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REFLECTIVITY OF ELECTROMAGNETIC (EM) WAVE IN SHALLOW GROUND PENETRATING RADAR (GPR) SURVEY

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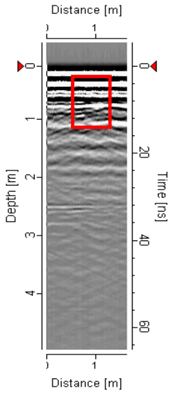
Graphical abstract



Abstract

Ground Penetrating Radar (GPR) is a geophysical method that is widely used in geophysical surveys, civil engineering applications, archaeological studies and locating underground utilities or hidden objects. It works by sending electromagnetic (EM) wave into the ground by transmitter and recording the returning signals by receiver. The returning signals bring information about the materials and changes in material parameters at different depths. The changes in dielectric properties (ε) of two adjacent media result in EM wave reflections. In this study, several types of materials with different dielectric properties (ε) are used in order to identify the reflectivity of the EM wave. Results prove that the larger the dielectric contrast, the higher the reflection coefficient thus the stronger the reflection.

Keywords: Dielectric properties; reflection

1.0 INTRODUCTION

Ground penetrating radar (GPR) is a high-resolution geophysical method which efficiently used in broad area including civil engineering and environmental study. It has become increasingly attractive particularly for shallow, high resolution applications such as concrete evaluation studies and underground utilities mapping. GPR involve the transmission of high frequency radar pulses from a surface antenna into the ground which dependent on the target, geologic environment, subsurface features and other factors that affect the contrast of the target to the surrounding medium. GPR works in the electrical conduction wavelength region of the electromagnetic (EM) spectrum and response in a function of electromagnetic properties; dielectric permittivity (ε), magnetic permeability (μ), and electrical conductivity (σ). Dielectric permittivity is a complex function having real and imaginary components where the real part is usually expressed as dielectric constant (ε_r) while imaginary part expressed as dielectric loss. Dielectric constant is defined as the ratio of the electric-field storage capacity of a material to that of free space while dielectric loss represents attenuation and dispersion [1]. Thus, dielectric constant is typically the primary component of dielectric permittivity. Generally dielectric constant increase with decreasing frequency however, their behavior is relatively consistent over the typical GPR antenna frequency range of 25-1500 MHz [2]. The changes of dielectric properties of two materials result in electromagnetic wave reflections. The greater the dielectric contrasts between two adjacent media, the greater the amount of reflected energy. The reflection coefficient (R) computes the reflective strength between two adjacent media [3].

2.0 THEORY

GPR transmit a very short electromagnetic pulse into the ground by the transmitter using an antenna. Abrupt changes in dielectric properties cause EM wave to be reflected back to ground surface, recorded and amplified by the receiver. The recorded signal is registered as amplitude and polarity versus two-way travel time known as radargram.

EM wave propagates at speed of light (0.3 m/ns) in air and reduced when it enter the ground. The velocity of EM wave in a host medium is given by Equation 1:

$$v = \frac{c}{\sqrt{\varepsilon_r \mu_r \frac{1+\sqrt{1+\left(\sigma/\omega\varepsilon\right)^2}}{2}}} \qquad (1)$$

where c is the EM wave velocity in vacuum (0.3 m/ns), $\varepsilon = \varepsilon_r\varepsilon_0$ the dielectric permittivity and ε_0 the dielectric permittivity in free space (8.854 x 10^{-12} F/m), $\omega = 2\pi f$ the angular frequency, where f is the frequency and expression $\sigma/\omega\varepsilon$ is a loss factor. The velocity of EM waves is reduced in the non-magnetic low-loss materials (gravel and clean sand) given by Equation 2:

$$v = \frac{c}{\sqrt{\varepsilon_r}} \qquad (2)$$

Based on equation presented, the velocity of EM waves propagating in ground is decreased compared to the velocity in the air. EM waves will be reflected when it encounters dielectric contrast between two adjacent media, known as reflection coefficient (R) given in equation 3:

$$R = \frac{\sqrt{\varepsilon_2} - \sqrt{\varepsilon_1}}{\sqrt{\varepsilon_2} + \sqrt{\varepsilon_1}} \qquad (3)$$

where ε_1 and ε_2 are the dielectric constants of two media (or layers) respectively [4]. The larger the dielectric contrast, the larger the reflection coefficient and subsequently, layer delineation and subsurface features/objects detection is more evident.

Table 1 lists the bulk dielectric constant values of common earth materials reported by [5].

3.0 METHODOLOGY

Simple laboratory measurements are carried out to identify the reflectivity of EM wave using different types of material. Antenna with nominal central frequency of 500 MHz is used in air medium while 800 MHz central frequency antenna used in water medium. The evaluated antenna used is a shielded antenna manufactured by MALA Geoscience. Two objects are inserted in air medium which are pvc hollow pipe and aluminium hollow pipe respectively at distance 0.9 m (Figure 1 and 2).

Measurements using water as host medium are divided into two which are the point (air) reflection and planar (ground) reflection (Figure 3 and 4).

Table 1 Bulk dielectric constants (ε_r measured at 100 MHz) of common earth materials [5]

Material	Typical dielectric constant	Radar propagation velocity (m/ns)
Air	1	0.30
Water	81	0.033
Granite	9	0.10
Limestone	6	0.12
Sandstone	4	0.15
Rocks	4-12	0.15-0.087
Dry sand	4-6	0.15-0.12
Wet sand	30	0.055
Dry clay	8	0.11
Wet clay	33	0.052
Dry soils	3-8	0.17-0.11
Wet soils	4-40	0.15-0.047
Asphalt	3-6	0.17-0.12
Concrete	9-12	0.10-0.087

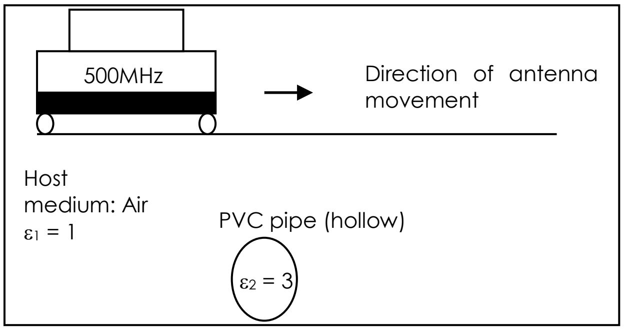


Figure 1 Data acquisition diagram for air medium and pvc pipe

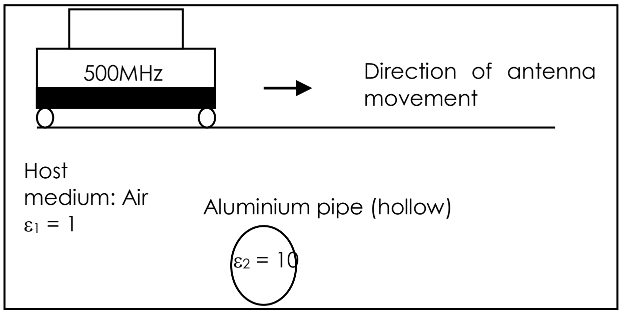


Figure 2 Data acquisition diagram for air medium and aluminium pipe

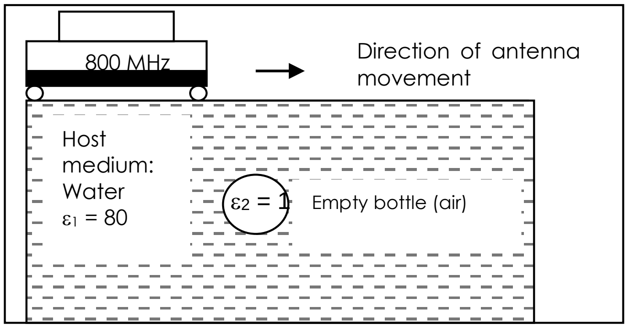


Figure 3 Point reflection of empty bottle (air) in the water medium

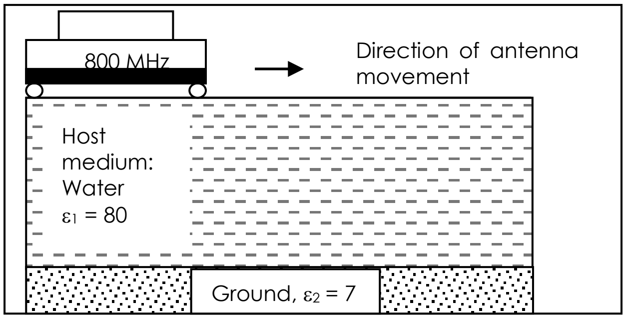


Figure 4 Planar reflection of ground beneath medium of water

The reflection coefficients are then calculated based on dielectric constant of each material and compared with the signal shown on radargram obtained from the data acquisition.

The study extended to real site conditions which are concrete evaluation (using 800 MHz nominal central frequency antenna) and underground utilities mapping (using 250 MHz nominal central frequency antenna).

4.0 RESULTS AND DISCUSSION

Based on radargram obtained, a weak reflection is identified in air-pvc materials. No clear indication of pvc pipe occurrence from the reflection signal of EM wave is observed (Figure 5). This is due to lack dielectric contrast between pvc (ε_{pvc} = 3) and air (ε_{air} = 1) and therefore, layer delineation would be difficult. The calculated reflection coefficient in this two media is R = 0.26795.

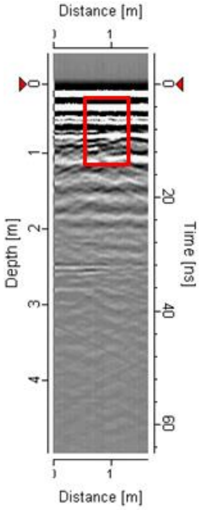


Figure 5 GPR radargram for air medium with pvc pipe inserted as an object

There is strong reflection observed in radargram with air as a host medium and aluminium pipe inserted as an object (Figure 6). The hyperbolic shape marked in the red box indicates the reflection event. The dielectric constant for air is 1 and aluminium is 10 therefore the corresponding reflection coefficient (R) is 0.51949.

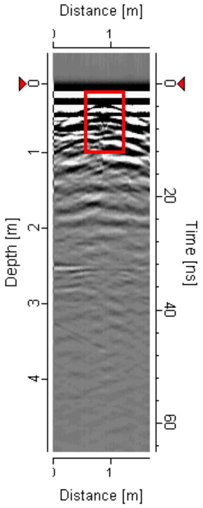


Figure 6 GPR radargram for air medium with aluminium pipe inserted as an object

For second medium which is water, very strong reflections are identified both for point reflection (air) as well as planar reflection (ground). Water has very high dielectric constant, ε_{water} = 80, air (ε_{air} = 1) and ground (ε_{ground} = 7). Sharp contrast of dielectric are observed between this two adjacent media resulting in very strong reflection of EM wave. Corresponding reflection coefficient between water-air interface and water-ground interface are -0.7989 and -0.5434 respectively. The negative reflection coefficient is a reversed polarity due to phase inversion that occurs when dielectric constant of layer 1 is higher than dielectric constant layer 2. Figure 7 shows the GPR radargram for point reflection (air) in a medium of water. Clear hyperbolic shape within the red box indicates the reflection from empty bottle (air).

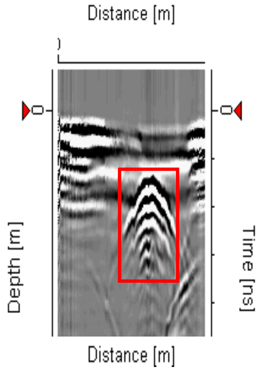


Figure 7 GPR radargram for water medium with point reflection of empty bottle (air)

Figure 8 shows the GPR radargram for planar reflection (ground) in a medium of water. Clear ground interface (red dashed line) indicates the reflection from ground underneath the water layer.

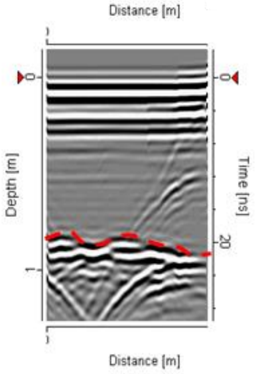


Figure 8 GPR radargram for water medium with planar reflection (ground)

Figure 9 provides representative radargram of concrete evaluation study using 800 MHz antenna. Results successfully classified layers of reinforcement bar (marked with red box) which clearly shown in radargram. Typically, concrete has steel reinforcement bar which is a metallic and therefore completely reflects GPR signal.

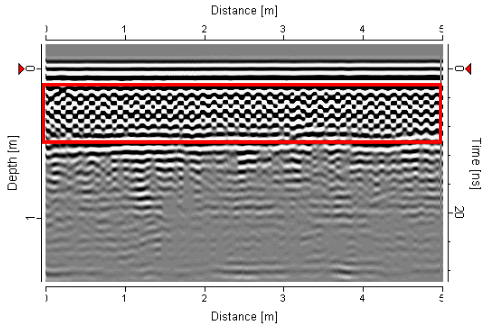


Figure 9 GPR radargram for concrete evaluation study

Figure 10 represent the radargram for underground utilities mapping using 250 MHz shielded antenna. Four hyperbolic reflection events successfully identified in the radargram. The utilities are most probably metallic and have very great contrast of dielectric compared to the ground.

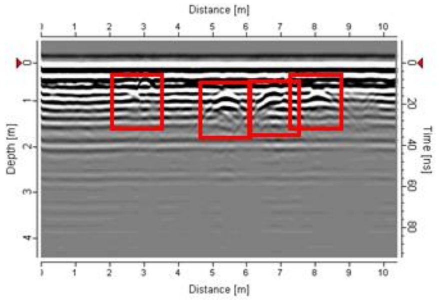


Figure 10 GPR radargram for underground utilites mapping

5.0 CONCLUSION

GPR provides an efficient and versatile means for shallow subsurface studies. Great contrast between dielectric constant of two adjacent media results in higher reflection coefficient and thus increases the reflectivity of the EM wave. The larger the dielectric contrast, the stronger the reflection. Based on this study, weak reflection observed with reflection coefficient < 0.3 while strong positive and negative reflections observed with reflection coefficient > 0.5. The closer the reflection coefficient gets to -1 or 1, the better for ground penetrating radar survey.

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