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Correlation of Electrical Resistivity Tomography and Geotechnical Field Data for Soil Profile Characterization

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Abstract: Geophysical method is a tool that can improves the experience of subsurface exploration in term of soil profiling. Electrical resistivity method has been used as one of the most well-known non-destructive methods for subsurface exploration. In this study, electrical resistivity tomography was utilized to determine a soil profile by using ABEM TERRAMETER LS 2. 80 meters' line of electrical resistivity surveying was conducted by using Gradient array protocol. The soil sample was then verified using a drilled tube to be compared to the electrical resistivity tomography results. The study found that the resistivity value of the measured subsurface at the borehole location to be less than 50 Ohm.m for the first 10 meters and followed by an increase of resistivity value to 170 Ohm.m from 10 meters to 15.30 meters deep. The soil obtained from the boreholes shows that the first 10 meters of the soil layers consists of silty clay with traces of sand. From 10 meters to 15.30 meters fractured rock with less than 50% RQD value was located. This study has verified the changes in the resistivity value by using drilled tube well to identify the type of soil layers.

Keywords: Resistivity, SPT, soil, fractured rock, groundwater

1. Introduction

In civil engineering or any development activities, site investigation is one of the key aspects in ensuring the success of any construction. The geological subsurface conditions can be extremely complex with much unknown variables. Traditionally, these processes involve direct sampling methods, such as SPT which involves excavating or drilling the soil subsurface to obtained the information on the conditions of the subsurface (Gonçalves et al., 2021).

This conventional method is reliable as the layers of the subsurface is obtained and can be observed directly on site and the different layers of the subsurface is identifiable. One of the drawbacks of this method is the extensive effort and cost it took to operate the drilling and excavating processes and also the SPT testing only gives the information on the exact layers of the targeted point of exploration (Hazreek et al., 2015). With that in mind, to obtained the overall site information of the subsurface, more time and effort are required to obtained the overall information of the site.

In recent years, the usage of geophysical methods in identifying the subsurface constituent of the earth have been imploded in popularity due to its effectiveness and accuracy in delineating the differences in between the composition of the earth subsurface (González-Quirós & Comte, 2020). Depending on the needs and accessible of the exploration, different geophysical methods require different approaches depending on the needs of the subsurface exploration (Suhip et al., 2020). One of the more popular geophysical techniques used in subsurface exploration is the electrical resistivity method. Electrical resistivity method is a geophysical technique that applies the electrical properties to

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identify the constituency of the earth subsurface. Electrical resistivity method may provide the 2-D tomography of the intended subsurface with much less effort and time compared to the conventional technique (Al-Heety et al., 2021).

The subsurface exploration experience is optimized if both the conventional and geophysical methods are being used in tandem with one another. In this study, standard penetration test (SPT) testing was conducted alongside the electrical resistivity tomography (ERT) testing and the correlation between the ERT and SPT value are assessed.

2. Electrical Resistivity Testing and Methods

Electrical method (electrical resistivity and induced polarization) was performed using ABEM Terrameter LS 2 to obtain the electrical resistivity imaging on site as showed in **Figure 1**. The electrode array used in the geophysical survey is Gradient XL array protocol. The array contains four collinear electrodes. The other current electrode is placed in the vicinity of the two potential (receiver) electrodes. The electrode cable arrangement is as shown in **Figure 2**. Four cables are used to maximize quantity of data, and thus able to provide better tomography plot. After electrode cable's position has been determined, the electrode cables are rolled out and the electrodes were connected to the electrode cable by using a jumper cable. At the sharing location, such as C1/C2 and C3/C4, the cables are joint using cable joint or cable connector.

The raw data obtained from the data acquisition was processed using commercialized RES2DINV software to provide an inverse model that approximates the actual subsurface structure. The inversion algorithm of RES2DINV was used to process the data in order to obtain the 2-D electrical results. After obtaining the resistivity imaging value of the surveyed line, the type of soil within the subsurface can be predicted by referring to the resistivity chart which is presented in **Table 1**. To validate the interpretation of the results from the imaging data, a chosen position along the surveyed line was drilled to obtain the actual type of soil from the subsurface. The drilling data however will only represent single point information (1D) at the actual drilling location and the data obtained was compared to the ERT result.

Fig. 1 - Electrical resistivity equipments

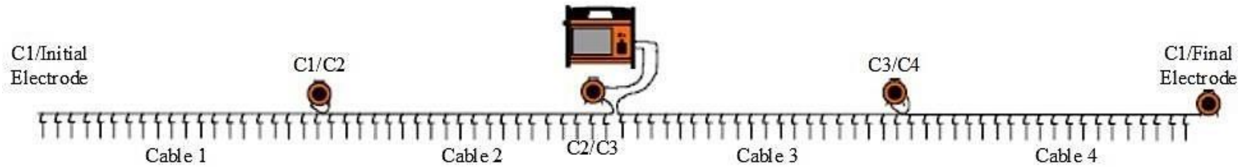


Fig. 2 - Schematic placement of cable and electrode

Table 1 - Electrical resistivity values of some types of waters in rocks (Keller and Frischnecht, 1966)

Type of water	Resistivity (Ohm.m)
Precipitation	30 - 1000
Surface water, in areas of igneous rock	30 - 500
Surface water, in areas of sedimentary rocks	10 - 100
Groundwater, in areas of igneous rocks	30 - 150
Groundwater, in areas of sedimentary rocks	> 1
Sea water	≈ 0.2
Drinking water (max. salt content 0.25%)	> 1.8
Water for irrigation and stock watering (max. salt content 0.25%)	> 0.65

3. Geotechnical Field Equipment and Testing Method

3.1 Boring and Standard Penetration Test (SPT)

The field boring exploration was carried out using multi-speed Spindle Driven Boring Machine as shown in **Figure** 3. Advancing boreholes was carried out using rods. Casings were used to prevent the collapse of the borehole wall. The boreholes were cleaned by circulating water and disturbed samples were collected for visual examinations.

SPT testing was carried out in accordance with clause 5.4: MS 1056: Part 9, “Determination of the penetration resistance using spilt-barrel sampler”, using a self-tripping hammer of 63.5+-0.5kg weight of an approved design. The tests were carried out at 1.50m interval. The value of penetration resistance N was reported together with the number of blow counts for each 75mm penetration of the sampling tube. The blow counts for the first 150mm penetration or 25 blows whichever was first reached (seating drive), which do not contribute to the value of N, was also included.

During the initial penetration, the test was carried out in two stages. The first one was Seating Drive-Using standard blows, the seating drive was driven to a penetration of 150mm or 25 blows whichever was first reached. The second is Test drive-The number of blows required for a further penetration of 300mm and this was termed the penetration resistance “N”. When the penetration was not achieved in 50 blows, the test drive was terminated. The number of blows required to affect each 75mm of penetration for both seating and test drives was recorded. When the seating or test drive was terminated before the full penetration, the depth of penetration for corresponding 25 blows and / or 50 blows respectively was recorded. The penetrated soil samples obtained during the testing were recovered inside a spilt barrel and was bought back to the surface for further examination.

The termination criteria for borehole termination were Five (5) consecutive SPT, N> 50/300mm of hard layers or a maximum depth of 30.0m has been reached (whichever arrives first). For harder materials such as rock, 4.5m length of continuous coring is needed for harder materials such as rocks. During the penetration test, the depth of inserted casing, borehole depth, and the water level in the borehole was also recorded.

Fig. 3 - Borehole drilling equipment

4. Results and Findings

One line of 80 meters electrical resistivity tomography testing was conducted in the study area. The electrical resistivity tomography obtained using Gradient XL array was presented in **Figure 4.** The tomography obtained from the testing site shows that the resistivity value is in the range of 1 Ohm.m to 4000 Ohm.m. However, almost all of the resistivity value falls below 300 Ohm.m value. The highest resistivity value are more concentrated in the first 2 meters of the observed line. Bellow the 2 meters line, most of the resistivity value were relatively low in the range of less than 300 Ohm.m. The discrepancy of the resistivity value between the first 2 meters of the tomography might be due to the effect of groundwater level which might lowered the apparent resisitivity value of the site (Helaly, 2017). It was expected that the high differences between the resistivity value is based off of different type of soil. In a site study conducted by Mohammed et al. (2019), the resistivity value of Gravel, sand and clay is different from one another. The range of resistivity for the diffrent size of gravel is in the range of 1150 - 600 Ohm.m, 500 - 200 Ohm.m and 150 - 20 Ohm.m for gravel and sand mixture, sand and clay mixture and also for clay layers respectively. Another study conducted by Malik et al., (2023) also shows that the differences between gravel, sand and silt sample is within the range of 160 - 128 Ohm.m, 128 - 86 Ohm.m, and 86 - 37 Ohm.m respectively. Considering the water level is below the 2 meters layers, it is expected the difference between the resisitivty value below the 2 meter soil layer is due to the differences in the type of materials and also the size of the soil itself instead of the presence of groundwater.

To further validate the interpration of the electrical resistivity tomography value, a drill tube was performed on the 30th meter of the resistivity line. The sub-profile for Borehole 1 consists of a thin soft layer of silty clay with traces of sand until 1.95-meter from the top soil. Followed by a layer of thin silty clay with traces of sand from 2.00-meter to 2.50- meter depth. Layer of stiff silty clay with traces of fine sand can be found at depth 3.00-meter to 3.45-meter. Silty clay with traces of fine sand is then found at depth 4.00-meter to 5.00-meter and followed by very hard silt at 7.50-meter to 7.65- meter depth. A layer of very hard silt is situated at depth of 9.00-meter to 9.24-meter. Very poor, highly fractured quartz is located from 10.80- meter until its termination depth which is 15.30-meter. From the drilling processes, it was found that the groundwater table is indeed located at 2.2 m below the surface as expected from the ERT testing.

Based on the electrical resistivity tomography testing, it was expected that the type of soil below the 30-meter resistivity line is a mixture of sand, silt and clay from the survey surface for the first 10 meters followed by gravel or larger sized sample after the first 10 meters. The low resistivity value below 50 Ohm.m of the first 10 meters of the soil profile for BH1 are proven with the borehole where most of the obtained sample is in the form of silty clay sample with some traces of sand as shown in Table 2. The resistivity value below 10 meters however showed an increase in resistivity value up to 170 Ohm.m. The change in resistivity can be relate to the change of the composition of soil, where the sample obtained starting from 10.80 meters to 15.30 meters were found to be in the form of fractured quartz as shown in Table 2. The rock sample was cored and the recovered rock sample's rock-quality designation (RQD) was measured. The obtained RQD from the cored rock sample were 12.7%, 46% and 30.7% for 10.80 m to 12.30 m, 12.30 m to 13.80 m, and 13.80 m to 15.30 m respectively. The low RQD value indicates that the obtained rock sample is highly fractured. The spaces in between the fractured rock allowed the groundwater to fill the void between the fractured rock which in return may lowered the apparent resistivity of the site tomography where fractured rock is located (Sekucia et al., 2020).

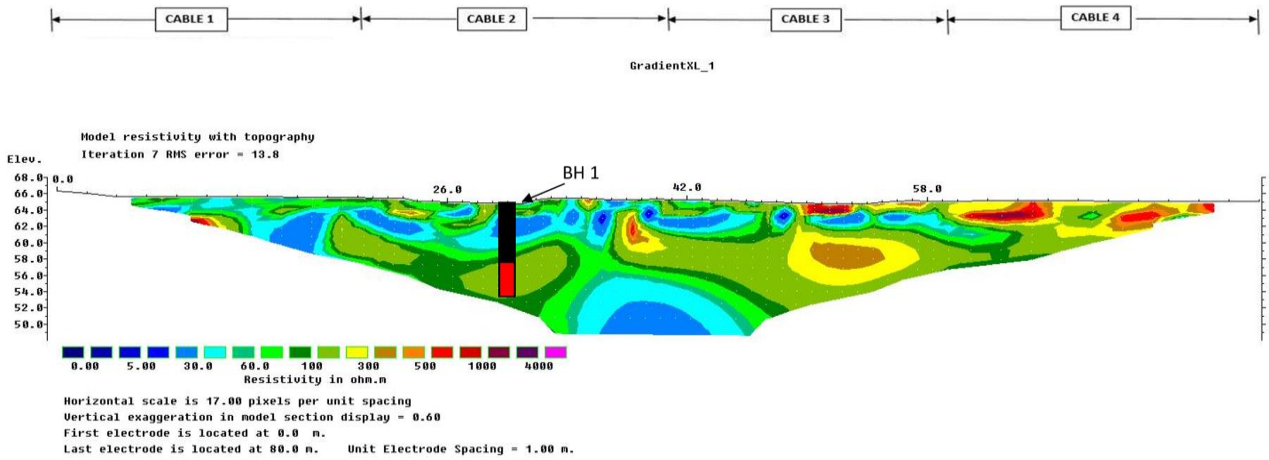
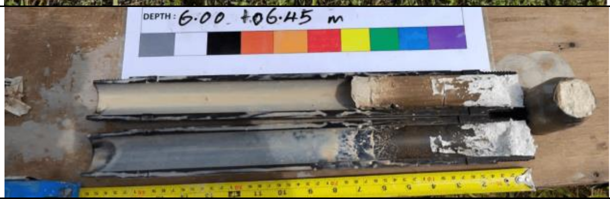


Fig. 4 - The electrical resistivity tomography of BH 1

Table 2 - Electrode cable distance according to profile lines length

Depth	Borehole profile
1.50 - 1.95	
2.0 - 2.50	
3.00 - 3.45	
4.0 - 5.0	
6.0 - 6.45	
7.5 - 7.95	
9.0 - 9.45	
10.8 - 15.30	

5. Conclusion

This study showed that the use of geophysical methods to obtain geotechnical information is capable to determine the change of soil layers of the earth subsurface with good accuracy. The retained soil from the borehole shows a direct correlation in term of changes in the resistivity value obtained from the ERT testing. From the observed borehole, the high contrast in the resistivity value for the first 10 m which was predominantly a silty clay layer with traces of sand followed by a fractured layer of rock until the observable borehole was terminated indicates the reliability of the ERT methods in delineating the differences in the soil layers. The outcome from this study highlights the relevancy and importance of ERT methods in aiding subsurface exploration especially for engineering purposes.

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