Slope Failure Investigation in Weathered Granitic Rock Mass Using Electrical Resistivity Imaging: Case Study in Kg Bukit Selar, Jeli, Kelantan, Malaysia

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Slope Failure Investigation in Weathered Granitic Rock Mass Using Electrical Resistivity Imaging: Case Study in Kg Bukit Selar, Jeli, Kelantan, Malaysia

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Abstract The slope failure phenomenon is a common natural hazard in Malaysia in which due to the change in slope angle, weathering, heavy rainfall, and overloading. This research is focusing on analyzing the subsurface condition of slope failure in Kg Bukit Selar, Jeli, Kelantan by the electrical resistivity imaging (ERI) method. Geologically, the study area mainly composed of granitic rocks (microgranite and porphyritic granite). A total of five resistivity survey lines using Schlumberger and Pole-Dipole array with a 200m spread was conducted at the failed slope. ABEM Terrameter LS was used to collect field data, and processed by using RES2DINV software. The results were presented in the form of two-dimensional (2D) resistivity profiles providing a view of the subsurface distribution of the granitic rock, geological structures, and water content. The results show that the slope failed due to the presence of groundwater. The findings in this study show that the resistivity survey is a reliable method for slope failure investigation. The slope failures due to seepage problems were successfully being investigated using the ERI method.

1. Introduction

Slope failure is a common natural hazard in Malaysia and many cases leading to significant economic losses and even fatalities [1]. The number of slope failure increase annually because massif and continuous development happen in Malaysia. Many new areas, especially in the hilly area open to new development. Hilly area can be categorized as a prone area for slope failure to occur. Among the factors which caused the slope failure in Malaysia are rainfall [2], geological structure [3–5], improper construction, and non-maintenance of slopes [6], and unsuitable used of mitigation measures [7].

Excessive rainfall is the paramount factor for various sizes of slope failure occurrences in Malaysia, especially during monsoon season, from September until January. There are several areas prone to a slope failure along the road towards TNB Hydropower in Gunung Basor, Jeli, Kelantan. Two slope failures had been chosen to study in this research. This location was selected because the size of failure is more significant compared to other failures. The resistivity method was used to study the subsurface modeled on a failed slope. The ERI method has been used in this study because it had been used in various research to investigate subsurface conditions, such as by [9–11]. This paper discussed the findings of the subsurface condition of slope failure by using the electrical resistivity imaging (ERI) technique.

2. Study Area

The study area located in Kg. Bukit Selar, part of Jeli district, Kelantan. The study area mainly composed of granitic rock (Figure 1). Forestry is very common in the study area, which includes Gunung Basor Reserved forest and Gunung Stong Utara reserved forest. The main geological structure serrounding study area is fault. The fault orietation are south east-north west and south west-north east, as shown in the map.

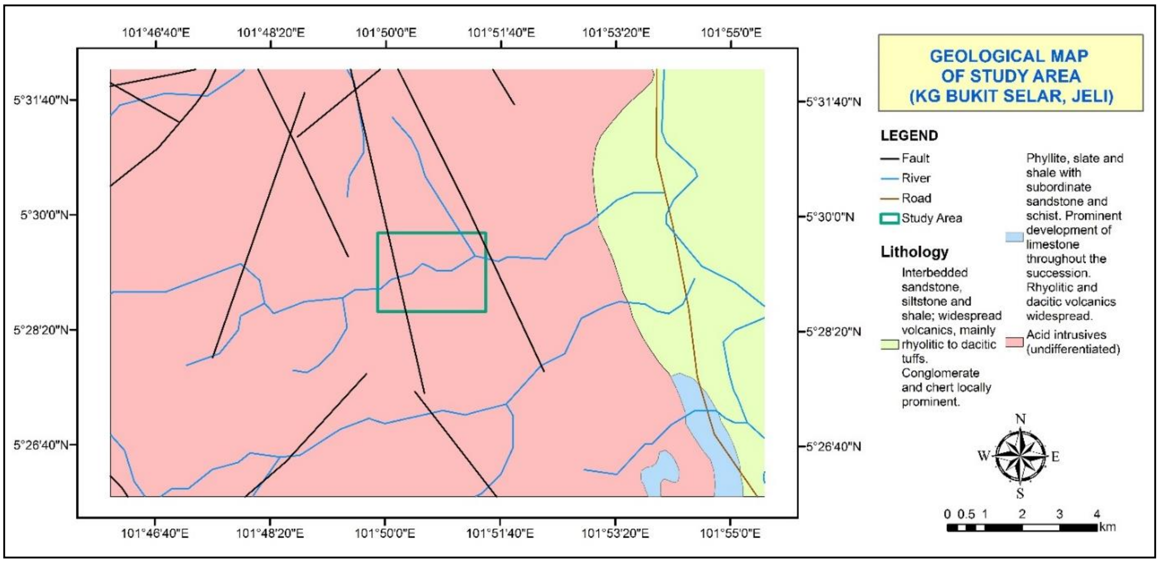

Figure 1. Geological map of study area [8].

Figure 2. Location of resistivity survey lines conducted in the study area. The scar of a slope failure can be seen in the image

3. Material and Method

3.1 Resistivity Survey.

In this study, the ABEM resistivity system was used to measure the resistivity value of earth material beneath the surface. The component of the ABEM resistivity systems is ABEM Terrameter LS, multi-purpose cable, 40 units of the jumper cable, 41 units of stainless-steel electrode, one unit of a 12-volt battery and one unit of remote cable. Schlumberger and Pole-Dipole configuration used in this resistivity survey. Two survey lines with 200 m were conducted in Pole-dipole protocol, while another three survey lines were using Schlumberger protocol. The electrode spacing for each survey line is 5 m. The total electrodes used are 41 electrodes. There are five lines have been conducted on two slopes in the study area, as shown in Figure 2. The coordinate for each survey line is shown in Table 1.

Table 1. Coordinate reading for each survey line

Number	Survey lines	Coordinate	Protocol
1	Line 1	N05˚29’12.8”, E101˚50’43.5”	Pole-dipole
2	Line 2	N05˚29’14.5”, E101˚50’40.8”	Schlumberger
3	Line 3	N05˚29’14.2”, E101˚50’40.8”	Schlumberger
4	Line 4	N05˚29’13.1”, E101˚50’41.8”	Pole-dipole
5	Line 5	N05˚29’15.5”, E101˚50’57.7”	Schlumberger

The apparent data obtained at the field is processes by using Terrameter LS Toolbox before being processed using Res2dinv from [12]. Pole-Dipole and Schlumberger configuration data obtained is inverted and the process by using Res2dinv software via apparent resistivity to obtain true resistivity and true depth of resistivity image. The inversion of resistivity and IP data is conducted by a least-square method involving finite-element and finite-difference methods. The 2D resistivity model is obtained from the ERI survey. Inversion pseudo-sections were interpreted to determine the resistivity of the materials. Each 2D resistivity image represents the subsurface soil layers underneath the spread lines.

4. Result and Discussion

For slope investigation, both resistivity and induced polarization parameters are utilizing to study the subsurface model for factors of slope failures interpretation. Results for the ERI surveys are presented in pseudo-section models in Figure 3 and Figure 4. In resistivity measurement, the lowest resistivity value ranging from 10 to 100 Ohm.m indicates saturated soil or water content zone. High resistivity value ranging from 700 Ohm.m to 3000 Ohm.m indicates a hard rock zone. For loose soil zone, the resistivity value is low, which ranging from 300 Ohm.m to 700 Ohm.m. Loose soil zone represents the slope failure area that occurred at the study area. Meanwhile, for model induced polarization (IP) measurement, the chargeability of water is 0 msec. Thus, by comparing the resistivity method and IP method, the existence of water can be predicted and detected either the water is existing in dense rock or fractured rock.

4.1 Profile 1

Survey Line 1 is 200 m in length in the vertical direction on the slope surface. Pole-dipole protocol is used for this line with 5 m electrode spacing. The survey line is directed from SSW to NNE. From Figure 3, the highest resistivity values zone is at 700 Ωm until more than 3000 Ωm in the bottom part, which interpreted as the fractured granite bedrock region. This zone is located at spread 0 m to 62.5 m and 120 m to 155 m. It is interpreted as a fractured rock due to the lower chargeability value (1 msec to 2 msec) in which shows the presence of water content in the zones. By comparing the resistivity method and IP method, the existence of water can be predicted existing in dense rock.

There is a seepage zone that can be seen clearly at approximately 87.5 m spread on Survey Line 1. There is a low resistivity zone at the bottom part of the pseudo section, which shows the source of seepage flow from the dense subsurface rock according to IP values ranging from 10 msec to 20 msec. Several rotated blocks, cracks, and head scarps can be seen at the upper part of the pseudo section. The zone is approximately 10 m deep from the ground surface. Vertical electrical contrast in the thin layer of the top part of the slope shows the sliding plane of the slope failure. There is a fault that can be seen due to the discontinuity of rock at spread 70 m and 97 m.

4.2 Profile 2

Survey line 2 is 200 m in length which the direction is parallel to the slope surface. Schlumberger protocol is used for this line with 5 m electrode spacing. The lowest resistivity values area around 1 Ωm to 20 Ωm in the bottom part in which resides most of the pseudo section, can be interpreted as the water content region. This zone located at an elevation between 415 m to 440 m. Low IP values which ranging from 2 msec to 3 msec is indicated water content (black circle). By comparing resistivity value and IP value, the existence of water can be detected existing in the fractured zone. Meanwhile, the top part of the pseudo section, which has high resistivity values start from 300 Ωm to more than 700 Ωm, is interpreted as the boulder blocks of porphyritic granite rock.

4.3 Profile 3.

Survey Line 3 is 200 m, and its directed parallel with slope face. Schlumberger protocol is used for this line with 5 m electrode spacing. The ERI survey spread Line 3 is in the W-E direction. The highest resistivity values area at 700 Ωm to more than 3000 Ωm in the bottom part, which can be interpreted as the granite bedrock region. This zone is located at an elevation between 400 m to 410 m.

The lowest resistivity zone in this pseudo section has resistivity values ranges from 10 Ωm to more than 20 Ωm. The colour of the region is blue to light blue at elevation 435 m to 475 m. Low resistivity values zone indicates the presence of water content or highly conductive materials. IP values ranging from 2 msec to 3 msec shows water content, which shown the existence of a weak zone for this slope. There is an overflow seepage zone can be seen clearly at approximately 10 m spread on survey Line 3

4.4 Profile 4

The length of the survey line 4 is 200. Pole-dipole protocol used for this line with 5 m electrode spacing. The total electrodes used are 41 electrodes which the first electrode start at the coordinate of N05˚29'13.1", E101˚50'41.8" and last electrodes at coordinate N05˚29'17.7", E101˚50'43.2". The orientation of the survey spread line 4 is in the SW–NE direction. The highest resistivity values zone is at 1000 Ωm until more than 3000 Ωm in the bottom part, which interpreted as the granite bedrock region. This zone is located at an elevation between 370 m to 420 m.

Low resistivity values show the existence of water content for this slope at almost 10 m deep from the ground surface. The line 4 pseudo section shown the presence of the seepage zone, which seen at the end of survey line 4. There is a low resistivity zone in the pseudo section, which shows the source of seepage flow from the subsurface. The uppermost zone shows the thin layer of loose to dense residual soil with moist to dry condition at spread 70 m to 200 m from the first electrode point. Several rotated

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blocks, cracks, and head scarps can be seen at the upper part of the pseudo section. Vertical electrical contrast in the thin layer of the top part of the slope shows the sliding plane (white lines) of the slope failure.

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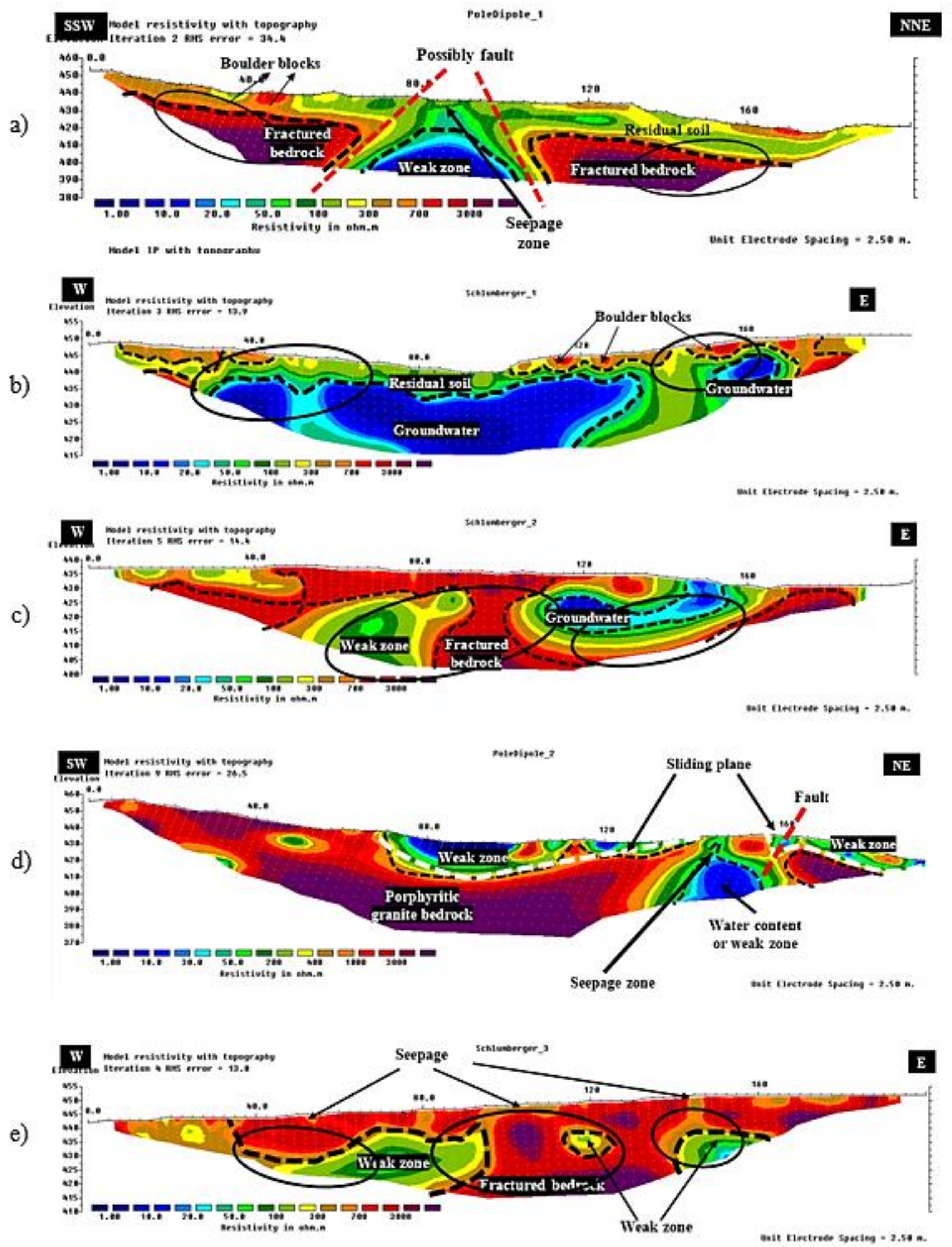

Figure 3. Pseudo section of resistivity survey from the study area; a) line 1, b) line 2, c) line 3, d) line 4, e) line 5

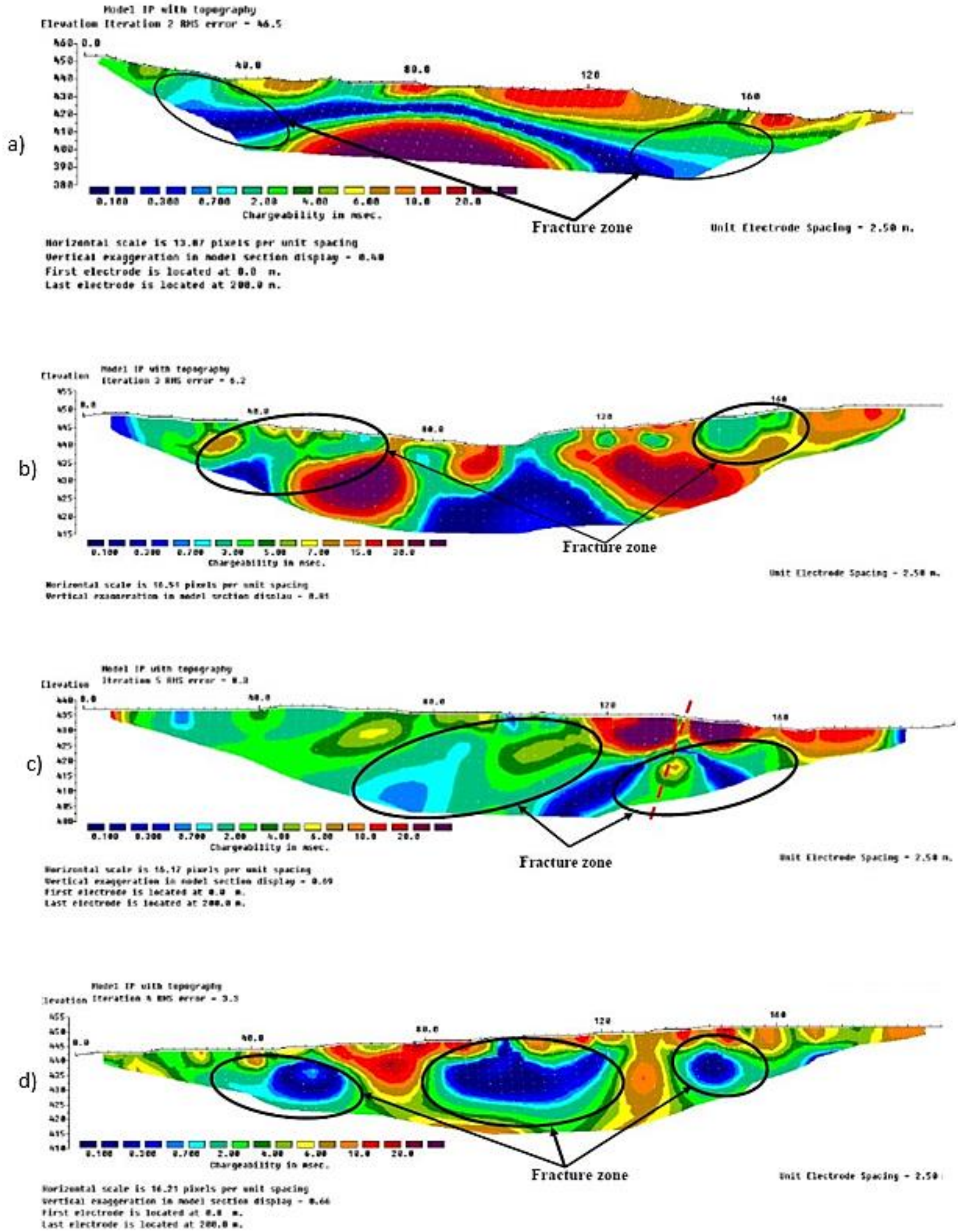

Figure 4. Result of IP pseudo section with the topography; a) line 1, b) line 2, c) line 3, d) line 5

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4.5 Profile 5

The Schlumberger protocol was used for a survey line 5 with 5 m electrode spacing. The total length for the survey spread was 200 m, with the survey orientation is in the E-W direction. Figure 3 shows the resistivity values for line 5, which is ranging from 700 Ωm to more than 3000 Ωm. This resistivity value was interpreted as the fractured granite. The IP values are 1 msec to 2 msec, which indicates the potential presence of groundwater. By comparing resistivity value and IP value, the existence of water can be detected existing in the fractured zone. The highest resistivity value (more than 3000 Ωm) covered at the bottom part of the profile at elevation 410 m to 420 m, and some are at elevation 430 m to 440 m. The low resistivity values zone indicates the existence of a weak zone for this horizontal spread line between Slope 1 and Slope 2. There are several seepages formed on the rock body.

5. Conclusion

The slope failures due to seepage problems were successfully being investigated using the ERI method. Based on the pseudo-sections, all the lines show the seepage zone was detected at the bottom part (Survey Line 1) and the uppermost part (Survey Line 4) at the center of resistivity line 1 and 4. The findings have proved that this approach is suitable and reliable for slope investigation as the triggering factors such as water content, seepage, faulting, and tension cracks. This ERI method is a new approach for slope failure assessment, especially for slope seepage assessment since this method can reduce time, cost, and destruction on the slope failure, especially by its 2D surface technique of investigation.

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