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Slope Stability Analysis for Landslides Natural Disaster Mitigation by Means of Geoelectrical Resistivity Data in Gedangan of South Malang, East Java, Indonesia

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Abstract. A study entitled slope stability analysis for landslides natural disaster mitigation by means of geoelectrical resistivity data in Gedangan of South Malang, East Java, Indonesia has been conducted. This study aims to obtain the physical parameters that cause landslides that occur in Gedangan village, Gedangan sub-district, Malang district. The research was conducted using geoelectrical resistivity method by applying a vertical electrical sounding (VES) model and Wenner-Schlumberger configuration. From the data as a result of field data acquisition, processing and interpretation are carried out to obtain landslide parameters. By merging each vertical electrical sounding (VES) point, physical parameters will be obtained as the basis for local landslide analysis. The results of the cross-sectional line A (GED4-GED1-GED2) indicate the presence of an average slope surface or topography that is relatively parallel with the average slope sliding plane which is about 7° whereas line B (GED1-GED3-GED5) is around 15°. The average thickness of the overlying layer in the slip plane both on line A and line B is around 65m. The slope condition of the slip plane (angle and thickness of the layer) indicates an unstable condition. For stable conditions F> = 1.2, the maximum thickness of the cover layer at line A is 54 m while in line B is 8.2 m. For stable conditions F> = 1.5, the maximum thickness of the cover layer for line A is 25.5 m while in line B is 5.85 m. To overcome the landslide, the proposed solution was by doing a reduction/dredging of the cover layer or installation of the bored piles.

Keywords: Slope stability, landslides, natural disaster mitigation, geoelectrical resistivity

1. Introduction

South Malang is considered as an area with relatively diverse topography. This condition makes the tendency for landslides, collapsing roads, and flash floods in this region during the rainy season that causes many losses [1], [2]. Some of the consequences of that disaster include weathering that naturally due to time or age, changes in land function, which originated in the form of trees turned into rice fields, plantations, and even settlements that decreases the soil carrying capacity for slope and rainwater. While the various things that are thought to be the cause of the geological disaster include: unstable and greatly varies slope conditions, relatively sharp angles river bend, logging in the highland area, and heavy rainfall occur continuously for 2 (two) consecutive days, thus changing the condition of soil stability [3].

The research will be conducted that refer to the preliminary research in the form of the geological data interpretation results and outcrop that develops on the surface [4]. In this study, geophysical measurements will be carried out to obtain physical parameters as the basis of local landslide analysis using the geoelectrical resistivity method with Vertical Electrical Sounding (VES) configuration. By knowing the quantitative parameters of the landslide, the next thing is that event can be engineered in such a way so it no longer occurs and the land use can be planned in the concept of mitigation-based spatial plans. Thus, the next outlook is that land zoning must be reorganized, including road construction and civil buildings so that the safety and security factors of road users and residents will be improved.

Landslides are a geological event that indicates that slope instability has occurred or the structure has weathered. Landslide parameters include the slope of the landslide area, the type of rock between the landslide and cover layer, and the thickness of the overburden. Visual and geological interpretation only describes these parameters qualitatively, without knowing the depth parameters, subsurface structure, and lithology. Therefore, by referring to the qualitative results from the interpretation of the local geology, these parameters will be measured using the geoelectrical resistivity method with vertical electrical sounding (VES) configuration.

The study area is the location of a landslide event located in Sumbernanas hamlet, Gedangan village, Gedangan sub-district, Malang district. The landslide location which is also the location of this study located at coordinates 08°17'14.07"S and 112°38'34.61"E which is the initial location of the landslide material. Landslides are on the edge of the roadway, so the road has decreased partially at one point which resulted in the road cannot be passed by the vehicle. According to residents, landslides occurred during heavy rains on January 30, 2018. As a result of the landslide incident, the road depressed as deep as 2 m in the initial part of the landslide. In April 2018 there was another landslide, which caused an initial landslide to increase by 1 m resulting in sugar cane plantations damage located next to the landslide location. Landslides occur with the direction of the landslide starting point heading northwest at the point 8°17'10.52"S and 112°38'33.49"E.

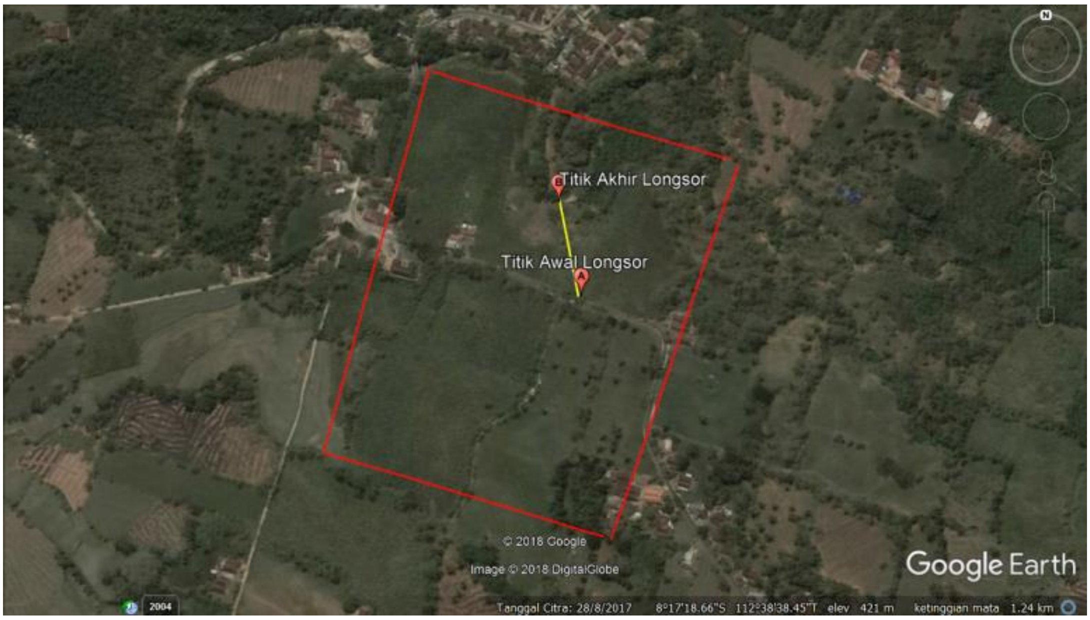

Figure 1. Landslide location/study area on Google Earth map.

At the landslide location, there is a river that is located 200 m from the initial location of the landslide. Landslides that occurred in April 2018 resulted in damage to the sugar cane plantations belonging to the residents and also resulted in the clogging of the river flow in the northwest of

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landslide location. This condition requires residents to work together to dig and get rid of mud deposits and soil that covers the river so that there is no blockage in the river. The landslide location has a geological landscape in the form of a sugar cane plantation which has an area of 100,000 m^2, where on the right and left the side of the main road that passes through the sugar cane plantations are residents' settlements. Figure 1 shows the location of the landslide.

2. Experimental

Resistivity measurement, in general, was done by injecting the current into the subsurface through two current electrodes (C1 and C2. See figure 2) and measuring the response of the potential difference caused to two potential electrodes (P1 and P2). From the data of current (I) and potential difference (V), then the value of apparent resistivity (ρa) can be obtained as in equation 1 [5]:

$$\rho_a = k\frac{V}{I} \quad (1)$$

k is a geometry factor that depends on the arrangement of the four electrodes mentioned earlier.

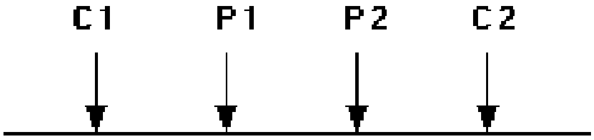

Figure 2. Four electrode arrangement to measure subsurface resistivity

The calculated resistivity value is not the actual subsurface resistivity value, but it is an apparent value which is the resistivity of the earth that is considered homogeneous and gives the same resistance value for the same electrode arrangement. The relationship between apparent resistivity and true resistivity is very complex [6], so computer assistance must be used to determine the true subsurface resistivity value which is required forward and inversion calculations.

The composition of the Wenner-Schlumberger configuration electrode is shown in figure 3. The spacing between electrodes is "a" which represent the total stretch of AB and the measurement point is denote with "c". The apparent resistivity equation of the Wenner-Schlumberger configuration written in equation 2.

$$\rho_a = \frac{\pi(AB/2)^2}{a}\frac{\Delta V}{I}(\Omega m) \quad (2)$$

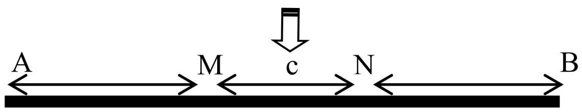

Figure 3. Wenner-schlumberger Electrode Configuration (Modified Schlumberger).

The composition of the Wenner-Schlumberger configuration electrode is a modified vertical electrical sounding (VES). Data processing can be done with the help of IPI2WIN, PROGRESS, and SURFER software. The research will be carried out on a minimum of 5 points vertical electrical sounding (VES) so that the method satisfies adequacy in interpolation. The primary of equipment used in the acquisition are OYO Mc Ohm geoelectrical resistivity set and its accessories, walkie talky for communication between technician-operator-technician, the global positioning system (GPS) for geographical positioning, and digital cameras for research documentation. The study was carried out by measuring vertical electrical sounding (VES) with the distribution of measuring points as shown in figure 4.

Obtained data from the acquisition are in the form of electric current (I), the potential difference (V), resistance (R), and the distance between electrodes (a and MN). These data cannot be analyzed or interpreted before the calculation is done to get the resistivity value. Therefore, it is necessary to process data using RES2DINV or curve matching (IP2WIN, PROGRESS) where the algorithm is based on the quasi-Newton method whose calculation is the approximation value of apparent resistivity partial derivative or curve matching data [7].

Figure 4. Measuring points distribution of geoelectrical resistivity on Google Earth

The calculated resistivity value is not the true resistivity value, but it is an apparent value which represents resistivity of the earth that is considered homogeneous and gives the same resistivity value for the same electrode arrangement at all depths within the measuring range of equipment.

Table 1 Coordinates of geoelectrical resistivity data acquisition in the research location.

NO	POINT	LAT (DEG)	LONG (DEG)	ALT (m)
1	GED1	-8.287372	112.642933	413
2	GED2	-8.287117	112.642594	413
3	GED3	-8.287286	112.642967	411
4	GED4	-8.287586	112.643333	420
5	GED5	-8.287158	112.642983	406

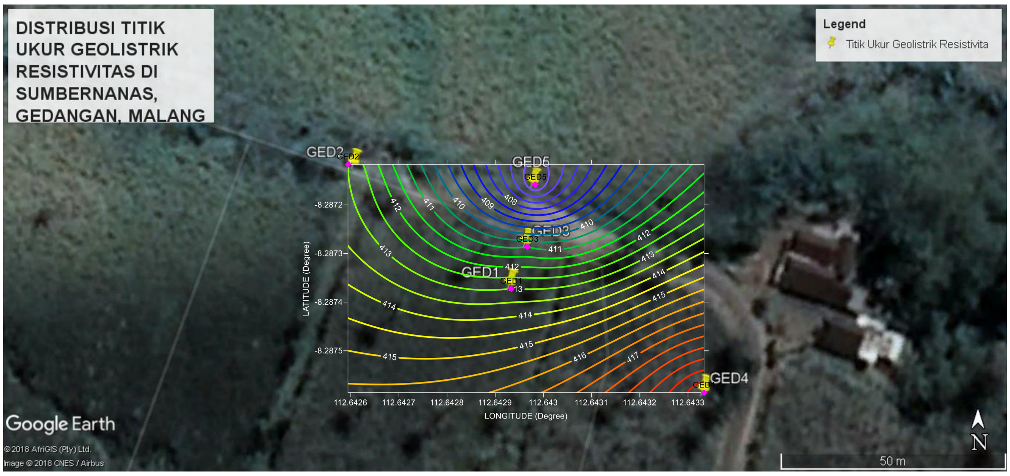

Figure 5. Distribution of geoelectrical resistivity measuring point and topographic contours in the research location overlapping on Google Earth

3. Results and Discussion

Processing and interpretation of 1-dimensional data were done in the form of vertical electrical sounding (VES). The processing and interpretation of 2-dimensional data were carried out by taking cross-sections along the GED2-GED1-GED4 geoelectrical measuring points for Line A, and GED1-GED3-GED5 for Line B. Images of Line A and Line B can be seen in figure 6 while the cross-section of Line A and Line B can be seen in figure 7 and figure 8. The terminology of resistivity conversion values to the local geology and aquifer can be seen in table 2.

Table 2. Terminology of resistivity conversion values to the local geology

RESISTIVITY	CLASS	COLOUR SYM.	LITHOLOGY/AQUIFER CLASS
$\rho<1$	0		Clay/Aquiclude
$1\leq\rho\leq100$	I		Alluvium/Good
$100<\rho\leq1000$	II		Sediment/Enough
$1000<\rho\leq3000$	III		Conglomerate/Less
$3000<\rho$	IV		Limestone/Aquiclude

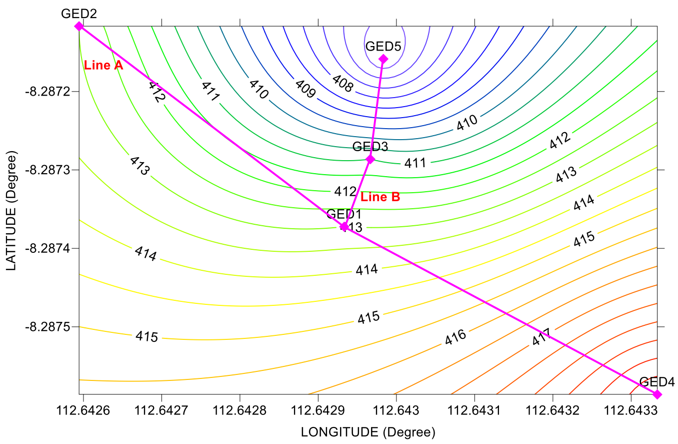

Figure 6. Cross section along the GED2-GED1-GED4 geoelectrical measuring points for Line A, and GED1-GED3-GED5 for Line B

IOP Conf. Series: Materials Science and Engineering **546** (2019) 022030 doi:10.1088/1757-899X/546/2/022030

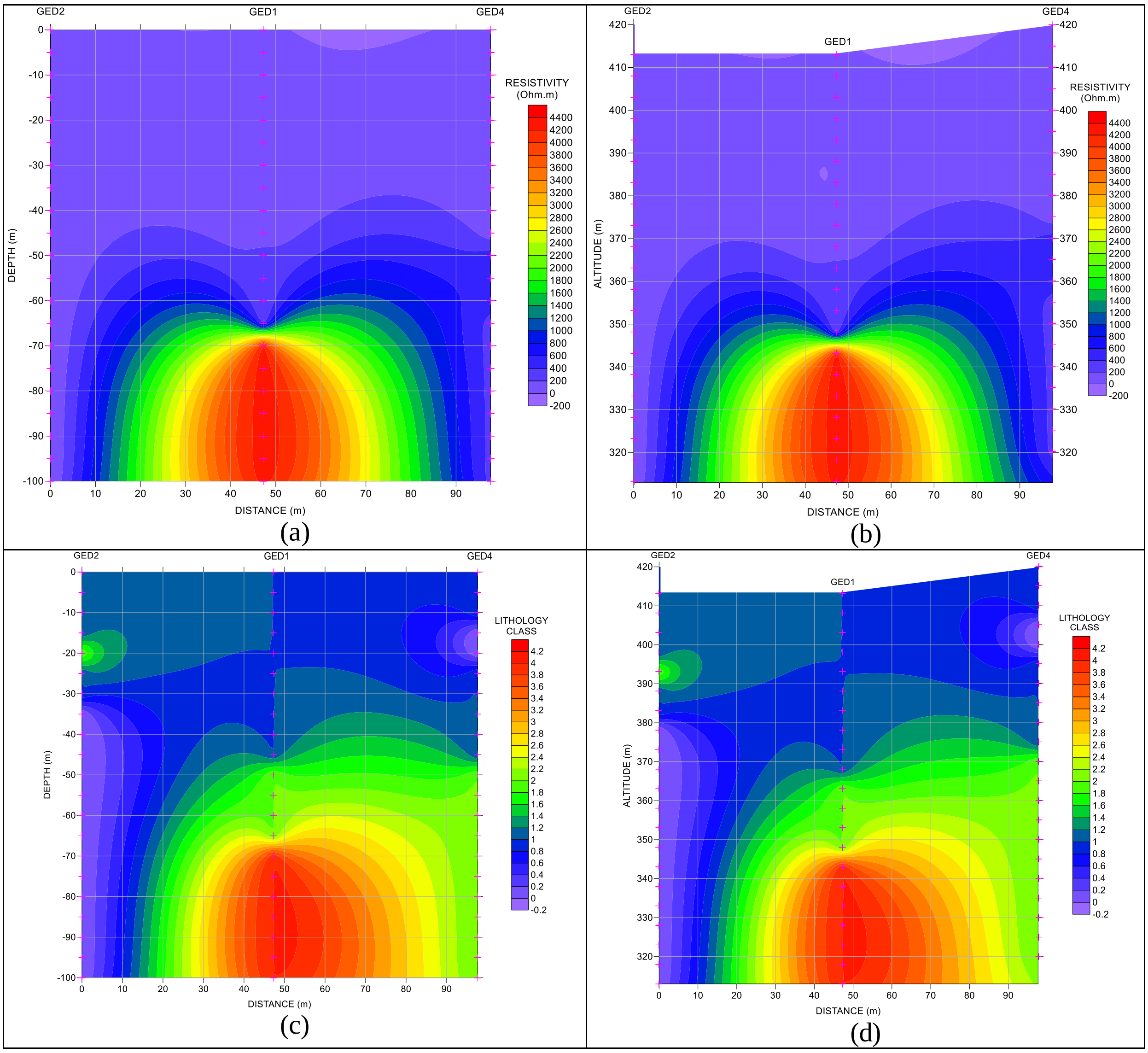

Figure 7. Cross section of Line A resistivity; (a) Resistivity value without topography, (b) Resistivity value with topography, (c) Lithology without topography, (d) Lithology with topography.

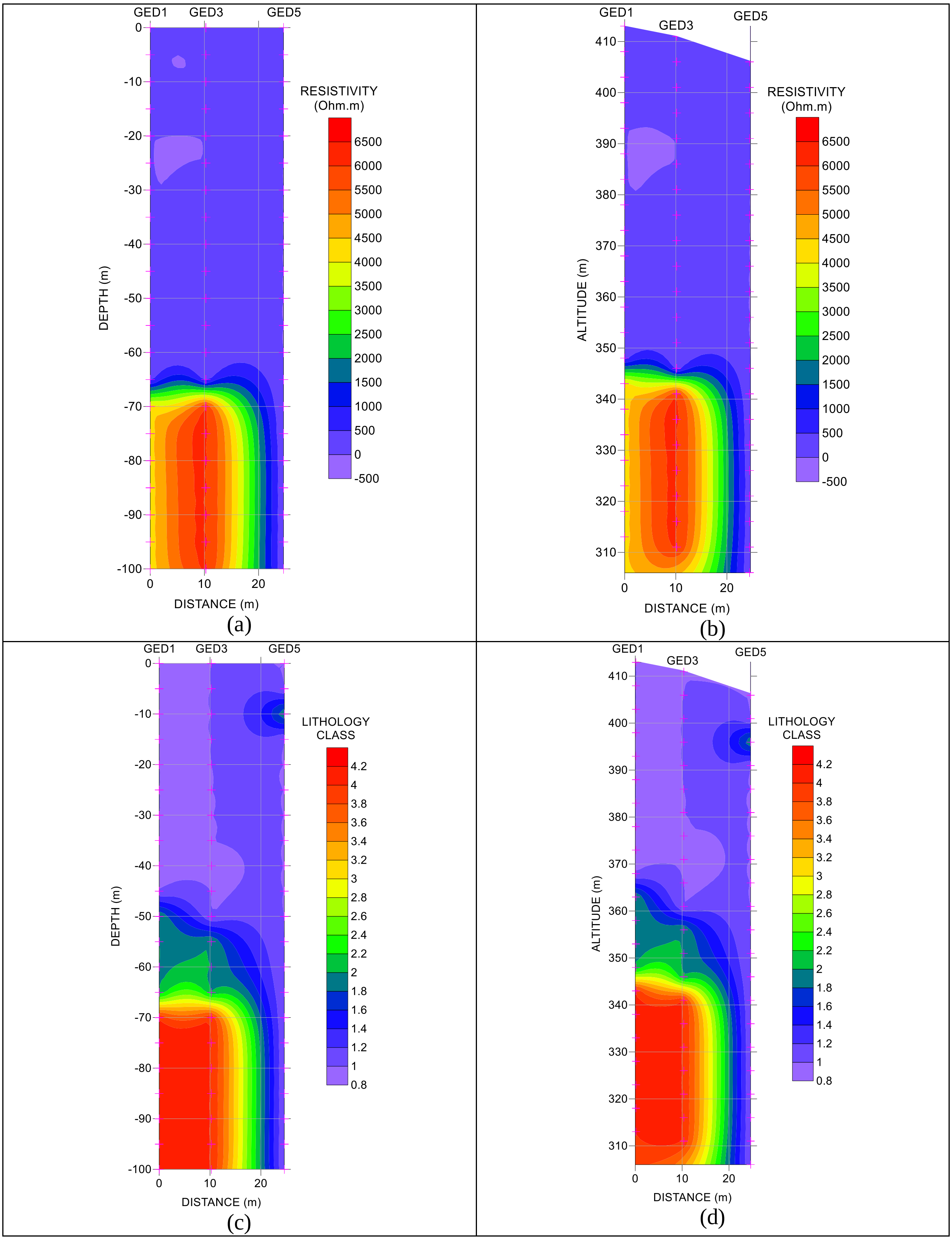

Figure 8. Cross section of Line B resistivity; (a) Resistivity value without topography, (b) Resistivity value with topography, (c) Lithology without topography, (d) Lithology with topography.

IOP Conf. Series: Materials Science and Engineering **546** (2019) 022030 doi:10.1088/1757-899X/546/2/022030

Line A, which connects GED4-GED1-GED2 measuring points, shows the presence of surface slope or topography which is approximately parallel to the slope of the slip plane indicated by the cross section of about 7°. Based on this same cross-section, it also shows that the average thickness of the overburden layer in the slip plane is around 65m. This large thickness becomes a heavy load for the slip plane, especially during the rainy season that the condition will increase the weight of the overburden because water fills between the spaces of the grain.

Whereas line B which correlates the measuring points GED1-GED3-GED5 also shows the presence of surface slope or topography which is relatively parallel to the slope of the slip plane indicated by the cross-section with a larger angle, which is around 15°. Based on the cross-section it also reveals that the average thickness of the overlying layer in the slip plane is comparatively the same as line A, which is about 65m. The thickness is quite large, and the greater slope angle on line B mean weight for the slip plane will increase, especially if in the rainy season because it will fill the gap between grain's space.

Calculations using the Universal Soil Loss Equation (USLE) provide a general estimation of the stability limit between the slope and thickness of the layers that pile up above the slip plane [8], [3], [9], [10], [11], [12], [13]. The calculation results are carried out for the stability limit $F \geq 1.2$ and also $F \geq 1.5$ as shown in table 3, table 4, and table 5, where: β is slope inclination angle in units of degrees, α is slip plane inclination angle in degrees, and F is a stability factor with the formula as can be seen in equation (3).

$$F=(c/(\gamma*H*\cos^2(\alpha)*tg\ \alpha)) + ((\gamma'*tg\ \varphi)/(\gamma*tg\ \alpha)) \quad (3)$$

Table 3. Slope stability calculation on the factual field condition

NO.	*CROSS SECTION*	β	α	H rerata (m)	F
1	A	7	7	65	1.16
2	B	15	15	65	0.53

Table 3 shows that line A has a stability factor (F) of 1.16 and line B has a stability factor (F) of 0.53. Both lines have a value that is far from the requirement value, which is $F \geq 1.2$ on land with standard loads or $F \geq 1.5$ on land with heavy loads. This shows that the ratio between the slope of the slip plane and the thickness of the cover layer is unbalanced.

Table 4. Slope stability calculation for $F \geq 1.2$.

No.	*CROSS SECTION*	β	α	H rerata (m)	F
1	A	7	7	54	1.20
2	B	15	15	8.2	1.20

Table 4 shows that line A has a stability factor (F) of 1.2 and line B also has a stability factor (F) of 1.2. Both lines have reached the ideal limit value of the stable requirement value, which is $F \geq 1.2$. That condition determines for slope angle of 7°, the maximum permissible thickness of the overlying layer is around 54 m for line A whereas for line B with a slope angle of 15° the maximum cover thickness allowed is around 8.2 m.

Table 5. Slope stability calculation for $F \geq 1.5$.

NO.	*CROSS SECTION*	β	α	H rerata (m)	F
1	A	7	7	25.5	1.50
2	B	15	15	5.85	1.50

Calculations are carried out using the following conditions:

F assumption for infinite slope with seepage	
Calculation of maximum weight with condition:	
cohesion (c) (kN/m^2)	18.75
angle of friction (φ) (derajat)	13
bulk unit weight (γ)(kN/m^3)	19.6
effective unit weight (γ')(kN/m^3)	9.79
stability factor (F)	1.2 and 1.5

Table 5 shows that line A has a stability factor (F) of 1.5 and line B also has a stability factor (F) of 1.5. These two lines have reached the ideal limit value from the standard value, which is F≥1.5. This condition shows with a slope angle of 7°, the maximum permissible thickness of the overlying layer is around 25.5m for line A whereas for line B with a slope angle of 15° the maximum permissible thickness of the cover layer is around 5.85 m.

Based on the stability figures, the efforts that must be made are:

1) Perform reduction/dredging of the cover layer corresponds to the stable thickness.

2) Install bored piles to a minimum depth of the slip plane of each location, especially on the location of the roadway.

4. Conclusion

From the research entitled Landslide Analysis in Gedangan village, Gedangan district, Malang Regency Based on Geoelectrical Resistivity Data, the following points can be concluded that he results of the cross section of line A (GED4-GED1-GED2) indicate the presence of average slope surface or topography which is relatively parallel to the slope of the slip plane average angle which is around 7° whereas line B (GED1-GED3-GED5) is around 15°. The average thickness of the overlay layer on the slip plane both on line A and line B is around 65 m. The slope condition (angle and thickness of the layer) of the slip plane indicates the field is unstable. For stable conditions F≥1.2 (standard load purposes), the maximum line A thickness is 54 m while line B is 8.2 m. For stable conditions F≥1.5 (heavy loads), the maximum line A thickness is 25.5 m while line B is 5.85 m. The recommendation to overcome the landslide problem so the disaster does not happen again in the future is by reducing/dredging of the overlay layer or installing bored piles.

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