Geophysical investigation of road failure the case of the main street of Alue Naga, Banda Aceh, Indonesia

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Abstract. A geophysical investigation has been conducted on the road to assess the subsurface soil characteristics. The study investigates the causes of road failure around the body of the damaged roads in the main street of Alue Naga, Syiah Kuala, Banda Aceh to determine the variations of rocks charge ability and resistivity value of the subsurface of the study area. The method employed for this study was 2D Electrical Resistivity and Induced Polarization (IP) method with using Wenner-Schlumberger array. Two profiles covering a distance of 100 meters each were established parallel to the road pavement along the stable and unstable sections of the road. Data were collected along the two profiles using ABEM Terra meter SAS 4000. The observed field data were processed and inverted using 2-D modelling inversion algorithm (RES2DINV Software). The result shows the presence of low resistivity and charge ability value at several parts of both line 1 and line 2. Both lines observed the 0-1.73 msec of charge ability value and <1 ohm.m of resistivity value; those values were interpreted as alluvium. In conclusion, the low resistivity and charge ability value present that the area investigation was a layer of permeable, especially in the central part which was cohesive, and led to the instability and weakness of the load-carrying capacity.

1. Introduction

In developing nations, the number of disappointments of structures such as buildings, dams, bridges and streets has expanded geometrically [1]. Numerous building professions, such as civil, geotechnical and electrical building, have a contention that geophysical assessment was taken significance portion amid the plan prepare of structure and utilities to support data of region projects such as bridges, dams, and interstates [6].

Road failure is one of the common failures of structure in developing countries. It has led to the loss of billions of dollars over decades due to either poorly constructed roads and under-maintained roads. The consequent daily loss of human life and economically significant properties should make road failure an alarming issue [10]. The Alue naga road is the major road that links Alue Naga and Banda Aceh. It has contributed significantly to the social-economic development of society surrounding the area. Its incessant failure has both economic and social effects on the inhabitant of suburban communities because it makes transportation difficult from moving into the region.

The study was conducted to investigate the effect of the geological factors in terms of the nature of the subsoil and the near-surface structures as the potential cause of failures around the body of the main road in Alue Naga Village, Syiah Kuala, Banda Aceh. The study utilized integrated geophysical
investigations. Geophysical surveys are efficient and cost-effective in providing geotechnical information since both the high speed- and appreciable-accuracy procedures are combined in providing subsurface information area [7].

2. Methodology

2.1. Geology of the study area
The location of the research was carried out at the main entrance from Banda Aceh City to Alue Naga Village, Syiah Kuala District. Geographically, Alue Naga Village is located at coordinates of $5^\circ58'48.02"$ N - $95^\circ35'25.59"$ E until $5^\circ59'72.19"$ N - $95^\circ34'37.66"$ E with elevations between 0.45 m to +1.00 m above sea level (asl), with an average of 0.8 m asl. Based on the Aceh Regional Geological map, the measurement locations generally consist of Alluvial (Qh) deposits composed of loose materials such as clay, silt, gravel sand to lumps [2], as in figure 1.

![Figure 1 Geology map of study area](image1)

2.2. Methodology
2-D resistivity method is an active method that is commonly applied in investigating the electrical properties of the subsurface by measuring the resistivity distribution of the material [3]. In 2-D resistivity method, the electrical current was injected into the ground through a paired electrode (A and B), and the measurement of the potential difference was made by another pair electrode (M and N), as shown in figure 2.

Induced polarization (IP) is a geophysical imaging technique used to identify the electrical charge ability of subsurface materials, such as ore. In this method, the researcher was looking for the portion of the earth where current flow is maintained for a short time after the applied current is terminated. The presence of chargeable material in the ground can often provide an excellent proxy for the distribution of sulphides in the subsurface. Traditionally, [8] charge ability is mapped using induced polarization (IP) surveys. In geotechnical and engineering, the use of IP has been limited mainly for groundwater exploration.
Earth materials such as igneous and metamorphic rock have high resistivity value based on the degree of fractures, while sedimentary rock has low resistivity value due to high water content. The resistivity value of rock and soil depends on several factors which are porosity, water saturation and mineral content. Table 1 shows the resistivity values of common rocks and soil types.

| Material                  | Resistivity (ohm.m) |
|---------------------------|---------------------|
| Alluvium                  | 10-800              |
| Sand                      | 60-1000             |
| Clay                      | 1-100               |
| Groundwater (fresh)       | 10-100              |
| Sandstone                 | $8.4 \times 10^3$   |
| Shale                     | $20.2 \times 10^3$  |
| Limestone                 | $50.4 \times 10^3$  |

Table 2 Chargeability value of rock and soil [8].

| Material          | Charge ability (m sec) |
|-------------------|------------------------|
| Volcanic Tuff     | 300-800                |
| Rock Flakes       | 50-100                 |
| Granite rocks     | 10-50                  |
| Limestone         | 10-20                  |
| Water             | 0                      |
| Alluvium          | 1-4                    |
| Gravel            | 3-9                    |
| Silt              | 5-20                   |
| Sand              | 3-12                   |
| Clay              | 3-10                   |

In the present study, the 2D resistivity and Ip survey were conducted out simultaneously along the same line. Two lines were used to measure both the resistivity and charge ability of subsurface material in the road failure area. The Wenner-schlumberger configuration array was used [9]. The lines were designed with 2.5 m electrode spacing with a total length of the spread of 100 m respectively. Figure 3 shows 2-D resistivity and IP lines surveys.
Figure 3. Layout line survey.

The IP-charge ability and resistivity data were generated and recorded automatically by the ABEM SAS4000 Terrameter that employed in a multi-electrode array using ES10-64C electrode selector, smart cable, 41 stainless steel electrodes and jumpers. These data were later extracted and processed using RED2INV software to convert the apparent resistivity data to true resistivity by inversion. The resistivity meter measures apparent resistivity from which pseudo sections were developed and subsequently inverted to true resistivity 2D sections.

3. Results and discussion

The line 1 (2-D resistivity and IP survey) was located in the east of Krueng Raya river (figure 3). The charge ability value of inversion results shown a range of 0 – 200 m.sec with the depth of 21 m approximately (figure 5). The charge ability value is 0 – 1.73 m.sec at the depth 0 - 5 m, approximately, which indicated the presence of low charge ability value as alluvium that contains sand.

Figure 4. Inversion result of 2-D resistivity section line R1.

The charge ability value of 5.66 - 100 m.sec was indicated as sand clay. At a depth of 10 - 25 m, the charge ability value was more than 100 m.sec, which is indicated as clay. Furthermore, there are three layers that are presented in the line 2 for the inversion result of 2-D resistivity. The first layer is topsoil as sandstone at a depth of 1 - 4 m, approximately with the resistivity value of > 126 ohm.m. The second layer, at a depth of 4 - 10 m, was indicated as sand with a resistivity value of 1.01 – 15 ohm.m. The last layer is Water-intruded clay with a resistivity value of less 1 ohm.m at a depth of 10 – 20 m approximately.
The position of the second line (2-D resistivity and IP survey) has a distance of 8 m with line 1 (figure 3). Lane 2 is located exactly on the road failure at a distance of about 30-70 m. The value of the charge ability value on line 2 is 0.01-200 m.sec with a depth of about 25 m. In general, the charge ability value of the second track is a low value (figure 7). A charge ability value of 0-1.73 m.sec at a depth of 0-5 m indicates a low power value as the sand containing river water seepage. While the charge ability value of 5.66-190 m.sec is indicated as the sand which is at a depth of 5-10 m. The charge ability value > 100 m.sec indicated the clay which is at a depth of 10-25 m. On the other hand, the resistivity value at line 2 yields the results with the same structure and the value of the resistivity range with line 1. The results of the resistivity method at line 2 indicate the presence of three layers for the inversion results from the 2-D resistivity. The first layer is top soil as sandstone at a depth of 1-4 m with a resistivity value of 13-70 ohms. The second layer, which is at a depth of 4-10 m, is shown as sand with resistivity values of 1.01-15 ohm.m. The last layer is an intrusion clay with a resistivity value of less than 1 ohm.m at a depth of about 10-20 m.
Figure 7. Inversion result of IP section line R2.

4. Conclusion
The indicated resistivity value is low (less than 1 ohm.m), and the chargeability value is also low (below 1 m.sec), which is obtained in several positions on paths 1 and 2. These facts indicate the flow of seepage. Seepage flow is indicated as an underground flow that connects 2 rivers namely the Krueng Cut river and the Krueng Titi Panyang river.

Acknowledgments
The authors would like to thank the Ministry of Education and Culture Indonesia, Syiah Kuala University, for its financial support in the scheme of Decentralized Research Competitive Grants Program PLK 2019, Geophysics team of Universiti Sains Malaysia, Penang (Malaysia), students and staffs of Faculty of Sciences and Faculty of Engineering, Syiah Kuala University, Banda Aceh (Indonesia).

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