Analysis of Ground Penetrating Radar’s Capability for Detecting Underground Cavities: A Case Study in Japan Cave of Taman Hutan Raya, Bandung

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Abstract. Underground cavities or voids detection is essential especially when it comes to building construction. By knowing the presence of void lying underground, one could consider whether the subsidence is likely to be prevented or not. Ground penetrating radar is a high-frequency electromagnetic sounding technique that has been developed to investigate the shallow subsurface using the contrast of dielectric properties. This geophysical method is suitable to be used to detect and locate voids beneath the surface especially those that lie in shallow depth. This research focused on how GPR could be implemented as void detector using model simulation or forward modelling. The models applied in the forward modelling process are to be made as similar as the real condition in the case study location which took place in Tahura Japan Cave, Bandung, Indonesia. Forward modelling needs to be done so in the future, we might use the modelling results as the references in measuring real GPR data in the location. We used three models that we considered fairly representative to prove that GPR is capable of detecting and locating voids underneath the ground. This research resulted in the different amplitude region around the considerably homogeneous region. The different amplitude region is characterized having an arc shape and is considered to be air which is known as the key component of voids.

1. Introduction

Underground voids could happen naturally as well as artificially like underground mining, tunnel and also cavities. Voids detection holds an important role in urban planning and construction. In such projects, especially those in the civil engineering field, it is necessary to identify every single void which lies underneath the construction site because it would bring unwanted effects such as subsidence and even total collapse to the ground surface [1][2]. Some geophysical methods commonly applied for detecting underground voids are GPR, seismic, gravity and also electrical measurement [3][4]. Ground Penetrating Radar (GPR) is one of non-destructive geophysical method most recommended to be used in studying shallow subsurface imaging [5]. GPR method has been used for many purposes due to its effectiveness in mapping the shallow depth subsurface including its application for detecting human buried body [6]. Its data sensitivity to dielectric permittivity variation make GPR method could be
applied to detect any void (natural or anthropogenic), for the reflection caused by the interface between soil-air and air-soil could be easily identified. This research aims to prove that GPR could be applied to detect underground voids by imaging subsurface structure where its voids positions have already been known. Hence, we chose Goa Jepang Taman Hutan Raya (Japan Cave of Tahura) as the area of the investigation.

2. Method

2.1. Ground Penetrating Radar in Void detection

GPR works by transmitting EM waves as a source that penetrates medias beneath the site of investigation. Any reflected wave caused by material interfaces in the subsurface is then detected by receiver antenna.

When a propagating electromagnetic wave encounters a discontinuity in electric, magnetic or conductive properties, part of the electromagnetic energy is reflected, and the reflection strength being proportional to the magnitude of change. For a perpendicular incident wave, the strength of a GPR reflection is a function of the contrast in relative dielectric constants across the reflecting boundary, and the reflection coefficient $RC$ can be expressed as [7]:

$$RC = \frac{\sqrt{\varepsilon_r_2} - \sqrt{\varepsilon_r_1}}{\sqrt{\varepsilon_r_2} + \sqrt{\varepsilon_r_1}}$$

Where $\varepsilon_{r1}$ represents relative dielectric constant of upper soil horizon and $\varepsilon_{r2}$ represents the relative dielectric constant of lower soil horizon. Another research executed by Kofman et al. [8] that aims to examine the relationship between voids dimensions and wavelengths of various antennas, and the corresponding GPR responses, shows that there were strong reverberations generated by the inner surface of the void targets [9].

2.2. Geological Setting

The models, applied in forward modelling or numerical simulation, were constructed to be as similar as the geological setting had by the site of investigation. Japan Cave Taman Hutan Raya is in Dago Pakar, Bandung, Indonesia and geographically located in latitude 6° 51' 23.6844'' S and longitude 107° 37' 56.5428'' E.

![Figure 1. Geology map of Dago (Silitonga, 1979)
Type of the rocks dominated in Dago Pakar belongs to the group of sandy tuff originated in Dano mountain and Tangkuban Perahu volcano, according to regional geology map published by Silitonga in 1979 [10] (Figure 1). The map indicated that the type of rocks in Dago Pakar belongs to Qyd formation which consists of sandy tuff sourced by Dano and tangkuban Perahu volcano. The brown sandy tuff contains coarse and hollow hornblende mineral crystal and it has glassy luster and also resembles reddish lava, lapilli layers and breccia [11]. The material that forms the cave wall is merely hard rock without being layered by cement-concrete. Based on regional geology map, this hard rock is considered to be tuff that resembles the rock formed in Dago Pakar and it is likely to be emanated from the eruption of Tangkuban Perahu Volcano [12].

![Figure 2. Pyroclastic tuff rock as the rock forming the cave wall](image)

2.3. Numerical Simulation
To conduct a preliminary study of the signal characteristics of GPR reflections in Japan Cave Dago, the numerical simulation or forward modelling was done using MatGPR. In this stage, we constructed three synthetic models, and also one homogenous model which is used as a comparison to distinguish whether any cave or void exists. The simulation is done using finite different time domain (FDTD) method. The chosen profiles are shown in Figure 3 as red, yellow and purple lines.
Figure 3. The illustration of Japan Cave. The white cylinder represents cavity, and colored lines (red, yellow and purple) are the profiles chosen to be modeled.

The physical parameters used in forward modelling process is shown in Table 1.

| Rock Type | Resistivity | Relative dielectric constant | Relative magnetic permeability | Velocity (m/ns) |
|-----------|-------------|------------------------------|-------------------------------|----------------|
| Tuff      | $10^3$ [13] | 2.6 [14]                     | 1.021 [15]                    | 0.14835        |
| air       | $1.3 \times 10^{16}$ [16] | 1 [17]                       | $1.00000037$ [18]            | 0.2998         |
| soil      | 1000 [19]   | 5 [19]                       | $1.0006$ [20]                 | 0.13401        |

3. Result

The models used in this research and the synthetic radargrams resulted by those models are shown in the figures below:

Figure 4. Homogenous model
Figure 5. Line 1 geological model
Figure 6. Line 2 geological model

Figure 7. Line 3 geological model

Forward modelling in 100 MHz frequency:

Figure 8. Homogenous synthetic radargram of 100MHz antenna
Figure 9. Line 1 synthetic radargram of 100MHz antenna

Figure 10. Line 2 synthetic radargram of 100MHz antenna
Figure 11. Line 3 synthetic radargram of 100MHz antenna

Forward modelling in 50 MHz frequency:

Figure 12. Homogenous synthetic radargram of 50MHz antenna
Figure 13. Line 1 synthetic radargram of 50MHz antenna

Figure 14. Line 2 synthetic radargram of 50MHz antenna
4. Conclusion

By assuming physical parameters used, modelling results indicate that forward modelling on a frequency of 100 MHz could not identify the interface between the tuff and air, but all the three synthetic models can still distinguish the boundary layer between the soil and tuff. However, forward modelling at a frequency of 50 MHz, with deeper penetration depth, all the three synthetic models can identify the boundary layer between the soil and tuff, and also the interface between the tuff and air. The comparison can be seen in Figure 16.
Figure 16. Comparison of forward modelling results of 50 MHz and 100 MHz frequency in line 2.

The differences between the forward modelling results happen because the energy assigned to send back wave reflection resulted by the interface of tuff-air toward the surface is insufficient at the test frequency of 100 MHz. Nevertheless, at a frequency of 50 MHz, with higher penetration depth, there is still enough energy left to deliver the reflection wave of tuff-air boundary layer toward the surface, and therefore the contrast can still be read via the receiver. However, this test should still be validated by using data from field acquisition; because the investigation depth of Japan cave (6-10 meters), should still be accommodated by a GPR 100 MHz.

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