SEMARAK ILMU
PUBLISHING
202103268166(003316878-P)

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Apparent Electrical Resistivity Value and Borehole Data Correlation

Melvern Goh Keat Heng[1], Aziman Madun[1,*], Mohd Khaidir Abu Talib[1], Faizal Pakir[1], Mohd Firdaus Md Dan[1], Shahrul Niza Mokhatar[1], Muhammad Nizam Zakaria[1,2], Saiful Azhar Ahmad Tajudin[1,2,3], Badee Alshameri[4]

[1] Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia
[2] Geo-Structure Rehabilitation Centre, Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, Malaysia
[3] Preston Geocem Sdn. Bhd., No.16A, Jalan Kencana 1A/25, Taman Pura Kencana, Sri Gading, 83300 Batu Pahat, Johor, Malaysia
[4] School of Civil and Environmental Engineering, National University of Sciences and Technology, Islamabad Capital Territory, Pakistan

ABSTRACT

Geotechnical engineering requires a thorough understanding of subsurface conditions to inform design and construction processes. Traditional borehole testing, while commonly used, has limitations in terms of cost, time, coverage, and its destructive nature. To overcome these challenges, geophysical methods like electrical resistivity have been adopted as complementary techniques. Electrical resistivity offers advantages such as faster data collection, larger subsurface imaging, non-destructive testing, and environmental friendliness. Previous research has also shown promising agreement between electrical resistivity and certain geotechnical parameters. This study aimed to establish correlations between apparent resistivity values and geotechnical parameters to predict soil properties. Four soil investigation projects combined borehole testing with electrical resistivity tomography (ERT) to analyse the data. Subsurface tomographic profiles were generated using ZondRes2D software. The standard penetration test number of blow (SPT N-value) was obtained directly from borehole drilling, and laboratory tests determined the liquid limit and percentage of fine grains (silt and clay). However, the correlation analysis between apparent resistivity values and the studied soil properties showed insignificant correlations. As a result, the ERT method was deemed insufficient in reliably predicting soil properties. The study concludes that there are limitations in using the ERT method for interpreting subsurface soil properties.

Keywords:

Apparent resistivity value; Borehole data; Soil properties; Correlation

1. Introduction

Subsurface exploration is a crucial stage before commencing any design or construction project [1,2]. It helps determine various geologic formations and geotechnical properties, including weathering profile, soil thickness, rock and soil types, and their strength, essential for project planning and design. However, traditional borehole testing can be expensive and fails to provide a

---

[*] *Corresponding author.*
E-mail address: aziman@uthm.edu.my

https://doi.org/10.37934/araset.56.1.203211

complete site understanding due to limited spatial coverage [3]. As a result, researchers have conducted studies to find correlations between Electrical Resistivity Tomography (ERT) surveys and geotechnical soil parameters, such as the standard penetration test number of blow (SPT N-value), which have shown positive results with good correlation [4]. Several other researchers [5-7] have also reported a strong correlation between ERT surveys and geotechnical data, leading to increased confidence in using electrical resistivity alongside borehole drilling for subsurface investigations in the Malaysian construction industry. To overcome the limitations of borehole tests in providing comprehensive soil profile information, engineers have turned to non-destructive geophysical technologies like Electrical Resistivity Tomography (ERT), seismic refraction, seismic reflection, and ground-penetrating radar (GPR) for subsurface investigations [8,9]. These methods offer extensive coverage over larger areas at lower costs and faster implementation, while also causing minimal site damage during data collection [10,11].

However, comprehensive understanding regarding the correlation between geotechnical parameters and electrical properties is limited [6]. Existing industrial reports often treat borehole and ERT tests as independent entities without establishing correlations between them. Despite this, some studies, like the work of Tello *et al.,* [6] and Hisyam and Syed [12], have demonstrated a strong correlation between Standard Penetration Test (SPT), moisture content and resistivity values. To improve correlation accuracy, further research can involve multiple sites, extended observation periods, and expanded data collection efforts [13,14]. By establishing a relationship between borehole parameters and ERT, it becomes possible to model a larger subsurface area in two dimensions (2D). The primary objective of this study is to establish correlations between apparent resistivity values and borehole soil data, including SPT-N value, liquid limit, and percentage of fine grains. This will enhance understanding of the relationships between ERT parameters and borehole data, facilitating a more comprehensive assessment of subsurface characteristics.

2. Methodology

The study focused on selecting sites that had both ERT (Electrical Resistivity Tomography) testing data and borehole drilling records. Boreholes were strategically drilled along the ERT survey lines to facilitate the correlation of soil properties with the apparent electrical resistivity values. Soil properties were evaluated both in the field and in the laboratory.

2.1 Study Area

Table 1 shows the study area with its information such as geological formation, bedrock, number of borehole and number of ERT line.

Table 1
Site locations and testing information

Site Location	Geological formation / bedrock	No. of Borehole	No. of ERT line
Ayer Keroh, Melaka	Hawthorndern Schist / quartz mica and graphite schist	3	1
Jerantut, Pahang	Semantan Formation / rhyollite	1	1
Shah Alam, Selangor	Kenny Hill Formation / sandstone	4	1
Senawang, Negeri Sembilan	Hawthorndern Schist / graphite schist	2	2

2.2 Methods

The raw data obtained from electrical resistivity tomography (ERT) were processed using ZondRes2D software to generate tomographic images. The SPT N-value was measured from the borehole test at every 1.5-meter depth interval. The borehole test was terminated after either five consecutive SPT readings of hard soil or after continuous coring up to a length of 4.5 meters with a rock quality designation (RQD) value of at least 50%. Soil index tests, such as the Atterberg limit test and particle size distribution, were conducted following the BS1377:1990 standard. For each depth, the apparent resistivity value was recorded and correlated with the SPT N-value, percentage of silt and clay (referred to as the percentage of fine grain) within the soil sample, and the liquid limit. The collected data were analysed and interpreted, leading to the development of correlations between the apparent resistivity values and the specific parameters measured within the boreholes.

3. Results

This study is to utilize ZondRes2D software to obtain a 2-D resistivity profile and establish correlations between the apparent resistivity value and borehole data, including SPT N-value, fine grain soil content, and liquid limit. A correlation analysis is conducted to examine potential relationships between the apparent resistivity value and the selected borehole data that was drilled at resistivity spread line. The analysis is performed individually for each site, and the results are then combined for all sites used to draw conclusions regarding the existence of any relationships between the apparent resistivity value and the chosen borehole data.

3.1 Results

Figure 1 depicts a resistivity line profile spanning 200 meters in Ayer Keroh, Melaka, with three boreholes labelled (Borehole 1, Borehole 2, and Borehole 3).

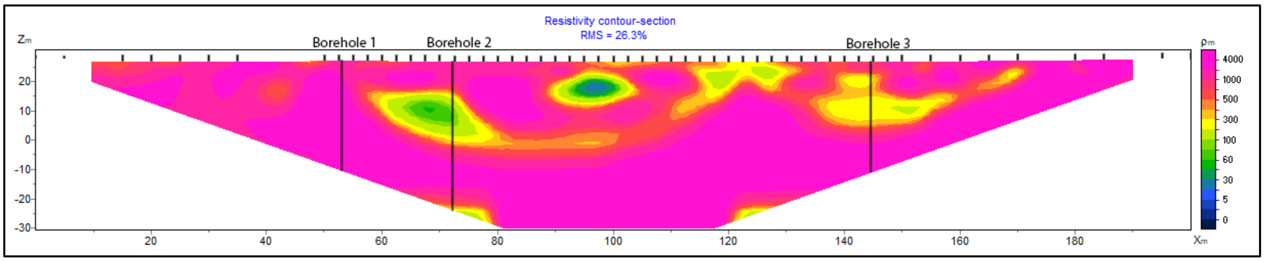

Fig. 1. Apparent resistivity tomography for line profile with borehole marking for Ayer Keroh, Melaka

In Borehole 1, Ayer Keroh, Melaka, the bedrock primarily consists of quartz mica and graphite schist. At a depth of 1.5 m, the SPT N-value is 16, with an apparent resistivity of 1250 Ωm. Between depths of 3 m to 19.95 m, the SPT N-values consistently measure 50, while the apparent resistivity ranges from 1250 Ωm to 4000 Ωm. The water table is observed at 9.07 m depth from ground level. The resistivity of the soil beyond 9.07 m remains higher, possibly due to the unaffected nature of the water table and the characteristics of grade III, moderately weathered quartz mica and graphite schist rock, which is resistant to water influence [15]. In Borehole 2, at a depth of 1.5m, the SPT N-value is 20, and the apparent resistivity is 1250 Ωm. Between depths of 3 m to 6.45 m, the SPT N-values remain at 50, with a constant apparent resistivity value of 1250 Ωm. The water table is observed at 9.30 m depth from ground level. Interestingly, despite an SPT N-value of 50, the apparent resistivity value does not increase as expected. In Borehole 3, at a depth of 1.5 m, the SPT N-value is 25, and the apparent resistivity is 875 Ωm. Between depths of 3 m to 10.95 m, the SPT N-values range from 41 to 50, with apparent resistivity values varying from 875 Ωm to 350 Ωm. The water table is observed at 2.31 m depth from ground level. Notably, the resistivity at and below 3 m depth is influenced by the water table, resulting in reduced apparent resistivity values.

Figure 2 displays a graph showing the relationship between the apparent resistivity value and SPT N-value at the Ayer Keroh, Melaka site. The R-squared value of 0.0918 suggests that no significant correlation exists between the apparent resistivity value and SPT N-value for the site.

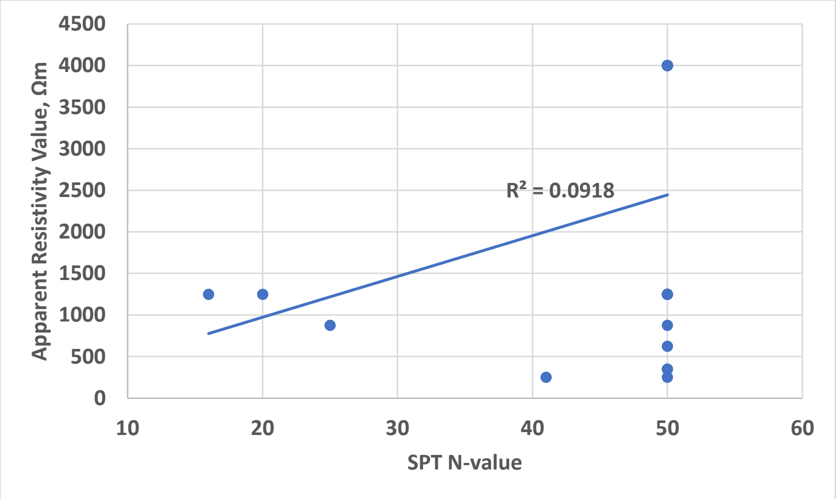

Fig. 2. Graph of apparent resistivity value versus SPT N-value for Ayer Keroh, Melaka

Meanwhile, Figure 3 presents a graph showcasing the relationship between the apparent resistivity value and the percentage of fine grain (silt and clay) across this site. The obtained R-squared value of 0.3591 indicates a relatively weak correlation between the apparent resistivity value and the percentage of fine grain at the site of Ayer Keroh, Melaka.

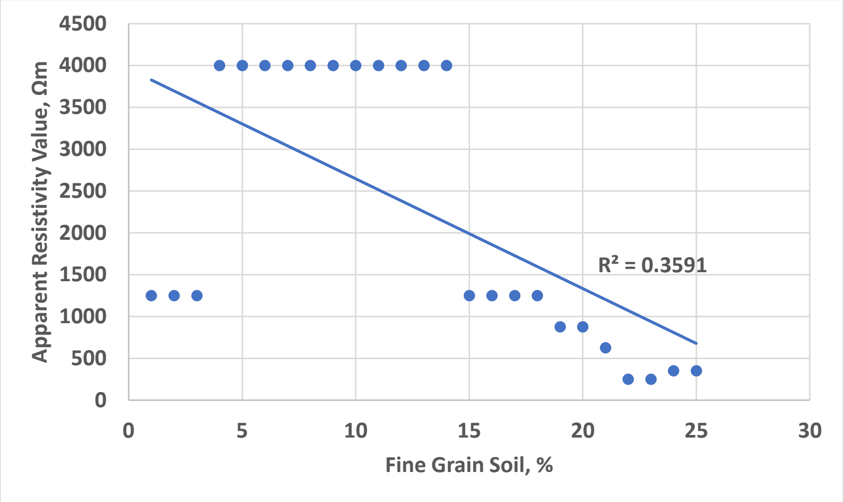

Fig. 3. Graph of apparent resistivity value versus fine grain soil for Ayer Keroh, Melaka

The relationship between the apparent resistivity value and the liquid limit at the Ayer Keroh, Melaka site is presented in Figure 4. The R-squared value of 0.0069 indicates that there is no significant correlation observed between the apparent resistivity value and the liquid limit for the site at Ayer Keroh, Melaka. These findings of Ayer Keroh, Melaka site from Figures 2, 3 and 4 highlight the complexity of the subsurface condition and suggest that other factors may be influencing the electrical resistivity values independently of the SPT N-value, fine grain soil and liquid limit.

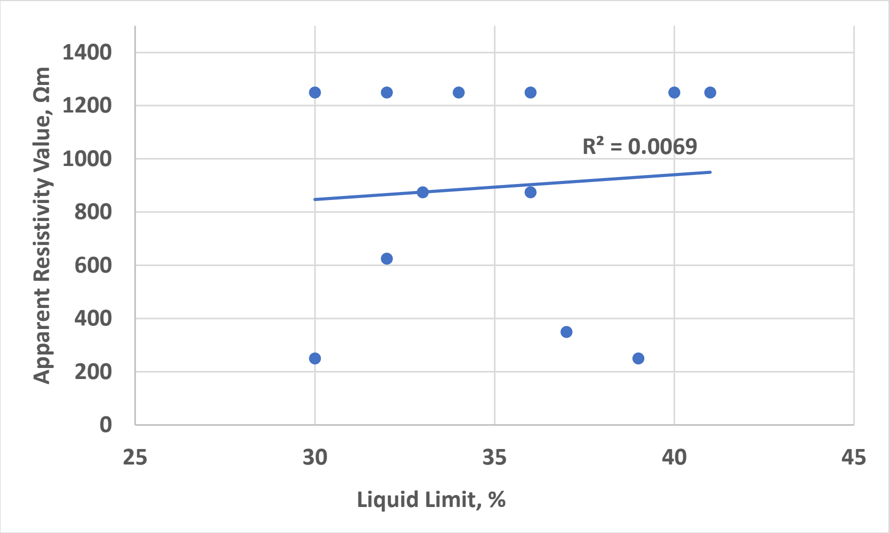

Fig. 4. Graph of apparent resistivity value versus liquid limit for Ayer Keroh, Melaka

The plotting of apparent resistivity values and SPT N-values for all sites: Ayer Keroh, Melaka; Jerantut, Pahang; Shah Alam, Selangor; and Senawang, Negeri Sembilan is presented in Figure 5. The R-squared value of 0.3016 indicates a weak correlation between the apparent resistivity value and the SPT N-value across all these sites.

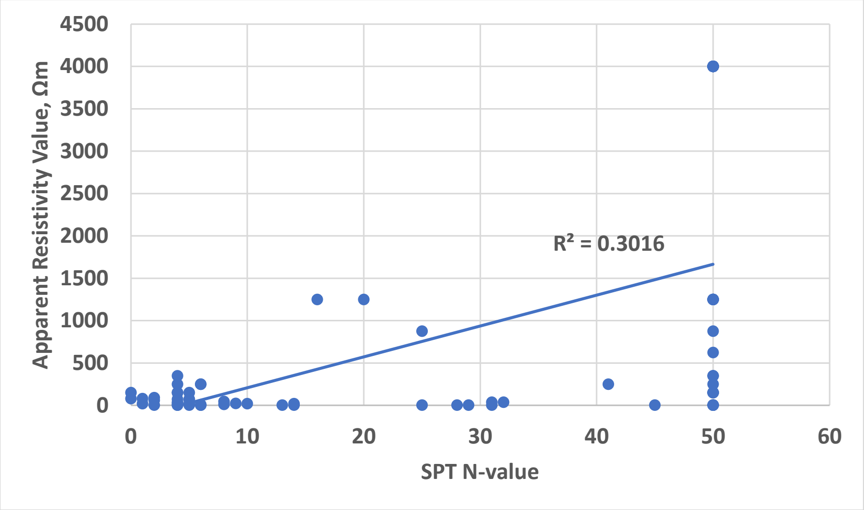

Fig. 5. Graph of apparent resistivity value versus SPT N-value for all sites

In addition, Figure 6 represents the graph illustrating the relationship between the apparent resistivity value and the fine grain soil content across all testing locations. The R-squared value of 0.2816 suggests no correlation between the apparent resistivity value and the fine grain soil across all sites.

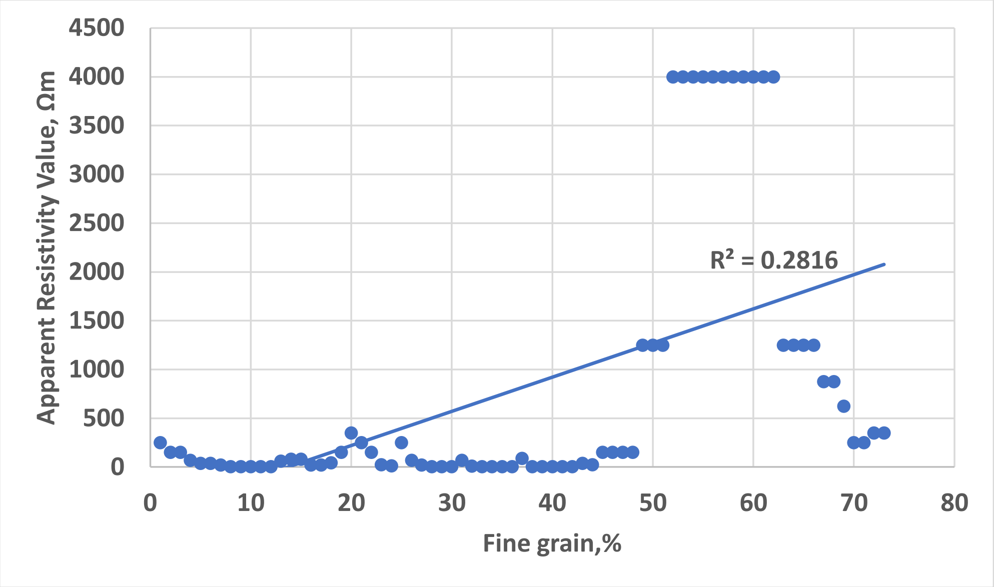

Fig. 6. Graph of apparent resistivity value versus fine grain soil overall for all sites

Meanwhile, Figure 7 depicts the graph showing the relationship between the apparent resistivity value and the liquid limit for all studied locations. The R-squared value of 0.1901 indicates no correlation between the apparent resistivity value and the liquid limit across all sites. All these plotting referring to Figure 5, 6 and 7, underscores the intricacies of subsurface conditions and strongly suggest that additional factors could be exerting influence on electrical resistivity values, irrespective of the SPT N-value, fine-grain soil composition, or liquid limit. This complexity highlights the need for a comprehensive understanding of the site's geotechnical aspects and emphasizes the importance of considering multiple factors when interpreting geophysical data.

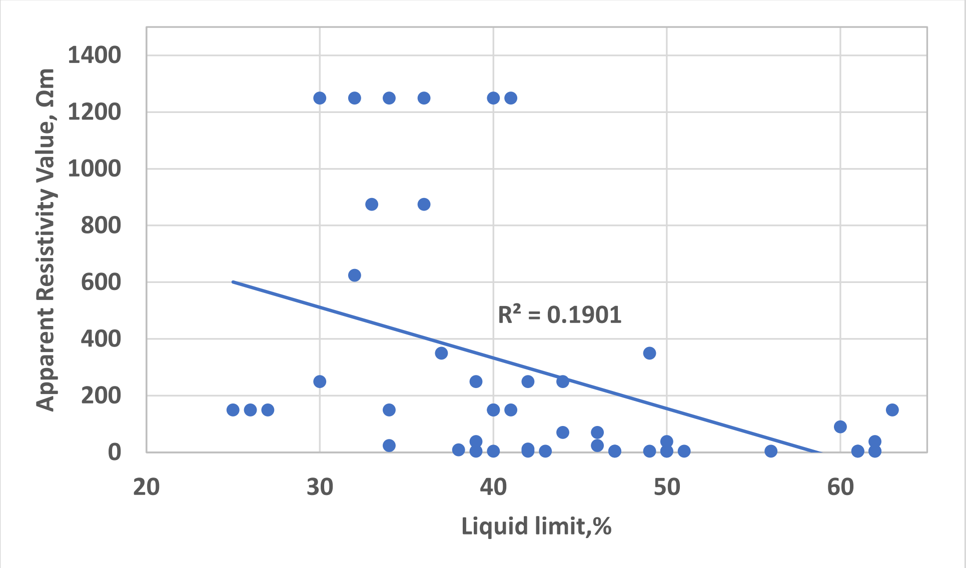

Fig. 7. Graph of apparent resistivity value versus liquid limit overall for all sites

3.2 Discussions

Table 2 summarizes the correlation between apparent resistivity values and borehole data at each testing site. Based on the information provided in the table, it can be concluded that there is no significant correlation between borehole parameters such as SPT N-value, fine grain soil, and liquid limit with the apparent resistivity values obtained from electrical resistivity tomography (ERT) testing.

Table 2
Summary of correlation of apparent resistivity value and borehole data at each site location

Borehole Parameters / Location	SPT N-value	Fine grain soil, %	Liquid limit, %
Ayer Keroh, Melaka	0.0918 (No correlation)	0.3591 (Weak)	0.0218 (No correlation)
Jerantut, Pahang	0.9799 (Very strong)	0.5596 (Moderate)	0.5725 (Moderate)
Shah Alam, Selangor	0.1152 (No correlation)	0.006 (No correlation)	0.0225 (No correlation)
Senawang, Negeri Sembilan	0.2522 (No correlation)	0.0588 (No correlation)	0.6348 (Moderate)

To further examine the correlation between apparent resistivity value and fine grain soil, it is valuable to consider Archie's Law. Archie's Law is based on an ideal model that assumes a proper classification of particle size distribution without the mixing of different sizes. Theoretically, coarser particle sizes exhibit a lower surface area-to-volume ratio, resulting in fewer interparticle voids and a more densely packed structure. Consequently, this leads to reduced overall porosity. According to Archie's Law [16], fine grain soil with higher porosity would be expected to demonstrate lower resistivity. However, in this research, no discernible relationship was found between these two parameters, contradicting previous research findings like Hatta and Osman [4], Listanti *et al.,* [5], Tello *et al*., [6], Mohd Hazreek *et al*., [7] and Malik *et al*., [17].

Apparent resistivity represents the observed resistivity at a specific location in the subsurface and is influenced by various factors, including the materials present related to porosity, degree of saturation, resistivity of groundwater, and survey configuration [18]. It provides an overall understanding of the resistivity distribution but does not directly reflect the true resistivity values of the materials. On the other hand, true resistivity refers to the actual inherent resistivity of the subsurface materials, independent of survey factors. In ERT, the purpose is to estimate the true resistivity distribution by interpreting the measured apparent resistivity data using mathematical inversion techniques.

4. Conclusions

The correlation analysis revealed that there was no significant correlation between the borehole parameters and the electrical resistivity values overall. This indicates that the resistivity data obtained from Electrical Resistivity Tomography (ERT) cannot be directly used to predict soil properties. For example, it is not possible to determine the SPT N-value based solely from an apparent resistivity value of 4000 Ωm. Similarly, deriving laboratory soil properties like the percentage of fine grains and liquid limit from an apparent resistivity value presents challenges. Therefore, this research clearly shows that site investigation procedures, such as borehole testing and laboratory soil testing, remain essential for a comprehensive understanding of the subsurface profile and properties. ERT, on the other hand, is most suitable for identifying underground water sources for tube well construction [19]. Additionally, ERT can effectively locate saturated ground conditions that may contribute to slope failure or impact the stability of retaining walls [20,21].

To overcome the limitation of ERT and improve the accuracy of the ground profile, it is suggested to consider integrating it with seismic-based techniques, such as seismic refraction, seismic reflection methods, or seismic surface wave methods, along with borehole data. Such integration can provide a more comprehensive subsurface characterization and enhance the reliability of predictions. In conclusion, this research highlights the importance of carefully selecting geophysical methods that align with specific project requirements and understanding the limitations of each technique in geotechnical engineering. By doing so, more accurate and reliable predictions of subsurface conditions can be achieved. Future studies may explore alternative or combined geophysical methods to further enhance the understanding of subsurface soil properties and advance geotechnical engineering practices.

Acknowledgement

This research was funded by a grant from the Research Management Center of Universiti Tun Hussein Onn Malaysia under Geran Penyelidikan Pascasiswazah (GPPS) with research grant number Q597 and Ministry of Higher Education (MOHE) through Fundamental Research Grant Scheme (FRGS/1/2020/TK01/UTHM/03/2).

References

[1] Reese, Lymon C. "Design and construction of drilled shafts." *Journal of the Geotechnical Engineering Division* 104, no. 1 (1978): 95-116. https://doi.org/10.1061/AJGEB6.0000579

[2] Kramer, Steven R., William J. McDonald, James C. Thomson, Steven R. Kramer, William J. McDonald, and James C. Thomson. "Pipe jacking and microtunnelling." *An Introduction to Trenchless Technology* (1992): 86-120. https://doi.org/10.1007/978-1-4615-7296-1_5

[3] Cueto, Manuel, Javier Olona, Gabriela Fernández-Viejo, Luis Pando, and Carlos López-Fernández. "Karst-induced sinkhole detection using an integrated geophysical survey: a case study along the Riyadh Metro Line 3 (Saudi Arabia)." *Near Surface Geophysics* 16, no. 3 (2018): 270-281. https://doi.org/10.3997/1873-0604.2018003

[4] Hatta, Khairul Anwar, and Syed Baharom Azahar Syed Osman. "Correlation of electrical resistivity and SPT-N value from standard penetration test (SPT) of sandy soil." *Applied Mechanics and Materials* 785 (2015): 702-706. https://doi.org/10.4028/www.scientific.net/AMM.785.702

[5] Listanti, Sinta Nur Rizqi, Darsono Darsono, and Yusep Muslih Purwana. "A Comparison between Drilling and Standard Penetration Test (SPT) Data to the Electrical Resistivity Sounding with Schlumberger Configuration in UNS Area." *Indones. J. Appl. Phys* 8, no. 2 (2018): 67-74. https://doi.org/10.13057/ijap.v8i2.17962

[6] Telló, Marcos, Lucas TC Pulz, Victor B. Telló, Renato G. Ferraz, Fábio F. Vidor, and Daniel S. Gazzana. "An Enhanced Soil Characterization Study Supported by Resistivity Data Processing and Standard Penetration Test." *IEEE Transactions on Industry Applications* 58, no. 1 (2021): 49-58. https://doi.org/10.1109/TIA.2021.3119266

[7] Abidin, Mohd Hazreek Zainal, Rosli Saad, Devapriya Chitral Wijeyesekera, Fauziah Ahmad, Mohamad Faizal Tajul Baharuddin, Saiful Azhar Ahmad Tajudin, and Aziman Madun. "The influences of basic physical properties of clayey silt and silty sand on its laboratory electrical resistivity value in loose and dense conditions." *Sains Malaysiana* 46, no. 10 (2017): 1959-1969. https://doi.org/10.17576/jsm-2017-4610-35

[8] Cosenza, Philippe, Eric Marmet, Faycal Rejiba, Yu Jun Cui, Alain Tabbagh, and Yvelle Charlery. "Correlations between geotechnical and electrical data: A case study at Garchy in France." *Journal of Applied Geophysics* 60, no. 3-4 (2006): 165-178. https://doi.org/10.1016/j.jappgeo.2006.02.003

[9] Madun, Aziman, M. E. Ahmad Supa'at, S. A. Ahmad Tajudin, M. H. Zainalabidin, S. Sani, and M. F. Yusof. "Soil investigation using multichannel analysis of surface wave (MASW) and borehole." *ARPN Journal of Engineering and Applied Sciences* 11, no. 6 (2016): 3759-3763.

[10] Clayton, C. R. I. "Stiffness at small strain: research and practice." *Géotechnique* 61, no. 1 (2011): 5-37. https://doi.org/10.1680/geot.2011.61.1.5

[11] Johnson, Timothy C., and D. Wellman. "Accurate modelling and inversion of electrical resistivity data in the presence of metallic infrastructure with known location and dimension." *Geophysical Journal International* 202, no. 2 (2015): 1096-1108. https://doi.org/10.1093/gji/ggv206

[12] Jusoh, Hisyam, and Syed Baharom Syed Osman. "The correlation between resistivity and soil properties as an alternative to soil investigation." *Indian Journal of Science and Technology* 10, no. 6 (2017): 1-5.

[13] Cygal, Adam, Michał Stefaniuk, Anna Kret, and Monika Kurowska. "The application of electrical resistivity tomography (ERT), induced polarization (IP) and electromagnetic conductivity (EMC) methods for the evaluation of technical condition of flood embankment corpus." *Geology, Geophysics and Environment* 42, no. 3 (2016): 279-279. https://doi.org/10.7494/geol.2016.42.3.279

[14] Chrétien, M., J. F. Lataste, R. Fabre, and A. Denis. "Electrical resistivity tomography to understand clay behavior during seasonal water content variations." *Engineering geology* 169 (2014): 112-123. https://doi.org/10.1016/j.enggeo.2013.11.019

[15] Martin, R. P., and S. R. Hencher. "Principles for description and classification of weathered rock for engineering purposes." *Geological Society, London, Engineering Geology Special Publications* 2, no. 1 (1986): 299-308. https://doi.org/10.1144/GSL.1986.002.01.53

[16] Archie, Gustave E. "The electrical resistivity log as an aid in determining some reservoir characteristics." *Transactions of the AIME* 146, no. 01 (1942): 54-62. https://doi.org/10.2118/942054-G

[17] Abd Malik, A. K., A. Madun, MK Abu Talib, N. Wahab, and MF Md Dan. "Interpretation of soil grain size effect on electrical resistivity method." *Physics and Chemistry of the Earth, Parts A/B/C* 129 (2023): 103324. https://doi.org/10.1016/j.pce.2022.103324

[18] Tsourlos, Panagiotis I., John E. Szymanski, and Gregory N. Tsokas. "The effect of terrain topography on commonly used resistivity arrays." *Geophysics* 64, no. 5 (1999): 1357-1363. https://doi.org/10.1190/1.1444640

[19] Ashraf, M. A. M., R. Yusoh, M. A. Sazalil, and M. H. Z. Abidin. "Aquifer characterization and groundwater potential evaluation in sedimentary rock formation." In *Journal of Physics: Conference Series*, vol. 995, no. 1, p. 012106. IOP Publishing, 2018. https://doi.org/10.1088/1742-6596/995/1/012106

[20] Aziman, M., Z. A. M. Hazreek, A. T. S. Azhar, K. A. Fahmy, T. B. M. Faizal, M. Sabariah, K. Ambak, and M. A. M. Ismail. "Electrical resistivity technique for groundwater exploration in quaternary deposit." In *Journal of Physics: Conference Series*, vol. 995, no. 1, p. 012110. IOP Publishing, 2018. https://doi.org/10.1088/1742-6596/995/1/012110

[21] Szalai, Sándor, Kitti Szokoli, Mohamed Metwaly, Zoltán Gribovszki, and Ernő Prácser. "Prediction of the location of future rupture surfaces of a slowly moving loess landslide by electrical resistivity tomography." *Geophysical Prospecting* 65, no. 2 (2017): 596-616. https://doi.org/10.1111/1365-2478.12421