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Sliding Plane Identification for Landslide Hazard Mitigation with Electrical Resistivity Tomography Method

Rahmat Catur Wibowo[1*], Ikram Maulia[1], Nandi Haerudin[1], Muh Sarkowi[1]

[1] Geophysics Engineering, Faculty of Engineering, Universitas Lampung, Indonesia

Corresponding Authors E-mail: rahmat.caturwibowo@eng.unila.ac.id

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ABSTRACT

Pidada area, Panjang sub-district, Bandar Lampung city, located on Barisan Hill complex, has been affected by the Sumatran fault movement and the Lampung-Panjang fault so that the morphological condition is hilly with steep slopes, which causes the risk of natural disasters such as landslides. In this article, the identification of subsurface rock lithology and sliding plane in the landslide-prone zone is carried out using the Wenner-Schlumberger configuration geoelectric method. Based on the Wenner-Schlumberger configuration, the top layer has lithology clay tuff and sandy tuff, which predicted a weathered rock with a resistivity of 1 - 133 ohm.m. Coarse-grained tuff and fine-grained tuff with resistivity values of 135 - 250 ohm.m in the middle. The bottom layer has a resistivity of more than 250 ohm.m, that predicted to have a lithology breccia (igneous rock) Tarahan Formation. The sandy clay layer (81 - 90 ohm.m) predict as a sliding plane in this area, at depths of 8.2 to 16 m. The type of landslide developed in the research area is a crawling soil landslide, with very steep slope characteristics (8^0 – 35^0).

Introduction

Geological disasters are disasters that occur due to natural geological processes whose cycles of occurrence start from a scale of several years to millions of years. Some listed geological disasters include earthquakes, tsunami waves, volcanic eruptions, soil and rock mass movements, landslides, and floods [1]. Geological disasters such as earthquakes, tsunami waves, and volcanic eruptions are natural disasters which caused by geological processes. It means that they cannot be prevented, but we can do the adaption and mitigation activites for reducing the impact of the disasters. Morevoer, while geological disasters in the form of soil and rock mass movements or landslides and floods often occur due to geological conditions that are vulnerable and also triggered by human activities [2].

Landslides are one of the natural disasters that often occur in Indonesia which results in substantial material losses and casualties [3]. Landslides are more often found in steep slopes and influenced by the gravity component. Gravity and seepage are the main causes of instability on slopes. Landslides are often associated with the arrival of the rainy season [4].

Areas with high rainfall have a fairly large landslide susceptibility. High rainfall intensity results in vulnerability to landslides, especially in hilly areas with steep slopes. Factors that cause landslides include rain, steep slopes, less dense and thick soil, less strong rocks, type of land use, earthquake vibrations, loss of water level in lakes or dams, additional loads, erosion/erosion, presence of material heaps on cliffs of deforestation, old landslides, and especially high rainfall [5].

According to the National Disaster Management Agency (BNPB) stated that during the beginning of 2020 in Indonesia there were 954 natural disasters. As many as 99% of these cases are hydrometeorological disasters which are dominated by floods, landslides, earthquakes, extreme weather, forest and field fires, tidal waves, and abrasion. During 1 January – 16 March 2020, there were 379 floods, 183 landslides, 335 extreme weather disasters, 44 forest and field fire disasters, 8 tidal waves and abrasion disasters, and 5 earthquake disasters [1]. Panjang District has medium to high ground movement potential. Preliminary research on the arrangement of mass movements/landslides in this area has been carried out by Mulyasari (2018) by making geomorphological maps for regional development recommendations [6]. Based on this research, Panjang District is included in a high level of potential hazard related to geomorphological conditions and the faults that control it. In addition, a zoning mapping of the potential area for mass movement along the Lampung-Panjang Fault has been carried out, Bandar Lampung. Based on this research, the area along the Lampung- Panjang Fault is known to be in the zone of medium-high mass movement potential. Landslide disasters for which there is no response, especially recorded, have occurred several times at several points in Panjang District [7].

One of the landslide-prone areas in the Bandar Lampung area is in the Pidada sub-district of Panjang which has rock conditions that are not compact and easily degraded so that it is very prone to landslides [8]. Seeing the losses caused by this landslide, it is necessary to make efforts to overcome landslides, one of which is the application of geophysics. One of the geophysical methods that can be used to determine subsurface lithology is the Electrical Resistivity Tomography (ERT) method. The resistivity ERT method has often been used to detect subsurface lithology in order to identify potential landslides in an area based on the resistivity properties of the soil or rock in the area [9]. The ERT method, which has the characteristics of high spatial resolution, low-cost field data acquisition process, and relatively fast process, was used to predict the investigated landslide geometry (e.g., sliding plane depth and the geometry of the material involved) than other geophysical methods [9].

Landslide-prone layers are usually characterized by the presence of an impermeable layer under the permeable layer, where this impermeable layer will act as a sliding plane that will attract soil materials that are above it, following the shape of the sliding plane. In this research, the author uses the ERT method to identify subsurface lithology and the sliding plane of landslide-prone zones using the Wenner-Schlumberger configuration based on variations in subsurface resistivity values, as well as identify types of landslides and their prevention efforts. The ERT in this research can explain in more detail subsurface conditions, especially in the Pidada sub-district of Bandar Lampung city.

Theory

The resistivity geoelectric method is one of the geophysical methods that utilize soil resistivity properties to study the subsurface conditions of the earth. The resistivity geoelectric method has several advantages, namely, it is non-destructive to the environment, has an easy and fast operation, is low cost, and can identify depths of up to several meters, so it is widely used in environmental surveys such as determining slope stability, surveying vulnerable areas and investigating mass movements [10]. The geoelectric theory is carried out by injecting an electric current (I) with two electrodes (C1 and C2) into the surface and measuring the resistivity of the subsurface layer (rock lithology) with the potential difference (ΔV) through potential electrodes (P1 and P2). The greater the electrode distance, the deeper the rock layer is detected. In accordance with Ohm's Law, the electric current (I) flowing through a conductor or conductor will always be directly proportional to the potential difference (ΔV) applied to it and inversely proportional to its resistance. In the earth medium, the current injection through the electrode will spread in all directions radially, so that the current distribution will be hemispherical for the assumption of a flat ground surface as shown in Figure 1.

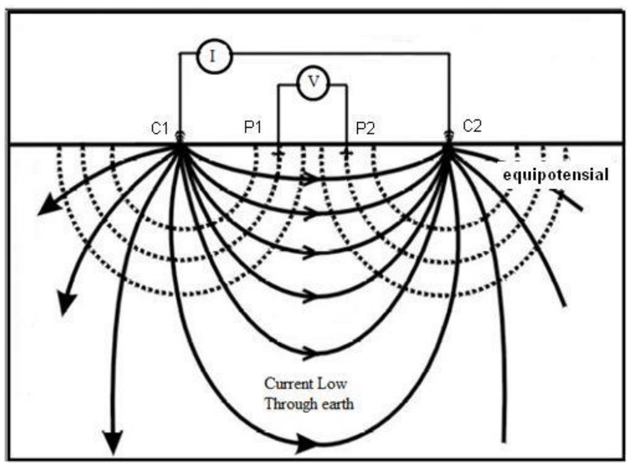

Figure 1. Geoelectric method working principle [11].

The rock resistivity obtained directly is the apparent resistivity that requires further data processing to obtain the actual resistivity.

a. Apparent resistivity

In this resistivity method, it is assumed that the earth is homogeneous isotropic. With this assumption, the measured resistivity is the actual resistivity and does not depend on the electrode. In fact, the earth consists of layers with different, so the measured potential is the influence of these layers. So the measured resistivity value is not a resistivity value for one layer only, this is mainly for wide electrode spacing. This apparent resistivity is formulated by the equation [12]:

$$\rho_a = k\,\frac{\Delta V}{I} \quad (1)$$

Where: ρ_a = apparent resistivity

k = geometry factor

b. Resistivity of rock

Geoelectric estimation is one way of research from the ground surface to determine rock layers. This estimation model uses the principle that rock layers or materials have varying resistance, which is called resistivity (resistivity or rho 'ρ'). The electrical properties of rocks are the characteristics of rocks in conducting electric currents. Rocks can be thought of as an electrical medium as in a conducting wire, so they have a specific resistance (resistivity). Rock resistivity is the resistance of rock to the flow of electricity.

Table 1. Rock and mineral resistivity value [12].

Material	**Resistivity value (Ohm.m)**
Meteorite water	80 - 200
Groundwater	30 - 100
Sand	10-200
Sand and granule	100-1000
Mudstone	20-200
Sandstone	50-500
Conglomerate	100-500
Tuff	20-200
Andesite group	100-2000
Granite group	1000-10000
Clay	1,5-3,0
Silt to clay	3,0-15
Silty sand	15-150
Wet basement	150-300
Silty granule sand	300
Non-weathered basement	2400
Water	20-60
Saline water	20-200
Sand	1-1000
Clay	1-100
Portable Well Water	0,1-1000
Brackish Water	0,3-1
Sea Water	0,05-0,2

c. Wenner-Schlumberger electrode configuration

The Wenner-Schlumberger configuration is a combination of the Wenner and Schlumberger configurations [13]. The electrode position of the Wenner-Schlumberger configuration is the same as that of the Wenner-Alpha, but the distance between the current and potential electrode is "n" times the distance between the two potential electrodes. In the Wenner-Schlumberger configuration the distance between the current electrode and the potential electrode is the same (C1P1 = P2C2 = na and the distance C1P2 = P1C2 = na + a) as in Figure 2.

The geometric factor of the Wenner-Schlumberger configuration is $k = n(n+1)\pi a$. The Wenner-Schlumberger configuration is not very sensitive to horizontal changes but has deep current penetration but poor resolution, therefore it is good for depth surveys. This configuration can be used for sliding plane, underground river, and geotechnical surveys [12].

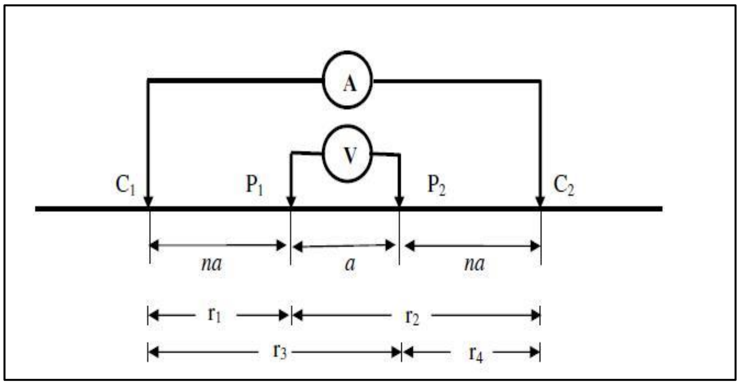

Figure 2. Wenner-Schlumberger configuration [12].

Method

The research area is on Suban street near 17 senior high schools, Pidada, Bandar Lampung City. Which is administratively located in Bandar Lampung City which is in the south of Sukabumi District, and is located between Merbau Mataram District and Bumi Waras. The study area is located at coordinates 5^0 27′ 49.4″ S, 105^0 19′ 29.9″ E, and the line has a length of 115 m with an electrode spacing of 5 m (Wenner-Schlumberger configuration) (Figure 3).

To get the actual resistivity value, further data processing is needed using the Res2Dinv software. Res2Dinv software is a computer program that automatically determines a 2-dimensional (2D) resistivity model for the subsurface from geoelectric survey data [14]. The inverse modeling program generates rectangular blocks that represent the resistivity model in 2 Dimensional forms. The distribution of data is connected by an arrangement of blocks which is a pseudo resistivity value and the program automatically generates a block size in which the model is less than the number of data points. The depth of the datum point is adjusted such that it is equal to the depth of the bottom of the beam, such as the most ideal electrode distance.

This program was created with the aim of displaying the apparent resistivity in the form of a cross-section that is close to the actual measurement. The inverse modeling is carried out using non-linear least squares optimization, while forward modeling is carried out to obtain the apparent resistivity value. This optimization method is carried out to try to obtain the smallest value of the difference between the measured and calculated apparent resistivity values while still considering the block model. The difference value obtained is generally displayed in the form of the Root Mean Square (RMS) value. The lower the RMS value in an iteration, the model (in that iteration) is considered fit with the real model [14].

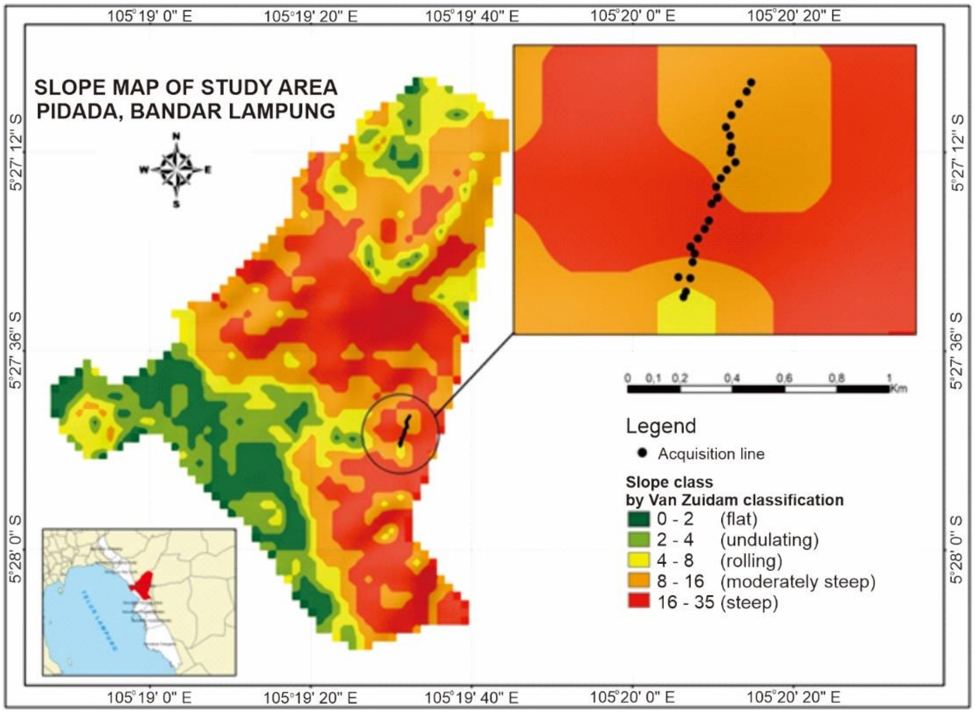

Figure 3. ERT line location and slope map of the study area.

Result and Discussion

The results of the interpretation of the Wenner-Schlumberger configuration can be obtained by iterating several times to approach the actual field conditions (fit model), on the geoelectrical measurement path; this time, it is carried out until the 5th iteration with a Root Means Square (RMS) error of 6.0% with the maximum measurable depth is 22.8 m. The following is a 2D view of the inverted data without topography and with topography in the Res2Dinv software, shown in Figure 4.

Figure 4 (top) is the result of the interpretation of resistivity data obtained from field data collection, the middle is the process of calculating the apparent resistivity of the acquired data. While the bottom is the result of the interpretation of the inverse modeling. The result of this interpretation is the opposite of modeling with forwarding modeling. This type of modeling is often called data fitting or data matching because the process in it is sought for model parameters that produce a response that matches the observed data.

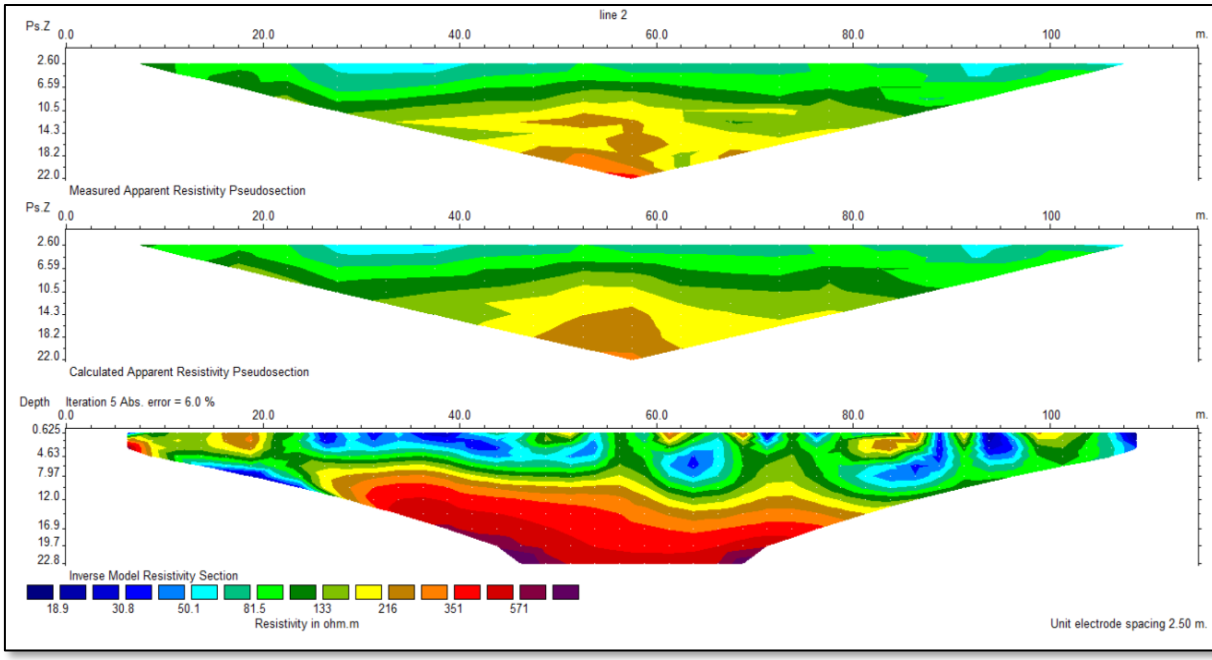

Figure 4. 2D cross-section Wenner-Schlumberger configuration result of inversion without topography, apparent resistivity (top), calculated apparent resistivity (middle), and true resistivity (bottom).

Based on the resistivity table [12] and the regional geological map of the Tanjung Karang [15], the resistivity value of 1 -133 ohm.m indicated by the dark blue-dark green color indicator is thought to be rock with low resistivity in the form of weathered rock or a landslide-prone zone that can being a water-saturated zone, it may be associated with clay tuff and sandy tuff lithology (tuff sediments) originating from volcanic products of the Tarahan Formation with characteristics of being prone to landslides at a depth of 0.93 – 12 m (Figure 5). At a distance of 7 – 108 m, this material has a thickness of 11 m. The resistivity value of 133 - 250 ohm.m which is indicated by a green-brown color indicator is estimated to be a loamy sand material from the Campang Formation. This material is located at a depth of 2-12 m. At a distance of 10-20 m, this layer has a thickness of 4 m. While at a distance of 22.5 - 67.5 m this layer has a thickness of up to 10 m.

On this cross-section, the resistivity is more than 250 ohm.m which is indicated by a dark brown-purple colored indicator which is thought to be a hard layer with poor porosity and cannot store water between rock pores which are thought to be a breccia (igneous rock) Tarahan Formation. This material is 27.8 – 70 m at a depth of 7.97 – 22.8 m with a thickness of 14.8 m.

In geoelectricity, the sliding plane is characterized by a resistivity contrast between two adjacent rocks where the impermeable layer has a large resistivity value which is between layers that have a smaller resistivity [16]. Clay sand is impermeable or watertight, and if there is water in the layer, the clay sand will become slippery and turn into a sliding plane which will derail all the material above it so that landslides and land subsidence occurred. The sliding plane on the measurement path (marked by the black dotted line) is between the tuff sediment layer and clay sand at a depth of 8.2 - 16 m from the ground surface. With a distance of 25 - 87.5 m which has a moderately steep slope and is very steep (Figure 3).

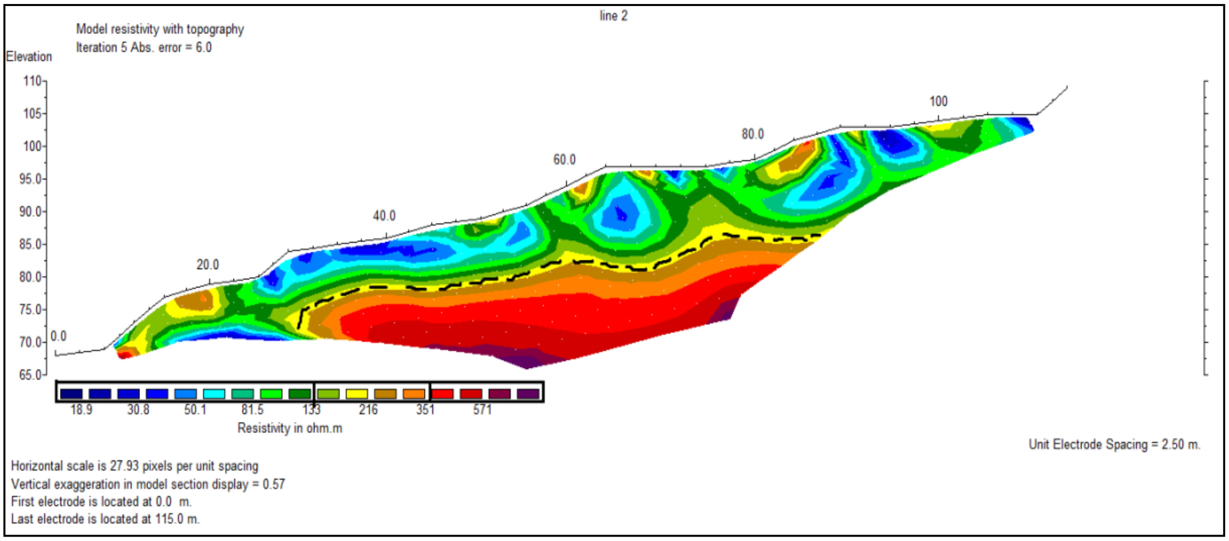

Figure 5. 2D cross-section of the inverted Wenner-Schlumberger configuration with topography.

Based on the shape of the sliding plane and referring to the classification of landslides, the type of landslide that developed in the study area was a translational type. To minimize the occurrence of landslides, reforestation is carried out so that sunlight and rainwater do not easily reach the soil surface so that physical weathering is hampered. Another effort is to make water ditches on the cliffs of the Suban hill so that rainwater does not accumulate on the cliffs and does not stretch the bonds between the soil so as to minimize the occurrence of landslides.

Conclusion

Based on the results of data processing and analysis carried out in this study, it can be concluded that the rock lithology on the cliff consists of clay tuff and sandy tuff, which predicted a weathered rock (top layer) with a resistivity of 1 - 133 ohm.m. Coarse-grained tuff and fine-grained tuff with resistivity values of 135 - 250 ohm.m in the middle layer. The bottom layer has a resistivity of more than 250 ohm.m, that predicted to have a lithology breccia (igneous rock) Tarahan Formation. The sliding plane on this cliff is located at a depth of 8.2 m to 16 m from the surface which has a layer of impermeable sandy clay. Based on the shape of the slip surface in the form of sloping waves with a relatively shallow. Referring to the landslide classification, the type of landslide in the study area was a translational type of soil slide, which had a steep and very steep slope with a slope of 8° - 35°. Further research is needed using other geophysical methods such as seismic refraction to complete the results obtained and can be compared with the results of this study.

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