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Introduction of a Ground Penetrating Radar System for Subsurface Investigation in Balik Pulau, Penang Island

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Abstract. Ground penetrating radar (GPR) are non-invasive geophysical techniques that enhance studies of the shallow subsurface. The purposes of this work are to study the subsurface composition of Balik Pulau area in Penang Island and to identify shallow subsurface geology features. Data acquisition for GPR is by using 250 MHz antenna to cover 200m survey line at Jalan Tun Sardon, Balik Pulau. GPR survey was divided into ten sections at 20 m each. Results from GPR shows that there is low EM reflection along the first 40 m of the survey line. Intense EM reflections were recorded along the distance 40 m to 100 m. Less noticeable radar reflections recorded along 100 m to 200 m distance of the survey line. As a conclusion, clear signal of radar wave reflection indicates dry region of the subsurface. Meanwhile, low signal of radar wave reflection indicates highly weathered granitic soil or clay of the subsurface.

1. Introduction

Ground penetrating radar (GPR) produces high frequency electromagnetic (EM) waves to map structure and utilities under the subsurface. GPR depends on physical characteristics of the subsurface to generate signal return. GPR works the same was as traditional radar. GPR produces strong frequency pulses EM waves normally at 10 MHz to 1000 MHz to obtain subsurface information [1]. GPR utilizes the principle of scattering electromagnetic wave (EM) to find target or interfaces covered inside opaque substances or earth material. Generally, ground penetrating radar works by an electromagnetic wave is transmitted into the ground and being reflected depend on the dielectric properties of the subsurface materials itself (Figure 1). At the surface, the reflected wave is received and according to general principle, depth of penetration decrease as the frequency increase with increase in resolution [2]. The recorded signal then registered as amplitude and polarity against two way travel time.



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Figure 1. EM wave propagation depends on dielectric and conductivity properties of material [3].

2. Theory of GPR

A typical GPR has three main components; Transmitter and receiver that are directly connected to an antenna, and a control unit (timing) (Fig. 2). The transmitting antenna radiates a short high-frequency EM pulse into the ground, where it is refracted (Figure 3), diffracted and reflected primarily as it encounters changes in dielectric permittivity and electric conductivity.



Figure 2. Flow chart for a typical GPR system (after [4]).

Magnetic permeability (μ) describes the measure of how intrinsic atomic and molecular magnetic moments respond to magnetic field therefore describes the degree of magnetization a material obtained in response to magnetic field. Electrical conductivity (σ) is related with an electric field (E) and conduction currents created as electrical conductivity applied to electric field.

 $J=\sigma E(A/m^2)$

$E = \rho J(N/C)$

J is the current density in unit Ampere per meter square (A/m^2) σ is the electrical conductivity in unit siemens per meter (S/m) ρ is the electrical permeability in unit newtons per ampere squared (N. A⁻²)

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The energy dissipating mechanism for an electromagnetic filed is represents by conductivity, thus it give effect to the EM wave depth penetration and velocity.



Figure 3. EM wave propagation velocity versus conductivity of the material involved [4].

Electrical conductivity of soils and sediments can influence the effectiveness of GPR. Soils with high electrical conductivity quickly weaken the signals of the radar, reduce the depth penetration and limiting GPR performance largely. The amount and type of salts in solution and the clay content are the factors that effecting the electrical conductivity of soils and sediments. Electrical conductivity is measure of water-soluble salt concentration in soils and directly related to concentration of dissolved salts in particular solution [5].

$$k = \epsilon_r = \epsilon / \epsilon_o (F/m)$$

K is the ratio of dielectric permittivity of material to that of free space or dielectric constant with unit in Farad per meter (F/m or $F \cdot m-1$).

 ϵ is dielectric permittivity with unit in Farad per meter (F/m or F·m-1).

 ϵ_0 is in vacuum, a finite value of 8.85 x10¹² F/m(Farads per meter)

When electric field (E) is applied, a dipole moment is created as bound charges moves to another static configuration .The dipole moment density (D) is given by: D=E ϵ with unit in Coulomb-meter (C. m)

Dielectric properties in rocks and sediments depend on mineralogy, porosity and rock lithology. In general, the changes in dielectric properties of rocks, variations in water content and changes in bulk density at stratigraphic interfaces generated the reflected EM waves from the subsurface [5].

3. Methodology

The equipment consists of 250 MHz shielded antenna, control unit, GPR screen display, battery, encoder wheel, connecting cable, pulling strip and measuring tape. The control unit is connected to the shielded antenna and GPR screen display by the connecting cables. Then the GPR monitor is connected to the battery while the encoded wheel is connected to the shielded antenna, control unit and GPR are turned on respectively. Ensure the signal can be detected by the antenna before starting the survey. The length of the survey line is measured by using measuring tape. The cart is slowly moved forward to collect the data. Ensure the encoder wheel is rotating and touching the surface of the study area. The reading is taken in the GPR monitor. The procedure is repeated until the survey area is completed. The procedure is repeated by changing spacing at another survey line. The procedure taken is to measure the magnitude of the received signals as a function of time after the transmitter started sending pulses into the ground. The distance range is resolved through the measurement of the time where the signals is sent out to and back

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from and being detected very fast. In seismic application, reflected signals produced from the trace are beneficial due to its zero-phase which is symmetrical about zero time property. Furthermore, the wavelet can be considered as a transient event with definite arrival time and finite energy content [6].

4. Study area

The location of study area is along Jalan Tun Sardon, Balik Pulau (Figure 4). The area is hilly area with high elevation from the sea level. The survey was done at higher altitudes areas as presence of a lot granite boulder. The coordinate is $5^{\circ}20'55.43"$ N, $100^{\circ}15'8.61"$ E and the elevation is about 350 m.



Figure 4. Location of study area at Balik Pulau [7].

5. Results and Discussions

The survey was conducted at Jalan Tun Sardon site near Balik Pulau along a 200m survey line. The study area is a hilly area where there was exposed granite rock can be observed. The profiles are divided into ten sections with each section covers 20 m length of the survey line. Based on the results, along the first 40 m of the survey line, there is low EM reflection recorded by the GPR as shown in Figure 5 and Figure 6. This is probably due to the homogeneous structure of the subsurface where there are no anomalies such as variation in weathering grade and presence of boulders in the ground.



Figure 5. GPR result at S1 (0-20 m).

Time [ns]

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Figure 6. GPR result at S2 (20-40 m).

The intense reflection recorded by the GPR started from distance 40 m until 100 m of the survey line. This reflection can be observed in the GPR profiles of S3 (Figure 7), S4 (Figure 8), and S5 (Figure 9). The noticeable reflections are marked by the red rectangular. This reflection probably was reflected by weathered granite boulders buried near the surface. Apart from that, this reflection probably caused by the non-homogeneous structure near the surface where there was variation in weathering grade and moisture content of the soil. Besides that, high reflection of radar wave is probably caused by a wet area in the subsurface [8].













Figure 9. GPR result at S5 (80 – 100 m).

There is less noticeable reflection of radar wave recorded from distance 100 until 200 m. This is probably because there are no significant factors such as the presence of boulders, variation in weathering grade and moisture content, along this distance, that produce an obvious reflection. Low radar wave reflection is also due to the dry condition of the subsurface [8]. However, there are still a few reflections can be seen in the GPR profiles of S6, S7, S8, S9 and S10 Figures 10-14).







Figure 11. GPR result at S7 (120-140 m).

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Figure 13. GPR result at S9 (160-180 m).



Figure 14. GPR result at S10 (180-200 m).

6. Conclusion

As a conclusion, the Ground Penetrating Radar is an efficient and practical method used to identify the shallow subsurface features such as granite boulders and weak zones at shallow depth. GPR technique is a good technique to identify the depth of target or buried object at shallow depth with great resolution. Observable features in form of radar wave's reflection from the GPR profiles give vertical subsurface information of the study areas. Clear signal of radar wave reflection indicates dry region of the subsurface. Meanwhile, low signal of radar wave reflection indicates highly weathered granitic soil or clay. At shallow depth, GPR technique is more effective as it has higher resolution.

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