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CASE STUDY

Subsurface Evaluation: A Case Study at Universiti Pertahanan Nasional Malaysia, Malaysia

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Abstract

Accurate subsurface information is essential for determining rock and soil layers for excavation works. This paper presents a subsurface evaluation (rock and soil) through the correlation of seismic refraction and 2-D resistivity values in a weathered sedimentary rock area. Borehole log data were also used to validate the subsurface data obtained from both methods. The study site was located at a construction site within Universiti Pertahanan Nasional Malaysia, Kuala Lumpur. The subsurface profile was produced by integrating data from seismic refraction, the 2-D resistivity method, and borehole logs to provide a more accurate depiction of the subsurface, particularly the bedrock profile.

Keywords: Subsurface, Seismic Refraction, Resistivity, Boreholes, Excavation

Introduction

Determining subsurface characteristics from borehole data alone is often inadequate due to the varied locations and distances between boreholes [1]. Geophysical methods such as the 2-D resistivity method and the seismic refraction method are employed to provide continuous subsurface information along the lines of investigation within the study area [2]. Accurate bedrock profiling is particularly crucial when construction development occurs in weathered sedimentary rock areas [3]. Surface excavation in tropically weathered sedimentary rock masses is challenging and frequently leads to disputes among engineers and clients in engineering projects [4]. These uncertainties encompass the selection of excavation methods, the types of machinery, and the rate of excavatability [5]. These decisions significantly impact the cost and time required for the entire project. Incorrect estimations or decisions made during the preliminary design phase can lead to unnecessary costs and substantial project delays. This study presents results from 2-D resistivity and seismic refraction methods, combined with borehole log data, to provide more accurate subsurface information, particularly for bedrock profiling. The integrated approach offers a more realistic assessment of the subsurface conditions encountered.

In construction projects, surface excavation work often becomes a point of contention between contractors and clients, especially when there is no mutual agreement regarding the cost of excavating rock and soil. This is due to the loosely defined terms “rock” and “soil” in contract documents. The term “hard material,” commonly used in contracts, can be confusing as it encompasses a wide range of materials, from dense soil to fresh rock. Similarly, the term “weathered rock” and its excavation methods are often subjectively and variably defined.

Complications further arise in sedimentary rock masses where interbedding of different rock layers can lead to misjudgments during early excavation assessments [6]. Different rock types have varying weathering profiles, and most existing rippability assessment methods are less accurate as they do not account for the weathering states across different rock mass layers. A more appropriate and practical rippability assessment method is needed to economically evaluate the site during the preliminary stage [7]. Typically, blasting is only considered when the physical limits of ripping are reached or when ripping becomes uneconomical [8]. Reliable subsurface information is crucial for many civil engineering purposes. Traditionally, subsurface parameters are primarily determined from borehole data. However, borehole logs provide information only at discrete locations, and often, information from several boreholes is combined to create a cross-section representing the subsurface profile of a wider area. This method is limited by the spatial distribution and distances between boreholes.

To improve subsurface information, geophysical methods such as seismic refraction and 2-D resistivity have been introduced [9, 10]. These methods provide continuous data along investigation lines, offering a more comprehensive view of the subsurface. By integrating traditional geotechnical methods with seismic velocity data, a more accurate correlation can be achieved [11]. This correlated data can then be used to categorize machinery for excavation work based on systematic analysis procedures for predicting rock rippability. The seismic velocity profile helps interpret rock layers within the ranges classified as rippable. The objectives of this study are to identify the subsurface profile using the seismic refraction method, 2-D resistivity methods, and borehole data and produce profile imaging that provides a better understanding of the bedrock and thickness, facilitating the appropriate selection of excavation methods for the project.

Review Study

Borehole

The conventional method of investigating the subsurface profile using drilling boreholes is relatively expensive and provides information only at discrete locations [12]. Soil and rock profiles are represented by borehole logs at specific locations. The description of the drilled material (bore log), the results of the standard penetration test (SPT), and the Rock Quality Designation (RQD) value are used as quantitative measures of the subsurface characteristics. According to Muhammad et al. [13], the characteristics of the rock mass can be determined and clearly described by seismic refraction at shallow depths when correlated with borehole data. However, seismic refraction alone cannot accurately describe the quality of the rock mass compared to information from boreholes (RQD value).

Seismic Refraction Method

Seismic refraction is a geophysical method used to investigate subsurface ground conditions by utilizing surface-sourced seismic waves. Data acquired on-site are processed and interpreted using computer models to produce seismic velocity and layer thickness models of the subsurface ground structure (see Figure 1). The method is commonly used to measure the thickness of overburden in areas where bedrock is at depth and to assess rippability parameters. According to Liang et al. [14], the assessment of tropically weathered sedimentary rocks cannot be accurately carried out using seismic velocity alone. The strength of rocks like granite can be estimated by the velocity of seismic waves (Primary or Secondary waves) propagating through the granite body. In tropical regions like Malaysia, chemical reactions between rainwater and the chemicals contained in the granite body can alter the rock strength through a process called weathering. The weathered grade of granite can be differentiated by the velocity of the P-wave propagating through the materials.

Figure 1. Seismic refraction equipment for the survey

Seismic Refraction Interpretation

The strength of rocks like granite can be estimated using the velocity of seismic waves (Primary or Secondary waves) propagating into the granite body (Table 1). In tropical regions like Malaysia, chemical reactions between rainwater and the chemicals contained in the granite body can alter the rock strength through a process called weathering. Granitic rock can be divided into five grades, as mentioned below. The weathered grade of granite can be differentiated by the velocity of the P-wave propagating through the materials.

Table 1. Geological classification of granite weathering profile against P-Wave velocity [14]

Geological Classification	P-Wave Velocity (km/sec)	N Value (%)	RQ Value (%)
Residual Soils	0.4-1.0	Less than 50	-
Completely Weathered Granite	1.0-1.7	50-65	Less than 50
Highly Weathered Granite	1.7-2.1	57-75	50-70
Moderate Weathered Granite	2.1-2.7	75-85	70-85
Fresh Granite	Over 2.7	Over 85	Over 85

2-D Resistivity Method

Ground resistivity survey methods have been widely used to address engineering, archaeology, environmental, and geological problems over the last few decades [15]. Subsurface resistivity distributions are measured by injecting electrical current into the ground using two current electrodes. Potential differences caused by the current flow between any two points in a linear line with the current electrodes are then measured using a pair of potential electrodes. From the measured voltage (V) and current (I) values, the resistance at the specified point in the subsurface can be determined. The differences in values of seismic refraction and resistivity for common rocks and materials are shown in Table 2.

Methodology and Study Area

This study was conducted at Universiti Pertahanan Nasional Malaysia, Malaysia. The research was carried out within the following limitations:

a. The study location is situated within a granite formation.

b. Subsurface data were obtained from four boreholes, with a focus on boreholes number 3 (BH3) and number 4 (BH4).

c. The geophysical survey comprised three resistivity survey lines and seven seismic lines within the study area.

d. The excavation methods studied were limited to surface excavation with direct mechanical excavation.

The study was conducted at the proposed new building site for a research complex within Universiti Pertahanan Nasional Malaysia, Malaysia. Seismic refraction and 2-D resistivity surveys were performed to detect the bedrock profile and estimate the depth of the granite body in the study area. Additionally, four boreholes were drilled, as shown in Figure 2, to determine the soil properties. Three resistivity survey lines and seven seismic lines were established within the study area (Figure 3). However, for this study, only borehole 3 (BH3) and borehole 4 (BH4), which are close to the survey lines within the new building layout, have been analyzed.

Table 2. Resistivity and velocity of some common rocks and minerals [16]

Material	Seismic (m/s)	Resistivity (Ohm-m)
Igneous/Metamorphic		
Granite	4580-5800	$5x10^3$-10^8
Weathered Granite	305-610	1-10^2
Basalt	540-6400	10^3-10^6
Quartz		10^3-$2x10^6$
Marble		10^2-$2.5x10^8$
Schist		20-104
Sediments		
Sandstone	1830-3970	8-$4x10^3$
Conglomerate		$2x10^3$-10^4
Shale	2750-4270	20-$2x10^3$
Limestone	2140-6100	50-$4x10^2$
Unconsolidated Sediment		
Clay	915-2750	1-100
Alluvium	500-2000	10-800
Marl		1-70
Clay (wet)		20
Groundwater		
Fresh Water	1430-1680	10-100
Salt Water	1460-1530	0.2

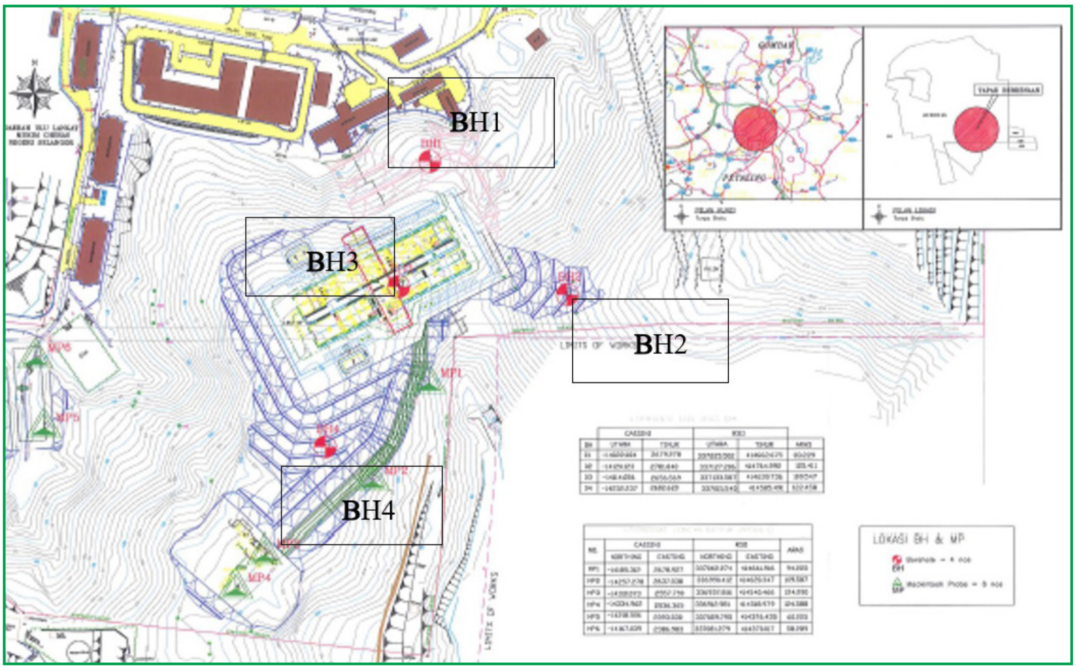

Figure 2. Layout plan for borehole

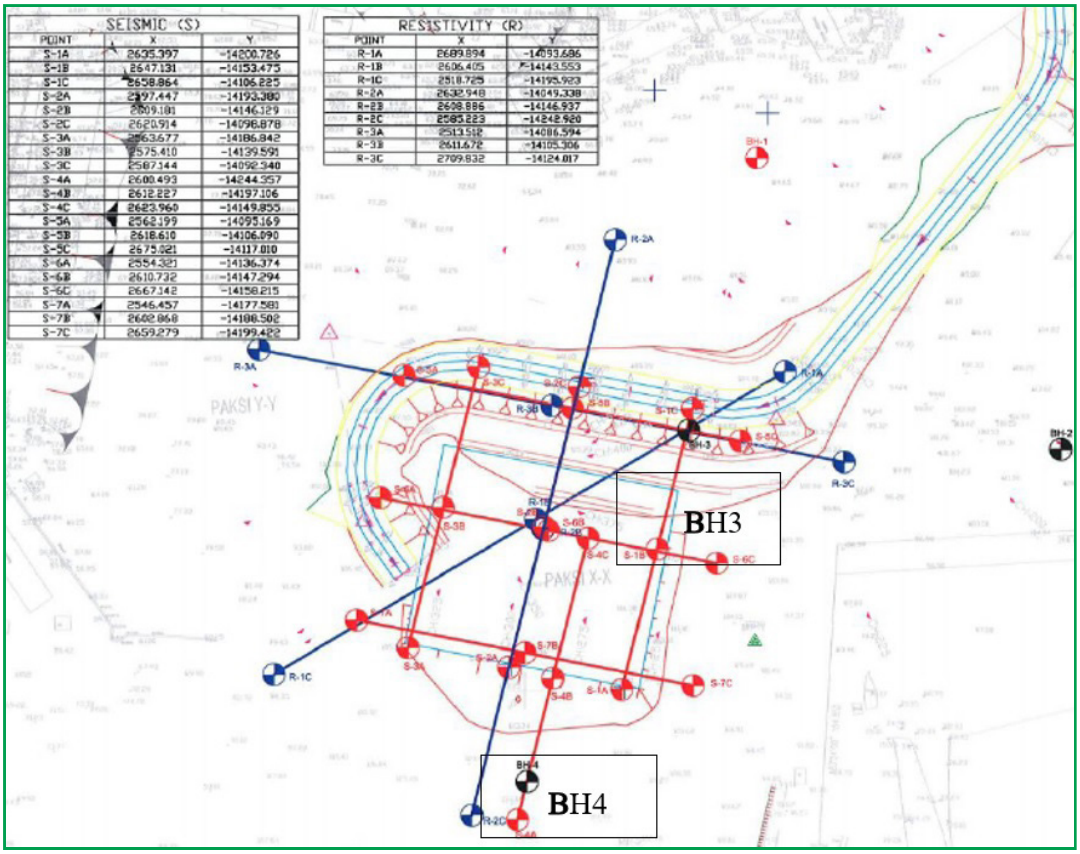

Figure 3. Resistivity and 7 seismic refraction survey lines

Rippability Assessments

Rippability assessment requires the evaluation of several rock mass parameters from core borings and/or geophysical work [17]. Six geological factors that are likely to influence rippability have been identified. Five factors are related to subsurface rock masses, including type, structure, hardness, weathering, and fabric, while the sixth factor is directly related to seismic wave velocity. The speed of a seismic wave depends on the density and degree of cementation of materials. Rock masses with lower wave velocities are generally more easily ripped. The seismic wave velocity method for rippability assessment was first developed in the last century by the Caterpillar Tractor Company [18]. The physical principle behind determining rippability is that seismic waves travel faster through rock with higher mass density than through less consolidated rock. Wave velocity is influenced by geological factors such as rock hardness, stratification, degree of fracturing, and amount of decomposition or weathering, all of which affect rippability.

In general, a lower seismic wave velocity indicates material that is more easily rippable [19]. Caterpillar has found that comparing wave velocities recorded with those obtained in similar materials from previous experience provides a good indication of ripper performance. They have published charts showing ripper performance related to seismic wave velocities for their equipment [18]. Rippability can be classified qualitatively as rippable, marginal, or non-rippable. Alternatively, it can be assessed semi-quantitatively on a scale of rippability ratings from 0 to 100, where 0 represents highly rippable and 100 represents unrippable. In either case, rippability is a dimensionless parameter. In this study, [18] was used to assess the rippability of investigated sedimentary rocks based on seismic wave velocity values (Figure 4).

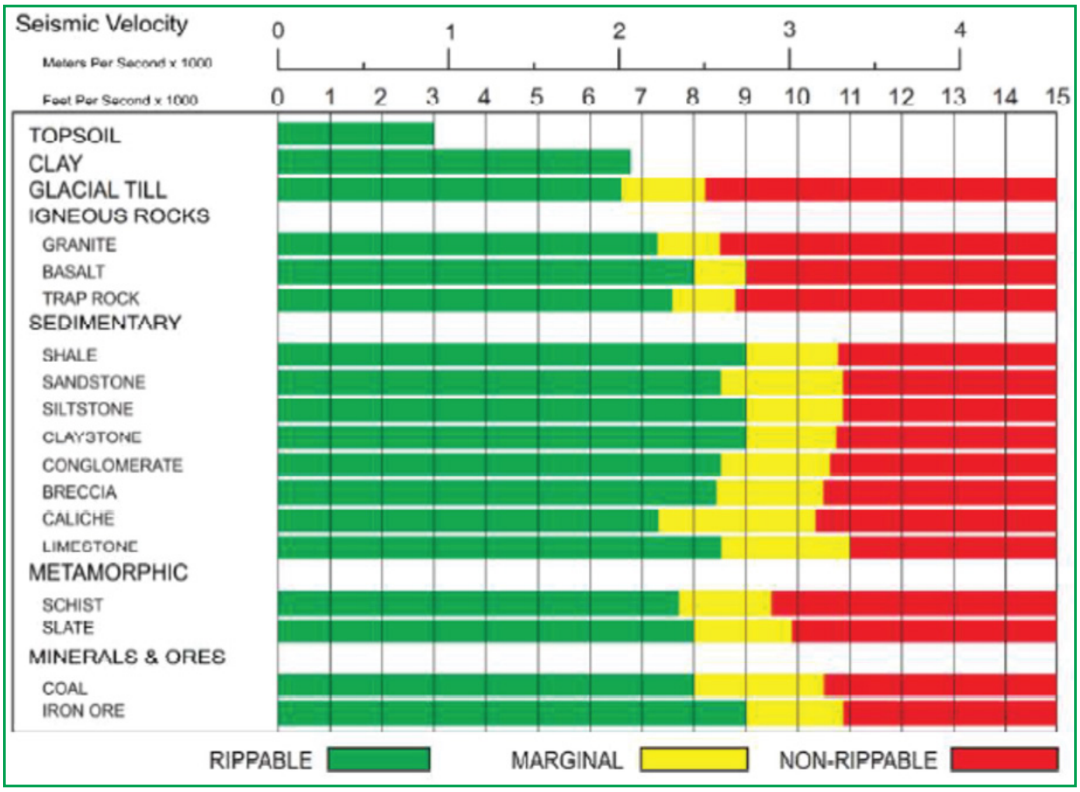

Figure 4. Rippability classification of different rock masses according to their P-wave seismic velocity values [18]

Results and Discussion

Borehole Record

According to the borehole log for BH3 (Figure 5), the soil type consists of silt from 0.00 to 21.5 meters depth, transitioning to granite from 21.5 meters to the termination depth of 24.6 meters. For borehole BH4, granite was encountered from 14.5 meters depth to 19 meters.

Resistivity Imaging Interpretation

Fresh granite generally exhibits higher resistivity values, which can reach up to 106 Ωm. However, in Malaysia's equatorial weather conditions, the physical properties of granite undergo changes, becoming more electrically conductive, especially in higher weathered grades of granite. In the study area, fresh granite outcrops are not present, except at the toe of the hill beside the entrance road to the site (under construction area), where it appears as highly to medium weathered granite (Table 3). This type of residual granite is expected to exhibit low resistivity values. Generally, the results and interpretation of the resistivity survey are shown in Figures 6-11.

BH3

Depth (m)	Lithology
1.00	Silt
2.00	Silt
3.00	Silt
4.00	Silt
5.00	Silt
6.00	Silt
7.00	Silt
8.00	Silt
9.00	Silt
10.00	Silt
11.00	Silt
12.00	Silt
13.00	Silt
14.00	Silt
15.00	Silt
16.00	Silt
17.00	Silt
18.00	Silt
19.00	Silt
20.00	Silt
21.00	Silt
21.50	Silt
22.00	Granite
23.00	Granite
24.00	Granite
24.60	Granite

BH4

Depth (m)	Lithology
1.00	Silt
2.00	Silt
3.00	Silt
4.00	Silt
5.00	Silt
6.00	Silt
7.00	Silt
8.00	Silt
9.00	Silt
10.00	Silt
11.00	Silt
12.00	Silt
13.00	Silt
14.00	Silt
14.50	Silt
15.00	Granite
16.00	Granite
17.00	Granite
18.00	Granite
19.00	Granite

Figure 5. Borehole Record for BH3 and BH4

Table 3. Interpretation of resistivity value for the study area

Resistivity Value	Material	Grade	Mark
< 1000 Ωm	Residual soil, highly weathered granite or fractured rock contained with water	(Grade V-VI)	blue-light green colour
1000 - 3000 Ωm	Medium weathered granite	(Grade III-Grade IV)	dark green - orange colour
> 3000 Ωm	Low weathered to fresh granite	Grade I-Grade II	Red-purle colour

2-Dimensional Subsurface Profile

The results of the 2-Dimensional electrical resistivity application for this study are shown in Figures 6 to 8.

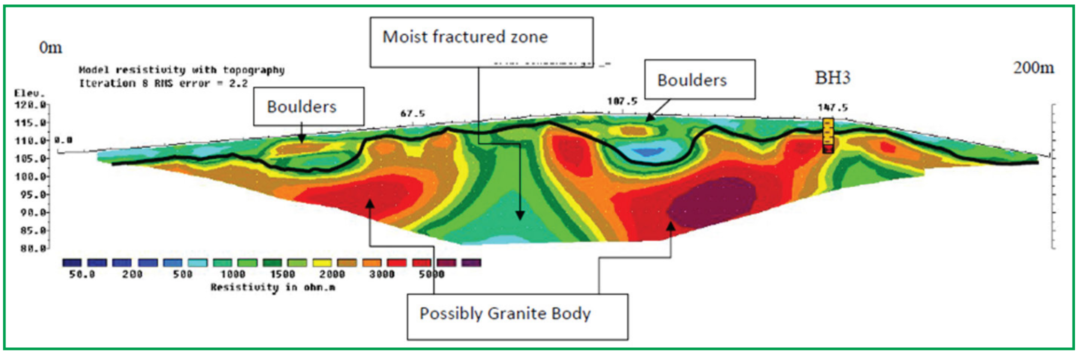

Figure 6. 2-Dimensional electrical resistivity imaging pseudosection along Line RS1

Interpretation for Line RS1

- Granite bodies are very shallow, with a depth between 5 to 15 meters from the surface (<1000 Ωm), as indicated by the area separated by the black line in the resistivity profile above.
- This layer is likely rippable and is expected to represent Grade V to Grade VI granite.
- There are some areas where boulders are present between 45 to 60 meters and 105 to 115 meters along the line.
- A fractured zone, likely moist and possibly water-filled, is indicated by low resistivity values present at 75 to 95 meters.
- Borehole BH3 shows good correlation with the resistivity data, both indicating a hard layer at 10 meters below the surface.

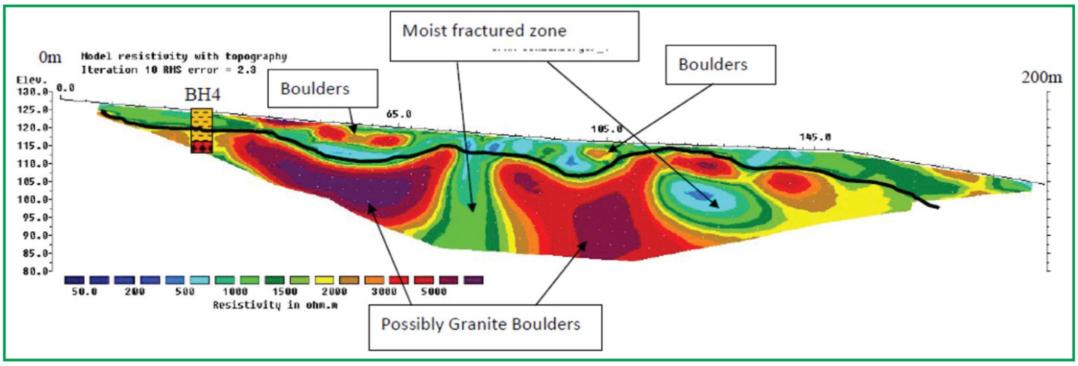

Figure 7. 2-Dimensional electrical resistivity imaging pseudosection along Line RS2

Interpretation for Line RS2

- Granite bodies are very shallow, with a depth between 5 to 15 meters from the surface (<1000 Ωm), as indicated by the area separated by the black line in the resistivity profile above.
- This layer is likely rippable and is expected to represent Grade V to Grade VI granite.

- There are some areas where a boulder layer is present between 40 to 65 meters and 103 to 107 meters along the line.
- A fractured zone, likely moist and possibly filled with water, is indicated by low resistivity values present at 75 to 90 meters, similar to RS1.
- Borehole BH4 shows the bedrock deeper compared to the resistivity result, possibly due to the borehole being about 25 meters away from the resistivity survey line.

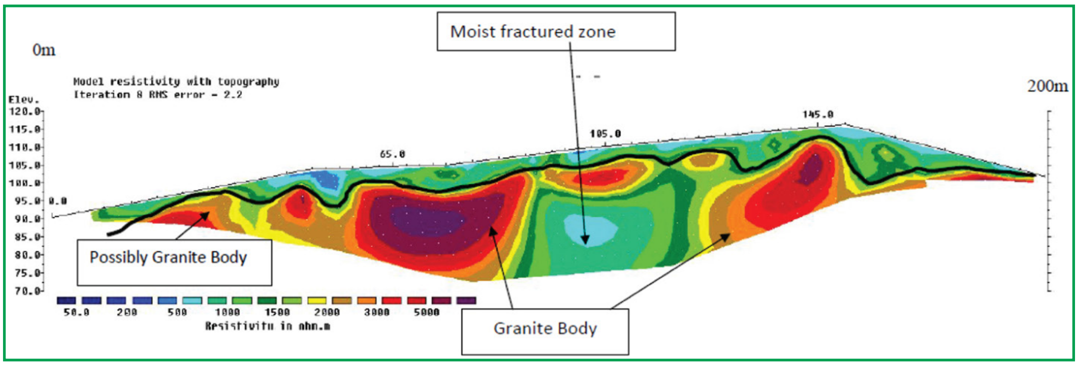

Figure 8. 2-Dimensional electrical resistivity imaging pseudosection along Line RS2

Interpretation for Line RS3

- Granite bodies are very shallow, with a depth between 5 to 15 meters from the surface (<1000 Ωm), as indicated by the area separated by the black line in the resistivity profile above.
- This layer is likely rippable and is expected to represent Grade V to Grade VI granite.
- There are some areas where a boulder layer is present between 40 to 65 meters and 103 to 107 meters along the line.
- A fractured zone, likely moist and possibly filled with water, is indicated by low resistivity values present at 90 to 125 meters, which is similar to RS1.

Combined Resistivity Profile

The combined resistivity profiles are presented in Figures 9-12.

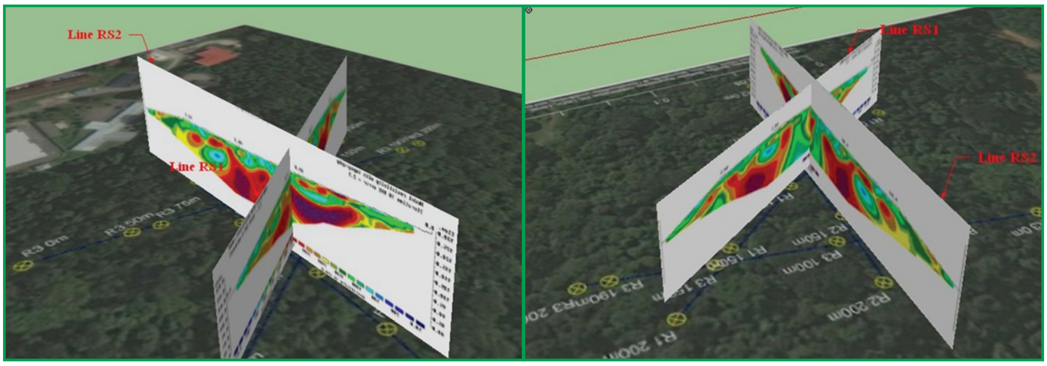

Figure 9. Resistivity Profile RS1 – RS2

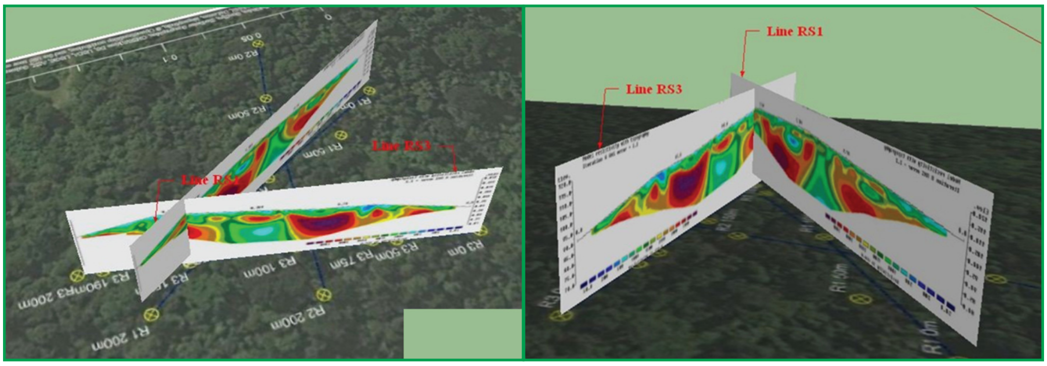

Figure 10. Resistivity Profile RS1 – RS3

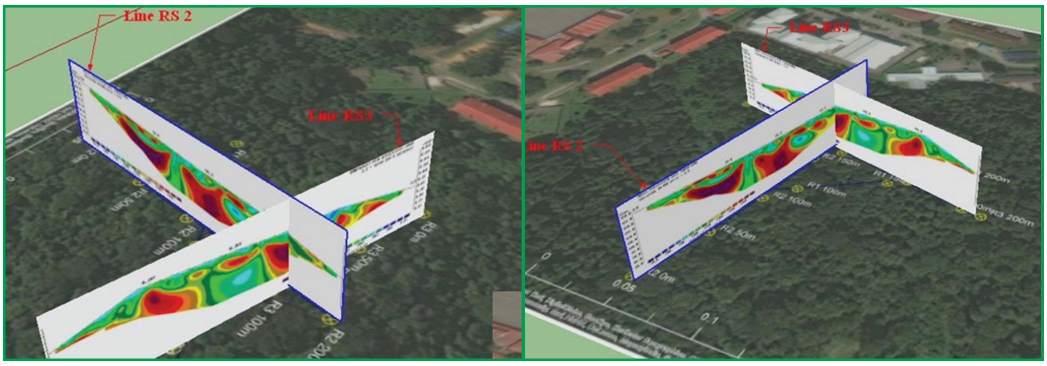

Figure 11. Resistivity Profile RS2 – RS3

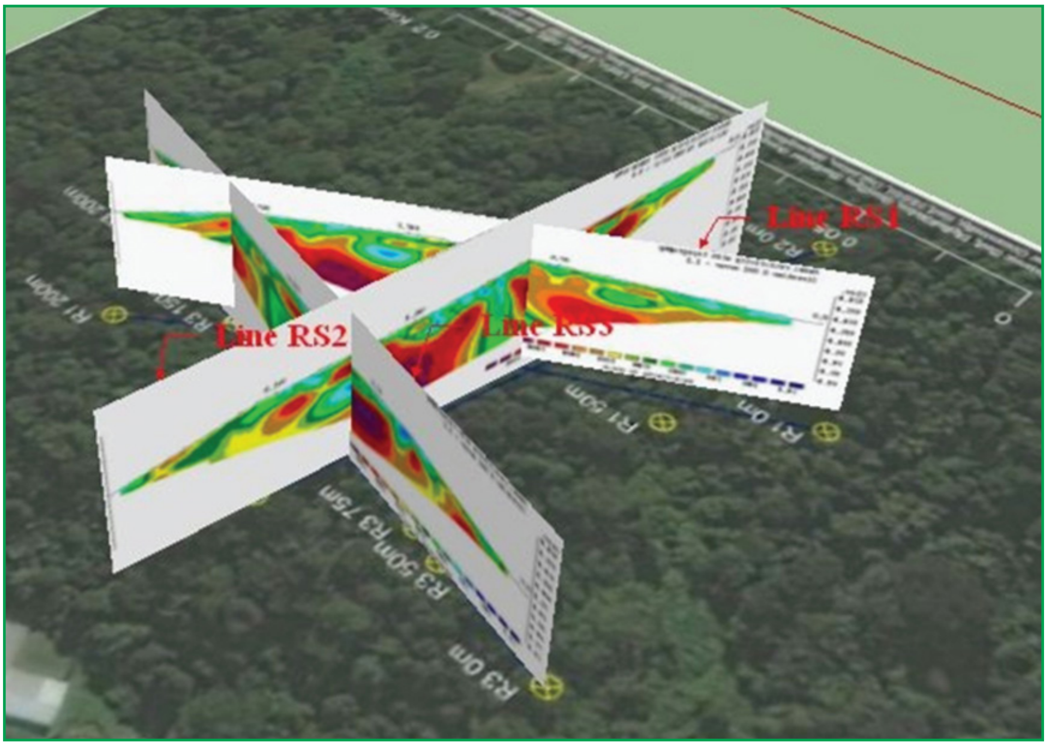

Figure 12. All resistivity profiles

Classification of Rippable

In this survey, seismic refraction survey shows range of the P wave velocity from 350m/s to about 4500m/s. The P wave velocity can be divided into three to in order to have a better understand setting of the underneath materials as we try to relate with the thickness of weak layer and the rippability parameter as suggested by [18].

The correlation of borehole data (N-value and lithology) with seismic data is essential before further explanation or interpretation can be made. Two seismic lines cross BH 3 (lines S1 and S5), and one line crosses BH 4 (line S4). Based on the gathered seismic data collected on site and information from the boreholes, the interpretation was made using Table 5, which was modified to include the seismic data.

Table 4. Classification of rippable granite at study area based on seismic and borehole information

Description of Material	Velocity of P-wave (m/s)	N-value	Rippability Assessment
Residual soil (Grade VI)	350-750	< 30	Rippable
Totally weathered rock (Grade V)	750-1500	31-49	Rippable
Semi weathered rock (Grade IV)	1500-2000	50-65	Marginal
Grade III to Grade I	> 2000	>65	Non Rippable

Based on the seismic results (Figures 13 to 20), the rippable layer has a thickness range of less than 15 meters. However, the thickness of this layer varies slightly across each seismic line. Most of the lines located at higher elevations, such as seismic 1, seismic 2, seismic 4, and seismic 6, exhibit a thicker rippability layer compared to lines at lower elevations (seismic 3, seismic 5, and seismic 7). The rippability layers are delineated by blue to green contours (<1500 m/s), while the yellow color represents marginal rippability with P-wave velocities between 1500 and 2000 m/s. P-wave velocities exceeding 2000 m/s indicate a hard layer, described as non-rippable. The seismic data correlates well with the borehole data. BH3 is located along seismic lines 1 and 5, and BH4 is situated along seismic line 4. All seismic results show hard layers detected at depths almost identical to those observed in the borehole data (see Figure 13 for seismic 1, Figure 16 for seismic 4, and Figure 17 for seismic 5).

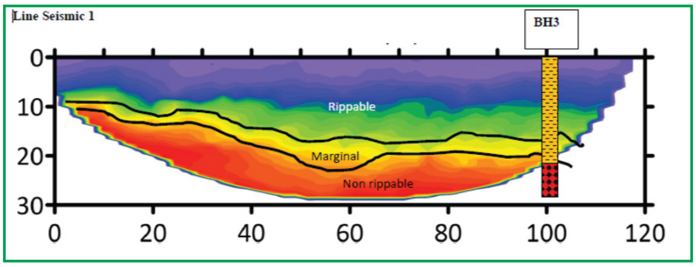

Figure 13. The combinantion of P-wave profile for line seismic 1 and borehole BH3

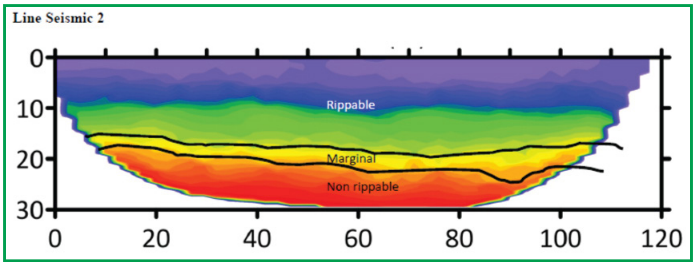

Figure 14. P-Wave profile for Line Seismic 2

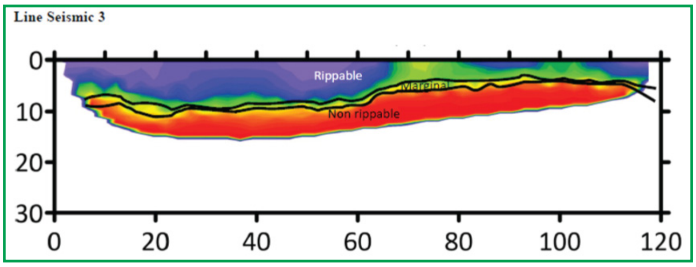

Figure 15. P-Wave profile for Line Seismic 3

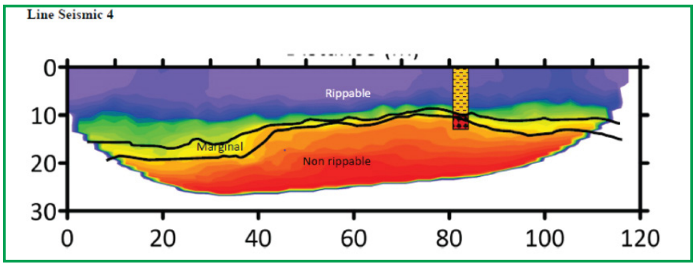

Figure 16. P-Wave profile for Line Seismic 4

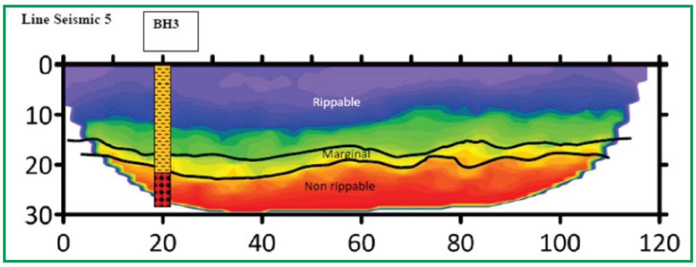

Figure 17. The combinantion of P-wave profile for line seismic 5 and borehole BH3

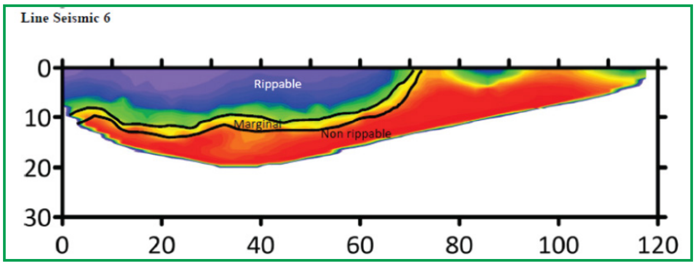

Figure 18. P-Wave profile for Line Seismic 6

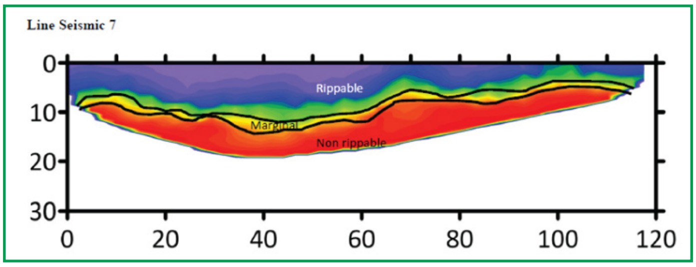

Figure 19. P-Wave profile for Line Seismic 7

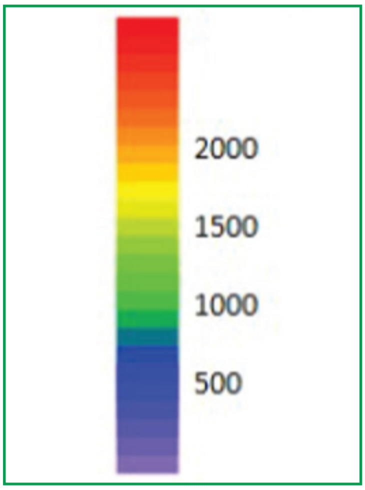

Figure 20. Legend (P-wave velocity in m/s)

Discussion

Resistivity and seismic refraction survey limitation and constraints. Both resistivity and seismic survey is actually non-destructive technique, fast and cost effective technique to acquire subsurface information including bedrock detection, groundwater exploration, cavity detection, slope study, archaeology investigation and etc. In case of determine the thickness of the overburden/ bedrock detection in this study area; several factors can influence the accuracy of the resistivity and seismic results compared to the borehole data. Highlight here are the factors:

a. Locations of the boreholes are not on the line. For the analysis, only boreholes close to the survey lines are used. Granite in general present in subsurface not as a flat topography. Mostly, has a dome structures and depend on weathered degree. Thus, shifted of the line from the borehole will giving not accurate comparison as shown by BH4 with RS2.

b. Resistivity technique is very sensitive with the present of water or low resistivity materials in the ground. This probably the main cause at some area the resistivity obtained is really low but the borehole and seismic result shows it was a hard layer (rock).

c. The main consent regarding seismic refraction survey is noise (other sources) which is come from vehicles and wind (strong). It generated another source will disturb the actual source from hammer.

Conclusion

The geophysical surveys conducted to detect the bedrock profile at the study area have yielded impressive results using both resistivity and seismic refraction techniques. Both methods detected a hard layer at almost similar depths, typically between 10 to 20 meters from the surface. In some sections of the resistivity profiles, the hard layer was detected shallower, likely due to the presence of boulders. Overall, the topography of the hard layer is deeper at higher elevations compared to lower elevations.

In the resistivity results, certain layers exhibit low resistivity values, especially in the middle of the profiles, which are interpreted as fractured rock likely filled with low resistivity materials such as clay or water. The seismic profiles delineate rippable layers by blue to green colors, indicating P-wave velocities lower than 1500 m/s, while marginal rippability is shown in yellow, with P-wave velocities between 1500 and 2000 m/s. Non-rippable layers are represented by red contours, indicating P-wave velocities greater than 2000 m/s.

In summary, resistivity and seismic refraction techniques are valuable tools for determining hard layers and estimating overburden thickness. They are non-destructive, easy, fast, and cost-effective compared to conventional techniques like drilling. Although they do not provide actual physical samples like drilling, the extensive and continuous data they provide is sufficient to justify their use in future projects.

Acknowledgement

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

Author Contributions

Noor Latifah Mohd Nassir: writing, original draft preparation. **Dayang Zulaika Abang Hasbollah:** writing, reviewing and editing. **Mohd Firdaus Md Dan@Azlan:** conceptualization, visualization. **Hafi Munirwan:** data curation,visualization.

Data Availability Statement

The data used to support the findings of this study are included within the article.

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