Using the Schlumberger configuration resistivity geoelectric method to estimate the rock structure at landslide zone in Malalak agam

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Abstract. Landslides that often occur in the Malalak sub-district are very detrimental to the community. Landslides in the Malalak sub-district have caused casualties and the closure of the Malalak road segment. According to studies that have been carried out factors that influence the occurrence of landslides are slope, skid field, rock structure and external factors such as rain and earthquake intensity. Rock structures of landslide-prone areas are urgently needed which will be used as reference data to predict potential landslides. This research aimed to estimate the structure of the rock as a reference or supporting data to determine the potential for landslides in the Malalak. The method used in this study is the Schlumberger configuration Resistivity Geoelectric Method. Based on the estimated structure of the rocks in the Malalak region, the rock types in the area consist of Clay, Sandstone, Limestone, Andesite, and Granite.

1. Introduction

West Sumatera is one of the provinces that is often affected by the landslide disaster [1]. This is because the West Sumatera region has morphology consisting of mountains and hills, and plate activity, wet climate, and has rainfall ranging from 5.498 to 11.749 mm/year [2]. The area West Sumatera which often occurs landslides is Malalak Agam district. The landslide that often occurs in the Malalak district is very detrimental to society. One of the landslides in the Malalak district was in 2017 which resulted in the closure of the Sicincin-Bukittinggi alternative because the road was buried by landslide material [3]. Besides that landslides cause damage to rock structures, infrastructure, plantations, animals and human life [4]. It also has an impact on social and economic [5]. So that it is necessary to survey the rock structure beneath the Malalak district as initial information to assess landslide references and as landslide mitigation in the area.

Landslide is mass movements along the surface of the field of landslide [6], which move downward and down the slope or fall from the foot of the slope [7] have soil, rock, soil artificial plantations or a combination of land and rock [8],[9] due to influence gravitational. A landslide can occur on land where soil or rock barriers are smaller than the weight of the soil or rock mass [10], [11],[8].

Factors that cause landslide are rock structures[12], the shape and slope, soil, rainfall, land use and earthquake [7]. One of the factors affecting the slope is the rock structure. So the rock structure is very important to know because it is one indicator to determine whether an area has the potential to experience landslide or not.
Rocks are a mixture of minerals that are joined physically to each other. Rock is composed of only one type of mineral, and a small part is formed by a combination of minerals, organic materials, and volcanic materials [13]. All the rocks on the surface of the earth come from magma which melts to the surface of the earth. The temperature of the earth’s surface which is much lower than the temperature below the earth’s surface results in the freezing of magma that forms rocks.

Based on the ability in conductivity and the inhibitory power of material electric current is divided into three types, namely conductors, semiconductors and insulators [14]. Conductors are materials that can conduct electric current because many have free electrons with resistivity values \((10^8 \ \Omega m < \rho < 1 \ \Omega m)\). Semiconductors are materials that can conduct electric current but are not as good as conductors with a type of resistivity value \((1 \ \Omega m < \rho < 10^7 \ \Omega m)\), while insulators are materials that cannot conduct electric current because they do not have free electrons with resistivity values \(\rho > 10^7 \ \Omega m\).

The greater values of resistivity from materials (resistance type) more difficult for electric current to flow. In otherwise, the smaller the value of the resistivity value, it’s easier for the electric current to flow. The resistance values of Igneous rock types, Sedimentary rocks, and Metamorphic rocks are shown in Table 1

| Rocks              | Resistivity Values (\(\Omega m\))       |
|--------------------|-----------------------------------------|
| Granite            | \(3 \times 10^2 - 10^5\)                |
| Diorite            | \(10^4 - 10^5\)                        |
| Andesite           | \(4.5 \times 10^4\) (wet) \(- 1.7 \times 10^5\) (dry) |
| Diabase Porphyry   | \(10^3\) (wet) \(- 1.7 \times 10^5\) (dry) |
| Basalt             | \(10 - 1.3 \times 10^7\) (dry)         |
| Tuffs              | \(2 \times 10^3\) (wet) \(- 10^5\) (dry) |
| Sandstone          | \(1 - 6.4 \times 10^8\)                |
| Limestone          | \(50 - 10^7\)                          |
| Dolomite           | \(3.5 \times 10^2 - 5 \times 10^5\)    |
| Clay               | \(1 - 100\)                            |
| Alluvium and Sands | \(10 - 800\)                           |
| Oil Sands          | \(4 - 800\)                            |

Rock types and structures were identified using the type resistivity geoelectric method. The type Resistivity geoelectric method investigating the subsurface of the earth by injecting electric current into the earth through two current electrodes to produce a potential difference measured though two potential electrodes [15], [14],[16],[17].

The type of rock is detainees then with further processing of data will get the type of resistance value of each rock layer so that it can be seen the difference in the value of the type of resistance of each layer. The picture of the flow of electricity into the earth can be seen in Figure 1 below:
Electric flows inside the earth, where the earth is considered a homogeneous isotropic medium so that the electric flows in all directions. The air has a very large type of resistance causing the current to not be able to flow into the air so that the current spreads only below the earth's surface by forming a half-ball equipotential field.

In general, the type of earth resistances is not homogeneous, meaning that the calculated are apparent resistivity ($\rho_a$) [18],[19]. The apparent type of resistance does not directly indicate the resistance of the medium, but it reflectance the distribution of medium type resistivity values. This is because the earth is a non-homogeneous medium consisting of many layers with different types of resistances, affecting the electrical potential measured. The apparent type of resistance is denoted by $\rho_a$ so that this equation can be written as in:

$$\rho_a = K \frac{\Delta V}{l} \quad (1)$$

$K$ is the geometrical factor that depends on the setting of the four electrodes or the lock configuration [15].

The configuration used in this research is the Schlumberger configuration. The Schlumberger configuration has a fairly deep current penetration of 1/5 from the distance of the current electrode spacing used. The Schlumberger configuration is preferable to the Wenner array for depth sounding because the field procedure is quicker and simpler and master curves and software are more readily available for result analysis [20]. The Schlumberger configuration has advantages over other configuration, including the penetration of the Schlumberger configuration depth better than the Wenner configuration, and to get vertical accuracy better than the dipole-dipole configuration [21]. The Schlumberger array is a variation on the gradient array, in which the potential electrodes remain at the center of the spread, and the spacing of the current electrodes is varied [22].

Figure 2 is an electrode installation scheme in the Schlumberger configuration. Schlumberger configuration uses 4 electrodes with 2 current electrodes (AB) and 2 potential electrodes (MN) [19],[22],[23],[24] arranged in a single line. The distance of each electrode in figure 2 is:
\[ r_1 = (L - l) \]  \hspace{1cm} (2)
\[ r_2 = (L + l) \]  \hspace{1cm} (3)
\[ r_3 = (L + l) \]  \hspace{1cm} (4)
\[ r_4 = (L - l) \]  \hspace{1cm} (5)

with \( L = \frac{AB}{2} \) and \( l = \frac{MN}{2} \). The price of each electrode distance has been simplified so that the K price of the Schlumberger configuration is obtained, as follows:

\[ K = \frac{\pi(L^2 - l^2)}{2l} \]  \hspace{1cm} (6)

Based on the price of K obtained in Equation (2), the apparent resistivity value can be calculated with Schlumberger configuration, namely:

\[ \rho_a = \frac{\pi(L^2 - l^2) \Delta V}{2lI} \]  \hspace{1cm} (7)

where \( \rho_a \) is apparent type resistance, \( L \) is the current electrode distance, \( l \) is the potential electrode distance, \( \Delta V \) is the potential difference, \( I \) is the current strength.

2. Methodology

This research is basic descriptive research. This research was carried out in Malalak Agam District. The parameters measured in this study were electric current (I), potential difference (V) and electrical spacing using the Schlumberger Configuration. The tool used in this study is the ARES Multielectrode. The working principle of ARES is to inject an electric current (I) into the surface of the earth to produce a potential difference (V) with the current source is the accu. Measurements are made using 2 tracks. Figure 3 shows the trajectory in the research area.

![Figure 3. Measurement location](image)

The parameters calculated in this research are apparent resistivity \( (\rho_a) \). The way to calculate apparent resistivity using equation (1). The apparent type of resistance obtained at the time of measurement does not directly indicate the resistivity value of a medium but reflects the distribution of the type of resistivity value of the medium.

The parameters interpreted in this research are the resistivity of the actual type and depth of the rock structure. The actual type of resistance was obtained by inversion Smoothness - Constraint Least Squares.
using Res2dinv software. The depth of each layer can be calculated by measuring the 2D cross-section, the depth is calculated at 3 sounding points. Each sounding has the same distance each sounding. The way to calculate the depth of each sounding is to draw a straight line from the color of the type of resistance that is sought and to obtain the depth and thickness of the rock.

The parameters estimated in this study are rock structures in the study area. The rock structure estimated by comparing the value of the type of resistance obtained by the value of rock type resistance (Table 1) and the geological conditions in the study area, so that conclusions were obtained regarding the depth and thickness of the rock structure in the study area.

3. Research Results and Discussions

3.1 The First Location Measurement

The First measurement has a track length of 315 m, starting at the coordinates (00° 22' 21.25" LS and 100° 17' 14.53" BT) to coordinates (00° 22' 15.52" LS and 100° 17' 18.03 "BT) with a 5-meter electrode spacing. Figure 4 shows 2D cross-section resistivity in the first location.

![Figure 4. The 2D cross-section resistivity in the first location](image)

Figure 4 shows a 2D subsurface crossing as long as track 1 has a range of species resistance values from 1.88 Ωm - 7829 with a percentage error of 21.8% in the 5th iteration. Value resistivity in the first location can be seen in table 2.

| Resistivity (Ωm) | Type of Rock | Depth (m) | The thickness of layer (m) |
|-----------------|--------------|-----------|----------------------------|
| 1.88-20.3       | Clay         | 8 – 35    | 27                         |
| 20.3-220        | Sandstone    | Surface to 8 | 8                          |
| 220-724         | Limestone    | 35 – 48   | 13                         |
| 724-2380        | Andesite     | 48 – 62   | 14                         |
| 2380-7829       | Granite      | 62-72     | 10                         |

Based on table 2 the value of type resistance in the first location with a cross-section of the 2D model, it is analyzed that the first location has 5 types of subsurface rock constituents. The type of resistivity value ranges from 1.88 Ωm - 20.3 Ωm is estimated as Clay. This is by the type of resistivity values in Table 1, where Clay has a range of resistances of 1 Ωm - 100 Ωm. The type of resistivity value range
from 20.3 Ωm - 220 Ωm is estimated as Sandstone. This is by the resistivity values of Table 1, where the range of resistance values is 1 Ωm – 6.4x10^8 Ωm. The type of resistivity value between 220 Ωm - 724 Ωm is estimated as Limestone. Based on Table 1, the Limestone type resistance value ranges from 50 Ωm – 10^7 Ωm. The type of resistivity value range from 724 Ωm - 2380 Ωm is Andesite [26],[27]. By Table 1, the range of Andesite species resistance values is 170 Ωm - 4.5x10^4 Ωm. The type of Resistivity value range from 2380 Ωm - 7829 Ωm is estimated as Granite. This is by the resistivity value types in Table 1, where the Granite type resistances range from 300 Ωm – 10^6 Ωm.

3.2 The Second Location Measurement
The Second measurement has a track length of 315 m, starting at the coordinates (00° 22′ 23.15″ LS and 100° 17′ 12.36″ BT) until (00° 22′ 17.29″ LS and 100° 17′ 9.00″ BT). The length of layer 2 is around 315 m with a spacing of 5 meters electrode. Figure 5 shows 2D cross-section resistivity in the second location.

Figure 5. The 2D cross-section in the second location

Figure 5 shows 2D subsurface crossings on track 2 having a range of types of resistivity values of around 5.67 Ωm - 2694 Ωm with a percentage error of 26.9% obtained in 5th iteration. The results of data processing on line 1 indicate that the accuracy of the results of the study around 73.1% of the level of measurement error. Value resistivity in the first location can be seen in table 3.

| Resistivity (Ωm) | Type of Rock | Depth of Rock (m) | The thickness of Rock (m) |
|------------------|--------------|-------------------|--------------------------|
| 5.67-33,0        | Clay         | 7-20              | 13                       |
| 33,0-192         | Sandstone    |                   |                          |
| 192-453          | Limestone    | Surface to 7 and 20-32 | 7 and 12               |
| 453-1117         | Andesite     | 32-40 and 60-75   | 5 and 15                 |
| 1117-2694        | Granite      | 40-60             | 20                       |

Based on table 3 The constituent rock on Location second measurement is identified as having 5 types of subsurface rock constituents. The type of resistivity values ranges from 5.67 Ωm - 33.0 Ωm is estimated as Clay. This is by the type of resistivity values in Table 1, where Clay has a range of resistances of 1 Ωm - 100 Ωm. The type of resistivity value range from 33.0 Ωm - 192 Ωm is estimated as Sandstone. This is by the resistivity values of Table 1, where the range of resistance values is 1 Ωm – 6.4x10^8 Ωm. The type of resistivity value between 192 Ωm - 463 Ωm is estimated as Limestone. Based on Table 1, the Limestone type resistance value ranges from 50 Ωm – 10^7 Ωm. The type of resistivity
values range from 463 Ωm - 1117 Ωm is estimated as Andesite. By Table 1, the range of Andesite resistance values is 170 Ωm - 4.5x10^4 Ωm. The type resistivity values range from 1117 Ωm - 2634 Ωm is estimated as Granite. By the resistivity value types in Table 1, where the Granite type resistances range from 300 Ωm – 10^6 Ωm.

4. Conclusions
Based on the results of the interpretation of the data on each track, the types of geological constituent rocks obtained by Malalak Agam District consist of Clay, Sandstone, Limestone, Andesite, and Granite. Ranges of resistivity Clay is 1.88 Ωm – 20.3 Ωm on first-line measurement and ranges 5.67 Ωm – 33.0 Ωm on second-line measurement. Ranges of resistivity Sandstone 20.3 Ωm – 220 Ωm on the first-line measurement and ranges 33.0 Ωm – 192 Ωm on second-line measurement. Ranges of resistivity Limestone 220 Ωm – 724 Ωm on the first-line measurement and ranges 192 Ωm – 463 Ωm on second-line measurement. Ranges of resistivity Andesite 724 Ωm - 2380 Ωm on first-line measurement and ranges 463 Ωm - 1117 Ωm on second-line measurement. Ranges of resistivity Granite 2380 Ωm – 7829 Ωm on the first-line measurement and ranges 1117 Ωm – 2634 Ωm on second-line measurement. Advice from the author is that the results of this study can be used as a reference for the government as landslide mitigation in Malalak Agam and the need for further research in the area with different methods as a comparison of the results of the research that has been achieved.

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References
[1] Lusy Fransiska, Boedi Tjahjono, Komarsa Gandasasmita. 2017. Studi Geomorfologi dan Analisis Bahaya Longsor di Kabupaten Agam, Sumatera Barat. Jurnal. Bogor: Fakultas Pertanian IPB. Hal 51-57
[2] Gustari, I. 2009. Analisis Curah Hujan Pantai Barat Sumatera Bagian Utara periode 1994-2007. Jurnal Meteorologi dan Geofisika Vol. 10 No. 1 hal 29-38
[3] Resty Prasuryani, Rusli HAR, Raimon Kopa. 2018. Analisis Potensi Longsor pada Ruas Jalan Malalak Km 33 di Kecamatan Malalak, Kabupaten Agam, Provinsi Sumatera Barat. Jurnal Bina Tambang, Vol. 3, No. 4
[4] Akmam, H Amir, A Putra, R Anshari and N Jalinus. 2018. Implementation of least-square constrain inversion method of geoelectrical resistivity data Wenner-Schlumberger for investigation the characteristics of landslide. The 2018 International Conference on Research and Learning of Physics
[5] A. Perrone, V. Lapenna, S. Piscitelli. 2014. Electrical resistivity tomography technique for landslide investigation: A review. Institute of Methodologies for Environmental Analysis, CNR, Italy. Earth-Science Reviews 135 (2014) 65–82
[6] Priyono. 2014. Hubungan Klasifikasi Longsor, Klasifikasi Tanah Rawan Longsor dan Klasifikasi Tanah pertanian Rawan Longsor. GEMA, Th. XXVII/49.Fakultas Pertanian UNISRI Surakarta.
[7] Matheus Souis, Lilik Hendrajaya, Gunawan Handayani 2016. Landslide hazard and risk assessment for Ambon city using landslide inventory and geographic information system. Journal of Physics: Conference Series 739 (2016) 012078
[8] Tommy Ilyas. (2011). Tanah longsor (landslide). Sumber Media Indonesia 13 Januari 2011. https://scele.ui.ac.id/berkas_kolaborasi/konten/mpktb_2014genap/093.pdf
[9] Muntohar. 2010. Tanah Longsor: Analisis-Prediksi-Mitigasi. Yogyakarta. Universitas Muhammadiyah Yogyakarta.
[10] Ginavie A. Pakasi, Karamoy Lientje Theffie, Zetty E. Tamod, Maria Montolalu. . Identifikasi Proses Pergerakan Massa Tanah Di Desa Rumengkor Kecamatan Tombulu. Manado: Unsrat.
[11] Muhammad Nursa’ban. 2010. Identifikasi Kerentanan dan Sebaran Longsor Lahan sebagai Upaya Mitigasi Bencana di Kecamatan Bener Kabupaten Purworejo. Yogyakarta. Universitas Negeri Yogyakarta. Vol 10, No 2
[12] Zakaria, Z. 2009. Analisis Kestabilan Lereng Tanah. Bandung: Universitas Padjadjaran
[13] Nandi. 2010. Geologi Lingkungan. Handouts. Bandung: Jurusan Pendidikan Geografi Fakultas Pendidikan Ilmu Sosial UPI.
[14] Telford, W.M. Geldart, L.P, Sheriff R.E and Keys, D.A. (1990). Applied Geophysics. USA: Cambridge University Press.
[15] Loke, M. H. 2000. Electrical Imaging Surveys forEnvironmental and Engineering Students. Geotomo Software Malaysia. Diunduh pada 13 November 2018.
[16] Yunus levent ekinci and alper demirci. 2008. A damped least-squares inversion program for the interpretation schlumberger sounding curves. Journal of applied sciences 8 (22):4070-4078,2008
[17] Akham dan Nofi, Y, S. 2013. Analisis Struktur Batuan dengan Metode Inversi Smoothness-Constrained Least-Squares Data Geolistrik Konfigurasi Schlumberger di Universitas Negeri Padang Kampus Air Tawar. Prosiding Semirata FMIPA Universitas Lampung. Hal 1-6
[18] Akham. (2004). “Existence of Spring in Batulimbak Village Simawang Kecamatan Rambatan Kabupaten Tanahdatar”. Jurnal Prosidin Seminar PPD Forum HEDS 2004 Bidang MIPA. Hal 593-608
[19] P. K. Bhattacharya and H. P. Patra. 1968. Directcurrent Geoelectric Sounding Principles and Interpretation. Department of Geology and Geophysics, Indian Institute of Technology, Kharagpur, West Bengal, India
[20] A.C. Ekwe, N.N. Onu and K.M.Onuoha. 2006. Estimation of Aquifer Hydraulic Characteristics from Electrical Sounding Data: the Case of Middle Imo River Basin Aquifers, South- Eastern Nigeria. Journal of Spatial Hydrology Vol.6, No.2, Fall 2006
[21] Reynolds, J.M. 1997. An Introduction to Applied and Environmental Geophysics. New York: Jhon Geophyscin Hidrogeological and Wiley and Sons Ltd.
[22] Gerhard Pratt. 2005. Applied Geophysics (Geology 319 / 829). Department of Geological Sciences and Geological Engineering, Queen's University
[23] El-Arabi Hendi Shendi. 2008. Electrical Prospecting Methods. Suez Canal University Faculty of Science Department of Geology
[24] Antonio Carlos Martins, Vagner Elis, Giorgio de Tomi, Jorge Bettencourt and Tatiane Marin. 2015. Resistivity and Induced Polarization to Support Morphological Modeling in Limestone Mining. Geofísica Internacional (2016) 55-4: 227-238
[25] Kementrian Sumber Daya Mineral. Tanggapan Bencana Gerakan Tanah. 2017. Padang.
[26] Akham, Amir Harman, Putra, Amali. 2017. Optimize of Least-Square Inverse Constrain Method of Geoelectrical Resistivity Wenner-Schlumberger For Investigation Rock Structures in Malalak Districts of Agam West Sumatra. Fakultas Teknik, Universitas Negeri Padang. 4th International Conference on Technical and Vocation Education and Training Padang : November 9-11, 2017
[27] Nizamullah, Akham, Syafriani. 2018. Struktur Batuan Pascalongsor Menggunakan Metoda Geolistrik Tahanan Jenis Konfigurasi Wenner. Pillar of Physics, Vol. 11, No 1, Maret 2018, 25-32