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Correlation of Geotechnical Properties and Soil Resistivity on the Mount Gumitir Banyuwangi-Jember Route

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ABSTRACT

The Gumitir Mountain roadway frequently experiences interruptions caused by landslides due to its steep slope gradient, which extends along approximately 24.30 hectares of terrain. The dominant factors contributing to these landslides include slope excavation, slope steepness, and soil texture. This study employs the geoelectrical resistivity method using the Wenner–Schlumberger configuration. The survey was conducted along a 102-meter line with an electrode spacing of 6 meters, consisting of one electrode point. The initial resistivity data obtained from field measurements were processed using Res2Dinv software to generate a two-dimensional (2D) resistivity cross-section illustrating the subsurface resistivity distribution. The correlation between the geoelectrical data and Standard Penetration Test (SPT) values reveals that at depths between 2 and 6 meters, the subsurface layer exhibits low resistivity values ranging from 4.21 to 30 Ω·m with N-SPT values of 4–6 blows, representing soft clayey and silty materials. At depths of 6 to 19 meters, the resistivity values increase significantly to 30–248 Ω·m, with corresponding N-SPT values of 10–30 blows, indicating denser materials such as sandy silt, weathered rock, and tuffaceous layers. These findings empirically confirm a positive correlation between soil resistivity and N-SPT values-lower resistivity corresponds to lower N-SPT (softer soils), while higher resistivity is associated with higher N-SPT (denser and harder strata). This relationship demonstrates the reliability of the resistivity method as a non-destructive approach to estimating subsurface strength and soil hardness.

Keywords: Geoelectrical, Wenner–Schlumberger Configuration, Res2Dinv, Standard Penetration Test (SPT).

INTRODUCTION

The Gumitir route connecting Banyuwangi and Jember Regencies serves as a major transportation corridor in East Java. However, this road frequently experiences interruptions due to landslides, primarily caused by the steep slopes of the Gumitir Mountain terrain, which covers an area of approximately 24.30 hectares. The dominant contributing factors to slope instability include slope excavation, slope steepness, and soil texture. In addition, extensive land-use changes, such as forest conversion into plantations, road construction, and commercial buildings, have further exacerbated soil erosion and landslide occurrences.

In this study, geotechnical properties were analyzed using Standard Penetration Test (SPT) data, while soil resistivity data were obtained through geoelectrical surveys.[1] The geoelectrical method is widely used to investigate the electrical properties of subsurface materials by measuring potential difference, current, and electromagnetic fields, either from injected or naturally occurring electrical currents. Among various geoelectrical techniques, the resistivity method is the most common approach for assessing subsurface geological conditions based on the electrical resistivity of soil and rock materials.[2], [3].

Both the geoelectrical resistivity method and SPT share the same objective—to identify the hard soil or bedrock layers beneath the surface. The SPT provides vertical soil strength data, while the geoelectrical method allows for lateral characterization of subsurface variations. Because resistivity values vary according to soil composition, grain size, and moisture content, combining these two methods provides a more comprehensive understanding of subsurface structure.[4] Therefore, this study aims to analyze the correlation between SPT data and resistivity values to identify soil types and mechanical characteristics as an alternative subsurface investigation technique along the Gumitir road section in Banyuwangi–Jember.

RESEARCH METHODS

Materials

The materials used in this study consisted of both primary and secondary data sources. The primary materials included field data obtained from geoelectrical resistivity measurements and Standard Penetration Test (SPT) results. The geoelectrical data consisted of measured current (I), voltage (V), and electrode spacing, which were used to calculate the apparent resistivity of the subsurface layers.[5] The SPT data were collected from borehole logs that contained N-SPT values describing soil strength and consistency at various depths. These primary materials served as the foundation for correlating electrical and geotechnical properties of the soil.

In addition to the field data, secondary materials were obtained from literature studies, geological maps, and technical references related to the Gumitir area. These materials provided supporting information regarding the geological characteristics, soil composition, and previous research findings relevant to the study. All materials and data were processed and analyzed to generate a comprehensive understanding of the relationship between soil resistivity and geotechnical properties for slope stability assessment along the Gumitir road section in Banyuwangi–Jember. Figure 1 shows an example of a flow chart with an arrow pattern.

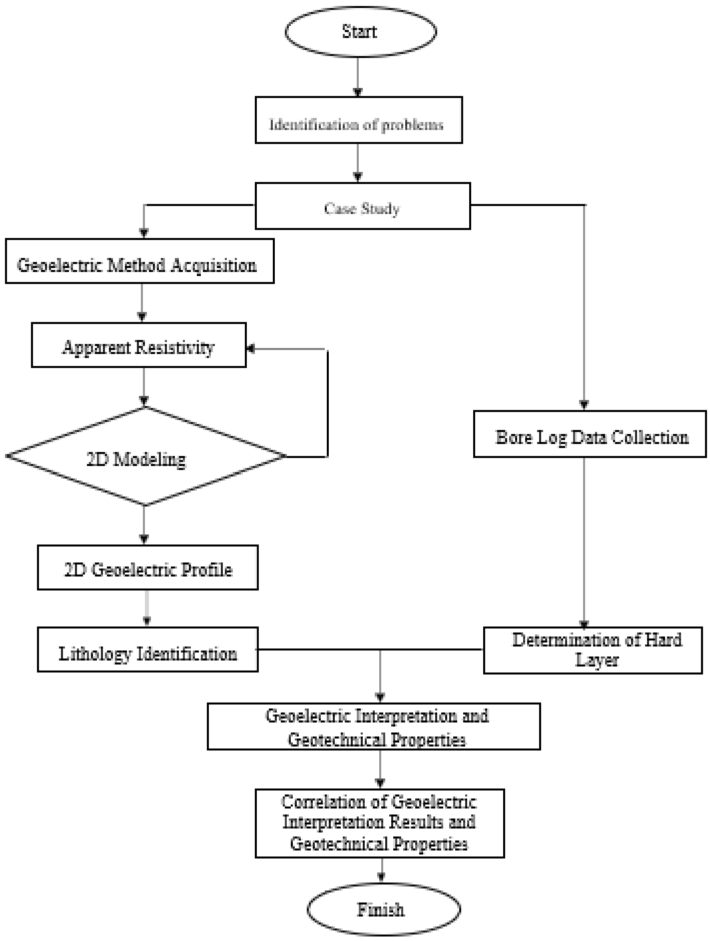

Figure 1. Flow chart

The research procedure consisted of several stages. The first stage, problem identification, focused on the need for accurate soil characterization along the Gumitir road section in Banyuwangi–Jember. This stage aimed to provide recommendations for developers and planners in road construction,

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particularly in landslide-prone areas. The second stage, case study, involved understanding the application of the geoelectrical method to determine the correlation between geotechnical properties and soil resistivity along the Gumitir road section. This process included conducting field surveys, data acquisition, and data processing to identify subsurface conditions effectively.

The third stage involved geoelectrical data collection and SPT data compilation. Field measurements were conducted to record electrode spacing, current (I), voltage (V), and resistance (R) values using a resistivity meter. The Standard Penetration Test (SPT) data were obtained from borehole logs that included N-SPT values, which describe subsurface soil density and hardness. The fourth stage, data interpretation, focused on generating two-dimensional (2D) resistivity cross-sections from processed geoelectrical data using Res2Dinv software. The color variations on the resulting resistivity model were analyzed to identify weak soil zones and correlated with N-SPT data to determine subsurface conditions. The final stage, correlation analysis, consisted of plotting borehole points onto the 2D resistivity cross-sections to align locations and depths. Through this process, the correlation between resistivity values and N-SPT data was established to determine their empirical relationship.[1], [2].

Methods

This study was conducted from March to June 2023 along the Gumitir road section connecting Banyuwangi and Jember, precisely located at KM 233+550 with geographic coordinates (−8.260560, 113.933636). The research involved collecting bore log data and soil resistivity data using the geoelectrical resistivity method. A single survey line with one sampling point was established for the resistivity measurements. The soil sample obtained from this line was used for subsequent geotechnical analysis. The geoelectrical resistivity method was employed in this study using the Wenner–Schlumberger configuration.[6] The survey line had a total length of 102 meters, with an electrode spacing of 6 meters and a single measurement line. The Wenner–Schlumberger configuration combines the advantages of both the Wenner array, which is more sensitive to lateral variations in subsurface resistivity, and the Schlumberger array, which is more sensitive to vertical changes in the subsurface structure. Therefore, this hybrid configuration is highly recommended for deep subsurface investigations where both lateral and vertical variations are significant.

Data Analysis

The raw resistivity data were processed using Res2Dinv software to generate a 2D subsurface resistivity cross-section showing resistivity distribution along the survey line.[2], [3], [7]. The resulting model was used to interpret subsurface layers based on resistivity variations. Laboratory-based SPT data were then compared to classify soil types and to verify the correlation between geoelectrical and geotechnical results. This combined analysis provides an integrated interpretation of subsurface characteristics and validates the reliability of both methods for soil investigation.

RESULT AND DISCUSSION

This study employed the geoelectrical resistivity method using the Wenner–Schlumberger configuration. The survey line had a total length of 102 meters, consisting of a single electrode line with an electrode spacing of 6 meters. The Wenner–Schlumberger configuration combines the advantages of the Wenner array, which is sensitive to lateral variations in resistivity, and the Schlumberger array, which is sensitive to vertical variations.[8], [9] Therefore, this hybrid configuration is widely recommended for deep subsurface investigations, as it provides a balanced sensitivity to both vertical and horizontal resistivity changes.

After conducting the geoelectrical survey along the Gumitir road section, the field data were processed using Res2Dinv software to generate a two-dimensional (2D) resistivity cross-section. The resulting model illustrates the variation of resistivity values along the survey line and enables the interpretation of subsurface geological structures. The interpretation results are presented as follows.

Interpretation of Geoelectrical Data

The identification of subsurface layers and their geological structures was determined based on the resistivity values and the color variations shown in the processed 2D resistivity cross-section. Each color pattern in the model represents a different resistivity range, which corresponds to specific soil or rock types.[6] The interpretation of these resistivity values was conducted qualitatively to infer the subsurface geological structure of the study area.

To classify the types of subsurface materials and to describe the resistivity characteristics of each layer, the analysis referred to standard resistivity literature and supporting geological data. These references provided benchmark resistivity values for various rock and soil types, allowing for an accurate interpretation of the lithological composition and subsurface layering obtained from the geoelectrical survey.

Table 1. Classification of Rocks and Resistivity Values

Material	Apparent Resistivity (Ω·m)
Surface Water	80 – 200
Groundwater	30 – 100
Silt – Clay	10 – 200
Sand	100 – 600
Sand and Gravel	100 – 1000
Mudstone	20 – 200
Sandstone	50 – 500
Conglomerate	100 – 500
Tuff	20 – 200
Andesite Group	100 – 2000
Granite Group	1000 – 10000
Clay Soil	1.5 – 3.0
Clayey Silt	3.0 – 15
Silty Sand	15 – 150
Moist Bedrock	150 – 300
Silty Gravel Sand	300
Unweathered Bedrock	2400
Freshwater Zone	20 – 60
Saline Water Zone	20 – 200
Chert / Slate Group	0.18 – 0.24

Source: Telford, W.M., Geldart, L.P., & Sheriff, R.E. (1990). Applied Geophysics, 2nd Edition. Cambridge University Press.

The geoelectrical survey conducted along the Gumitir road section produced a survey line length of 102 meters with an electrode spacing of 6 meters. A total of 67 datum points were recorded, and the maximum penetration depth reached approximately 19.1 meters. The processed data were visualized as a two-dimensional (2D) resistivity cross-section, represented by various color patterns indicating differences in resistivity values.

The color interpretation on the 2D resistivity model shows that the resistivity values increase toward the right side of the section, representing denser geological structures that correspond to igneous rock formations. The variation in resistivity is influenced by several factors, including grain size, soil composition, moisture content, and clay mineral concentration. Finer-grained materials tend to have better electrical conductivity, resulting in lower resistivity values. Conversely, an increase in clay mineral content reduces resistivity due to higher ion exchange capacity, while denser and more compact rock formations exhibit higher resistivity values.

The 2D resistivity model obtained from the geoelectrical survey along the Gumitir road section is illustrated in Figure 3, showing the subsurface structure and the distribution of resistivity variations at different depths.

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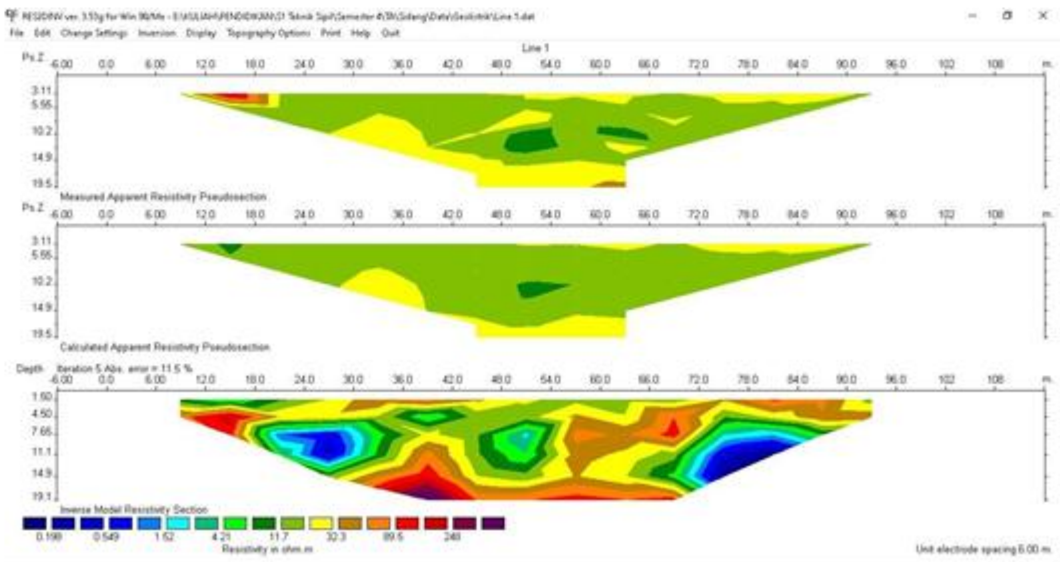

Figure 3. 2D Resistivity Cross-Section Model of the Geoelectrical Survey Line

The observation of the geoelectrical survey results along the measurement line showed a root mean square (RMS) error of 11.5%, indicating a satisfactory level of data accuracy from the inversion process. Based on the generated 2D resistivity cross-section, the lithological interpretation was performed by correlating the resistivity values with the subsurface geological characteristics. The interpretation results of the geoelectrical section are summarized in Table 2 below.

Table 2. Lithological Interpretation Results of the Geoelectrical Survey Line

No.	Color Scale	Resistivity Value (Ω. m)	Rock Density
1	-	0.198 - 1.52	Chert, Slate, Sand, Clay, Loam
2	-	4.21 - 32.3	Clay, Silt, Silt with sand
3	-	32.3 - 248	Silt with sand, Clay.

It should be noted that the study area is located within a mountainous region, which significantly influences the subsurface geological structure. Based on the 2D resistivity cross-section obtained from the geoelectrical survey, the subsurface layers along the survey line are characterized by color variations ranging from dark blue to light blue, green to yellow, and orange to purple, each representing distinct resistivity zones.[10], [11].

The dark blue to light blue zone, with resistivity values ranging from 0.198 to 1.52 Ω·m, is interpreted as chert, slate, sand, clay, and clayey silt. This layer is distributed between 70–86 meters and 19–32 meters along the survey line, with depths reaching approximately 11.1 to 14.9 meters. The green to yellow zone, which exhibits resistivity values of 4.21–30 Ω·m, corresponds to clay, silt, silty sand, mudstone, and tuff, extending from 8–90 meters with a maximum depth of around 16 meters.

Meanwhile, the orange to purple zone, which shows higher resistivity values between 30–248 Ω·m, is identified as silty sand, clay, mudstone, sandy gravel, moist bedrock, andesite, tuff, and conglomerate. This layer extends from 8–93 meters along the survey line and reaches a maximum depth of 19.1 meters. These variations indicate differences in lithological composition and compaction, reflecting the heterogeneous subsurface structure of the Gumitir mountainous area.

Standard Penetration Test (SPT) Results

The results of the soil boring and data analysis conducted by researchers from the Public Works Office of Banyuwangi (PU Banyuwangi) revealed the subsurface conditions along the Gumitir road section at KM 233+550. Two borehole locations were identified, namely Bore Log 1 and Bore Log 2. The drilling for Bore Log 2 reached a depth of 30 meters below the surface, which was considered sufficient for foundation analysis. Deeper drilling was deemed unnecessary since the underlying rock layers at greater depths become denser and harder, resulting in significantly higher construction costs.

In this study, the researchers primarily utilized data from Bore Log 2, as its location was more accessible for the implementation of the geoelectrical resistivity method. In contrast, Bore Log 1 was located on a steep slope below the Bore Log 2 site, making it difficult to access and unsuitable for integrated geoelectrical correlation. The SPT (Standard Penetration Test) results obtained from Bore Log 2 are presented and analyzed as follows.

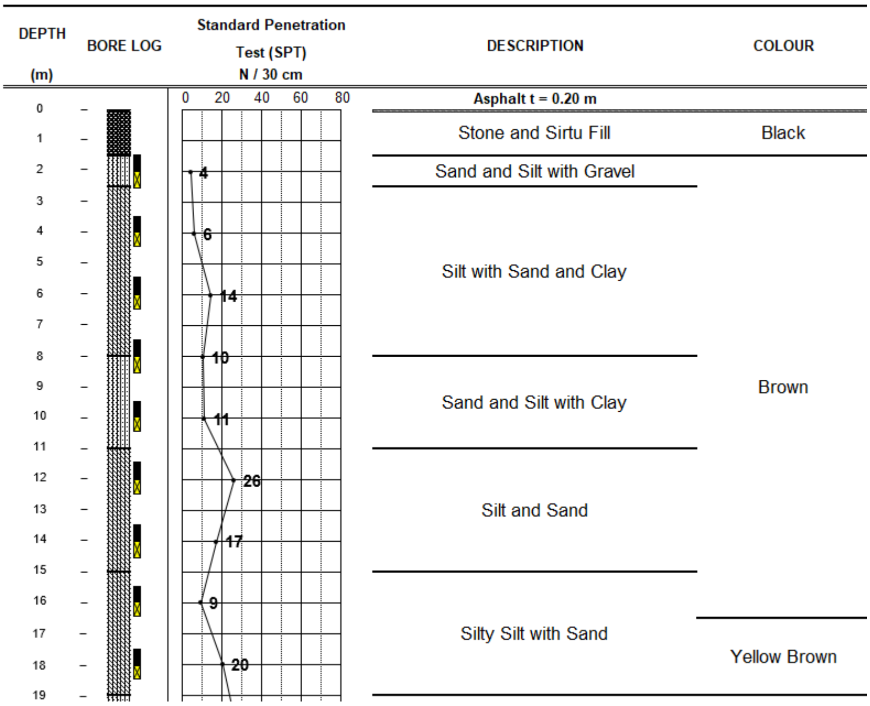

Figure 4. N-SPT Bore Log 2 Results

Based on Figure 4, the rock and soil hardness classification can be interpreted according to the N-SPT (Standard Penetration Test) values. When N-SPT < 4, the layer is categorized as very soft soil. An N-SPT value between 4–10 indicates a soft soil structure, while N-SPT values of 10–30 correspond to medium-density soil. Layers with N-SPT values between 30–50 are classified as dense, and those with N-SPT > 50 represent very dense or hard soil layers.[7], [12].

The results of the SPT data from Bore Log 2 indicate that the subsurface condition in the test area is predominantly composed of soft to medium soil layers. Specifically, at depths of 2, 4, 8, and 16 meters, the layers are classified as soft soil, characterized by N-SPT values ranging from 4 to 10. Meanwhile, at depths of 6, 10, 12, 14, and 18 meters, the soil layers exhibit medium density, with N-SPT values ranging from 10 to 30.

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The soft soil layers are primarily composed of sand and silt mixed with gravel, while the medium-density layers consist of sand and silt with clay content. These findings demonstrate the vertical variation in soil hardness and support the correlation with resistivity data, indicating consistent geotechnical and geophysical interpretations along the Gumitir road section.

Correlation Between Geoelectrical and Standard Penetration Test (SPT) Data

The correlation analysis was conducted by combining the results of geoelectrical resistivity interpretation and Standard Penetration Test (SPT) data to strengthen the overall findings of this study. The correlation aimed to identify the relationship between electrical resistivity values and soil strength parameters (N-SPT values) obtained from borehole testing.[13] In this study, the borehole location was positioned approximately at the center of the geoelectrical survey line, ensuring a direct comparison between the two datasets. The correlation was performed up to a depth of 19 meters, focusing only on specific depth intervals that corresponded to the resistivity model and available SPT data points. Through this correlation, the subsurface layers obtained from the 2D resistivity section were aligned with the SPT borehole data, allowing for an integrated interpretation of geophysical and geotechnical characteristics of the subsurface materials. The detailed results of the correlation between the geoelectrical and SPT data are presented as follows.

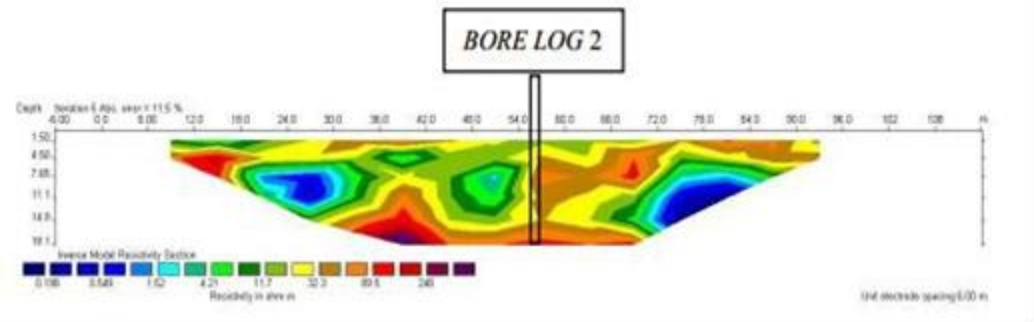

Figure 5. Correlation Between the 2D Geoelectrical Cross-Section and Bore Log 2

Based on the correlation illustrated in Figure 5, the lithological and mineral composition of the subsurface can be inferred by integrating the geoelectrical resistivity data with the Standard Penetration Test (SPT) results at each depth interval. This correlation enables the identification of rock or soil types corresponding to specific resistivity ranges and N-SPT values, providing a more accurate understanding of subsurface characteristics. The following interpretation summarizes the inferred rock and mineral types obtained from the correlation analysis between the geoelectrical survey line and Bore Log 2.

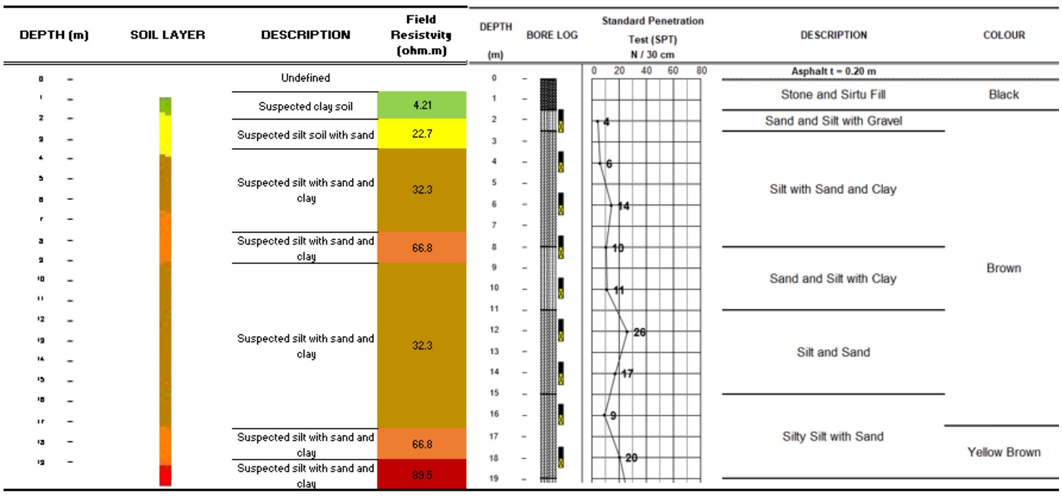

Figure 6. Correlation Results Between the Geoelectrical Survey Line and Bore Log 2

Based on the results presented in Table 3, it can be observed that at depths ranging from 2 to 6 meters, the subsurface layer exhibits resistivity values between 4.21 and 30 Ω·m with N-SPT values ranging from 4 to 6 blows. These parameters indicate that the layer is composed of clay, silt, silty sand, mudstone, and tuff, which represent soft soil materials with relatively low compaction. At depths between 6 and 19 meters, the resistivity values increase significantly to approximately 30–248 Ω·m, while the N-SPT values range between 10 and 30 blows. These values suggest the presence of silty sand, clay, mudstone, sandy gravel, moist bedrock, andesitic rock, tuff, and conglomerate. The higher resistivity and N-SPT values at these depths indicate denser and more compact soil and rock formations, reflecting stronger subsurface structures in comparison to the upper layers.[14]

The results of the geoelectrical resistivity data and the Standard Penetration Test (SPT) show a high degree of similarity when analyzed through correlation and synchronization. These two methods are complementary in nature, each possessing distinct strengths and limitations. The SPT method provides precise and detailed information regarding the subsurface soil strength and layering, but it cannot determine the origin or composition of the parent rock. Conversely, the geoelectrical resistivity method offers a broader overview of the subsurface geological structure and can infer the material composition based on resistivity values, but it cannot specifically identify the exact mineralogical or lithological characteristics of the rocks.[15], [16]

The correlation between geoelectrical and SPT data reveals that the subsurface structure in the study area consists of rock layers exhibiting high resistivity values and high N-SPT values, particularly at depths ranging from 6 to 19 meters. This indicates the presence of dense and compact subsurface formations. Empirically, the correlation between rock resistivity values and N-SPT values demonstrates a consistent relationship — low resistivity values correspond to low N-SPT values, representing soft and less compact soils, whereas high resistivity values correspond to high N-SPT values, indicating harder and more consolidated rock formations.

CONCLUSION

This study analyzed the subsurface conditions of the Gumitir road section in Banyuwangi–Jember using the geoelectrical resistivity method with the Wenner–Schlumberger configuration and correlated the results with data obtained from the Standard Penetration Test (SPT). The integration of these two approaches aimed to identify the relationship between electrical resistivity values and soil strength, providing an empirical basis for evaluating the geological and geotechnical characteristics of the study area. The results of the 2D resistivity modeling indicated variations in resistivity values ranging from 4.21 Ω·m to 248 Ω·m, which correspond to differences in lithological composition and compaction levels. At depths between 2 and 6 meters, low resistivity values (4.21–30 Ω·m) and low N-SPT values (4–6 blows) were identified, indicating soft soil materials such as clay, silt, silty sand, mudstone, and tuff. In contrast, at depths between 6 and 19 meters, the resistivity values increased to approximately 30–248 Ω·m, with corresponding N-SPT values of 10–30 blows, signifying medium to dense subsurface formations dominated by silty sand, clay, mudstone, sandy gravel, tuff, and andesitic rocks. The correlation analysis demonstrates a clear empirical relationship between resistivity and N-SPT values. Layers with low resistivity values tend to have low N-SPT values, representing soft and less compacted soils, whereas layers with high resistivity values show high N-SPT values, reflecting dense and consolidated geological structures. This consistency confirms that geoelectrical resistivity methods can effectively complement geotechnical investigations by providing a broader view of subsurface variability and assisting in identifying potential weak zones. The findings contribute to a better understanding of the subsurface characteristics of the Gumitir mountain area, which is prone to landslides due to steep slopes and geological heterogeneity. The combined use of resistivity and SPT data provides a reliable and cost-efficient approach for road infrastructure planning, slope stability assessment, and foundation design in similar mountainous terrains. Future studies are recommended to integrate seismic refraction and cone penetration test (CPT) data to enhance subsurface modeling accuracy and to conduct time-lapse monitoring for identifying dynamic changes in soil moisture and resistivity that may influence slope instability over time.

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