Small Soil Embankment Electrical Resistivity Value on its Array, Moisture Content and Density Influences

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Abstract— This study presents the results of an investigation into the influence of electrical resistivity setting with particular reference to array and basic geotechnical properties with particular reference to soil moisture content and density on its electrical resistivity value (ERV) using small trial embankment. In the past, ERV obtained from resistivity survey has demonstrated some ambiguous results that prove to be difficult to deliver in sound and definitive ways especially in engineering point of view. Traditional practice in the past has always been query due to its qualitative anomaly and being image obsessed which led to several undefined ambiguities derived from the nature of uncertainties of soil. Several black boxes such as dissimilarity of electrical resistivity value for the same type of soil also have being debate by the engineers due to the lack of basic fundamental of geophysics. Hence, a small embankment of Gravelly SAND and Silty SAND was tested using ABEM Terrameter SAS (4000) set in place to obtain the resistivity value in this small embankment constructed with soil placed in a loose condition. Electrical resistivity array of Wenner and Schlumberger was used during the resistivity field model measurement with soil moisture content (w) and density (ρ) was performed soon after the resistivity test was finished. Three soil samples were obtained in selected location in line with the resistivity test were also being tested for particle size distribution test using wet and dry sieve method. It was found that the ERV was a function of the array, moisture content and density variations of the soil and was also associated to soil particle variations. Both arrays have produced a different ERV even the measurement was performed on the exact location of resistivity spread line. However, the ERV for both arrays has shown some consistent relationship to the soil moisture content and density by showing Gravelly SAND has a relationship of ERV ∞ 1/w and ERV ∞ ρ while Silty SAND showed a relationship of ERV ∞ 1/w and ERV ∞ 1/ρ. This finding has shown that both resistivity arrays were applicable for producing good ERV which varied due to the moisture content and density variations. Furthermore, this study also found that the ERV was highly influence by air void content which caused by loose soil embankment condition used in this study. Hence, it was found that ERV produced was relative to the types of array used during the field measurement in line with the variation of physical soil characteristics.

Keywords— Electrical resistivity, moisture content, density, array.

I. Introduction

Electrical resistivity technique (ERT) was among several techniques which originated from geophysical methods. Today, geophysical methods such as electrical resistivity have improved considerably due to the continuous rapid development of electronics technology. As a result, these methods facilitated the improvements in measurements and their accuracy compared to the past due to the high technology and sophisticated innovative equipment. However, the standard performance of individual geophysical method always depends on fundamental physical constraints, e.g. penetration, resolution, and signal to-noise ratio [1].

Geophysical methods such as ERM has increasingly become popular in geotechnical and structural engineering works due to its good efficiency in terms of cost (lower cost), time (less time) and provides large data coverage (2D image) which is therefore able to complement the existing borehole data [2] – [6]. Conventional geotechnical drilling test can only determine information at particular drilling (1D information) point thus require soil interpolation which may be wide in contrast against ERM which can possibly provide a continuous image of the subsurface profile [7]. Field operations require less manpower while data processing and results have become quite easy and fast to be produced compared to the conventional drilling method. ERM consist of several separated set of devices and equipment is suitable to be used as an alternative tool for subsurface site investigation especially in situations of difficult accessibility for the application of conventional borehole method. Furthermore, ERM adopts surface techniques which require minimal contact to the ground thus reducing site damageability during the field measurement [8]. Nowadays, preservation of site

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damageability can be considered as vital due to current global issue towards creating a sustainable environment with particular reference to construction industry. In the past, ERM has contributed as an alternative technique in the application of engineering, environment and archeological studies. The main objective of ERM utilization was for the detection and as a mapping tools to detect boulder, bedrock and overburden materials [9], groundwater [10] – [12], contamination plumes [13], [14] meteorite crater [15], tectonic environment [16] etc.

Previously, the entire operational process of ERM involving data acquisition, processing and interpretation was championed by physicists due to it being within their field of expertise. Hence, previous ongoing problem regarding the application of ERM gave rise to some lack of confidence among the engineers who were often bemused by the lack of clarity of results and justification produced by geophysicist. There is too much unclear information being covered up by geophysicists especially when they are dealing with geophysical methods related to geotechnical works. According to [8], geophysicists still possess only little appreciation from an engineer's point of view and lack the knowledge of the soil science. Furthermore as reported by [2], some geophysical results and conclusions are difficult to assimilate in sound and definitive ways as some geophysicists attempt to hide their expertise for business reasons.

In the past, conventional geophysicist interpretation practice was too obsessed with qualitative anomaly approach which sometimes creates some unconvincing justification and weak results verification. Furthermore, conventional reference tables of geomaterials used for anomaly interpretation also sometimes was difficult to decipher due to its wide range of variation and overlapping values [17]. As a result, a strong verification is vital to support the interpretation outcome which otherwise have been traditionally interpreted based on a qualitative approach depending on the experience of the expert [18]. Otherwise, ERM interpretation will always be subjected to doubts arising from uncertainties and unreliability. Moreover, too many geophysical methods have been used without any reference to the geological situation thus producing disappointed results that lead to a mistrust of the geophysical method by many engineers [8].

The solutions to these challenges will require multidisciplinary research across the social and physical sciences and engineering [19]. The success at any site investigation works is based on the integration of method [20]. According to [21], studies that relate to geophysical data and geotechnical properties are much rarer and lesser known. Hence, this study proposed a relationship of geotechnical properties (soil moisture content and densities supported by grain size characteristics) with electrical resistivity value using small scale trial embankment with soil fill placed in a loose condition in order to reduce some black box and ambiguities of electrical resistivity anomaly interpretation via quantitative integration analysis between electrical resistivity value and geotechnical properties with particular reference to moisture content and density of soil. Based on [7], the quantification of geotechnical properties has become an important factor for rigorous application of resistivity imaging in engineering applications.

II. Material and Methods

This study consists of three phases viz; constructing a small trial embankment with the fill in a loose condition, electrical resistivity imaging (2D) and basic geotechnical testing with particular reference to moisture content, density and grain size analysis test of soil.

A. Trail Embankment Model Setting

Two (2) miniature trial embankments as shown in Figure 1, were built using sandy and lateritic soil respectively. Dimensions of both of these were 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°.

Fig. 1 small model of soil trail embankment built up using sandy soil (left) and lateritic (right) soil

B. Electrical Resistivity Imaging

Electrical resistivity imaging was performed using a single leveled line of 2D tomography imaging on the top of each soil model. Both models were tested with similar electrode configurations using ABEM SAS 4000 equipment as shown in Table 1. 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) during the data acquisition. This study used Wenner and Schlumberger array due to its simplicity and for good near surface data. As reported by [22], [23], Wenner and Schlumberger array was applicable to obtain a dense near surface cover of resistivity data.

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 ERV outcome. For example in order to reduce boundary effect that may reduced 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 [24], electrical current may propagate in geomaterials via the process of electrolysis where the current is carried by ions at a comparatively slow rate. Hence, both 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. Both models under 2D Electrical resistivity data acquisition are shown in Fig. 2 and 3.

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 [25] to provide an inverse model that approximate the actual subsurface structure.

Table 1. Configuration used in 2D electrical resistivity test for both soil models.

No	Setting	Description
1	Array	Wenner and Schlumberger
2	Electrode specification	Small steel electrodes: 6 inch of length with 2 mm of diameter
3	Electrode spacing	0.05 m (50 mm)
4	Total number of electrode	41
5	Total number of small jumper cable	42
6	Total length of 2D resistivity test	2 m (2000 mm)

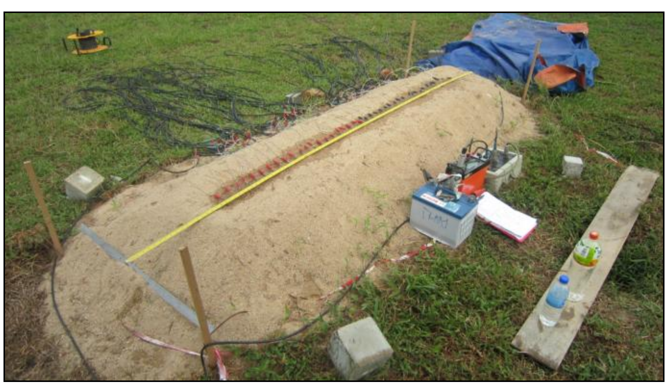

Fig. 2 soil model 1 (sandy soil) tested by 2D electrical resistivity imaging

Fig. 3 soil model 2 (lateritic soil) tested by 2D electrical resistivity imaging

C. Basic Geotechnical Test

Three (3) disturbed samples were obtained immediately after resistivity test was completely finished. Before that, field density test was performed at lateritic soil model specifically at point A, B and C using sand replacement method as shown in Fig. 4. Density test for sandy soil model was unable to conduct at model due its non cohesive materials which unable to get an intact cylindrical cored shaped as required by sand replacement method. Hence, the sandy soil sample at the specific point A, B and C was carefully dug and taken to the laboratory for density determination using a laboratory calibration sand mould. Dimension of soil samples taken at point A, B and C were based on sand replacement standard (Diameter, d: 150 mm and Height, h: 100 mm).

All soil samples were immediately tested for moisture content using oven drying method. After that, sieve test was performed for soil model 1 (sandy soil) and soil model 2 (lateritic soil). Dry sieve test was performed for soil model 1 due to its coarse and granular gains soil (sandy soil) while dry and wet sieve test was performed for soil model 2 (lateritic soil) due to its mixture of composition between coarse and fine grain of particles. Dry sieve test was conducted using mechanical shaker while hydrometer test was used for wet sieving as shown in Fig. 5. All related basic geotechnical test was based on [26]. Schematic diagram representing soil sampling and electrical resistivity line alignment was given in Fig. 6.

Fig. 4 field density test using sand replacement method at lateritic soil model

Fig. 5 mechanical sieve (left) and hydrometer test (right) in progress

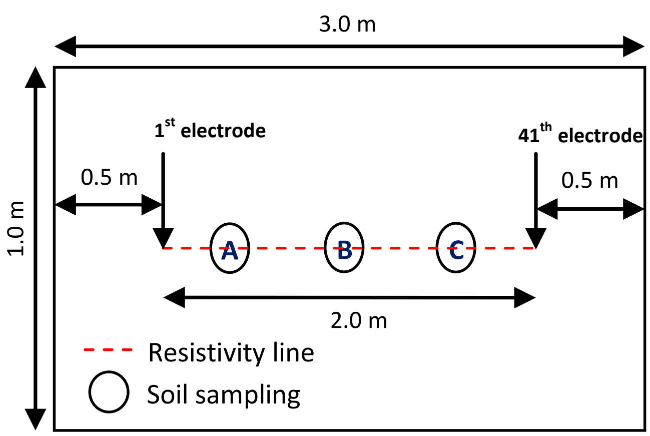

Fig. 6 schematic diagram of the soil sampling position and resistivity line alignment (drawing not to scale)

III. Results and Discussions

All results presented and discussed are based on field electrical resistivity value (ERV), geotechnical properties value and relationship of field ERV with moisture content (w), density (ρ) and grain size of soil (d). All results are presented in Fig. 7 – 16 and Table 2 – 4.

A. Electrical Resistivity Value (ERV)

ERV was determined by measuring the potential difference at points on the ground surface which caused the propagation of direct current through the subsurface [27]. The ERV obtained in Table 2 was originally extracted from the global 2D electrical resistivity tomography section particularly at point A, B and C given in Fig. 7 and 8. Each point of ERV was extracted at the exact location (horizontal: x and depth: y) of the soil sample tested.

It was found that the highest ERV for soil model 1 was located at point C (Wenner = 96376 Ωm & Schlumberger = 37383 Ωm) and reduced at point B (Wenner = 76212 Ωm & Schlumberger = 37261 Ωm) and A (Wenner = 45811 Ωm & Schlumberger = 35246 Ωm) respectively while soil model 2 has demonstrate that the highest ERV was located at point B (Wenner = 48763 Ωm & Schlumberger = 29160 Ωm) and gradually decreased at point A (Wenner = 48499 Ωm & Schlumberger = 17701 Ωm) and C (Wenner = 48218 Ωm & Schlumberger = 12463 Ωm) respectively. Generally, soil model 1 has a greater ERV compared to the soil model 2 due to the different composition of soil particles and moisture. Electrical propagation in soil is largely electrolytic process by flowing in connected pore spaces and along grain boundaries of geomaterial [28]. It was also found that the ERV of Wenner array has a greater ERV compared t the ERV of Schlumberger array due to the different geometry factor, K.

Table 2. Extracted ERV at soil model 1 and 2

Soil model	1 (Gravelly SAND)			2 (Silty SAND)		
Soil sample (point)	A	B	C	A	B	C
Wenner array Resistivity, ρ (Ωm)	45811	76212	96376	48499	48763	48218
Schlumberger array Resistivity, ρ (Ωm)	35246	37261	37383	17701	29160	12463

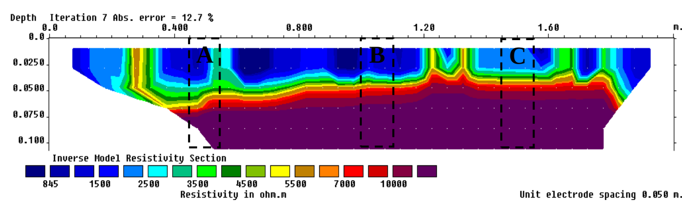

Fig. 7 global 2D electrical resistivity tomography section and localize selected point (A, B and C) of ERV using Wenner array at soil model 1

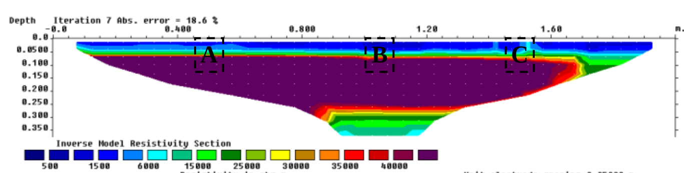

Fig. 8 global 2D electrical resistivity tomography section and localize selected point (A, B and C) of ERV using Schlumberger array at soil model 1

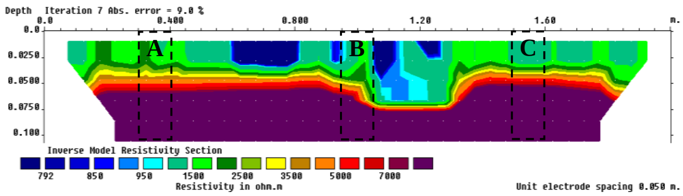

Fig. 9 global 2D Electrical resistivity tomography section and localize selected point (A, B and C) using Wenner array at soil model 2

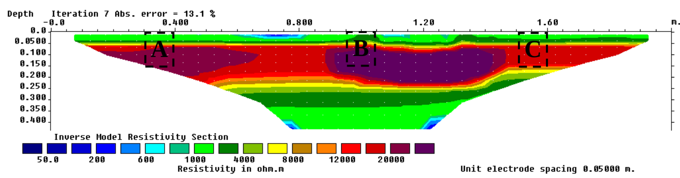

Fig. 10 global 2D Electrical resistivity tomography section and localize selected point (A, B and C) using Schlumberger array at soil model 2

B. Soil Moisture Content, Density and Grain Size Results

Basic geotechnical test results for three soil samples from each soil model obtained at point A-C are given in Table 3-4 and Fig. 11-16. At soil model 1, it was found that the moisture content (w) value was highest at point A (3.88 %) and slightly less at point B (3.10 %) and C (2.40 %) respectively. For soil model 2, it was noted that the moisture content (w) value was highest at point C (16.54 %) and slightly decreased at point A (16.15 %) and B (15.83 %) respectively. It was found that the moisture content value varied for all points of soil model due to a random wetting process of soil model performed at the beginning of field electrical resistivity measurement. Generally, soil model 2 has demonstrate a higher moisture content value compared to the soil model 1 due to the dissimilarity of grain sizes present at both soil models. Soil model 2 composed of a mixture between coarse and fine grain particles which able to retained more water compared to the soil model 1 which dominantly consist of coarse gain particles.

In soil mechanics and geotechnical engineering, soil density was basically described using bulk density (ρ) and dry density (ρ_{dry}). Bulk density was defined by total mass of solids and water per total volume while dry density was defined by mass of solids per total volume. Quantities of densities provide a measure of the material quantity related to the space amount it occupies [29]. For soil model 1, it was found that the highest densities (ρ & ρ_{dry}) was located at point C (ρ = 1.534 Mg/m^3 & ρ_{dry} = 1.498 Mg/m^3) and slightly reduced at point B (ρ = 1.508 Mg/m^3 & ρ_{dry} = 1.462 Mg/m^3) and A (ρ = 1.504 Mg/m^3 & ρ_{dry} = 1.448 Mg/m^3) respectively while soil model 2 has shown that the highest densities was located at point C (ρ = 1.347 Mg/m^3 & ρ_{dry} = 0.961 Mg/m^3) and slightly reduced at point A (ρ = 1.299 Mg/m^3 & ρ_{dry} = 0.959 Mg/m^3) and B (ρ = 1.289 Mg/m^3 & ρ_{dry} = 0.867 Mg/m^3) respectively. Soil model 1 has demonstrates a higher densities value compared to the soil model 2 due to the geomaterials and moisture content variation. It can be observed that the densities of each point (A-C) of soil model were relative to the moisture content variations. For soil model 1, the relationship of density was inversely proportional with moisture content while soil model 2 has shown that the densities was linearly proportional with the moisture content. Those contradictions of relationship were greatly influence by the grain size quantity variations as presented in Table 3-4 and Fig. 11-16. For soil model 1, high densities of soil were produced due to the influence of high quantity and composition of coarse grain (gravel and sand) geomaterial. Based on Table 4, quantity of gravel at point C was greater than those at point B and A respectively. Sandy soil has a lower capability to absorb water due to its highly porous characteristics. Hence, it was strongly believed that the coarse grain variation has played major influences to a sandy soil densities compared to the moisture content factor. For soil model 2, density variation was greatly influenced by the quantity of fine grain soil and moisture content factor. For example, a higher soil density can be produced due to the high water content presence in a fine grain soil. Hence, it was strongly believed that the densities of soil model 2 which consist of lateritic soil was linearly proportional to the presence of moisture content and fine gain geomaterial.

Generally, soil can be in the form of both granular and fine particle. Based on Table 4, it was found that soil model 1 and 2 was classified as Gravelly SAND (granular particle) and Silty SAND (mixture of both granular and fine particle) respectively. 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. Detailed results obtain in Table 4 was originally extracted from particle size distribution curve (PSD) presented in Fig. 11-16.

Table 3. Soil Moisture content and density results

Soil model	1 (Gravelly SAND)			2 (Silty SAND)		
Soil sample (point)	A	B	C	A	B	C
Moisture content, *w* (%)	3.88	3.10	2.40	16.15	15.83	16.54
Bulk Density, ρ (Mg/m^3)	1.504	1.508	1.534	1.299	1.289	1.347
Dry Density, ρ_{dry} (Mg/m^3)	1.448	1.462	1.498	0.959	0.867	0.961

Table 4. Grain size quantification results

	Soil sample	Geomaterial	Quantity, %	Quantity, %
Soil Model 1 (Gravelly SAND)	A	Gravel	13.05	99.94
		Sand	86.89	
		Silt	0.06	0.06
		Clay	0.00	
	B	Gravel	14.79	100.00
		Sand	85.21	
		Silt	0.00	0.00
		Clay	0.00	
	C	Gravel	16.52	99.82
		Sand	83.30	
		Silt	0.18	0.18
		Clay	0.00	
Soil Model 2 (Silty SAND)	A	Gravel	12.74	60.09
		Sand	47.35	
		Silt	36.51	39.91
		Clay	3.40	
	B	Gravel	11.77	64.00
		Sand	52.23	
		Silt	32.62	36.00
		Clay	3.38	
	C	Gravel	14.22	60.54
		Sand	46.32	
		Silt	36.08	39.46
		Clay	3.38	

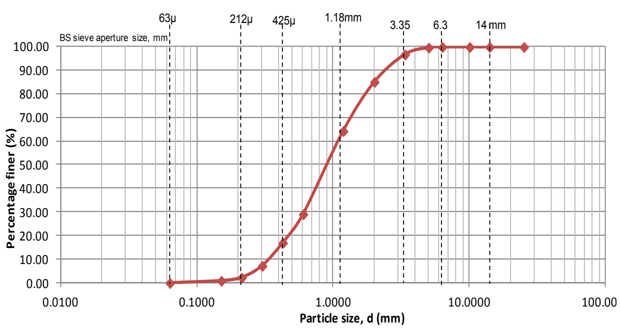

Fig. 11 PSD curve for sandy soil model at point A

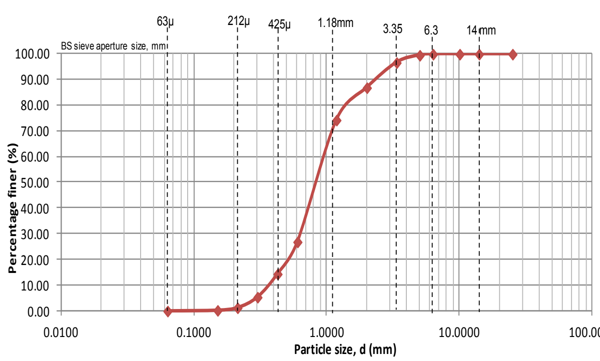

Fig. 12 PSD curve for sandy soil model at point B

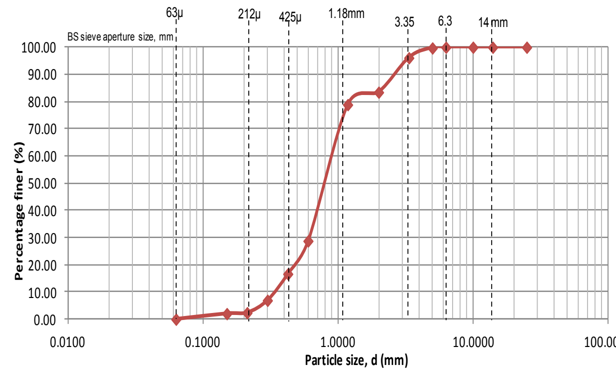

Fig. 13 PSD curve for sandy soil model at point C

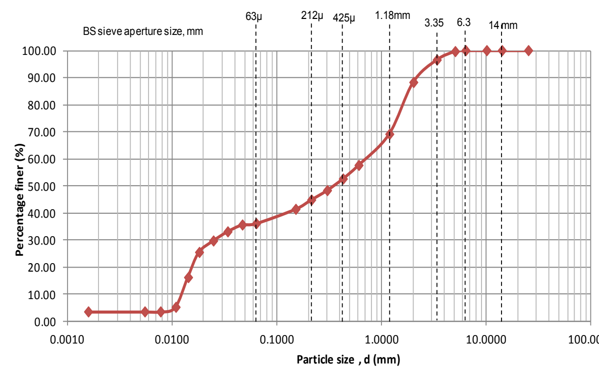

Fig. 14 PSD curve for lateritic soil model at point A

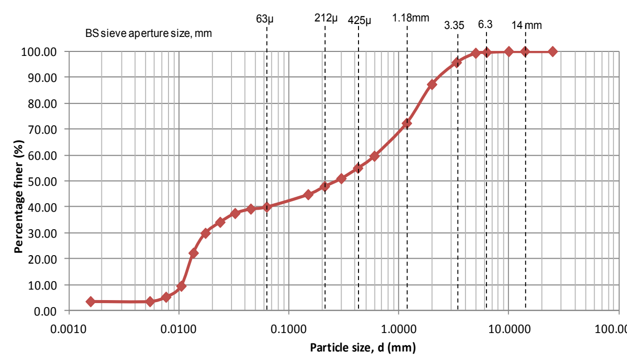

Fig. 15 PSD curve for lateritic soil model at point B

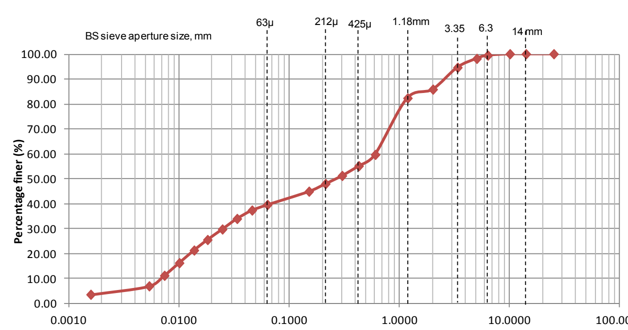

Fig. 16 PSD curve for lateritic soil model at point C

C. Relationship of Different Array on ERV due to the Soil Moisture Content and Density

Generally, ERV was relative to several factors such as equipment setting (e.g. array, etc.) and basic physical and chemical properties of soil. Electrical resistivity value can be influenced by the concentration and type of ions in pore fluid and grain matrix of geomaterials via the process of electrolysis where the current was carried by ions at a comparatively slow rate [30]. According to [4], 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 [31], a decrease of ERV was results from an increased of metal ions or inorganic elements in geomaterials. Based on [32], soil parameters determined in grain size analysis could replicate the variety of resistivities obtained on the site very well.

Based on Table 2, both arrays was demonstrated different ERV due to the dissimilar array of Wenner and Schlumberger. As reported by [33], the ERV was largely influenced by geometry factor, k derived for each array used together with different scale of measurement. The value of apparent ERV (ρ_a) was greatly influenced by K factor applied in every measurement. Geometry factor, K describes the geometry of the electrode configuration used in data acquisition. Different types of array will produced a different K factor thus producing dissimilar ERV in electrical resistivity measurement. Field model ERV was determined using two different arrays setting with particular reference to Wenner and Schlumberger with a geometry factor as given in basic four electrode measurement system from Eq. 1. The schematic diagram Wenner and Schlumberger array was given in Fig. 17 and Fig. 18 while the schematic diagram for the four electrode system is given in Fig. 19.

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

where $r_1 = r_4 = a$ and $r_2 = r_3 = 2a$ for Wenner array and $r_1 = (L - x)$, $r_2 = (L + x)$, $r_3 = (L - x)$ and $r_4 = (L + x) - l$ for Schlumberger array

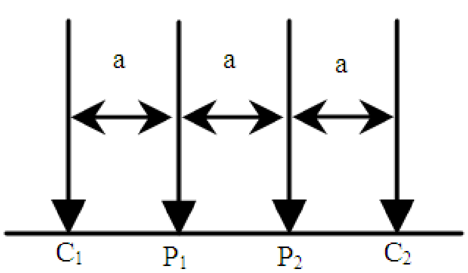

Fig. 17 Wenner electrode array

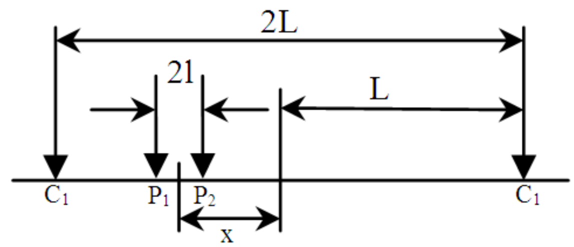

Fig. 18 Schlumberger electrode array

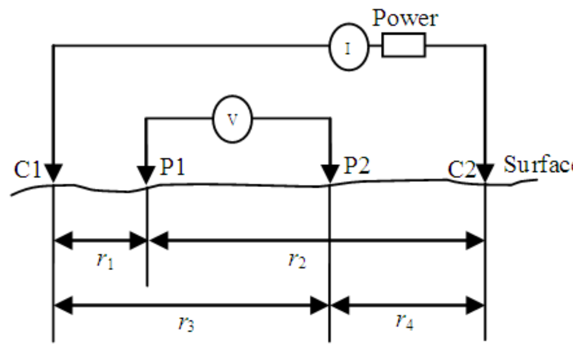

Fig. 19 four electrodes on the surface of homogeneous isotropic ground of resistivity

Each array used in practice such as Wenner, Schlumberger, Pole-dipole, Dipole-dipole, Gradient, etc has a different K value. Basically, any of the ρ_a was derived based on Eq. 1. As a result, the apparent resistivity (ERV) calculated from the electrical resistivity measurement is not the same due to the different K value. Hence, it was intrinsically clear that the ERV obtained from different scales using different types of arrays will produce a dissimilar ERV. Other factors which contribute to the dissimilar of ERV were the geomaterials physical and chemical influence. According to [30], resistivity value is highly influenced by water concentration and lithology variations. However this factor can be considered as a secondary factor since the main factor which causes the dissimilar ERV was strongly caused by a different type of array used and if the scale and type of array used was similar, then the geomaterials physical and chemical factor will possibly take a big role for influencing the ERV [33].

Based on section 3.1, the highest ERV for soil model 1 (Gravelly SAND) was located at point C (Wenner = 96376 Ωm & Schlumberger = 37383 Ωm) and reduced at point B (Wenner = 76212 Ωm & Schlumberger = 37261 Ωm) and A (Wenner = 45811 Ωm & Schlumberger = 35246 Ωm) respectively. From the laboratory soil test results, it was noted that the moisture content value was highest at point A (3.88 %) compared to the other points while the lowest moisture content value was at point C (2.40 %). Hence it was proved that the ERV of soil model 1 (Gravelly SAND) using Wenner and Schlumberger array has a relationship which varies inversely propotional to the proportion of water ($\rho_C > \rho_B > \rho_A$ due to the

w_C<w_B<w_A) which can be represented using general relationship of ERV ∞ 1/*w*. In other words, higher ERV value can be produced due to the lower water content and vice versa. Meanwhile, the densities for soil model 1 was highest at point C (ρ = 1.534 Mg/m^3 & ρ_{dry} = 1.498 Mg/m^3) and slightly reduced at point B (ρ = 1.508 Mg/m^3 & ρ_{dry} = 1.462 Mg/m^3) and A (ρ = 1.504 Mg/m^3 & ρ_{dry} = 1.448 Mg/m^3) respectively. It was found that the ERV was linearly proportional to the densities of soil Gravelly SAND at soil model 1. A higher ERV will be produced due to the higher value of soil densities which associated by higher quantity of granular soil with particular reference to gravel particles as shown at point C. As reported by [34], the bulk resistivity of soil will increase with the grain size increment since it offers more resistance to the ionic current flow. Moreover, higher granular soil will produced lower moisture content which also contributes to the increasing of ERV. Hence, general relationship between ERV and soil densities of Gravelly SAND using Wenner and Schlumberger array can be found as ERV ∞ ρ.

According to section 3.1, ERV of soil model 2 (Silty SAND) was highest at point B (Wenner = 48763 Ωm & Schlumberger = 29160 Ωm) and gradually decreased at point A (Wenner = 48499 Ωm & Schlumberger = 17701 Ωm) and C (Wenner = 48218 Ωm & Schlumberger = 12463 Ωm) respectively. A laboratory soil test result has shown that the moisture content value was highest at point C (16.54 %) compared to the other points while the lowest moisture content value was at point B (15.83 %). Hence, it was found that soil model 2 (Silty SAND) using Wenner and Schlumberger array has demonstrated that ERV was inversely proportional to the presence of water (ρ_B>ρ_A>ρ_C due to the w_B<w_A<w_C) and also can be represent by ERV ∞ 1/*w*. However, soil densities for model 2 was found to be highest at point C (ρ = 1.347 Mg/m^3 & ρ_{dry} = 0.961 Mg/m^3) and slightly reduced at point A (ρ = 1.299 Mg/m^3 & ρ_{dry} = 0.959 Mg/m^3) and B (ρ = 1.289 Mg/m^3 & ρ_{dry} = 0.867 Mg/m^3) respectively. It was found that the ERV was inversely proportional to the densities of Silty SAND at soil model 2 in contrast with ERV and densities relationship at soil model 1. A higher ERV will be produced which associated by lower soil densities due to the lower quantity of water as shown at point B. Silty SAND composed of a mixture between granular and fine grain particles which able to absorb more water compared to the Gravelly SAND. Hence, this phenomenon was possibly has affected the relationship between ERV and densities. Commonly, it was expected that the ERV was supposedly to be high due to the higher soil densities. However in Silty SAND, this hypothesis was unable to be used due to the presence of more water within the fine soils with particular reference to clay and silt particles. Hence in Silty SAND case, higher density was associated with a higher moisture content thus producing a low ERV using both of Wenner and Schlumberger array which can be represent by ERV ∞ 1/ρ. In other words, the higher moisture content causes easily a flow of current within the soil which finally produced a lower ERV.

Apart from the influence of water and density, 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 [35], air filled void posses a higher resistivity value compared with the water filled void. As reported by [36], ERV for sand and gravel was varied from 50 Ωm (wet) – 10,000 Ωm (dry) while as referred to [37], sand and gravel with silt was 1000 Ωm. 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.

Geophysical techniques such as electrical resistivity offer the chance to overcome some of the problem inherent in more conventional ground investigation techniques [8]. Nevertheless, according to [38], [20], geophysical methods are insufficient to stand alone in order to provide solutions to any particular problems. This study was applicable to assist and improve the confidence level of conventional geophysical anomaly interpretation due to its quantitative verification thru geotechnical basic properties. Geotechnical property quantification is an important factor for geophysical method used in engineering application [39]. Moreover, integrated geophysical and geological data also proved a successful method for engineering and environmental studies especially to characterize the local geological structure [40]. Hence, the confidence level and reliability of traditional anomaly interpretation and conclusion can be enhanced using supported additional numerical data with particular reference to soil moisture content and densities.

IV. Conclusion

The electrical resistivity value of Gravelly SAND and Silty SAND were successfully performed under small model of soil trial embankment. The influence on soil resistivity data due to changes in the array, moisture content, densities and grain size was successfully and methodically studies and presented. The electrical resistivity value was observed to be very sensitive to the quantitative proportion of water, and geomaterial particle fractions in line with previous researcher findings despite having a dissimilarity of ERV which derived from different array used during the data acquisition stage. Furthermore, ERV from different array was still able to present a consistent trend on its relationship due to the water, density and grain size characteristics. The integration of geophysical results such as electrical resistivity value with laboratory geotechnical test provided a meaningful contribution to the geophysicist and geotechnical engineers since it applicable to minimize and explain some of the ambiguity during the data interpretation stage.

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