Integration of Ground Penetrating Radar (GPR) and 2-D Resistivity Imaging methods for soil investigation

Nabila Sulaiman¹, M.M. Nordiana¹, I.N. Azwin¹, Z.M. Taqiuddin¹, Umi Maslinda¹, Hazrul Hisham¹, M.K.A. Nur Amalina¹, Muhamad Afiq Saharudin¹ and A.N. Nordiana¹

¹School of Physics, Universiti Sains Malaysia, 11800 USM, Penang, Malaysia
E-mail: nabilasulaiman93@gmail.com

Abstract. Rock lithology influences the electrical properties representing soils or rocks. Electrical conductivity value can be measured using geophysical methods like Ground Penetrating Radar (GPR) and 2-D resistivity imaging. The objective of this survey is to integrate GPR, 2-D resistivity imaging and borehole log based on the conductivity value with soil description and N-value from borehole. Borehole is conducted in the middle of the survey line at a distance of 20 m. GPR method used 250 MHz frequency antenna. The result was filtered using Band Pass, Time Varying Gain and DC removal. 2-D resistivity imaging used two arrays; Wenner-Schlumberger and pole-dipole with total distance of 40 m and 1 m minimum electrode spacing using ABEM SAS4000. The results of both arrays are represented in the form of inversion models. Electrical conductivity values for GPR are calculated based on the conductivity values obtained by 2-D resistivity imaging. The conductivity values calculated from GPR are in good agreement with the values from 2-D resistivity imaging method. Electrical conductivity for the top soil is 0.7 – 3.0 mS/m with no soil description and N-value due to imprecise sample of the loose soil condition. The results showed that soil composed of loose silty gravel with some sand at the depth of 1.81 – 2.99 m has higher value of conductivity (0.4 – 3.0 mS/m) while soil dominated by very stiff sandy silt with some rock fragment (gravel) at the depth of 3 – 3.5 m has lower conductivity values of 0.4 mS/m to 0.7 mS/m. Soil having low electrical conductivity is probably due to the stiff condition (minimum water content) confirmed by greater N-value. Integration of geophysical methods and geotechnical method is a success and the geophysical parameters can be used in understanding soil condition.

1. Introduction
Electrical conductivity value is vital in understanding the subsurface condition as each type of soils or rocks has specific electrical properties. Both GPR and 2-D resistivity imaging method implement the conductivity value to acquire the data. Borehole log will provide more details of the ground in terms of soil type, grain size, colour consistency, texture, plasticity and N-value. N-value is the blow count as the borehole sampler penetrates into the ground by automatic trip hammer. N-value indicates the relative density of overburden at that particular depth [1]. The soil mineralogy especially the cohesive soils like clayey silt and sandy silt will affect the electrical conductivity [2]. The integration between GPR, 2-D resistivity imaging and borehole log will produce more reliable information of the study area.
GPR works by emitting electromagnetic (EM) wave in tiny pulse of energy using a transmitter into the ground and receive the reflected wave using a receiver. Materials underground that have contrast of electrical conductivity and dielectric permittivity from the surrounding ground will reflect the signal and produce hyperbola signatures on the radargram based on the time taken and amplitude. Strong reflected signal with high amplitude value is produced when the difference of the conductivity and dielectric permittivity between two materials is pronounced. The conductivity value can be calculated from GPR radargram by calculating the dielectric permittivity [3].

2-D resistivity imaging method measures the electrical potential distribution by injecting the current using two electrodes into the ground [4]. The inversion of the data will produce the value of resistivity and conductivity of the datum point. The values can be used to plot contour map of the study area for better interpretation.

GPR has the ability to detect near surface anomaly on any type of surfaces such as concrete, soil, asphalt and even water while resistivity method is suitable to image near surface and deeper conditions of the subsurface depending on the electrode spacing and type of array used [4]. Since electromagnetic wave from the GPR tend to attenuate when encounter presence of water within the subsurface [5], the 2-D resistivity imaging is used to facilitate in identifying the lost data from GPR.

2. Study area
The study area is located in Universiti Sains Malaysia (USM), Penang with coordinate of N5.362310° E100.306370° and N5.362350° E100.306670°. The survey line was at a flat field with a small slope from the 0 – 18 m of the survey line and the ground during the survey was dry due to the hot weather. In general, Penang is dominated by granitic rocks. The area has geology of medium to coarse grained biotite granite [6].

3. Methodology
One survey line was conducted in the study area with a total length of 40 m for both GPR and 2-D resistivity imaging methods. Borehole was conducted at the centre of the survey line at 20 m distance. The geophysical methods were conducted on the same line to correlate the results of the area.

The GPR method used shielded antenna of 250 MHz. The radargram is filtered using Band Pass, DC removal and Time Varying Gain to improve the result for better interpretation.

The arrays used for 2-D resistivity imaging method are Wenner-Schlumberger and Pole-dipole due to different maximum depth obtained and the sensitivity in terms of lateral and vertical resistivity variations of each array. Wenner-Schlumberger is adequately sensitive for lateral and vertical structures with lower maximum depth obtain while pole-dipole is good for horizontal coverage with deeper penetration [4]. The survey used ABEM SAS4000 with minimum electrode spacing of 1 m. The data was processed using RES2DINV software to plot the inversion model of the area. Surfer 10 software was used to plot the contour map and the point for every datum point.

Electrical conductivity value for 2-D resistivity imaging method was obtained from the RES2DINV software. There are several calculations that needed to be done before the conductivity value for GPR method is obtained. Velocity, $v$ of the EM wave is calculated using the value of depth, $d$ and time, $t$ from the radargram substituted into equation (1).

$$v = \frac{2d}{t}$$

The relative dielectric permittivity value, $\varepsilon_r$ is calculated using equation (2) where $c$ is the speed of light. Radar energy attenuation, $\alpha$ is calculated using equation (3) where $\sigma$ is electrical conductivity value acquired from 2-D resistivity imaging method. $\alpha$ is in the unit of dB/m [7]. From Maxwell’s equation, $\alpha$ can also be calculated in the form of equation (4) and can be derived to form equation (5).
Equation (5) is used to calculate $\sigma$ that represents electrical conductivity for GPR method where $\omega$ is the angular frequency, $\varepsilon$ is the dielectric permittivity and $\mu_0$ is the magnetic permeability constant.

$$\varepsilon_r = \left(\frac{\varepsilon}{\varepsilon_0}\right)^2$$  \hspace{1cm} (2)

$$\alpha = 1.69 \frac{\sigma}{\sqrt{\varepsilon_r}}$$  \hspace{1cm} (3)

$$\alpha = \omega \sqrt{\varepsilon_0 \mu_0} \left\{ \frac{1}{2} \left[ \left( \frac{\sigma}{\omega \varepsilon} \right)^2 - 1 \right] \right\}^{\frac{1}{2}}$$  \hspace{1cm} (4)

$$\sigma = \frac{2\alpha^2}{\omega^2 \varepsilon \mu_0} \left[ \frac{1}{\omega^2 \varepsilon \mu_0} + 1 \right]^{\frac{1}{2}}$$  \hspace{1cm} (5)

4. Results and discussions
GPR result is shown in figure 1 in the form of radargram. The maximum depth of penetration is approximately 8 m. The 20 m position is chosen for calculation of electrical conductivity of GPR because the value obtained for that position is used to compare with the 2-D resistivity imaging method and borehole log. There are several shapes that have hyperbolic features on the radargram but the shapes are not distinct. The chaotic signal from 27 m to 37 m distance is due to tree roots. The maximum depth for conductivity calculation is 3.5 m. Figure 2 shows brief soil description that is obtained from the borehole log and is used to integrate with the results from GPR and 2-D resistivity imaging method. The position of borehole log is denoted on the radargram as shown in figure 3.

The results of 2-D resistivity imaging method for Wenner-Schlumberger and pole-dipole arrays are shown in figure 4 and 5. The position of the borehole which is at 20 m distance is shown on the inversion results. The inversion of pole-dipole array showed better resistivity variations laterally than the inversion result from Wenner-Schlumberger array. Both inversions showed that the area at 20 m distance possibly composed of loose soil (150 – 1500 $\Omega$m) with mixed grain sizes which can affect the resistivity value due to the ability to hold water. There is a boulder (1000 – 5000 $\Omega$m) that can be seen in both inversions that situated near to the 20 m distance position. Saturated zone can also be seen in the pole-dipole array inversion with values ranging from 0 $\Omega$m to 200 $\Omega$m. The conductivity values at 20 m distance for certain depth are obtained from 2-D resistivity imaging data.
Figure 1. The radargram for the survey line.

Figure 2. Brief soil description from the borehole log.

Figure 3. The position of the borehole is shown on the radargram.

Figure 4. Inversion model of 2-D resistivity imaging method using Wenner-Schlumberger array.
Table 1 shows the electrical conductivity values from GPR and 2-D resistivity imaging (Wenner-Schlumberger and pole-dipole array) with soil descriptions and N-value from borehole log. From Table 1, near the surface (depth of 0.29 – 1.3 m) shows that the value of conductivity keeps on increasing with 3.0 mS/m as the highest value at depth of 1.3 m. The soil description for near surface depth is not available from the borehole log due to the loose top soil condition. The recovery for loose soil sample is not available due to the imprecise information of the soil. Hence, there is no recovery and N-value of the top soil. The conductivity value decreases from 2.0 mS/m to 0.4 mS/m which indicate loose silty gravel (depth of 1.81 – 2.99 m). Lower conductivity value may be due to the presents of gravel. The N-value representing depth of 1.81 – 2.99 m is 6. Sandy silt has lower conductivity from 0.4 – 0.7 mS/m due to the stiff condition of the soil that also contain some rock fragment (gravel). Since electrical conductivity is mainly affected by the water content [5], very stiff sandy silt with low conductivity values shows that presence of water is low. This is proven by the borehole log which indicated the N-value of 19 at depth of 3 – 3.5 m. The existence of silt in the area restricts the penetration depth of EM wave from GPR due to higher electrical conductivity [5]. The table conclude that soil having low electrical conductivity value (sandy silt) exhibits stiff condition that signifies low water content with greater amount of N-value.
Table 1. The integration of conductivity value, soil description and N-value.

| Depth | Conductivity, mS/m | Soil Description | N-value |
|-------|--------------------|-----------------|---------|
|       | 2-D resistivity    | GPR had to be repeated |         |
| 0.29  | 0.74 - 0.97        | 0.70 - 1.00     |         |
| 0.6   | 1.08 - 1.30        | 1.05 - 1.35     |         |
| 0.96  | 2.37 - 2.57        | 2.30 - 2.70     | N/A     |
| 1.3   | 2.76 - 2.92        | 2.70 - 3.00     |         |
| 1.81  | 1.67 - 1.97        | 1.60 - 2.0      |         |
| 1.89  | 1.61 - 2.94        | 1.60 - 3.00     |         |
| 2.32  | 0.81 - 0.93        | 0.80 - 0.96     |         |
| 2.99  | 0.43 - 0.45        | 0.40 - 0.46     |         |
| 3     | 0.47 - 0.66        | 0.45 - 0.70     |         |
| 3.5   | 0.41 - 0.51        | 0.40 - 0.53     |         |
|       |                    |                 |         |

5. Conclusions

The conductivity values calculated from GPR are in range with the values from 2-D resistivity imaging method. Electrical conductivity for the top soil is 0.7 – 3.0 mS/m. The soil description and N-value is not available due to imprecise sample of the loose soil condition. The integration of both methods with borehole showed the value of conductivity for loose silty gravel soil (N-value = 6) are between 0.4 – 3.0 mS/m. Presence of gravel may have produced the lower value of conductivity (0.4 mS/m). Very stiff sandy silt with rock fragment (N-value = 19) has conductivity value of 0.4 – 0.7 mS/m. Lower values of electrical conductivity consist lower amount of water content resulting stiff soil condition which is confirmed by the higher N-value. Integration of geophysical methods and geotechnical method is a success and the geophysical methods parameters can be used in understanding soil condition.

References

[1] Price D G 2009 Engineering Geology, ed de Freitas M H (UK: Springer) p 160
[2] Glendinning S, Jones C J F P and Lamont-Black J 2005 Ground Improvement Case Histories vol 3, ed I Buddhima and J Chu (UK: Elsevier) p 997
[3] Davis J L and Annan A P 1989 Geophysical Prospecting 37 531-51
[4] Loke M H 1999 Electrical Imaging Surveys for Environmental and Engineering Studies 6574525 4
[5] McNeill J D 1980 Electrical Conductivity of Soils and Rock (Ontario: Geonics Limited) pp 10-4
[6] Ahmad F, Yahaya A S and Farooqi M A 2006 J. of Environmental Sc. 2 121-28
[7] Takahashi K, Igel J, Preetz H, and Kuroda S 2012 Problems, Perspectives and Challenges of Agricultural Water Management, ed M Kumar (Croatia: InTech) chapter 8 pp 155-80

Acknowledgements

The authors would like to extend sincere gratitude to all Geophysics Department Staff, Postgraduate students of School of Physics and Institute of Postgraduate Studies, Universiti Sains Malaysia for their assistance in acquiring the geophysical data and making the research a success.