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Subsurface Profile Mapping for Infrastructure Foundation Laying

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Abstract

Proper evaluation of soil layers is crucial to prevent potential construction issues. The selection of the layer for the foundation of a construction project impacts the loading, stability, and fundamental behavior of the structure. In this research, the geological structure and lithology of the earth's subsurface layers will be mapped to identify suitable locations for infrastructure foundations. The resistivity geoelectric method was utilized for predicting structural conditions beneath the soil's surface layer by measuring a material's specific resistance. The obtained results were refined by conducting geological and geophysical analysis. The study site's resistivity values ranged from 16.8 Ωm to 584 Ωm and were interpreted as layers of mud, sand, and gravel. The investigation determined that the suitable layers for foundation construction consist of sand and gravel situated beyond a depth of 37.06 meters beneath the surface.

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1. INTRODUCTION

Soil serves as the primary engineering material for constructing and maintaining roads and is the foundational layer responsible for imparting the desired stiffness and structural durability [1]. Hence, proper soil testing is imperative to ensure the desired structural integrity and performance of the proposed road network. Soil properties at the subgrade level play an indispensable role in the design of road infrastructures that are compatible with the traffic flow, regional climate, and topography [1]. Soil testing is an essential initial step for any construction project, particularly involving roadways [2]. A soil's ability to support a structure depends on its intrinsic properties, including particle density and moisture content. Determination of soil strength is vital to ensure structural stability and safety [3]. The critical factor to consider when choosing a road binder is its compatibility with the soil type. Determining soil characteristics is crucial in selecting suitable subsurface layers [4].

Various methods, such as geoelectric, soil testing, hand probing, Cone Penetration Test (CPT), and seismic methods [5]–[7], are used to identify soil type, whether composed of fine-grained or coarse particles or with a high clay, silicate, or organic content. These techniques aid in identifying the depth, thickness, and composition of resilient soil layers, which are significant in the creation and development of building and road structures. The geoelectric approach was utilized in this study, which can furnish resistivity data of the underlying stratum in a non-destructive manner, thereby aiding in gauging the thickness and depth of the robust soil layer. Geoelectric methods can identify subsurface water and assess the stability of hard soil layers [8]. The obtained data can also create subsurface profiles for designing and constructing structures such as buildings and roads [9].

The resistivity geoelectric method uses specific resistance to determine the conditions beneath the surface soil layer. The determination of rock or material layers is based on the principle that each layer has a unique resistivity value or specific resistance [10], which is obtained by measuring the potential created by injecting current into the surface of the Earth. Measurements in the field were conducted using the geoelectric method of specific resistance with four electrodes. The resistance measurement type used the Wenner-Schlumberger configuration, which is a combined method of both the Wenner and Schlumberger configurations. Schlumberger was utilized to capture information regarding resistivity variations both vertically and horizontally. As a result, this method is typically employed for sounding or depth.

The geoelectric method was employed to map the geological structure and lithology of the earth's subsurface layers for this study. The subsurface profile produced through this method is valuable for designing and constructing structures that can withstand the loads and stresses experienced by road and construction structures during their service life.

2. RESEARCH METHOD

The Geoelectric Resistivity Method

The geoelectric resistivity method was employed in the research. This approach is valuable for identifying rock or material layers by measuring resistivity values or specific resistance. The resistivity method has versatile applications, including mineral and mining exploration, agriculture, environmental assessments, groundwater detection, and geotechnical analysis [11][12]. Field measurements using the resistivity method comprise four electrodes, with two electrodes responsible for current injection, and the other two measuring voltage. Generally, test depths can be enhanced by increasing the gap between current electrodes.

This research employs the Wenner-Schlumberger configuration, a blend of Wenner and Schlumberger configurations. Both configurations use the same electrode sequence but differ in their measurements. The first potential measurement ($n = 1$) is carried out using the Wenner configuration, while subsequent measurements ($n > 1$) use the Schlumberger configuration. This geoelectric technique for data collection employs a constant spacing rule system, and the comparison factor "n" for this configuration is the ratio between the distance separating the AM electrodes and the distance between MN (refer to Figure 1). The measured resistivity value of the underlying rock layer can be obtained. Equation 1 indicates the material's resistivity value using the Wenner-Schlumberger configuration geoelectric method, while Figure 1 shows the configuration illustration.

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

with:

ρ_a = apparent resistivity (Ωm)
n = ratio between distance A-M or N-B with distance M-N
a = smallest electrode distance (m)
ΔV = voltage (volt)
I = current (A)

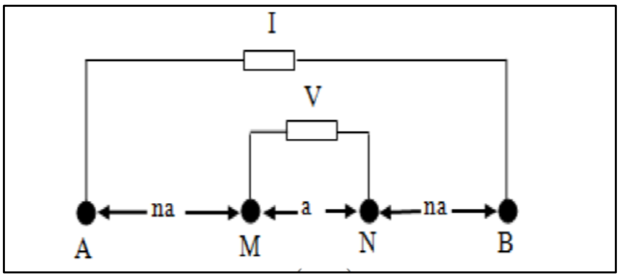

Figure 1. Illustration of the Wanner-Schlumberger configuration concept

Data Acquisition

Geoelectric data was acquired using one track measuring 240 meters in length, equipped with 25 electrodes spaced evenly at 10-meter intervals. The track extends from the southwest to the northeast and is located in Rasau Jaya Village, Kuburaya Regency, West Kalimantan, as shown in Figure 2.

Figure 2. Plot of acquisition trajectory from GPS

Data Processing

Data collected in the field in the form of apparent resistivity undergoes an inversion process to determine actual resistivity values. This process generates a two-dimensional (2D) cross-section of resistivity values, which are then further analyzed based on the type of rock or material present to produce lithological modeling. This process entails correlating the resistivity data pattern to a lithology model that corresponds with the pattern.

Interpretation

The 2D resistivity cross-section and lithological modeling results were analyzed with local geological maps and resistivity values of soil and earth materials. Table 1 illustrates the resistivity values of different rocks:

Table 1 Resistivity values of various rocks

Material	Resistivity Value (ohm.m)
silt	10-200
clay	1-100
Mudstone	3-70
Peat Soil	30-200
Sea Water	0,2
Groundwater	0.5-300
Sand	1-1000
Gravel	100-600
Alluvium	10-800
Sandstone	200-8.000
Dry Gravel	600-10.000

4. RESULTS AND DISCUSSION

Topography and Geological Structure

The topography of Rasau Jaya Village is predominantly flat, except for the area around the Punggur River which is comparatively low, rendering it susceptible to flooding during high tides. To the north of the river, the higher terrain comprises peat up to 5 meters in thickness.

As per the Geological Map of Pontianak/Nanga Taman Sheet, the geological composition of Rasau Jaya covers alluvial, tidal, lake, swamp, and undak deposits. The research area is situated in the Alluvium formation and swamp deposits (Qa), the youngest Quarter age formation. These deposits consist of gravel, sand, silt, mud, and peat, covering both alluvial and tidal plains in the west, the Kapuas River – River valley, and other significant river valleys that flow into the terrain of the truncated hills and alluvial plains. Refer to Figure 3 for the geologic map of the Pontianak/Nanga Taman Sheet (red column).

Rock Resistivity Value

Rock resistivity values can be visualized using 2D resistivity cross-section mapping. The value magnitude differs depending on the rock or material type. The diverse composition of the material creates a spectrum of resistivity values. The maximum resistivity value ranges from 1.6 x 10-8 Ωm (native silver) to 1016 Ωm (pure sulfur) [13].

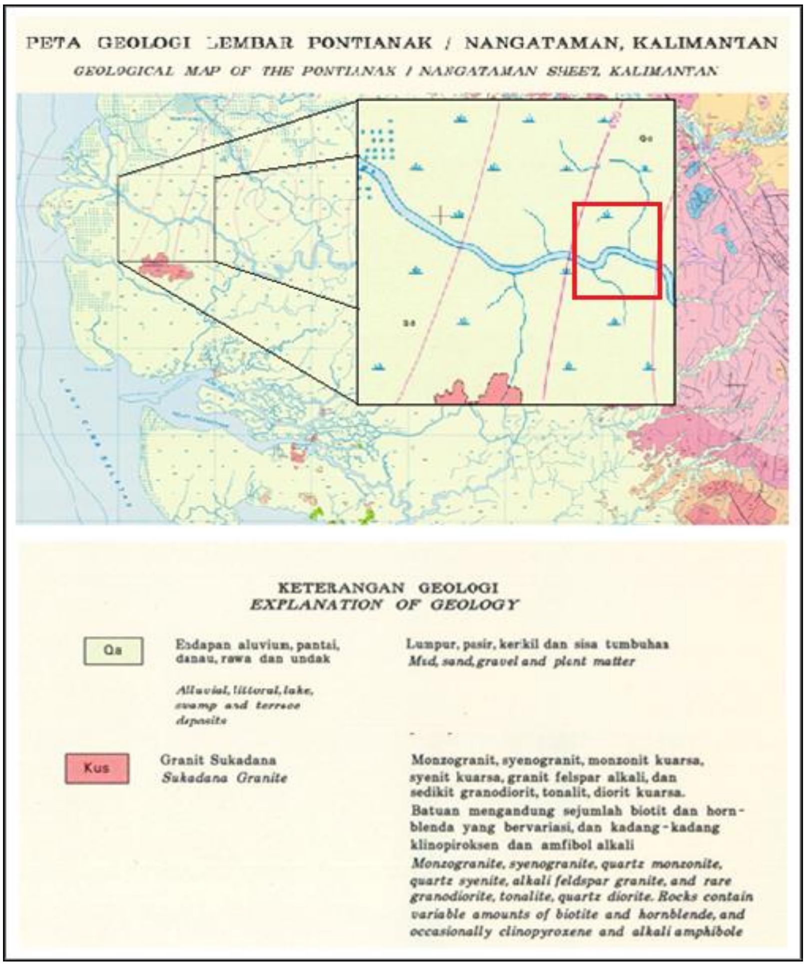

Figure 3. Geological map of the study area

Figure 4 displays the field's resistivity values, with a 240 m track length and a 10 m electrode spacing distance. The layer, composed of sand, mud, and gravel, was detected up to 46 m below the surface from the resistivity value analysis.

The layer's resistivity values range from <2.00 to 15.5 Ωm (dark blue to light blue colour) at a depth of 0 to 20 m, indicating wet (saturated) sand. The green to light green coloured section with a resistivity value of 15.6 - 37.05 Ωm found at a depth of 9 to 15.5m is identified as passive mud. The dark green to green coloured area with a resistivity of 37.06 - 83.15 Ωm at a depth of 16 to 33.8m is classified as sand. Lastly, the yellow to brown coloured section with a resistivity value of 83.16 to >584 Ωm, found at depths ranging from 0 to 9m and 39 to 45m, is designated as gravel.

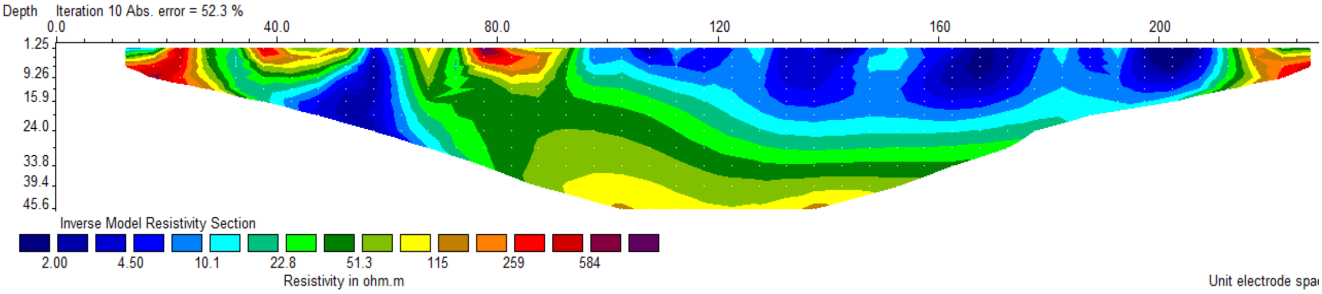

Figure 4. 2D resistivity value cross-section of the research location

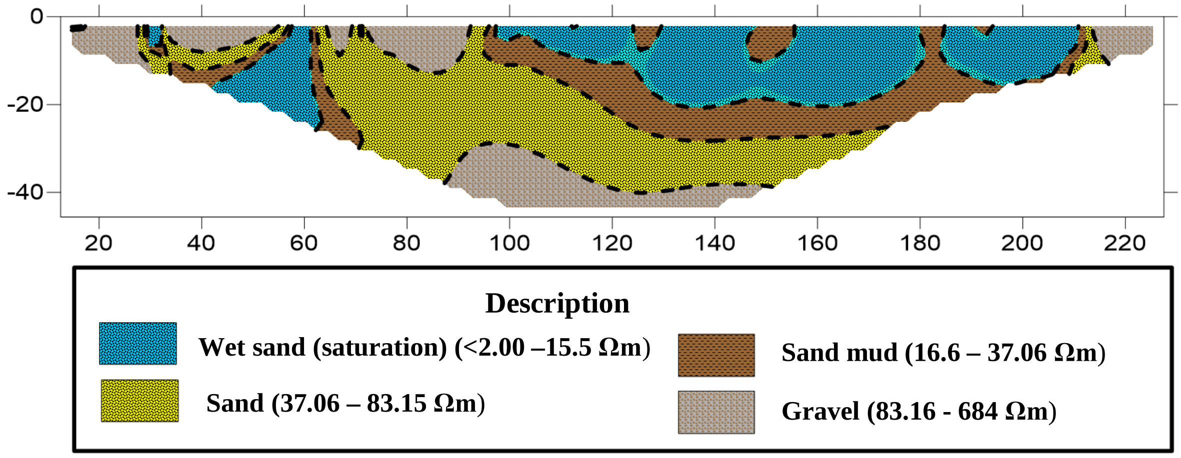

Figure 5. Cross-section of lithology in the field

Lithology Modelling

Lithology modeling aids in comprehending the spatial correlation between lithology and geological structures within the study area. Based on the modeling (Figure 5), it is known that the resistivity value of sand tends to be low due to river water intrusion at a distance of 40 m and due to surface water at a distance of 100 m. The mud layer associated with sand settles at a depth of 9 to 33.8 m with a layer thickness of ±7 m. The sand layer beneath the mud layer has a thickness of ±17 m. The lowest layer that can be identified is the gravel layer. Although there are also gravel layers on the surface at a distance of 0 to 90 m.

The soil layers that make up the upper part of the study site (0 to 37.6 meters in depth) are primarily composed of wet sand and passive mud. Wet sand and sandy silt generally have lower bearing capacity compared to dry sand or compacted soil. Their high water content reduces their cohesive properties, resulting in weaker resistance to structural loads and lower bearing capacity. Additionally, wet sand and silt layers are more susceptible to deformation and settling due to poor compaction and limited bearing capacity, potentially leading to significant settlement and sliding under load. The soil strength of these layers is low

At a depth of 37.06m and below, they consist of sand and gravel. Sand and gravel are frequently utilized as foundation layers in construction due to their firmness and resistance to structural loads. They can evenly distribute loads from the overlying structure as the sand and gravel particles interact to create a stable matrix. The uniform distribution of load prevents high-pressure points that could lead to foundation settlement or displacement. Sand and gravel layers possess natural stability, making them less prone to volumetric changes and deformation. Such stability plays a crucial role in maintaining the foundation's structural integrity over time. Moreover, sand and gravel can be compacted to create a solid, robust structure. Good compaction enhances the overall strength and stability of the foundation. Therefore, sand and gravel are considered as a relatively stable stratum for constructing foundations, roads, and other structures. Additional planning and analysis are necessary to confirm that the selected foundation layer is suitable for the construction project.

4. CONCLUSION

Based on the research findings, the research site comprises layers of mud, sand, and gravel with resistivity values ranging from 16.8-37.06 Ωm, 37.06-83.16 Ωm, and 83.16 - >584. Ωm. The layer suitable for foundation construction is located more than 37.06 m beneath the surface, composed of sand and gravel.

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