Mapping Subsurface Structure at Guar Kepah by using Ground Penetrating Radar

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Abstract. A Ground Penetrating Radar (GPR) survey was conducted at Guar Kepah to detect buried object before commencement of archaeological gallery construction. The study area covered around 20 m length and 14 m width. 15 GPR lines were constructed from north to south with 20 m length, 1 m spacing and parallel to each other. The 500 MHz closed antenna had been used in this study. The surface findings were noticed before started GPR survey. The data was analysed and interpreted by using Groundvision software and several filters were applied to radargrams to enhance the data. Based on the result, several anomalies were detected. The surface findings also detected by GPR which cause hyperbolic curve in radargrams. The subsurface layer was detected by GPR survey. The anomalies are assigned to several classes based on the pattern of signals obtained in radargrams.

1. Introduction
Ground Penetrating Radar (GPR) is a method used to image the subsurface. GPR works based on the reflection, diffraction and refraction of propagating electromagnetic wave in the subsurface. GPR is a good choice for high-resolution subsurface imaging in certain condition such as ice region, snow, dry and sandy soil and concrete [1]. GPR method can be applied in archaeology sector such as imaging skeletal remains [2]. The GPR method also can be used in geoeengineering to detect pipes, buried object and measure pavement thickness [3]. In this study, GPR method had been used on a former house site located in Guar Kepah to detect and located buried objects in the subsurface before the construction of archaeological gallery. Based on a study, 800 and 900 MHz frequencies were the most optimum frequency to obtain radargrams with enough resolution and penetration to characterize buried objects with relatively small lateral dimension [4]. GPR is the most suitable method as it is cheap, time efficient and non-damaging to subsurface.

2. Study area
The study area was located at Guar Kepah in Seberang Perai, Penang (Figure 1). The coordinate of the site is N 5.557862° and E 100.424412°. It was in Kampung Guar Kepah with paddy field nearby. There was a road about 50 m from the site and 8 km from the shoreline. There was a former house site that had been demolish for the construction of archaeological gallery. There was an abandon well at the centre of the site and still contain water which was 2 m below the surface. On the surface, concrete fragments were scattered around the study area. Based on the geological observation, the study area composed of shell which was believed to be a natural occurring event. Guar Kepah also referred as Guar Kepah hill or Bukit Cengkerang (shell midden) as the site consists of shell middens located on sandy ridges [5]. The study area covered about 14 m X 20 m.
3. Methodology
A GPR system consists of a signal generator, transmitter and receiver antenna. The radar system caused the transmitter antenna to generate an electromagnetic wave which propagates away in broad beam at the speed of light [7]. The basic principle of the system is shown in the Figure 2. The GPR principle is similar with seismic reflection profiling and sonar surveying. The radar velocity in the subsurface is controlled by dielectric constant and conductivity of the subsurface [8]. The radar velocity can be determined by using equation (1).

\[ v = \frac{c}{\sqrt{\mu_r \varepsilon_r}} \] (1)

Where \( v \) is the radar velocity, \( c \) is the speed of light in vacuum (\( 3 \times 10^8 \) m/s), \( \mu_r \) the relative magnetic permeability and \( \varepsilon_r \) is the relative dielectric permittivity.

According to reflection coefficient \( R \), a radar reflection with diminution of energy will occur cause by a contrast in dielectric properties across interface [8]. (equation 2)

\[ R = \frac{(\sqrt{\varepsilon_{r2}} - \sqrt{\varepsilon_{r1}})}{(\sqrt{\varepsilon_{r2}} + \sqrt{\varepsilon_{r1}})} = \frac{(v_2 - V_1)}{(v_2 + V_1)} \] (2)

Where \( \varepsilon_{r2} \) and \( \varepsilon_{r2} \) are the relative permittivities of the two mediums separated by interface and \( V_1 \) and \( V_2 \) are the radar velocities. Table 1 shows the velocity and dielectric permittivity properties for several materials.

In this study, 11 lines of GPR were constructed starting from north to south. Each line is 20 m in length and 1 m spacing between lines. A 500 MHz closed antenna has been used in this study. The
obstacles on the site are cleared as much as possible. All the surface findings are noted to avoid misinterpretation.

Table 1. GPR velocity and relative dielectric constants for geological and man-made materials [6].

| Material                              | v (m/ns) | $\varepsilon_r$ |
|---------------------------------------|----------|-----------------|
| Air                                   | 0.3      | 1               |
| Asphalt                               | 0.173-0.134 | 3-5             |
| Clay (dry)                            | 0.173    | 3               |
| Clay (wet)                            | 0.11-0.086 | 8-15            |
| Coal                                  | 0.15-0.134 | 5-40            |
| Concrete                              | 0.134-0.095 | 5-10            |
| Dolomite                              | 0.122-0.106 | 6-8             |
| Dry, sandy, flat coastal land         | 0.09     | 10              |
| Limestone                             | 0.12     | 4-8             |
| Clayed soils                          | 0.19     |                 |
| Sandy soils                           | 0.13     |                 |
| Average soil                          | 0.075    | 16              |
| PVC, Epoxy, Polyesters, vinyls, rubber| 0.173    | 3               |
| Sand (dry)                            | 0.17-0.12 | 3-6             |
| Sand (wet)                            | 0.06-0.055 | 25-30           |
| Water                                 | 0.033    | 81              |

Figure 2. Basic principle of GPR system [6].
4. Result and discussion

Based on radargrams, there were several anomalies detected in the 15 GPR lines. The objects were identified by correlating with the surface findings and dielectric table. The different objects were marked with different colours of circle to ease the classification. For example, the blue circle represents subsurface layer, red circle indicates surface object, yellow circle shows reinforcement bar, orange circle shows PVC pipe and black circle is interested anomaly in the subsurface.

4.1. Cement fragment (red circle)

Based on the Figure 3 below, there were two anomalies detected with the same pattern and marked with red circles. The surface objects were cement fragments that scattered around the study area. The relative dielectric of cement is 5-10 while air is 1. Since the dielectric contrast was high, the strong reflection was detected in radargram. The cement fragments located at distance of 1 m and 14 m in the radargram. There were also same pattern of anomalies that indicates the cement fragments at line 2, 3, 5, 6 and 7.

![Figure 3. Radargram of line 1.](image)

4.2. Polyvinyl Chloride (PVC) pipe (orange circle)

In line 2 (Figure 4), there was an anomaly of hyperbolic shape of reflection at distance of 7 m and depth of 0.2 m. The anomaly was assumed as a buried broken PVC pipe because an exposed PVC pipe was found in line 1 and 3 at distance of 6.3 m and 8 m respectively. In line 1 and 3, the reflection of the exposed PVC pipe was not detected because of the weak reflection due to the small relative dielectric contrast between PVC pipe (3) and air (1) [9]. While in line 2, the strong hyperbolic shape reflection was detected as the reflection coefficient R, was high due to high relative dielectric contrast between PVC pipe and ground.

![Figure 4. Radargram of line 2.](image)
4.3. Well (green circle) and Cement Slab (black circle)
Based on Figure 5, there were two anomalies found in line 8 at the distance of 2 m and 9 m, at the depth of 0.4 m and 0 m respectively. The green circle (8.9 m) indicates a well which was exposed to the surface and cause high contrast due to the high relative dielectric contrast of air inside the well and surrounding (Table 1). The black circle was an interested anomaly that located at distance of 2 m and depth of 0.4 m. After referred to the surface finding, the anomaly was assumed as buried cement slab as it is not related with the surface findings.

![Figure 5. Radargram of line 8.](image)

4.4. Reinforcement Bars (yellow circle)
Figure 6 shows the radargram for line 15. On the surface, the reinforcement bars were exposed at distance of 3 m and 11 m of line 15. In the radargram, two strong reflection were detected at distance of 3 m and 11.2 m. These two anomalies were confirmed as reinforcement bar. In line 13, there is an anomaly which had same pattern as reinforcement bar at line 15. Hence, the anomaly was assumed as a reinforcement bar. At the distance 19 m, an anomaly was detected at depth 0.5 m. The anomaly was assumed as buried cement slab because of the strong reflection. There were several interested anomalies found at line 3, 4, 8 and 14 which can refer to appendix and marked with black circle.

![Figure 6. Radargram of line 15.](image)

4.5. Subsurface layer (blue circle)
In this study, subsurface layer had been detected at line 1, 2, 3, 4, 5 and 6. The Figure 7 shows subsurface layer at line 2 at distance of 14 m to 20 m and depth range of 1 m to 0.2 m. The reflection of the layer was believed as interface between shell layer and sand layer.
5. Conclusion
GPR method provide a good result in detecting subsurface structure such as buried object. However, surface object can affect radargrams and cause misinterpretation if operators are not alert to surrounding. Reinforcement bars were detected at line 15 as it is exposed to the surface and cause high contrast in radargram. Buried object which had higher dielectric permittivities than surrounding will cause reflection, refraction and diffraction such as slab, reinforcement bar, well, slab and cement fragment. GPR also able to detect subsurface layer as shown in radargram of line 1 until line 6 in appendix and marked with blue circle.

6. Appendix

![Figure 7](image7.png)

**Figure 7.** Subsurface layer at line 2.

![Figure 8](image8.png)

**Figure 8.** Radargram of line 1.
Figure 9. Radargram of line 2.

Figure 10. Radargram of line 3.

Figure 11. Radargram of line 4.

Figure 12. Radargram of line 5.
Figure 13. Radargram of line 6.

Figure 14. Radargram of line 7.

Figure 15. Radargram of line 8.

Figure 16. Radargram of line 9.
Figure 17. Radargram of line 10.

Figure 18. Radargram of line 11.

Figure 19. Radargram of line 12.

Figure 20. Radargram of line 13.
Figure 21. Radargram of line 14.

Figure 22. Radargram of line 15.

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Reference
[1] Burger, H R, Sheehan, A F, and Jones, C H 2006 Introduction to applied geophysics: Exploring the shallow subsurface: WW Norton.
[2] Damiata, B N, Steinberg, J M, Bolender, D J, & Zoëga, G 2013 Imaging skeletal remains with ground-penetrating radar: comparative results over two graves from Viking Age and Medieval churchyards on the Stóra-Seyla farm, northern Iceland Journal of Archaeological Science, 40(1), 268-278.
[3] Loizos, A, & Plati, C 2007 Accuracy of pavement thicknesses estimation using different ground penetrating radar analysis approaches NDT & E International, 40(2), 147-157.
[4] Ayob, L, & Queen, N W 2015 Early History of Penang (Penerbit USM): Penerbit USM.
[5] Sagnard, F., Norgeot, C., Derobert, X., Baltazart, V., Merliot, E., Derkx, F., & Lebental, B. (2016). Utility detection and positioning on the urban site Sense-City using Ground-Penetrating Radar systems. Measurement, 88(Supplement C), 318-330.
[6] Google Earth Pro 2017.
[7] Reynolds, J M 2011 An introduction to applied and environmental geophysics: John Wiley & Sons.
[8] Kearey, P, Brooks, M, & Hill, I An Introduction to Geophysical Exploration.
[9] Ismail N A, Muztaza, N M, & Saad R 2016 Reflectivity of Electromagnetic (EM) Wave In Shallow Ground Penetrating Radar (GPR) Survey. Jurnal Teknologi, 78(7-3), 117-121.