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Determination of Soil Moisture Content using Laboratory Experimental and Field Electrical Resistivity Values

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Abstract. The efficiency of civil engineering structure require comprehensive geotechnical data obtained from site investigation. In the past, conventional site investigation was heavily related to drilling techniques thus suffer from several limitations such as time consuming, expensive and limited data collection. Consequently, this study presents determination of soil moisture content using laboratory experimental and field electrical resistivity values (ERV). Field and laboratory electrical resistivity (ER) test were performed using ABEM SAS4000 and Nilsson400 soil resistance meter. Soil sample used for resistivity test was tested for characterization test specifically on particle size distribution and moisture content test according to BS1377 (1990). Field ER data was processed using RES2DINV software while laboratory ER data was analyzed using SPSS and Excel software. Correlation of ERV and moisture content shows some medium relationship due to its $r = 0.506$. Moreover, coefficient of determination, R^2 analyzed has demonstrate that the statistical correlation obtain was very good due to its R^2 value of 0.9382. In order to determine soil moisture content based on statistical correlation ($w = 110.68\rho^{-0.347}$), correction factor, C was established through laboratory and field ERV given as 19.27. Finally, this study has shown that soil basic geotechnical properties with particular reference to water content was applicably determined using integration of laboratory and field ERV data analysis thus able to compliment conventional approach due to its economic, fast and wider data coverage.

1. Introduction

Conventional and basic geotechnical properties (BGP) determination from site investigation (SI) work covers from geomaterials sampling and laboratory experimental. The whole conventional technique process effectiveness decreases due to the increasing cost and time especially when dealing with the investigation in huge and challenging construction sites. Classical SI using drilling methods experience difficulties in rugged terrain, swampy environment, coastal and heterogeneous geological areas which essentially investigated [1]. Furthermore, classical SI technique involving huge and



heavyweight instrument (i.e. boring machine) to obtain subsurface data via soil and rock sampling that are likely to be inefficient in tough environment which require struggling of instrument mobilization, shifting, demobilization and operational. Based on [2], huge number of geomaterials sampling was crucial to obtain reliable soil parameter output and according to [3], this objective was difficult to obtain via drilling which known to be time-consuming and costly. Traditional lab experiment also may experience expensive and time consuming especially during working with high quantity of soils tests.

Geophysical method (GM) is increasingly being used as an alternative tool to support and assist the existing conventional SI. Today, GM such as geoelectrical, gravity, seismic, GPR, magnetic, etc has develop lots due to the electronics technology rapid growth. Hence, these methods were able to improve measurement precision due to its sophisticated technology and innovative instrument. Nevertheless, individual geophysical method typical performance always relative to fundamental physical restrictions, e.g. penetration, resolution, and signal to-noise ratio [4]. Classically, GM are widely used for ground exploration since its economic, fast and huge data coverage capability [5]. GM can be applied faster and cheaper and can cover large sites thoroughly [1, 6, 7, 8]. Common geophysical application are often used in engineering, environment and archeological studies which are usually applied to detect and locate boulders, bedrock, overburden materials, earth work related to the rippability, leachate migration, groundwater sources and contamination, cavity, sinkhole, etc. [9].

GM was actually expert by geophysicist is now increased popularity in civil engineering. Due to the prospective of geophysical method in engineering is yet to be understood and entirely established, the utilization of these method are still not being entirely explored. Difficulties rise when the applications of geophysics is lack of exploration by civil engineers because of experience shortage and skills in geophysics area. According to [10], geophysical survey poor preparation by engineers that shortage skills in the techniques, and geophysicists over expectation leading to unsuitable utilization of the available techniques. As reported by [10], geophysicists still having little appreciation from the engineer's perspectives and lack the information of the science in soil mechanics. According to [5], some geophysical outcome and conclusions are difficult to deliver in sound and definitive ways since some of geophysicists attempt to hide their skills for business motives. These scenarios have created some black box between engineers and geophysicist due to the lack of knowledge, appreciation and cooperation. Uncertainties are raised by engineer to the geophysicist such as the best equipment setting and operation, processing technique and interpretation of data which are still considered as an ongoing mystery by engineers. Moreover, classical geophysical interpretation is relative to anomaly and geomaterials references thus may considered unconvincing in term of its precision due to the qualitative perspectives.

According to [10], GM has a prospect to minimize the problems experienced from conventional SI methods. In geotechnical engineering point of view, awareness sense and gratitude is remarked by the potential contribution and meaningful relative to the precision of geomaterials properties determination and its reliability. Performance of GM can be enhanced when it is capable to serve greater its classical anomaly results since the engineer mission and concern was to built structure efficiently. Furthermore as reported by [8], research related to geophysical data for geotechnical properties determination are limited and fewer being established. As a result, this study established electrical resistivity method in prediction of basic physical properties of soil. Past experience has revealed that the application of electrical resistivity at laboratory and field scale will produce different electrical resistivity value (ERV) for the same particular type of soil. This situation created a never ending debate and argument among related parties because of the black box of fundamental knowledge. As a result, the study was conducted to develop a combination analysis of lab experimental and field ERV thru correction factor, C for soil moisture content determination.

2. Material and Methods

This research was performed based on three phases via fieldwork, lab and data analysis using statistics and utilities software. Field measurement was performed by a single spread line according to pole dipole protocol. Field survey setting was performed using small electrode (2 mm diameter with 150 mm long) with 17 cm electrode spacing for a small study area. Total of 42 small electrodes was used during the survey where 41 numbers of electrodes was assigned with two resistivity land cables connected by jumper cables and the remaining single electrode was used for remote current electrode. Then, two resistivity land cables and a single remote cables was connected to the Terrameter SAS (4000) (data logger) and switch box (electrode selector devices) for data acquisition process. Finally, raw data obtained from field measurement was transferred to the computer for processing. After completion of the field resistivity measurement, three disturbed soil samples was quickly collected from specific points A, B and C which were locate in line with the 2D electrical resistivity survey line as shown in Figure 1. A very shallow disturbed soil samples were taken using hand auger from the surface to a depth of 24 cm. Soil samples were send to the geotechnical laboratory for further laboratory study.

Laboratory experimental task was performed using classification and moisture content tests. Soil classification was conducted via dry and wet sieve methods while oven drying method was used for moisture content determination. All those tests were performed based on [11]. Four numbers of sieve test was performed via soil samples A, B, C and a combination of all (A – C). Lab ER test was conducted using soil box test via Nilsson's resistance meter and Miller's box instrument. Oven dried soil samples (1500 g) was taken for the soil box experiment. Oven dried soil (1500 gram) with 2 % of distilled water (30 ml) was uniformly mixed. Soil box test was conducted under dense state for site similarity condition. For dense state, soil was compacted through a completely horizontal wooden plate which fully fitted inside the box. Compacting process was performed in three layers sequences where each layer was impacted by constant driven force based on 27 numbers of blows to obtain constant dense compacted soil condition. Then, electrical resistance of soil was measured using the soil resistance meter devices. After soil electrical resistance was obtained, moisture content tests was performed using soil taken from the present tested box. Two samples of soil moisture content were measured for averaging purposes. The entire steps of soil box experiment was constantly repeated at 25 times.

Data analysis and processing and was performed via the utilization of statistics (Statistical Product and Service Solutions: SPSS and Microsoft Excel), RES2DINV software (field resistivity data analysis) and the interpolation of field and lab ERV and moisture content to developed a field ERV correction factor, C according to calibrated laboratory ERV.

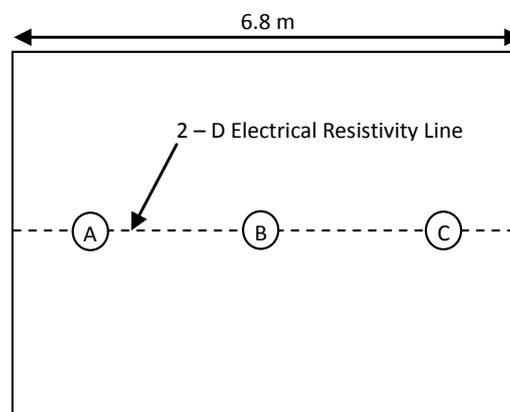


Figure 1. Schematic drawing (Plan view) of the location of soil sampling and 2D electrical resistivity survey line alignment.

3. Results and Discussions

Three (3) point of localized field ERV was take out from resistivity section on the particular soil samples location obtain that used for laboratory tests. The results shows the largest field ERV was situated at location A (395 Ωm) followed by location C (289 Ωm) and B (263 Ωm). Outcome from resistivity section conducted from field measurement and the point extracted data was shown in Figure 2.

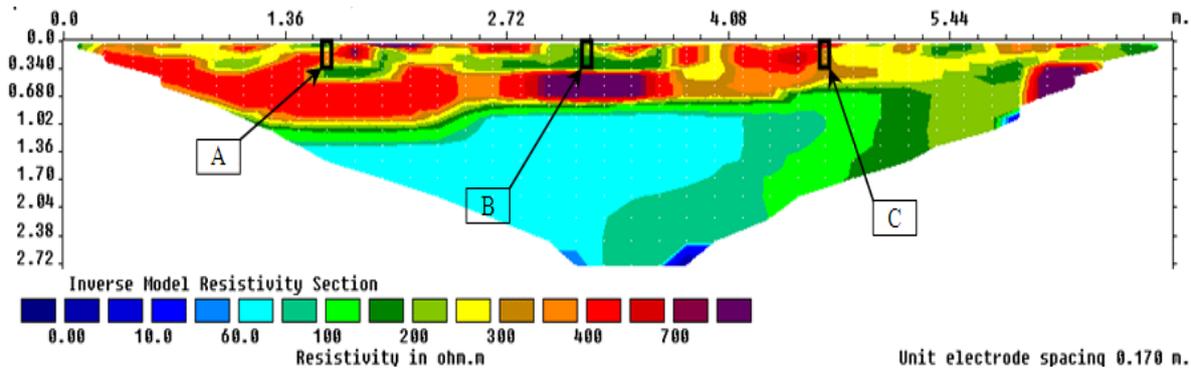


Figure 2. Resistivity section with ERV point of extraction (based on location of soil sampling).

Soil classification test revealed that soils tested were classified as Clayey SILT due to its domination of fine particles of soil. Soil particles was highly composed of silt and clay remained by sand and gravel. Grain size distribution curve and specific soil grained quantity found from the experiment was studied and given in Figure 3 – 6 and Table 1. Soil moisture content (w) at location B (48.68 %) was the largest than location C (40.12 %) and A (35.52 %).

Soil box resistivity tests was conducted via blended soil (soil A – C) because of the similarity soil type (Clayey SILT). Laboratory ERV was measured at 5600 Ωm (largest record) with w of 6.36 % while the smallest lab ERV was establish at 14 Ωm for a w of 64.24 %. All lab ERV and its w findings was shown in Table 2. w against ERV series was analyzed using statistical tools that revealed the ERV was gradually reduced with additional w by curvilinear trend line as given in Figure 7. Laboratory ERV was measured for 25 data numbers for consistency purposes. Based on analysis of statistical correlation, r via SPSS, r value was revealed at 0.506 thus indicate that the correlation strength among ERV and w was at medium strength that further confirmed that the correlation among ERV and w was satisfactory. Precision of r was defined as medium when the r-value was varied at 0.40 – 0.59 [12]. After that, coefficient of determination, R² was 0.9382 thus indicate that the correlation was very good since the result was closed to the value of 1.0. As a result, the entire statistical analysis have shown that laboratory ERV data experienced good correlation associate with soil moisture content w, given by $w = 110.68\rho^{-0.347}$. The entire statistical outcomes are shown in Table 3 and Figure 7.

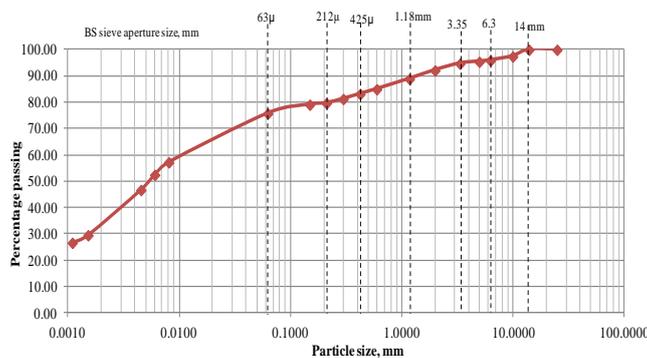


Figure 3. PSD curve for soil sample A.

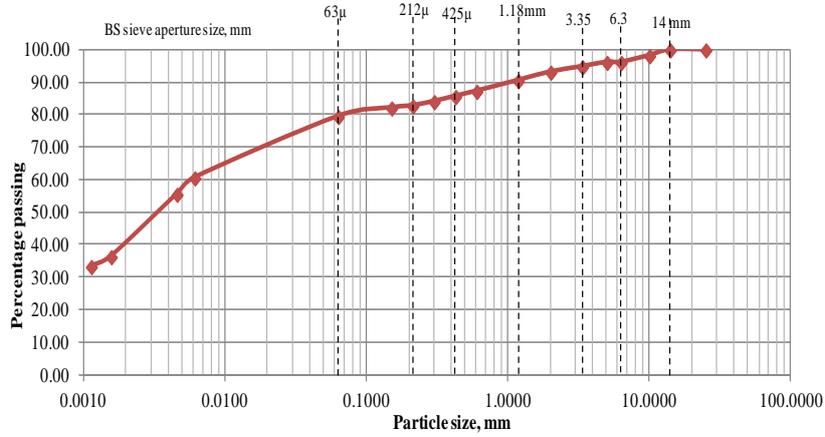


Figure 4. PSD curve for soil sample B.

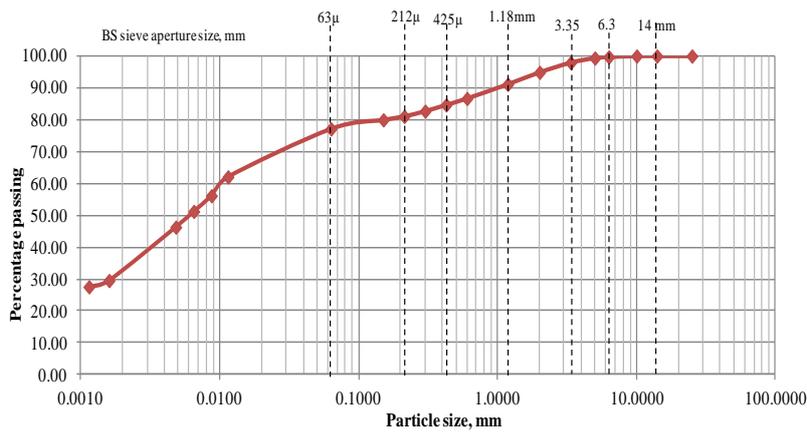


Figure 5. PSD curve for soil sample C.

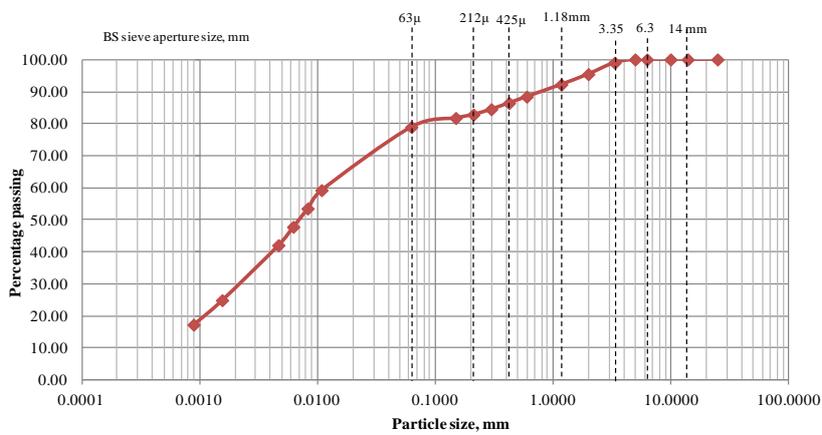


Figure 6. PSD curve for a mixture of soil sample A – C.

Table 1. Soil particle quantification.

Soil sample	Material	Quantity, %	Quantity, %
A	Gravel	7.85	24.19
	Sand	16.34	
	Silt	46.22	75.81
	Clay	29.59	
B	Gravel	6.85	20.51
	Sand	13.66	
	Silt	43.12	79.49
	Clay	36.37	
C	Gravel	5.12	22.86
	Sand	17.74	
	Silt	47.58	77.14
	Clay	29.56	
A – C	Gravel	4.59	21.10
	Sand	16.51	
	Silt	54.08	78.90
	Clay	24.82	

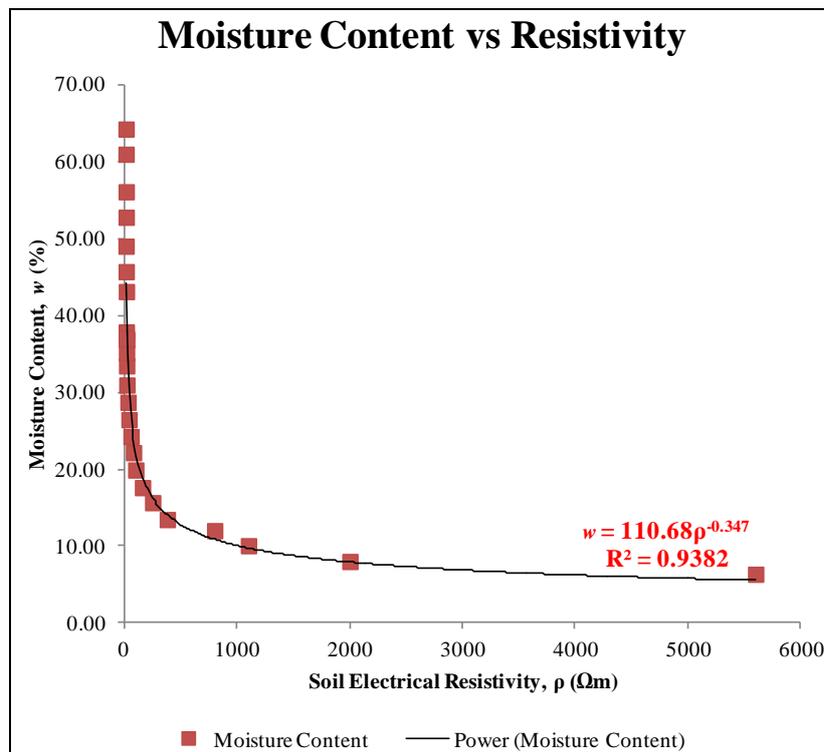
Table 2. Laboratory data of ERV and w .

Lab ERV (Ω m)	Moisture Content, w
5600	6.36
2000	8.02
1100	10.07
800	12.03
380	13.47
250	15.67
160	17.62
100	19.91
80	22.17
58	24.25
40	26.45
31	28.71
21	30.96
19	33.45
18	35.14
19	36.82
16	37.86
16	37.05
17	43.11
15	45.70
14	49.01
15	52.78
15	56.09
14	60.97

14 64.24

Table 3. Summary of statistical analysis.

Correlation (r)		Coefficient of determination (R^2)	Equation
Resistivity (ρ)	Moisture Content (w)	Moisture Content, (w)	$w_{(C)}$
1.0	-0.506	0.9382	$110.68\rho^{-0.347}$

**Figure 7.** Laboratory w versus ERV.

In line with past research, electrical resistivity values from laboratory and field are dissimilar creating argument as stated previously. Principally, this issue happened because of geometry factor, K variation between lab experiment and site measurements. In every measurement, apparent ERV (ρ_a) was significantly influenced by K factor selected. K defines as electrode configuration geometry selected during the data acquisition. Apparent resistivity (ρ_a) is ERV obtained by half-pace geometry hypothesis that relative to the field ERV. Apparent resistivity may similar to the true resistivity as long as the current and configuration was performed on homogeneous isotropic ground [13]. Laboratory experimental ERV was obtained via soil box instrument thru K as given in Eq. 1. Field ERV was obtained through Pole-dipole protocol based on K as shown in final Eq. 2 that established from principle Eqs. 3 and 4. Pole-dipole K was derived from Eq. 4 according to basic four electrode measurement configuration. Laboratory and field resistivity arrangement diagram was shown in Figure 8 and Figure 9 whereas the illustration for the four electrode arrangement is shown in Figure 10.

$$\rho = (A/L) * (R) \tag{1}$$

where R is a resistance known as $R=\Delta V/I$, A/L is geometry factor, K of current and potential in soil box instruments, A is area of the conducting material and L is material length

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

where R is a resistance known as $R=\Delta V/I$

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

where R is a resistance known as $R=\Delta V/I$, K is geometry factor according to pole-dipole electrode arrangement

$$\rho_s = ((2\pi\Delta V) / I) * ((1/(1/r_1 - 1/r_2) - (1/r_3 - 1/r_4))) \tag{4}$$

where $K = ((1/(1/r_1 - 1/r_2) - (1/r_3 - 1/r_4)))$ and was defined as a pole-dipole electrode geometry when one of the current electrodes is fixed at a larger distance from the other three (substitute $r_1 = a$, $r_3 = b$, $r_2 = r_4 = \infty$ into equation of K)

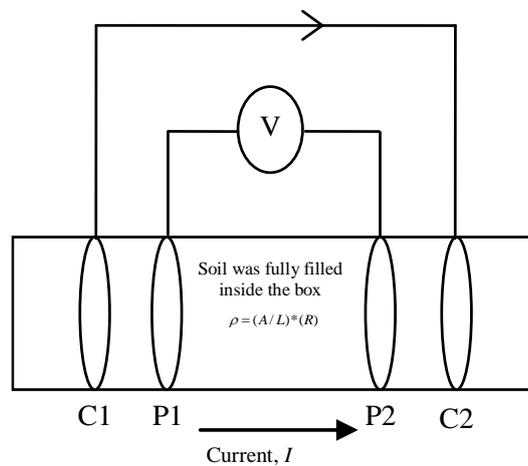


Figure 8. Soil box resistivity schematic diagram involving its geometry factor, K .

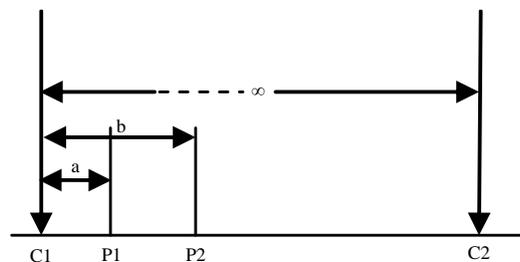


Figure 9. Pole-dipole electrode protocol.

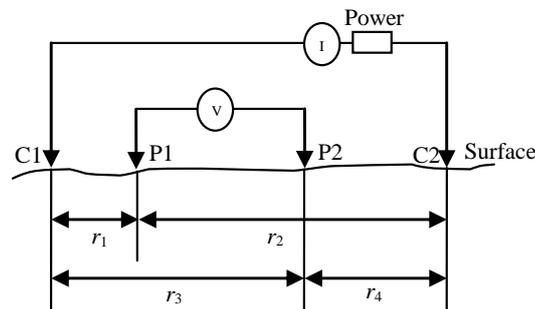


Figure 10. Four electrodes on the surface of homogeneous resistivity isotropic ground.

Every array or protocol used during data acquisition (Wenner, Schlumberger, Pole-dipole, Dipole-dipole, etc) has its own K value. Theoretically, the entire ρ_a was derived using Eq. 4. Therefore, ρ_a determined from the ER data acquisition is different due to the K value variations. As a result, it was fundamentally understand that the ERV determined using dissimilar scales via different protocols will generate a different ERV. Moreover, geomaterials physical and chemical influence also may contribute to the ERV variations. ERV is highly associated with water intensity and lithology variations [14]. In some cases, this aspect is taken as a secondary aspect because the crucial factor is influenced by K . Physical and chemical factor of geomaterials may influencing the ERV if the environment and protocol used was same.

Both ERV from laboratory and field environment was able to be connected and correlated using moisture content interpolation for development of correction factor, C thus able to stable the ERV differences from lab and field. Recorded soil moisture content was similarly measured for both ERV environment thus capable as a guidance for field ERV correction. This study aimed to explore a new electrical resistivity practice that can contribute to the determination of basic geotechnical properties with reference to soil moisture content, w according to lab and field ERV correlation. As a result, correction factor, C , was established thru field ERV correction according to interpolation of field and laboratory w . The study revealed that the correction factor, C for field ERV of Clayey SILT was 21.67 Ωm (Point A), 18.65 Ωm (Point B) and 17.50 Ωm (Point C). Therefore, average C for Clayey SILT was found at 19.27 Ωm . C values summary and its related properties are shown in Table 4. In the end, this study has contribute to the establishment of an alternative method for soil moisture content determine based on corrected field ERV via laboratory ERV. Soil moisture content determination was able to be envisaged via equation model established by the statistical processing as given in Figure 6.

The research has shown that the electrical resistivity experienced a good prospects in obtaining basic geotechnical properties correlations via statistical model. Soil moisture content determination can easily obtain from lab and field (using correction factor, C) thus contributing the geotechnical engineers in term of fast, economic and larger data. This approach also able to contribute to the improvement of anomaly interpretation this is classically too much depending on stand-alone qualitative point of view. As reported by [15 and 16] single methods are not enough to stand alone in providing solutions to particular problems. Hence, this study can contribute to support and enhanced the precision of classical geophysical anomaly interpretation since its capability to determine soil moisture content in quantitatively point of view. The quantification of geotechnical properties is vital consideration for geophysical techniques conducted in engineering application [17]. Therefore, classical anomaly interpretation and conclusion reliability was able to be reinforced via additional numerical properties with reference to soil moisture content.

Table 4. Correction factor, C of field ERV established from the field and laboratory data.

Soil Sample	A	B	C
Field ERV, ρ (Ωm)	395	263	289
Lab ERV, ρ (Ωm)	18 ~ 19	15 ~ 14	16 ~ 17
Field Moisture content, w (%)	35.52	48.68	40.12
Lab Moisture content, w (%)	35.14 ~ 36.82	45.7 ~ 49.01	37.05 ~ 43.11
Correction factor, C	21.67	18.65	17.50
Average correction factor, C		19.27	

4. Conclusion

ERV for field and lab environment was effectively conducted using Clayey SILT soil. ERV was essentially effected via geometry factor, K developed by each particular protocols with different scale measurement. The study managed to reduce black boxes via fundamental of resistivity theory. The study revealed that the combination of ERV from laboratory and field environment can contribute to a significant improvement due to its applicable for determination of field and laboratory soil moisture content properties thru statistical correlation together with introducing new field ERV correction factor.

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