, swampy area, hilly terrain, limited working space, etc. Moreover, target location of the buried object was hard to be predicted due to the large unknown target area. Furthermore, unsuccessful excavation work based on trial and error may highly risk due to the unnecessary ground destruction thus give a bad impact to our environment. Hence, the alternative method needs to be discovered in order to minimize those previous limitations.

In multidisciplinary era, most researchers diversify their research area with an alternative method to improve the existing conventional method [1]. Nowadays, geophysical method has been increasingly used as an alternative technique in buried object detection. Geophysical method related to the electrical resistivity, seismic, ground penetration radar, gravity, magnetic etc. was highly adopted in engineering, environment, mining and archeological studies. Basically, geophysical method used to study an earth using physical properties such as electrical resistance, velocity, density, magnetic susceptibility, etc. Previously, geophysical method was commonly used to detect leachate migration [2,3,4], bedrock and overburden materials [5], boulder and cavity [6], groundwater [7,8,9], utilities, piling, archeology [10,11,12] etc. Generally, geophysical techniques contributes several advantages for example, it can be implemented more quickly and less expensively and has the ability to cover greater areas more thoroughly [13,14,15,16]. Moreover, the applications of geophysical method will applicable to minimize environmental destruction due to its non-destructive measurement thus preventing unnecessarily excavation. Furthermore as reported by [15], it provides a large-scale characterization of the physical properties under undisturbed conditions. As a result, site damageability was able to be minimized thus creating sustainable environment in buried object detection project. According to [17], geophysical method offers the chance to overcome some of the problems inherent in more conventional ground investigation techniques. However, the standard performance of individual geophysical method were still depends on fundamental physical constraints, e.g. penetration, resolution, and signal to-noise ratio [18].

This study used electrical resistivity method which one of the geophysical tool that heavily adopted in underground mapping. Electrical resistivity property was determined by measuring the potential difference at points on the ground surface which caused the propagation of direct current through the subsurface [19]. Good variation of the electrical resistivity contrast between the buried object and surrounding material need to be obtained for successful results. By determine the subsurface resistivity distribution, the purpose of electrical resistivity surveys can be determined by making measurements on the ground surface in order to estimate the actual resistivity of the subsurface [20]. Hence, this study performed a small scale study related to the buried object detection using electrical resistivity method with its relationship due to the different condition of the buried object strength. Finally, this study was able to prove and convince those related parties regarding the applicable of electrical resistivity method in underground structure mapping.

2. Materials and Methods

This study was divided into three phases; via laboratory, fieldwork and data processing. Laboratory works involve the preparation of concrete cube with different strength (grade 20, 25 and 30 MPa). Concrete cube with different strength was used as buried object due to this small scale study (field miniature model). Concrete strength of 20, 25 and 30 MPa was choose since it has been widely used in a construction industry. Hence, those stated assumption was used to simulate the underground buried structure with different strength/stiffness of material based on small scale study. A total of five concrete cube for each grade was designed in the laboratory. Three of five concrete cube was used to measure the compressive strength machine due to the strength verification purposes. In order to obtain good buried object prototype, the compressive strength of concrete need to achieve its matured strength before it was used as a buried object. Difference age of concrete strength contains difference strength of cement bond [21]. Then, the remaining two concrete cube for each grade was used as a buried object in the soil trial embankment model.

Fieldwork of this study has been divided into two phases via construction of soil trial embankment in miniature scale and electrical resistivity data acquisition (field measurement). A miniature model of soil trial embankments as shown in Figure 1, were built using lateritic soil. Dimensions of the model was 3.5 (length, m) x 1.0 (wide, m) x 0.5 (height, m) with all sides of the model edge shaped into a

gentle slope < 45°. During the construction of soil trial embankment miniature model, three different locations of concrete cubes were buried at center of the soil model as shown in Figure 1. After the completion of soil model construction, electrical resistivity test was performed using a single leveled line of 2D electrical resistivity survey (electrical resistivity imaging, ERI) on the top and center of the soil model. The ERI was performed twice since the first measurement was performed on soil model without buried object (control purpose) while the second measurement was performed under soil model with buried concrete cube. The data acquisition of ERI test was performed using ABEM SAS 4000 set of equipment. During the data acquisition (ERI measurement), two land resistivity cables were connected to 41 steel electrodes via jumper cables. Then, both resistivity land cables were connected to the electrode selector and Terramater SAS 4000 data logger for field setup. Finally, 12 volt battery was connected to the data logger to supply direct current (DC) for field measurement. This study used Schlumberger array due to its ability to produce dense surface data and deeper image penetration. Several considerations involving device and equipment setting, position of electrical resistivity line, ground condition, raw data processing etc. needed to be carefully considered and performed in order to determine the best electrical resistivity outcome. For example in order to reduce boundary effect that may reduce the electrical resistivity result accuracy caused by refracted and reflected current, the electrical resistivity line was placed at the center of the soil model.
Finally, raw data from field measurement (Terrameter SAS 4000 data logger) was transferred to the computer for processing. During the processing stage, smooth constraint least square method was used in order to produce a smooth boundary representing soil and concrete cube underneath. According to [22], smooth constraint least square method will produce a smooth boundary change which was considered more suitable for representing the soil material in contrast with rock and fractured material which preferred to analyzed using a robust method due to its sharp geomaterial boundary. RES2DINV commercialize software [23] was used to process and analyze the raw data thus producing an inverse model that estimate the actual subsurface structure. The inversion algorithm of RES2DINV was used to process the data, as proposed by [24] in order to obtain the 2-D resistivity section which replicate the subsurface profile of the soil model.

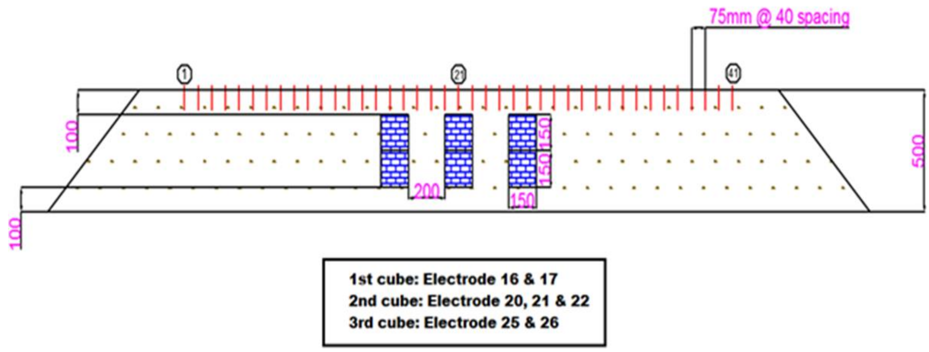

Figure 1. Arrangement of soil trial embankment with ERI (elevation view).

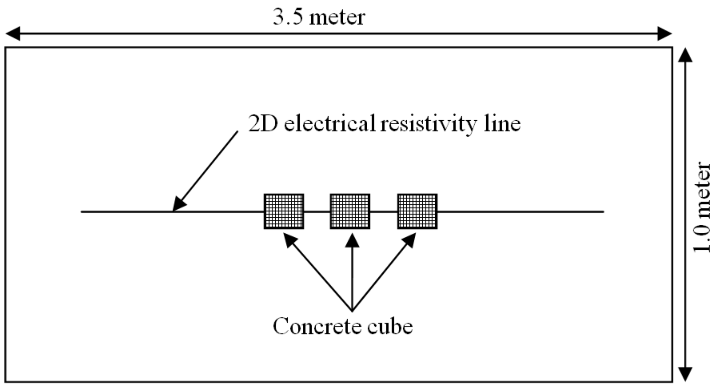

Figure 2. Position of the ERI and buried object (plan view).

3. Results and Discussions

All results presented and discussed are based on electrical resistivity value (ERV) and its relationship due to the existing of the concrete cube with different strengths. All results are presented in Figure 3, 4 and 10 representing electrical resistivity tomography section and its relationship due to the existing of the different strength of concrete cube.

According to Figure 3 and 4, it was found that the schlumberger array with 75 mm of electrode spacing was able to determine the resistivity section of the soil model with up to 0.6 m depth. Hence, the location of the targeted buried concrete cube was able to obtain as shown in Figure 4. According to Figure 3, it was found that the resistivity section has been dominated by low to moderate resistivity value (< 200 Ωm) representing soil model without buried object. As reported by [25] and [26], lateritic soil consist of silty and sandy soil has an electrical resistivity value from 15 – 152 Ωm and 100 – 250 Ωm respectively. Hence, it was prove that the resistivity section (electrical resistivity result or ERI result) of the soil model without buried concrete cube consist of homogeneous lateritic soil based on low to moderate of the electrical resistivity value (ERV) as shown in Figure 3. Furthermore, it was found that the homogeneous lateritic soil has produce some variation in term of ERV. This variation may due to the influence of soil gain and moisture content within the soil model. According to [27], the soil electrical resistivity data was observed to be very sensitive to the quantitative proportion of water and geomaterial particle fractions. As reported by [6], air filled void may influence the electrical resistivity variations since which commonly increased the electrical resistivity value compared with the water filled void. Furthermore, condition such as porosity, degree of saturation, salt concentration in pore fluid, grain size, size gradation, temperature and activity may influence to the electrical resistivity value variations [28].

Electrical resistivity section for soil model with buried object (concrete cube with different strength) was presented in Figure 4. It was found that the center of the resistivity section consist of high value of the ERV (1000 – 2000 Ωm). This anomaly has demonstrated that the existing of buried object with particular reference to concrete cube was able to influence the increment of the ERV. It was clearly observed that the surrounding buried concrete cube possess low to moderate ERV (50 – 200 Ωm) representing lateritic soil. Hence, this finding has proved that the electrical resistivity method was able to detect the buried object based on the variation of the ERV. However, it was found that the resistivity section was unable to produced real shape of the buried concrete cube due to several reasons. For example, the size (150 mm3) and spacing (200 mm) of the buried concrete cubes was too small thus unable to produce much resistivity plot based on the 75 mm of electrode spacing configuration. Hence, the contouring process in data processing may involve certain degree of interpolation thus producing rounded shape of the buried concrete cube. Furthermore, influence of resistivity array such as Wenner, Schlumberger, Wenner-schlumberger, Dipole-dipole, Pole-pole, Pole-dipole, Gradient, etc. may produce different outcome. Each array have their own strength and weakness relative to the several reasons. The consideration related to the targeted object, depth of interest, surrounding working area, etc. was crucial since it able to influence the array selection in order to produce the best subsurface profile result. According to [2,30], the ERV was largely influenced by types of array used due to the different geometry factor (K) derived from each different types of array used. Geometry factor, K describes the geometry of the electrode configuration used in data acquisition. As reported by [6], the best selection of array was based on signal strength, sensitivity of resistivity value due to the changing of vertical and horizontal structure, depth of investigation, type of structure which needs to be mapped and noise level. Apparent resistivity (ρa) is ERV estimated based on half-pace geometry assumption which refers to the field ERV. Apparent resistivity will be equal to the true resistivity provided the current and configuration was applied over the homogeneous isotropic ground [31]. However, the anomaly trend (electrical resistivity image) at certain same depth of the tomography may produce some similarity for most of the array used. This trend has proved that ERV was always subjective to some ranges of properties as given in the past reference charts and tables of ERV properties interpretation. The fundamental of the ERV based on Wenner, Schlumberger, Dipole-dipole and Pole-dipole array were presented with a geometry factor, K as given in Equations 1 – 4 which are derived from basic Equations 5 and 6. All the geometry factors, K was derived from Equation 6 based on basic four electrode system of measurement. The schematic diagram of field electrical resistivity configuration was given in Figure 5 – 8 while the schematic diagram for the basic four electrode system is given in Figure 9.

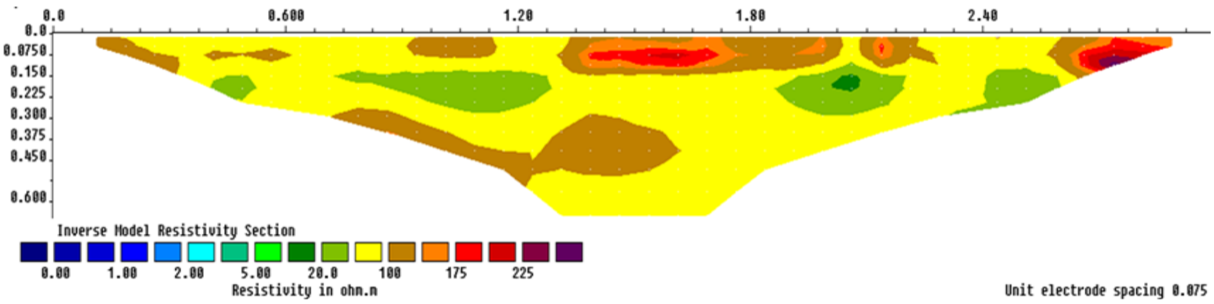

Figure 3. 2D electrical resistivity section of homogeneous lateritic soil.

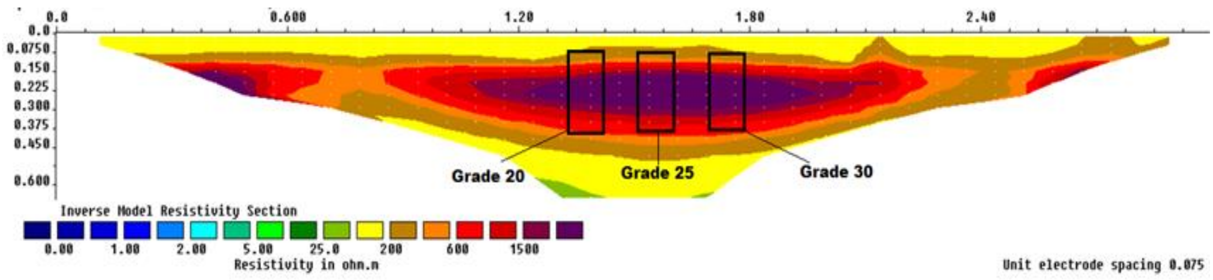

Figure 4. 2D electrical resistivity section with buried concrete cube.

$$\rho_a = 2\pi a * R \quad (1)$$

where R is a resistance term given by R=ΔV/I

$$\rho_a = ((2\pi\Delta V)/I)) * ((1/(1/r1 - 1/r2) - (1/r3 - 1/r4)) \quad (2)$$

where r1 = (L – x), r2 = (L + x), r3 = (L – x) and r4 = (L + x) - l

$$\rho_a = (\pi a n(n+1)(n+2)) * R \quad (3)$$

where R is a resistance term given by R=ΔV/I

$$\rho_a = ((2\pi ab)/(b-a))*R \tag{4}$$

where R is a resistance term given by R=ΔV/I

$$\rho_a = K*(R) \tag{5}$$

where R is a resistance term given by R=ΔV/I, K is geometry factor based on pole-dipole electrode configuration

$$\rho_a = ((2\pi\Delta V)/I))*((1/(1/r1-1/r2)-(1/r3-1/r4)) \tag{6}$$

where
$K = ((1/(1/r1-1/r2)-(1/r3-1/r4))$

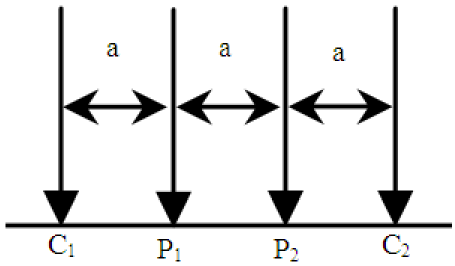

Figure 5. Wenner electrode array arrangement.

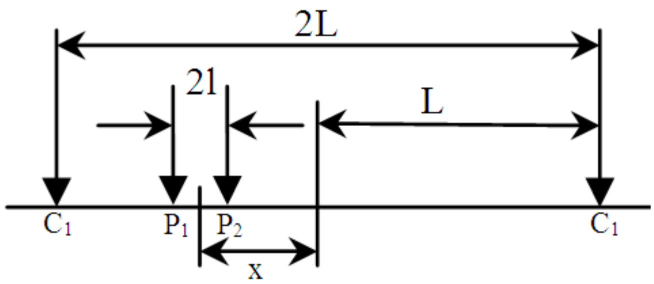

Figure 6. Schlumberger electrode array arrangement.

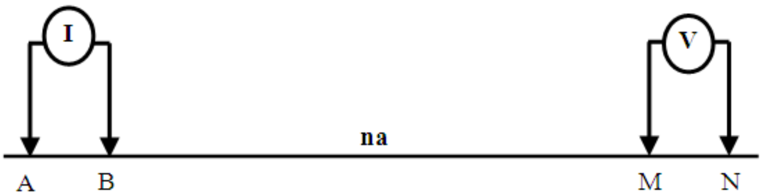

Figure 7. Dipole-dipole electrode array arrangement.

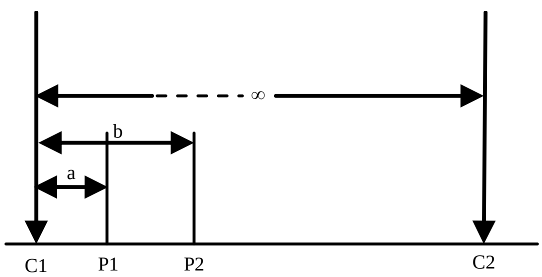

Figure 8. Pole-dipole electrode array arrangement.

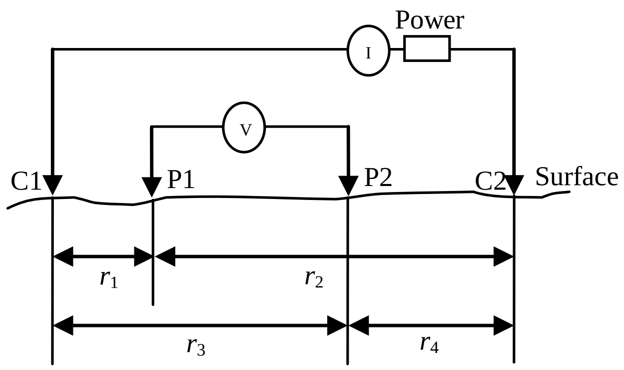

Figure 9. Four electrodes arrangement on the surface of homogeneous isotropic ground of resistivity.

Finally, this study has demonstrated the relationship of ERV due to the different strength of the concrete cube (grade 20, 30 and 35). The behavior of the ERV due to the different concrete cube strength were analyzed and presented using statistical bar chart as shown in Figure 10. This study found that the strength maturity of the concrete cube for grade 20, 25 and 30 were 22.3 MPa, 27.5 MPa and 32.5 MPa respectively. The localize ERV at the exact location of the buried concrete cube were extracted from the Figure 3 as 170.33 Ωm (grade 20), 226.82 Ωm (grade 25) and 502.88 Ωm (grade 30). Based on Figure 10, it was found that the concrete cube from grade 30 (32.5 MPa) has produce the highest of the ERV (502.88 Ωm) followed by the grade 25 (ERV = 226.82 Ωm) and grade 20 (ERV = 170.33 Ωm). Highest concrete cube strength (32.5 MPa) has rapid hydration process due to the sulphate reaction between the cement content and water [32] thus producing strong bond properties. Hence, those chemical reactions has produce low permeability of the highest concrete strength which promoting to the highest value of ERV. In other words, higher concrete strength produced a low conductivity which causes an increasing of the ERV. This phenomenon may due to the different composition of the concrete strength which relative to the concentration of cement, aggregate and sand. For example, concrete strength of 30 MPa was designed based on low coarse material compared to the others. This condition may cause the concrete to have lowest void thus decreasing its ability of conductivity. According to [31] electrical resistivity value was influenced by several factors such as the concentration and type of ions in pore fluid and grain matrix of geomaterials through electrolysis process where the current was carried by ions at a relatively slow rate. It was clearly observed that the ERV was greatly influenced by the stiffness variations of the material (S) which can be represented using general relationship of ERV ∞ S.

This study has successfully demonstrated that the different concrete strength will able to influence the electrical resistivity value as shown in Figure 10. Finally, the confidence level regarding the application of the electrical resistivity method in buried object detection can be enhanced due to the better understanding of electrical resistivity basic fundamental mapping performed in this study.

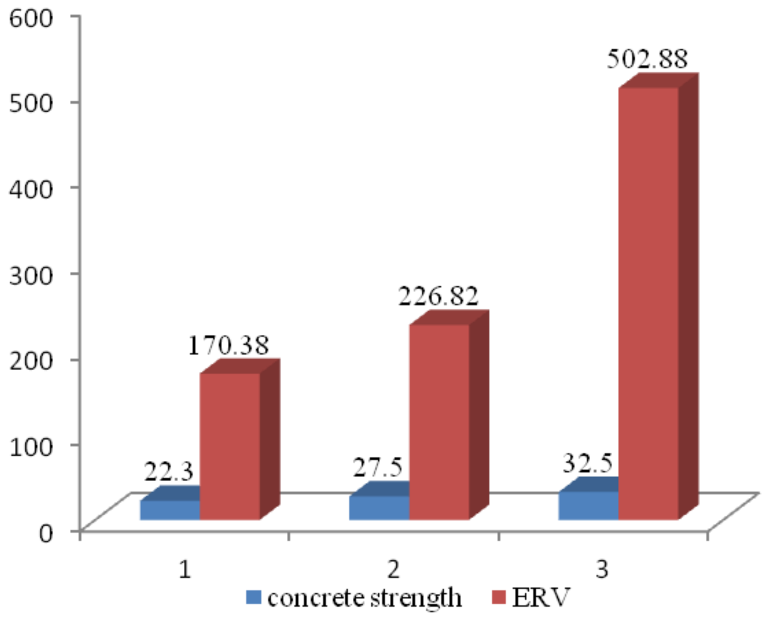

Figure 10. Relationship between ERV and concrete strength.

Conclusion
The electrical resistivity value from resistivity image was successfully performed on different strength of buried object. The influence on buried object detection using electrical resistivity method was successfully and methodically studied and presented. The electrical resistivity value was largely influenced by the variations strength of buried object under soil sample. The concrete cube was detected through the different value of electrical resistivity between surrounding material (soil model) and the buried object. The soil sample showed the resistivity value ranges from 50-200 Ωm while, location of concrete cube with different strength was presence by the resistivity value of 170-500 Ωm. The resistivity value ranges from 170-500 Ωm was found to be hard materials represented by concrete cube. Hence, this study shows that the ERV has a strong relationship with different stiffness of material thus applicable to be a useful alternative tool in underground structure detection. However due to the electrical resistivity configuration constraint, interpretation of the underground buried structure need to be supported by other comprehensive data in order to produce high accuracy and reliability of the result interpreted.

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