INTEGRATING GEOPHYSICAL METHODS IN DETERMINING THE GEOPHYSICAL PARAMETERS FOR SUBSURFACE STRUCTURES

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ABSTRACT
This research aims to determine the geophysical parameters differences for the subsurface structures. In particular, two geophysical methods employed were 2-D Resistivity Imaging and Ground Penetrating Radar (GPR). The 2-D Resistivity Imaging data was inverted and interpreted using RES2DINV and Surfer 8 software while the GPR data was processed using MALA Ground Vision software. Concrete structure and sediment-filled cavity can be compared based on the attenuation value of EM wave obtained from GPR method. Research was conducted at two study areas which are located at Universiti Sains Malaysia (USM) and Gunung Baling. Within USM, investigations were conducted at two sites to analyze geophysical parameters of the concrete structure while in Gunung Baling was to analyze geophysical parameters of sediments-filled cavity. The geophysical parameters results obtained from Gunung Baling are then compared with the results at USM. It was found that all study areas exhibit low resistivity value and have the same hyperbolic curve. However at USM, the attenuation value of electromagnetic (EM) wave was found to be higher compared to the value at Gunung Baling. Based from geophysical parameters obtained, Gunung Baling survey area was considered as mainly dominated by sediments-filled cavity. Method and results of this study could be useful in solving problems related to subsurface structures in environmental engineering.

Keywords: Geophysical Parameters, Subsurface Structures, Environmental Engineering
1. INTRODUCTION

There are several approaches available in obtaining informations about subsurface area. The best technique is having direct observation of the subsurface area but this is rarely possible in terms of financially and work rates. The discovery of cavities at the subsurface area using geophysical methods has gained wide interest in the past few decades. This discovery is important since the presence of natural voids or cavities at the subsurface area particularly at limestone topography may cause many severe engineering problems [1]. The geophysical methods are most likely to be successful if it is used in conjunction with other methods to scrutinize the findings since the limestone will also have high resistivity value [2]. Geophysical studies can be used to determine the subsurface structures such as depth of bedrock, nature of overburden materials and near surface structures such as sinkholes, cavities, voids, faults and boulders.

A physical contrast between cavities and the surrounding rocks can be detected using the geophysical methods. For example, the resistivity value that indicates the void or air-filled cavity is higher than the surrounding materials hence 2-D Resistivity Imaging is used successfully [3] [4]. Ground Penetrating Radar (GPR) has been a very useful method for mapping shallow targets based on the geological engineering and environmental management prospect [5]. GPR also can be considered as one of the geophysical methods that are useful to detect and identify the cavities or voids with diameters less than 10 m at the subsurface area [6-8]. The previous research conducted by integrating geophysical methods in karst topographic study as the analysis from GPR data revealed the high electromagnetic (EM) energy attenuation due to the presence of water filling the subsoil and the pavement while 3-D Resistivity Imaging surveys were performed in order to confirm the presence of water in the subsoil and allowed to locate the cavity. The comparison between the map of the anomalies obtained with GPR measurements and the 3-D Resistivity Imaging, confirmed the effectiveness of the geophysical application that able to investigate the subsoil conditions [9]. 2-D Resistivity Imaging and GPR methods were used in detecting and mapping the fractures, voids, filled cavities, collapsed cavities, pinnacles, cliff subsurface and overhangs that often occur in limestone topography areas in urban area. The results show that there are many weak zones can be detected that can be associated with the karst features occur in limestone topography such as the cavities and pinnacles [10]. 2-D Resistivity Imaging survey was conducted and the results were correlated with borehole record in investigation land subsidence at karst topographic area. Based on the results from the borehole record showed the cavity filled with clay materials and tomogram for this region indicated resistivity value <50 Ωm [11].

2-D Resistivity Imaging and Ground Penetrating Radar (GPR) methods were used with the main purpose to integrate both of the geophysical methods and obtaining the geophysical parameters for both of subsurface structures. This research focused on to accumulate the geophysical parameters such as velocity of the EM wave propagation, the dielectric permittivity, attenuation of the EM wave, and conductivity value of the subsurface area that can be obtained from the correlation between both geophysical methods. The geophysical parameters acquired can help to differentiate the types of subsurface structures which are the concrete structures and sediments filled cavity. There are two main field models as for in-
filled cavity in this research that was represented by the concrete structures. Inhomogeneity in subsurface medium is causing the variations of properties at the subsurface area like the conductivity ($\sigma$), electric permittivity ($\varepsilon_r$) and magnetic permeability ($\mu$) due to different composition of the media [12-14]. The resistivity value, dielectric permittivity and velocity of EM wave for some materials through different medium can be acquired from [15] [16].

2. THEORY AND METHODOLOGY

The 2-D Resistivity Imaging method is based on injecting electrical current into the subsurface using the electrodes known as the current electrodes, $C_1$ and $C_2$ and then measuring the potential between electrodes known as the potential electrodes, $P_1$ and $P_2$. Fundamentally, a mathematical procedure was used to calculate apparent resistivity value of the subsurface by which physical parameter distribution is estimated based on field measurements [17-19].

The GPR data can be obtained by the transmitting antenna distribute the EM waves into the subsurface and later on being reflected diffracted by features coincide to the changes in the electrical properties of the earth materials. The waves that are reflected and diffracted back toward the earth’s surface detected by a receiving antenna. GPR method is high resolution electromagnetic, non-destructive and environmental friendly for shallow subsurface mapping [20]. The contrast in the electrical properties of the materials leading to the reflections of electromagnetic waves is used in obtaining vital information about the subsurface structure [21]. By analyzing some of characteristic properties of the returned EM waves, all the details such as the dimensions of the target at the subsurface area and the possible depth about the target can be obtained [16] [22].

Equation 1 is used to calculate the velocity of the materials at the subsurface area where $V$ is the velocity of the EM waves, $d$ is the possible depth of cavities and $t$ is the time taken of the EM wave propagation to travel at the subsurface [5]. Equation 2 is used to calculate the attenuation value of the EM wave, where $\alpha$ is the attenuation of the EM wave, $\sigma$ is the conductivity value from the 2-D Resistivity Imaging data, and $\varepsilon_r$ is the dielectric permittivity of the earth materials [23]. Equation 3 is used to calculate the conductivity value with correlation of both geophysical methods data sets, where $\alpha$ is the attenuation of the EM wave, $\sigma$ is the conductivity value, $\omega$ is the angular frequency, and $\mu$ is the magnetic permeability constant [24].

\[
V = \frac{(2\cdot d)}{(t)}
\]

\[
\alpha = 1.69 \cdot \left(\frac{\sigma}{\sqrt{\varepsilon_r}}\right)\frac{1}{t}
\]

\[
\sigma = (2\alpha) \left(\frac{\sqrt{\sigma^2 + \omega^2 \varepsilon_r \mu}}{\omega \mu}\right)\frac{1}{t}
\]

All the study areas have one 2-D Resistivity Imaging survey line and one Ground Penetrating Radar (GPR) survey line. The study areas at USM are labeled as USM Site 1 and USM Site 2 that represent Desasiswa Bakti Permai and Convocation Site respectively. All the GPR survey lines lie on the same line as 2-D Resistivity Imaging survey line but differ in total length of the survey line at all the study areas. Table 1 shows the summary of the details associated with all study areas.
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Table 1 Array used and the total survey lines length associated with all the study areas

<table>
<thead>
<tr>
<th>Study areas</th>
<th>Types of array</th>
<th>Total length of 2-D Resistivity Imaging survey line (m)</th>
<th>Total length of GPR survey line (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USM Site 1</td>
<td>Pole-Dipole</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>USM Site 2</td>
<td>Wenner Schlumberger</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Gunung Baling</td>
<td>Pole-Dipole</td>
<td>60</td>
<td>40</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION

The inversion profile of the 2-D Resistivity Imaging data in Figure 1 shows the possible depth of the bunker at USM Site 1 is about 1 m from the surface. The suspected distance that represents the bunker structure starting at 23-55 m with the resistivity value that indicates the bunker is between 50-250 $\Omega$ m. A larger scale of the hyperbolic pattern taking an inverted chevron shape that can indicate the presence of soil or air-filled void, while a reflection free pattern may indicate a homogeneous materials such as clay-rich soils, bedrock or groundwater at which all the three materials contain highly conductive dissolved minerals that help the attenuation process of the EM wave produced by the GPR antenna [25]. The resistivity value >80 $\Omega$ m indicates the presence of concrete foundation [26]. Based on Figure 2, the hyperbolic shape representing the bunker structure at USM Site 1 is located at 24-26 m in distance and about 1 m in depth at the subsurface area. From Table 2 the conductivity obtained from the 2-D Resistivity Imaging data is 0.0909 S/m. The calculated conductivity value using Equation 3 is 0.0926 S/m. The calculated attenuation value of EM wave using Equation 2 at this study area is 57.0448 dB/m.

![Figure 1 - 2-D Resistivity Imaging inversion profile at USM Site 1](http://www.iaeme.com/IJCIET/index.asp)

![Figure 2 - GPR profile at USM Site 1](http://www.iaeme.com/IJCIET/index.asp)
Table 2 Parameters obtained for USM Site 1

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (m)</td>
<td>23-55</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>≈1</td>
</tr>
<tr>
<td>Resistivity value (Ωm)</td>
<td>50-250</td>
</tr>
<tr>
<td>Conductivity from 2-D Resistivity Imaging, σ (S/m)</td>
<td>0.0909</td>
</tr>
<tr>
<td>Conductivity from GPR, σ (S/m)</td>
<td>0.0926</td>
</tr>
<tr>
<td>Attenuation, α (dB/m)</td>
<td>57.0448</td>
</tr>
</tbody>
</table>

The inversion profile of 2-D Resistivity Imaging data in Figure 3 shows the possible depth of the man-made hole at USM Site 2 is about 1.5 m in the subsurface area. The resistivity value that indicates the man-made hole is between 5-40 Ωm at distance between 8-12 m. Based on GPR result (Figure 4) it shows a hyperbolic shape that indicates the suspected target at USM Site 2 is about 1.5 m depth. Table 3 shows the conductivity value obtained from the 2-D Resistivity Imaging result is 0.0728 S/m. The calculated conductivity value obtained from GPR using Equation 3 is 0.0772 S/m. The calculated attenuation value of EM wave using Equation 2 at this study area is 41.5438 dB/m. The primary limitation for the EM wave propagation in the conductive materials will experience high attenuation of wave propagation [27].

Figure 3 2-D Resistivity Imaging inversion profile at USM Site 2

Figure 4 GPR profile at USM Site 2
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Table 3 Parameters obtained for USM Site 2

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (m)</td>
<td>8-12</td>
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<tr>
<td>Depth (m)</td>
<td>≈1.5</td>
</tr>
<tr>
<td>Resistivity value (Ωm)</td>
<td>5-40</td>
</tr>
<tr>
<td>Conductivity from 2-D Resistivity Imaging, σ (S/m)</td>
<td>0.0728</td>
</tr>
<tr>
<td>Conductivity from GPR, σ (S/m)</td>
<td>0.0772</td>
</tr>
<tr>
<td>Attenuation, α (dB/m)</td>
<td>41.5438</td>
</tr>
</tbody>
</table>

Based on 2-D Resistivity Imaging inversion profile at Gunung Baling in Figure 5, the cavities can be seen at depth about 1 m from the surface with resistivity value of 10-20 Ωm. Clayey material have the ability to store more water and have a higher ion concentration that could contribute to the resistivity value to be <100 Ωm [28]. The clear hyperbolic shape that may represent the possible presence of cavity at Gunung Baling is located at depth about 1 m and at distance about 26-27 m (Figure 6). The red and yellow lines indicate the clear hyperbolic shape while the red color dashed line indicates the other possibility of less significant hyperbolic shape. Based on Table 4, the conductivity value obtained from the 2-D Resistivity Imaging is 0.0076 S/m. The calculated conductivity value from GPR result using Equation 3 is 0.0078 S/m. The calculated attenuation of EM wave using Equation 2 at this area is 4.3712 dB/m which is the lowest compared with both of the concrete structure results. This is because the material at this study area is less conductive compared with the concrete structures. Based on parameters obtained in Table 4 with the integration of both geophysical methods, it can be concluded that the cavity in study area of Gunung Baling is being filled with clayey materials.

![2-D Resistivity Imaging inversion profile at Gunung Baling](image1)

![GPR profile at Gunung Baling](image2)
Table 4 Parameters obtained for Gunung Baling

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance (m)</td>
<td>26-27</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>≈1</td>
</tr>
<tr>
<td>Resistivity value (Ωm)</td>
<td>10-20</td>
</tr>
<tr>
<td>Conductivity from 2-D Resistivity Imaging, $\sigma$ (S/m)</td>
<td>0.0076</td>
</tr>
<tr>
<td>Conductivity from GPR, $\sigma$ (S/m)</td>
<td>0.0078</td>
</tr>
<tr>
<td>Attenuation, $\alpha$ (dB/m)</td>
<td>4.3712</td>
</tr>
</tbody>
</table>

4. CONCLUSION

This research findings is particularly important in distinguishing the differences of the subsurface structures based on the geophysical parameters obtained from integrating between 2-D Resistivity Imaging and GPR methods. The in-filled cavity associated with the concrete structures at USM has slightly higher resistivity value, ranging between 5-250 Ωm. In contrast, the in-filled associated with the sediment filled cavity at Gunung Baling have much lower resistivity value with 10-20 Ωm. This research also indicates that it is difficult to identify between concrete structure and sediment-filled cavity based on resistivity values obtained from 2-D Resistivity Imaging method with both of subsurface structures have low resistivity values. The application of GPR method and calculating the geophysical parameters acquired from both geophysical methods used help to differentiate the subsurface structures more accurately. Hence, the proposed method would offer a more comprehensive information to investigate the subsurface structures related with any environmental and engineering problems. The conductivity value for the concrete structures is higher compared to the sediment filled cavity. The attenuation value of the EM wave for the concrete structure is also higher with 57.0448 dB/m and 41.5438 dB/m. The sediment filled cavity has 4.3712 dB/m for the attenuation value of EM wave. The attenuation value of EM wave from GPR method can differentiate between concrete structure and sediment-filled cavity.

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