Determination of Electrical Resistivity of Organic Clay from Moisture Content and Dry Density

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Abstract. The electrical resistivity of soil is its ability to oppose the passage of electric current through soil. It plays a vital role in various engineering applications such as determining soil corrosivity, designing grounding systems, etc. Organic clay is abundant in many places of the world, and sometimes it is necessary to know its electrical resistivity immediately. Whereas, measurement of the electrical resistivity of soils in the field condition is tedious. So, determining the electrical resistivity from geotechnical parameters will be very useful to field professionals for immediate judgment during construction. For the present study, five organic clay samples have been collected from different locations of Bangladesh. The collected soil samples are found to have organic content between from 22.2% to 36.8%. From the electrical resistivity test, it is observed that the high organic content behaves as a dielectric material absence of moisture. The electrical resistivity of organic clay is higher when the moisture content of organic clay is lower and the density is less. The decrease of electrical resistivity is very high at low moisture con-tent and the change is logarithmic within the range of moisture content studied. The current study also attempted to develop the relationships for the electrical resistivity of organic clay with moisture content, density, and organic content by using multiple regression analysis techniques. These correlations will help to estimate the electrical resistivity of organic clay. However, further detailed investigation may be required before field application by the field professionals.

Keywords: Electrical resistivity, organic clay, dielectric, multiple regression analysis, investigation.

1 Introduction

The electrical resistivity of soil is its ability to oppose the passage (i.e., conductivity) of a current through soil. It is an important parameter that plays a crucial role in various engineering applications, such as determining soil corrosivity, designing grounding systems, assessing geotechnical properties etc. Organic clay, characterized by its high organic content, exhibits unique geotechnical properties that can significantly affect its electrical resistivity [1-4].

Although extensive research works were already performed on the electrical resistivity of inorganic soil, the number of studies on organic soil in this field is very few.

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The studies [5-12] on inorganic soil depicted the dependency of electrical resistivity on the particle size, moisture content, mineralogical composition, salt concentration, degree of saturation, pH, porosity, and compaction of soils. Some researchers have reported the prediction of electrical resistivity from different parameters of organic soil [1-4]. The studies on inorganic soils demonstrate the relationships among electrical resistivity, water content, density, porosity, salinity, etc.

A comprehensive study is scarce that investigates the relationship between various geotechnical parameters (such as moisture content, density, etc.) and the electrical resistivity of organic clay. Existing literature focuses more on inorganic soil [5-12] neglecting the unique characteristics and behavior of organic clay.

2 Methodology

In this study, organic clay from five separate locations in Bangladesh was collected and their basic properties were determined in the laboratory according to ASTM standard test methods. Five separate organic clay samples were collected during the soil boring in the field investigation. The experiments were conducted with disturbed organic clay samples. Both conventional geotechnical tests and electrical resistivity tests [13] were used to determine the geotechnical properties of the organic clay soil samples. Various geotechnical conditions were used to conduct electrical resistivity tests after soil characterization. The experimental program was observed in two stages. The first stage was the effect of different moisture content of the organic clay on the electrical resistivity. The second stage was the effect of the different density of the organic clay on the electrical resistivity.

2.1 Geotechnical Properties of Organic Clay

An experimental program was planned to determine the properties of the collected soils. The experiments included in this laboratory study include a) Organic content (determined according to ASTM standard) [14], b) Natural moisture content, c) specific gravity, d) grain size distribution, d) Atterberg limits, f) water content and unit weight. The collected organic clays samples were classified according to the Unified Soil Classification System (USCS) and confirmed the soil samples were organic clay using liquid limits and plastic limits test results. The Table 1 below summarizes the tests conducted on the organic clay soil specimens. The primary objective of the study was to investigate the resistivity response of soils for different geotechnical parameters. To achieve the objectives, resistivity tests were conducted for different conditions as presented in Table 2.

Table 1. Geotechnical tests summary.

Name of test	Test method	No. of test
Organic content	ASTM D2974	5
Natural Moisture content	ASTM D2216	5

Specific gravity	ASTM D854	5
Grain size distribution	ASTM D7928	5
Atterberg limits	ASTM D4318	5

Table 2. Summary of organic clays resistivity tests for different conditions.

Fixed parameters	Variable parameters	No. of tests
Moisture Content	Dry Density	200
Dry Density	Moisture Content	200
Moisture Content and Dry Density	Organic Content, NMC, Specific Gravity, Fine Content, Atterberg Limits	200

2.2 Electrical Resistivity Test of Organic Clay

The resistivity of the collected organic clay samples was measured in the laboratory according to ASTM G187 [13]. Organic clay samples have been dried at 60^0C temperature for air drying and sieved by #10 sieves. 10% incremental water every time added and compacted in the resistivity box in a predetermined dry density (0.56 gm/cc, 0.58 gm/cc, 0.60 gm/cc and 0.62 gm/cc) and moisture content up to 100%. Thereafter, two voltage electrodes were inserted in the soil sample through the holes in resistivity box. Cables were connected with current and the voltage electrodes. Then the box has been connected with the DT9205A Digital Multi-meter equipment for higher resistance measurement and AEMC Model 4602 made in U.S.A for lower resistance measurement. Electrical resistance of soil sample has been recorded in manual mode of the equipment. Measured resistance was multiplied by calibration box factor (4) to obtain resistivity of the sample. Step by step procedures of electrical resistivity measurement are presented in Fig. 1. Organic clays resistivity tests were conducted at different conditions such as-

a. At a fixed moisture content and changing dry density.
b. At a fixed dry density and changing moisture content.
c. At a fixed moisture content and dry density.

Organic clays resistivity tests were conducted at fixed dry density with different moisture condition. Moisture content was varied from 10% to 100%. The samples were compacted in the resistivity box after thorough mixing with moisture. To obtain organic clays resistivity and dry density correlation, for dry density of 0.56 gm/cc, 0.58 gm/cc, 0.60 gm/cc and 0.62 gm/cc in each sample. Test was repeated for ten moisture conditions such as 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100% in each sample. According to the dry density, soil samples were weighed and compacted in the resistivity box at specific moisture content.

To identify the variation organic clay resistivity with moisture content and density, five organic clay samples were utilized. The followed procedures can be summarized below-

a. Organic clay's resistivity was determined for the moisture condition and dry density.

b. Therefore, organic clay resistivity was correlated with dry density and state of moisture at that condition.
c. Organic clay resistivity tests were conducted to determine the effects of fine fraction, liquid limit, and plastic limit on the resistivity of the organic clays samples.

3 Results

This section presents the results and data interpretation of the evaluation of the electrical resistivity of organic clay. These results demonstrate the change in moisture content and density in the different organic clay samples.

3.1 Geotechnical Properties of Organic Clay

The laboratory tests for the geotechnical properties of organic clays are presented in Table 3.The results of tested organic clays are fine content 96% to 99%, sand content 1% to 4%, silt content 74% to 90%, clay content 7% to 25%, specific gravity 2.081 to 2.121, liquid limit before oven dry 217% to 282% and after oven dry 43% to 55%, plasticity index 111% to 146%, organic content 22.2% to 36.8% and salinity 0.79% to 1.90%. The test results indicate the soils are organic clay (OH) type and the plasticity index values below "A" line according to USCS.

Table 3. Different properties of organic clays used in the present study.

Designation of soil sample	Fine content (%)	Sand (%)	Silt (%)	Clay (%)	Gs	LL (%)	PI (%)	LL* (%)	Organic content (%)	Salinity (%)
OC-1	96	4	87	9	2.08	217	111	55	22.2	0.79
OC-2	97	3	90	7	2.12	269	135	54	25.6	1.57
OC-3	98	2	85	14	2.11	233	122	43	28.9	1.14
OC-4	97	3	90	8	2.12	253	142	47	31.8	1.71
OC-5	99	1	74	25	2.12	282	146	49	36.8	1.90

3.2 Electrical Resistivity of Organic Clay

The electrical resistivity test has been performed in the laboratory of DUET shown in Fig.1. The results indicate that the high organic content behaves as a dielectric material absence of moisture. The electrical resistivity test results of organic clays used in the present study are shown in Table 4.

Fig. 1. Step by step procedures followed in resistivity test

Table 4. Electrical resistivity of organic clay

Sam-ple	Electrical resistivity (kΩ.cm)
	Moisture content (%)

num-ber	Dry density (gm/cc)	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
OC-1	0.56	3,932	628.8	69.32	26.760	8.760	1.860	1.164	0.880	0.756	0.690
	0.58	2,716	444.4	57.76	24.200	7.000	1.776	1.106	0.860	0.748	0.684
	0.60	2,340	208.8	45.96	22.760	4.360	1.604	1.066	0.848	0.740	0.680
	0.62	1,812	104.4	40.08	18.000	3.040	1.500	1.028	0.808	0.716	0.668
OC-2	0.56	4,060	276.8	56.48	21.960	2.840	1.524	1.056	0.808	0.684	0.644
	0.58	3,744	266.0	48.52	17.960	2.792	1.508	1.048	0.784	0.680	0.624
	0.60	2,152	255.6	44.32	15.000	2.604	1.488	1.044	0.752	0.672	0.608
	0.62	1,608	117.2	39.92	12.560	2.488	1.464	1.036	0.712	0.664	0.580
OC-3	0.56	3,556	232.4	45.36	5.576	2.756	2.010	1.080	0.820	0.748	0.700
	0.58	3,152	157.2	38.52	5.356	2.708	1.940	1.064	0.812	0.740	0.677
	0.60	3,004	135.2	27.92	5.004	2.672	1.844	1.040	0.792	0.732	0.653
	0.62	2,496	92.8	24.68	3.956	2.580	1.740	1.004	0.772	0.720	0.609
OC-4	0.56	5,704	346.4	67.92	3.812	1.399	0.911	0.895	0.752	0.682	0.580
	0.58	5,428	290.4	49.12	3.432	1.066	0.907	0.891	0.740	0.648	0.564
	0.60	5,016	173.6	42.20	3.196	1.047	0.904	0.888	0.728	0.625	0.540
	0.62	4,824	158.0	28.48	3.064	1.026	0.900	0.884	0.700	0.582	0.516
OC-5	0.56	7,556	476.4	31.84	3.012	0.999	0.511	0.495	0.479	0.464	0.448
	0.58	6,548	343.2	29.80	2.632	0.666	0.507	0.491	0.475	0.461	0.441
	0.60	4,864	311.2	28.80	2.396	0.647	0.504	0.488	0.472	0.456	0.414
	0.62	4,224	220.8	21.44	2.264	0.626	0.500	0.484	0.468	0.452	0.392

3.3 Impact of Moisture Content on Electrical Resistivity of Organic Clay

Effects of moisture content on electrical resistivity over various types of organic clay at different dry density are presented in Fig. 2, 3, 4, and 5. The electrical resistivity of organic clay is higher at lower moisture content and lower dry density. The electrical resistivity of organic clay has been decreased with increased moisture content and dry density. It is understood that the impact of moisture content and density on the electrical resistivity of organic clay carry crucial role. The electrical resistivity of organic clay decreased with the increase in moisture content at fixed dry density. The rate of reduction in electrical resistivity decreased power with the increase in moisture content.

The electrical resistivity increases from lower to higher at a specific dry density when organic content increases from lower to higher. Another way, electrical resistivity is lower when organic content is lower at a specific dry density, and electrical resistivity is higher when organic content is higher at a specific dry density (except 0.56 gm/cc and 0.58 gm/cc dry density of 20% moisture content). It was observed that there was a high flow of current through the organic clay in the low moisture content, organic content and density which means low conductivity and low flow of current through the organic clay in the high moisture content, organic content and density which means more conductivity. Thus, test results indicated that organic clay samples behaved as a dielectric (a medium or substance that transmits electric force without conduction; an insulator) material in the low density, low moisture and high organic content and resistivity changes dramatically at 10% and 20% of moisture content. Due to the higher electrical resistivity in the higher void and the lower moisture content of organic clay (i.e. infinity in air).

3.4 Impact of Density on Electrical Resistivity of Organic Clay

Fig. 2. The effect of dry density on electrical resistivity over various types of organic clay at 10% to100% moisture content are presented in Fig. 6 to Fig. 15. The electrical resistivity increases from lower to higher at a specific dry density when organic content increases from lower to higher. Another way, electrical resistivity is lower when organic content is lower at a specific dry density, and electrical resistivity is higher when organic content is higher at a specific dry density (except 0.56 gm/cc and 0.58 gm/cc dry density of 20% moisture content) in Fig. 6 and Fig. 7. The electrical resistivity decreases from higher to lower at a specific dry density when organic content increases from lower to higher. Another way, electrical resistivity is higher when organic content is lower at a specific dry density, and electrical resistivity is lower when organic content is higher at a specific dry density in Fig. 8 to Fig. 15.It was observed that there was a high flow of current through the soil in the low density which means low conductivity and low flow of current through the soil in the high density which means more conductivity. Thus, test results indicated that soil samples behaved as a dielectric (a medium or substance that transmits electric force without conduction; an insulator) material in the low density, low moisture and high organic content.

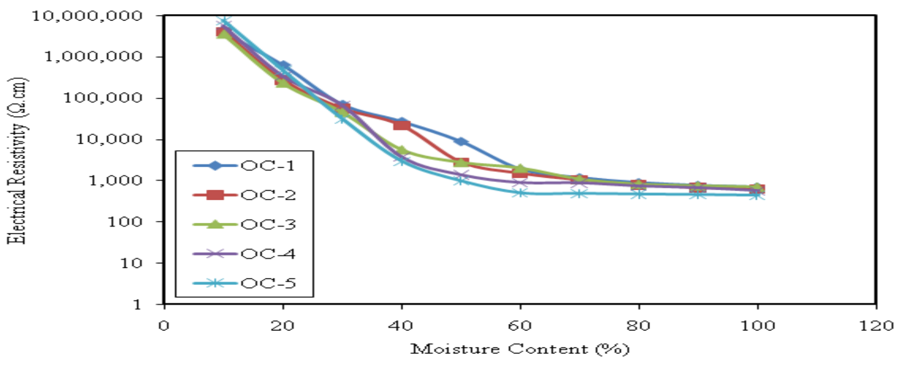

Fig. 2. Effect of moisture content on electrical resistivity over various types of organic clay at 0.56 gm/cc dry density.

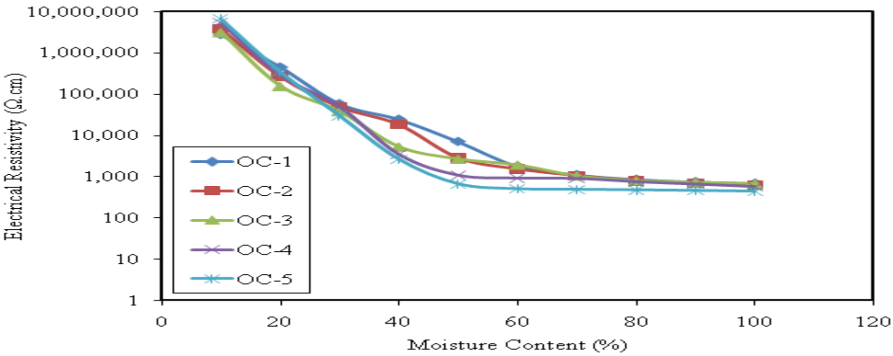

Fig. 3. Effect of moisture content on electrical resistivity over various types of organic clay at 0.58 gm/cc dry density.

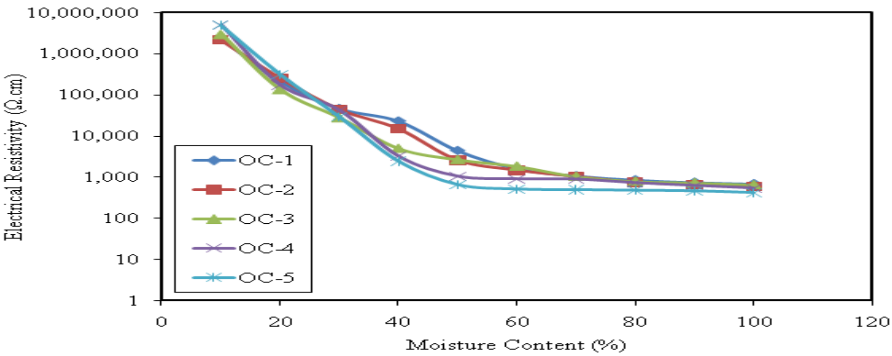

Fig. 4. Effect of moisture content on electrical resistivity over various types of organic clay at 0.60 gm/cc dry density.

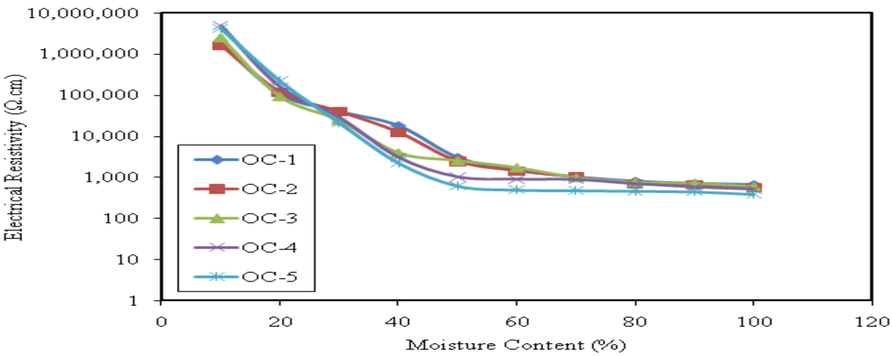

Fig. 5. Effect of moisture content on electrical resistivity over various types of organic clay at 0.62 gm/cc dry density.

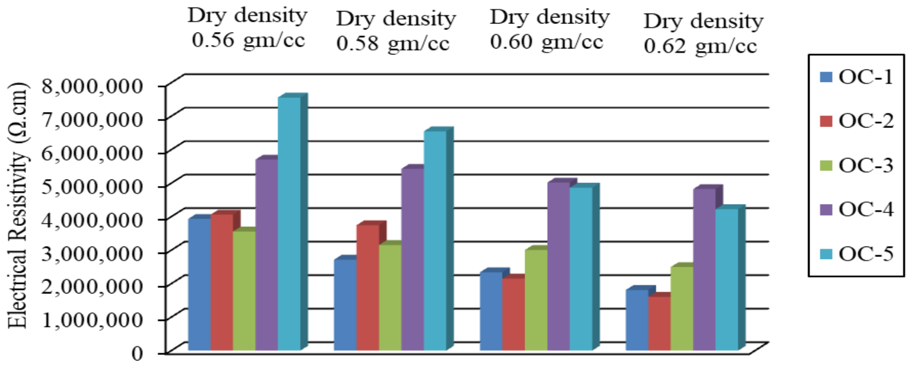

Fig. 6. Effect of density on electrical resistivity over various types of organic clay at w=10%.

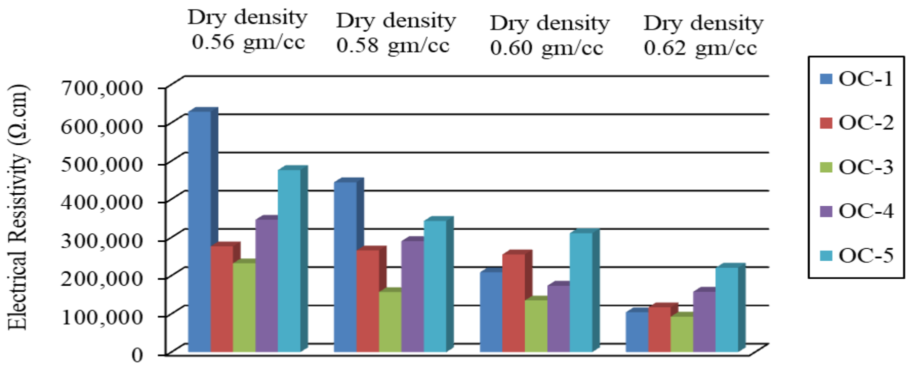

Fig. 7. Effect of density on electrical resistivity over various types of organic clay at w=20%.

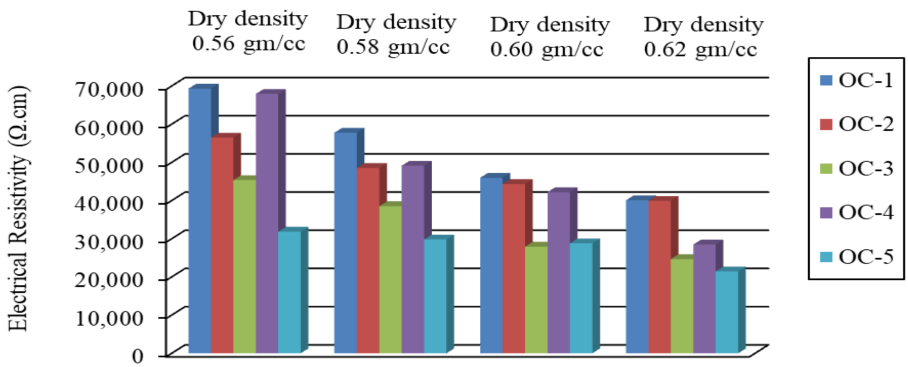

Fig. 8. Effect of density on electrical resistivity over various types of organic clay at w=30%.

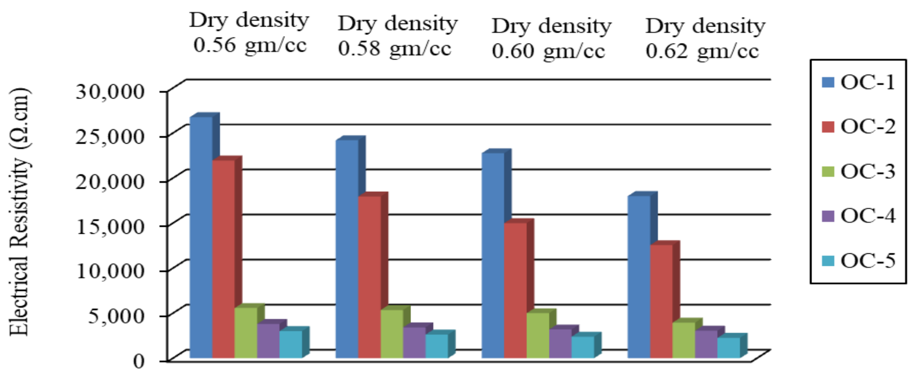

Fig. 9. Effect of density on electrical resistivity over various types of organic clay at w=40%.

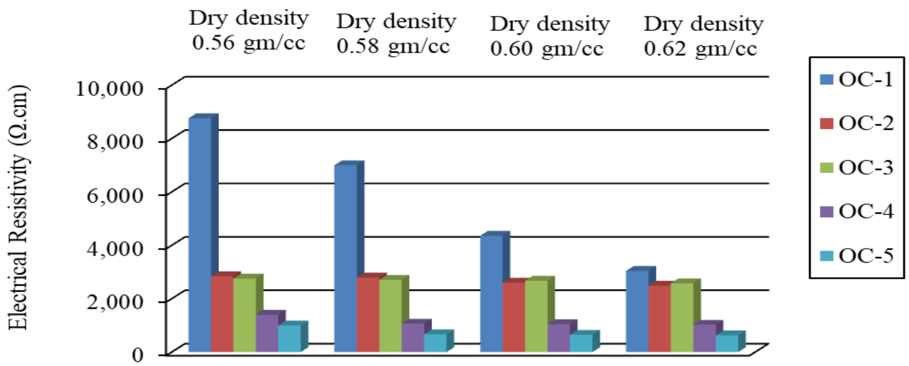

Fig. 10. Effect of density on electrical resistivity over various types of organic clay at w=50%.

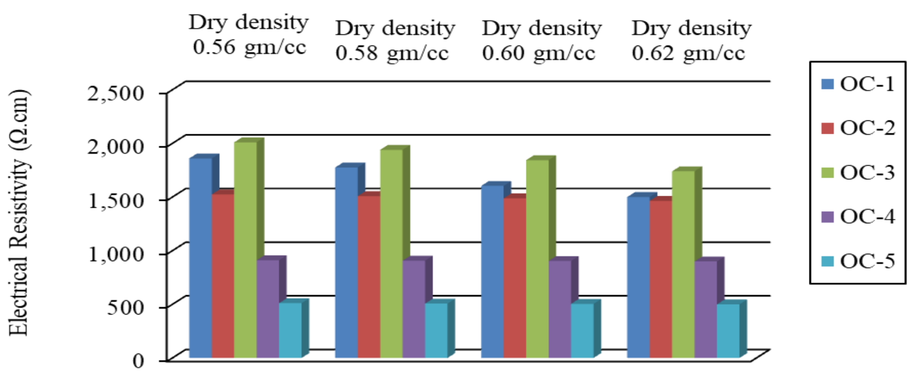

Fig. 11. Effect of density on electrical resistivity over various types of organic clay at w=60%.

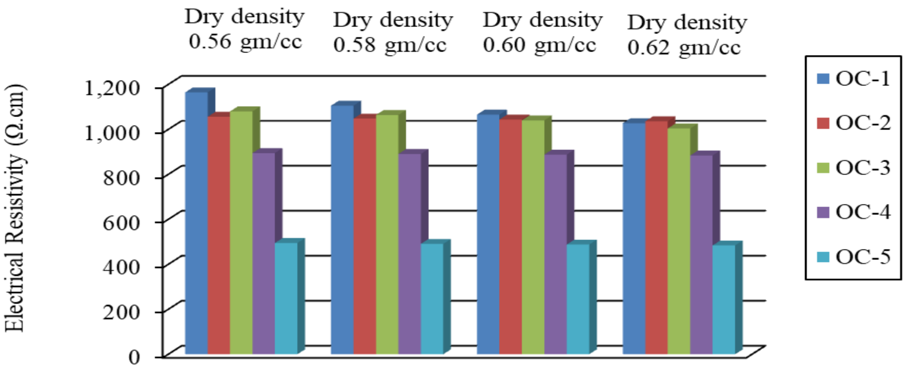

Fig. 12. Effect of density on electrical resistivity over various types of organic clay at w=70%.

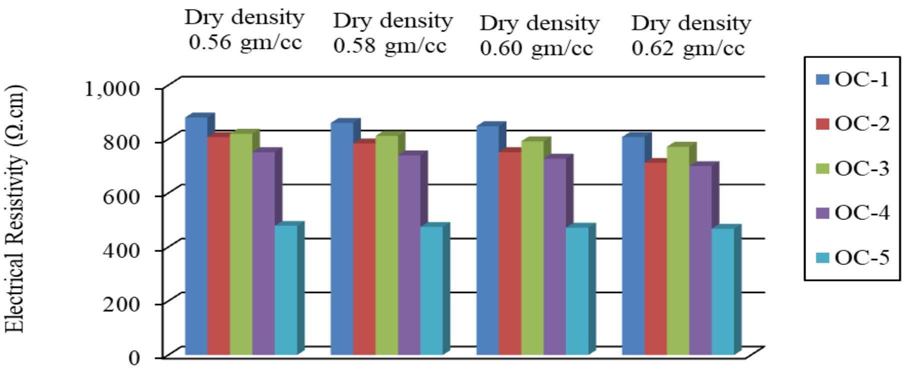

Fig. 13. Effect of density on electrical resistivity over various types of organic clay at w=80%.

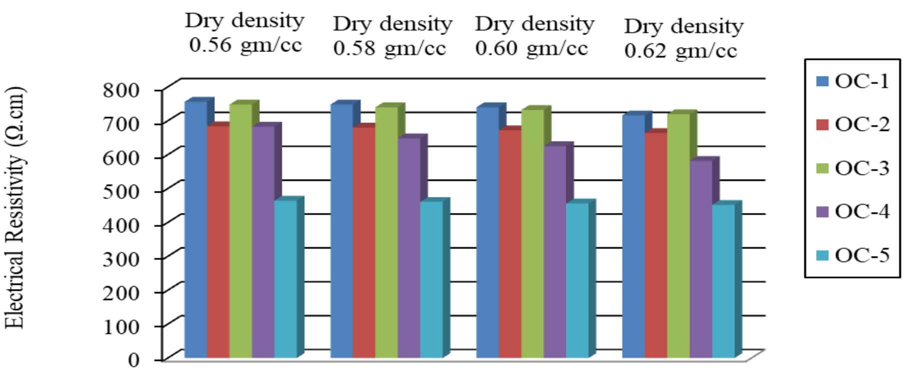

Fig. 14. Effect of density on electrical resistivity over various types of organic clay at w=90%.

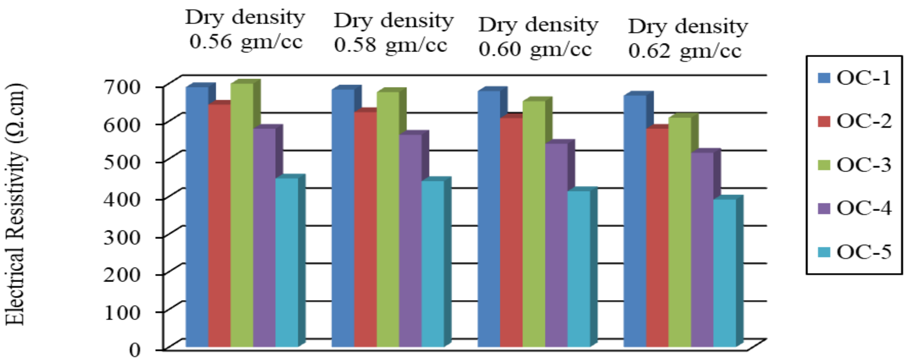

Fig. 15. Effect of density on electrical resistivity over various types of organic clay at w=100%.

3.5 Multiple Regression Analysis of Organic Clay

Multiple regression equation of the form as shown in equation-1 has been used and the value of equation-1 will not be less than 0.

$$\rho = \beta_0 + \beta_1 f(x_1) + \beta_2 x_2 + \beta_3 x_3 \geq 0 \tag{1}$$

Where,

ρ = Electrical resistivity of organic clay,
β_0=Intercept,
$\beta_1, \beta_2, \beta_3$= Multiplying factors,
$f(x_1)$= It is a nonlinear function ofx_1, the moisture content of the soil,
x_2= Dry density, and
x_3= Organic content

The parameters of the equation have been computed by two steps using Microsoft Excel software. First step was nonlinear graphical method and second step was linear regression analysis method.

First Step:

The measured results from the electrical resistivity test in Fig. 16 and Fig. 17 were used to create the electrical resistivity vs. moisture content curve. Fig. 16 and Fig. 17 depict moisture contents, respectively, ranging from 30% to 50% and 50% to 100%. To create a correlation equation between electrical resistivity and moisture content, a trend line was added to the curve. It is equipped with a power formula. The trend line power equations that are provided below are equation (2) from Fig. 16 and equation (3) from Fig. 17.

$$\rho_{w1} = 1.52\times10^{13} w^{-5.82E+00} \tag{2}$$

$$\rho_{w2} = 2\times10^{6} w^{-1.78} \tag{3}$$

Equations (2) and (3) are considered to impact the moisture content. The remaining electrical resistivity of organic clay is considered due to the organic content and dry density. Now, electrical resistivity is determined due to the organic content. Electrical resistivity due to the organic content is calculated by measuring electrical resistivity minus the calculated electrical resistivity of the impact of moisture content by equation (2) and (3). Then the remaining electrical resistivity versus organic content curve was generated in Fig. 18 and Fig. 19. Fig. 18 is for 30% to 50% moisture content and Fig. 19 is for 50% to 100% of moisture content. A trend line was added to the curve for a correlation equation between remaining electrical resistivity and moisture content. It is fitted with a linear equation. The equation (4) from Fig. 18 and equation (5) from Fig. 19, both equations are trend line linear equations given below-

$$\rho_{oc1} = -1099.7\ OC + 34301 \tag{4}$$

$$\rho_{oc2} = -82.952\ OC + 2486.8 \tag{5}$$

Equations (4) and (5) are considered to impact the organic content. The remaining electrical resistivity of organic clay is considered due to the dry density. Now, remaining electrical resistivity is determined due to the dry density. Electrical resistivity due to the dry density is calculated by measuring electrical resistivity minus the calculated electrical resistivity of the impact of moisture content by equation (2) and (3) minus the calculated electrical resistivity of the impact of organic content by equation (4) and (5). Then the remaining electrical resistivity versus dry density curve was generated in Fig. 20 and Fig. 21. Fig. 20 is for 30% to 50% moisture content and Fig. 21 is for 50% to 100% of moisture content. A trend line was added to the curve for a correlation equation between remaining electrical resistivity and moisture content. It is fitted with a linear equation. The equation (6) from Fig. 20 and equation (7) from Fig. 21, both equations are trend line linear equations given below-

$$\rho_{\gamma d1} = -141313\gamma_d + 83674 \tag{6}$$

$$\rho_{\gamma d2} = -4425.8\ \gamma_d + 2621.3 \tag{7}$$

Second step:

After the determination of the electrical resistivity of organic clay due to the moisture content, ρ_w, organic content, ρ_{oc}, and dry density, ρ_d, it is analyzed by in Microsoft Excel. Where, the measured electrical resistivity of organic clay was considered as the dependent variable, and the electrical resistivity of organic clay due to the moisture content, ρ_w, organic content, ρ_{oc}, and dry density, ρ_d as independent variables. As outcomes the coefficient of moisture content, ρ_w, organic content, ρ_{oc}, and dry density, ρ_d as independent variables in Table 5 and Table 6.

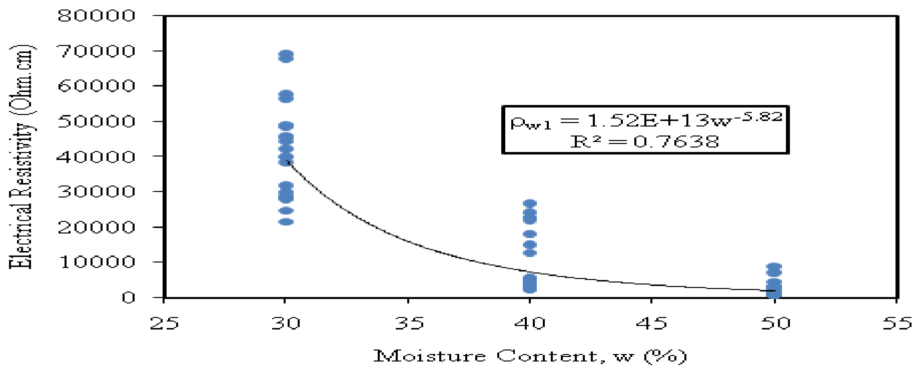

Fig. 16. Electrical resistivity versus moisture content curves at w=30% to 50%.

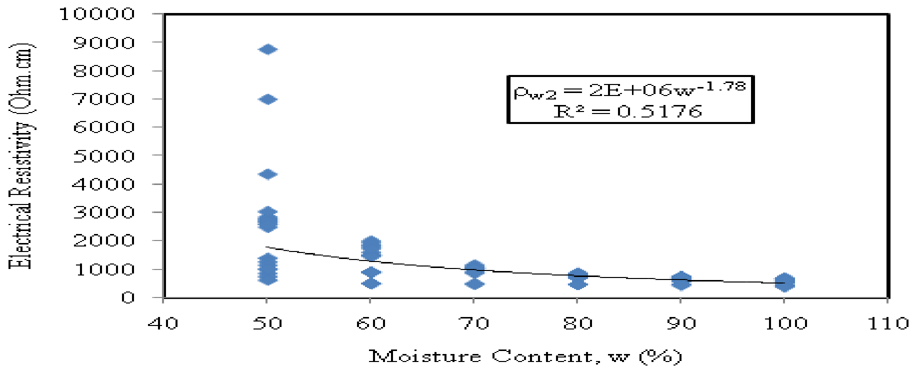

Fig. 17. Electrical resistivity versus moisture content curves at w=50% to 100%.

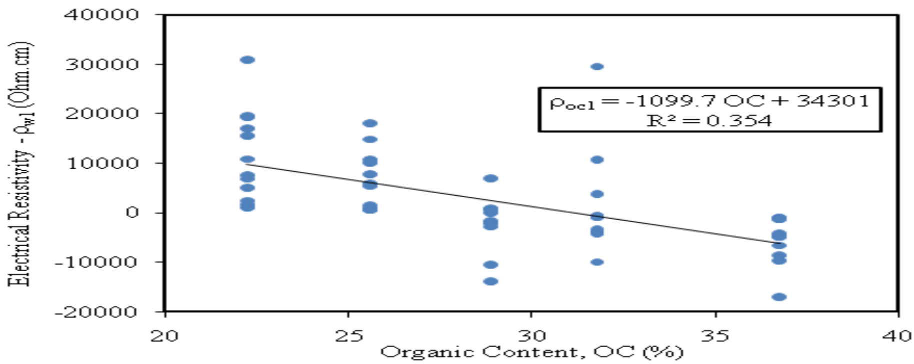

Fig. 18. Electrical resistivity versus organic content curves at w=30% to 50%.

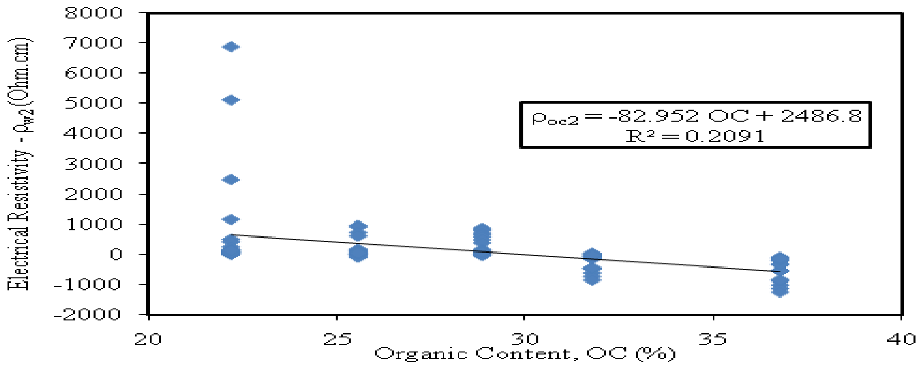

Fig. 19. Electrical resistivity versus organic content curves at w=50% to 100%.

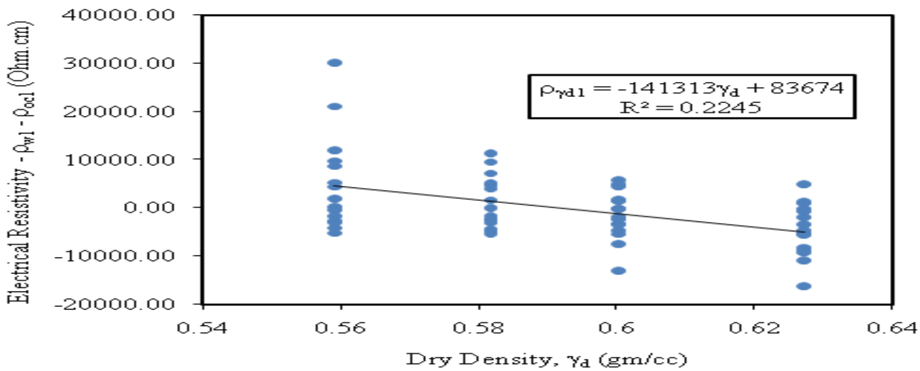

Fig. 20. Electrical resistivity versus dry density curves at w=30% to 50%.

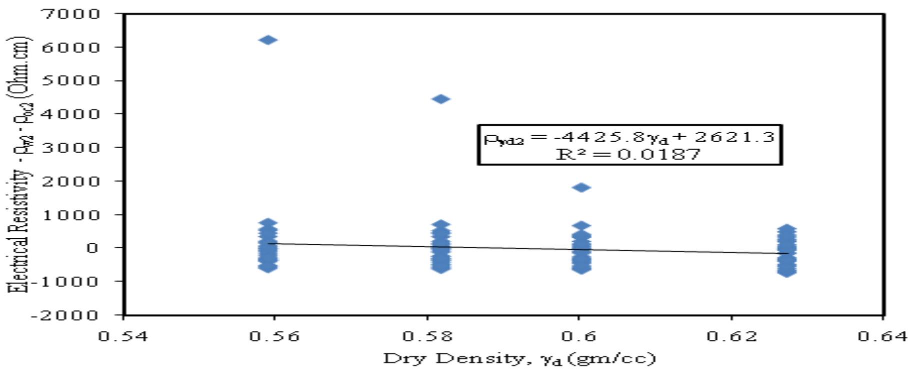

Fig. 21. Electrical resistivity versus dry density curves at w=50% to 100%.

Table 5. Coefficient of variables for w=30% to 50%

	Coefficients

Intercept	-753964.67
X Variable, moisture content, y_w	1.06
X Variable, organic content, y_{oc}	1.00
X Variable, dry density, yd	10.00

Electrical resistivity of organic clay for w=30% to 50%

$$\rho_1 = 1.61\times10^{13}\, w^{-5.82} - 1099\, OC - 1413130\gamma_d + 117076.33 \geq 0 \quad (8)$$

Table 6. Coefficient of variables for w=50% to 100%

	Coefficients
Intercept	-512.24
X Variable, moisture content, yw	1.49
X Variable, organic content, yoc	1.00
X Variable, dry density, yd	1.00

Electrical resistivity of organic clay for w=50% to 100%

$$\rho_2 = 2.98\times10^{6} w^{-1.78} - 82.95 OC - 4425\, \gamma_d + 4594.76 \geq 0 \quad (9)$$

Where,

ρ = Electrical resistivity of organic clay,
w = Moisture content of organic clay,
OC = Organic content of organic clay, and
γ_d= Dry density of organic clay

The observed electrical resistivity (ER) of organic clay is shown in Fig. 8 together with the electrical resistivity (ER) computed using equations (8) and (9). Up to 10,000 ohm.cm of measured electrical resistivity, the calculated electrical resistivity is greater than the measured electrical resistivity of organic clay. Consequently, the computed electrical resistivity (ER) values of the organic clay are either smaller or similar to the measured ER values. The moisture content is known to be a nonlinear function. Significant correlation existed even then between the measured and calculated electrical resistivity's (R^2= 0.929).

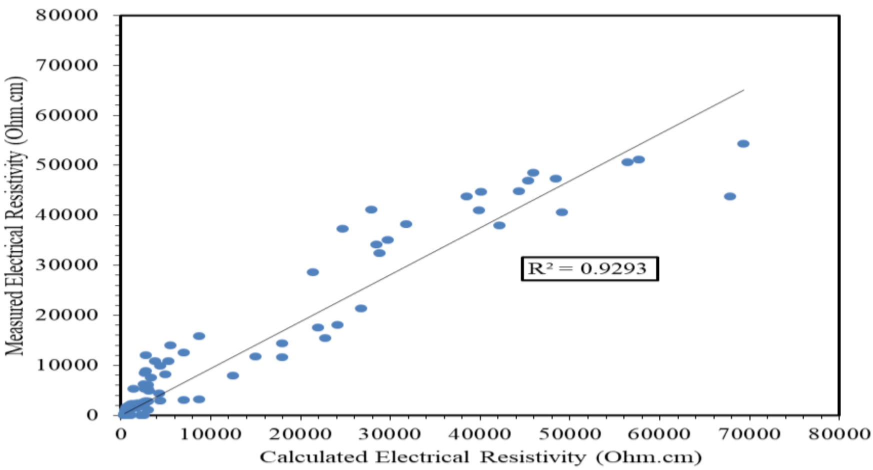

Fig. 22. Correlation between measured and calculated electrical resistivity of organic clay.

4 CONCLUSIONS

The main outcome of the study has been summarized below-

1. Electrical resistivity of organic clay decreased with the increase in moisture content. The rate of reduction in electrical resistivity decreased exponentially with the increase in moisture content.
2. Electrical resistivity of organic clay decreased with the increase of density of organic clay. The rate of reduction in electrical resistivity is to increase linearly with an increase in the density of organic clay.
3. The electrical resistivity increases with the decrease in the organic content of organic clay.
4. Some mathematical relations have been formulated for various ranges of moisture content and dry density by using multiple regression analysis from the test results obtained under this study shown in equation (8) and equation (9).
5. Organic clay behaved as a dielectric (a medium or substance that transmits electric force without conduction; an insulator) material with low density, low moisture, and high organic content. The high organic content behaves as a dielectric material absence of moisture.

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