Aceh Int. J. Sci. Technol., 13(1) 1-9
April 2024
doi: 10.13170/aijst.13.1.34605

Aceh International Journal of Science and Technology
ISSN: p-2088-9860; e-2503-2398
Journal homepage: http://jurnal.usk.ac.id/aijst

Identification of Slip Surfaces Using Vertical Electrical Sounding Method in Desa Seumadam for The Study of Landslide-Prone Areas

Sabrian Tri Anda[1,4], Fajriani[1,4], Haikal Fajri[2], Zul Fadhli[3,*], Muhammad Ari Fahril[1,4], Rachmad Almi Putra[1,4]

[1]Physics Study Program, Engineering Faculty, Universitas Samudra, 24416, Indonesia
[2]Civil Engineering Program, Engineering Faculty, Universitas Samudra, 24416, Indonesia
[3]Geophysics Engineering Department of Engineering Faculty of Syiah Kuala University, 23111, Indonesia
[4]Geophysics Study Program, Engineering Faculty, Universitas Samudra, 24416, Indonesia

*Corresponding author: zulfadhli@usk.ac.id

Received : October 06, 2023
Received in revised from: January 25, 2024
Accepted : January 28, 2024
Online : June 28, 2024

Abstract – This study explores the application of the Vertical Electrical Sounding (VES) method for identifying potential slip surfaces in the Desa Seumadam region, a known landslide-prone area. By employing geophysical techniques, the assessment has been made in order to delineate the subsurface characteristics for slip surface identification landslide volume estimation. Based on data interpretation regarding the resistivity model of the subsurface in the study area, the slip surface or weak zone is classified as a clay layer underlain by sand and clayey sand layer. The clay is identified with resistivity value varying from 7 – 54.5 Ωm and located at depth of 6 to 11.68 m while the sand and clayey sand layer are categorized with resistivity value of 4 – 1395 Ωm with a thickness of <11.68 m. As for the estimation of landslide volume, the calculation was made using the landslide mass volume potential approach and found that the landslide volume is estimated at around 2.139 m^3. It is believed that the study not only reveals the potential slip surface of the study area but also enhances the understanding of landslide mechanisms. The findings reveal valuable insights into the geological factors contributing to landslides, facilitating informed decision-making for landslide risk mitigation and land-use planning.

Keywords: VES, resistivity, clay, slip surface, landslide volume estimation

Introduction

Geological disasters, such as landslides, are a recurring phenomenon in various regions, primarily when specific contributing factors align. This occurrence is largely attributed to the natural equilibrium process (Arif and Widodo, 2008). Examining the causal factors behind landslides, several key elements stand out, including geology, vegetation, climate, and land use. As Indonesia enters the rainy season, there is a heightened susceptibility to landslides, presenting both economic and life-threatening repercussions (Souisa *et al.*, 2016). Notably, soil conditions in a given area are significantly influenced by the intensity of rainfall, with heavy rains saturating the soil by infiltrating its pores. This saturation, in turn, compromises the soil's ability to support structures placed upon it (Bujung *et al.*, 2019).

Seumadam region, which is located at the border of Aceh and North Sumatera Province, is classified as one of the areas in Aceh Province which prone to landslide phenomenon. It is emphasized by the data provided by the National Disaster Management Agency in 2019 classifies, Seumadam Region, as a moderately hazardous landslide-prone area (BNPB, 2019). This classification underscores the region's substantial susceptibility to landslide occurrences, especially during the rainy season, as substantiated by the landslides that transpired in 2022. These incidents culminated in a complete blockade of the Medan – Banda Aceh national road, attributing the obstruction to soil accumulation resulting from landslides. Furthermore, this calamity propagated a domino effect, leading to severe traffic congestion and consequently, disrupting socio-economic activities for

Aceh Int. J. Sci. Technol., 13(1) 1-9
April 2024
doi: 10.13170/aijst.13.1.34605

communities residing along the East to West Provincial route in Aceh. In response to that, this paper will provide a preliminary study regarding the cause and feasibility of the landslide by conducting the geophysical method.

Regarding the landslide investigation, various study attempts to explain the soil structure through field investigation. In fact, soil structure investigations are typically conducted at a smaller or limited scale (Helliwell *et al.*, 2013; Schlüter *et al.*, 2014), primarily due to the constraints imposed by the precision of imaging capabilities. Nevertheless, conventional soil structure studies are beset by several limitations. Specifically, these limitations pertain to the capacity of traditional methods to swiftly yield non-invasive insights into soil conditions while maintaining cost-efficiency. According to these considerations, this research presents an approach to address the challenges inherent in identifying soil structures, particularly in delineating potential slip zones within landslide-prone areas. The proposed approach seeks to optimize efficiency by harnessing geophysical techniques, with a particular emphasis on the Vertical Electrical Sounding (VES) method. The evolution of geophysical methodologies has seen widespread adoption in the realm of soil structure investigations due to its inherent ability to promptly furnish dependable information without necessitating perturbations to the natural state of the land or the designated area of interest. Furthermore, these methods are characterized by relatively modest measurement costs (Sabrian *et al.*, 2019; Syukri *et al.*, 2020).

Several prior studies, conducted by various researchers, have delved into the investigation of landslide-prone areas employing geophysical methods (Abdullah *et al.*, 2020; Christopher *et al.*, 2023; Pratiwi *et al.*, 2019; Tejakusuma, 2020). These earlier investigations have generally spanned various regions across Indonesia and have predominantly utilized the Electrical Resistivity Tomography (ERT) method, frequently referred to as the 2D geoelectric method.

In this particular study, the research endeavours to elucidate the soil structure as a crucial component in the field-based identification of potential slip zones within landslide-prone areas. This objective is pursued through the application of the 1D geoelectric method, also known as the VES method (Vertical Electrical Sounding), which assesses subsurface conditions along a single dimension. Furthermore, the outcomes derived from the lower cross-sectional model will serve as a pivotal reference for the estimation of the volume of embankments susceptible to landslide events.

General Geology

The study was conducted in the eastern part of Aceh Tamiang district, an area characterized by its hilly and mountainous terrain from a geomorphological perspective. In terms of geological stratigraphy, this region falls within the Langsa regional stratigraphy framework as shown by the geology map in Figure 1.

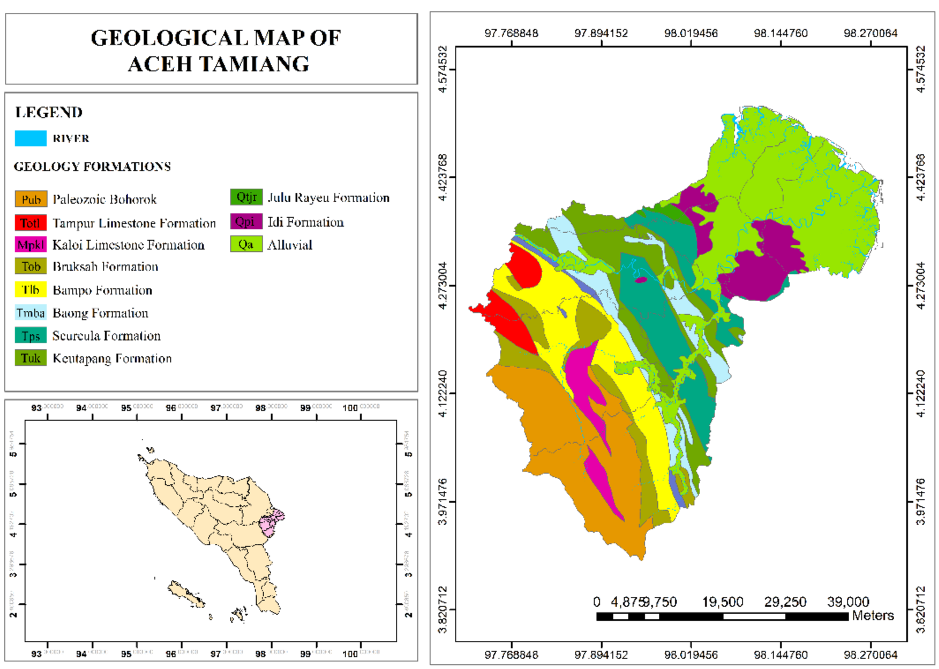

Figure 1. Geology map of Aceh Tamiang district.

The geological history of the area reveals a sequence of rock formations, with the oldest being the Paleozoic Bahorok (Pub) formation, which is subsequently overlain by the Kaloi Limestone Formation (MPkl). Tampur Limestone Formation (Totl), which dates to the early Oligocene period overlain the Kaloi Limestone Formation, and is followed by the Bruksah Formation (Tob). Moving forward in geological time, the Miocene epoch introduces several formations, including the Bampo Formation (Tmb), the Baong Formation (Tmb), the Seureula Formation (Tps), the Keutapang Formation (Tuk), the Julu Rayeu Formation (QTjr), and the Idi Formation (Qpi). It is worth noting that these formations eventually evolved into Alluvial (Qa) deposits, indicating a transition towards sedimentary environments. Hereinafter, the research primarily focused on the hilly and mountainous areas which are predominantly formed by Alluvial deposits.

Material and Methods

The research methodology employed in this study is the 1D geoelectric method, commonly known as Vertical Electrical Sounding (VES). This method stands as one of the most widely favored approaches for delineating the subsurface structure of the Earth, with a specific focus on identifying potential slip surfaces within the target area (Alonso-Pandavenes *et al.*, 2023; Sunaryo *et al.*, 2019). In essence, the operational principle of this 1D resistance geoelectric method revolves around the injection of electric current into the Earth's subsurface, thereby facilitating the measurement of potential differences among the various rock layers concealed beneath the Earth's surface (Figure 2). The measurements are executed utilizing a configuration of four electrodes arranged sequentially. Among these electrodes, two are assigned the task of introducing electric current into the soil, each bearing different charges. Simultaneously, the remaining two electrodes serve as instruments for gauging the voltage generated by the current flowing between the soil and the aforementioned electrodes, thus enabling the comprehensive characterization of subsurface conditions. In addition, a number of prior investigations pertaining to the resistivity values of soil and rocks have been employed as foundational references for estimating subsurface structures within the confines of the research area (Arekumo and Oghale, 2019; Park *et al.*, 2017). The following formula is used to characterize the subsurface shown by equation 1.

$$\rho_a = \mathrm{K}\,\Delta \mathrm{V}/\mathrm{I} \tag{1}$$

Where, ρa = resistivity (ohm.m), ΔV = potential difference, K = geometric factor, I = current.

In particular, in this research, Schlumberger array was utilized. It is based on the consideration that the Schlumberger array is one of the most commonly array used in VES measurement and this type of array provide a more detailed and accurate measurement of the subsurface (Akintorinwa and Abiola, 2020). A total of four measurement points were utilized in order to obtain the information on the subsurface with maximum spacing between electrodes is up to 40 m. The point alignment was set as shown in Figure 3 in order to obtain not only the information regarding the subsurface to identify the slip surface for landslide study, but also to predict the overburden volume that collapse if the landslide occurs. The formula used to calculate the landslide volume is shown in Equation 2.

$$V = \frac{1}{6}\,\pi\,(l.d.w) \tag{2}$$

Where:

V = volume of landslide (m^3)
l = length of slip surface (m)
d = thickness of slip surface (m)
w = width of slip surface (m)

doi: 10.13170/aijst.13.1.34605

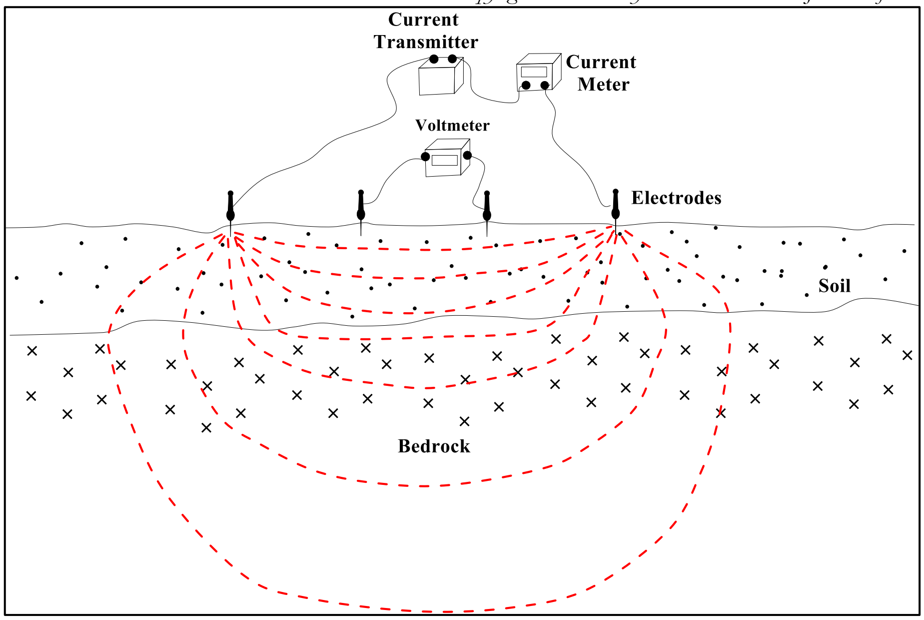

Figure 2. Sketch of the general layout of vertical electrical sounding measurement (Dahlin, 2001).

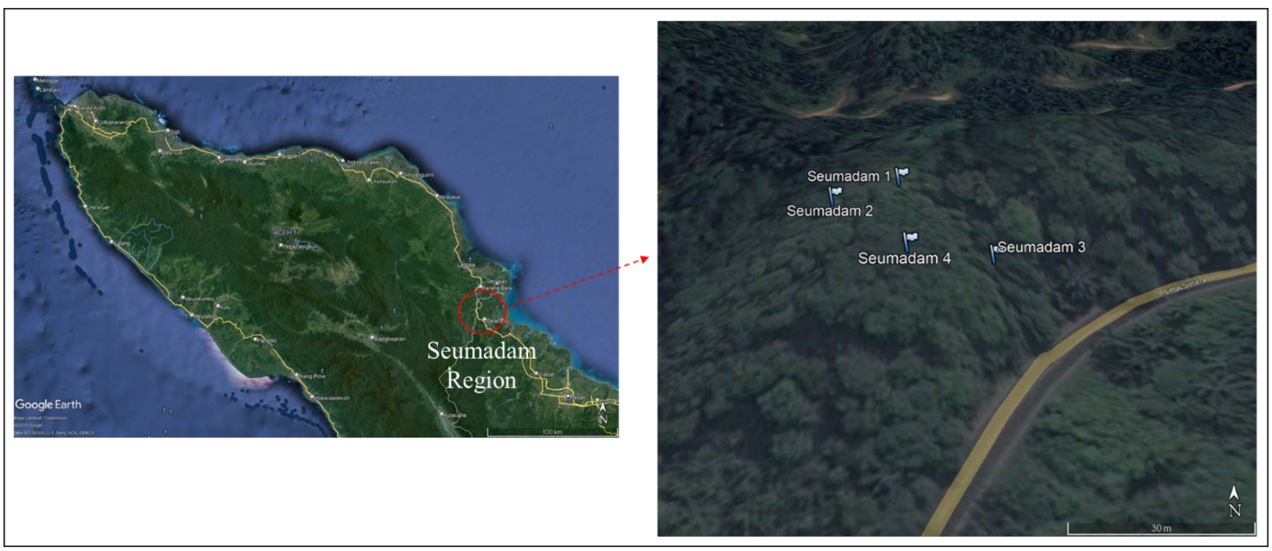

Figure 3. Measurement points at study area

The data processing was made using a P with AGI EarthImager™ 1D. The model of the subsurface layer based on resistivity value was processed using the software Surfer to interpret the slip surface for the landslide study.

Results

Figure 4a illustrates the result of VES measurements conducted at point Seumadam 1, situated at coordinates 4°11'14.87"N and 98° 3'15.56"E. Through a comprehensive analysis of resistivity variations within the subsurface, it has discerned that the geological composition within the research area comprises multiple strata, encompassing sandy soils, clayey sand, and clay. Moreover, following an exhaustive interpretation process aimed at identifying potential landslide-prone zones, the subsurface cross-sectional model at Seumadam 1 measurement point has been stratified into three primary layers, as depicted in Figure 4b. The initial layer, spanning a depth of less than 0.5 meters and characterized by resistivity values ranging from 139 – 379 Ωm, is predominantly composed of dry sandy soils. Additionally, the second layer, extending from 0.5 to 3.05 meters in depth, has been classified as a clayey sand layer, exhibiting resistivity values ranging from 11 – 93 Ωm. Henceforth, the

Aceh Int. J. Sci. Technol., 13(1) 1-9
April 2024
doi: 10.13170/aijst.13.1.34605

tertiary stratum, discerned at a depth ranging from 6.10 to 22 meters, predominantly consists of clay characterized by a resistivity value within the range of 6 to 33 Ωm.

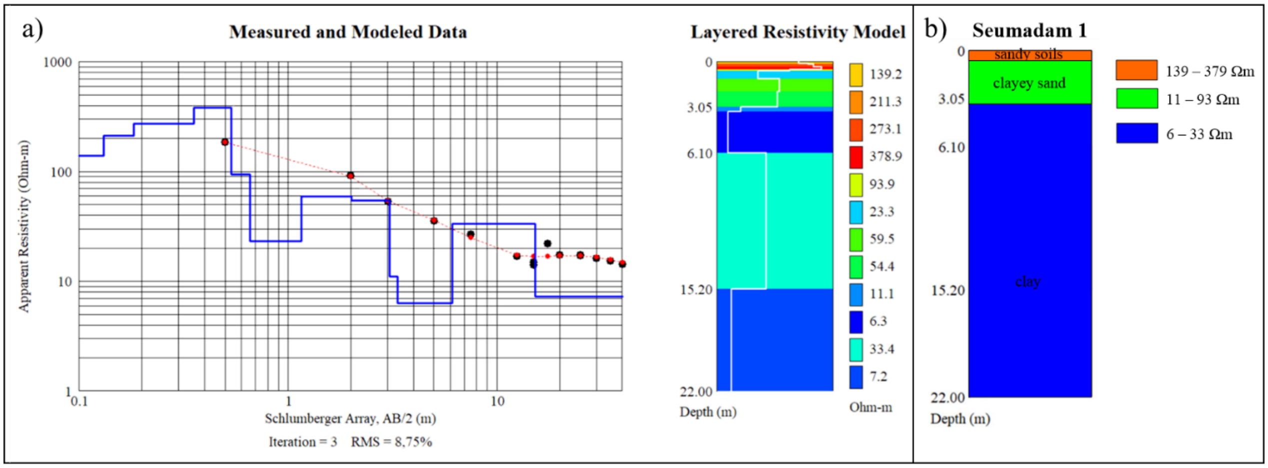

Figure 4. VES result of Seumadam 1; (a) subsurface layer processed by AGI EarthImager™ 1D, (b) interpreted subsurface layer of Seumadam 1.

Figure 5 presents the results of Vertical Electrical Sounding (VES) measurements conducted at the Seumadam 2 measurement point. The obtained data reveals a range of resistivity values spanning from 12 to 1395 Ωm, encompassing a depth of 22 meters. Based on these resistivity values, the soil types in this region have been categorized as comprising sandy soils, clayey sand, and clay. At the point Seumadam 2, three primary zones have been delineated. The initial zone, or layer, is characterized by a dominance of sandy soils, displaying a resistivity value range of 12 to 1395 Ωm, and is situated at a depth of less than 6.37 meters. Subsequently, the second layer is identified as a clayey sand layer with a resistivity value of 333 Ωm, extending from a depth of 6.37 meters to 11.7 meters. Lattermost, the fourth layer, with depth of 11.7 – 22 meters has been classified as a clay layer with resistivity value of 50 Ωm (Figure 5b).

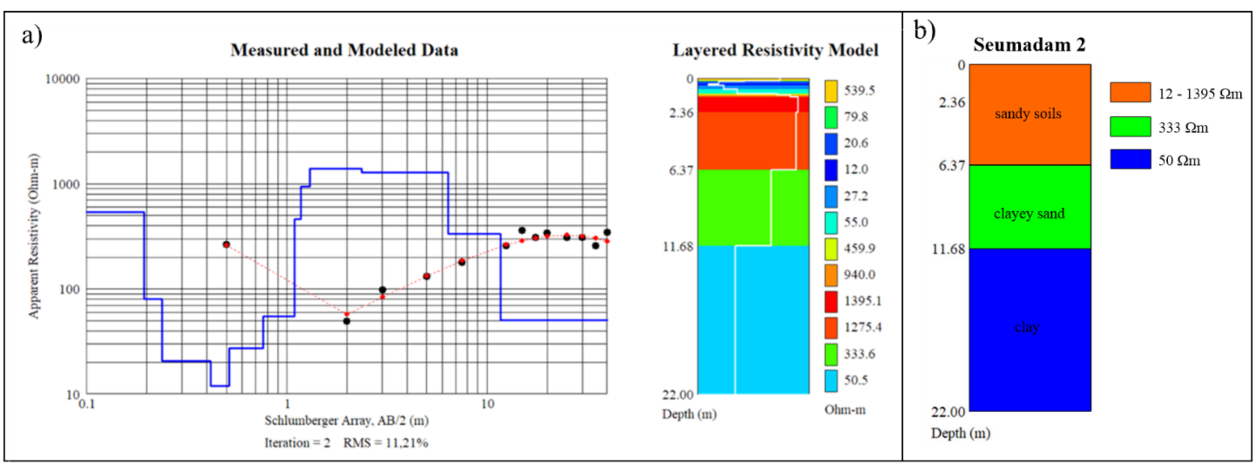

Figure 5. VES result of Seumadam 2; (a) subsurface layer processed by AGI EarthImager™ 1D, (b) interpreted subsurface layer of Seumadam 2

Figure 6 presents the results of Vertical Electrical Sounding (VES) measurements that depict the subsurface profile at the Seumadam 3 measurement point. The resistivity measurements of the subsurface layers at this point reveal the presence of three primary strata, which consist of clayey sand, clay, and sandstone. Clayey sand is identified at depths shallower than 7.6 meters, characterized by resistivity values ranging from 5 to 13.4 Ωm. Clay layers are encountered at depths between 7.6 and 11.22 meters, marked by a resistivity value of approximately 33 Ωm. The subsequent layer, constituting the third stratum, is composed of sandstone with a resistivity value of 162 Ωm, identified at depths ranging from 11.22 to 22 meters. The layer classification and interpretation results are succinctly depicted in Figure 6b.

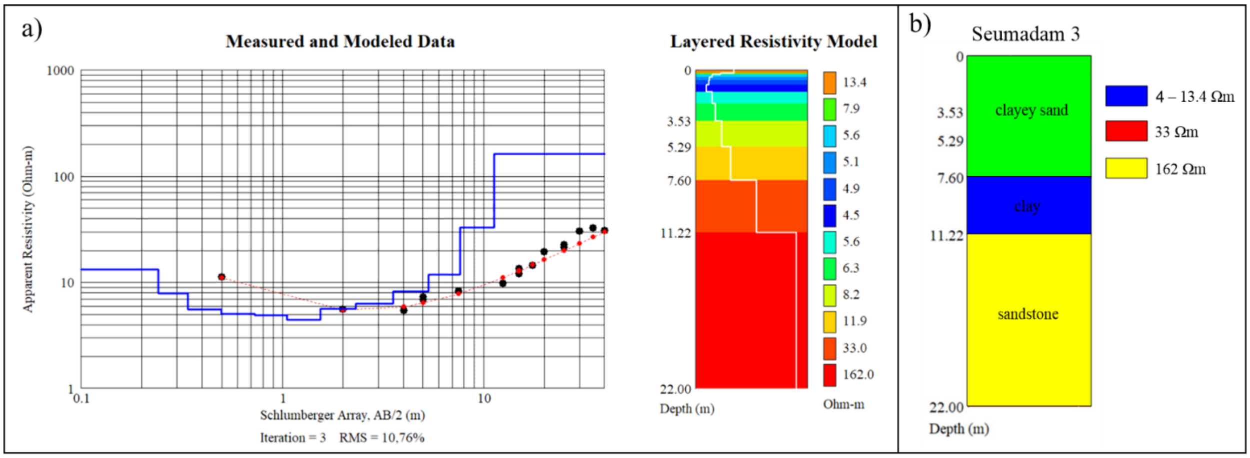

Figure 6. VES result of Seumadam 2; (a) subsurface layer processed by AGI EarthImager™ 1D, (b) interpreted subsurface layer of Seumadam 3

The results of subsurface layer measurements utilizing the VES method at point Seumadam 4 are displayed in Figure 7. The identified resistivity values exhibit a range of 5 to 166.8 Ωm. From these results, a subsurface layer interpretation was conducted, revealing that this measurement point comprises three distinct strata. The first stratum consists of clayey sand, with resistivity values ranging from 5 to 19.6 Ωm, and is found at depths shallower than 6.96 meters. Subsequently, the second stratum, composed of clay, is encountered at depths between 6.96 and 9.18 meters, with a resistivity value of 54.4 Ωm. The third stratum, which is presumably comprised of sandstone, is situated at depths of 9.18 to 22 meters and has been identified with a resistivity value of 166 Ωm. A simplified interpretation of the subsurface layers at Seumadam 4 is presented in Figure 8 for clarity.

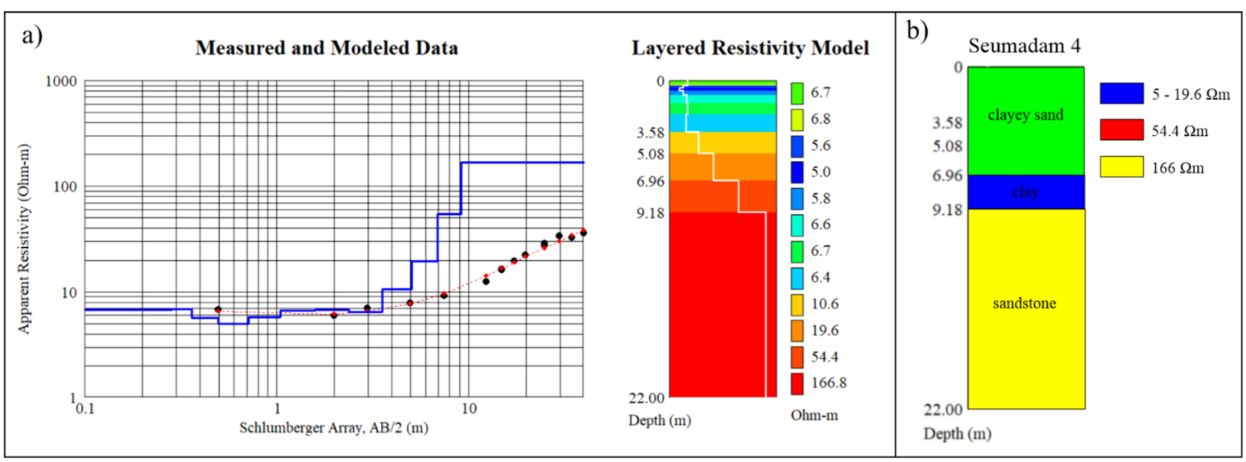

Figure 7. VES result of Seumadam 1; (a) subsurface layer processed by AGI EarthImager™ 1D, (b) interpreted subsurface layer of Seumadam 4.

Furthermore, based on the calculations conducted using Equation 2 to predict the total mass of potential landslides in the research area, it has been determined that the predicted landslide volume at the study site is approximately 2252.5 m^3. The calculation employed in this study utilized the landslide mass volume potential approach, wherein the average dimensions of length, width, and thickness of the layer above the clay stratum at each measurement point were considered. The specifics of each measurement point are detailed in Table 1.

Aceh Int. J. Sci. Technol., 13(1) 1-9
April 2024
doi: 10.13170/aijst.13.1.34605

Table 1. Detailed of length, width, and thickness of measurement points

Length (m)	
Seumadam 1 – Seumadam 2	18
Seumadam 3 – Seumadam 4	24
Width (m)	
Seumadam 1 – Seumadam 3	31
Seumadam 2 – Seumadam 4	25
Thickness (m)	
Seumadam 1	3.05
Seumadam 2	11.68
Seumadam 3	7.6
Seumadam 4	6.96

Discussion

Given the documented occurrence of landslide events in the study area, with visible remnants persisting in various locations, the primary objective of this research is to ascertain the underlying cause of these landslides by pinpointing the slip surface or weak zone responsible. This critical endeavor is achieved through the application of the geoelectrical method, a well-established and widely employed technique within the field of landslide studies (Alonso-Pandavenes *et al.*, 2023; Jianjun *et al.*, 2020;). Preceding the identification of the slip surface, a pivotal phase involves the classification of subsurface soil layers based on the interpretation of the resistivity model. It is essential to note that this interpretation is not solely reliant on resistivity values, as many soil and rock types exhibit overlapping resistivity values. In this context, the geological characteristics and configuration of the study area assume a vital role in facilitating accurate data interpretation.

Through interpretation, it has been determined that the layer composed of clay is categorized as a potential slip surface. The classification of the clay layer as a potential slip surface is grounded in the fact that this layer exhibits low levels of porosity and permeability. This characteristic hinders the movement of water accumulated in the layer above it, which is a permeable clayey sand layer. Consequently, the increasing load due to water accumulation diminishes the cohesion and friction between the clay layer and the clayey sand layer, thereby elevating the potential for landslides. This reduction in shear strength is also influenced by increased pore pressure within the clayey sand layer (Souisa *et al.*, 2016b).

Henceforth, it is believed that the landslide volume calculated based on geophysical approach gave a significant effect when the events occurred. Moreover, the identified landslide-prone area is strategically situated, encompassing a crucial zone, specifically along a national thoroughfare linking two provinces. The potential threat of fatalities resulting from soil entrapment remains ever-present for road users. Additionally, the disturbance of this key transportation route is poised to exert a noteworthy influence on the economic landscape of the region. Considering this discovery, it is anticipated that the local government will proactively implement targeted measures to preclude the onset of landslides, acknowledging the persistent likelihood of such catastrophic events reoccurring.

Conclusion

The application of the Vertical Electrical Sounding (VES) method has proven highly effective in elucidating the underlying cause of the landslide phenomenon and providing valuable insights into landslide volume estimation within the study area. The identification of the slip surface or weak zone has been accomplished through a meticulous process involving the classification and interpretation of resistivity models derived from the VES method. This research culminates in the determination that the slip surface can be characterized as a clay layer, which is underlain by a substantial layer comprised primarily of sand and clayey sand. This categorization has been established by considering the distinctive physical properties of clay, notably its low porosity and permeability. This particular geological configuration renders the overlying layers susceptible to collapse under the influence of excessive rainfall-induced weight. The clay layer, pivotal in this context, is situated at depths ranging from 3.05 to 11.68 meters, exhibiting resistivity values within the range of 6 to 54.4 Ωm. Meanwhile, the layers consisting of sand classified by resistivity values within the range of 12 to 1395 Ωm, extend

doi: 10.13170/aijst.13.1.34605

to a depth not exceeding 6.4 meters while the clayey sand identified at depth of 0.5 – 11.68 meters. The research also concludes the estimation of landslide volume which is approximately around 2252.5 m^3.

Acknowledgment

The authors would like to thank the Ministry of Education, Culture, Research, and Technology, Indonesia, Universitas Samudra, and Institute for Research and Community Services of Universitas Samudra for funding the research through the scheme of Penelitian Asisten Ahli with contract number 585/UN54.6/PG/2023. Moreover, special thanks to student and staff of Physics Study Program of Universitas Samudra and Engineering Geophysics Department of Syiah Kuala University for the effort during data acquisition.

References

Abdullah, N.H., Mohamed Jais, I., and Awang, H., 2020. Geophysical method exploration for slope failure investigation. IOP Conference Series: Materials Science Engineering, 917, 012008. http://dx.doi.org/10.1088/1757-899X/917/1/012008.

Akintorinwa, O., and Abiola, O., 2020. Comparison of Schlumberger and Modified Schlumberger Arrays Ves Interpretation Results. Research Journal in Engineering and Applied Sciences, 1(3), 190–196.

Alonso-Pandavenes, O., Torrijo, F.J., Garzón-Roca, J., and Gracia, A., 2023. Early Investigation of a Landslide Sliding Surface by HVSR and VES Geophysical Techniques Combined, a Case Study in Guarumales (Ecuador). Applied Sciences*,* 13(2), 1023. https://doi.org/10.3390/app13021023

Arekumo, T.G., and Oghale, L.O., 2019. Evaluation of Lateritic Soil from Field Resistivity Data at Okada, South-South, Nigeria. International Journal of Science and Research*,* 8(6). http://dx.doi.org/10.21275/ART20198933

Arif, M., and Widodo, A., 2008. Analisa Balik Kelongsoran (Studi Kasus di Jember). Media Komunikasi Teknik Sipil, 16(2), 140–147. https://doi.org/10.14710/mkts.v16i2.3689

BNPB, I., 2019. Katalog Desa Kelurahan Rawan Longsor. BNPB. URL https://bnpb.go.id/buku/katalog-desa-kelurahan-rawan-longsor (accessed 5.20.23).

Bujung, D.P.A.P., Turangan, A.E., and Sarajar, A.N., 2019. Pengaruh Intensitas Curah Hujan Terhadap Kuat Geser Tanah. Tekno*,* 17(2), 47–51. https://doi.org/10.35793/jts.v17i72.25793

Christopher, W.A.P.P., De Silva, N., Attanayake, A.M.A.N.B., and Jayasingha, P., 2023. Characterization of landslides: a vertical electrical sounding approach. Geoscience Letters*,* 10(1), 18.

Dahlin, T., 2001. The development of DC resistivity imaging techniques. Computers & Geosciences*,* 27(9), 1019–1029. https://doi.org/10.1016/S0098-3004(00)00160-6

Helliwell, J.R., Sturrock, C.J., Grayling, K.M., Tracy, S.R., Flavel, R.J., Young, I.M., Whalley, W.R., and Mooney, S.J., 2013. Applications of X-ray computed tomography for examining biophysical interactions and structural development in soil systems: a review: X-ray computed tomography for soil physical properties. Eur J Soil Sci, 64, 279–297.

Jianjun, G., Zhang, Y.X., and Xiao, L., 2020. An application of the high-density electrical resistivity method for detecting slide zones in deep-seated landslides in limestone areas. Journal of Applied Geophysics*,* 177, 104013. https://doi.org/10.1016/j.jappgeo.2020.104013

Park, C.-S., Jeong, J.-H., Park, H.-W., and Kim, K., 2017. Experimental Study on Electrode Method for Electrical Resistivity Survey to Detect Cavities under Road Pavements. Sustainability*,* 9, 2320. https://doi.org/10.3390/su9122320

Pratiwi, E.S., Sartohadi, J., and Wahyudi, 2019. Geoelectrical Prediction for Sliding Plane Layers of Rotational Landslide at the Volcanic Transitional Landscapes in Indonesia. IOP Conference Series: Earth and Environmental Science*,* 286, 012028.

Sabrian, T.A., Saad, R., Saidin, M., Andika, F., Muhammad, S.B., and Yusoh, R., 2019. Utilisation of Seismic Refraction Method in Producing Shale Topography Map of Sungai Batu Ancient River. Journal Physical Science*, 30(1)*, 169–178. http://dx.doi.org/10.21315/jps2019.30.1.12

Schlüter, S., Sheppard, A., Brown, K., and Wildenschild, D., 2014. Image processing of multiphase images obtained via X-ray microtomography: A review. Water Resources Research, 50, 3615–3639. https://doi.org/10.1002/2014WR015256

Souisa, M., Hendrajaya, L., and Handayani, G., 2016a. Prediksi Volume Potensi Longsoran Berdasarkan Inversi Resistivitas (Studi Kasus di Amahusu dan Erie Ambon), in: Prosiding Seminar Nasional Fisika (E-Journal)

Aceh Int. J. Sci. Technol., 13(1) 1-9
April 2024
doi: 10.13170/aijst.13.1.34605

SNF2016. Presented at the Seminar Nasional Fisika 2016 UNJ, Pendidikan Fisika dan Fisika FMIPA UNJ, pp. SNF2016-EPA-17-SNF2016-EPA-22. http://dx.doi.org/10.21009/0305020404

Souisa, M., Hendrajaya, L., and Handayani, G., 2016b. Landslide Dynamics and Determination Critical Condition Using of Resistivity Method in Desa Negeri Lima Ambon. Indonesian Journal of Physics*,* 26(1), 1–4.

Sunaryo, Susilo, A., Yuwono, A.M., and Wiyono, 2019. Slope Stability Analysis for Landslides Natural Disaster Mitigation by Means of Geoelectrical Resistivity Data in Gedangan of South Malang, East Java, Indonesia. IOP Conference Series: Materials Science Engineerin*g*, 546, 022030.

Syukri, M., Sabrian, T.A., Rini, S., Zul, F., and Saad, R., 2020. Prediction of Soil Liquefaction Phenomenon in Banda Aceh and Aceh Besar, Indonesia Using Electrical Resistivity Tomography (ERT). Geomate*,* 18. https://doi.org/10.21660/2020.70.12814

Tejakusuma, I.G., 2020. Determination of Landslide Slip Plane Using Geology and Geoelectrical Analysis at Mount Geger Pulus Legok Emo Slope Segment, Cililin, West Java. Jurnal Sains dan Teknologi Mitigasi Bencana, 15, 63–73. http://dx.doi.org/10.29122/jstmb.v15i1.4114