Velocity Effect Over Ground Penetrating Radar (GPR) Signal

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ABSTRACT

This paper illustrates the effect of EM wave velocity applied in medium while processing GPR data towards depth calculation. The velocity applied effect the depth of an object (target) but not laterally. The importance of knowing or estimating the velocity of EM waves in soil (medium) in order to identify a good result, is emphasized.

KEYWORDS: GPR, EM wave velocity, depth, scattered EM waves

INTRODUCTION

Ground Penetrating Radar (GPR) is geophysical method used for very shallow and utilities study. It applies electromagnetic wave (1-4,000 MHz) and also designed to investigate building materials, roads and bridges (Annan and Davis, 1978; Olhoeft, 1992; Daniels et al., 1998). It can also operate in boreholes. This high resolution geophysical technique developed for investigations using time-dependent measurement. The results provide a depth for common subsurface objects including defining size, shape, orientation, and material properties of buried objects (Roberts, 1994; Roberts and Daniels, 1996; 1997). Result accuracy is always depending on the wave propagation velocity in medium (Marwan et al., 2014). The basic principles used were the scattering of electromagnetic (EM) wave with moving antennas over surface rather than rotating about a fixed point. This field operation is analogous to seismic reflection method. GPR is a method that is commonly used for environmental, engineering, archeological, and other shallow investigations.

BASIC THEORY

GPR system consists of control unit (CPU), display unit which display the reflected/diffracted EM wave, transmitter that emits an EM wave and receives (Figure 1). If there is a change in electric properties in the ground or if there is an anomaly that has different electric properties surrounds the media, part of the wave is reflected and detected by the receiver. GPR profile can be constructed by plotting amplitude of the received signals as a function of time and position, representing a vertical slice of the subsurface (Figure 2). The time axis can be converted to depth by assuming a velocity of the EM wave propagates in the subsurface.

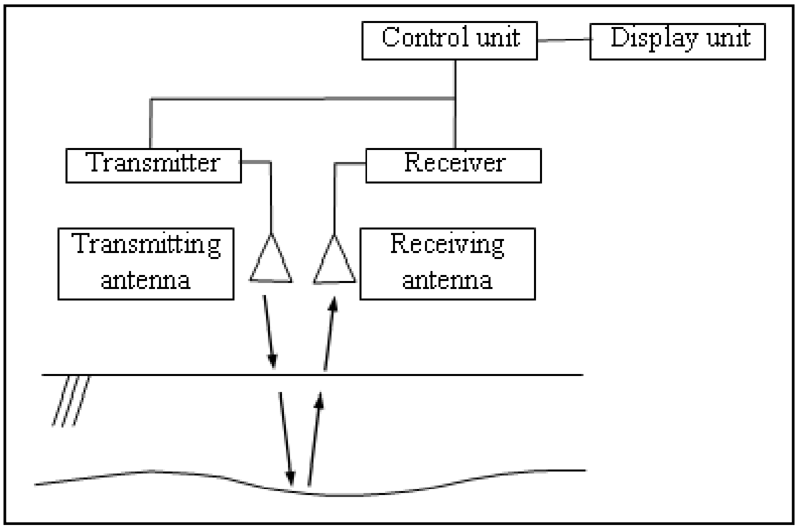

Figure 1: GPR system schematic diagram (Marwan, et al., 2014).

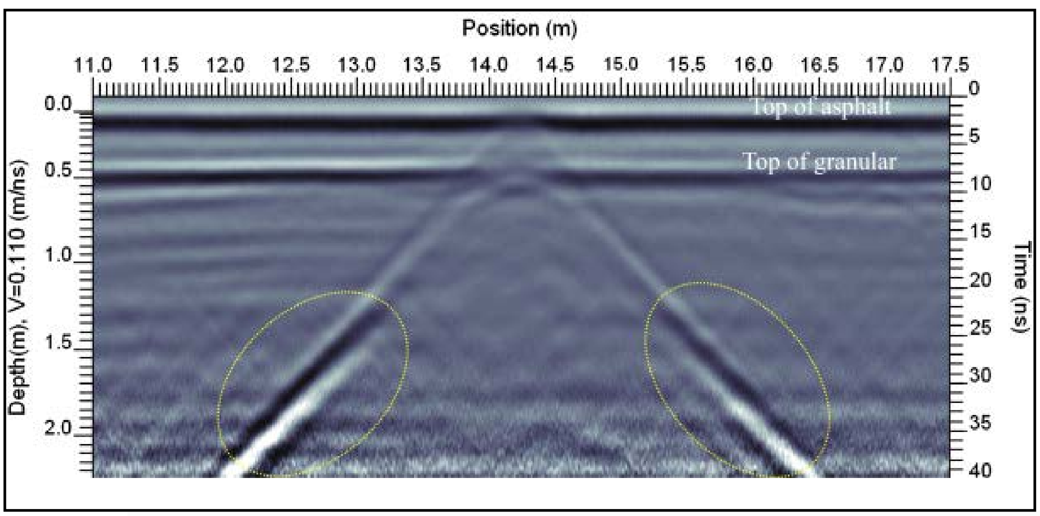

Figure 2: Cross-sections of 250 MHz GPR on asphalt pavement with thickness of 350 mm. The dashed circles indicate areas with shingling effects (Diamanti and Redman, 2012).

The EM wave propagation velocity, *v* in soil is characterized by dielectric permittivity, ε and magnetic permeability, μ of the medium:

$$v = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{1}{\sqrt{\mu_o \mu_r \varepsilon_o \varepsilon_r}} \tag{1}$$

and $c = \frac{1}{\sqrt{\mu_o \varepsilon_o}}$

where;

ε_o = permittivity of free space = 8.854 X 10^{-12} F/m,
ε_r = relative permittivity (dielectric constant) of the medium = $\varepsilon/\varepsilon_o$,
μ_o = free-space magnetic permeability = 4π x 10^{-7} H/m,
and μ_r = relative magnetic permeability = μ/μ_o.

In most soils, magnetic properties are negligible, yielding $\mu = \mu_o$, and Eq. (1) becomes Eq. (2),

$$v = \frac{c}{\sqrt{\varepsilon_r}} \tag{2}$$

where *c* = speed of light = 3 x 10^8 m/s.

The wavelength, λ is defined as the distance of the wave propagation in one period of oscillation and is obtained by;

$$\lambda = \frac{v}{f} = \frac{2\pi}{\omega\sqrt{\varepsilon\mu}} \tag{3}$$

where f = frequency, and ω = angular frequency = $2\pi f$.

Generally the attenuation of GPR signal is proportional and strongly controlled by frequency (Eq. 4), while the velocity is not so dependent on frequency (Eq. 1). This explains why lower frequency GPR signals penetrate deeper than higher frequency.

$$\text{Attenuation constant, } \alpha = \omega\sqrt{\mu\varepsilon}\left(\frac{1}{2}\left[\sqrt{1+\left(\frac{\sigma}{\omega\varepsilon}\right)^2} - 1\right]\right)^{1/2} \tag{4}$$

An inverse of the attenuation constant is called skin depth (Eq.5). Table 1 provides the typical range of permittivity, conductivity and attenuation of various materials.

$$\delta = \frac{1}{\alpha} \tag{5}$$

Table 1: Typical range of dielectric characteristics of various materials measures at 100 MHz (Daniels, 2004; Cassidy, 2009).

Material	Relative permittivity	Conductivity(S/m)	Attenuation constant(dB/m)
Air	1	0	0
Freshwater	81	10^{-6}-10^{-2}	0.01
Clay, dry	2–6	10^{-3}-10^{-1}	10-50
Clay, wet	5-40	10^{-1}-10^{-0}	20-100
Sand, dry	2-6	10^{-7}-10^{-3}	0.01-1
Sand, wet	10-30	10^{-3}-10^{-2}	0.5-5

GPR measures reflected or scattered EM waves from changes in an electric properties of materials. Figure 3 shows a planar boundary between two media with different electric properties.

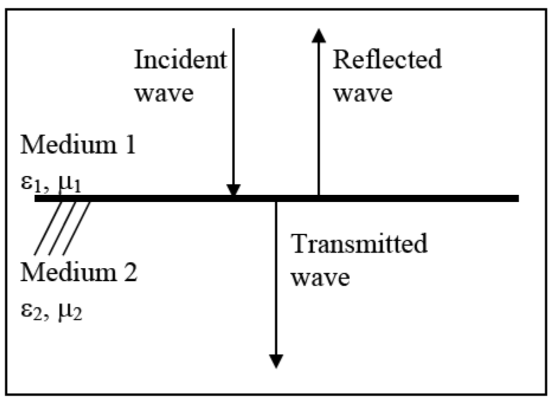

Figure 3: Reflection and transmission of EM wave to a planar interface between two media.

When EM waves hit a planar dielectric boundary, some energy is reflected from the boundary and the remainder is transmitted into the second medium. The relationships of the incident, reflected and transmitted electric field strengths (Eq. 6-8).

$$Ei = Er + Et \tag{6}$$
$$Er = R.Ei \tag{7}$$
$$Et = T.Ei \tag{8}$$

where

R = reflection coefficient,

and T = transmission coefficient.

The most important for GPR processing techniques to acquire accurate depth is analyzing the EM wave velocity in medium. Surface GPR measures EM wave which the only wave that travels through the ground with known propagation path and the wave velocity can be calculated directly from the travel-time. Analyzing the EM wave has proven to be a fast technique that can be used to map large areas and yield reasonable results in comparison to other methods, such as TDR or gravimetric soil moisture determination (Du, 1996; Grote et al., 2003; Huisman et al., 2001, 2003; Overmeeren et al., 1997).

METHODOLOGY

The research conducted at Lamnyong, Banda Aceh, Indonesia. The study site was under a concrete bridge which crossing a man made channel (Figure 4). The GPR survey conducted under the Lamnyong Bridge. GPR used was IDS system with 80 MHz antenna. The research objective is to study the effect of EM wave velocity towards depth and to identify scattered EM waves.

The processing used two values of EM velocity to see the depth effect towards GPR result. The first velocity used was 3 x 10^8 m/s, which is the EM velocity in the air. The second velocity used was 1 x 10^8 m/s, which is the EM average velocity of soil.

Figure 4: GPR study site, Lamnyong Bridge, Banda Aceh (Indonesia).

RESULTS AND DISCUSSION

Figure 5 shows a processed GPR data conducted under the Lamnyong Bridge, Banda Aceh (Indonesia). Figure 5 (a) was a result processed using EM wave velocity of 3 x 10^8 m/s. The diffraction of EM waves from bridge beams was clearly seen at depth of 4 m. This shows the hight of the bridge since the wave travels in the air. The first and second layer reflection were identified with depth of <1 m and 1-1.5 m respectively. This reflection depth was not accurate since the velocity used was EM velocity in the air. Figure 5 (b) was a result processed using EM average velocity of soil with a value of 1 x 10^8 m/s. The diffraction of EM waves from bridge beams was clearly seen at depth of 1.4 m. The hight of the bridge is not accurate since the velocity used was EM average velocity of soil. The first and second layer reflection were identified at depth of <0.4 m and 0.4-0.7 m respectively. This reflection depth was accurate since the velocity used was EM average velocity of soil.

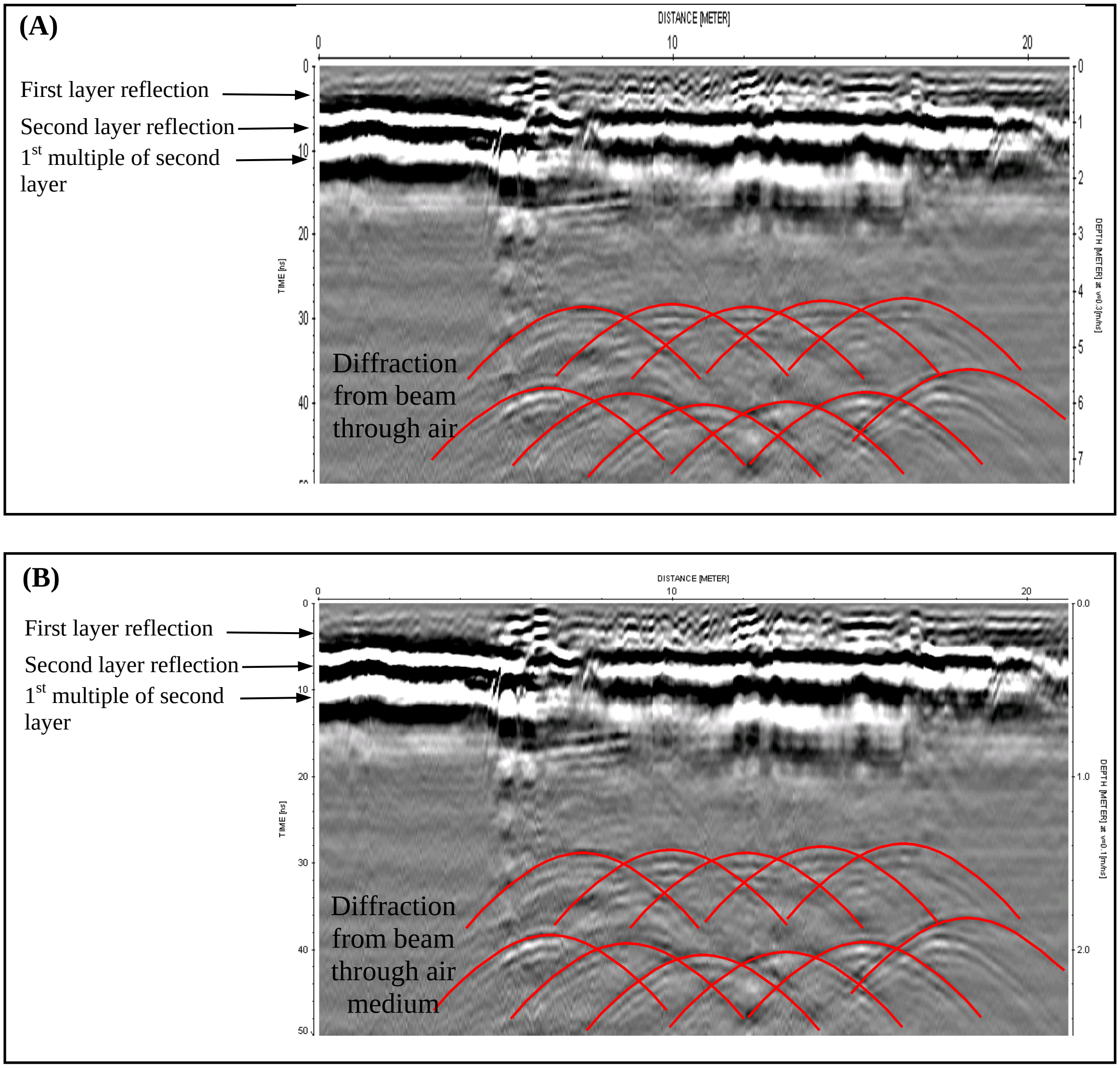

Figure 5: GPR results at Lamyong, Banda Aceh (Indonesia). (a) Processing with EM velocity of 3×10^8 m/s, (b) Processing with EM velocity of 1×10^8 m/s.

CONCLUSSION

The application of EM wave velocity for processing is important. The velocity apply will affect the depth of an object (target) but not the lateral distance. It is important to know or estimate the velocity of EM waves in soil (medium) in order to identify a good result.

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