Soil Moisture Content and Density Prediction Using Laboratory Resistivity Experiment

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***Abstract*—Natural soils are an intimate mixture of solid, liquid and gas phases. This study establishes a correlation for moisture content and density of a soil with its electrical resistivity. In the past, most of the conventional geotechnical site investigation required bulky and heavy equipment to determine the geotechnical parameters necessary for design and construction purposes. Consequentially, time and cost of the project is increased especially when dealing with some difficult site such as on mountainous terrain. This study is based on laboratory soil box resistivity meter observations made on soils mixed with additions of consistent increments of 1-5 % of water to 1500 gram of remolded soils in loose condition. At least 24 repetitive resistivity test observations were made and the moisture content and soil density was determined concurrently for each of the tests. The observations showed that the electrical resistivity variation decreased in a curvilinear manner with increasing percentage of moisture content. A regression equation and coefficient of determination, R2 for moisture content against soil electrical resistivity value was established by moisture content, *w* = 152.87ρ-0.312 (*ρ* = soil electrical resistivity) and R2 = 0.7718 respectively. While a regression equation and R2 value for bulk density versus soil electrical resistivity value was observed to be ρbulk = -0.107 ln (*ρ*) + 1.7249 and 0.7016 respectively. Hence, a viable method is demonstrated where the electrical resistivity value was applicable and has a great potential for geotechnical data prediction of parameters such as moisture content and soil density.**

***Index Terms*—Correlation, moisture content, soil electrical resistivity and soil density.**

I. Introduction

Geotechnical site investigation faces a challenge from time to time especially when working on sites with difficult accessibility in order to gain the parameter for design and construction purposes. Geotechnical parameters are most important in design and construction for most of the natural or manmade civil engineering structure such as slopes, building, foundation, etc. Conventional and important basic soil properties were moisture content, density, specific gravity, cohesion, friction angle, etc. For some construction on sites with difficult access, the problem faced was always with the difficulty of machinery mobilization and operation. This problem solicits alternative techniques to solve or minimise the current problem with the adoption of geophysical methods. According to [1], geophysical method has a good prospect in order to solve some of the problems related to the conventional site investigation methods.

Geophysical method was originally championed by people from physical sciences and is now gaining increased popularity with geotechnical and structural engineers. The basis of geophysics is the study of earth using a quantitative physical scence approach. In Malaysia, most ongoing geophysical methods are effectively used for field exploration purposes relating to the engineering, environmental and archeological studies such as subsurface profile mapping in order to locate bedrock [2], boulder and cavity [3], groundwater resources [4] – [7] and contamination [8], [9], leachate migration [10], mining [11] and archeology [12]. Geophysical techniques are an indirect or surface method which consists of seismic, geoelectrical and induced polarization, ground penetrating radar, gravity, magnet and electromagnetic. In Malaysian case studies, resistivity and seismic method was the most practical geophysical method used due to the successful contrast outcome, easily mobilized and time saving. According to [13], most of the popular geophysical methods applied in engineering were seismic and resistivity technique. Traditionally, results of those geophysical methods was based on and used for anomaly contrast and verified with the other direct exploration methods such as drilling outcome (borehole) etc. Since such potential of geophysics in engineering is yet to be realized and developed, the application of these techniques are still not being fully utilized. Problems may arise during the applications when the geophysical methods are not being fully explored by the civil engineers due to their lack of exposure and expertise in this field. According to [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.

In geotechnical engineering perspectives, sense of concern and appreciation was commonly viewed from the prospective of contribution and significance due to the geomaterial properties determination and its reliability. The application of alternative methods such as geophysical techniques can be increasingly meaningful in contributing more than its well-known anomaly based outcome since the main task and responsibility of engineers was to design and construct a structure safely. In a developing country like Malaysia, the statistical correlation of geophysical and geotechnical method in soil properties prediction is still an ongoing research with several limitation such as lack of interest,

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confidence, expertise and exposure. The necessity to gain more data with this approach is considered important since it can develop a new technique and database used for properties guidelines prediction which will be applicable in construction industry. According to [14] and [15], resistivity value was highly influenced by pore fluid and grain matrix of geomaterials. Furthermore as stated by [14], electrical current may propagate in geomaterials via the process of electrolysis where the current was carried by ions at a comparatively slow rate. Hence, this study proposed a geotechnical properties prediction (soil moisture content and density) using the statistical correlation of soil resistivity laboratory test and geotechnical laboratory test. This technique has a potential to supply and compliment conventional geotechnical data acquisition due to the efficiency in cost, time and environmental sustainability.

II. Material and Methods

ll tests were conducted using laboratory based geophysical and geotechnical experiments. Disturbed soil sample was taken from Universiti Sains Malaysia, Engineering campus site. Soil classification tests such as particle size distribution test based on [16] was carried out. Electrical soil box resistivity test was performed using Nilsson model 400 soil resistance meters by mixing an original mass of 1500 g of oven dried soil with 1-5 % of distilled water and tested repeatedly at least 24 times (each test used 15, 30, 45, 60 and 75 ml of distilled water based on percentage of water used for 1500 g of soil). For example, a 15 ml of distilled water was added consistently and mixed thoroughly into the originally loose oven dried soil and continuously tested with each increment of distilled water added using soil box resistivity meter for at least 24 determinations of resistivity. After that, the same procedure was repeated using a 30, 45, 60 and 75 ml of distilled water. Soil box resistivity meter consisted of a 4 pin arrangement consisting of 2 current pin (both being located at the end of the soil box) and 2 potential pin (these being located along the middle of the soil box). The function of two end current pins were to inject direct current (DC current) into the soil while the other two potential pins were used to measure a potential difference for calculating the soil resistivity value. Soil moisture content and density was taken immediately after the soil resistivity was measured. Moisture content test was determined for two samples from each soil box test for final averaging purposes. All results obtained from the experiments were analyzed using a statistical regression method. As referred to in [16], the following equations 1 – 3 were used to calculate the resistivity value, bulk density and moisture content.

$$\rho = RA / L \quad (1)$$

where A is the cross-sectional area of the sample, L is the length of the sample between the electrodes and R is the mean resistance of the soil sample ($R=V/I$)

$$\rho_{bulk} = m / V \quad (2)$$

where m is the mass of the soil specimen (solids + water) and V is the volume of the test specimen (total volume)

$$w = ((m_2 - m_3)/(m_3 - m_1)) \times 100 \quad (3)$$

where m_1 is the mass of container, m_2 is the mass of container and wet soil and m_3 is the mass of container and dry soil

III. Results and Discussion

A result from wet and dry sieve test showed that the soil was classified as a Clayey SILT. The statistical correlation results from geophysical and geotechnical laboratory test are presented in Fig. 1 and 2. Detailed results from all the percentage of water (1-5 %) used was given in Table I.

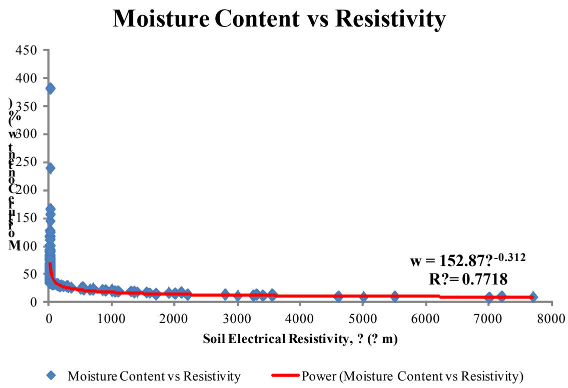

Fig. 1. Moisture content and soil electrical resistivity correlation.

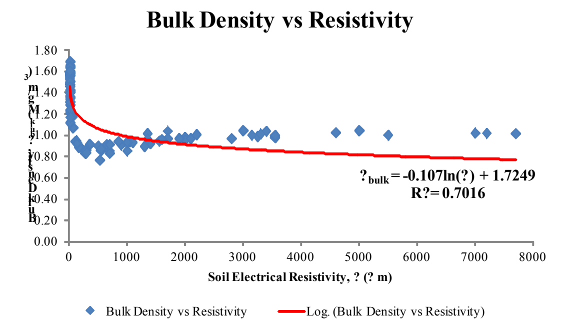

Fig. 2. Bulk density and soil electrical resistivity correlation.

It was found that both correlations showed a curvilinear trend in line with previous researcher findings [17] – [21]. According to Fig. 1 and 2, moisture content and bulk density value was higher with the decrease in soil electrical resistivity value due to the presence of more water content in soil tested. This finding confirmed the past findings which indicated the moisture content value will increase with the decreasing of soil resistivity value [17]–[21]. When water was added continuously from dry soil until it reach oversaturated condition, the ease of current propagation in soil will be increased, thus producing a high to low resistivity value. As reported by [20], ions in pore fluid finds hard to propagate in the low moisture content soil thus producing a low soil conductivity which will cause an increasing of resistivity value.

This study used 1-5 % of water (15, 30, 45, 60 and 75 ml) since it will allow the reading for some limit and variations. For example, the 1 & 2% of water will give more variations for the large resistivity value while 3-5% of water will increased the variation of low resistivity value. Hence, it was found that the range of 1-5 % of water was good enough to produce a soil electrical resistivity correlation with moisture content and soil density from low to high variation.

At the beginning of test, it was found that all the soil tested cannot give any reading due to the limitation of soil sample condition (100 % dry soil conditions which cause the difficulty of current propagation in soil). All soil tested will start give readings after passing some limit of percentage of water added. For this soil box resistivity meter, it was found that the reading will start to exist at 8 % and above of the water added. This phenomenon can also be related to the field resistivity survey where dry condition always gave erroneous observations.

This study found that the resistivity value will continuously decrease as water was continuously added. Despite an overall continuous decrease in resistivity value, a small inconsistency of value reduction from high to low was also recorded. This inconsistency resistivity value was caused by small inconsistent quantity of soil tested for each percentage of water added due to the difficulty of soil handling from dry-moist-saturated-oversaturated. The experiment was carefully performed by filling the soil (mixed thoroughly with water) inside the box without being compacted with the lowest possible void left. However, the workability of soil inside the box was difficult especially when it was at moist to saturated state where the soil was in a highly cohesive condition. The problems continued when it reached saturated to oversaturated state where the quantity of soil tested can be varies due to the large quantity of water added.

Apart from the influence of water, this controlled laboratory study also revealed that the soil electrical resistivity value was highly influenced by the presence of air void content. For example during the moist to nearly saturated condition, the soil tested consisted of some inconsistent voids which increased the soil electrical resistivity value. Furthermore at moist state to nearly saturated state, volume of void was inconsistently present and filled by air which increased the soil electrical resistivity value. According to [3], air filled void posses a higher resistivity value compared with the water filled void.

This study was established to prediction some of the geotechnical parameter such as moisture content and density using controlled laboratory environment. Hence, the prediction is still exposed for some limitation to match the actual field value due to the environmental condition that prevail in the field scale is having higher uncertainties parameter influence compared to the controlled laboratory scale. Based on [20], detailed study related to the field condition such as porosity, degree of saturation, salt concentration in pore fluid, grain size, size gradation, temperature and activity can produce more accurate correlation performed from the laboratory experiment.

IV. Conclusion

The laboratory experiment of soil box resistivity test was successfully being performed. The soil electrical resistivity was greatly influenced by the presence of water and porosity. The correlation of soil electrical resistivity to moisture content and density was presented. The integration of laboratory geophysical and geotechnical method can provide a meaningful contribution for the geotechnical engineers instead of their previous established geophysical field application.

Appendix

All the results from laboratory experiment are given in Table I-V.

TABLE I: Soil Electrical Resistivity Value, Moisture Content and Bulk Density Data for 1 % (15 ml) of Water

MC (%)	P_{bulk} (Mg/m^3)	ρ (Ωm)
7.76	1.02	7000
8.50	1.04	5000
9.59	1.02	4600
10.28	1.04	3000
11.39	0.99	3250
12.56	1.04	1700
13.05	1.00	2200
14.10	0.98	2000
14.87	0.97	1700
15.98	1.01	1350
17.38	0.92	1400
18.07	0.93	1050
18.90	0.93	1100
20.16	0.91	900
21.33	0.91	650
22.44	0.86	550
23.32	0.90	500
25.17	0.91	355
26.96	0.87	300
27.70	0.87	225
29.61	0.94	130
31.52	1.07	70
32.62	1.19	48
32.76	1.42	24
34.55	1.42	19

TABLE II: Soil Electrical Resistivity Value, Moisture Content and Bulk Density Data for 2 % (30 ml) of Water

MC (%)	P_{bulk} (Mg/m^3)	ρ (Ωm)
9.77	1.00	5500
11.42	0.98	3550
13.45	0.97	2800
15.25	0.95	2000
17.18	0.94	1550
18.91	0.89	1300
21.32	0.85	1000
23.38	0.85	700
25.65	0.76	530
27.68	0.83	280
29.95	0.89	190
32.07	1.16	47
34.19	1.40	24
37.07	1.59	16
39.04	1.59	16
41.40	1.58	14
43.27	1.59	14
45.69	1.56	14
48.54	1.57	13
51.50	1.57	13
54.32	1.55	13
56.92	1.59	13
60.92	1.57	13
64.31	1.47	13
67.88	1.47	13

TABLE III: SOIL ELECTRICAL RESISTIVITY VALUE, MOISTURE CONTENT AND BULK DENSITY DATA FOR 3 % (45 ML) OF WATER

MC (%)	P_{bulk} (Mg/m^3)	ρ (Ωm)
8.34	1.01	7700
10.66	1.03	3400
13.10	1.01	3300
16.22	0.96	2100
18.18	0.96	1350
21.07	0.94	850
24.62	0.87	550
27.24	0.85	290
31.03	0.94	110
34.54	1.47	26
36.84	1.65	18
32.85	1.69	16
43.35	1.59	17
46.07	1.56	16
49.37	1.55	15
52.90	1.57	15
56.96	1.56	15
61.32	1.60	14
65.55	1.52	14
67.16	1.50	14
69.58	1.49	14
74.86	1.46	14
88.69	1.45	14
93.29	1.36	14
100.45	1.36	14

TABLE IV: SOIL ELECTRICAL RESISTIVITY VALUE, MOISTURE CONTENT AND BULK DENSITY DATA FOR 4 % (60 ML) OF WATER

MC (%)	Pbulk (Mg/m3)	ρ (Ωm)
9.13	1.02	7200
15.77	1.00	3150
19.27	0.97	1900
23.47	0.93	1000
27.75	0.83	700
31.91	0.88	170
36.04	1.17	50
39.52	1.60	17
43.49	1.58	16
47.12	1.59	16
51.52	1.56	15
55.17	1.58	14
61.31	1.58	14
63.26	1.57	14
67.99	1.54	14
77.68	1.53	14
75.66	1.46	14
83.48	1.47	14
91.52	1.46	14
81.48	1.37	15
110.22	1.41	15
116.39	1.31	15
100.73	1.33	15
75.12	1.31	16
	1.31	16

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