Subsurface Investigation using 2D Resistivity and Ground Penetrating Radar at Teluk Kumbar, Penang

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Abstract. The objective of this study is to determine the structure and condition of the subsurface by using 2D resistivity and Ground Penetrating Radar (GPR) methods. The study was conducted at SK Sungai Batu, Teluk Kumbar, Penang Island. For 2D resistivity method, Wenner-Schlumberger array was used while for GPR, 250 MHz antenna was used at the site. The survey consists of 200m length survey line. GPR result shows that there is high intensity of EM. 2D resistivity result shows that the low resistivity region (200 Ωm to 340 Ωm) appears to be at the centre of the survey line from depth 7 m to 13 m. Meanwhile, the higher resistivity region (4000 Ωm to 6000 Ωm) may indicate the bedrock structure of the subsurface, which is the granitic rock. This region is bedrock which rested at depth 14 m and below. In conclusion, data obtained from GPR and 2D resistivity methods can be easily correlated to determine the features of the subsurface.

1. Introduction
Geophysical investigation by using Ground-Penetrating Radar (GPR) and 2D Resistivity techniques are non-destructive ways to study the subsurface of the earth [1]. 2D resistivity technique provides data about greater subsurface depth according to arrays that is set up, GPR provides us with the data about the shallower part of the subsurface of the Earth. GPR method normally implemented to study the underground utilities such as pipelines and underground cables. It is very useful method in engineering field as it is easy to operate and non-destructive. However, GPR method usually produces data about shallow subsurface of the earth unlike 2D resistivity method [1]. It only can detect boulders, utilities, or other buried anomalies in the soil that are shallow enough beneath the surface. Therefore, GPR technique alone is not enough to further testify the condition of the subsurface. This is because GPR profiles only provide data for a smaller depth. 2D resistivity survey will provide deeper depth of the survey area according to the configuration of the array.

2. GPR and 2D Resistivity
Ground penetrating radar 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 [2]. The greater the frequency applied, the greater the resolution but lower penetration. Frequency ranging from 10 MHz until 500 MHz normally used in study of geology for optimum penetration. Meanwhile, frequency ranging from 500 MHz and 1000 MHz is normally used in engineering for shallow penetration but obtain higher resolution.
The aim of electrical resistivity surveys is to ascertain the resistivity distribution of the surrounding soil volume [3]. Electric currents generated are supplied to the soil and the resulting potential difference are measured. The survey data is processed to produce resistivity pseudo sections. The higher the electrical difference between the soil matrixes, the easier the detection. Electrical resistivity of the soil can be considered as a proxy for the variability of soil physical properties [4]. Generally, igneous and metamorphic rocks have great resistivity number. The resistivity of the rocks and soil mainly dependent on their porosity, moisture content, concentration of dissolved electrolytes, and clay content.

3. Methodology
Basic of GPR data acquisition is easy to operate. It is probably the only method which can be done at least by two people. 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 by connecting cables. After all the equipment is connected, 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. 2D resistivity was conducted after GPR survey was completed. The survey line was 200 m with 5.0 m electrode spacing. The protocol that used was Wenner-Schlumberger. Figure 4 shows the electrical resistivity profile of the study area. The equipment to conduct 2D resistivity survey are ABEM Terrameter SAS4000 and others such as electrodes, measuring tape, and hammer. Processing of 2D Resistivity was performed by using Res2DinV and surfer 10 software.

4. Study area
Study area is hilly area with high elevation from the sea level (Figure 1). The location is at Teluk Kumbar area near Sekolah Kebangsaan Sungai Batu. Coordinates of the study area are 05° 17’ 21.82” N and 100° 14’ 32.43” E.

Figure 1. Location of study area at Teluk Kumbar, Penang Island [5].
5. Results and Discussions

The result from GPR method presented in radargram form as the underground features was detected by the EM waves. The GPR profile give information of the subsurface region at the survey sites up to 4 m. As it covered a shallow depth, detail information is obtained regarding the underground features buried within 4 m depth. The results shows that clear reflection events by the EM waves in the GPR profiles arise due to stratigraphy of the subsurface layer at both study areas. The presence of granite boulders at shallow depth and non-homogenous subsurface layer play importance roles in the movement of EM waves through medium as EM waves require the presence of a material medium in order to transport their energy from one location to another. The amplitude EM reflection of radar wave is affected by the geology condition at the study areas. More reflection events happens related to the soil condition which is less consolidated and loose meanwhile compacted soil inhibit further movement of waves through the material. According to [6], consolidation of soil is process which involves a decrease in water content of saturated soil without replacement of water by air, which means consolidated soil is become compacted.

GPR survey was conducted from distance 100 m to 110m (L1) and from 110 m to 120 m (L2). The frequency of the GPR antenna that was used was 250 MHz because it would provide a reasonably clear GPR profile of the study area. Figure 2 and Figure 3 show the processed GPR results at L1 and L2. Based on the results, both show a noticeable radar wave reflection which may indicate the presence of weathered rocks beneath the surface as marked by red rectangle. Both results also indicate a non-homogeneous structure at the study area. Low reflection of radar signal related to high moisture content while high reflection of radar signal related to low moisture content [7].

![Figure 2. GPR result at L1 with 250 MHz frequency.](image-url)
Figure 3. GPR result at L2 with 250 MHz frequency.

Figure 4. Resistivity profile at SK Sungai Batu, Teluk Kumbar site.

2D resistivity profiles give a detailed overview about the electrical resistivity value of the shallow subsurface including the depth and distance of the study areas where the survey is done. The study that carried out at the SK Sungai Batu, Teluk Kumbar shows that a distinct region with a low resistivity value compared to its surrounding part which can be explained as its composed of loose soil with high moisture content in its. Less consolidated soil condition contribute to the low resistivity region as its can be referred as saturated zone. The application of field electrical resistivity has theoretically stated that the water content in subsurface materials has a close positive correlation with the electrical conductivity materials has a close positive correlation with the electrical conductivity [8].

The low resistivity region (200 Ωm to 340 Ωm) appears to be at the centre of the survey line with depth at around 7 m to 13 m. This region has significantly low resistivity values and is suspected to be highly weathered soil that has high moisture content. The higher resistivity region (4000 Ωm to 6000 Ωm) may represent the bedrock structure of the subsurface [9].

6. Conclusion
By understanding the geology of the study area, GPR method gives vital information about the shallow part of the subsurface. High intensity of radar wave reflection indicates a poorly consolidated region of the subsurface. Meanwhile, low intensity of radar wave reflection indicates a highly consolidated and dry region of the subsurface. Besides that, 2D resistivity survey is also an effective technique to determine the condition of the subsurface of the study area. From the electrical resistivity profiles provided, we can geologically explain the condition of the subsurface. High resistivity regions (4000-6000 Ωm) indicate area with dry condition, or the presence of boulders. The location or depth
of the bedrock also can be known by studying the resistivity profile. From the evidence found at the study area, which are exposed granitic rocks, it can be inferred that the bedrock at both study area is granitic rock. Meanwhile, low resistivity regions (200-340 Ωm) indicate the highly weathered soil, highly porous rock, or high moisture content. In addition to that, 2D resistivity also provide information of the subsurface at a greater depth. However, at shallow depth, GPR technique is more effective as it has higher resolution. From the objectives, it was found that GPR and 2D resistivity techniques are two effective techniques as they will further match the information that were obtained using each of the technique. Both techniques will ease the correlation of the data and able to testify the condition of the subsurface.

References

[1] Saharudin, M. A., Nordiana, M. M., Nordiana, A. N., & Maslinda, U. (2016). Application of Ground Penetrating Radar (GPR) In Detecting Target of Interest.
[2] Smith, G.S. (1997). An introduction to classical electromagnetic radiation. Cambridge Univ. Press, Cambridge, UK, 653 pp.
[3] Samouëlian, A., Cousin, I., Tabbagh, A., Bruand, A., & Richard, G. (2005). Electrical resistivity survey in soil science: a review. Soil and Tillage research, 83(2), 173-193.
[4] Banton, O., Cimon, M. A., & Seguin, M. K. (1997). Mapping field-scale physical properties of soil with electrical resistivity. Soil Science Society of America Journal, 61(4), 1010-1017.
[5] Google Earth, 2016.
[6] Terzaghi, K. (1943). Theory of consolidation (pp. 265-296). John Wiley & Sons, Inc.
[7] Arifin, M. H., Jamaluddin, T. A., Husin, H., Ismail, A., Abbas, A. A., Nordin, M. N. M., & Setu, A. (2016). Comparison of geological mapping with electrical resistivity and ground penetration radar methods for rock fractured system study. Chiang Mai Journal of Science, 43(6Special Issue 2), 1346-1357.
[8] Abidin, Z., Hazreek, M., Saad, R., Fauziah, A., Wijeyesekera, C., Baharuddin, T., & Faizal, M. (2012). Integral analysis of geoelectrical (resistivity) and geotechnical (SPT) data in slope stability assessment. Academic Journal of Science, 1(2), 305-316.
[9] Loke, M. H. (1999). Electrical imaging surveys for environmental and engineering studies.

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