GROUND SUBSURFACE CHARACTERIZATION USING ELECTRICAL RESISTIVITY AND CONE RESISTANCE VALUE IN GEOTECHNICAL INVESTIGATION

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ABSTRACT

Detecting subsurface geological structures and features is crucial in geotechnical design to prevent potential hazards in the future. To achieve fast and precise interpretation, efficient testing is required in geotechnical engineering. This study aims to evaluate soil characteristics utilizing electrical resistivity and cone resistance methods to determine soil consistency and resistance to external forces. The parameters employed in this study include electrical resistivity, cone resistance, consistency, cohesion, and total friction. The electrical resistivity value is obtained through geoelectric method field measurements, while the value of cone resistance is acquired through the CPT test conducted in the field. Consistency, cohesion, and total friction are determined by measuring cone resistance. The data analysis indicated that changes in cone resistance value significantly impact soil resistivity value, leading to a consistent interpretation of soil layers. The layer located 6 meters below the surface exhibits consistent stiffness, ranging from very stiff to hard soil. In layers at 9 meters and below, the maximum cumulative resistance of shear stress value reaches 588.31 kg/cm. The electrical resistivity and cone resistance data can be used in conjunction to enhance geotechnical investigations.

Keywords: *Geotechnical, cone resistance, electrical resistivity, consistency, cohesion*

1. INTRODUCTION

Field and laboratory soil investigations are performed to determine physical and mechanical soil parameters which serve as an aid for foundation analysis and design, as well as a reference for similar soils. The lithology of the site has a significant impact on geotechnical design, hence it is crucial to conduct soil analysis comprehensively and effectively. The resistivity parameter indicates the soil's ability to impede the flow of electrical current through it. A low resistivity value enables electric current to flow more easily, and vice versa. Each material, comprising soil and rock, possesses a unique resistivity value (Reynold, 2011), which allows for the interpretation of soil layers. The cone resistance value represents the vertical force at the tip of the cone per unit area or is the measure of the ground resistance to the working cone penetration movement (SNI 2827:2008, How to Test Field Penetration using a Probe).

The geoelectric resistivity method has been employed as a supporting instrument for geotechnical analysis (Agustina et al., 2018; Marzan et al., 2021). It is a geophysical technique utilizing the resistivity properties of rocks to gauge the layers of rocks beneath the earth's surface. Geophysical methods are non-invasive, afford good spatial resolution, and can cover large areas in a relatively short amount of time (Sudha et al., 2009). Cone penetration testing (CPT) is an in-situ method for determining soil geotechnical parameters and soil geo-stratigraphy (Akinshipe et al., 2020). The method assesses soil type, cohesion, and consistency by measuring cone resistance and sleeve friction values.

Accurate determination of soil characteristics during planning is essential to ensure security, stability, efficiency, and safe environmental conditions. The planning process considers the importance of soil consistency, cohesion, and accuracy. Soil consistency relates to the physical and mechanical properties of soil, reflecting the ability to alter shape or move when loaded or pressured. The total friction value (T_f) of the soil denotes the maximum shear stress or resistance that it can endure under different loading conditions (Wahyudi, 2018). The cohesive force between soil particles permits them to generate a dense soil structure, boosting the soil's strength as a whole.

To characterize subsurface layers for geotechnical design, this study will employ cone electrical resistance values and soil resistivity values, utilizing both metrics to evaluate the soil's consistency, cohesion, and maximum cumulative resistance of shear stress value. Based on Akinlabi and Adeyemi's (2021) findings, a strong correlation exists between the measured cone resistance and soil resistivity. This research is expected to provide an overview of the layers below the earth's surface so that it can be used for geotechnical design.

2. METHODOLOGY

The research objective of the method is to determine the characteristics of the subsurface layer for geotechnical purposes. The research incorporates parameters such as electrical resistivity value (ρ), cone resistance value (q_c), consistency, cohesion (c), and total friction (T_f). The parameter values were collected using the geoelectric resistivity and Cone Penetration Test (CPT) methods in the field.

2.1 The Resistivity Value

The resistivity value (ρ) represents the capacity of a material to impede the flow of electric current through it. Different types of soil and rock formations exhibit varying resistivity values, which can aid geotechnical assessments in uncovering the geological structure below the Earth's surface. Soil resistivity readings are procured in the field through the use of a resistivity meter. Measurements are conducted using the geoelectric resistivity method, employing four electrodes consisting of two current-injecting electrodes and two voltage-measuring electrodes. The utilized configuration is the Wenner-Schlumberger combination, incorporating the Wenner and Schlumberger configurations. The initial potential measurement (n=1) employs the Wenner configuration, followed by the Schlumberger configuration for subsequent measurements (n > 1). It should be noted that the comparison factor "n" for this configuration is the ratio between the distance of the AM electrodes and the distance of the MN electrodes (see Figure 1). From these measurements, we obtain the resistivity value of soil or rock layers below the surface. Equation 1 displays the soil resistivity value using the Wenner-Schlumberger configuration geoelectric method. Meanwhile, Figure 1 illustrates the Wenner-Schlumberger configuration.

$$\rho_a = \pi n(n+1)a\frac{\Delta V}{I} \tag{1}$$

With;
ρ_a = apparent resistivity (Ωm)
n = the ratio between the A-M or N-B distance and the M-N distance
a = the smallest electrode distance (m)
ΔV = potential difference (*volt*)
I = currents (A)

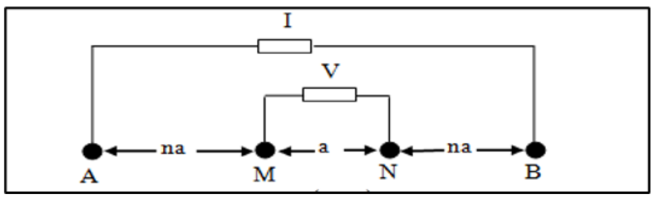

Figure 1: Illustration of the Wenner-Schlumberger Configuration Concept

2.2 The Cone Resistance Value

Cone Resistance Value
The cone resistance value measures the soil's resistance to the cone's tip, expressed in force per unit area. Pressing the cone's tip onto the soil generates resistance, which a pressure measuring manometer reads as C_w. Additionally, the soil surrounding the biconus generates a sticky resistance to the biconus mantle, which is also read from the manometer as T_w (Ukiman, 2017).

Soil Consistency Level
The soil consistency level denotes the soil's degree of hardness and its susceptibility to change due to pressure or water. The determination of soil consistency level relies on cone resistance values obtained from CPT measurements, applying the Terzaghi and Peck (1993) classification system. Table 1 presents the consistency level of clay soil based on q_c values.

Table 1: The consistency level of clay soil based on Terzaghi and Peck (1993)

Symbol	Soil consistency	Cone resistance (kg/cm^2)
1	very soft	<5
2	soft	5 – 10
3	medium soft	10 – 35
4	stiff	30 – 60
5	very stiff	60 – 120
6	hard	>120

Cohesion Value

Based on Terzaghi's bearing capacity theory, a correlation between the cone resistance value (q_c) and the cohesion value (c) was developed and expressed in equation 2 (Terzaghi, 1943).

$$c = 0.02qc \tag{2}$$

Total Friction

The total friction (T_f) value is obtained by adding up the sleeve friction (f_s) value multiplied by the reading interval (20 cm is used in this measurement) and calculated using equation 3.

$$T_f = f_s \times 20cm \tag{3}$$

3. ILLUSTRATIONS

3.1 Ground Subsurface Characterization

The cross-section resistivity values in Figure 2 show the results of the 2D resistivity geoelectrical survey carried out along a 147 meters section with a maximum measured depth of 29.5 meters. The resistivity values indicate that the soil layers investigated comprise alluvium, very dry clay, and dry sandy soil, giving a total of three layers. Alluvium was found in the first layer with a resistivity value of 0 to 65 *Ωm*, then interpreted as clay very dry with a resistivity of 66 to 620 *Ωm* and dry sandy soil with a resistivity value of 1430 to 15,000 *Ωm*. The dry sandy soil layer is interpreted from a depth of 6m below the surface.

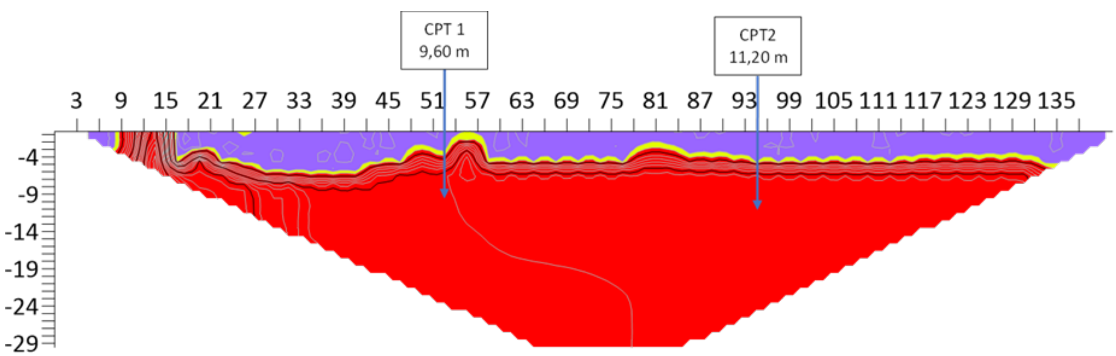

Figure 2: Cross-sectional resistivity values of the study site.

Geoelectrical resistivity data and Cone Penetration Test (CPT) data were collected and analyzed to determine the resistivity values of the soil and rock as well as the cone resistance and total friction values. This allows for the interpretation of soil consistency values, cohesion values, and the maximum resistance values that the soil or buildings can withstand. The measurement points are described in the following section.

Figure 3 displays the result of measurements taken at point 1 of the research site. The image illustrates the resistivity value, ranging from 72.01 to 374 Ωm, and the cone resistance value, from 0 to 50 kg/cm^2, at a depth of 0 to 3 meters. The soil is classified as an alluvium layer with a consistency categorized as medium soft. A change in the layer is discernible at a depth of 3 to 6 meters, as evidenced by the dissimilarity in the resistivity value and cone resistance value. This transition is attributed to the presence of a very dry clay layer with a consistency classified as stiff. At a depth of 6 to 9 meters below the surface, the resistivity value ranges from 8624 Ωm to 8844 Ωm, and the cone resistance value ranges from 55.61 kg/cm^2 to 146.6 kg/cm^2, indicating highly stiff soil. However, at a depth greater than 9 meters, the resistivity value is >8600 Ωm and the cone resistance value is >126.38 kg/cm^2, indicating hard soil.

The findings from point 2 of the research location are demonstrated in Figure 4. Greater resistivity and cone resistance values were observed at a depth of 0-3m compared to 3-4m, which is interpreted as silt mixtures with a very stiff consistency representing embankment soil. The resistivity values decreased to 53.22-172.9 Ωm and the cone resistance values were in the medium soft category at a depth of 3-4.6m. At a depth of 4.6 to 6.2 meters, there is an observable alteration in both the resistivity and cone resistance values, ranging from 841.3 to 7449 Ωm and 15.17 to 75.83 kg/cm^2 respectively. This marks a transition in the layer with a consistency value classified as stiff. The resistivity values range from 8526 Ωm to 9714 Ωm, whilst the cone resistance values fall between 35.39 kg/cm^2 to 80.88 kg/cm^2 for depths between 6.4 to 10.8 meters and are classified as very stiff. At depths exceeding 11 meters, the soil is categorized as hard, with a resistivity level of above 9600 Ωm and a cone resistance value over 131.43 kg/cm^2.

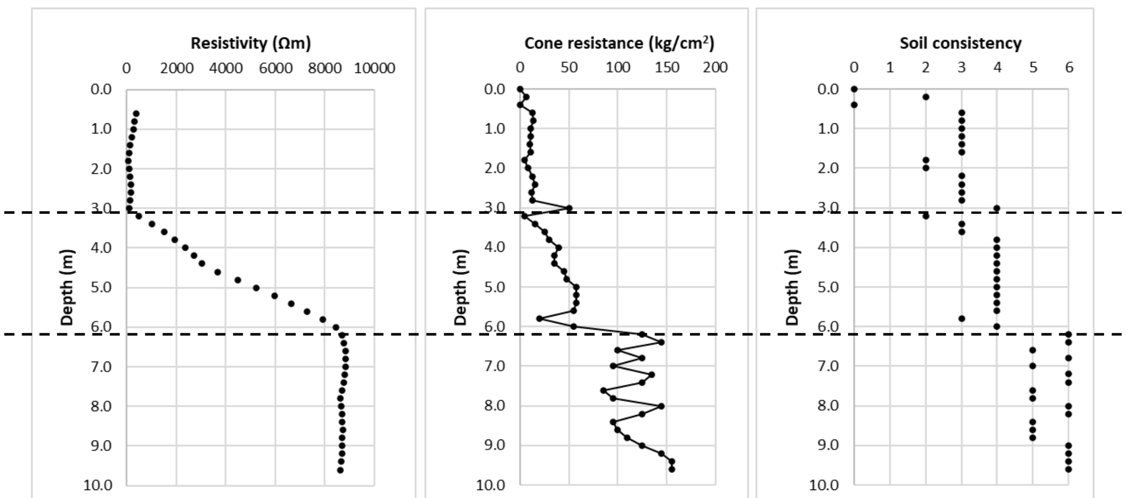

Figure 3: Resistivity values, cone resistance, and soil consistency at point 1

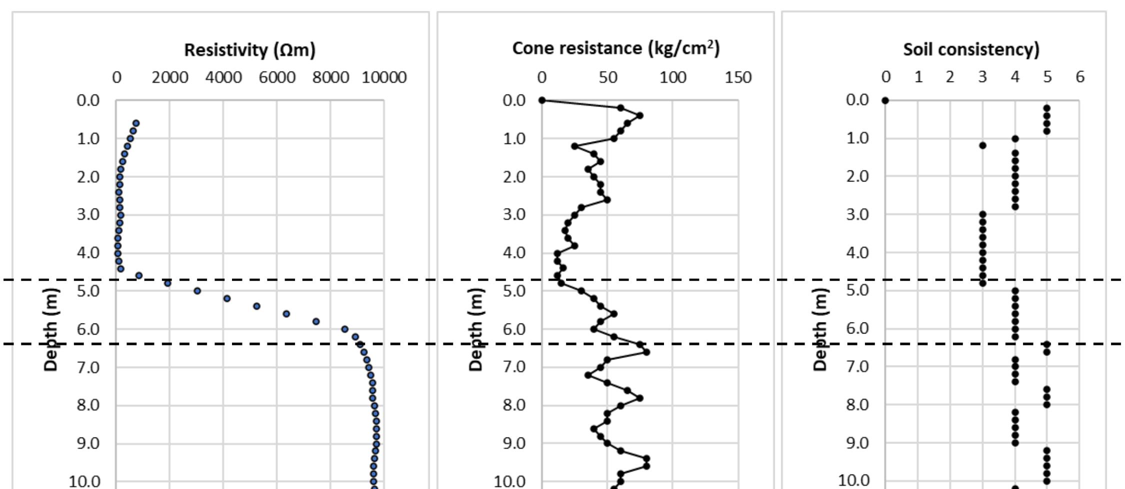

Figure 4: resistivity values, cone resistance, and soil consistency at point 2

From Figures 3 and 4, it is evident that the resistivity value changes significantly with changes in cone resistance value. The higher the resistivity value, the more substantial the cone resistance, and thus the density of the soil. Soil consistency pertains to the ability of soil to withstand deformation or shape alteration resulting from applied load. The scale of consistency indicates the soil's ability to support constructions or roadways safely. Hard soil consistency denotes that pressure has little to no impact on the soil's stability, thereby ensuring the stability of the structure above it.

3.2 Analysis of Soil Investigation Results

Subsurface geological conditions can be intricate and diverse. The rock structure plays a significant role in geotechnical planning, thus ensuring an efficient preliminary soil analysis is of utmost importance.

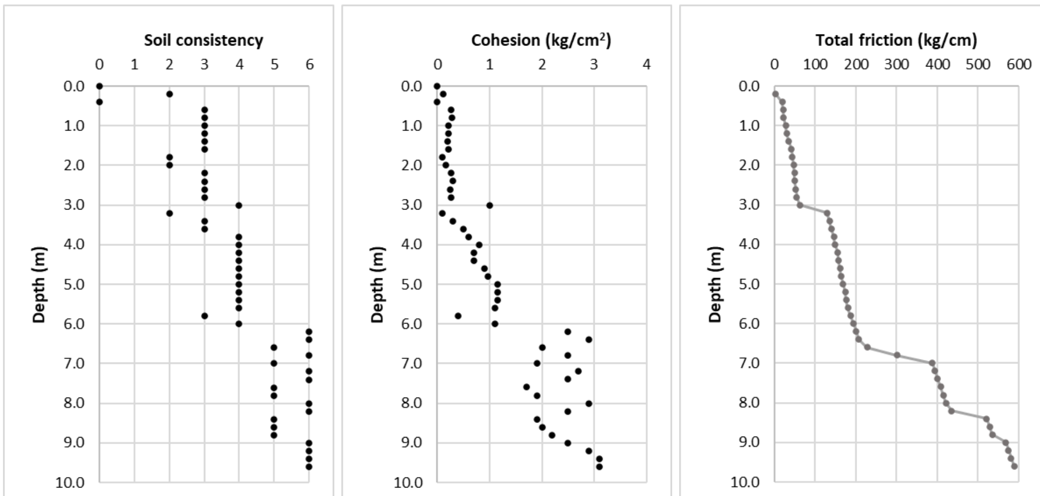

Figure 5: Soil consistency, cohesion value and total friction at point 1

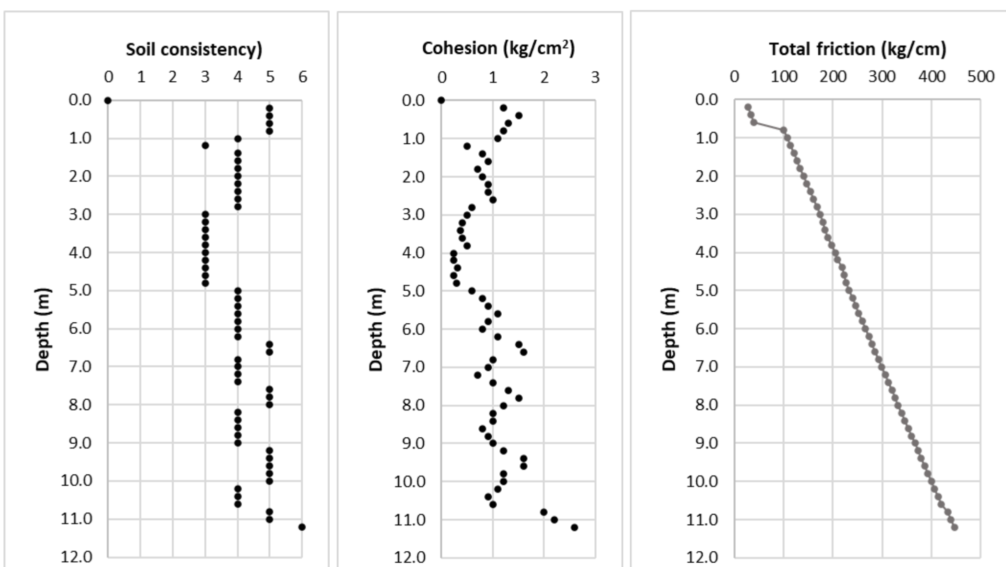

Figure 6: Soil consistency, cohesion value, and total friction at point 2

Soil cohesion refers to the attractive force between particles in the soil, expressed in units of weight per unit area. The cohesive force arises from the mutual attraction between fine particles, which holds them together in a solid mass without the need for external forces (Smith and Smith, 1998) and is related to the soil's shear strength (Sahara, 2020). Soil with a high cohesion value typically exhibits a firm or rigid consistency, as illustrated in Figures 5 and 6. The level of cohesion denotes the ability of soil particles to interact with each other and withstand forces that tend to disintegrate them. Soil resistance to deformation under tension can be related to the soil cohesion value. The greater the cohesion, the greater the shear strength, as soil cohesion is directly proportional to it. Moreover, soil cohesion affects soil strength, as it can resist the forces that tend to separate soil particles, thus enhancing the overall strength of the soil. The cohesion value decreased with the increase in moisture content, which was attributed to the decrease in molecular interactions between soil particles (Pezowicz, 2015) and an increase in clay content can increase the soil's cohesion value (Akayuli, 2013).

The maximum resistance or shear stress value that soil can withstand under specific loading conditions is known as the total friction value of soil (T_f) (Wahyudi 2018). In the CPT test, this value refers to the total amount of friction generated when the biconus is pushed into the soil to a certain depth. Total friction is a direct measure of the hardness of the soil below the surface, as seen in Figures 5 and 6: the higher the total friction, the higher the value of soil consistency and cohesion. Based on the total friction at point 1 in Figure 5, at a depth of 9.6m and below, the maximum cumulative resistance of shear stress that the soil can withstand reaches 588.31kg/cm. A sudden increase in the total friction value may indicate a transition from soft soil to hard soil or rock layers, e.g. at a depth of 6m there is a transition from stiff soil to hard soil. Meanwhile, at point 2, the maximum shear stress that the soil can withstand is up to 446.6 kg/cm (Figure 6).

The compressibility of the soil is related to its strength and consistency. A higher cohesion value and a stiffer soil consistency index (IC) indicate a lower compressibility of the soil (Akayuli, 2013). Higher skin friction values in soils with lower compressibility suggest a stronger and more cohesive soil. This information is very useful in determining the ability of the soil to support the foundation of a building or other structure.

4. CONCLUSIONS

Based on the resistivity and CPT methods, the results of the subsurface soil characterization consist of alluvium buried at the top, followed by very dry clay soil and dry sandy soil. The level of consistency from the surface to a depth of 9 m falls into the categories of medium soft, stiff, very stiff to hard soil. The higher the cohesion value, the greater the resistance of the soil to reflection due to load stress, while from the total friction value it is known that the soil has a maximum cumulative resistance of shear stress value reaches 446.6 kg/cm (point 1) and 588.31 kg/cm (point 2) in hard soil layers.

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