Using the Schlumberger configuration resistivity geoelectric method to analyze the characteristics of slip surface at Solok

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Abstract. Landslides are the frequent disaster in the wavy topography zone, such as Sungai Lasi Solok. Landslide disaster was difficult to predict. Based on these conditions, we need to do the research. The aims of the research were to find out the characteristic of landslide slip surface at Sungai Lasi Solok base on Geoelectric Data. Data were collected by Automatic Resistivity Multi-electrode using Resistivity Geoelectric Method with Schlumberger configuration. The interpretation of the Geoelectric data was used Two Dimensions Least-Square Inversion Method. Characteristics of the landslide such as were estimated by Trigonometry theory in order to get both the angle and the depth of landslide slip surface. The results of the research are both the angle and the depth of the slip surface is 40 degrees and 14 meters.

1. Introduction

Landslides are a very dangerous and deadly disaster. Landslides occurred in Indonesia usually take place on the steep topography with a slope angle of 15–45°[1]. Landslides are the frequent disasters in wavy topographic zones, such as the Sungai Lasi Solok. Sungai Lasi is an area that has wavy topography and has a high potential for landslides. One of the causes of landslides is that there is the rock from the weathering process, moving through a field called the slip surface. Landslide can cause damage to the structure of rocks, infrastructure, plantation, animal, and the human life[2]. Therefore, landslide is a natural disaster that has a wide impact. Based on this condition, the research to analyze the slip surface was landslide factor impact is needed to do.

Landslide is a natural process of the earth's surface degradation, occurring when there are mass displacements of rock, debris, or soil material that slides along certain slope areas[3],[4]. Landslides are movements of land (including rocks), sediment layers haven't been consolidated or soil layers on the slopes with sloping to very steep slope towards the slope as a result of exceeding the slope endurance balance[5]. Landslide is a natural phenomenon caused by the influence of the slip surface or shear surface[6]. Thus, lands that have landslides move above the slope with a certain slope.

The slip surface is dense and has a low porosity which is capable of acting as a layer where weathering soil undergoes movement. Water that penetrates into the depths of the slip, where it forms a layer that facilitates the movement of rock material, is one of the primary causes for the formation or further development of a landslide[7]. Rocks that act as skid fields have a type of resistivity value that contrasts with the surrounding layers. The slip surface consists of a waterproof layer and a weathering layer. Geoelectrically, the slip surface can be seen in rocks that have a rock resistance value of 100-200Ωm[8].
The slip surface is a boundary between the moving and silent material period [9]. The slip surface has characteristics, namely the surface of rock lining in the form of a contact area located between the cover land with bedrock, between cracked rocks with strong rocks, and between rocks that can pass water with rocks that cannot pass water or are impermeable water [10]. The characteristics are geoelectric sliding surface is the presence of a layer that has a value large enough resistivity between two adjacent layers. Layer with low resistivity was flanked by two layers which have a high resistivity [11]. So the slip surface is a field where the material that landslides move. Material movement is caused by the disruption of the soil or slope stability constituent rocks.

The characteristics of the slip surface are there too about the form of depth and slope angle which means the level of landslide hazard from a measurement location. Likewise such as the angle. The landslide has a class about a depth too, such as deep and shallow. It was important for the research cause will give a notice about how much a hazard landslide status. The slope will be landslide when there some balance disturbances in the forces acting on the slope, where the driving force is greater than the retaining force. The steep slope has a driving force greater than the retaining force, the smaller the stability. Thus, the active landslide always moves on the surface at all times or throughout the season, while the old landslide can re-activate as long as there are trigger factors for landslides [12].

The characteristics of the slip surface are unknown in the study area, so they need some method to find out. One method that can be used is the Geoelectric Method. One of the geoelectric methods frequently used in the measurement of the flow of electricity and to study the state of the subsurface geology is the resistivity method. The resistivity is one possessed physical properties of rocks, namely, the ability to pass electrical current if the rock was increasingly difficult to pass by an electric current, the greater the rock resistivity values. The resistivity of a material is a measure of how well the material retards the flow of electrical current. Resistivities vary tremendously from one material to another. Due to this great variation, measuring the resistivity of an unknown material has the potential for being very useful in identifying that material, given little further information [13]. The resistivity value can be seen in Table 1.

| Rocks             | Resistivity Values (Ωm) |
|-------------------|-------------------------|
| Granite           | 3x10^2–10^6            |
| Andesite          | 4.5x10^4 (wet)–1.7x10^2 (dry) |
| Tuffs             | 2x10^3 (wet)–10^5 (dry) |
| Consolidated shale| 20–2x10^3              |
| Sandstones        | 1–6.4x10^8             |
| Limestone         | 50–10^7                |
| Dolomite          | 3.5x10^2–5x10^3        |
| Clays             | 1–100                  |
| Alluvium and Sand | 10–800                 |

Resistivity can be used to estimate subsurface geological conditions by utilizing the properties of electrical current in the rock with regard to earth as a conductor [14], [15]. Rock type and other parameters listed below the earth's surface can be detected by an electric current into the earth. An overview of the propagation of electrical currents beneath the earth's surface can be seen in Figure 1.
Figure 1. Point source of current at the surface of a homogeneous medium[14]

Figure 1 shows the flow of current from an electrode is able to flow in all directions by forming an equipotential half-sphere below the surface of the earth which has a direction perpendicular to the current and electric field, assuming the earth is homogeneous and isotropic by electric[13]. The current does not flow into the air because the value of the type of resistance possessed by the air is very large. The earth is subsurface which is layered which has different types of resistivity values between layers[11]. Apparent resistivity value can be calculated using Equation (1).

\[ \rho \alpha = k \frac{V}{I} \quad (1) \]

\( k \) is a geometry factor whose magnitude depends on the type of configuration used. The configuration used is the Schlumberger array. Schlumberger is a configuration that has a larger electrode current than the potential electrode spacing. The arrangement of the Schlumberger array can be seen in Figure 2.

Figure 2. Schlumberger Array

Figure 2 was shown the equation with description an A is an electrode of positive current, B is an electrode of negative current, M is an electrode of positive potential, and N is an electrode of negative potential. Geometry factor can be calculated using Equation (2).

\[ k = 2\pi \left( \frac{1}{r_1} - \frac{1}{r_2} \right) - \left( \frac{1}{r_3} - \frac{1}{r_4} \right)^{-1} \quad (2) \]

\( r_n \) (n = 1,2,3,4) Were an inter-electrode spacing owned. \( r_1 \) Was distance A with M, \( r_2 \) M with B, \( r_3 \) N with A, and \( r_4 \) N with B. So, geometry factor of Schlumberger array can be calculated by Equation (3).

\[ k = \pi \frac{a^2}{b} \left( 1 - \frac{b^2}{4a^2} \right) \]

Interpretation of data using the Least-Square Smoothness Constraint Inversion method. Regression linear is exemplified in the data (d) that varies linearly with depth (z) that can be expressed in the equation \( d = m_1 + m_2z \)[16]. Curve fitting can be seen in Figure 3.
Inversion method Least-Square 2-D can be used to interpret of the subsurface resistivity structure\[14,\[15,\[17]. The Least-Square method in Geoelectric is an inversion method that tends to produce a model with variations value based on the data obtained by minimizing the difference in deviation in type resistivity values as measured by the calculated ones. The estimation of true resistivity distribution against depth from the apparent resistivity data essentially lead to solving the inverse problem\[11]. One famous method is Smoothness Constraint which is formulated according to Equation (4).

\[
(J^T J + \mu F)d = J^T g - \mu Fr
\] (4)

The Inversion method is able to minimize the difference between field data and data predicted through 2D subsurface forms\[18,\[19]. In inversion process, the number of iterations and error interpretation results generally depend on the value of the initial guess\[20]. The results of the interpretation produce a 2D cross-section with variations in the smooth resistivity value. So, the results of the interpretation will get better.

2. Methodology
This research is explorative research. Data was taken through measurement activities directly on the surface. By applying the Schlumberger Configuration Resistivity Geoelectric Method and using the ARES measuring instrument, the data was successfully obtained as many as 2 lines. Data are interpreted by the Least-Squares Smoothness-Constrain Inversion Method. Measurements are made by moving the current electrode to a cross section with fixed potential electrode spacing\[17]. Then the transfer of the potential electrode at the next space n is followed by the transfer of the current electrode along the next path to the measurement of the potential electrode at the last point on that path. Resistivity data are used to obtain the slope and depth of the sliding surface area in the potential landslides area. The measurement locations were in frame of Figure 4.

Figure 4. Measurement Location
Frist and second lines were on the same slope. The data was achieved has been processed to the data processing step. The steps to processing the data are as follows:

- Download data from ARES Multi-electrode by connecting it to Windows XP.
- Save data in *.dat file format.
- Enter topographic data into resistivity data to produce inversion using topography.
- Change the field data into model data using the Least-Square Smoothness Constraint Inversion method with the help of RES2DINV software to find out the actual resistance value and depth of the slip surface.
- Save the picture in BMP format for inversion image.
- Enter the data with the rocks resistivity values table based on references and the maps of geological conditions on the measurement area.
- Estimate the slope angle and slip surface of the two-dimensional cross-section of the processed product.

After processing, the data need to be estimated by comparing the results of interpretation with Tables 1 and geology condition. Based on this, it will be known two-dimensional sub-surface resistivity values and the depth. The inversion results in the form of a two-dimensional cross-section that has shown the relationship between the line's length and the depth. Then, an additional theory is needed to calculate the slope angle and slip surface, namely the Trigonometry theory. The two-dimensional cross-section has been produced shows the electrode spacing of 1.25 meter, it is obtained from the use of refinement interpolation techniques[27] that can be applied in inversion activities. This technique is regarded as a good action to produce results that are more accurate and neat. Then, it can be identified the depth and the angle of the slip surface to determine the potential of landslides.

3. Results and Discussions
Based on, the object of this research is to analyze the characteristics of landslides on Solok, such as the depth and the angle. For this reason, characteristics of the landslides can be identified on two lines. The results and discuss will be given by season.

3.1 The First Line Measurement
The first measurement was undertaken from Southeast to Northwest on 00°46.128’ S 100°44.409’ E altitude 487 meters above sea level until 00°46.053’ S 100°44.363’ E altitude 343 meters above sea level. The sounding is on 00°46.065’ S 100°44.362’ E altitude 416 meters above sea level. Figure 5 are the data interpretation of first line.

![Figure 5. a) 2-D Cross-Section on First Line without Topography](image-url)
Figure 5 shown the slip surface was marked with a dotted line. Located at a depth 13.5 meters at Figure 5 a) and has the angle of slope is 38.6° and the angle of slip surface is 39.16° can be seen at Figure 5 b). The type of rocks who would be a slip surface is a Clay[12],[21],[22],[23] with resistivity values were 45.4-174 Ωm[14],[10],[11],[8],[25],[26]. Sliding surface is the presence of a layer with low resistivity flanked by two layers which have a high resistivity[11]. Slip surface was located at altitudes 489-483 meters above sea level with the long are 25 meters.

Measuring activities carried out at the surface are known for each line on the side of the Sumatran-route which has an important role in terms of transportation and domestic needs. The northwest direction of the first line is opposite with the house where the sloping area has around 260 meters from the Sumatran-route with a steep slope and deep slip surface. Furthermore, we can see of the Figure 5 b) that there is a very steep fault and is able to drop the ground above it if it rains very heavily[2],[22]. To reduce the risk of landslides, the community should not build buildings on slopes or just below the track slope[23]. In addition to, it is necessary to make landslide retaining walls that may occur.

3.2 The Second Line Measurement
The second measurement was undertaken from northeast to southwest on 00°44.701’ S 100°45.261’ E altitude 458 meters above sea level until 00°44.785’ S 100°44.153’ E altitude 291 meters above sea level. The sounding is on 00°44.735’ S 100°44.221’ E altitude 390 meters above sea level. Figure 6 are the data interpretation of second line.

![Figure 5. b) 2-D Cross-Section on First Line with Topography](image)

![Figure 6. a) 2-D Cross-Section on Second Line without Topography](image)
Figure 6. b) 2-D Cross-Section on Second Line with Topography

Figure 6 shown the slip surface was marked with a dotted line. Located at a depth 15 meters at Figure 6 a) and has the angle of slope is 53.13° and the angle of slip surface is 41.81° can be seen at Figure 6 b). The type of rocks who would be a slip surface is a Clay[12],[21],[22],[23] with resistivity values were 51.7-204 Ωm[14],[10],[11],[8],[25],[26]. Sliding surface is the presence of a layer with low resistivity flanked by two layers which have a high resistivity[11]. Slip surface was located at altitudes 326-305 meters above sea level with the long are 60 meters.

Measuring activities carried out at the surface are known for each line on the side of the Sumatran-route which has an important role in terms of transportation and domestic needs. Southwest from the second track there is a pillows shop where the sale of pillows, cooking grinders, and workshops where the location of the slip surface is 35 meters from the Sumatran-route with steep slopes and deep slip surface. To reduce the risk of landslides, the community should not build buildings on slopes or just below the track slope[23]. In addition to, this would be very dangerous for residents[24] and road users if landslide retaining walls are not built, given the distance from the slip surface which is close to the road and located at a deep depth.

4. Conclusion
The conclusions of this research were for the first line, slip surface has on the depth 13.5 m and the angle of slip surface is 39.16°. The slip surface was located on 00°46.122’ S and 100°44.401’ E altitudes 489 meters above sea level until 00°46.115’ S and 100°44.396’ E altitudes 483 meters above sea level with the long of slips surface were 25m and it is suspected that the slip surface was a rotational slides. Furthermore, the second line has a slip surface on the depth 15 m and the angle of slip surface is 41.81°. The slip surface was located on 00°44.763’ S and 100°44.187’ E altitudes 326 meters above sea level until 00°44.777’ S and 100°44.166’ E altitudes 305 meters above sea level with the long of the slips surface were 60 meters and it is suspected that the slip surface was translational slides. Based on this condition, the slope which on the location of this research could be found have a large potential of landslides and less about safety for residents to live in.

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