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Identification of Landslide Area Using Geoelectrical Resistivity Method as Disaster Mitigation Strategy

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***Abstract*— Extreme weather triggers high-intensity rainfall, and it triggers land movement that eventually becomes landslides. The water of rain will enter to the ground through the rock gaps and accumulate along the landslide area to reduce effective stress and reduce the shear strength of the soil. Morphologically, Sukaresmi Village, Cisaat Sub-District, Sukabumi Regency is located at the foot of Mount Gede with a bumpy surface relief. This condition is one factor that triggers landslides because the soil is prone to movement. This research aims to identify the field slope zone for landslide prediction in the Sukaresmi village, hoping that the surrounding community could anticipate further landslides. The research was carried out using the Geoelectrical Resistivity method of the Schlumberger configuration as many as eight measuring points with 1 m electrode spacing. This research indicates that the subsurface conditions are divided into three constituent rocks: Clay, Tuff, and Volcanic Breccia. The field slide zone is located between the Tuff rock and turf layer at a depth of 4-7. 5 m long, 82 m (Line 1), and 40 m (Line 2), with a resistivity value range of 56-158 Ωm. The efforts that the local government can make to anticipate the condition of the building to remain safe include analyzing soil stability, strengthening slopes, and making retaining walls to increase the value of the safety factor.**

***Keywords*— Disaster mitigation; landslide; geoelectrical resistivity; Sukabumi.**

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I. INTRODUCTION

Changes in extreme weather cause an increase in rainfall intensity [1]. Several disasters often occur when the rain intensity is high enough, such as floods and landslides. Landslides are a danger that causes damage to economic assets, including buildings, productive land, and casualties [2]. Indonesia is one of the countries that often experiences landslide natural disasters with high risk and is spread across almost all provinces.

Rain is one of the triggers for soil movement; falling water will enter the ground through rock gaps and accumulate along the landslide area to reduce effective stress and reduce the shear strength of the soil [3]. Heavy rain is more effective at triggering landslides on slopes where the soil absorbs water easily. The process of landslides begins with water infiltration into the soil, which adds to the weight of the soil. When the water enters to impermeable soil layer, which functions as a field slide zone, the rotten soil above it will move along the slope and get out of its initial state [4]. Infiltration of water in the soil on the slope is one factor that triggers landslides. The condition of the increasingly steep slopes can trigger the intensity of landslides due to low soil stability. Landslides are influenced by soil conditions that are prone to movement.

One area of Indonesia that often experiences landslides is Sukabumi Regency. Based on the information collected from the Indonesian Disaster Information Data (DIBI), the National Disaster Management Agency (BNPB), from 2014 to 2018, there were 95 landslides recorded. Whereas in 2019 (January-May), there were 26 landslides recorded [5]. One of the villages that experienced landslides is Sukaresmi Village, Cisaat Sub District, Sukabumi Regency; based on a field survey in July 2019, at least there are 3 points inside the village experienced landslides.

Morphologically, Sukaresmi Village, Cisaat Sub-District, Sukabumi Regency is located at the foot of Mount Gede at an altitude of approximately 650 meters above sea level with a fairly bumpy surface relief. This condition is one factor that supports the area being easy to landslides. Meanwhile, based on the Geological Map of the Bogor Sheet (1998) shown in Figure 1, Sukaresmi Village, Cisaat Sub-District, Sukabumi Regency is included in the Mount Pangrango Volcanics Formation and the Mount Gede Volcanics Formation, which are classified as quarter Holocene or approximately 9500 years BC [6]. However, the topsoil layer is composed of very weathered sediment.

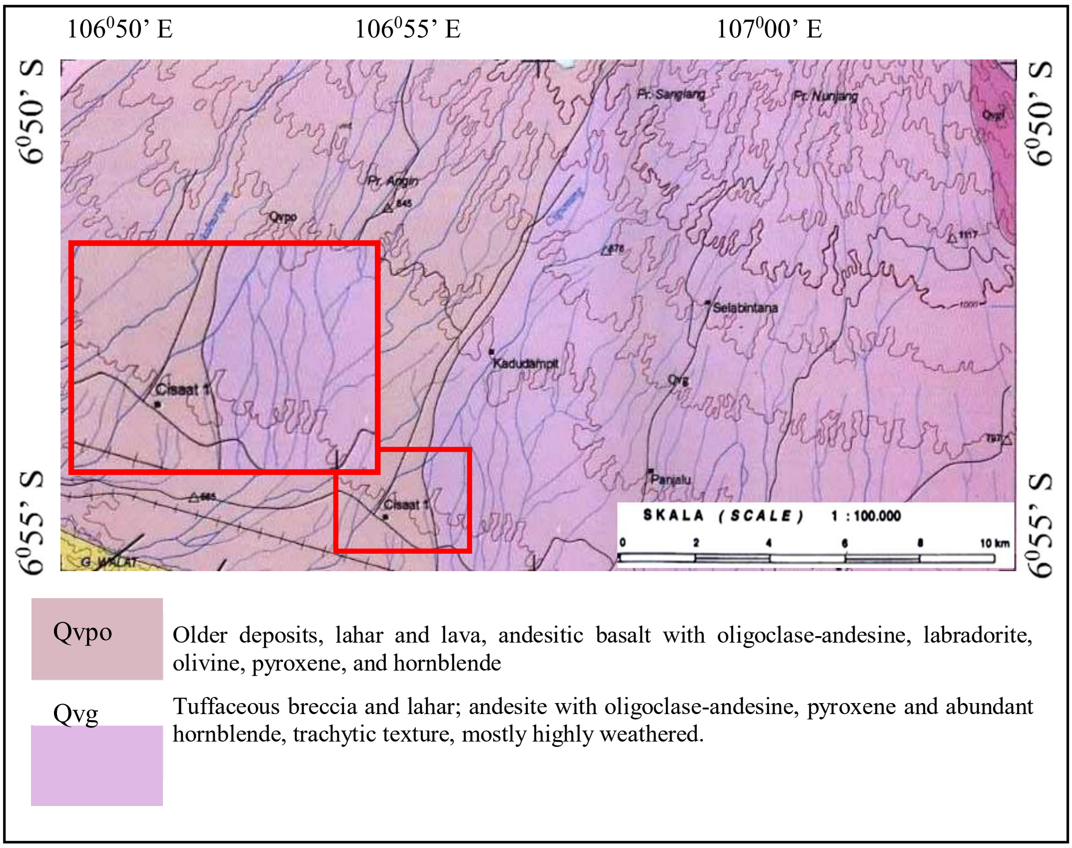


Fig. 1 Regional geological map of Bogor sheet [6]

Based on these conditions, it is important to identify the field slide zone around the landslide location to anticipate further landslides and the efforts that can be made to overcome the problem. The method commonly used to investigate subsurface layers is the geophysical method. One of the geophysical methods commonly used to identify soil subsurface layers is the geoelectrical resistivity method [7]. The geoelectrical resistivity method can determine the condition of the soil surface layer based on the distribution of the resistivity value of the rock [8]. The geoelectrical resistivity method is widely used in disaster mitigation, hydrogeology, and archaeology [9]. The measured resistivity value will be related to geological parameters such as water content, porosity, minerals, and so on [10]. Research about landslides using the geoelectrical resistivity method has been carried out by Abidin et al. [11] in Malaysia, Bellanova et al. [12] and Hojat et al. [13] in Italy, and Cebulski et al. [14] in Poland. Some of these studies indicate that the geoelectric resistivity method effectively determines subsurface conditions in landslide-prone areas [15].

In Indonesia, Susilo et al. [16] analyzed the landslide zones using the geoelectrical resistivity method in Ponorogo Regency. The results show that the geoelectrical resistivity method can provide a reasonable interpretation for analyzing landslides, such as landslide conditions and the thickness of the material that has the potential for landslides. The landslide area starts at a depth of 8–35 m below the soil surface, interpreted as a Tuff rock.

The analysis of the field slide zone is an important point in this study because soil stability affects the sliding rate. So, this research aims to identify the field slide zone in the Sukaresmi Village, Cisaat Sub-District, Sukabumi Regency, hoping that the surrounding community can anticipate the impact of and make efforts to prevent further landslides in areas prone to landslides.

II. Materials and Methods

Land subsurface investigations using the geoelectrical resistivity method were carried out by measuring the difference potential of an area by flowing an electric current into the ground through the current electrode [17]. The measurements use four electrodes, two current injection electrodes, and two other electrodes that work as a potential difference meter. The geoelectrical resistivity method has different types of electrode displacement configurations. Some of the most used configurations are Schlumberger, Wenner, and Dipole-dipole configurations. We use the Schlumberger configuration in this research because it is the most appropriate for measuring Vertical Electrical Sounding (VES). The data collection is the most efficient and optimal for error accumulation [10].

A. Schlumberger Configuration

The working principle of the Schlumberger configuration for the geoelectrical resistivity method is illustrated in Figure 2. Based on this figure, the (MN) electrode distance is made small so that theoretically, there is no change in the (MN) electrode distance. In comparison, the current electrode (AB) is moved to the specified distance length. The distance between electrodes (A) and (M) or (B) and (N) is a multiple of the length of the distance (MN) (See Fig. 2). The geometric factor (K) for the Schlumberger configuration can be determined by the equation (1) as follows [16]:

$$K = \frac{\left(\pi\left(\frac{AB}{2}\right)^2\right)}{a} \quad (1)$$

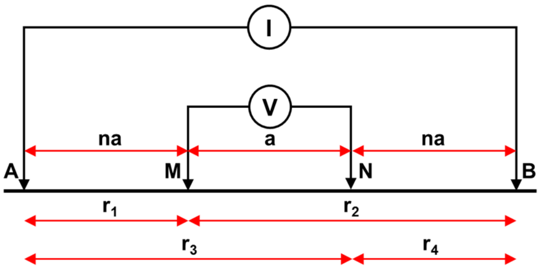


Fig. 2 The electrode position of the Schlumberger configuration

The results of field measurements are not the actual resistivity value but a mixture of various resistivity values of several rock types, either due to lateral or vertical variations; this result is referred to as the apparent resistivity value (ρa). The value of the geometry factor (K) from the equation (1) is then substituted into equation (2) by knowing the value of the potential difference (ΔV), the value of current (I), then obtaining the apparent resistivity value (ρa).

$$\rho_a = K\frac{\Delta V}{I} \quad (2)$$

B. Data Acquisition

Before the process of data acquisition, a field survey is required to determine the geological conditions of the research area and determine the measurement design for easier data acquisition in the field [18]. The process of data acquisition was carried out in Sukaresmi Village, Cisaat Sub-District, Sukabumi Regency. The data acquisition process was carried out using the geoelectrical resistivity method of the Schlumberger configuration as many as eight measurement points were divided into two parallel lines. The length of the measuring line is 20-40 meters at every measuring point, and the length of the electrode spacing is 1 meter. The measurement point design is adjusted to the location around the landslide incident at Sukaresmi Village, Cisaat Sub-District, Sukabumi Regency. The data obtained from data acquisition are the distance of the current electrode to the center point (AB/2), the distance of the potential electrode to the center point (MN/2), injection current (I), measured potential difference value (V), and geometry factor (K).

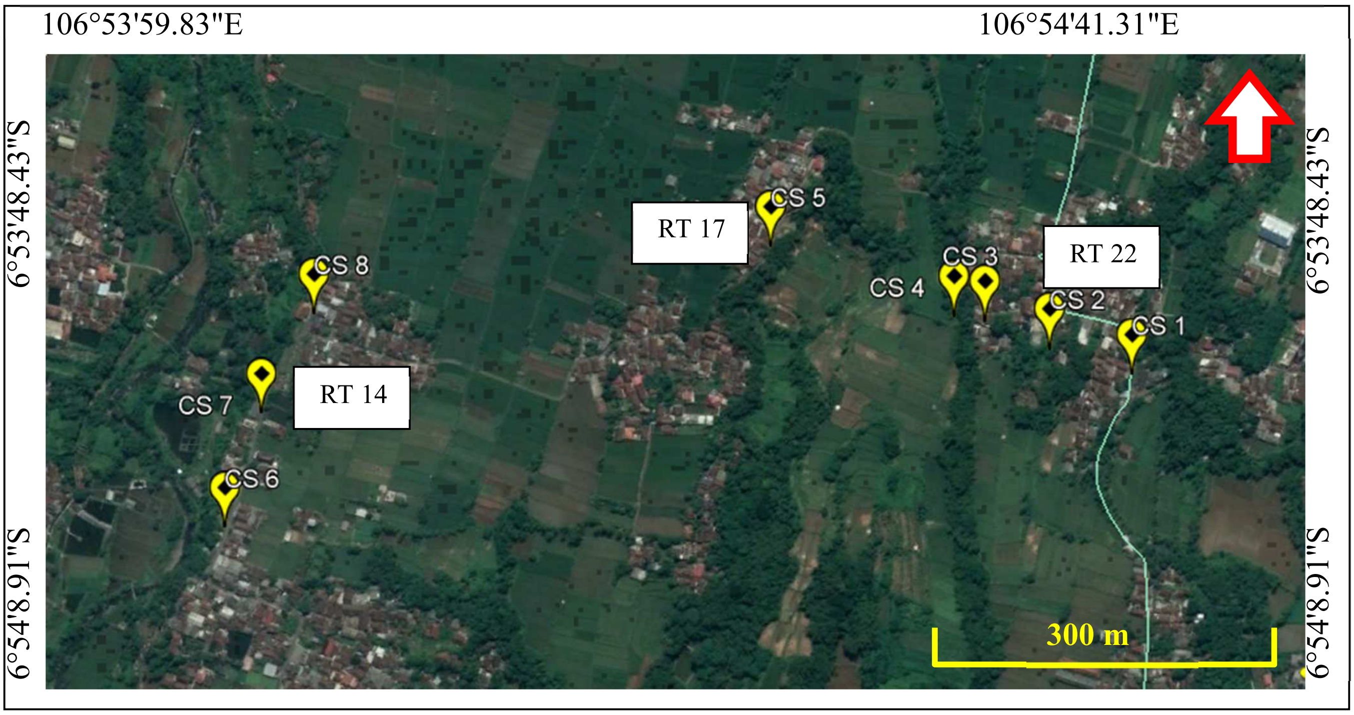


Fig. 3 Geoelectrical resistivity measurement survey design

C. Processing and Interpretation

The data needed in the data processing process are the apparent resistivity value (ρa). Then the least-squares inversion process was performed, which is one of the approaches methods used for regression or equation formation based on points [19]. That inversion process aims to convert all values in the apparent resistivity data into resistivity values close to the actual state. The results of the first processing obtained the 1D model, which consists of the resistivity value of depth. The 1D model at each sounding point is then correlated with the interpolation process. The interpolation process is done in a 2D pseudo-cross-section model. This process can be done by combining at least two parallel sounding points. The results of 2D cross-sectional interpolation are resistivity values, line length, and depth variations. The 2D cross-sectional interpretation was carried out with the help of geological data of the study area to determine whether there is a research target.

III. Result and Discussion

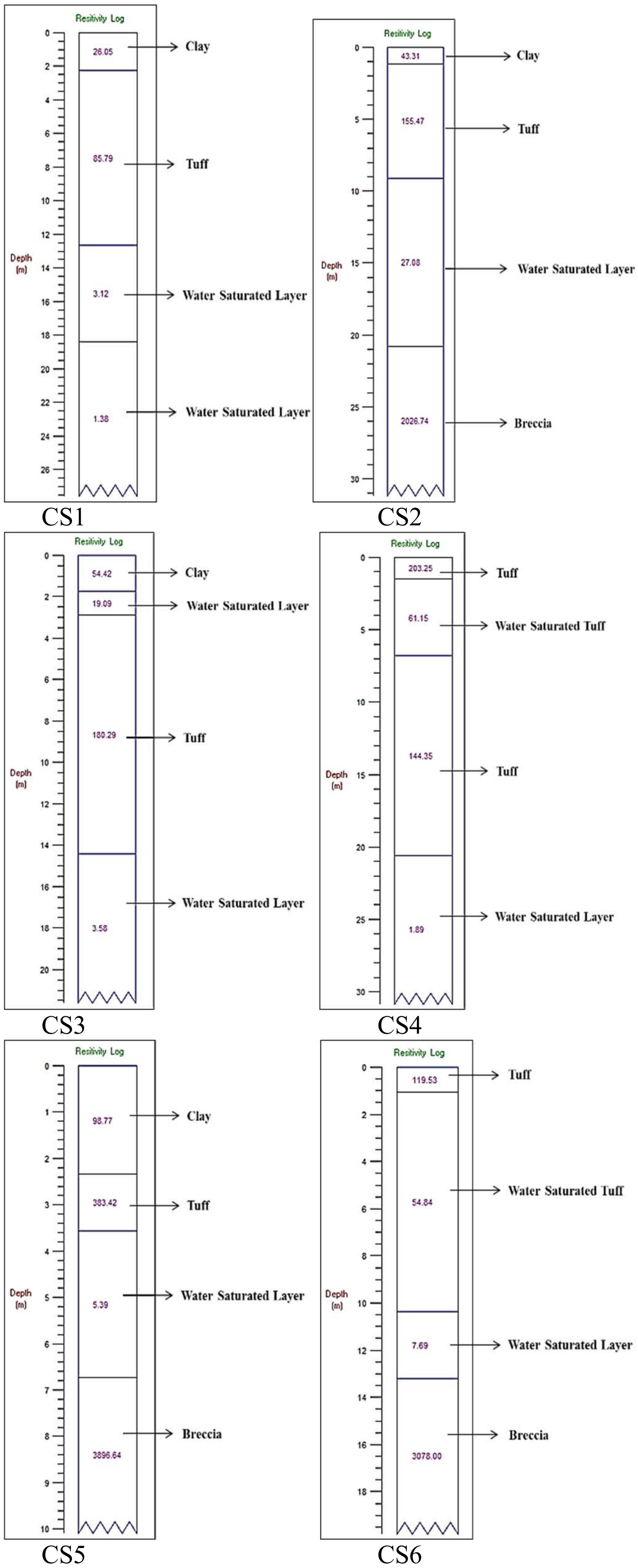
The resistivity data acquisition process has been carried out with the Schlumberger configuration. The results of data processing are a 1D resistivity log shown in Figure 4. In comparison, the interpolated 2D cross-section of the measurement points is shown in Figures 5 and 6. Based on Figure 4, the subsurface conditions are divided into three constituent rocks, including Clay (1-100 Ωm), Tuff (20-200 Ωm), and Volcanic Breccia (>1000 Ωm) [20]. During the dry season, the condition of the area, which is dominated by clay rock, will be strong, but this does not apply during the rainy season.

Geologically, the research location is included in the Mount Pangrango Volcanics Formation and the Mount Gede Volcanics Formation. The Mount Pangrango Volcanics Formation is composed of: older deposits, Lahore and lava, andesitic basalt with oligoclase-Andesine, Labradorite, olivine, pyroxene, and hornblende. While the Mount Gede Volcanics Formation is composed of: Tuffaceous breccia and lahar, andesite with oligoclase-andesine, pyroxene, and abundant hornblende, trachytic texture, mostly highly weathered [6]. Morphologically, the measurement location is in a mountainous area at an altitude of approximately 650 meters above sea level with bumpy surface relief, so this research location has a greater potential for landslides. The areas that experience weathering become a supporting factor for landslides so that they have a higher level of risk because weathered materials have loose properties, are not compact, and are easily saturated with water, so the potential for landslides to occur is greater.

A. 1D Interpretation

The field slide zone is indicated as a weathered layer that is impermeable so that it is no longer able to pass water. Water infiltration into the soil causes the soil to become saturated so that the bearing capacity and soil strength will decrease. If the soil layer above the impermeable layer is saturated with water, the soil is unable to support the weight of the soil, so it can trigger landslides [21]. This is because, in addition to passing water, the soil is also capable of storing water. This condition can occur because of the porosity and permeability, which is one of the factors causing the soil to become saturated; in this case, the clay has the highest porosity and permeability values, so that is prone to saturation.

The field slide zone can be found in the difference in resistivity value between the two layers of soil that is quite significant, such as the border between clay and breccia rocks that are quite contrasting at a certain depth. In this research, landslides occurred at the CS3 measurement point with a depth of about 0-3 meters. If we look at the results of CS3 research, the depth of 0-2 meters is dominated by clay rock. Then the next layer is water-saturated soil. The next landslide was found at CS5 with a depth of about 0-4 meters. The results of research on CS5 show that at a depth of 0-2 meters, the soil surface is dominated by clay, then Tuff, while at a depth of 3. 5-7 meters, it is saturated with water. Landslides were also found around CS7 at a depth of about 10 meters. The results of research on CS7 show that at a depth of 18-20 meters, there is a water-saturated zone. The three landslide conditions are caused by the soil being saturated with water and unable to support its weight so that landslides occur at that point.



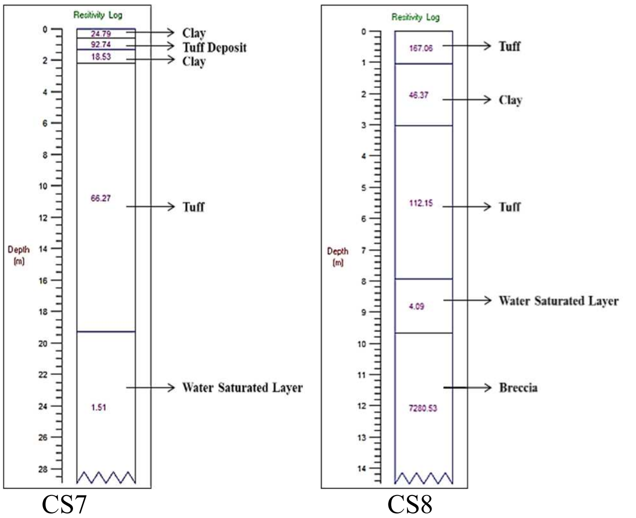


Fig. 4 One dimensional data processing result

B. 2D Interpretation

Line 1 is a 2D cross-section from the results of the interpolation of the measuring points parallel and forming a straight line, namely: CS1, CS2, CS3, CS4, and CS5. The position of line 1 stretches from West to East past the landslide point. Based on the 2D cross-section shown in Figure 5, there is a water-saturated layer (blue color) on the soil surface to a depth of 5 m with a resistivity value range of 3-56 Ωm. Below the water-saturated layer, there is a zone with a high resistivity value (158-400 Ωm) which is thought to be the Tuff rock at a depth of 5-10 m below the ground surface. This field slide zone is located between the Tuff rock and the water-saturated layer at a depth of 5-7. 5 m with a resistivity value range of 56-158 Ωm and extends along 82 meters at the CS1 to CS3 measurement point. The slope condition on line 1 is steep, with a degree of slope of approximately 20^0 on CS2 until CS4.

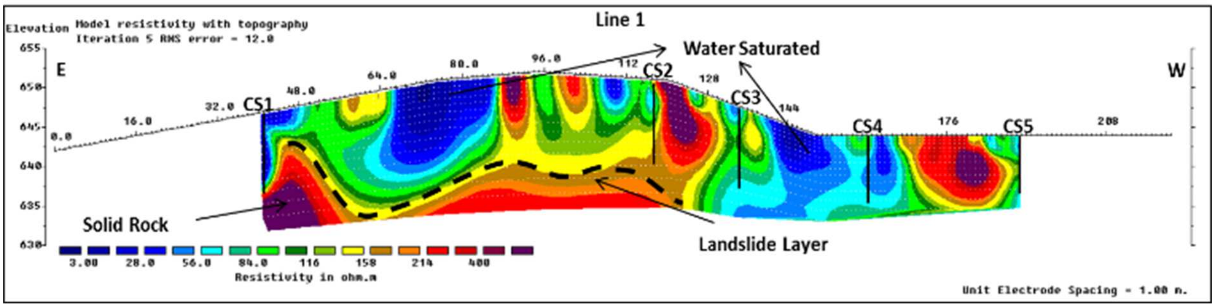


Fig. 5 2D subsurface cross-section resistivity of line 1

Line 2 is a 2D cross-section from the results of the interpolation of the measuring points parallel and forming a straight line, namely: CS6, CS7, and CS8. The position of Line 2 stretches from North to South. Based on the 2D cross-section shown in Figure 6, there is a water-saturated layer (blue color) and volcanic deposits with a resistivity value range of 3-56 Ωm. Its position is at ground level to a depth of 8 m, stretching for 40 meters between CS7 and CS8. Besides, Tuff rock inserts were found around point CS8 with a resistivity value range of 158-400 Ωm on the ground surface to a depth of 4 m. This Tuff rock layer has a high resistivity value due to the compactness of the rock. Online 2, the indication of the field slide zone is found at a depth of 4-6 m below the ground surface with a resistivity value range of 56-158 Ωm. While the slope condition on line 2 is approximately 5^0 or gentle.

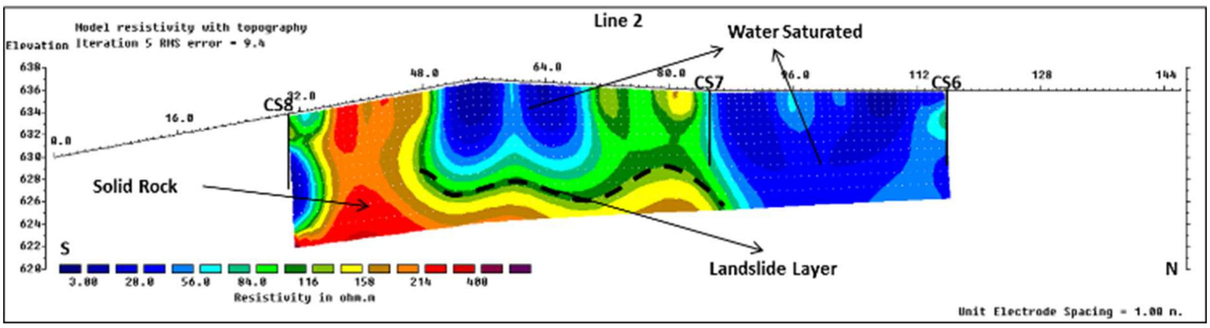


Fig. 6 2D subsurface cross-section resistivity of line 2

Generally, the study area is dominated by clay, tuff, and volcanic breccia. The surface layer is dominated by Tuff rock and clay, while the next layer is filled with water-saturated layers. The water-saturated layer makes it possible to experience movement when the load being supported is heavy enough. This increases the effective stress, which results in slope landslides [22]. Based on the information we obtained from the field survey, landslides occurred in the area around points CS3, CS5, and CS7. As for the area around point CS1, some buildings have cracks, as shown in Figure 7. This condition is an indication of the weak soil structure in the area. The position of CS1 is on Line 1, which is dominated by clay rocks at a depth of 0-2 meters, while the field slide zone is at a depth of 5-7. 5 m below the ground surface. The measured depth of the field slide zone is slightly shallower than the research conducted by Susilo et al. [16], which is around 5-35 meters; this is due to differences in the measurement range and differences in regional geological conditions.

Figures 5 and 6 show that the field slide zone is marked with a dotted black line imaged by green and yellow colors. The indication of the field slide zone is thought between the water-saturated layer and the zone that has a high resistivity value. This zone is indicated as a possible weathered Tuff unit from the Mount Gede Volcanics Formation. The characteristics of Tuff rocks that are impermeable to water and clay rocks that are easy to pass-water cause the upper boundary of the duff layer to move easily. Besides, an increase in water content in the soil can increase pore pressure and weaken slope stability. The existence of this water-saturated layer is one of the factors that trigger landslides when coupled with other factors such as soil bearing capacity, slope, and high rainfall.

Fig. 7 Cracked building conditions in the research area

Based on figures 5 and 6, the field slide zone is quite long, namely 82 and 40 meters at a depth of 4-7. 5 meters. This condition needs special attention from the local village government. The deeper the field slide zone, the greater the danger of landslides, and conversely, the lower the landslide hazard level, the lower the field slide zone. Meanwhile, additional research is needed with a grid-shaped survey design covering the entire village area for 3D mapping to determine land movement prediction and potential direction. In addition to the field slide zone factor, landslides are also influenced by rainfall rate, geological conditions, and social factors in the form of human activities, such as land use for settlements [23].

The efforts that the local government can make to anticipate the condition of the building to remain safe include analyzing soil stability, strengthening slopes, and making retaining walls to increase the value of the safety factor [3]. Retaining walls are designed to withstand several external forces such as hydrostatic pressure, earthquakes, and additional loads [24]. Retaining walls are generally built to strengthen vertical earth embankments and are commonly used for hillside roads, elevated and depressed roads, erosion protection, canals, bridge abutments, etc. [25]. This recommendation is based on landslide conditions in the field that occur on the slopes; in this study, the landslides are included in the type of translation, so Geotechnical measures are needed.

Research about the use of retaining walls as an effort to strengthen soil has been carried out, such as research conducted by Salimah and Hasan [3], Gordan et al. [24], Song et al. [26], Castro et al. [27], and Silva et al. [28]. Based on that research, the use of retaining walls is proven to be able to increase the value of the safety factor so that it is closer to Geotechnical design standards. Meanwhile, the increase in the safety value of each research location varies depending on the geological conditions of the research area. The construction of retaining walls can be carried out in the field slide zone that has the potential to cause landslides, as shown in the research results in Figures 5 and 6.

IV. CONCLUSION

This research shows that the subsurface conditions are divided into three constituent rocks: Clay, Tuff, and Volcanic Breccia. The field slide zone is located between the Tuff rock and turf layer at a depth of 4-7. 5 m long, 82 m (Line 1), and 40 m (Line 2), with a resistivity value range of 56-158 Ωm. Landslides were found at measurement points CS3, CS5, and CS7, which were dominated by clay rock at a depth of about 0-4 meters. The efforts that can be made to anticipate the condition of the building to remain safe include analyzing soil stability, strengthening slopes, and making retaining walls to increase the value of the safety factor. Meanwhile, additional research is needed to cover the entire village area for 3D mapping to determine the prediction and potential direction of land movement.

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