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Implementation of least-square constrain inversion method of geoelectrical resistivity data Wenner-Schlumberger for investigation the characteristics of landslide

Akmam^{1,*}, H Amir¹, A Putra¹, R Anshari¹ and N Jalinus²

¹ Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Negeri Padang, Jl. Prof Hamka, Padang 25131, Indonesia ²Technology and Vocational Education Faculty of Engineering, Universitas Negeri Padang, Jl. Prof Hamka, Padang 25131, Indonesia

*akmam_db@fmipa.unp.ac.id

Abstract. Parameters that used to find out how landslides occur and how much the risk of disasters due to landslides is the characteristics of the slide surface. There are many studies conducted using the Geoelectric method which uses single configuration electrodes to assess landslides. Conversely, The results of previous studies have not been generally accepted. This condition is caused by each study area having unique and very complex conditions. In addition, the results of interpretation with inversion methods are not unique and bivalent. Nevertheless, inversion methods are used to interpret the Geoelectric data. In this research, we implementation of Least-Square constrain Geoelectrical resistivity that the data are measured through Wenner-Schlumberger configurations. The characteristic of landslide depends on, such as the type of rock, the slide surface, the depth and the slope angle of the landslide. Accordingly, we implementation of Least-Square Inversion Constrain Geoelectrical resistivity data Wenner-Schlumberger configurations to determine the characteristic of landslide. Data obtained through Geoelectrical exploration using with an automatic resistivity meter. The result, the rock structure in Malalak of Agam consists of clay, sandstone, Andesite, and Limestone and Dolomite. The depth and the slope angle of the slide surface of the active landslide are 43 degrees and 23 meters. Implementation this research can be used to develop mitigation of landslide deserter.

1. Introduction

West Sumatra which located on Semangko fault that have a slope of more than 30 degrees is a province have nature and beautiful panorama, but prone to earthquake and landslide disaster. Landslide can cause damage to the structure of rocks, infrastructure, plantation, animal and the human life. Therefore, landslide is a natural disaster that has a wide impact. Landslide at some point area of Lima Puluh Koto, 6 people died and 2 people seriously injured in this disaster. The Center for Volcanology and Geological Hazard Mitigation of Indonesia (PVMBG) inform that 144 sub-districts in 16 districts which are predicted to have medium to high landslide potential[1],[2]. Therefore, this problem needs to get the attention and scientific

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study the extent to which the landslide re-occur and how the distribution of rock point prone to landslides, as a preliminary study of the landslide disaster mitigation.

Landslides are complex natural phenomenon that usually occurs, such as near mountains, hills and bays [3]. Generally, soil coasting, rock falling, and debris sliding that move on the sliding surface are recognized as typical landslides, which usually start on the slope and eventually fall into the water bodies such as bays [4]. Considering the deformation of the sliding block, landslides can be recognized as non-deformable landslides or deformable landslides, while based on the initial sliding position, landslides can also be classified as submerged landslides and unsubmerged landslides. Landslide caused much loss of life and infrastructure [5]. Few previous studies have paid attention to systematic research of the landslides based on the combination of different conditions that reflects most of the nature landslide types. Hence, over the recent centuries, researchers have made continuous efforts to further understanding of the landslides and minimize the damaging impacts of the vast affected areas.

The quantity of damage on landslide are depend on the volume and speed of the landslide on the volume and speed of the landslide. Volume landslide depends on the depth of the sliding surface, while the landslide speed depends on the angle of the sliding surface the landslide. The study on landslide is important as the initial assessment of the landslide disaster mitigation. Boundaries between rock weathering or soil that was eroded with the impermeable rocks (the hard rock beneath which acts as a foundation) is called sliding surface of the landslide. The geophysical techniques which are intensively used for the investigation of the deep and shallow structure of the subsurface is the Geolectrical resistivity method. Accordingly, by introducing the electric current directly into the ground through a pair of current electrodes, the difference of the resulting voltage can be measured between the other pair of potential electrodes, the apparent resistivity of the subsurface can be calculated in this way in order to get the resistivity variation with depth.

Increasing the depth of the penetration can be carried out by enlarging the distance between the current electrodes from a small distance in the beginning to larger distances at the end of the array. An electrode array is a configuration of electrodes used for measuring either current or voltage. Therefore, the true resistivity of the subsurface can be estimated based on measurements at the earth's surface. Some electrode arrays can be used to provide the structure of subsurface such as Wenner, Shlumberger, Dipole-dipole and square. The Wenner array is commonly used in profiling for lateral exploration of the ground, like defining horizontal layers. The logistic advantage of using the Wenner array when profiling is you only have to move four electrodes for each new measurement along the line. Detection of horizontal changes of resistivity is achieved by moving the four electrodes across the surface while maintaining constant electrode separation. This method is called profiling or sometimes electrical trenching. Because all electrodes are moved for each reading, this method can be more susceptible to near-surface, lateral variations in resistivity. Consequently, the near-surface lateral variations could potentially be misinterpreted in terms of depth variations in resistivity.

The Schlumberger electrode array is at an advantage, since, for most measurements, only the current electrodes needs to be moved. Vertical electrical sounding (VES) using the Schlumberger array provides better resolution, and take less time to deploy than the Wenner array. The Schlumberger array is also used for mapping or profiling for lateral resistivity changes. Because the potential electrodes remain in fixed locations, the effects of near-surface lateral variations in resistivity are reduced, but interpretations based on DC soundings will be limited to simple, horizontally layered structures. However, it is possible to get a picture of the subsurface in terms of resistivity for finding the best-grounded location using methods like electrical resistivity imaging (ERI) that are used the combination electrode arrays such as Wenner-Schlumberger array. The ERI method uses the same measurement, but in significantly more automated geometries to extend the method of measurement. So, it produces a more accurate and complete solution for the same amount of field effort and cost

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The relationship between the apparent resistivity data and the layer parameters is expressed by an integral equation. The very well-known expression of the computation of a forward response to Schlumberger electrode configuration (ρ_a) over an earth model consisting of homogeneous and isotropic layers is related to the kernel function through the Hankel integral and can be formulated as follows [27].

$$\rho_a = \delta^2 \int_0^\infty T(\lambda) J_1(\lambda \delta) \lambda d\lambda \tag{1}$$

where, δ is half the current electrode spacing such as Wenner-Schlumberger configuration, J1 denotes the first-order Bessel function of the first kind and λ denotes the integral variable. The resistivity transform function, T(λ), is given by the recurrence relationship as follows [27];

$$T_{i}(\lambda) = \frac{T_{i+1} + \rho_{i} \tanh(\lambda \mathbf{h}_{i})}{\left[1 + T_{i+1}(\lambda) \tanh(\lambda \mathbf{h}_{i} / \rho_{i})\right]} \text{ where } i = n-1, n-2, \dots, 1$$
(2)

where, *n* denotes the number of layers, ρ_i and h_i are the resistivity and thickness of the it layer, respectively. In this case, Equation (2) is used to compute the forward model response for DC resistivity sounding data.

The electrical resistivity method, which is one of the most widely practiced geophysical prospecting methods, has in the past usually been applied to civil and environmental areas because of new developments that allow it to image underground structures effectively such as shallow structure of the subsurface such as sliding surface of the landslide [6]. Resistivity of rock as the sliding surface around (100-200 Ohm.meter) [7,8]. The obsolete part of the Cretaceous Rock block is where the mass of wheels (slip plots) or triggers of collapsed rocks [9]. Zone with type resistance (<10 Ohm-m) at the depth (1100 - 1500) meters is a combination of Clays and Chinshui Shale is a fault zone [10]. The behavior of the electrical properties of the earth's subsurface (resistivity and thickness) were studied based on the electrical parameters (true resistivity distribution against the depth of the apparent resistivity data, essentially leads to solving the inverse problem. Further, relation between the observed "apparent resistivity" and the model parameters ("true resistivity" and "layer thickness") is non-linear.

The problem of distribution true resistivity to a depth based on the apparent resistivity data can be solved by mathematical and statistical techniques to obtain information about the physical properties of the subsurface of the earth ^[12]. Inverse modeling, in contrast starts with the data and a general principle or a model, in which the model parameters are estimated by minimizing the error set up between the data and model parameters [13]. Inversion method Least-Square 2-D can be used to interpret the subsurface resistivity structure [14,15] but the results of inversion aren't having a smooth response. However, this concept causes students to experience misconceptions [30]. The depth of the sliding surface can be predicted by using the least squares inversion constrain method of Geoelectric Resistivity. According to the above, the objective of this research was to implementation of Least-Square Constrain Inversion method of Geoelectrical Resistivity data Wenner-Schlumberger for investigation the characteristic of landslides in Malalak districts Agam West Sumatra. Therefore, the characteristic of the landslide was studied based on rock structure, the slope angle and the depth of the sliding surface of landslide. This is undertaken because Malalak districts of Agam West Sumatra that passed by highway Padang and Bukittingi is a frequent area of landslide. Furthermore, the frequency of the landslide depends on the type of rock and the angle of the slope

2. Metodology

This research is an explorative research. Data are interpreted by the least-squares smoothness-constrained inversion method. Resistivity data are used to obtain the slope and depth of the sliding surface area in the potentially landslide area. Therefore, data that results of interpretation are used to estimate the distribution of potentially landslide disaster areas in Malalak Agam West Sumatra. Measurement of resistivity data was done in the landslide area at coordinates (00.22.488 S, 100.16.593 E) - (00.25,496 S, 100,17,214 E). The location measurement such as Figure 1.



Figure 1. Measurement Locations in Kecamatan Malalak Agam West Sumatra[16].

The main equipment used to obtain apparent resistivity is the multichannel Automatic Resistvity System GF Instrument (ARES) with the Ares-G4 model specification of Cheko production, belonging to the FMIPA UNP Padang. The arrangement of electrode array in the Wenner-Schlumberger configuration is shown in Figure 2.



Figure 2. Configuration of Wenner- Schulamberger configuration electrode.

Therefore, the apparent resistivity of measurement is calculated by the equation:

$$\rho_a = n(n+1)\pi a \frac{\Delta V}{I} \tag{3}$$

The apparent resistivity data are interpreted using a Least-Square inversion in order to obtain a 2D resistivity cross section. Furthermore, the data are interpreted using a weighted nonlinear inversion method starting from the smallest squares inversion which is replicated with the added weight [17] such as Equation (4)

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$$m_{n+1} = m_n + [J_n^T W_e J_n]^{-1} J_n^T W_e (d - g(m_n))$$
(4)

In this case, the least-linear linear inversion equation with damping factor

$$\Delta m = \left[G^T G + \varepsilon^2 \underline{W} \right]^{-1} G^T \Delta d \tag{5}$$

where Δm is the vector of the correction parameter, Δd is the data difference vector, G Jacobian matrix containing the partial differential data to the model parameter and ε is called the correction factor. The result of interpreted are displayed on the 2D cross-section of true resistivity. Based on the obtained 2D cross-section, it knows that the location where the layer has the contrast, true resistivity value and the type of rock or mineral on the sub-surface where the landslide will be occurs.

The resistivity value that was obtained from the processed data was compere with resistivity of rock (material) on a resistivity reference in the table and the geological condition of site. Furthermore, characteristics of the landslide such as the slop of the sliding surface and depth of the sliding surface of the landslide in West Sumatera also can be estimated. The sliding surface of the landslide is identified with two layers of rock that have contrast resistivity [18,19,20,21]. The sliding surface on landslide usually consists of a solid hard rock layer covered by a layer of soft and groundwater [16]. So, Structure of rock as the sliding surface of the landslide can be seen from the value of resistivity of rock.

3. Results and Discussions

Based on, the objective this research that was to implementation of Least-Square Constrain Inversion method of Geoelectrical Resistivity data Wenner-Schlumberger for investigation the characteristic of landslide in Malalak districts Agam West Sumatra. For this reason, at follow we will be explained interpretation of Geoelectric data in two locations each two-track measurement.

3.1 The First Location Measurement.

The First measurement was undertaken (00'25.488 S,100'16,412', altutide 1182 meter) to (00'25.488'S,100'16,412'E, altitude 1300 meters). Characteristics of the sliding surface at (00'22.259'S, 100'17,300' E) to (00'25.488' S, 100'16,412', 100'16,318' E) are divided into two sections such as (00'22.259'S,100'17,300' E, altitude 1300 meters) to (00'25.488 S,100'16,412', altitude 1299 meters) and 00'22.705 S,100'16,318', altutide 1299 meters) to (00'25.488 S,100'16,412', altitude 1182 meter). The 2-D cross-section resistivity in the first location as shown in Figure 3.



Figure 3. The 2-D cross section of the sliding surface (00'22.259 S,100'17,300', altitude 1300 meters) to (00'25.488 S,100'16,412', altitude 1299 meters)



Figure 4. the 2-D cross section of the sliding surface at 00'22.705 S,100'16,318', altutide 1299 meters) to (00'25.488 S,100'16,412', altutide 1182 meters)

Figure 3 and Figure 4: shows that Clay (Resistivity = $3 \Omega m - 30$ Ohm.meter) are found between the Andesite rocks (Resistivity = $481 \Omega m - 3267 \Omega m [14,15]$. This rock layer structure shows that the sliding surface of the landslide is present in this position [22,23]. According to Figure 3 and Figure 4, the rock structure on the site can be made such as Table 1.

Table 1. The rock structure at (00'25.488 S,100'16,412', altutide 1182 meter) to (00'25.488'S,100'16,412'E, altitude 1300 meters)

Coordinat / altutide	Resistivity (Ωm)	Type of Rock	Depth of Sliding Surface	The Slop Sliding Surfce
(00'22.259'E S,100'17,300' E, 00'25.488 S,100'16,412', Altitude 1299 meters – 1300 meters	3 - 30 37 - 150 350 - 450 1228 - 400 4500 -	Marl Limestone, Sandstone Andesit Dolomit	15 meters	43.42 degree
00'22.705 S,100'16,318', (00'25.488 S,100'16,412', (1299 – 1182) meter	10 - 37 45-190 250 - 500 582 - 3267 3500 -	Marl Limestone, Sandstone Andesit Dolomit	15 meters	44.42 degree

The sliding surface is a factor that triggers landslides. The sliding surface is a surface where the material of a landslide moves on it. The boundary between the mass of moving material and the stationary is called the sliding surface. The sliding surface that the plane of presumption where the movement of the mudslides material. The material that moves above the sliding surface is called the landslide. Consequently, material movement is caused by disruption of soil stability or slope constituents. The comparison of the resistivity of two layers of rocks allows us to determine the critical landslide criterion level, where this condition contributes to developing a landslide early warning system using the Geoelectrical method [24]. A low resistivity zone that forms a sloping arch consisting of clay and has a high degree of saturation is a plane, as observed in the borehole [22]. The presence of clay reliefs above the Dolomite aid has led to the formation of the sliding surface [17],[25]. So, both the slope and the thickness of the sliding in this location are 44 degrees and 15 meters. Therefore, on the location of large avalanche possibility, if in this region washed down with a large volume.

Figure 4, shows that the rock resistivity anomalies in this area are estimated due to Andesit rocks. Andesit is a solid, hard and waterproof rock, but it's straightforward to be through weathering. Accordingly, the list of rock resistivity in [14],[15], the rock's structure in this track is Clay, Limestone Sandstone, Andesite, Dolomite. The sliding surface of this track has a slope of 44 degrees, with a layer thickness of 15 meters. Where, the effects of Clay on Dolomite's aid are as sliding surface surface ^{[7], [25].} This condition triggers in this area often landslide when heavy rains occur. Rock type resistance anomalies in this area are estimated due to Andesite rocks. The effect of Clay that is above the Andesite aids is a sliding surface. Dolomite and Andesite are solid and hard rocks that are waterproof but weathered. As well as the requirements of the first location, the plane at the second location has both the slope and the thickness of the sliding are 44 degree and 15 meters. Hence, this condition indicated that in this area is often landslide occurs, when washed down by heavy rain. Then, the type of sliding surface is translation.

3.2. The Second Location Measurement.

The second location measurement was 00'25.452 S,100'16,273'E, altitude 746 meters) to (00'22.250 S,100'17,214'E, altitude 1296 meters). Characteristics of the sliding surface at (00'25.452 S,100'16,273'E, altitude 746 meters) to (00'22.250 S,100'17,214'E, altitude 1296 meters) are divided into two sections such as (00'25.496 S, 100'16,357', altitude 834 meters) to (00'22.250 S,100'16,273'E, altitude 746 meters) and (00'22.250 S,100'16,357', altitude 1296 meters) to (00'22.385 S,100'16,273' E, altitude 1207 meters). The 2-D cross-section resistivity in the first location as shown in Figure 5 and Figure 6.



Accordingly, Figure 4a, there are Gravel (Resistivity = 297 Ω m - 1653 Ω m) found between Andesite rocks (Resistivity = 481 Ω m - 3267 Ω m, [14],[15] this location, there is no slip field because it does not comply with the requirements of landslide ([22],[23], [26],[27]. Based on Figure 4, the rock structure of the measurement site can be made in Table 2.

Table	2.	The	rock	structure	at	(00'25.488	S,100'16,412',	altutide	1182	meter)	to
(00'25.4	488'S	,100'1	6,412'E	E, altitude 1	300 1	neters)					

Coordinat / altutide	Resistivity	Type of	Depth of	The Slop
	(Ωm)	Rock	Sliding Surface	Sliding Surfce
(00'25.496 S, 100'16,357'E,	45-190	LimestoneG	Not present	
altitude 834 meters) to	250 - 1653	ravels		
(00'25.452 S,100'16,273' E,	1700 - 2978	Andesit		
altitude 746 meters	4500 -	Dolomit		
00'22.705 S.100'16.318'E.	5 – 75	Clav-Soil	15 meters	43.00degree
(00'25.488 S,100'16,412',	85-350	LimestoneSa		8
(1299 – 1182) meter	1330 - 3000	ndstone		
	3000	Dolomit		

Figure 5, show that Andesite rocks above Limestone are watertight coatings. Small-scale landslides may occur at this location because the hill at this location is quite steep. Moreover, Mass that moves during landslides at this location is estimated to be Clay and soil humus.

Moreover, Figure 6, also shows that Clay (resistivity = $10 \Omega m - 30 \Omega m$) is found between the Andesite rocks (resistivity = $481 \Omega m - 3267 \Omega m$) [7,8]. Such a layer structure indicates the existence of the surface of the landslide [19,20]. The presence of Clay's aid over Dolomite's aid causes the surface of the slip-covered ground [8,28]. The surface of the slope of this location has a slope of 43 degrees, with a layer thickness of 15 meters. The type of surface of the landslide slip in this location is translation. At the location of a large landslide opportunity, if in this region washed down with a large volume. The large-scale landslide in this first location occurs at this point in November 2016. The rock types in this path are Clay-mixed Soil (resistivity 5 Ωm to 75 Ωm), Limestone (resistivity 85 Ωm to 350 Ωm), Sandstone (resistivity 360 Ωm to 1000 Ωm), Gravel (resistivity 1050 Ωm up to 1320 Ωm) and Dolomite (resistivity 1330 Ωm up to 3000 Ωm), and Andesite (resistivity more than 3000 Ωm). Therefore, the effect of Clay on Dolomite's aid is a plot of a landslide [29]. That is what triggers this area often landslides, in case of rain with a high volume. So, landslides with large volumes are expected to occur rarely at this location.

4. Conclusions and Implementation

The rock structure in the Malalak Agam district of West Sumatra is dominated by Marl, Limestone, Sandstone, Andesite and Dolomite. The anomaly of the two-dimensional cross-section is caused by Andesite and Dolomite igneous rocks. Then, the slope of the landslide is found at the coordinates (00'22.259 S, 100'17,300', 1300 meters above sea level up to (00'25.488 S, 100'16,412', 1209 meters altitude). The slope of the field of the slip is 44 degrees, with a depth of 15 meters. Next, The slope of the landslide at the coordinates (00'22.250 S, 100'17,214 ', the height of 1296 meters above sea level until 00'22.385 S, 100'17,206', the height of 1207 meters above sea level. the slide of the landslide on this track is 43 degrees to a depth of 13 meters.Location area of the landslide at coordinates (00'22.705 S, 100'16,318', 1299 meters above sea level up to 00'25.488 S, 100'16,412', 1182 meters dpl, with a slope angle of 44 degrees with a depth of 15 meters.The sounding coordinates 00'22.491S, 100'16,880 ', altitude of 1203 meters above sea level until 00'22.514S, 100'16,738', altitude 1080 meters dpl dipped slope 39 degrees, with a depth of 17.5 meters. Implimentation is the civilian side, making a porous soil dam to be able to withstand large volumes of landslides at 00'22.259 S, 100'17,300 ') up to (00'25.488 S, 100'16,412', 100'16,318 '). Moreover, related to this area is widely used as leafwood plantations, harvest should be done without killing the main tree, so the roots of trees still grow in this location.

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