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The Sliding Surface Determination of A Deep-seated Landslide on Cisumdawu Highway, West Java, Based on The Electrical Resistivity Tomography

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Abstract - Sumedang is one of the regencies in West Java Province that usually experiences landslides due to its lithology, slopes, and water level conditions. Previously slow-moving landslides occurred between 2016 and February 2021, affected the new Cileunyi-Sumedang-Dawuan (Cisumdawu) Highway at Section 2, Station 21 in the North Sumedang District. This research aims to identify the causes of these landslides using a combination of geological field observation, subsurface geo-electric resistivity-based survey, and borehole drilling. A total of fourteen boreholes were drilled to collect geotechnical data from the subsurface of the researched area, including the soil material and N-SPT value. The soil hardness and resistivity were measured and compared to establish the relationship between resistivity and engineering properties. The result of the resistivity measurement showed that the percolating water zone in the permeable loose soil was located above the impermeable layer, estimated as a slip surface. The subsurface measurement and borehole data show that the lithology of the sliding surface is a layer of clay with a thickness of 5 - 12 m, the slope of the sliding surface is 20^{o}, and the depth is between 24 - 26 m. The cover layer of the sliding surface is a layer of silty clay and gravelly clay with a thickness of 5 - 10 m. Thus, based on the data presented, installation of bore piles and groundwater level monitoring need to be done as mitigation efforts.

Keywords: Cisumdawu Highway, boreholes, resistivity, soil, subsurface

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Introduction

Background

A landslide is the movement of rock masses, debris, soil, or the flow of rock boulders toward the bottom of a slope due to gravity (Cornforth, 2004). Many variables, such as natural occurrences, human activity, or a combination of both, can cause landslides. Other factors such as heavy rain that raises the groundwater level which saturates the soil, or earthquakes frequently also cause landslides.

Some countries with mountainous or hilly topography deal with the severe problems of landslide (Hardiyatmo, 2012). A previous report has discovered that Indonesia is one of the countries vulnerable to landslides in Southeast Asia and the world. The country recorded a total of 1,038 landslides in 2021. Subsequently, as reported by Badan Nasional Penanggulangan Bencana (BNPB) in 2021, twenty-two of these hazards occurred in Sumedang (BNPB, 2023).

A landslide occurred at Cisumdawu Highway, Station 21, North Sumedang Subregency, Sumedang Regency, West Java Province (Figure 1). This landslide damaged about eighteen houses and delayed Cisumdawu Highway construction. The landslide phenomenon observed on the surface might be a manifestation of the subsurface movement. Therefore, it is important to understand the subsurface conditions related to the landslide slip surface and lithology. The landslide occurred in 2016 and continued until February 2022. The impacts of the event are widespread, such as cracks in buildings and infrastructure (highway). Therefore, the recovery will be a lengthy process and costly (Figure 2).

According to Kementerian PUPR (The Ministry of Public Work and Housing of Indonesia) (2022), the Cileunyi-Sumedang-Dawuan Highway, abbreviated as Cisumdawu Highway, is 62 km long. The efficient operation of Kertajati In-

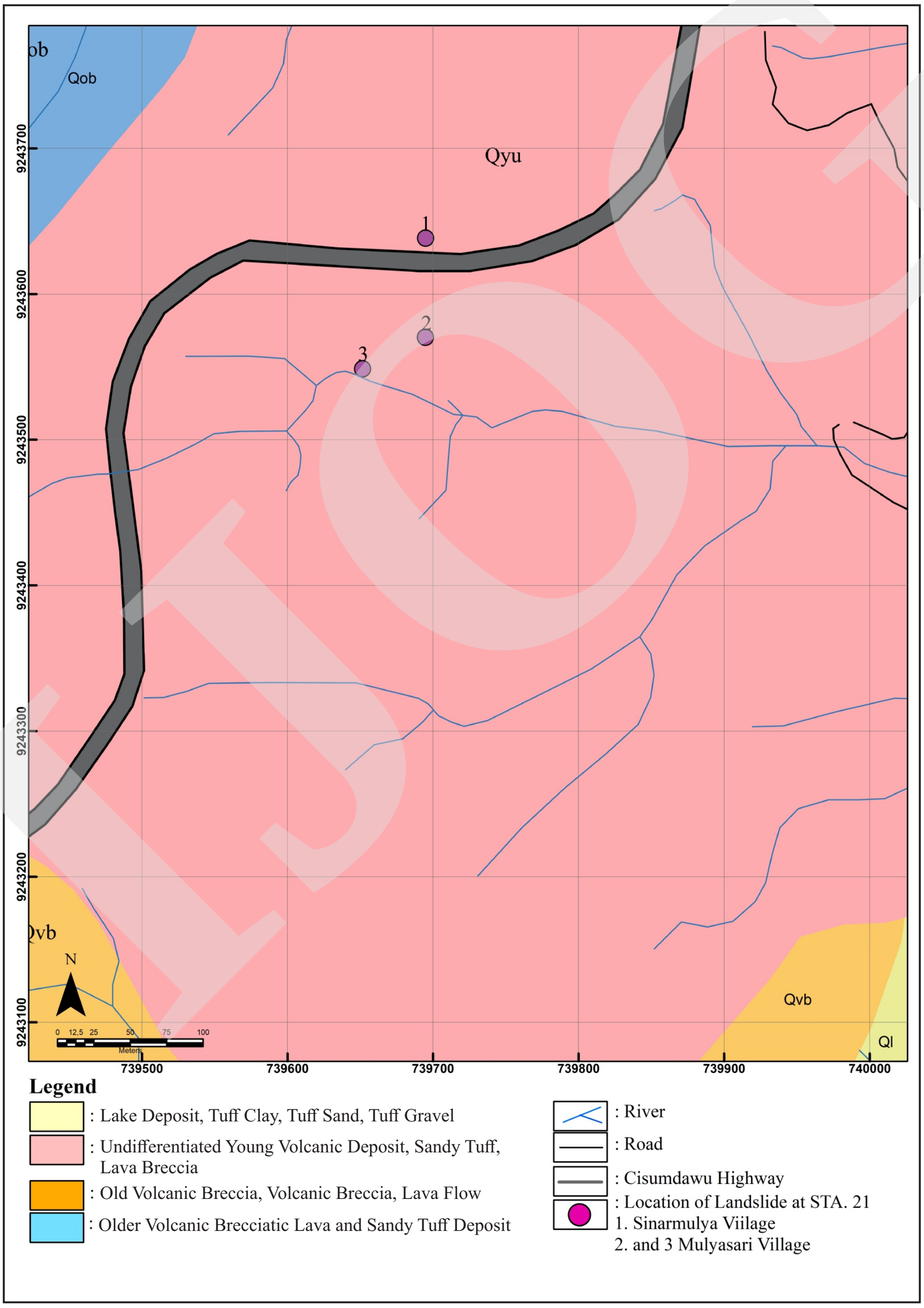

Figure 1. Researched area and simplified geological map (modified from Silitonga,1973).

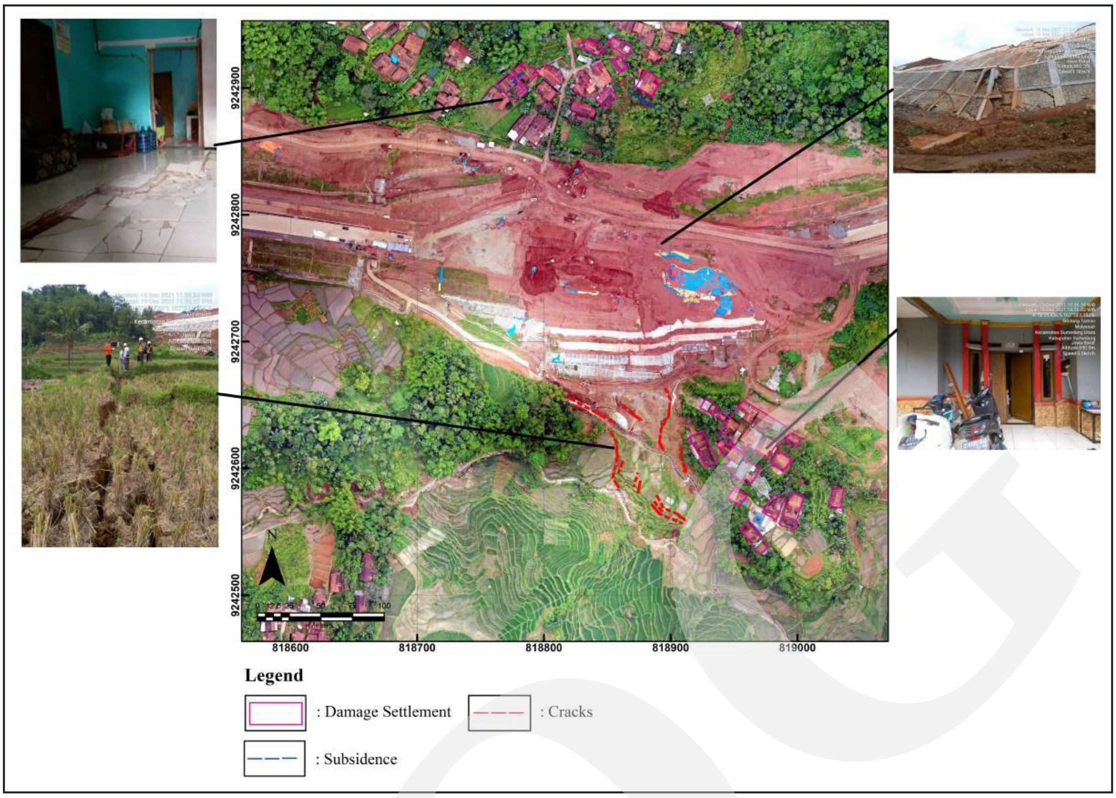

Figure 2. Landslide effects on infrastructure and buildings on Cisumdawu Highway Station 21.

ternational Airport, Patimban Port, and the growth of Ciayu Majakuning (Cirebon, Indramayu, Majalengka, and Kuningan) economic area in West Java depends significantly on the completion of the Cisumdawu Highway construction. The distance between Bandung - Kertajati using the existing local roads is around 160 km, and the highway will be reduced to approximately 60 km (Kementerian PUPR, 2022).

Several research investigations have indicated the landslides on the Cisumdawu Highway. Sholehah *et al.* (2020) stated that the stability of the slope, using the 2D Plaxis software, had a safety factor of 0.97, and the displacement on the slope after being given traffic and pavement load was 0.7463 m. This indicated that the slope was unsafe or had the potential for landslides, and could only be overcome through reinforcement.

The Atterberg limit value of soil analyzed by Kurniangga (2020) showed that the slope of Station Number 18+000 had a highly expansive layer of 0−10 m. Meanwhile, the value of the soil physical properties suggested that the slope at station 18+000 had a safety factor of 0.900, which indicated a high level of susceptibility to landslide.

Based on the susceptibility to landslide zone map of Sumedang Regency (Pusat Vulkanologi dan Mitigasi Bencana Geologi, 2016), the researched area has the low to moderate susceptibility to landslides. Over the past five years, several geophysical techniques, particularly the resistivity method, have been used to investigate landslides. For example, 1) Resistivity method and core drilling data for preliminary studies (Susilo *et al*, 2018), (2) Self-potential method and electrical resistivity tomography for landslide investigation (Santoso *et al*, 2019), and (3) Electrical Resistivity Tomography method for monitoring landslides (Syukri *et al*, 2020; Prastowo *et al*, 2021; Tsai *et al*, 2021; Juwono *et al*, 2022, and Rizqi *et al*, 2022). Previous studies on landslides along Cisumdawu Highway have not provided a clear understanding of the subsurface condition. This research aims to identify the factors that cause landslide hazards at Station 21 based on surface and subsurface investigation and measurement, which is very useful to determine the next mitigation measures. To obtain data and information about the causes of landslide factors as well as the damaged and affected area, fieldwork employing geological observation, supported by resistivity measurement, and borehole core data was conducted.

Geological Setting

Based on the Geological Map of the Bandung Sheet, Java (Silitonga, 1973), the researched area consists of young undifferentiated volcanic rocks (Qyu) of Quaternary age, composed of tuffaceous sandstone, lapilli, volcanic breccia, and agglomerate lava, as illustrated in Figure 1.

Field observations showed that the pyroclastic fall and lava flow deposits were found in the northern part of the researched area. The pyroclastic fall is deposited in more than 50 % of the area, composed of scoria, lapilli, as well as ash. Scoria fall deposits are grey in fresh outcrop and light brown in weathered, but they are strongly weathered. The fragments are subangular to rounded grain shaped. Furthermore, clast size ranges from 1.5 to 5.5 cm in diameter, and basaltic andesite to andesite lithic has clasts of 0.2–3 cm in diameter.

The lava flow deposits showed grey to light brown basaltic andesite to andesite compositions, massive to sheeting joint, porphyritic with plagioclase and pyroxene phenocrysts, moderately to highly weathered. Organic soil was also at the top with 0.75-1 m thickness.

The direction of the slow-moving landslide is N 170-180° E, and is characterized by cracks and land subsidence in residential areas, plantation lands, rice fields, and highways. The slow-moving landslide and land subsidence occurred on an under-construction highway, settlements, and paddy fields. These caused eighteen residents' houses, including the foundation and floor, be moderately damaged. Generally, the land in this area is used as settlement and rice field. (Figure 2).

Methods And Materials

Borehole Drilling Method

Borehole drilling has been carried out by the Ministry of Public Work and Housing to obtain undisturbed core samples, to conduct SPT (Standard Penetration Test), to observe and to determine the depth of the groundwater table. A total of fourteen boreholes are named BH1 (50 m), BH2 (50 m), BH3 (50 m), BH4 (40 m), BH5 (40 m), BH6 (40 m), BH7 (50 m), Station 21+500A (30 m), Station 21+550B (45 m), Station 550A (40 m), Station 550B (35 m), Station 600A (40 m), Station 600B (40 m), and Station 600 (40 m) (Figure 3). However, two boreholes, Station 600 and Station 550A, located near the landslide area as shown in Figure 3, were selected due to the significant data observed. In this research, an SPT was conducted to determine the soil consistency. The interval of SPT is 2 m.

Resistivity Method

The resistivity method provides information on the behaviour of electrical resistivity underlying a sloped area, which is mainly controlled by the lithological nature and water content variation. It can also give information on the behaviour of the subsurface condition.

The resistivity method measurement was conducted by Kementerian PUPR in the researched area (Figure 4). The interpretation of resistivity measurement results was done by analyzing the resulting 2D cross-section. The resistivity value obtained was compared with the rock resistivity value from the reference (Telford, 1990), so that the subsurface structure of the studied area can be determined. In principle, the interpretation of this data processing was done to identify the presence of a slip surface as the first step in landslide mitigation.

Materials

This research applied different approaches: geological, geophysical, and geotechnical analyses. The geological approach used in this research includes a geological map of the Bandung Sheet,

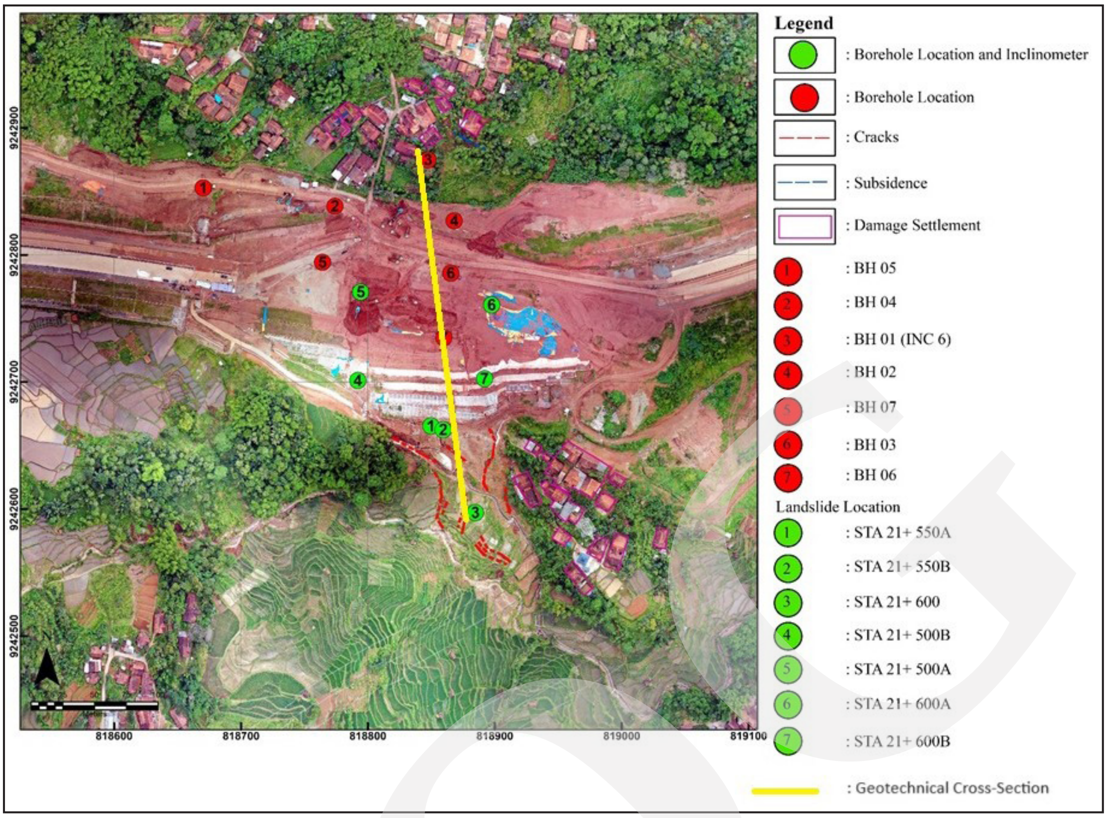

Figure 3. Borehole locations along the Cisumdawu Highway of Station 21.

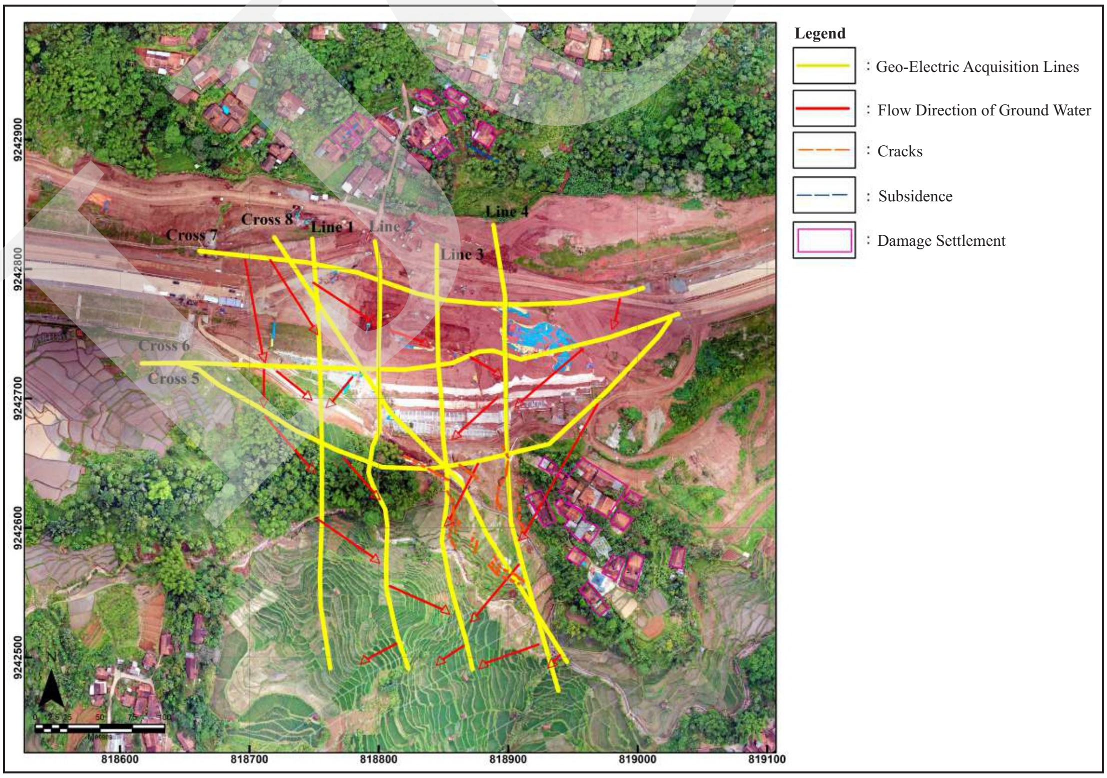

Figure 4. A map of the resistivity measurement area (Kementerian PUPR, 2022). The yellow lines are geo-electric data acquisition lines. Red arrows show the general direction of groundwater.

Java, at a scale of 1:100,000. Resistivity subsurface image of Sections of 2D for Lines 2A and 4A were used to interpret the subsurface condition. The materials used in this research include sixteen core samples from two boreholes that have been described for geotechnical purposes.

Result and Analysis

Material Description

Tables 1 and 2 show the results of laboratory tests and data from bore cores that were used to determine the material description. For Station 21+550A and Station 21+600, the N-SPT value and soil material description were evaluated.

The results of the borehole analysis revealed that the subsurface soil profile was not homogeneous. The soil layer is predominantly clay. Tables 1 and 2 also provide information of the soil hardness. For station 550A and station 600, the N-SPT values were higher at a depth of 26 m and above 26 m, respectively.

Resistivity Measurement

Figures 5, 6, and 7 show the profiles of the two-dimensional (2D) electrical resistivity section (resistivity subsurface images). The results of the 2D resistivity measurement gave the distribution of the electrical resistivity values. The resistivity contrasts due to the lithological nature of the terrain and water content variation were identified. Furthermore, the results of the 2D resistivity images were obtained from Lines 2A, 3A, and 4A (first stretch processing results). The resistivity value obtained was compared with the rock resistivity values from the reference (Telford, 1990) and is presented in Figure 8.

Table 1. Material Description and N-SPT Value of Station 21+550A

Depth (m)	Description	N-SPT value
4	Tuffaceous clay, brownish yellow, clay with tuff fragments, medium stiff consistency	10
10	Sandy clay, blackish brown, andesitic fragments, very stiff consistency	27
14	Clay sand, brownish grey, dominantly clay with some tuff fragments, hard consistency	40
20	Sand, brown, noncohesive, very stiff consistency	24
26	Weathered volcanic breccia, angular-subangular fragment, light brown, clay-sand grain size, hard consistency	50
30	Weathered volcanic breccia, angular-subangular fragment, light brown, clay-sand grain size, hard consistency	53
38	Sand cobble, gray, clay dominant in grain size, very hard consistency	>60
44	Sand pebble, grey, weathered from volcanic rocks (grade III), very hard consistency. Tab	>60

Table 2. Material Description and N-SPT Value of Station 21+600

Depth (m)	Description	N-SPT value
4	Silty clay, light brown, clay-silt grain size, medium stiff consistency	10
10	Gravely clay, reddish light brown, clay-gravel grain size, very stiff consistency	30
16	Silty clay, light brown, dominantly clay with gravel size fragments, very stiff consistency	28
22	Gravely silt, light brown, very stiff consistency	27
26	Clay-silty clay, dark brown, clay-silt grain size, hard consistency	60
30	Clay, light brown, clay-silt grain size, very hard consistency	>60
34	Sandy clay, light brown, clay-sand grain size, very hard consistency	>60
40	Gravely silt, grayish brown, grey gravel, very hard consistency	>60

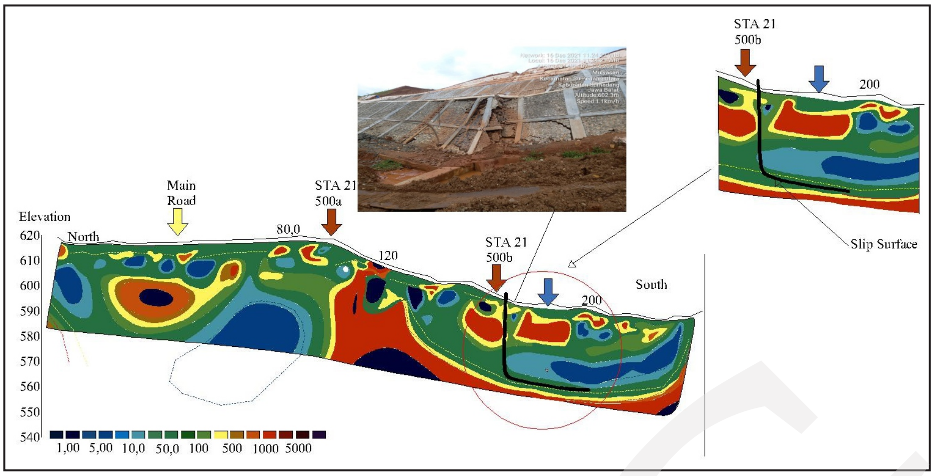

Figure 5. Section of 2D resistivity for Line 2A.

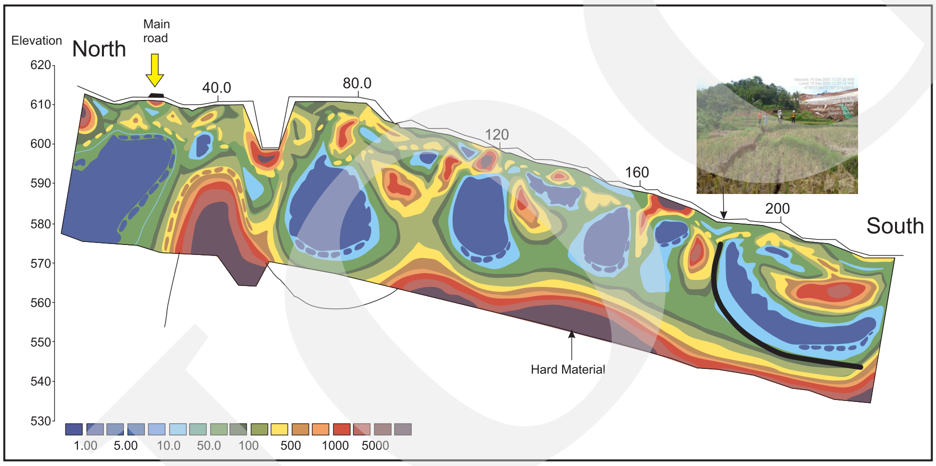

Figure 6. Section of 2D resistivity for Line 3A.

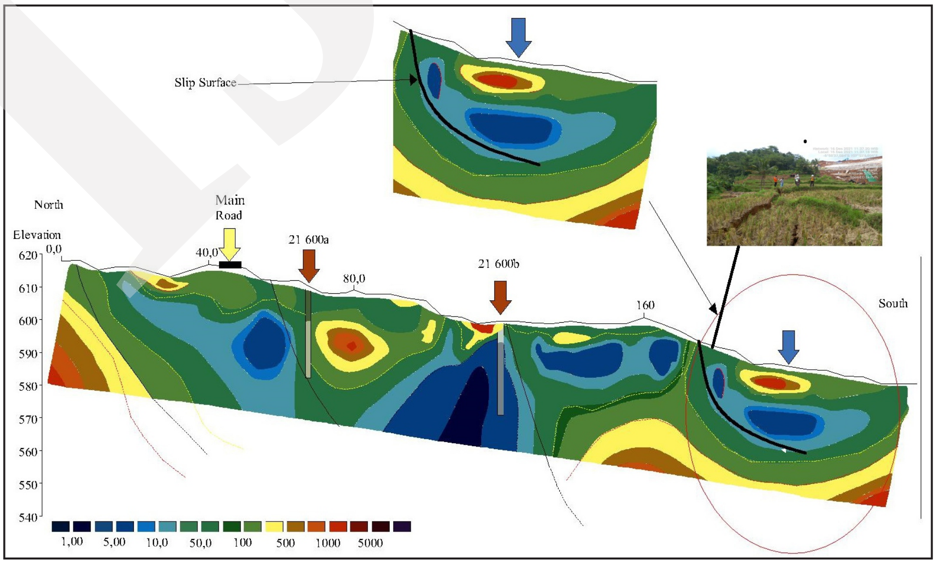

Figure 7. Section of 2D resistivity for Line 4A.

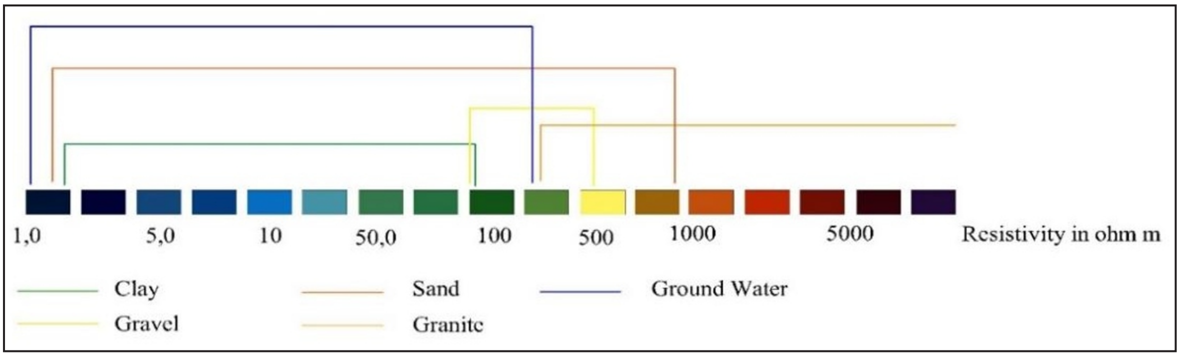

Figure 8. Summary of resistivity interpretation on Cisumdawu Highway.

The layer with a low resistivity value is water-saturated and silt or clay at 1–100 Ωm. A fairly higher resistivity value was discovered below the water-saturated layer and a harder rock in some places, with a resistivity of 50−200 Ωm, which is assumed to be clay. The boundary between the two layers or fields with different resistivity values was considered a slip surface.

For Line 2A (Figure 5), several soil gradations were detected in a scattered distribution. In Line 3A (Figure 6), the result showed that several water-saturated zones were detected from the north to the south. The boundary between the zone with a low resistivity value and a harder rock in the south part is interpreted as a slip surface. The localized weak zone extending from the left to the right side was 24−26m deep from the north to the south.

However, the majority of Line 4A (Figure 7) was in the centre, on the right with a shallower depth, and on the left with some deeper depths inside the resistivity images. The bore core data of Station 21+600 and Station 21+550A were used to interpret the subsurface layer. Based on Station 21+600, the subsurface profile material began as a medium stiff layer of clay to sandy clay at a depth of 9 m, which gradually changed to a harder layer at a deeper level.

In line 4A (Figure 7), the result showed that the resistivity tomography for permeable soil percolated with water was mainly located at the left-hand side with a shallow depth, the right-hand side, and within the resistivity image produced. For Line 2A (Figure 5), it was discovered that the resistivity tomography of permeable soil percolated with water accumulation was mainly located at the centre and slightly downslope to the southern area. Due to the presence of a percolated water zone, the zone of low resistivity value was produced. This zone might have developed due to water seepage from surface runoff, direct precipitation through porous subsurface materials, and the pre-existing groundwater zone in the area.

Based on both resistivity images produced in Figure 7, the hard zone was randomly distributed. The resistivity images in Figures 5, 6, and 7 also demonstrated that the thickness of the existing hard materials varied approximately from 10 m to 30 m.

Discussion

Since a weak zone was found in Figures 5, 6 and 7, it was assumed that Line 2A, 3A, and Line 4A were particularly vulnerable to soil erosion or slope failure. This weak zones were close to the downslope of the pictures, underneath, on the right-hand side. The phenomenon might be influenced by surface water seepage that reaches the natural drain/valley or water path through the permeable material. Figures 5, 6, and 7 show significant differences in resistivity values on Line 2A, 3A, and Line 4A, respectively, with the depth of 24−26m from the ground surface. The high resistivity value originated from hard materials, including gravel, boulders, and bedrock. The localized weak zone extending from the left to the right side was 24-26m deep, from the north to the south. Due to its low resistivity levels, the section of the segment can develop into a hazardous zone. A weakness plane (slip surface) for any slope failures can be viewed as the boundary between high and low resistivity values.

Based on the geotechnical cross-section through boreholes BH1, BH2, BH3, BH6, Sta 21+550A, and Sta 21+600 along Line 3A (Figure 9), the lithology of the researched area can be divided into four sections. They are the embankment soil (clayey soil) at a depth of 0-10 m with an N-SPT value of 5-10. The weathered volcanic rocks (tuff and andesitic breccia) at a depth of 10-15 m have an N-SPT value of 6-27. The weathered volcanic rocks (tuff and andesitic breccia) at a depth of 15-37 m have an N-SPT value of 10-32. The bedrock (gravelly sand and gravelly clay) at a depth of >37m has an N_SPT 32-60. Lithology of the sliding surface (red dashed line) is sandy silt, sandy clay, and clay with an N-SPT of more than 40.

A combination of geological field observation, subsurface geoelectric resistivity-based survey, and borehole drilling were applied to obtain the subsurface data of the researched area. The data of resistivity value and geo-engineering, including the soil material and N-SPT value, were compared to establish the relationship between resistivity and engineering properties. The result at Station 21+600 and Station 21+550A of Cisumdawu Highway reveals that the percolating water zone in the permeable loose soil is located above the clay that is impermeable zone having N-SPT values between 40–60 at a depth of 24–26m, and is a landslide sliding surface (Figure 8). Therefore, this region needs to be strengthened or protected in the future using proper geotechnical ground stabilization procedures.

Conclusions

Some conclusions can be drawn as follows:

The case study demonstrated that relevant techniques for slope failure investigation included the resistivity method validated by N-SPT value and geotechnical cross-section. The resistivity data showed the presence of saturated soil layers above the impermeable zone, which functioned as the slip surface. These methods offered a reliable result throughout the analysis.

Lithology of the sliding surface is sandy silt, sandy clay, and clay at a depth of 24 –26 m. The slope of the sliding surface is 20° with an N-SPT of more than 27. The results of this study can be used practically for determining a slip surface at the site .

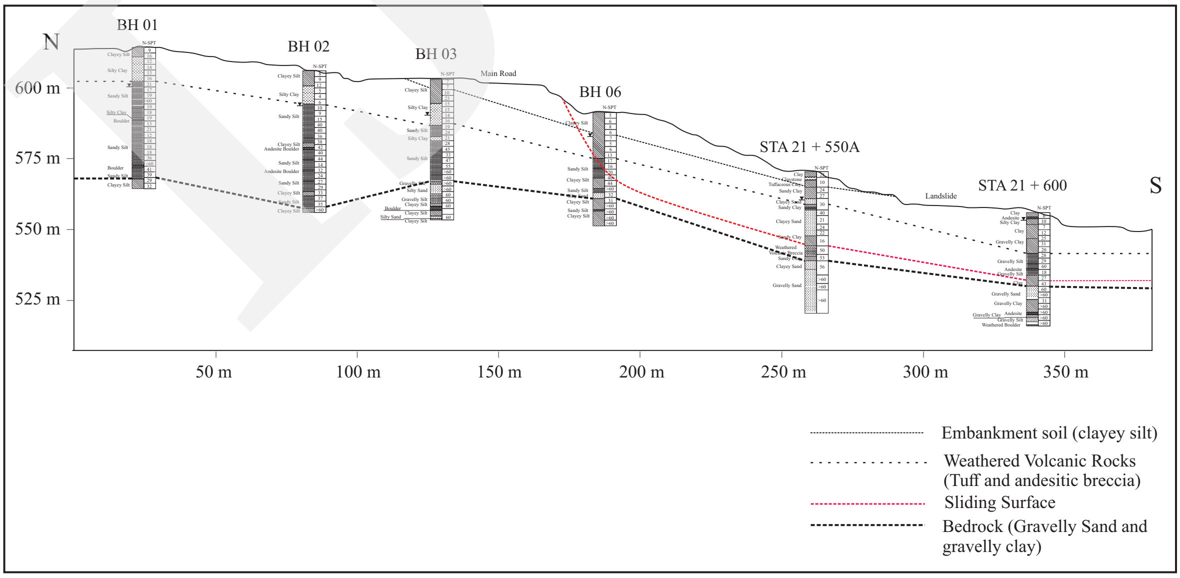

Figure 9. Geotechnical cross-section for some boreholes at Cisumdawu Highway Station 21. The cross-section shows the lithologic correlation between each borehole. The dashed red line shows the estimated sliding surface of each borehole.

Based on the data presented, the installation of bore piles and groundwater level monitoring need to be done as mitigation efforts. The framework implemented in this study is beneficial, and other landslide investigations can benefit from the combination of similar methods. For further research, the determination of rocks or soil weathering is recommended. Planning landslide mitigation using the advice from previous studies is also beneficial.

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