INVESTIGATION OF LANDSLIDES USING ELECTRICAL RESISTIVITY TOMOGRAPHY IN CIAWI DRY DAM, WEST JAVA, INDONESIA

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ABSTRACT

Landslides are disasters that can cause damage to the environment and infrastructure and disrupt community activities, especially in mountainous and hilly areas. Identifying the geometry and some physical characteristics of the landslide material is essential to determining the appropriate mitigation method. This study used electrical resistivity tomography (ERT) to investigate landslides on the spillway slope of Ciawi Dam, West Java. The identification was carried out a 2-D resistivity data along seven profiles over the landslide area using a Dipole-dipole configuration. Borehole data also supported it. Electrical resistivity tomography analysis shows that the northern part of the landslide location is dominated by the water-saturated zone and weathered rocks in the southern part. Borehole data support that the rock at the landslide location consists of tuffaceous sandstone with tuffaceous clay inserts that are moderate to highly weathered. The resistivity data from the line recorded along the axis of the landslide also indicated the failure surface.

Keywords: landslides, electrical resistivity tomography, dry dam

1. INTRODUCTION

In Indonesia, landslides are the most frequent geomorphological hazard. The shape of the land with hilly and mountainous relief and high population density make West Java have a high potential for landslides [1]. Based on the Regional Forecast Map for landslide occurrence in August 2022, West Java province[2], the southern part of Bogor Regency is included in the potential for medium to high landslide. Several studies related to landslides in Bogor Regency have been carried out, both research on the level of vulnerability[3][4][5], spatial modeling of landslide hazard[1], landslide potential maps[6], and landslide-prone zoning[7].

The resistivity approach is one of the widely used techniques for geophysical prospecting to solve shallow geological issues. It has been used in landslide investigations to help identify some landslide features, including the main body, geometry, and rupture surface[8]. Several studies have used a geophysical approach to identify landslides, both using electrical resistivity tomography (ERT)[8][9][10][11], seismic reflection, refraction, and ground penetrating radar (GPR)[9]. In Indonesia, many studies use electrical tomography resistivity (ERT) to determine the landslide area [10][12][13][14]. On the left slope of the Ciawi dam spillway, several landslides occurred throughout 2021[15]. The spillway construction was affected by this landslide incident. Therefore, this research aims to determine the landslide by applying the geophysical method. The electrical Resistivity Tomography method is 2-D using a Dipole-dipole configuration,

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and measurements are made on seven lines. The Electrical Resistivity Tomography (ERT) survey was conducted in the landslide area and combined with borehole data. This study aimed to obtain landslide geophysical data, understand the landslide lithology, and characterize the landslide geometry. It is intended that this research would reveal the reasons behind the landslides on the left slope of the Ciawi dam spillway, serving as a guide for choosing the most effective approach for hillside improvement.

2. STUDY AREA

The study area is located in the Ciawi Dry Dam, Megamendung District, Bogor Regency, West Java, Indonesia, as shown in Figure 1. Ciawi dam is located on the northern side of the Pangrango Mountain and is situated at around 6°39'25.51" S and 106°52'50.01" E. The amount of rainfall in this area in 2021 was 3,921 mm and 211 rainy days[16]. Based on the Kȯppen-Geiger climate classification, the climate of the study area is classified as tropical rainforest[17].

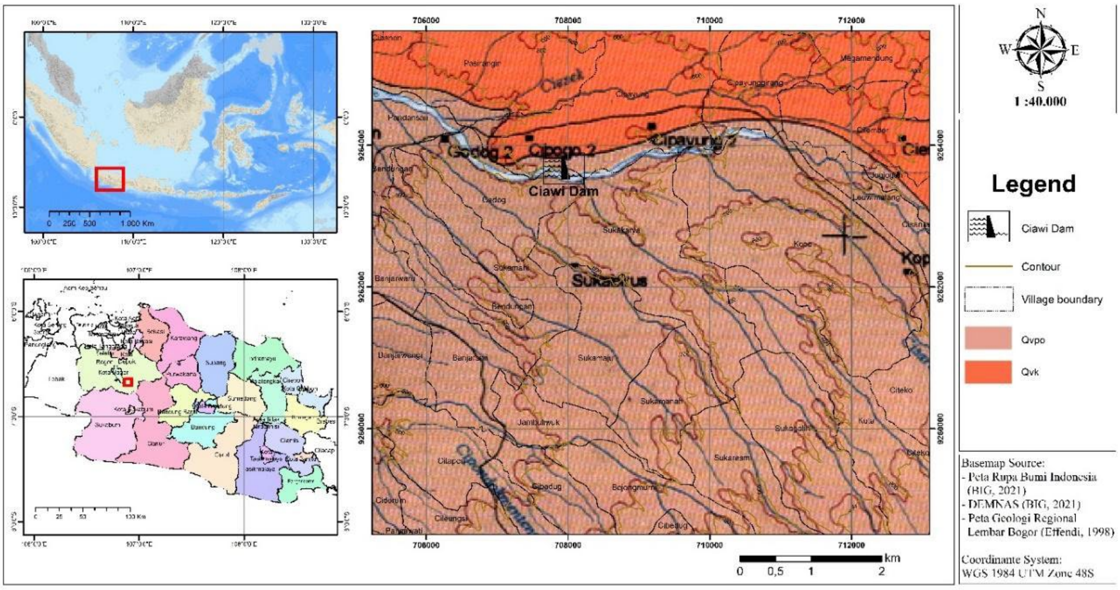

Figure 1 Research area and geological map of Ciawi Dry Dam

As shown in Figure 1, the dam is situated on the volcanic rock unit of Mount Pangrango (QVpo). This unit consists of lahar, lava, basal andesite with oligoclase-andesine, labradorite, olivine, pyroxene, and hornblende[18]. This unit is early Holocene in age. From old to young, the constituent rock in the dam consists of volcanic breccia, andesite lava, tuffaceous sandstone, and colluvial and alluvial deposits[19]. Ciawi Dry Dam is located in the Bogor groundwater basin, which according to the hydrogeological map, is a productive aquifer with a wide distribution [20]. Ciawi dry dams are located in the Upper Ciliwung Sub-Watershed, an area prone to landslides and landslides caused by natural physical conditions[5]. The morphology of the dam area is undulating hills, where escarpments indicate landslide activity[19].

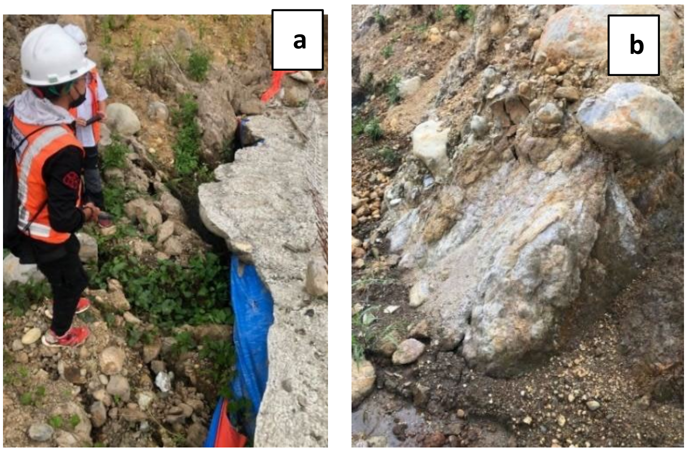

Figure 2 a Possible location of springs; b weathered rock at the research site

The location of the landslide is on the left slope of the spillway; this area has an elevation of about 520 m asl until 571 m asl. The slopes also found the location of springs, but due to landslides, it was covered by collapsed materials (Figure 2a). The research area has a shallow groundwater table and weathered rock, as shown in Figure 2b. The investigated research area lies within the Ciliwung River Basin, and the distance between the river channel and the investigated landslide is 209 meters. Before the construction of the dam, the area was residential. In July 2022, there was another landslide on the slope.

3. Materials and methods

ERT survey is used to determine the resistivity below the surface by taking measurements at the ground surface. It is based on the electric potential created by injecting a direct current between two pairs of electrodes[8]. The ERT measurement was carried out on 15-16 March 2021 by a supervising consultant for constructing the Ciawi Dam. The tools consist of a resistivity meter superstring R8, a switch box, electrodes, current and potential cables, laptops, and accu. The 2D lateral mapping method was used in this resistivity data collection [21]. The electrode configuration used in 2D geoelectric data acquisition is the Dipole-dipole configuration; the distance between the electrodes is 5 meters.

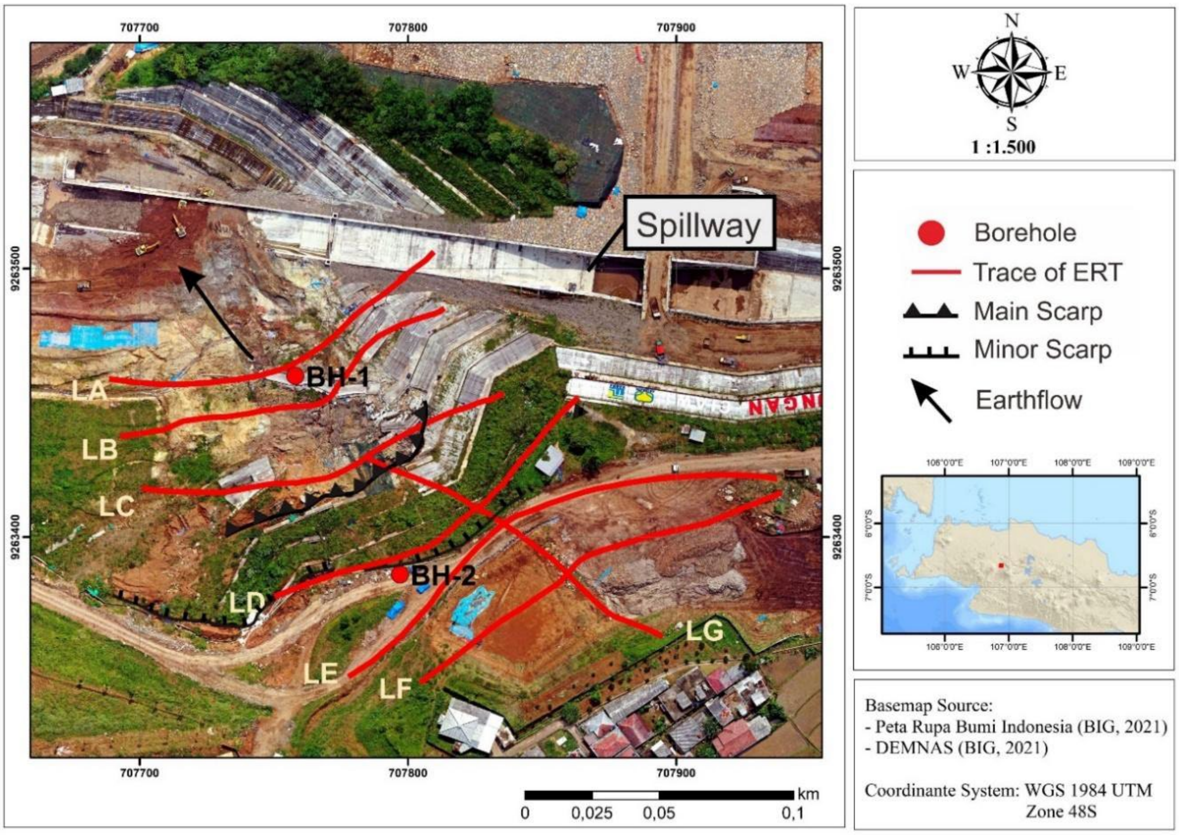

Figure 3 ERT line and borehole location

The electrical resistivity tomography survey in the study area was carried out on seven lines. Line A to Line F crosses the landslide, while Line G is in the direction of the landslide movement (Figure 3). The data was processed using RES2DINV software utilizing a 2-D tomographic inversion approach. The data processing is carried out by analyzing and interpreting the data regarding the anomaly pattern resistivity to obtain the depth of the slip field and structure slip plane geometry.
To complete the resistivity data, combined with borehole data. The borehole data were obtained from field measurements during the construction of the Ciawi Dam. Two borehole data located at the landslide site are used for underground geological interpretation. The borehole has a depth of 35 meters and 40 meters; the borehole locations are shown in Figure 3.

4. RESULT AND DISCUSSION

The results of the resistivity data that have been processed are in the form of a two-dimensional image; the acceptable value of root means square error (RMSE) is less than 10%[21]. In Figure 5 and Figure 6, the result of seven ERT surveys are shown; these profiles are selected because resistivity measurements can be carried out at landslide locations. Resistivity values obtained from data processing ranged from 0.7 Ωm to 1,424 Ωm. Resistivity values can be divided into groups of values below 25 Ωm, between 25-150 Ωm, and above 150 Ωm. Groups less than 25 Ωm may indicate relatively soft rock saturated with water. Groups with resistivities between 25 Ωm and 150 Ωm indicate medium to hard rock with water-saturated. A group indicates hard rock with a resistivity of greater than 150 Ωm.

Line A was approximately in the direction of NE-SW (Figure 3), located at the lowest elevation among the other lines. The results of the tomogram in this profile have a resistivity in the range of 2 Ωm to 83 Ωm, and there are two different resistivity groups along the line. In this profile, the low resistivity zone is dominated, and only a small part has a resistivity between 25-150 Ωm. Low resistivity represents a material with higher water content or filled by groundwater from the surface. On-line A, there is the closest borehole, namely BH01. The borehole data shows that the zone with low resistivity is a tuffaceous sandstone with a high level of weathering and inserts tuffaceous clay.

Line B is parallel and higher than Line A, and the line length was about 140 m. As shown in Figure 5b, the resistivity distribution of Line B is similar to that of Line A. It consists of a group below 25 Ωm and between 25-150 Ωm. Line B is dominated by a resistivity value less than 25 Ωm as in Line A. An isolated group with a resistivity of 25Ωm - 150Ωm can be seen at a depth of 8-20 meters. This group indicated weathered rock. In addition, the resistivity value group of 25Ωm - 150Ωm is also visible on the surface to a depth of 8 meters.

Line C is at a higher elevation than Line A and Line B, where Line C is close to the main scarp of landslide. As seen in Figure 4c, the resistivity group of 25-150 Ωm dominates the surface to a depth of 10 meters. On this line, hard rock is also at a depth of 8 meters on the west sideline. The surface of this line is uneven due to the landslide at the top. The eastern hill that did not participate in the landslide became groundwater recharge, as can be seen from the resistivity, which is less than 25 Ωm and has high groundwater content in the east and deepens towards the west.

Line D is at a higher elevation than the last three lines. There is a difference in resistivity between the lines in the west and east. In the east, the resistivity is higher, and hard rock is found, as evidenced by a resistivity of more than 250 Ωm at a depth of 7.5 meters. To the west, after the midline, the resistivity changes to less than 25 Ωm m. Low resistivity may be caused by the water content of unconsolidated material, whereas higher resistivity levels may signify consolidated material. As a result, there may be a fault at this place. As shown in Figure 4d, Line D contains borehole BH02, where the results of the soil layer on the borehole show tuffaceous sandstone with strong weathering dominance. This result is the same as the comparison of Line A with BH01.

From the measurement results, it can be seen that resistivity values of 25 Ωm to 150 Ωm dominate Line E; this indicates line E is dominated by weathered rock. Resistivity values less than 25 Ωm are at the bottom of the line; it is suggested that the groundwater in this line is more profound than the last line, about 20 meters from the ground surface. It is supported by the location of line E, which is located on a hill that is more stable than line A, Line B, Line C, and Line D, which are located on hillsides with landslides.

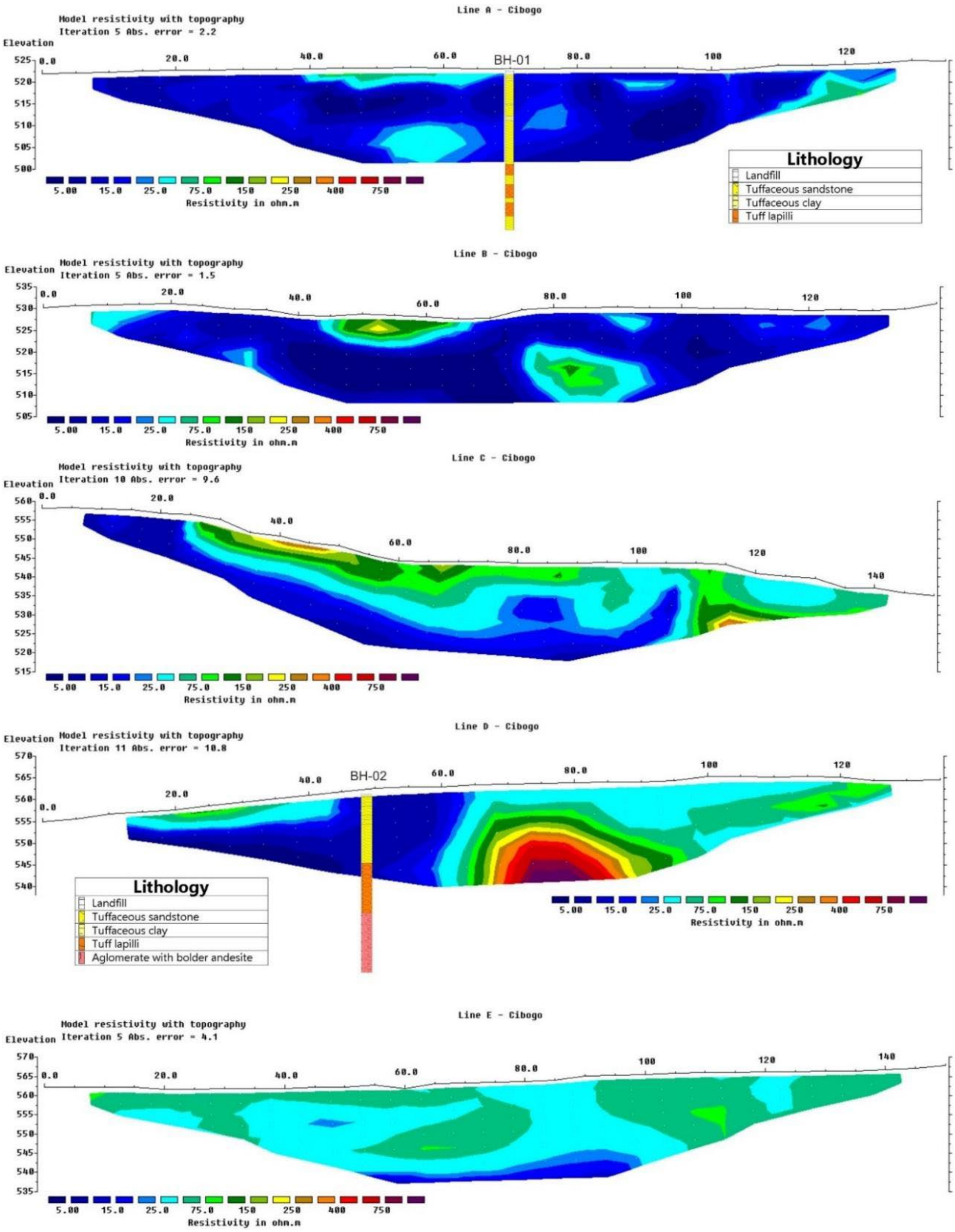

Figure 4 Resistivity value of lines were across the landslide mass: a Line A; b Line B; c Line C; d Line D; e Line E.

Line F is a line in the direction of the landslide mass located at the highest elevation. Similar to line E, line F is dominated by resistivity values of 25-150 Ωm, which identify the constituents of this line as weathered rock. In the middle, at a depth of 8-15 meters, there is a resistivity greater than 150 Ωm. In this line, low resistivity values are also at the bottom line, where groundwater is estimated at a depth of more than 10 m. Even though

line F is on a hill that does not experience landslides, when viewed from the resistivity results, there is a possibility of landslides in the eastern part, as shown in Figure 5a.
The G line is the only line measured in the direction of the landslide movement. The line is in the direction of SE-NW (Figure 3). The ERT results obtained on this line are shown in Figure 5b. The resistivity section of this line provides information in determining the geometry of the landslide. It can be seen from Figure 3 that there is a part of Line G, which is located on the mayor scarp and minor scarp. The zone of 25–150 Ωm resistivity, whose thickness ranges from 1–5 meters, appears to be quite comparable to rotational type, and its bottom may serve as the landslide's failure surface. However, this line has drilled no borehole to validate the subsurface lithology. This zone might be composed of weathered rock that contains water. Low resistivities are considered while determining the water content, which may be the most significant factor in sliding.

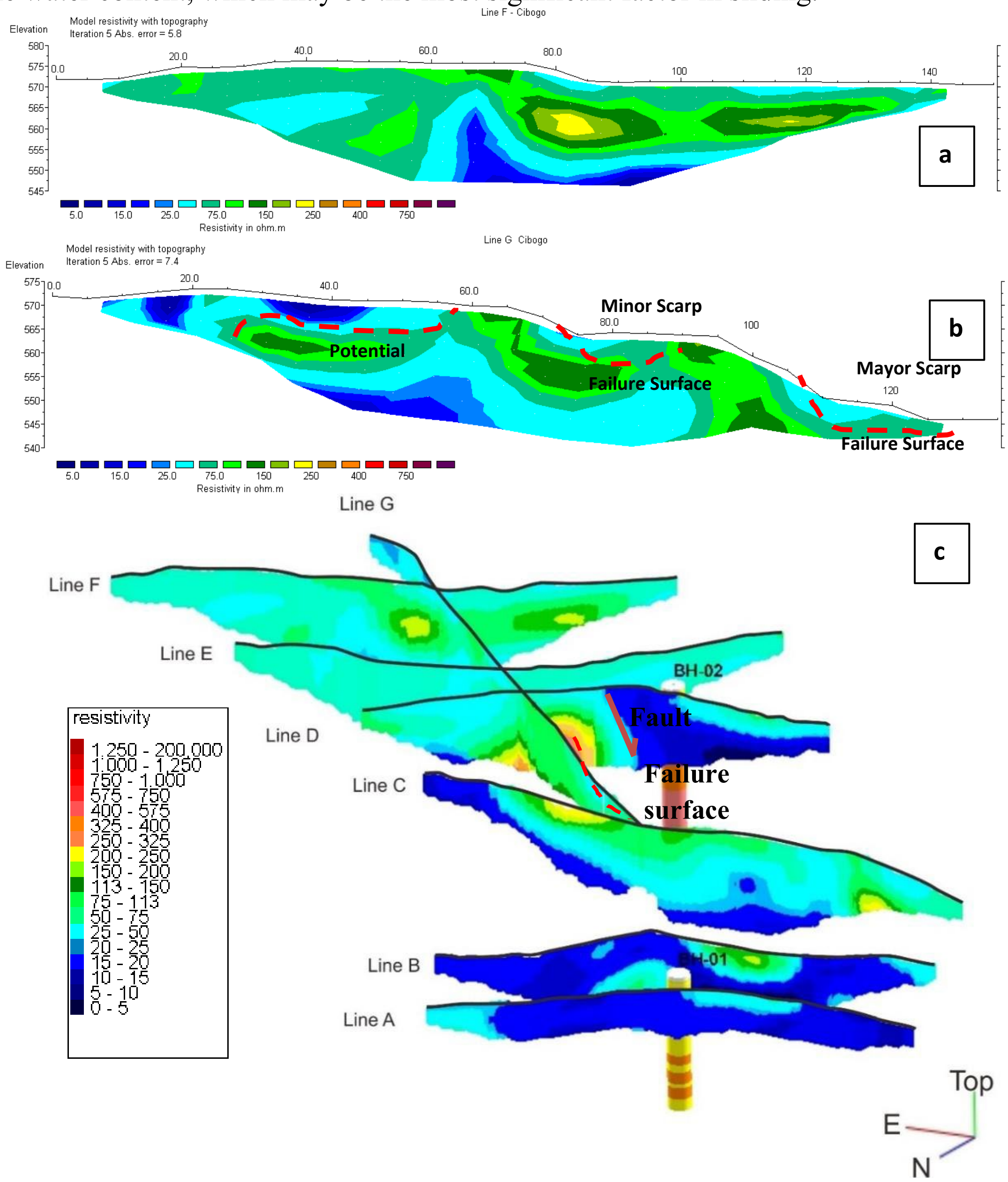

Figure 5 Electrical resistivity tomography result: a Line F, b Line G, c 3-D fence diagram of resistivity section.

The ERT result is shown in Figure 5c as a 3-D fence diagram, and the portions complement one another well. Fence diagrams show low-altitude areas are dominated by resistivity values less than 25 Ωm, indicating the water-saturated zone. The lines at higher elevations are dominated by resistivity values of 25-150 Ωm, indicating weathered rock. The fence diagram shows that the failure surface is on Line G and the fault is on Line D.

5. CONCLUSION

This case study shows how electrical resistivity tomography can be used to investigate landslides. The resistivity imaging may identify water-saturated zones, the landslide material's geometry, and some physical characteristics. In this research, the resistivity data inversion produced information for identifying the failure surface and the water-saturated zone in the landslide that occurred on the spillway's left hill. From the ERT result of Line G, it is a rotational type of landslide, with the depth to failure surface varying between 1 and 5 meters. According to the ERT result, the lower landslide area is a water-saturated zone with a value of resistivity less than 25 Ωm, and the upper part is dominated by weathered rock with a resistivity value between 25 Ωm – 150 Ωm. The ERT results estimate a fault in the study area and can distinguish between consolidated and unconsolidated geological units, which may potentially become a future landslide. From the borehole data (BH02), it is estimated that the layer that can become a potential landslide is tuffaceous sandstone with a strong weathering level with a depth of 15 meters. In addition, the tuffaceous clay layer found in the borehole data (BH01) also has the potential for surface failure.

6. CONCLUSION

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