JOURNAL OF APPLIED GEOSPATIAL INFORMATION

Vol 7 No 1 2023

http://jurnal.polibatam.ac.id/index.php/JAGI
ISSN Online: 2579-3608

Identifying Probable Slip Surface in Wanurejo, Borobudur District, By Subsurface Analysis Utilizing the Dipole-Dipole Configuration of Resistivity Method

Nurul Dzakiya[1]*, Robertus Belardo Laksmana[2], Radhitya Adzan Hidayah[3]
[1,3] Institut Sains & Teknologi AKPRIND, Geological Engineering, Kalisahak Street No 28 Yogyakarta, Indonesia
[2] Karya Jaya Consulting, Geologist, Purwomartani, Kalasan, Yogyakarta, Indonesia
*Corresponding author e-mail: dzakiya@akprind.ac.id

Received: October 15, 2022
Accepted: January 31, 2023
Published: January 31, 2023

Abstract

Research has been carried out on the existence of slip surfaces in Wanurejo, Borobudur District, Magelang Regency, Central Java. The location of the slip surface is identified using the resistivity method of the dipole-dipole configuration. This research was conducted at a relatively flat measurement location and at an altitude of around 95–105 meters above sea level. Measurements were made on 6 different lines with a length of track 1 of 250 m. The results of data processing indicate that the layer that acts as a slip surface is a layer of clay. The clay layer has a resistivity value ranging from 15 to 35 ohm.m, which is relatively thin, so it has the potential to become a slip surface because it is located between two rocks that have a significant resistivity contrast: compact andesite rock and water-saturated sandstone. If the water-saturated sandstone layer is no longer able to withstand the weight above it, the surrounding andesite rocks will easily slip. This is also reinforced by the presence of a layer of clay that is slippery, so the potential for landslides or slipping is greater.

Keywords: slip surface, resistivity, dipole-dipole, wanurejo, borobudur

1. Introduction

One of the susceptible nations is Indonesia. Natural calamities are a good example of this. Due to its geographical situation, which includes numerous groups of islands, Indonesia is susceptible to disasters of various intensities. Its geography, which takes the shape of a collection of islands, and climate, which is tropical, are further factors (Hidayah & Dzakiya, 2018). Experiences in both the dry season and the rainy season can cause a change. Bad outcomes from extreme weather can include the occurrence of calamities like floods, droughts, and landslides (Pangaribuan, Jauhari; Sabri, L.M.; Amarrohman, 2019)

One of the places where the incident occurred The catastrophe occurred near the Magelang Regency. Due to its geographical location in the highlands, the Magelang Regency Area is prone to natural disasters, surrounded by hills and mountains, creating a region that is extremely vulnerable to disasters Magelang News in 2018, as quoted: Magelang Regency experienced 375 catastrophes in 2017, with landslides accounting for 270 of the incidents (Hamidah, A.P; Subandrio, A; Yudiantoro, 2022). Other disasters in the area during 2017 included floods and severe winds. Landslide disasters pose the greatest hazard to Magelang Regency, where calamities frequently occur. One of them is the village of Wanurejo. The area that requires investigation into landslides or slips surfaces. Other than the reasons that have been discussed using the data, this community was chosen as a research area. This is because geography is characterized by potential slopes and landslides (Darsono; Nurlaksito, B., Legowo, 2012)

Landslide events are defined as the movement of soil masses or the displacement of slope-forming materials. It can be natural rock, weathered soil, backfill material, or a combination of materials. The material is sliding down and away from the slope. a mass movement of soil or rock or a combination of the two, often occurring on natural or artificial slopes, but a natural phenomenon, where nature seeks to find equilibrium due to disturbances or factors that influence it and cause a reduction in shear strength and an increase in shear stress.

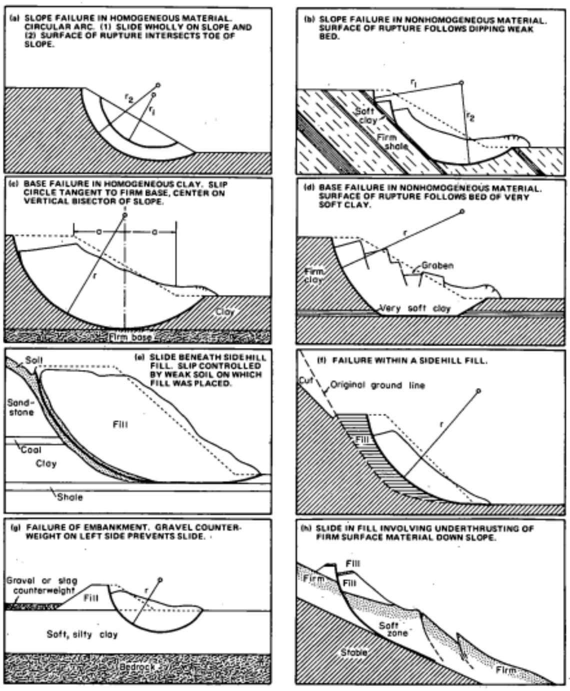

Fig.1. Varietes of Slumb ((Varnes, 1978)

Regionally, the lithology of the study area is composed of Penyatan Formations, Andesite and Dacite Formations, Volcanic Breccias, Old Sumbing Volcano Deposits, Old Merapi Volcano Deposits, Lahar and Porphyry Andesites, Condong Volcanic Rocks, Gianti Volcanic Rocks, Gilipetung Volcanic Rocks, Andong Volcanic Rocks and Kendil, Kekep Volcano Rock, Telomoyo Volcano Rock, Old Mount Sindoro Deposit, Young Sindoro Deposit, Young Sumbing Deposit, Merbabu Mount Deposit, Young Merapi Deposit, Ash Cone Deposit, Lava Dome, Hot Cloud Avalanche Deposit, Lava Dome and Alluvium, and Quaternary Alluvium (Darsono; Nurlaksito, B., Legowo, 2012).

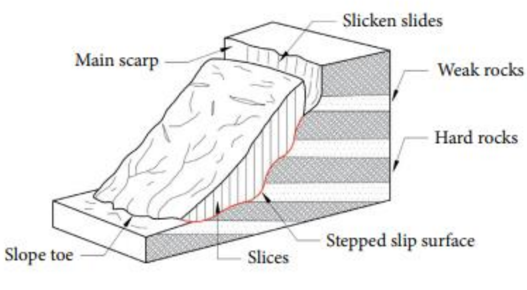

Fig.2. A landslide with a step slip surface is depicted in a schematic design (Fan et al., 2020)

Landslide studies in this area has revealed that a stepped slipsurface is frequently created in andesit and clay materials, which are common in soft and hard interbedded rocks. Such occurrences are caused by the differential weathering impact on interbedded rocks, which contributes to the establishment of a topographic condition for the production of a sliding mass and its specific sliding surface (Fig 2).

Approximations are used to accomplish this. One technique in geophysics that makes use of Ohm's law is resistivity. The resistivity value is the method's derived parameter. Land in the subsurface layer (specific resistance). Several options are used to apply the geoelectric approach. Dipole-dipole configuration was employed in this study for configuration. Dipole-dipole design collects data analysis, enabling the analysis of subsurface strata more exact (Telford, W.M; Geldart, L.P; Sheriff, 1990). This study aims to determine subsurface conditions. The study area to determine the conditions and rock constituents to obtain information on the causes of landslides locally and identify slip areas, which are one of the factors causing landslides in Wanurejo Village, for mitigation purposes landslide disaster. Application of the geoelectric method of dipole-dipole configuration satisfies a research need. There is a sliding surface on the subsurface layer.

One of the causes of landslides is the geological environment. An approach to geophysical technology is required to determine the geological state of the landslide-prone area. Resistivity is a geophysical technique that can be used. To determine the rock spread resistivity in a lateral direction, mapping is used. The rock distribution beneath the soil at the research site can be predicted using this mapping technique.

The proper way for identifying fissures as the origins of landslides below the surface is the geoelectric method (Zakaria, Muhammad Faizal; Maisarah, 2019). A field slip is a layer in between rock strata that are light in weight and modestly absorbs water.This study's slip area has a crucial role in determining whether a landslide has a cause or not. As a result, it is necessary for this research to pinpoint sections of soil that are susceptible to landslides by analysis of the slip surface that is acquired, Fig.1. (Varnes, 1978).

2. Methodology

This study used the dipole-dipole configuration of geoelectric approach to examine slip surfaces that may cause landslides in Wanurejo Village, Borobudur Regency, Central Java Province. For the 2D modeling method to ascertain the distribution of rock resistivity values at the study site, RES2DINV software was employed as the data processing and analysis tool in this study. It was conducted at a relatively flat measurement location and at an altitude of around 95–105 meters above sea level. Measurements were made on 6 different lines with a length of track 1 of 250 m.

Research for the measurement activities of slip and geoelectric fields has the same initial method, namely secondary data from literaly and primary data collection in the field. Primary data collection is data obtained directly in the field; this aims to detail the research results (Loke, 2015). The geological activities carried out are direct morphological observations, plotting of rock outcrop locations, lithological descriptions, and observing existing geological structures. The landslide vulnerability investigation activity was to collect soil samples from seven points of collection by inserting and hitting iron pipes into the ground, while for geoelectric activities, namely direct measurements in the field with a dipole-dipole configuration (Dzakiya et al., 2018).

The measurement is interpreted with the presumption that the surface is made up of many layers with different resistivity rates. Each layer is an isotropic homogeneous medium that is divided by a horizontal boundary. A mathematical correlation between the measured parameters and the parameters that define the distribution of the under-surface layer distribution and the resistivity of various rocks must be established in order to determine the layer resistivity and the horizontal border according to the measurement of voltage and electrode space (Yulianto et al., 2016).

The resistivity method is one of the geophysical methods, and this method can be used to estimate subsurface hydrogeological conditions such as rock types and rock water conditions based on the rock's electrical properties, which is the resistivity value. The working principle of the resistivity geophysical method is that an electric current is injected into the earth through two current electrodes (Telford, W.M; Geldart, L.P; Sheriff, 1990). The resulting potential is measured using two potential electrodes. From the measurement results for the current and potential difference for each specific electrode distance, the value can be calculated using pseudo-type imprisonment (Yatini & Suyanto, 2018).

3. Result and Discussion

The research was carried out in Wanurejo Village, Borobudur District, Magelang Regency, Central Java Province. The equipment used is ARES, along with equipment and GPS to know latitude and longitude. Measurements were carried out over six passes, with a 250-meter track measured, Fig.3. The topographic and morphological conditions are shown in Fig.4.

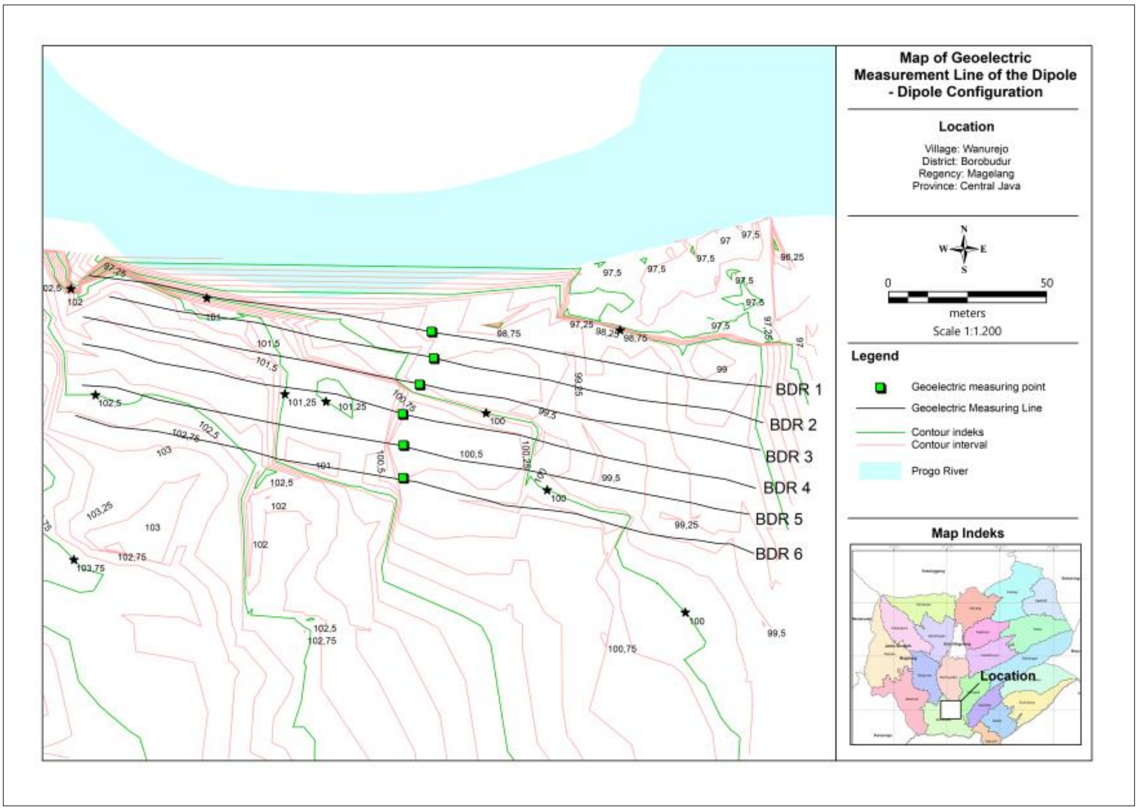

Fig. 3. Map of the study area and geoelectric measurement track

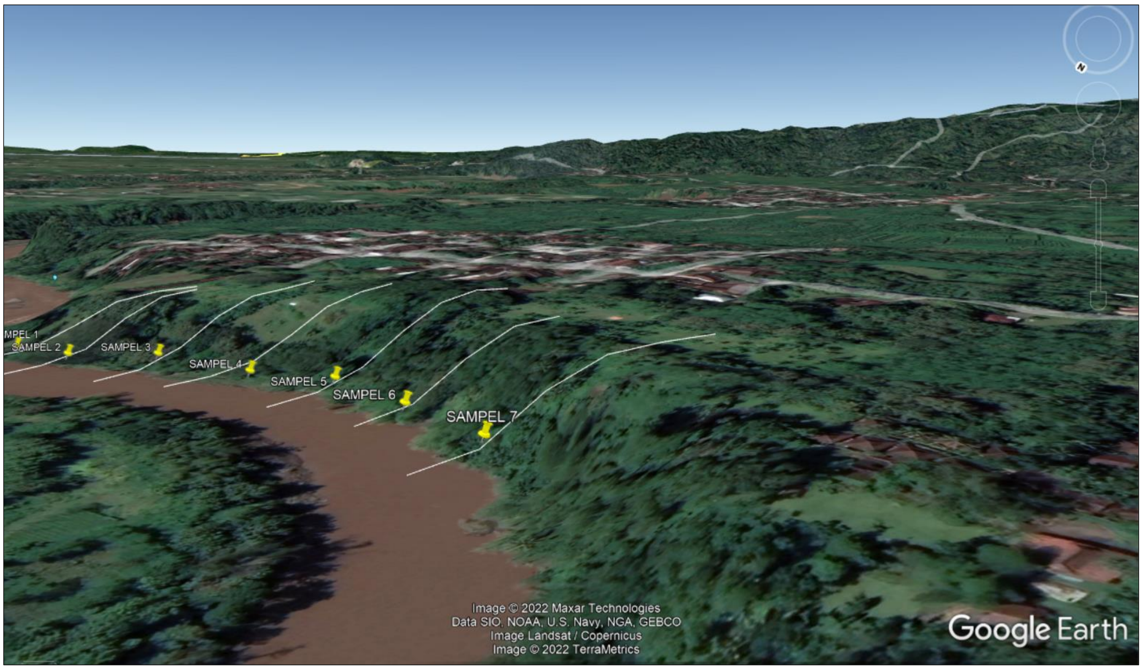

Fig.4. On the left, Google Earth-based slope geometry is depicted

The BDR 1, Tract 1 is located at an altitude of 95–105 meters above sea level as shown in Fig.5. Estimation by the geoelectric method can be used to estimate the depth of the slip surface boundaries. The resistivity values of soil and rock that slide below the slip surface generally have a marked difference. Fig.5. shows an overview of the slip surface estimation. The prediction of the existence of a slip surface can be seen from the shape of the layer, which is thought to act as a concave slip surface. The topography on this track follows a non-steep slope. The boundary of the avalanche slip surface is between the impermeable layer (andesite and clay) and the water-saturated layer (sandstone filled with water), shown in blue with a resistivity of 0.736–737 Ωm . The layer that is thought to act as a waterproof layer is estimated to be the andesitic rock, which is shown in yellow, red, and purple, with a high resistivity value of around 700-2340 Ωm at a depth of about 15-20 m below the surface (Yulianto et al., 2016). The measurement location is dominated by sandstones with a resistivity of 73.8 Ωm which are spread out and shown in light green. The sandstone is also interspersed with 23.3 Ωm clay, which becomes an impermeable layer. While the layer that acts as a slip surface or water-saturated zone is estimated to be a layer of sandstone filled with water and bounded by a relatively thin layer of clay, it has the potential to become a slip surface because it is located between two rocks that have a significant resistivity contrast, namely compact andesite rocks and water-saturated sandstones. If the water-saturated rock layer is no longer able to withstand the load above it, then the andesite rocks that are near or even above it will easily slip. This is also reinforced by the presence of a layer of slippery clay, so the potential for landslides and slips is even greater (Zhang et al., 2022).

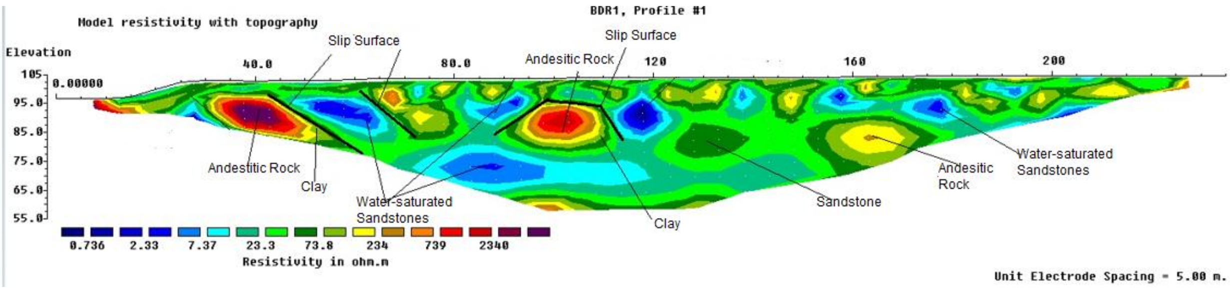

Fig.5. The BDR 1, Tract 1 is located at an altitude of 95–105 meters above sea level

The BDR 2, Track 2 is located at an altitude of 95-100 meters above sea level which is relatively flat. It is shown in Fig. 6. Estimation by the geoelectric method can be used to estimate the depth of the slip surface boundaries. The resistivity values of soil and rock that slide below the slip surface generally have a marked difference. Figure 5.60 shows an overview of the slip surface estimation. The estimation of the existence of a slip surface can be seen from the shape of the layer which is thought to act as a concave-shaped slip surface (light blue-dark blue) (Zou, Zongxing; Yan, Junbiao; Tang, Huiming; Wang, Shun; Xiong, Chengren; Hu, 2020). The topography on this track follows a non-steep slope. The boundary of the avalanche slip surface is between the impermeable layer (andesite and clay) and the water-saturated layer (sandstone filled with water) shown in blue with a resistivity of 1.14-10.7 Ωm. The layer that is thought to act as a waterproof layer is estimated to be the andesitic rock which is shown in yellow-red-purple color with a high resistivity value of around 310-2919 Ωm at a depth of about 20-50 m below the surface

(Yulianto et al., 2016). On track 2 the measurement location is dominated by andesite rocks and resistivity sandstones of 32.9-101 Ωm and more which are spread out and shown in light green. The sandstone is also interspersed with 30 Ωm clay which becomes an impermeable layer. While the layer that acts as a slip surface or water-saturated zone is estimated to be a layer of sandstone filled with water and bounded by a relatively thin layer of clay so that it has the potential to become a slip surface because it is located between two rocks that have a significant resistivity contrast, namely compact andesite rocks. massive with water-saturated sandstones (Zhang et al., 2022). If the water-saturated rock layer is no longer able to withstand the weight above it, then the andesite rocks that are nearby will easily slip. This is also reinforced by the presence of a layer of slippery clay so that the potential for landslides/slips is even greater. On track 2 the position of the andesite rocks is relatively under the water-saturated sandstone layer. For andesitic rocks above water-saturated sandstones, they are only found near the surface, so they are still considered safe.

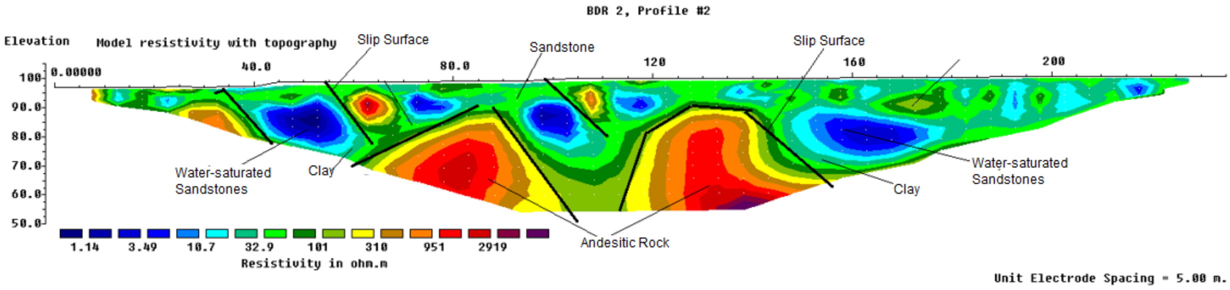

Fig.6. The BDR 2, Tract 2 is located at an altitude of 95–105 meters above sea level

The BDR 3, Track 3 is situated at a relatively flat elevation of 100–105 meters above sea level. The depth of the slip surface borders can be calculated using the geoelectric approach. The resistivity values of the rock and soil that slide beneath the slip surface typically differ significantly. An overview of the slip surface estimation is shown in Fig. 7. The estimation of the existence of a slip surface can be seen from the shape of the layer which is suspected to act as a concave-shaped slip surface (light blue-dark blue). The topography on this track follows a non-steep slope. The boundary of the avalanche slip surface is between the impermeable layer (andesite and clay) and the water-saturated layer (sandstone filled with water) Having a resistivity of 0.256-7.87 m, it is displayed in blue. Andesitic rock, which is yellow-red-purple in color and has a high resistivity value of around 1340-41169 m at a depth of about 10 to 50 meters below the surface, is assumed to be the layer that serves as a waterproof layer. On track 3, the andesite and resistivity sandstones (43.6-242 m), which are dispersed and indicated in light green, dominate the measurement location. The sandstone is also interspersed with 8 Ωm clay which becomes an impermeable layer. While the layer that acts as a slip surface or water-saturated zone is estimated to be a layer of sandstone filled with water and bounded by a relatively thin layer of clay so that it has the potential to become a slip surface because it is located between two rocks that have a significant resistivity contrast, namely compact andesite rocks. massive with water-saturated sandstones. If the water-saturated rock layer is no longer able to withstand the weight above it, then the andesite rocks that are nearby will easily slip. This is also reinforced by the presence of a layer of slippery clay so that the potential for landslides/slips is even greater. On track 3, the position of the andesite rocks is relatively above the water-saturated sandstone layer, so the potential for slipping is quite large (Hewaidy, AGA; El-Motaal; Sultan, S.A; Ramdan, T.M; El-Khafif, 2015).

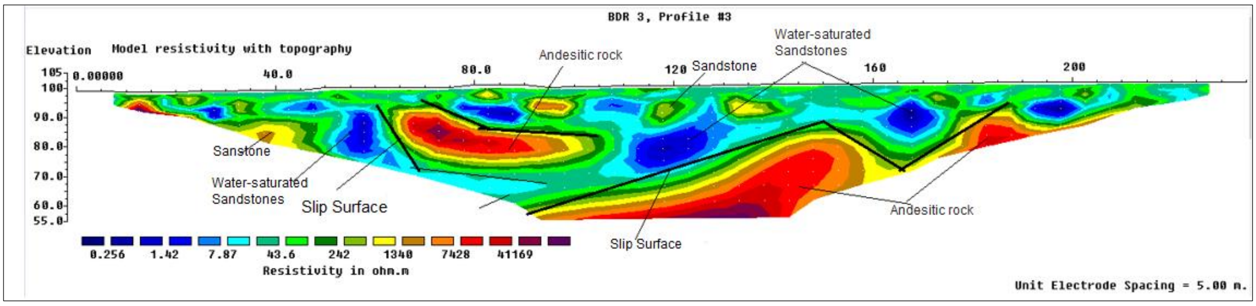

Fig.7. The BDR 3, Tract 3 is located at an altitude of 95–105 meters above sea level

The BDR 4, Track 4 is situated at a relatively flat elevation of 100–105 meters above sea level. The depth of the slip surface borders can be calculated using the geoelectric approach. The resistivity values of the rock and soil that slide beneath the slip surface typically differ significantly. An overview of the slip surface estimation is shown in Fig. 8. The layer's shape, which is believed to function as a slip surface with a concave shape, can be used to estimate the existence of a slip surface (light blue-dark blue). This track's topography follows a non-steep slope. The impermeable layer (andesite and clay) and the water-saturated layer are where the avalanche slip surface begins and ends (sandstone filled with water) shown in blue with a resistivity of 1.12-6.63 Ωm.

The andesite rock layer, which is depicted in reddish-purple and has a high resistivity value of roughly 90-436 m at a depth of approximately 10 to 50 meters below the surface, is assumed to function as a waterproof layer. Additionally, there are bolders that are a little dispersed in the measurement area. Andesite and resistivity sandstones (15.3–15.4 m), which are dispersed and indicated in light green, make up the majority of the measurement location on track 4. Additionally, there are 8 m of clay interspersed throughout the sandstone, forming an impervious layer. While the water-filled layer of sandstone believed to be the layer that serves as a slip plane or water-saturated zone. It has the potential to become a slip plane since it is situated between two rocks with a significant resistivity contrast, notably compact andesite rocks, and is surrounded by a relatively thin layer of clay (Shuzui, 2001). huge sandstones drenched with water. The andesite rocks nearby will readily slip if the water-saturated rock layer can no longer support the weight above it. The possibility of landslides and slips is increased by the presence of a layer of clay that is slick. The andesite rocks on track 4 are situated comparatively above the water-saturated sandstone layer, which increases the likelihood of slipping (Zhang et al., 2022).

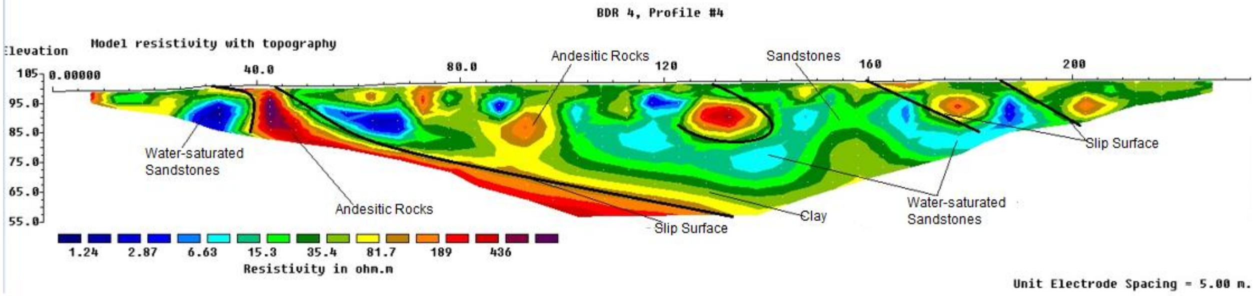

Fig.8. The BDR 4, Tract 4 is located at an altitude of 95–105 meters above sea level

The BDR 5, Track 5 is situated at a relatively flat altitude of 100–105 meters above sea level. The depth of the slip plane borders can be calculated using the geoelectric approach. The resistivity values of the rock and soil that slide beneath the slip surface typically differ significantly. An overview of the slip plane estimation is shown in Fig.9. The layer's form, which is thought to function as a slip plane with a concave shape, provides evidence for the presence of a slip plane (light blue-dark blue). This track's topography follows a non-steep slope. The impermeable layer (andesite and clay) and the water-saturated layer are where the avalanche slip plane begins and ends (sandstone filled with water), shown in blue with a resistivity of 0.827–6.75 Ωm. The layer that is thought to act as a waterproof layer is thought to be a layer of andesite rock, which is shown in red-purple color with a high resistivity value of around 449–1283 m at a depth of about 10–50 m below the surface, which is similar to an intrusion, and there are also boulders that almost spread around the measurement area.

On track 5, the measurement location is dominated by andesitic rocks and resistivity sandstones (19.3–157 Ωm), which are spread out and shown in light green. The sandstone is also interspersed with 8-m clay, which becomes an impermeable layer. While the layer that acts as a slip plane or water-saturated zone is estimated to be a layer of sandstone filled with water and bounded by a relatively thin layer of clay, it has the potential to become a slip plane because it is located between two rocks that have a significant resistivity contrast, namely compact andesite rocks. massive with water-saturated sandstones. If the water-saturated rock layer is no longer able to withstand the weight above it, then the andesite rocks that are nearby will easily slip. This is also reinforced by the presence of a layer of slippery clay, so the potential for landslides and slips is even greater. On track 5, the position of the andesite rocks is relatively above the water-saturated sandstone layer, so the potential for slipping is quite large. The layer that is thought to act as a waterproof layer is thought to be a layer of andesite rock, which is shown in red-purple color with a high resistivity value of around 449–1283 Ωm at a depth of about 10–50 m below the surface, which is similar to an intrusion, and there are also bolders that almost spread around the measurement area. On track 3, the measurement location is dominated by andesitic rocks and resistivity sandstones (19.3–157 Ωm), which are spread out and shown in light green. The sandstone is also interspersed with 8-m clay, which becomes an impermeable layer. While the layer that acts as a slip plane or water-saturated zone is estimated to be a layer of sandstone filled with water and bounded by a relatively thin layer of clay, it has the potential to become a slip plane because it is located between two rocks that have a significant resistivity contrast, namely compact andesite rocks. massive with water-saturated sandstones. If the water-saturated rock layer is no longer able to withstand the weight above it, then the andesite rocks that are nearby will easily slip. This is also reinforced by the presence of a layer of slippery clay, so the potential for landslides and slips is even greater. On track 5, the position of the andesite rocks is relatively above the water-saturated sandstone layer, so the potential for slipping is quite large.

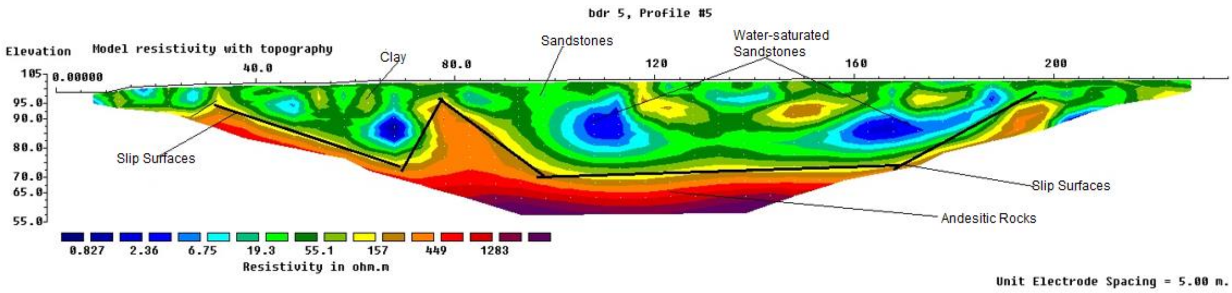

Fig.9. The BDR 5, Tract 5 is located at an altitude of 95–105 meters above sea level

The BDR 6, Track 6 is located at an altitude of 100-105 meters above sea level which is relatively flat. Estimation by the geoelectric method can be used to estimate the depth of the slip plane boundaries. The resistivity values of soil and rock that slide below the slip surface generally have a marked difference. Fig.10. shows an overview of the slip plane estimation. The estimation of the existence of a slip plane can be seen from the shape of the layer which is suspected to act as a concave-shaped slip plane (light blue-dark blue). The topography on this track follows a non-steep slope. The boundary of the avalanche slip plane is between the impermeable layer (andesite and clay) and the water-saturated layer (sandstone filled with water) shown in blue with a resistivity of 1.03-4.56 Ωm. The layer that is thought to act as a waterproof layer is estimated to be a layer of andesite rock which is shown in red-purple color with a high resistivity value of around 89.5-188 Ωm at a depth of about 1-50 m below the surface where there are bolders which are almost spread around measurement area. On track 5 the measurement location is dominated by andesite rocks and resistivity sandstones (9.59-42.5 Ωm) which are spread out and shown in light green. The sandstone is also interspersed with 6 Ωm clay which becomes an impermeable layer. While the layer that acts as a slip plane or water-saturated zone is estimated to be a layer of sandstone filled with water and bounded by a relatively thin layer of clay so that it has the potential to become a slip plane because it is located between two rocks that have a significant resistivity contrast, namely compact andesite rocks. massive with water-saturated sandstones. If the water-saturated rock layer is no longer able to withstand the weight above it, then the andesite rocks that are nearby will easily slip. This is also reinforced by the presence of a layer of slippery clay so that the potential for landslides/slips is even greater. On track 6, the position of the andesite rocks is relatively above the water-saturated sandstone layer, so the potential for slipping is quite large.

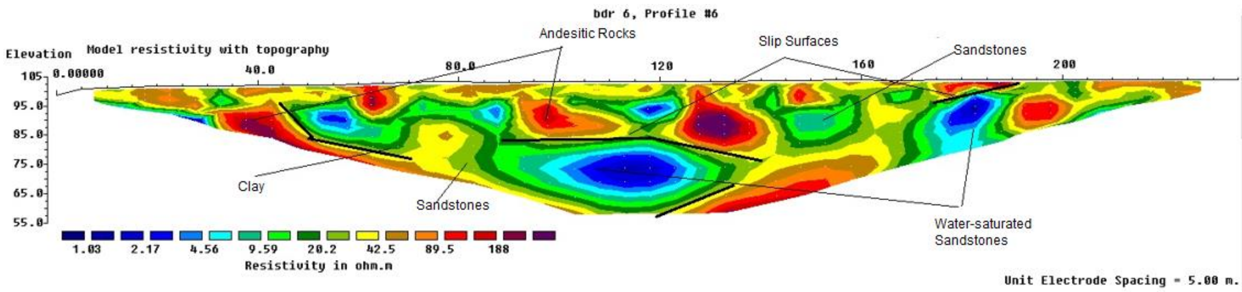

Fig.10. The BDR 6, Tract 6 is located at an altitude of 95–105 meters above sea level

4. Conclusion

Based on the geophysic-geology diagnosis of Slip Surfaces or landsliding, a combinative technique for landslide hazard assessment and identification has been provided. According to our analysis, this region is highly prone to landslides and the hazard mix of predisposing elements that might lead to slope instability conditions in the near future. As a result, the suggested geology-geophysic data integration is a helpful tool that can also be used to detect regions impacted by landslides and assess the chance of failure in presently unaffected areas. The results of data processing indicate that the layer that acts as a slip surface is a layer of clay. The clay layer has a resistivity value ranging from 15 to 35 ohm.m, which is relatively thin, so it has the potential to become a slip surface because it is located between two rocks that have a significant resistivity contrast: compact andesite rock and water-saturated sandstone.

5. References

Darsono; Nurlaksito, B., Legowo, B. (2012). Identifikasi Bidang Gelincir Pemicu Bencana Tanah Longsor Dengan Metode Resistivitas 2 Dimensi Di Desa Pablengan Kecamatan Matesih Kabupaten Karanganyar. *Indonesian Journal of Applied Physics*, *2*(1), 51. https://doi.org/10.13057/ijap.v2i02.1292

Dzakiya, N., Hidayah, R. A., & Larikiansyah, L. (2018). Analisis Potensi Longsor Menggunakan Metode Geolistrik Konfigurasi Dipole-dipole di Desa Kasihan Kecamatan Tegalombo Kabupaten Pacitan Jawa Timur. *Jurnal Materi Dan Pembelajaran Fisika*, *2*, 17–22. https://jurnal.uns.ac.id/jmpf/article/view/28430

Fan, Z., Tang, H., Yang, Y., Zheng, Y., Tan, Q., & Wen, T. (2020). Extension of Spencer's Circular Model to Stability Analysis of Landslides with Multicircular Slip Surfaces. *Mathematical*

Problems in Engineering, *2020*. https://doi.org/10.1155/2020/1298912

Hamidah, A.P; Subandrio, A; Yudiantoro, D. F. (2022). Geologi dan Analisis Kuantitatif Wisata Kawasan Candi Borobudur. *Prosiding Seminar Nasional Aplikasi Sains & Teknologi (SNAST)*, *1*(November), 106–115.

Hewaidy, AGA; El-Motaal; Sultan, S.A; Ramdan, T.M; El-Khafif, A. S. (2015). Groundwater exploration using resistivity and magnetic data at the northwestern part of the Gulf of Suez, Egypt. *Egyptian Journal of Petroleum*, *24*(3), 255–263.

Hidayah, R. A., & Dzakiya, N. (2018). Analysis Geological and Geophysical Data for Prediction Landslide Hazard Zone with Weight of Evidence Method in Pacitan District East Java. *Journal of Applied Geospatial Information*, *2*(1), 117–123. https://doi.org/10.30871/jagi.v2i1.830

Loke, M. H. (2015). *Tutorial: 2D and 3D electrical imaging surveys*. *January*. http://www.geotomosoft.com/coursenotes.zip

Pangaribuan, Jauhari; sabri, L.M.; Amarrohman, F. J. (2019). Analisis Daerah Rawan Bencana Tanah Longsor di Kabupaten Magelang Menggunakan Sistem Informasi Geografis Dengan Metode Standar Nasional Indonesia dan Analythical Hierarchy Process. *Jurnal Geodesi Undip*, *8*(1), 288–297.

Shuzui, H. (2001). Process of slip-surface development and formation of slip-surface clay in landslides in Tertiary volcanic rocks, Japan,. *Engineering Geology*, *61*(4), 199–220.

Telford, W.M; Geldart, L.P; Sheriff, R. E. (1990). *Applied Geophysics*. Cambridge University Press.

Varnes, D. (1978). Slope Movement Types and Processes. *Special Report*, *176*, 11–33.

Yatini, Y., & Suyanto, I. (2018). Identification of slip surface based on geoelectrical dipole-dipole in the landslides hazardous area of Gedangsari District, Gunungkidul Regency, Province of Daerah Istimewa Yogyakarta, Indonesia. *IOP Conference Series: Earth and Environmental Science*, *212*(1). https://doi.org/10.1088/1755-1315/212/1/012013

Yulianto, T., Gernowo, R., & Krisna, W. (2016). The determination of slip surface layer in Trangkil settlement area, Sukorejo Village, Gunungpati District, Semarang Municipality using two dimensional resistivity method with dipole-dipole configuration. *International Journal of Applied Environmental Sciences*, *11*(6), 1363–1373. http://www.ripublication.com

Zakaria, Muhammad Faizal ; Maisarah, S. M. (2019). Identifikasi Bidang Gelincir Pada Daerah Rawan. *Jurnal Geofisika Eksplorasi*, *5*(3), 55–63. https://doi.org/10.23960/jge.v

Zhang, W., Meng, X., Wang, L., & Meng, F. (2022). Stability analysis of the reservoir bank landslide with weak interlayer considering the influence of multiple factors. *Geomatics, Natural Hazards and Risk*, *13*(1), 2911–2924. https://doi.org/10.1080/19475705.2022.2149356

Zou, Zongxing; Yan, Junbiao; Tang, Huiming; Wang, Shun; Xiong, Chengren; Hu, X. (2020). A shear constitutive model for describing the full process of the deformation and failure of slip zone soil. *Engineering Geology*, *276*.