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Determining The Depth of Hard Soil Layers Using Geoelectric Resistivity and Cone Penetration Test Methods (Case Study: Kelurahan Bontoramba Kecamatan Somba Opu Kabupaten Gowa)

Nurhasanah [1*)], Achmad Bakri Muhiddin [2], Abdul Rahman Djamaluddin [3], Muhammad Niswar [4]
Universitas Hasanuddin, Indonesia[1,2,3,4]
[*)]Corresponding E-mail: nurhasanah@physics.untan.ac.id

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ABSTRACT

Hard soil layers can impact the loading, stability, and behavior of structures in the geotechnical field. Comprehensive understanding of the depth and properties of hard soil layers can aid in designing suitable structures. Therefore, this study employed the resistivity geoelectric and Cone Penetration Test (CPT) methods to map the features of hard soil layers. Resistivity data were acquired through measurements utilizing the geoelectric method, while data on cone resistance, shear resistance, and friction ratio were gathered through field measurements using the CPT tool. The collected data was analyzed comprehensively to obtain a complete understanding of soil conditions. Based on resistivity values, the results indicated the research site comprises alluvium, very dry clay, and dry sandy soil. Based on the CPT test, it is determined that the layers contain mixtures of fine-grained soils, clay, silt, and sand. Therefore, it can be inferred that the dense sand lithology constitutes the hard soil layer geologically. The employment of both approaches delivers supplementary details on soil features and depth.

INTRODUCTION

Safe and effective construction planning and design requires an understanding of both the bedrock and hard soil layers present at a site. These layers have a significant impact on the stability, behavior, and long-term performance of geotechnical structures. In the context of foundation predesign, a hard soil profile provides information about the location and depth of hard soil layers in a given area [1]. Information on the characteristics and depth of compacted soil strata can aid in selecting and designing foundations appropriate for the current geotechnical conditions. Geotechnical professionals must objectively assess site conditions and develop precise solutions to guarantee the project's safety and stability.

The subsurface structures or conditions exhibit a significant degree of variation due to the highly heterogeneous nature of the materials stored in the subsurface [2]. Inadequate subsoil characterization prior to construction leads to continued building failures through structural defects and collapses [3]. Careful and precise geotechnical design is necessary to prevent negative consequences after construction concludes. Multiple approaches have been utilized by researchers and geotechnical experts to conduct soil analysis. Combining geophysical and geotechnical methods can provide a more comprehensive understanding of soil conditions and properties, resulting in more efficient and economical geotechnical engineering solutions. Researchers employ multiple techniques for natural resource exploration [4] [5], environmental monitoring [6], foundation design [7] [8], and hazard mitigation/assessment [9] [10]. Alabi describes fractures or weak shear zones, which are potentially hazardous to building settlement and structural collapse [11].

For construction of foundations, it is necessary to identify the lithology of the area concerned by investigating subsurface conditions [12]. The geoelectric method and the Cone Penetration Test (CPT) are commonly utilized in designing foundations [9] [13] to determine the appropriate type and depth of foundation for construction sites. During construction projects, both the geoelectric method and CPT sounding are valuable tools for acquiring detailed information about hard soil layers and determining soil geotechnical parameters and stratigraphy in a non-invasive manner [14] [15]. By utilizing the unique qualities and capabilities of each method, a more accurate geotechnical model can be achieved, thus facilitating the work of geotechnical engineers.

This study aims to provide an objective overview of geoelectric and CPT methods for characterizing hard soil layers. Highlighting the benefits of using both techniques simultaneously. This location comprises a vast tract of land that has been cleared for the construction of new housing. The obtained information will be sufficient and reliable in identifying subsurface layers, supporting decision-making in the design, implementation, and evaluation of an engineering project.

METHOD

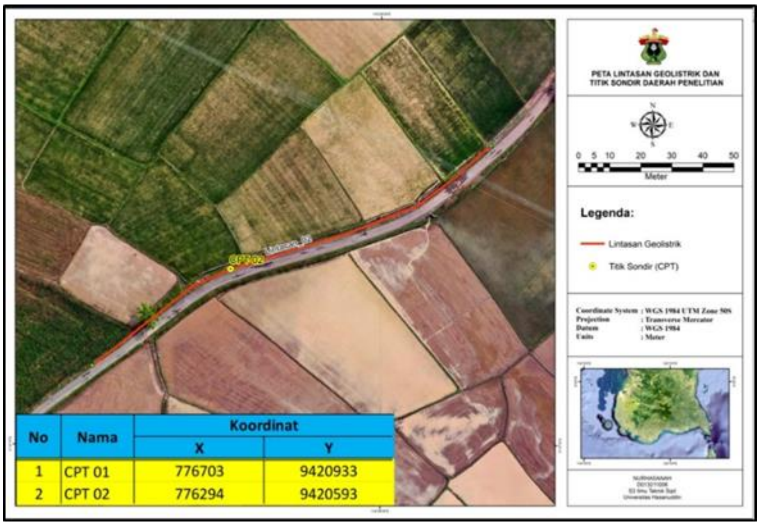
The research objectives can be achieved through a specific set of procedures, which includes a literature review, field data collection through Cone Penetration Testing (CPT) and resistivity measurements, and subsequent data interpretation and analysis to determine results. The literature review provides an overview of prior relevant research and highlights areas that require further exploration. The field data collection involves obtaining conus resistance (qc), shear resistance (fs), friction ratio (Rf), and resistivity (ρ) data. The qc, fs, and Rf data were obtained through field measurements with the CPT tool, while the ρ data was measured using the resistivity geoelectric method. The research methodology is described in detail below.

Research Sites

The geoelectric resistivity data and CPT data were collected at the same location, in Bontoramba Village, Somba Opu District, Gowa Regency, South Sulawesi, stretching from northeast to southwest. CPT data point recorded at coordinates 776294; 9420593 is displayed in Figure 1.

Geoelectric Method

The geoelectric method explores the electrical resistivity characteristics of rock layers beneath the earth's surface. This technique distinguishes between various rock layers and materials based on their resistivity values, enabling identification of layers and materials below the surface. The resistivity values for various materials and rocks are provided in Table 1.



No	Nama	Koordinat	
		X	Y
1	CPT 01	776703	9420933
2	CPT 02	776294	9420593

***Fig 1**. Research data collection locations*

Table 1. Resistivity values of some geological materials [2]

Material	Nominal resistivity (Ωm)
Alluvium and sand	10 – 800
Clays	1 – 100
Clay (very dry)	50 – 150
Sand clay/clayey sand	30 – 215
Dry sandy soil	80 – 1050
Limestones	$50 - 10^7$
Sandstones	$1 - 7{,}4 \times 10^8$
Sand and gravel	30 – 225
Gravel (dry)	1400
Gravel (saturated)	100
Conglomerates	$2 \times 10^3 - 10^4$

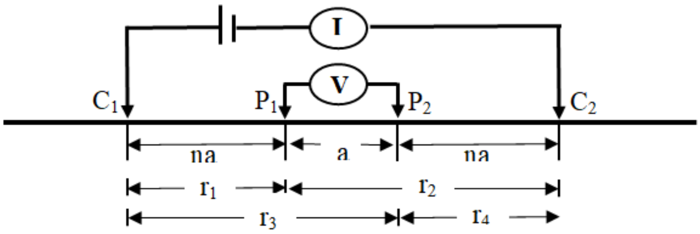


***Fig 2**. Electrode array configuration of Wenner-Schlumberger geoelectric method* [16]

Field measurements were conducted using the resistivity geoelectric method employing four electrodes. The electrode arrangement, depicted in Figure 2, comprises two current injecting electrodes (C_1 and C_2) and two voltage measuring electrodes (P_1 and P_2). The voltage value (V) measured at electrodes P_1 and P_2 (ΔV) can be calculated using Equation 1.

$$\Delta V = \left[\frac{I\rho}{2\pi}\left(\frac{1}{r_1}-\frac{1}{r_2}\right)\right]-\left[\frac{I\rho}{2\pi}\left(\frac{1}{r_3}-\frac{1}{r_4}\right)\right]$$

$$= \frac{I\rho}{2\pi}\left[\left(\frac{1}{r_1}-\frac{1}{r_2}\right)-\left(\frac{1}{r_3}-\frac{1}{r_4}\right)\right] \quad (1)$$

Where the current strength (in amps) at electrodes C_1 and C_2 is represented by I, the medium resistivity (in ohms per meter) by ρ, and the distances (in meters) between electrodes and points by r_1, r_2, r_3, and r_4 respectively.

The apparent resistivity of the measured ground is assumed to represent an isotropic homogeneous medium. The arrangement of electrodes and the resistivity of materials within geological formations can impact the apparent resistivity value. Typically, increased distance between current electrodes can improve depth penetration. Additionally, denser rock can elevate the apparent resistivity value. Equation 2 demonstrates how to calculate the magnitude of the apparent resistivity (ρ_a) by multiplying the geometry factor (K) with the resistance ($\Delta V/I$).

$$\rho_a = K\frac{\Delta V}{I} \tag{2}$$

$$K = 2\pi\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right)$$

The study's configuration employs a combination of the Wenner and Schlumberger configurations, also known as the Wenner-Schlumberger configuration. The Wenner configuration is applied to the first potential measurement ($n=1$), while the Schlumberger configuration is used for subsequent potential measurements ($n > 2$). Therefore, the geometry factor (K) in the geoelectric method utilizing the Wenner-Schlumberger configuration is:

$$K = \pi n(n+1)a \tag{3}$$

The equation (2) utilizes a ratio, n, between r_1 or r_4 to the smallest electrode distance (P_1-P_2) in meters, denoted as a.

By substituting equation (3) into equation (2), the apparent resistivity value for the geoelectric method utilizing the Wenner-Schlumberger configuration can be obtained.

$$\rho_a = \pi n(n+1)a\frac{\Delta V}{I} \tag{4}$$

Inversion and interpretation

The data is processed using the least squares inversion method to generate a 2D resistivity cross section, which can be interpreted for analysis. Identifying the subsurface structure and soil thickness involve 2D mapping, consulting the local geological map, and analyzing Reynolds' prior research [2].

Cone Penetration Test Method

Following resistivity data collection, testing with the Cone Penetration Test (CPT) method is carried out. This in situ testing method is widely used to assess subsurface stratigraphy and determine the geotechnical engineering properties of soil due to its efficiency and simplicity. Cone penetration testing (CPT) can be performed from ground level to the depth of the hard soil layer. The values of the static cone resistance or conus resistance (q_c) gathered from the test can be directly associated with the soil's bearing capacity.

The parameters of soil layer penetration resistance in the field using CPT tools, according to SNI 2827:2008, comprise of cone resistance (q_c), shear resistance (f_s), friction ratio (R_f), and total soil shear (T_f). These parameters aid in interpreting soil layers. Equation (5) [17] can be used to calculate the friction ratio (R_f).

$$R_F = \frac{fs}{qc} \times 100\% \tag{5}$$

Cone data can be directly used in design and is occasionally linked with other properties. The determination of Soil Behavior Type (SBT) from Cone Penetration Test (CPT) data frequently employs the SBT chart, which was recommended by Robertson et al. (1990) and updated in 2010 [18]. The non-normalized CPT Soil Behavior Type chart is depicted in Figure 3 and Table 2.

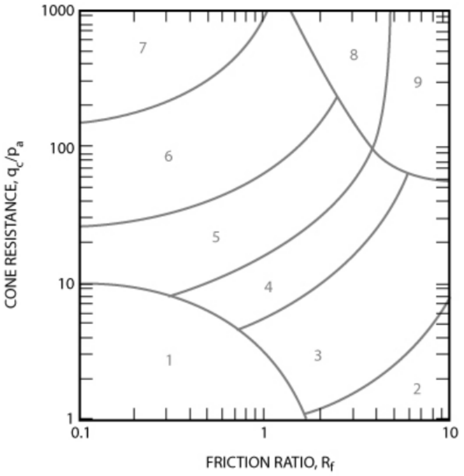


***Fig 3**. Graph of non-normalized CPT Soil Behaviour Type*

Table 1. Description of non-normalized CPT chart Soil Behavior Type [18]

Zone	Soil Behaviour Type (SBT)*
1	Sensitive, fine grained
2	Organic Material-clay
3	Clay-silty clay to clay
4	Silt mixtures-clayey silt to silty clay
5	Sand mixtures- Silty sand to sandy silt
6	Sands-clean sand to silty sand
7	Gravelly sand to dense sand
8	Very stiff sand to clayey sand
9	Very stiff fine grained

Soil consistency level describes the physical properties of soil particles to transform their shape and structure under pressure and water. The level of soil consistency is determined using the Terzaghi and Peck (1993) classification system. This determination of consistency is founded on the cone resistance (q_c) value acquired from the CPT method. Table 3 shows the consistency level of the clay based on the value of q_c.

Table 3. Consistency of clay based on Terzaghi and Peck classification [19]

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

RESULTS AND DISCUSSIONS

Geological Condition of the Research Site

The geological composition of the research site, located in the Sombaopu Subdistrict and based on the Geological Map of Ujung Pandang Sheet [20] comprises the Coastal Quarter Alluvium Formation (Qac Formation) and Baturappe-Cindakko Volcanic Rock Formation (Tpbv Formation. The Qac Formation is made up of gravel, sand, clay, silt, and coral limestone, and was formed in environments such as rivers, beaches, and deltas. The alluvial deposits in this area originate from rock fragments of the Lompobattang volcano [21]. The Tpbv formation is a geologic formation comprising of lava, breccia, tuff, and conglomerate. Figure 4 displays the geologic map of Ujung Pandang Sheet (red column).

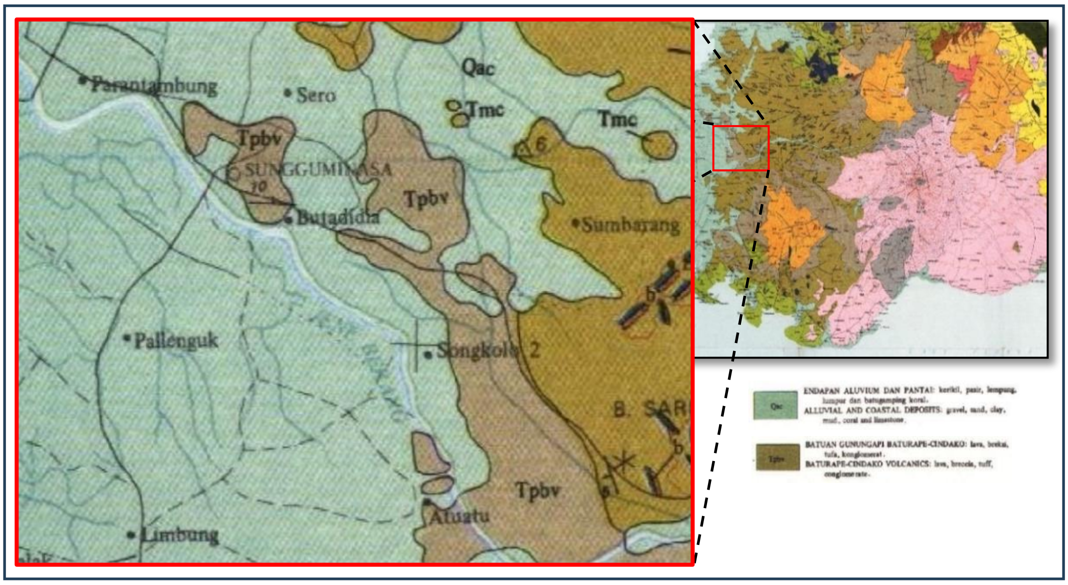


Fig 4. *Geological map of ujungpandang sheet*

Resistivity Measurement

The resistivity measurement findings are illustrated in Figure 5, which represents the cross-section of the resistivity value, obtained from the measurement of the 2nd track, stretching 147 m in length with a measured depth of up to 29.5m. The soil profile, determined by resistivity values, comprises three distinct layers. The initial layer contains alluvial deposits, with resistivity values ranging from 0 to 65 Ωm. The subsequent two layers are characterized by very dry clay and dry sandy soil, with resistivity values of 66 to 620 Ωm and 1430 to 15000 Ωm, respectively. The dry sandy soil layer begins at a depth of 8 m below the surface.

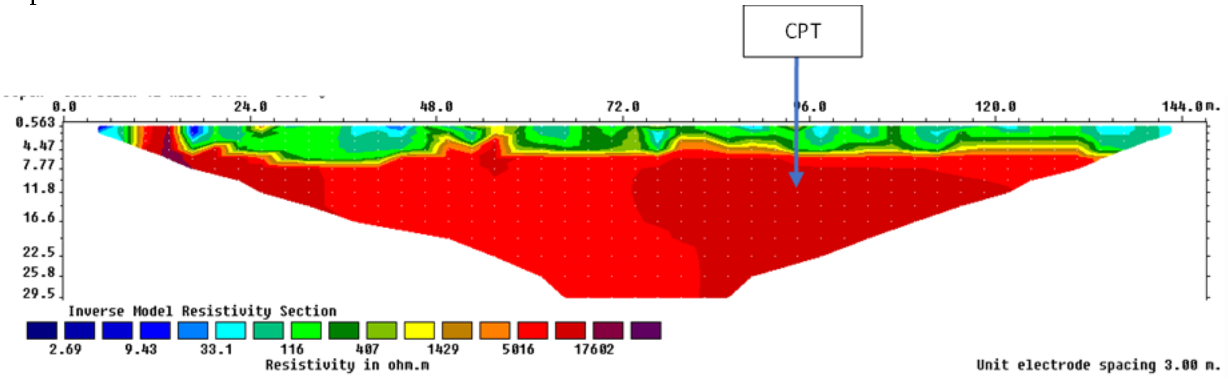


Fig 5. *Resistivity value cross section of the research location*

CPT Measurement

CPT measurements are useful for predicting the soil's mechanical characteristics and behavior type (SBT). Soil type determination commonly utilizes the updated Robertson et al. graph [18]. CPT measurements are presented as cone resistance (q_c) and friction ratio (R_f) in Figure 6.

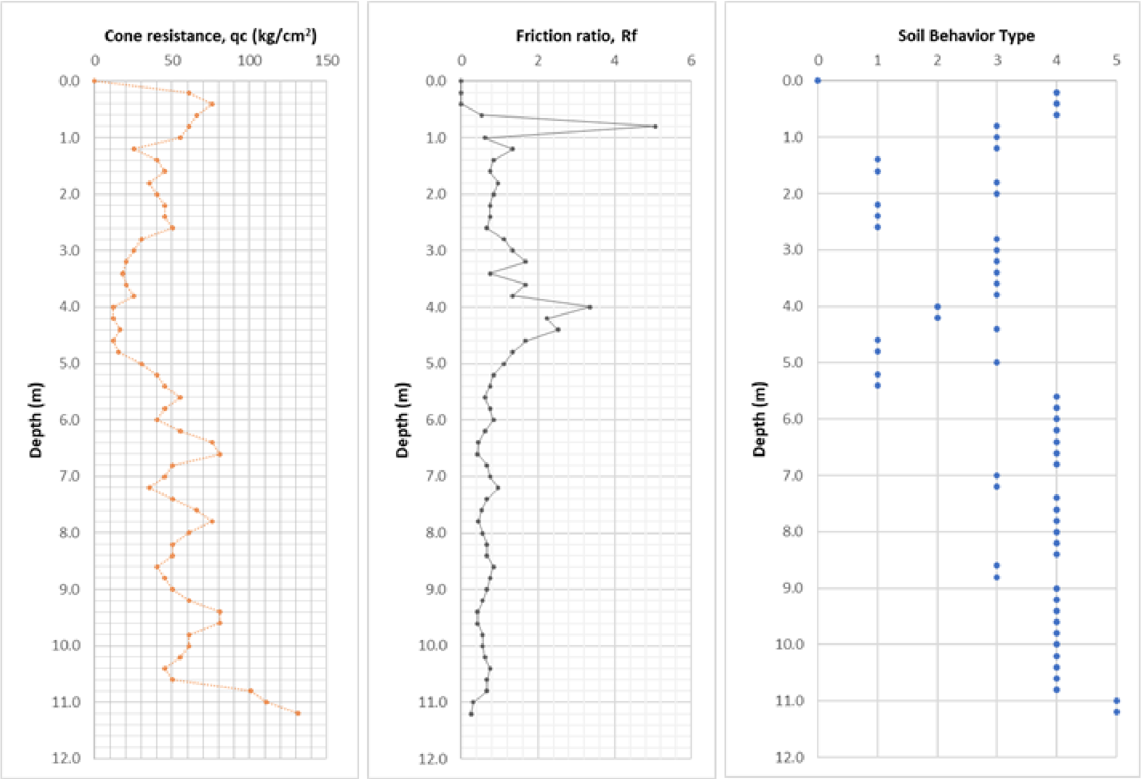


Fig 6*. Cone resistance value, friction ratio, and Soil Behavior Type of the research site*

The values of q_c and R_f from the graph in Figure 6 indicate that the investigated soil layers comprise three distinct layers: clay (silty clay to clay), silt mixtures (clayey silt to silty clay), and sand mixtures (silty sand to sandy silt). The top layer, reaching to a depth of 0.6 meters, consists of silt mixtures, with a q_c value ranging from 60.66 to 75.83 kg/cm^2. The layer extending from a depth of 0.8 to 5.4 meters is composed of clay, with a q_c value ranging from 16.18 to 40.44 kg/cm^2. Between depths of 5.6 to 10.8 meters exists another layer containing silt mixtures, with a q_c value of 40.44 to 80.88 kg/cm^2, and sand mixtures, which display a q_c value of 111.21 to 131.43 kg/cm^2, while the deepest layer at 11 meters is composed of sand mixtures with the same q_c value.

Soil Consistency

Soil consistency level pertains to a scale that reflects the physical properties of soil particles to alter their shape and structure under pressure and water application. This information aids in determining the technical properties of soil useful in planning structures including buildings, roads, and irrigation. As soil particles exhibit robust binding force and stable structure, their consistency becomes increasingly rigid and hard.

Based on the conical resistance results (Figure 7), the soil demonstrates a medium soft consistency from a depth of 3 to 4.8 meters, with a q_c value ranging from 12.13 to 25.28 kg/cm^2. From a depth of 5 to 9 meters, the soil is mostly characterized by a stiff consistency. At depths of 9 to 11 meters, the soil layers exhibit a very stiff consistency, with a hard consistency (q_c >120 kg/cm^2) observed at depths of 11 meters and below.

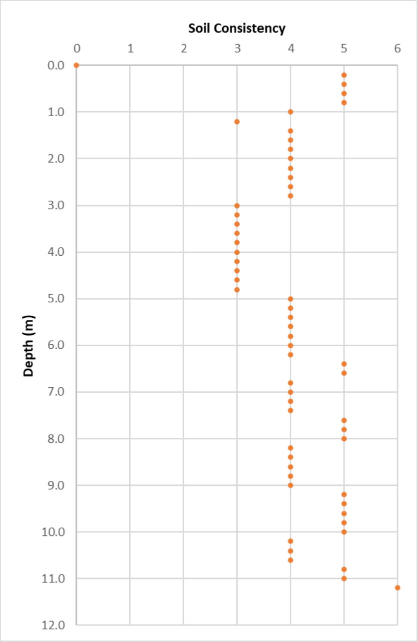


***Fig 7**. Soil consistency value of the study site*

Hard Soil Layer

In geotechnical engineering, a hard soil layer refers to a soil layer possessing high strength and stiffness properties, and low permeability. Hard soil layers are formed through natural geological processes or as a result of human activities such as excavation or compaction. These layers commonly contain materials such as igneous rocks, hard sedimentary rocks, highly compacted clayey soils, or soils that have been hardened by natural or artificial pressures.

Interpretation of hard soil layers based on cone resistance, friction ratio, resistivity values, and consistency at each depth reveals consistent soil type interpretations. The layer at a depth of 11 m and below is the sand layer. The interpretation based on the geoelectric method indicates dry sandy soil, while the CPT method calls it sand mixtures (silty sand to sandy silt). Geologically, the layer is interpreted as a dense sand lithology.

Silty sand, sandy silt, and dry sandy soil contain sand particles, which have greater size and coarser texture in comparison to clay and silt, resulting in high strength and stiffness [22] [23]. Silty sand, sandy silt, and dry sandy soil contain sand particles, which have greater size and coarser texture in comparison to clay and silt, resulting in high strength and stiffness [22] [23]. The high sand content facilitates the movement of water through the spaces between its particles, thereby reducing the risk of water accumulation that leads to subsidence.

Sand layers exhibit a higher shear strength in comparison to other types of soil, thereby rendering them challenging to excavate and penetrate [24]. Silty sand and sandy silt layers display varying degrees of plasticity, ranging from low to high, indicating a reduced susceptibility to deformation under pressure [23]. Moreover, it has been determined that silty sand and sandy silt layers exhibit greater resistance to liquefaction than clean sand under equivalent conditions [22].

Hard consistency soil is located 11 meters below the surface, and said layer evenly distributes the building load into the soil beneath. In addition, the soil particles' physical attributes, which possess strong binding power and a stable structure, maintain the building structure's integrity.

Comprehensive information on soil conditions is obtained via the geoelectric and CPT methods of soil characterization. The geoelectric resistivity method provides insight into the type and depth of soil and rock layers, while the CPT method offers information on the physical and mechanical properties of soil and rock. Integrating the data from both techniques enables a more comprehensive and precise evaluation of soil conditions.

Describes the outcome can be an increase in knowledge, skill or product. The results also reveal the level of achievement of the target activity. If in the form of objects there needs to be an explanation of product specification, its advantages and disadvantages. Output writing should include photos, charts, graphs, charts, drawings and more. The discussion is sequential in the order in which the objectives are, and it has been described first. The discussion is accompanied by a logical argument by linking the results with theories, other results and/or research results.

CONCLUSION AND SUGGESTION

Based on the conducted research, the hard soil layer at the research location can be observed to exist at a depth of 11 m and below, which is interpreted as having dense sand lithology. To obtain more comprehensive information about soil conditions, mapping of hard soil layers can be accomplished through the combination of resistivity geoelectric and Cone Penetration Testing (CPT) methods.

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