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Full Length Research

Evaluating the geotechnical and electrical properties of soil samples around Delta State Polytechnic, Ozoro, Nigeria

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ABSTRACT: Effective earthing system is the lifeline of any electrical wiring and installations. This study was done to evaluate the geotechnical (moisture content and electrical conductivity) and electrical properties of soil samples within the school of engineering complex, Delta State Polytechnic, Ozoro, Nigeria. All the geotechnical and electrical parameters investigated in this study were done in accordance to ASTM International approved methods. The electrical conductivity meter was used to measure the soil electrical conductivity; while the soil resistance was measure through the Wenner four probes method. Results obtained from but the field and laboratory tests revealed that the soil electrical conductivity, soil moisture content and the soil resistances varied greatly across the study area. The moisture content ranged from 15.48 to 24.45% (wb); while the electrical conductivity ranged between 3.09 and 5.41 dS/m. The results revealed that the soil resistance decreases as the probe distance increased from 5 to 10 m. At 5 m probes distance, the soil resistance varied between 4.8 and 17.2 Ω; at 10 m probes distance, the soil resistance ranged from 2.9 to 14.8Ω; while at 15 m probes distance, the soil resistance fell between 1.5 and 10.5 Ω. In terms of the soil resistivity, the results showed the region with clay soil had the lowest soil resistivity (mean~158.15 Ωm), while the region with the sandy recorded the highest soil resistivity of 820 Ωm. The knowledge of these soil properties is crucial for design of earthing systems for structures within the school of engineering complex. This will help to minimize electrical hazards to both human being and the materials within the complex.

Keywords: Earthing, electrical conductivity, moisture content, soil resistance, soil resistivity.

INTRODUCTION

The earth consists of different strata which are made of different materials, and acts as a reservoir of excessive charges. Earth had electrical properties that are practically utilized daily basics, in power distribution and consumption. One of these electrical properties is the resistance, which determines the amount of electric current that passes through it. The resistance developed by each earth's stratum depends on the materials it is made of. According to Idoniboyeobu et al. (2018), different earth location had different electrical resistance which can be high or low. Although earth had poor electrical conductivity properties, due to its high resistivity; but under high current and high moisture content, the earth becomes a fairly good conductor of electricity (Adelakun, 2018; Arshad et al., 2020). According to Johnson (2006), soil resistivity is the resistance between two opposing surfaces of a 1 m^3 cube of the soil. It is a key factor using the design of earthing systems, and it is affected by the soil electrical conductivity, soil type, temperature, water content, heavy metals content etc. (Omar, 2012; Oyubu, 2015). According to Omar (2012), soils with coarse particles and low pH had higher electrical resistivity; while soils with fine particles and high pH usually have power electrical resistivity. Soils with low pH or very high pH have negative impacts on the earthing rod, as corrosion or pitting can set in with time. According to Olowofela et al. (2020), soil resistivity greatly influenced the performance of earthing systems. It had been observed that soils with high resistance are not considered appropriate for operative earthing system, as they will compromise the proper function of the earthing system (Ronda et al., 2020). The European standards EN-62305-3 recommend earth resistance of 10 Ω for structures in which direct equipotential bonding is applied (International Electrotecnical Commission [IEC], 2010). Therefore, special treatments (conditioning) are administered to the soils with high resistance, before they are used for earthing purposes. Some of these treatments are made of carbon-based materials or clay-based materials. According to IEC 62561-7, the treatment material must be chemically inert to the subsoil and environmentally friendly; most importantly, it should not be corrosive to the earthing electrodes and other material used (IEC, 2018). El-Tous and Alkhawaldeh (2014) reported that materials that are used for soil treatment are to be poured into the hole around the earth electrode, at the distance not exceeding 10 cm to the electrode, to prevent corrosion of the electrode.

Earthing is an essential part of electrical wiring and installation; that protect the system against excess voltage, which can occur either through electrical fault or lightning. Earthing is the flow of excessive voltage directly to the earth body through the low resistance cables, usually copper cables or strips. Appropriate earthing ensures safety of all the electrical materials and the people using them, during the event of an excessive voltage. Therefore, electrical design of the earthing system must withstand the high voltage that passes through it, while guaranteeing the safety of the electrical materials and human within the environment (Aplicaciones, 2018; Malanda et al., 2018). Apart from the destruction of lives and properties, faulty earthing system can induce electromagnetic disorder; hence, causing sensors failure, surface noise, computer malfunction, communication loss, etc. (Aplicaciones, 2018). Optimizing the performance of earthing systems has become a great concern to electrical engineers, during electrical wiring design. Dwarka and Sharma (2012) reported that poor earthing design and installation will lead to technical failure that can caused electrocution and material damaged. Therefore, appropriate earthing is a vital tool required for the stabilization of electricity production, transmission and consumption. Several earthing techniques such as; cable or strip, rod, pipe, plate earthing, are been used by engineers nowadays (Circuitglobe, 2018). Since electrical resistivity is very essential in electrical wiring and installation, the determination of the resistance of the various earth stratum and location become inevitable. Oyeleye and Makanju (2020) evaluated the soil resistivity of the Federal University of Technology, Akure, Nigeria, and reported that the soil resistivity varied across the tested area. The soil resistivity of Delta State University, Oleh campus was determined by Oyubu (2015), and reported that resistivity varied with soil depth and location. Although several works had been done on the electrical resistivity of various soil samples at different locations, there is no reported literature on the electrical resistivity of Ozoro community soil samples. Hence, this study was carried out to determine the electrical resistivity of soil around School of Engineering Complex, Delta State Polytechnic, Ozoro, Nigeria. Results obtained from this research will provide useful information for appropriate earthing systems for the buildings around and inside the complex.

MATERIALS AND METHODS

Study site description

This study was carried out at the School of Engineering Complex, Delta State Polytechnic, Ozoro, Nigeria. The complex is about 50,000 m^2 (5 hectares) and altitude of 14 meters. It has bimodal rainfall distribution pattern with peaks in July and September, with average temperature of 28 ±5ºC (Eboibi et al., 2018). Within the study area, four geographically locations were selected for soil resistivity test. The area was devoid of buried electrical cables or other metals that can influence the results. The geographical co-ordinates of the four points are given in Table 1. At each test location, soil samples were collected with the aid of soil auger for geotechnical analysis.

Soil resistivity determination

The soil resistivity test was done according to the Wenner four-electrode method described by ASTM G57 (2006). The Wenner four-electrode method is one of the best methods in determining the resistivity of soil samples both *ex situ* and *in situ* (Oyeleye and Makanju, 2020). This method uses a ground resistance meter and 4 probes. At each test location, the probes (electrodes) were inserted into the soil at a defined depth (1 m) and distance and coded accordingly. Three distances of 5, 10 and 15 m between probes were used in this study. The C1 and C2 terminals are connected to the outer (current) probes; while the P1 and P2 are connected to the inner (voltage) probes (Dharmendra, 2012). After the connections had been secured, the earth resistivity meter was turn on, and left to run for about 30 seconds until a stable result was displayed on the meter screen the values were recorded. When the meter is turn on, a current is made to pass between the C1 and C2 terminals; while the resulting voltage is measured between the P1 and P2 terminals. The measured resistance is the ratio of the applied voltage to the resulting current flow, and it is expressed in Equation 1 (Oyeleye and Ale, 2019). Then the resistivity of the soil was calculated using Equations 3, which was derived from Equation 2 (Southey and Dawalibic, 2005).

$$R = \frac{V}{I} \quad (1)$$

Where: R = resistance (Ω), V = potential difference across the conductor (V) and I = current flowing through the conductor (A).

Table 1. Co-ordinates of the test locations

Location	Co-ordinates	Remark
A	Lat. 5 º 33`36`` North; Long. 6º14`56`` East	Scare vegetative cover
B	Lat. 5º 33`41`` North; Long. 6 º 14`54``East	Thick vegetative cover
C	Lat. 5º 33`58`` North; Long. 6 º 15`13``East	Little vegetative cover
D	Lat. 5º33`75`` North; Long. 6 º 14`98``East	Thick vegetative cover

Figure 1. Taking the weight of the soil samples.

$$\rho = 2\pi a \frac{\Delta V}{I} \quad (2)$$

$$\rho = 2\pi aR \quad (3)$$

Where: ρ = Resistivity (Ωm), a = Probe spacing (m), ∆V = Voltage measured (V), I = applied current (A) and R = Measured resistance (Ω)

Geotechnical analysis of the soil samples

Soil moisture content test

The moisture can was weighed with a digital weighing balance, and 20 g of the soil sample was poured into it (Figure 1). The cans were dried in the laboratory oven at 105ºC, and the weight was constantly monitored every 3 hours, until a stable weight was attained. Then the moisture content of the soil sample was calculated using equation (4) (Akpokodje et al., 2018).

$$MC = \frac{W_2 - W_3}{W_2 - W_1} x100 \text{ (wet basis)} \quad (4)$$

Figure 2. Determining the electrical conductivity of soil samples.

Where: MC = Moisture content, W_1 = Weight of moisture can (g), W_2 = Weight of wet sample + moisture can (g) and W_3 = Weight of dry sample + moisture can (g).

The soil electrical conductivity

The electrical conductivity of the soil samples was measured according to the procedures recommended by ASTM D1125. An electronic electrical conductivity meter (model DDS-11C, Shanghai Puchun Measure Instrument Co., Ltd, China) was used to measure the electrical conductivity of the soil samples (Figure 2).

Data analysis

The obtained data were subjected to descriptive statistical analysis such as mean, standard deviation and table.

RESULTS AND DISCUSSION

Soil electrical conductivity and textural nature

The electrical conductivity and textural quality of the tested soil locations are given in Table 2. The soil electrical

Table 2. The electrical conductivity and texture of the soil samples.

Location	Electrical conductivity (dS/m)	Textural nature
A	3.09	Sandy-loam
B	5.41	Clay
C	3.23	Loam
D	4.15	Loamy - Clay

dS/m = deci Siemens per metre.

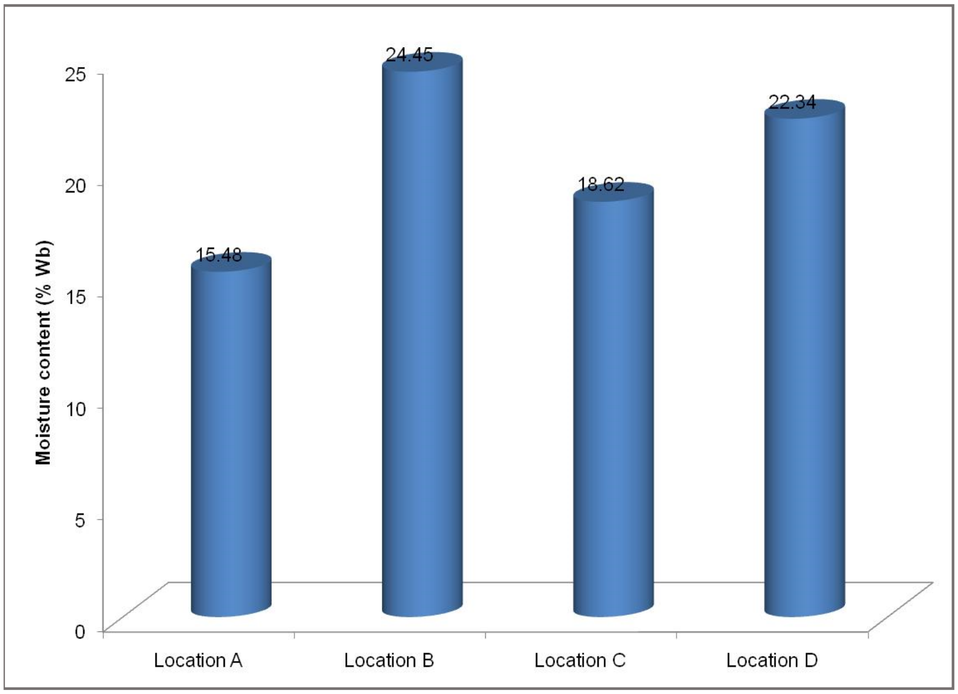

Figure 3. Location soil moisture content.

conductivity varied across the study site. The highest electrical conductivity was recorded at spatial point B (5.41 dS/m); while the lowest electrical conductivity was observed at spatial point C (3.23 dS/m). The high electrical conductivity observed at spatial points C and D could be attributed to the fine grains nature of the soil particles and high humus contains. According to Wightman et al. (2003), soil with fine grain particles and good humus content has the capacity of having high electrical conductivity due to the present of dissolved salts solution.

As seen in Table 2, soil within location A was mainly sandy-loam, location B had clay soil nature, location C was loamy soil, while location D had loamy-clay textural nature. This depicted that the study area does not have uniform textural nature as the grains sizes varied widely across the area. This anomaly will surely affect the soil resistivity of the area. Akwukwaegbu and Gerald (2017) reported the nature (size) of soil particles greatly influences the resistivity of the area; as fine particle soils tend to have lower resistivity, compared to the coarse particle soils. Kalinski and Kelly (1993) stated that soils with high percentage of dry un-compacted fine particles will have smaller soil resistivity values when compared with soil having high percentage of dry coarse particles. This is because the compaction will negatively affect the hydraulic conductivity of the soil; hence affecting the conduction of electric current through it.

Soil moisture content

Results obtained for soil moisture content as presented in Figure 3 showed that the soil moisture content varied broadly across the region. The soil samples collected from location B had the highest moisture content of 24.45% (Wb), while the soil samples collected from location A recorded the lowest moisture content of 15.45% (Wb). Location C and D recorded soil moisture content of 18.62 and 22.34% (Wb) respectively. This portrayed that location B and D had high water retention capability, compared with

Table 3. Resistance of the soil at different location and spacing

Spatial point	Soil resistance (Ω)		
	5 m apart	10 m apart	15 m apart
Location A	17.2±1.2	14.8±1.8	10.5±1.3
Location B	4.8±0.8	2.9±0.5	1.5±0.5
Location C	9.5±1.1	7.1±.08	4.9±0.8
Location D	7.8±0.2	5.4±0.5	2.4±0.9

± = standard deviation.

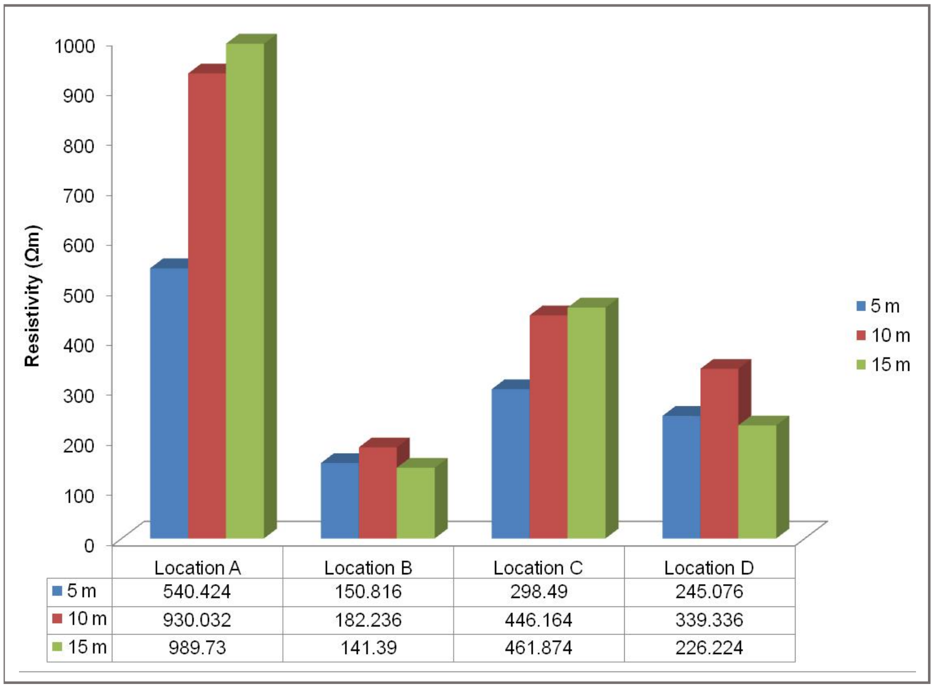

Figure 4. The soil resistivity at different location and spacing.

the soil at location A and C. The high moisture content in location B and D helps in dissolving the salts present in the soil, hence enhancing the electrical conductively and soil resistivity. According to Kižlo and Kanbergs (2009), soils with high moisture contents usually have very low soil resistivity, since the conductivity of ions in the soil is dependent on the concentration of dissolved salts solution present in the soil. Additionally, Kazmi et al. (2016) stated that clay soils had poor electrical resistivity because of its high water retaining capacity. Similarly, Cosenza et al. (2006) observed a sharp decline in the electrical properties of soils samples as their moisture content declined.

Soil resistivity

The results of the electrical tests obtained from this study are presented in Table 3 and Figure 4. As presented in Figure 4, the electrical resistance of the soil varied across the study area, and decreases at the distance between the probes and increased from 5 to 15 m. Generally, the study revealed that location A had the high soil resistances, while location B had the lowest soil resistance. An average soil resistance of 14.16 Ω was record at location A, which was followed by location C which had soil resistance of 7.1 Ω. Location B and D developed soil resistance of 3.1 and 5.2 Ω respectively. In terms of the soil resistivity, it was observed from the results given in Figure 4 that location A had the highest resistivity (mean ~ 820.06 Ω m); while location B recorded the lowest soil resistivity of 158.3 Ωm. Likewise, spatial point C and D had mean soil resistivity of 402.18 and 270.2 Ω m respectively. The lowest resistance and resistivity recorded at locations B and D of the study area could be attributed to the clayey nature of the soil and its high moisture content. According to Lim et al. (2013), fine grains soils with high moisture content and high salts solution have the tendency of having lower resistivity; compared to coarse dry grains soils, with little salts solution. Apart from the soil texture, the high soil resistivity recorded at location A could be attributed to the compaction the area is subjected to. Location A is an open ground, in front of the complex, and it is subjected to high human and vehicular traffic regularly. According to Seladji et al. (2010), high soil compaction increased soil resistivity, and it is more obvious in dry compacted soils. These results confirmed the previous results obtained by Telford et al. (1990) that very coarse grains soil recorded higher resistivity (greater than 3000 Ωm), when compared to fine grains soils that recorded very low resistivity of about 18 Ωm. Lukong et al. (2015) reported that a good grounding system must be reliability in protecting lives and properties during lightning or electrical faults.Very low soil resistance (about 5 Ω) is ideal for earthing system, because low resistance facilitates fast protection structure that will isolate the voltage source; hence, making the earth potential rise less hazardous to human and electrical materials (Idoniboyeobu et al., 2018). From this study, it can be seen that location B and D and very good locations for installation of earthing systems, due to the superiors electrical and geotechnical properties that they displayed.

Conclusion

This research work was carried out to determine the electrical and geotechnical properties of soil samples at different locations. The results revealed that electrical and geotechnical properties of the school of engineering complex, Delta state Polytechnic, Ozoro, Nigeria, varied widely across the area. The four selected points within the study area revealed that, the soil texture varied from sandy-loam to clay soil. The soil electrical conductivity ranged between 3.23 and 5.41 dS/m, with the clay soil having the highest electrical conductivity. With regards to the soil electrical properties, a great variation in the soil resistance and resistivity was observed. Despite the probes' distances, the soil resistance was highest at location A, and lowest at location B. Location A developed mean soil resistances of 14.16 Ω, while location B recorded mean resistance of 3.1 Ω. Likewise, location C had mean soil resistance of 14.16 Ω, and location D developed soil resistance of 5.2 Ω. The study established that, the soil resistivity of the area was generally low. It was observed that at location A, the mean soil resistivity was 820.06 Ωm, which was highest in the whole area. At locations B, C and D, the soil resistivity was 158.14, 402.18 and 270.21 Ωm respectively. The knowledge of these geotechnical and electrical properties of the area will be helpful during the design of electrical wiring systems for building within the area.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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