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Dependency of dry density of soil on water content in the measurement of electrical resistivity of soil

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Abstract— Density is defined as the weight of soil per unit volume of soil. Often in the construction of different types of structures in-situ 'fill' is required. In-situ measurement of density is vital for such projects. When soil is being used as fill material it is usually compacted to a dense state to obtain satisfactory engineering properties. Dry density of soil basically depends on many properties of soil. For this reason it is difficult to establish an empirical relationship between electrical resistivity and dry density of soil. For similar typ of grain size distribution and dry density of soil, electrical resistivity widely varies with different percentages of water content. In this study dry density of soil was determined using standard proctor test. After compaction electrical resistivity of soil was measured for different dry density of soil. From the graph of volumetric dry density of soil versus water content of soil, a slightly steeper increment in dry density can be observed with increasing water content. On the other hand in the case of dry density versus electrical resistivity graph, electrical resistivity remains almost same for increasing dry density until it reaches to the peak value. After achieving the maximum dry density a detrimental slopes can be observed in the both graphs. In the case of electrical resistivity of soil, after achieving maximum density of soil it does not decrease in remarkable extent. So except some dissimilarity a common trend can be observed in the both of the graphs. In both graphs after a maximum value, dry density tends to reduce. Also in both cases measured maximum dry density of soil was 1.79, 1.936, 1.792 and 1.821 gm/cm3 respectively. So it can be concluded that for both cases electrical resistivity mostly depends on percentages of water in the soil rather than dry density. It is difficult measure dry density of soil from only electrical resistivity. But the maximum dry density of soil can be found from the least resistivity value.

Index Terms— density, electrical resistivity, percentages of water, maximum soil density

I INTRODUCTION

Density is the mass of solid particles divided by the volume of solid particles. The mass of soil excludes pore space and organic material. A high bulk density is indicative of either soil compaction or high sand content. Most soils have a density between 1 and 2 g/cm^3. Dry density of soil represents well-defined properties of the materials. It is an indicator of soil compaction and soil health [1]. It also provides valueable inforformations such as porosity and void ratio of soil. In terms of agriculture dry density of soil indicates structure of the soil and soil suitibility for growth of plants. Different physical, chemical and biological properties of soil such as infiltration, available water capacity, soil porosity, plant nutrient availability, and soil microorganism activity affected by dry density of soil. So many geophysical methods were used to measure the degree of compaction both at the site and in the laboratory. Among all geophysical methods electrical resistivity is a non destructive and comparatively less time consuming method. Other conventional methods for determination of soil compaction are invasive as well as costly [2]. As it is basically the ratio between mass and volume of the soil, theoretically the value of dry density mostly depends on the mass and the volume of the soil. So the properties that affect both mass and volume such as grain size distribution, soil compaction etc indirectly affect soil dry density. However water content is one properties of soil that directly affect dry density. For every type, grain size of particles there is a specific moisture content in which the density of soil is maximum. But properties of soil such as grain size distribution and soil compaction have comparatively less effect than moisture content in the electrical resistivity of soil. This is a major problem for determining soil dry density using soil resistivty.

II PREVIOUS WORKS ON DRY DENSITY MEASUREMENT USING DIFFERENT GEO-PHYSICAL METHOD

Among many geo-physical methods that have been used for the measurement of soil density, Multichannel analysis of surface waves (MASW), soil conductivity and soil resistivity are most popular methods . Kalinski and Vemuri studied soil compaction using Electrical Conductivity Measurements in 2005. The researchers proposed a new method CQA based on θ [3]. In the year of 2011, Laloy and Javaux used electrical resistivity in moisture content or bulk density of soil measurement incorporate with "pedo-electrical" function. In that study five pedo-electrical models were used to reproduce electrical resistivity as measured by ERT in silt loam soil sample within specific range of moisture and bulk density. In this purpose the Waxman and Smits model, the Revil model, the volume-averaging (VA) model, the Rhoades model, and the Mojid model were inverted within a Bayesian framework to identify the optimal parameter, parameter uncertainty and its effect on model prediction. Sensitivity of the electrical resistivity was studied using calibrated VA model and found that approximately 1.5 times higher sensitivity to soil moisture content than to soil bulk density. In addition, the sensitivity of electrical resistivity to soil moisture and soil bulk density was found to increase as soil moisture and bulk density decreased [4].

On the same year of 2011, Chik and Islam studied on soil compaction estimation using electrical resistivity including chemical characterizations in the soil. In that study four different types of soil was considered. Standard Proctor compaction tests, was carried out for all types of soil sample. Electrical resistivity was measured for compacted soil sample with different percentages of water contents (Figure 1).

Recently Lin and Sun evaluated model-based relationship between cone index, soil water content and bulk density using

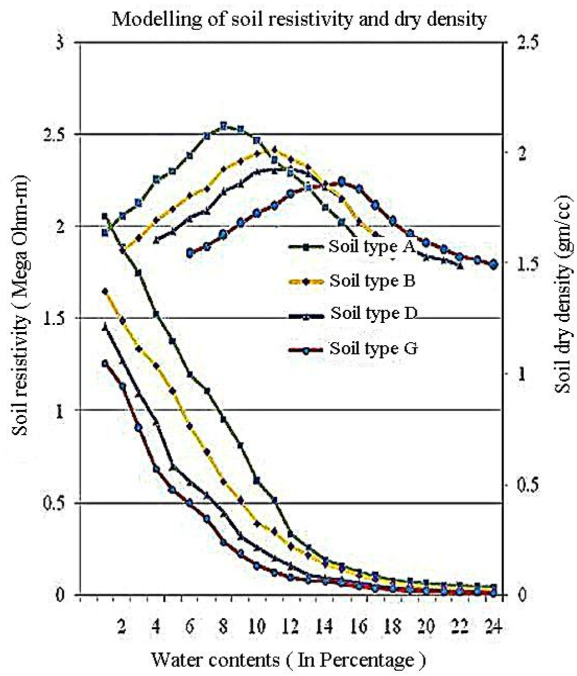

Figure 1 Dry density and soil resistivity for different of water contents in various soil sample [5].

dual-sensor penetrometer [6].

III METHODOLOGY

Soil sample was collected from a slope side near New FKAB building UKM, Malaysia. Four samples were collected from

Figure 2: Location of soil sample collection

four boreholes at different slopes. Then soil grain size distribution was determined using sieve analysis . Sieve analysis was important because soil resistivity defers with the type of soil.

According to Unified Soil Classification System (USCS), this

TABLE 1

Grain size analysis

Sieve No	Sieve opening (mm)	Wt. of soil retained (gm)	Percent soil retained	Cumulative percent retained	Percent finer
4	4.750	117.15	6.5	6.5	93.5
8	2.360	595.19	33.2	39.7	60.3
16	1.180	383.62	21.4	61.1	38.9
30	0.600	235.77	13.2	74.3	25.7
40	0.420	181.87	10.1	84.4	15.6
50	0.300	208.58	11.6	96.0	4.0
100	0.150	66.48	3.7	99.7	0.3
200	0.075	3.31	0.2	99.9	0.1
Pan		12.20	0.7		

average type of soil taken from four boreholes is basically clayey sand (SC). The portion of sand in this type of soil is more so the resistivity value was less. Because clay fillup the voids between which eases the transfer electricity between soil particles.

Soil sample was mixed with different percentages of water within the range of 5 % to 25% (Figure 2). For measuring the exact percentages of water mixed with soil sample following equation (Equation 1) was used,

$$u = \frac{m_{Wet} - m_{Dry}}{m_{Dry}} X100\,\% \qquad (1)$$

Where,

$u =$ Percentage of moisture content

$m_{Wet} =$ Wt. of soil + water

$m_{Dry} =$ Wt.of dry soil

Then the sample is compacted using standard proctor. After that the dry density of soil was measured. As the percentages of water increased dry density of soil also increases gradually. But just after the maximum dry density of 1.79, 1.936, 1.792 and 1.821 gm/cm^3 respectively, it started to decrease with higher percentages of water content. For measuring the dry density of soil follwing equation (Equation 2) was used,

$$\rho_B = \frac{M_B}{V_T} \qquad (2)$$

Where,
ρ_B = Bulk Density of soil
M_B =Mass of the soil particle
V_T = Volume of the soil particle
Just after compaction the resistance of soil was measured using two probe electrical resistivity meter (KYORITSU) (Figure 4). 4 cm distance was considered between the probes.

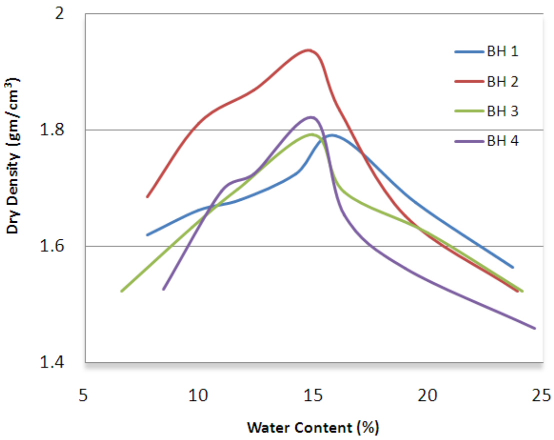

Figure 3: Graph between Dry Densities vs. Water Content

Finally the resistivity of soil was measured using following equation (Equation 3),

$$\rho = 2\pi a A \qquad (3)$$

Where,
ρ = Resistivity of soil
a = Distance between the probes
A = Ristance of the soil between the probes

IV RESULTS AND DISCUSSION

Electrical resistivity of is the opposite electrical properties of conductivity. As water is a covalent liquid, the ions are held

Figure 4: Measurement of electrical resistance after compaction of soil

together by sharing electrons. Most covalently bonded liquids are not electrically conductive because the electrons, which essentially act as the medium by which the electricity travels, are tied up between the atoms they are related to. Also small amount of water does ionize and increase the electrical conductivity of soil.

Due to the effect of water content electrical resistivity of soil tends to decrease with the increasing amount of water con-

TABLE 2

Dry density and Electrical resistivity of soil for different percentages of water content

Borehole	Percentages of water (%)	Dry Density (gm/cm^3)	Electrical Resistivity (KΩ-m)
BH 1	7.7	1.62	108.071
	9.94	1.662	20.86022
	11.78	1.68	5.02656
	14.18	1.724	3.76992
	15.96	1.79	2.51328
	19.42	1.676	2.261952
	23.68	1.564	2.261952
BH 2	7.723	1.685	123.2451
	9.95	1.812	40.36958
	12.36	1.868	13.365916
	14.88	1.936	3.3211
	16.12	1.8345	3.293211
	18.98	1.652	3.2995
	23.87	1.523	3.2855
BH 3	6.6	1.523	196.211
	9.65	1.632	22.3311
	11.65	1.698	11.321
	14.962	1.792	4.31544
	16.33	1.6932	4.325
	19.97	1.6236	4.3111
	24.102	1.523	4.3211
BH4	8.44	1.526	160.2113
	10.95	1.695	63.2525
	12.3669	1.725	9.255
	14.978	1.821	5.361
	16.321	1.654	5.321
	18.966	1.5622	5.35111
	24.654	1.459	5.3569

tent. For borehole 1, from 7.7 % to 11.78 % of water content electrical resistivity between the soil sample drop-off about 104 (KΩ-m). But after a certain level, resistivity does not decrease with the increasing amount of water content. Because at that certain percentage of water content, soil density is maximum so the electrical conductivity is also maximum at that specific water content (Figure 5). Simillar trends can also be observed for other boreholes.

From the graph between dry density and electrical resistivity it can be observed that electrical resistivi-ty gradually decreases with the increase of soil dry density (Figure 6). But just point density increases dramatically with the slight reduction of electrical resistivity soil. However electrical resistivity almost stops changing at approximately 2.51 KΩ-m. After

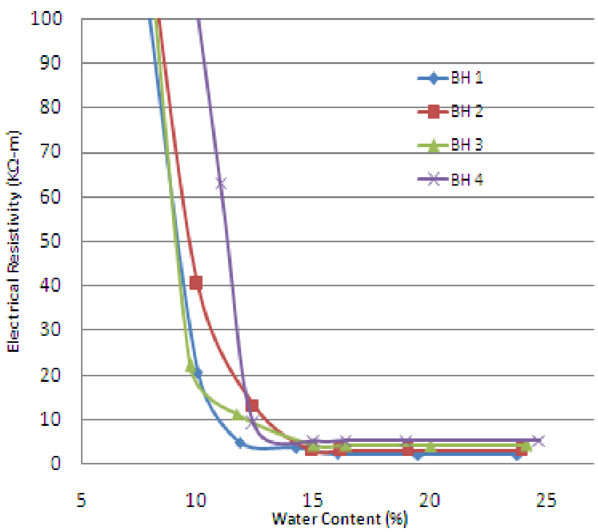

Figure 5: Graph between Electrical Resistivity and Water Content

that dry density of soil, electrical resistivity remains constant with the lower dry density of soil sample.

From Fig 2 and 6 it can be observed that, in both graphs for the dry densities of 1.79, 1.936, 1.792 and 1.821 gm/cm3, trend line of changes its direction. But water content decreases gradually with decreasing dry density of soil. On the other hand after maximum density of soil sample, electrical resistivity does not change with the dry density.

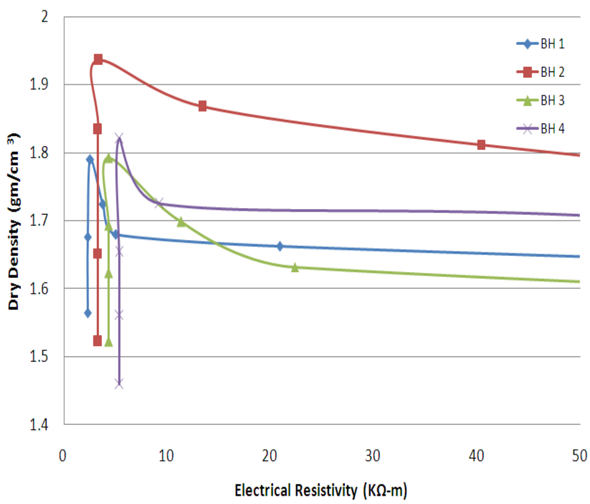

Figure 6: Graph between Dry Density and Electrical Resistivity

So it can be understand that for optimum mois-ture content of soil sample, electrical resistivity is minimum. Within this specific percentage of water, electrical conductivity of soil is maximum. Even if more water is added with the soil, it does not have any effect in electrical conductivity. Also at maximum dry density, soil grains supposed to be placed closest position with each other. For this reason maximum dry density provides minimum resistivity of soil sample.

V CONCLUSION

Compaction of soil is one of the vital parameter for geotechnical engineering. Dry density of soil is directly related with the compaction soil. It is more expensive and time consuming to collect the soil sample from the site and measure the dry density of soil in laboratory. For this reason it is much convenient to measure the dry density at the site of construction using electrical resistivity of soil. But it is very difficult to measure the exact soil density because of water content of soil. In this purpose resistivity ratio between different layers of soil can be considered to avoid the effect of water content on resistivity of soil. Though resistivity mostly depends on the water content of soil, at least maximum dry density of soil can be deter-mined using soil electrical resistivity.

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