https://doi.org/10.1051/bioconf/202413104014

Application of Electrical Resistivity Tomography and Induced Polarization for Pre-Construction Site Assessment in Ipoh, Perak, Malaysia

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Abstract. This study investigates the application of Electrical Resistivity Tomography (ERT) and Induced Polarization (IP) methods for subsurface characterization at a proposed construction site in Ipoh, Perak, Malaysia. The research aims to determine the subsurface resistivity distribution and identify geological features critical for construction planning. By employing ERT and IP techniques along 2 profiles, L1 and L2 at the site, the study evaluates variations in soil and rock characteristics and potential instability zones. The results indicate that areas with high resistivity (11 to 93 Ωm), corresponding to fractured limestone, exhibit greater stability, while regions with low resistivity (20-69 Ωm) and higher chargeability (5-10 msec) are clay-rich and pose potential risks. Borehole data were integrated to validate geophysical findings, revealing an absence of solid bedrock, necessitating careful foundation design to ensure structural stability. The combined use of ERT and IP using machine learning (twostep clustering) analysis provides a comprehensive understanding of subsurface conditions, supporting informed decision-making for construction projects and mitigating risks associated with subsurface uncertainties.

1 Introduction

Geophysical inquiries have become an integral part of modern geological and engineering practices due to their ability to investigate subsurface conditions without resorting to intrusive methods. Among the array of geophysical techniques available, Electrical Resistivity Tomography (ERT) and Induced Polarization (IP) have emerged as powerful tools for detailed subsurface characterization [1-3]. These techniques are particularly effective in delineating geological formations, assessing hydrogeological properties, and supporting various engineering and environmental applications [4].

ERT and IP methods provide complementary insights into the subsurface, with ERT focusing on the resistivity distribution of underground materials and IP measuring the ability of these materials to store electrical charge [5]. The integration of these techniques allows for a comprehensive approach to subsurface visualization, offering detailed information on the

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electrical resistivity and chargeability features of geological formations. This dual approach is crucial for understanding complex subsurface dynamics, identifying lithological variations, and assessing potential hazards [6].

The primary objective of this study is to employ ERT and IP methodologies to evaluate the subsurface conditions at a proposed construction site in Ipoh, Perak, Malaysia. The site is currently characterized by unknown subsurface features, which poses significant challenges for assessing feasibility and risks associated with construction. A thorough understanding of the subsurface is essential to ensure the stability and safety of heavy structures, preventing potential structural failures, financial losses, and safety hazards [7].

This study aims to bridge the knowledge gap by providing a detailed geophysical characterization of the site. By analyzing differences in soil and rock properties and areas of possible instability, the study seeks to determine the site's suitability for large and heavy buildings. The results will inform the design and construction processes, contributing to risk reduction and the structural soundness of the project. This research also aims to advance the application of ERT and IP techniques in geophysical exploration, with implications for environmental monitoring, mineral prospecting, and civil engineering.

2 Methodology

2.1 Study Area

The study was conducted at a proposed construction site in Ipoh, Perak, Malaysia, located at coordinates 4°36’1.8” N and 101°4’32.88” E as shown in Fig. 1. The region is characterized by a limestone bedrock formation known as the Kinta Limestone, which presents significant geological features including steep limestone hills and granitic uplands on the valley edges.

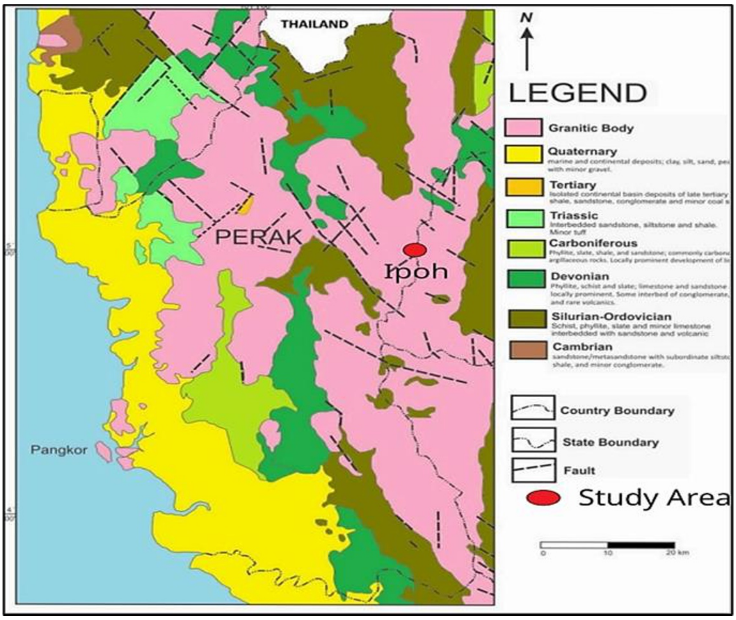


Fig. 1. The geological map of the study area at Ipoh, Perak [8].

2.2 Data Acquisition

Two primary geophysical techniques, Electrical Resistivity Tomography (ERT) and Induced Polarization (IP), were employed to investigate the subsurface conditions. The survey was conducted using the ABEM SAS4000 Terrameter with a Wenner-Schlumberger array configuration. The survey consisted of two intersecting lines, labeled L1 and L2, each spanning 200 m with an electrode spacing of 5 m. The lines intersected at borehole BH2, which was 50 m along L1 and 50 m along L2.

Fig. 2. Map showing the layout of the profile line during data acquisition.

2.3 Borehole Drilling

Four boreholes (BH1, BH2, BH3 and BH4) were drilled using conventional rotary drilling techniques with water as the flushing medium. The boreholes were strategically located to validate the geophysical survey results and to provide detailed information on soil and rock characteristics through standard penetration testing (SPT) [9].

2.4 Data Processing and Inversion

The field data collected from the resistivity surveys were processed and inverted using Res2Dinv software. The inversion process involved setting a robust inversion method to handle potential outliers and noise. A Least Squares Inversion technique was applied to generate 2D models of the subsurface from the apparent resistivity data and IP models. Three distinct resistivity model sections were produced: measured apparent resistivity, calculated apparent resistivity, and inverse model resistivity. The inversion process included five iterations to enhance model accuracy by minimizing the discrepancy between observed and computed resistivity and IP values. The borehole data were integrated with the geophysical survey results to provide a comprehensive understanding of the subsurface conditions. The alignment of borehole records with the resistivity profiles allowed for identifying variations in soil composition, stratigraphy, and other geological features.

3. Results and Discussion

The geophysical surveys conducted using Electrical Resistivity Tomography (ERT) and Induced Polarization (IP) techniques provided a detailed characterization of the subsurface conditions at the study site. The results from the 2D resistivity surveys revealed distinct layers with varying resistivity values along the survey lines.

3.1 Survey Line 1 Results

Figure 3 shows resistivity Line L1, which spans 200 meters and reaches a depth of 40 meters, the inversion model showed the topsoil layer with resistivity values of 192.66 to 265.40 Ωm, extending to around 0 to 3 m. Below this, medium stiff to soft clay with some silt, observed from 1.50 to 9.45 m deep in Borehole BH2, exhibited low to medium resistivity values of 20 to 69 Ωm [10]. In Borehole BH3, continuous silt and sand composition down to 45 meters had resistivity values of 29 to 57 Ωm. A layer between 40 and 65 meters along the line displayed resistivity values of 11 to 93 Ωm, indicating moderately weathered fractured limestone, with high resistivity values (100 to 1000 Ωm) suggesting limestone intrusions.

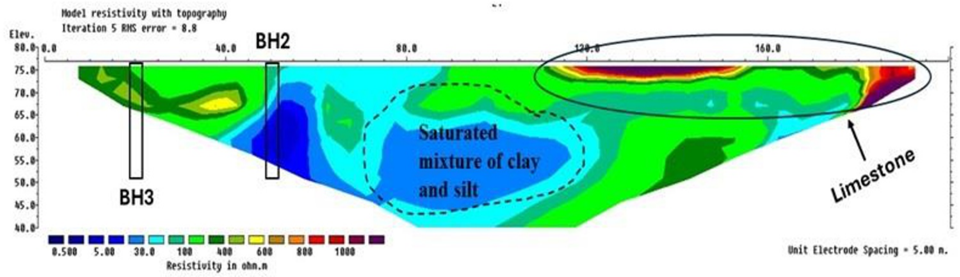


Fig. 3. Resistivity model L1.

The IP model for Line L1 as shown in Fig. 4, provided insights into the chargeability of subsurface materials. The clay with silt layer described in BH2 had medium chargeability values ranging from 5 to 10 msec [11], while BH3 showed IP values ranging from 5 to 12 msec for silt and sand layers. Limestone in BH2 exhibited IP values of 10 to 20 msec, reflecting low chargeability due to the absence of significant metallic minerals.

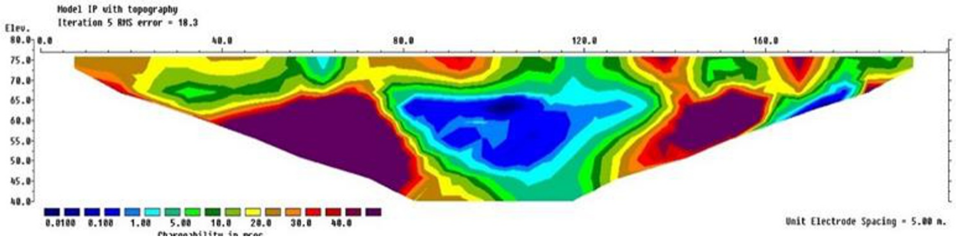


Fig. 4. IP model L1.

3.2 Survey Line 2 Results

For Resistivity Line L2, which also spans 200 meters and reaches a depth of 40 meters, the topsoil and superficial layers extended to approximately 3 m, with very low SPT N-values indicating very loose soil conditions. Medium stiff to soft clay with some silt from around 1.50 to 9.45 meters deep in BH2 showed resistivity values between 20 to 69 Ωm, while medium stiff to very stiff silt with clay and sand from around 1.50 to 24.50 meters deep in BH4 showed resistivity values ranging from 20 to 97 Ωm. At greater depths, fractured limestone in BH2 and BH4 showed resistivity values ranging from 11 to 93 Ωm [7].

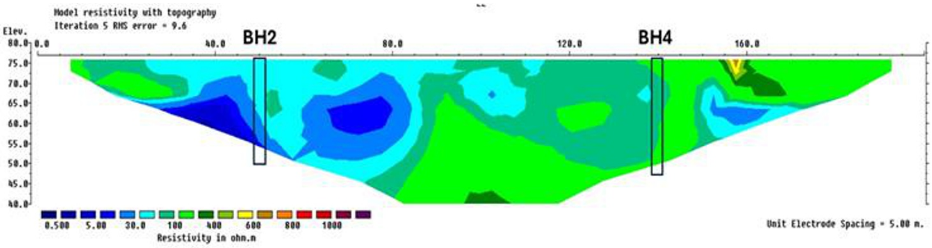


Fig. 5. Resistivity model L2.

The IP model for Line L2 highlighted chargeability characteristics of different subsurface materials. The medium stiff to soft clay layer at 50 meters along the line, from around 1.50 to 9.45 meters deep, had chargeability values ranging from 3 to 10 msec. In BH4, the medium stiff to very stiff silt with clay and sand layers showed IP values between 5 to 10 msec. The fractured limestone layer seen in both BH2 and BH4 exhibited chargeability values typically ranging from 10 to 20 msec.

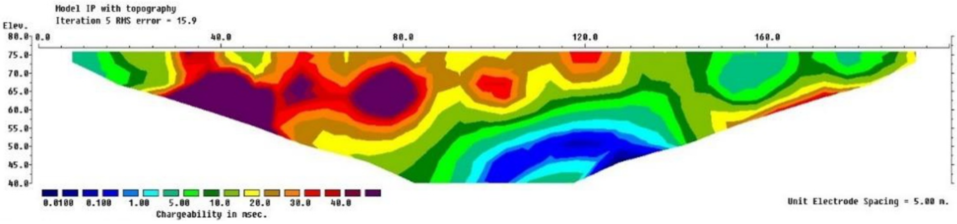
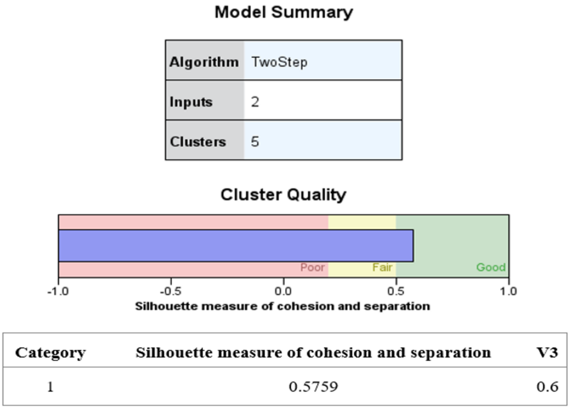


Fig. 6. IP model L2.

3.3 Twostep Clustering Analysis

Two-step clustering is a method used to group large datasets into meaningful clusters, handling both continuous and categorical data. It combines k-means and hierarchical clustering to manage large datasets efficiently and handle both continuous and categorical variables. In this study, this method effectively categorized the resistivity and induced polarization data into five distinct clusters. The k-means algorithm initially grouped the data into small sub-clusters by minimizing within-cluster variance, and hierarchical clustering further refined these sub-clusters by merging the closest pairs based on their distances. The utilization of this method proves to be highly advantageous in the realm of resistivity investigations and induced polarization analyses, particularly in the classification of geological formations according to their electrical characteristics. By utilizing two-step clustering, patterns and groupings within the resistivity and induced polarization data can be discovered, leading to more accurate interpretations of subsurface structures (Table 1). In this study, the clustering solution achieved a silhouette score of 0.6, which indicates good level of cohesion and separation, suggesting that the identified clusters are reasonably well-defined. Figure 7 below shows the two step clustering outputs related to the resistivity and induced polarization models.



Model Summary

Algorithm	TwoStep
Inputs	2
Clusters	5

Cluster Quality

Category	Silhouette measure of cohesion and separation	V3
1	0.5759	0.6

Fig. 7. Two-step clustering outputs from SPSS analysis.

Table1. Integration of geophysical parameters and engineering N-values.

Cluster No.	Range of resistivity values (Ωm)	Range of chargeability values (msec)	SPT (N) values	Lithologic units
1	192.66 - 265.40	4.057 – 20.63	0 - 3.45	Topsoil
2	145.29 - 195.68	4.029 – 19.19	3.45 - 6.45	Medium stiff, medium brown CLAY with a little silt
3	57.85 - 95.82	4.12 – 39.43	6.45 - 16.95	Medium stiff, very stiff brown SILT with a trace of clay
4	47.11 - 129.52	7.90 – 35.81	16.95 - 31.95	Light grey to pale grey moderately weathered fractured limestone
5	53.42 - 256.5	5.09 – 13.29	31.95 - 37.95	Medium brown SILT with some sand

These clustering results corresponded well with the identified subsurface layers, aiding in the interpretation of geophysical data. The integration of ERT and IP techniques provided a detailed and accurate characterization of the subsurface conditions at the study site. Areas with high resistivity values corresponded to fractured limestone, which offered greater stability, while regions with low resistivity and higher chargeability values indicated clay-rich areas that posed potential risks for construction [1,12]. Borehole data corroborated the geophysical survey findings, revealing an absence of solid bedrock and highlighting the importance of careful foundation design to ensure structural stability. This study demonstrates the effectiveness of combining ERT and IP methods for subsurface investigations, providing valuable insights for construction planning and risk mitigation. The findings emphasize the need for additional boreholes to greater depths to accurately locate solid bedrock, ensuring reliable data for foundation design and improving the overall stability and safety of construction projects [13-16].

4. Conclusion

This study utilized Electrical Resistivity Tomography (ERT) and Induced Polarization (IP) techniques to assess subsurface conditions at a proposed construction site in Ipoh, Perak, Malaysia. The findings revealed significant subsurface variations, with high resistivity areas indicating stable fractured limestone and low resistivity areas suggesting clay-rich instability zones. Borehole data validated these results, underscoring the need for careful foundation design. This integrated geophysical approach provides critical insights for construction planning and risk mitigation, emphasizing the importance of additional boreholes to accurately locate solid bedrock and ensure structural stability to locate solid bedrock and ensure structural stability accurately.

Acknowledgement

We would like to express our sincere gratitude to all laboratory staff for their invaluable guidance, support, and encouragement throughout the course of this research. Their expertise and insights were instrumental in the successful completion of this study. We also want to express our authors' gratitude to Universiti Sains Malaysia (USM) for the GOT Incentives (R502-KRGOT001-0000000157-K134), which have enabled the funding of this research endeavours.

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