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The Influence of Electrical Resistivity Array on its Soil Electrical Resistivity Value

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Abstract. Electrical resistivity technique has become a popular alternative tool by the geotechnical engineers in subsurface investigation. This study presents the influence of soil electrical resistivity value (ERV) due to the different types of electrical resistivity array used in practice. The dissimilarity of ERV was become a popular debate by the engineers which posses less fundamental knowledge in this area. In the past, the theory of electrical resistivity technique was less being discovered by the engineer which creates lots of black boxes during the utilization of electrical resistivity method (ERM) in engineering purposes. Hence, the result which produced from the ERM was difficult to deliver in a sound of definitive ways due to lack of knowledge and experienced of most engineers. Hence, this study presents the influence of soil ERV due to the different types of array used with particular reference to as Dipole-dipole and Pole-dipole. A line of electrical resistivity imaging was performed on small embankment of sandy and lateritic soil with different types of array using ABEM SAS (4000) equipment. Three in line of soil samples were tested for moisture content (w) test immediately after the electrical resistivity data acquisition was completely measured. Moreover, particle size distribution test also was performed for all soil samples in order to support the findings. It was found that the ERV was never be the same for each types of array used even on the same particular location of the survey line. However, it was found that there was a consistent relationship between ERV and moisture content for both types of soil tested which can be represent by ERV ∞ $1/w$. Hence, it was found that ERV produced was relative to the types of array used during the field measurement. Each types of array were applicable to be used in subsurface profiling and its selection was subjected to the target of interest.

Introduction

Site investigation (SI) is a preliminary stage to the design and construction of any of civil engineering structure. According to [1], site investigation is the process in which geological, geotechnical and other relevant information which might affect the construction or performance of a civil engineering or building project are acquired. Commonly, SI works was performed using conventional drilling technique or other alternative technique such as geophysical method. Based on [1], the foremost classical geotechnical site investigation method for subsurface profile exploration is the application of boring (light percussion drilling, power augering and washboring), drilling (rotary drilling and coring), probing (Mackintosh probe, dynamic probing) and examination in-situ (trial pitting, large bored shafts, tunnel and drifts). The results from the conventional methods were produced exactly in a direct output due to its destructive method (drilling) thus producing a good parameter for design and

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construction purposes. However, the problems in most traditional boring and drilling method encounter when the area of the investigation was large which will increase the number of borehole thus increasing money and time of the project. Furthermore, the information obtained was a single point data and the interpolation between a large boreholes spacing can lead to increase the degree of uncertainties of the subsurface profile investigated [2,3,4].

Hence, alternative technique such as geophysical method was required in order to compliment the conventional method which may reduce cost and time of SI works. Geophysical method consists of several techniques such as resistivity, seismic, magnetic, gravity, ground penetration radar, etc. The basis of the geophysical method is qualitative studying of earth using physical properties such as electrical resistance, velocity, magnetic susceptibility, density, 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 [5,6,3,7]. Furthermore, it provides a large-scale characterization of the physical properties under undisturbed conditions [3]. According to [1], site damageability remains minimal and can be negligible although the resistivity method requires ground contact during the data acquisition. The process of geophysical technique starts from data acquisition (field measurement for raw data collection), data processing (raw data analysis using utility software), and finally, result interpretation (anomaly outcome). In the past, the resistivity method was recognized as a popular technique applied in engineering, environmental and archaeology such as subsurface profile mapping in order to locate bedrock [8], boulder and cavity [9], groundwater resources [10,11, 12,13] and contamination [14], [15], leachate migration [16], mining [17] and ancient crater [18]. Generally, the majority of those studies were solely focused on the basis of mapping perspective (such as for detection purposes) in order to assist the conventional method. Most techniques are applied in engineering, environmental and archaeological purposes.

Geophysical method was truly championed by people from physical sciences (geophysicist) and is now gaining increased popularity with geotechnical and structural engineers. In the past, the application of geophysical techniques such as resistivity method was increasingly used by engineers in SI works especially when dealing in a difficult site and due to its high efficiency of cost and time of its operational. However, the results produced were always unconvinced due to several reasons such as reported by [19] that GM is not being fully explored by the civil engineers due to their lack of exposure and expertise in this area. As reported by [1], some of the reasons are due to poor planning of geophysical survey by engineers who lack experience in the techniques, and over optimistic geophysicists leading to inappropriate application of the available techniques. Furthermore, several geophysicists always try to hide their expertise for business reasons [19]. Several black boxes were raised during the stage of data acquisition, processing and interpretation. Those problems create most of the geophysical results to be very difficult due to its weak and ambiguity justification.

Hence, this study presents a field electrical resistivity and laboratory moisture content data with different array setting in order to discover the influenced of electrical resistivity array to the soil resistivity electrical value. This study aims to reduce some black box and ambiguities via relationship of different array of ERV and basic geotechnical properties with particular reference to moisture content and supported with soil grain size characteristics. Furthermore, this fundamental study can possibly increased the confidence level of engineers when dealing with resistivity method in SI works.

Material and Methods

This study consists of three stages: viz fieldwork, data processing using utility software and laboratory experimental. Fieldwork was begin with the construction of small soil embankment with size of 3.0 (length, m) x 1.0 (wide, m) x 0.3048 (height, m) with all sides of the model edge shaped into a gentle slope < 45°. The embankment was constructed without any compaction effort due to the loose condition of lateritic soil study purposes. Then, a line of 2D resistivity imaging was performed using ABEM SAS 4000 equipment. Two land resistivity cables were connected to 41 small steel electrodes (6 inch of length with 2 mm of diameter) with 50 mm equal spacing via 42 jumper cables for total spread line of 2 m length. 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) during the data acquisition. This study used dipole dipole and pole dipole array due to its dense data with deeper penetration. In order to reduce boundary effect that may reduce the ERV accuracy caused by refracted and reflected current, the electrical resistivity line was placed at the center of the soil model with additional offset (0.5m) from each end of its length. Based on [20], electrical current may propagate in geomaterials via the process of electrolysis where the current is carried by ions at a comparatively slow rate. Hence, soil models were poured with water before the electrical resistivity test was conducted. Otherwise, current will be loathed to propagate through the model due to the dry soil condition which will cause some error in the electrical resistivity readings. The model under 2D Electrical resistivity data acquisition was shown in Fig. 1. All raw data obtained from field measurement was transferred to the computer using SAS4000 utilities software. Then, those data was processed and analyzed using RES2DINV software of [21] to provide an inverse model that approximate the actual subsurface structure. Finally after the resistivity test finished, three soil samples were taken at different point of location in line of the resistivity test immediately and tested for soil moisture content using oven drying method and particle size distribution test using dry and wet sieve based on [22]. Total depth of soil samples taken was 0.1778 m from 1 inch of the ground surface. Schematic diagram representing soil sampling and electrical resistivity line alignment was given in Fig. 1.

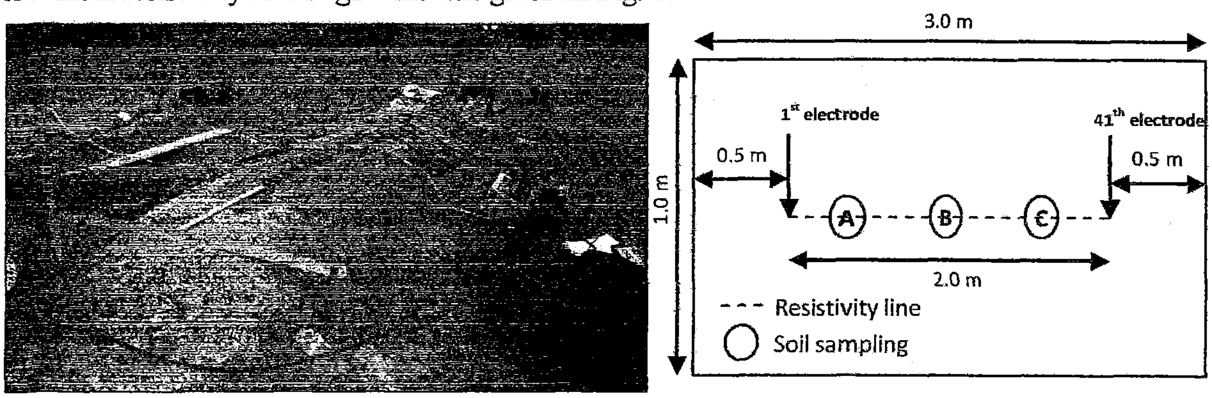

Fig.1 Soil embankment model (lateritic soil) tested by 2D electrical resistivity imaging (Left) and Schematic diagram of the soil sampling position and resistivity line alignment (Right)

Results and Discussions

Electrical resistivity results at point A, B and C was extracted from 2D resistivity section produced from the processing stage. It was wound that the electrical resistivity value (ERV) at point C has the lowest ERV followed by ERV at point A and C respectively. The result for 2D resistivity section and localized ERV at point A, B and C was given in Fig. 2 – 3 and Table 1.

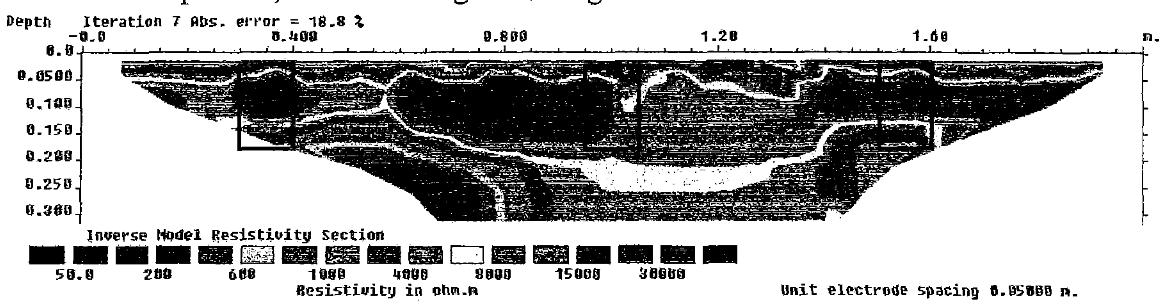

Fig.2 Global 2D electrical resistivity tomography section and localize selected point (A, B and C) of ERV used for further detail study at soil model using Dipole-dipole array

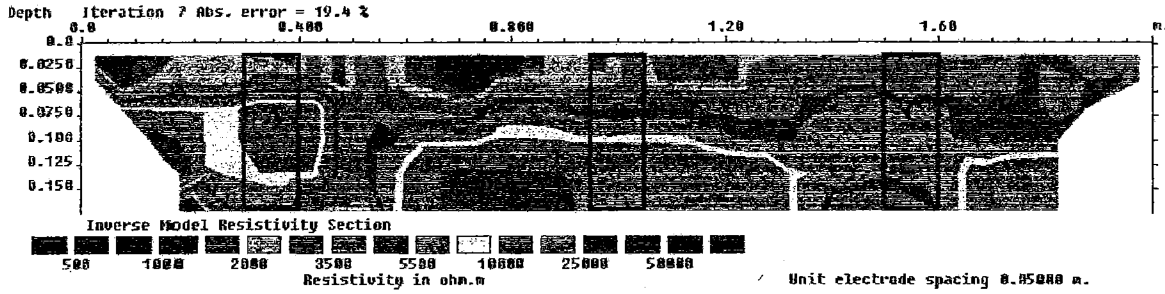

Fig.3 Global 2D electrical resistivity tomography section and localize selected point (A, B and C) of ERV used for further detail study at soil model using Pole-dipole array

Table 1. Localized ERV at point A, B and C extracted from 2D ERV tomography section

Resistivity array	Dipole-dipole			Pole-dipole		
Soil sample (point)	A	B	C	A	B	C
Resistivity, ρ (Ωm)	17178	17720	15625	9200	12965	5501

From geotechnical laboratory test, it was found that the soil material was classified as Silty SAND based on its composition which dominantly composed from sand and silt fraction. All sieve analysis results of soil specimen tested from both models has shown some variation in terms of grain size quantification due to the natural heterogeneity features of soil. Detail classification results obtained from sieve analysis was given in Table 2 and Fig. 4. Soil moisture content test has revealed that point C (16.54 %) was the highest compared to point A (16.15 %) and B (15.83 %) respectively. ERV was found to be higher using Dipole dipole array compared to the pole dipole array used during the resistivity data acquisition.

Table 4. Grain size quantification results.

Soil sample	A				B				C			
Geomaterial	Clay	Silt	Sand	Gravel	Clay	Silt	Sand	Gravel	Clay	Silt	Sand	Gravel
Quantity, %	3.40	36.51	47.35	12.74	3.38	32.62	52.23	11.77	3.38	36.08	46.32	14.22

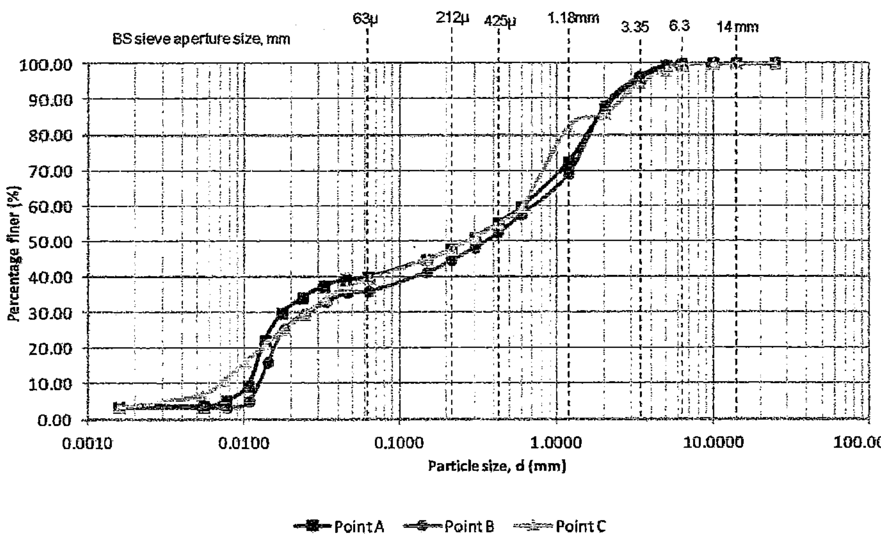

Figure. 4. PSD curve for lateritic soil model at point A

According to results from resistivity value, both array (Dipole-dipole and Pole-dipole) has found to be dissimilar which indicate that the application of electrical resistivity technique has an influence due to the array setting used during the field measurement. The ERV for both array used was found to be different even the measurement was performed on the same survey line. Basically, this factor occurred due to the different geometry factor, K derived from the different types of array used. The value of apparent ERV (ρa) was greatly influenced by K factor applied in all measurement. Geometry factor, K describes the geometry of the electrode configuration used in data acquisition. Apparent resistivity (ρa) is ERV estimated based on half-pace geometry assumption which refers to the field ERV. According to [20], apparent resistivity will be equal to the true resistivity provided the current and configuration was applied over the homogeneous isotropic ground. Field ERV was determined using Dipole-dipole and Pole-dipole array with a geometry factor as given in final Eq. 1 and 2 which is derived from basic Eqs. 3 and 4. Both array geometry factor, K used in this study was derived from Eq. 4 based on basic four electrode system of measurement. The schematic diagram of field resistivity configuration was given in Fig. 5 and Fig. 6 while the schematic diagram for the basic four electrode system is given in Fig. 7.

$$\rho_a = (\pi an(n+1)(n+2)) * R \tag{1}$$

where R is a resistance term given by $R=\Delta V/I$

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

where R is a resistance term given by $R=\Delta V/I$

$$\rho_a = K * (R) \tag{3}$$

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

$$\rho_a = ((2\pi\Delta V)/I)) * ((1/(1/r1-1/r2)-(1/r3-1/r4)) \tag{4}$$

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

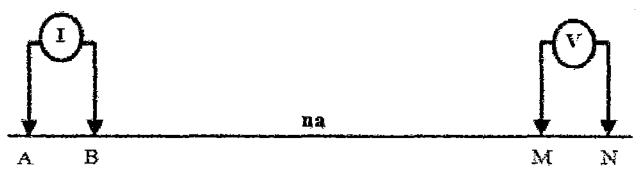

Fig.5 Dipole-dipole electrode array arrangement

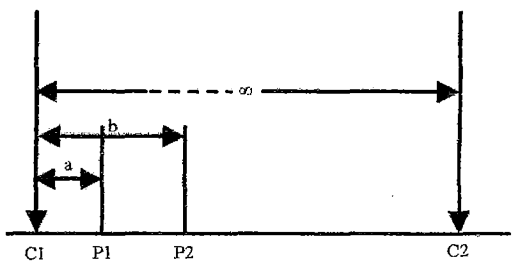

Fig.6 Pole-dipole electrode array arrangement

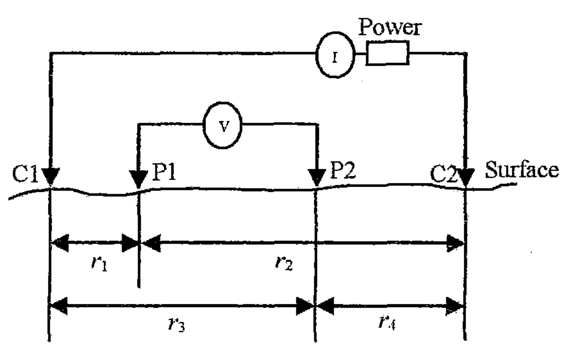

Fig. 7 Four electrodes on the surface of homogeneous isotropic ground of resistivity

However, both array has demonstrate that the ERV was lowest at highest moisture content (w) value (point C) and vice versa (point B). This finding has confirmed the previous theory that stated that ERV will be decreased with the increasing water content or can be represent using relationship with ERV ∞ $1/w$. According to [6], a soil's electrical resistivity value generally varies inversely proportional to the water content and dissolved ion concentration as clayey soil exhibit high dissolved ion concentration, wet clayey soils have lowest resistivity of all soil materials while coarse, dry sand and gravel deposits and massive bedded and hard bedrocks have the highest ERV. As reported by [23], a decrease of ERV was results from an increased of metal ions or inorganic elements in geomaterials. Apart from the influence of array, water content and particles fractions, this controlled miniature model study also revealed that the soil electrical resistivity value was highly influenced by the presence of air void content. The ERV was found to be very high due to the inconsistently present of low moisture content and high volume of void based on this study which focused on loose trial embankment model. Due to the loose condition of soil model, it enables a higher air filled void which able to increased the ERV over the range of the previous reference charts and tables. According to [9], air filled void posses a higher resistivity value compared with the water filled void. As reported by [24], ERV for sand and gravel was varied from 50 Ωm (wet) – 10,000 Ωm (dry). Hence, careful considerations such as supported data from others need to be considered in order to interpret a reliable result from loose soil condition. Otherwise, it can be wrongly interpreted as hard rock materials.

This study has demonstrated that the electrical resistivity array proves to have an influenced in producing the electrical resistivity value together with the influence of geomaterial features such as fine or coarse gained fraction and water content quantity. Each array has a specific strength and weakness and the option for array was always relative to the target interest. For example, Wenner array has a good application for horizontal structure while Pole-dipole was the best array for deeper imaging. As reported by [9], 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. Finally, the confidence level and reliability of electrical resistivity anomaly interpretation and conclusion can be enhanced due to the better understanding of basic fundamental of resistivity array used during each of field measurement.

Conclusion

The electrical resistivity value of Silty SAND was successfully performed under small model of soil trial embankment under loose condition. The influence on soil resistivity data due to different types of array was successfully and methodically studies and presented. The ERV was largely influenced by types of array used due to the different geometry factor derived from each different types of array. This study has reduced few of the black boxes (uncertainties) through some of the basic resistivity theory presented. This study has also proved that the ERV was influenced by physical characteristic of soil such as the quantity of moisture content and geomaterials fraction.

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