The Effect of Ground Penetrating Radar (GPR) Image Reflection on Different Pipes and Soil

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Abstract. Ground Penetrating Radar (GPR) works as an instrument to look for buried objects whether it is natural or man-made. GPR transmits electromagnetic (EM) wave to the ground by transmitter and the signal reflects back to the receiver. In this study, the soil characteristics were monitored based on various types of pipe underground in order to determine the reflectivity of the EM wave. Two types of pipes; iron and polyvinyl chloride (PVC) pipe were buried in two different types of soil; clay and sand. These simulations were used to monitor which type of pipe will give the most effective reflection of EM wave on that particular type of soil. The study was performed by using multiband frequency GPR of 250MHz, 400MHz, 700MHz and 900MHz. The use of multiband frequency was to identify the most suitable frequency in order to gain the most effective reflection of EM wave. The data was processed by using Reflex2DQuick software. The higher the frequency, the lower the depth penetration, but the better the resolution. The study findings showed that the power of reflectivity was high at 700MHz frequency for both pipes in both clay and sand soil types. However, the value of power reflectivity for iron pipe was higher than compared to PVC pipe at both soil textures. Meanwhile, the resolution of radargram for both pipes were much better at sand compared to clay. This information would be a helpful to the surveyors and this knowledge will make their consumed work time more efficient as they get to know more specific value of frequency that is the most suitable to gain the most effective reflection of EM wave

1. Introduction

GPR has been widely used in extracting information of buried utilities for better utility maintenance and management [1]. GPR is the most suitable technique for locating and identifying the underground utilities in term of accuracy and time. By using this device, it is possible to locate accurately a wide range of buried utilities including both metallic and non-metallic pipes and cables [2]. It uses various frequency of electromagnetic (EM) pulse to analyze the earth by transmitting the signal from the antenna. These reflected signals are known as a radar trace. However, these reflected signals always contain unwanted echoes caused by heterogeneous media such as sand, clay, rock, gravel and utilities. As such, these media appear as black and white streaks in the radargram. For cylindrical targets such as

pipelines in underground utilities, they will appear in the form of black and white streaks having the shape of a hyperbola in the radargram [1].

1.1 Principle of GPR

GPR has the capability to conduct scanning continuously, over a wide area in a short period of time. Plus, GPR data can be viewed in real-time, giving advantage to the user to judge the quality of data obtained on the spot, and adjusting the acquisition parameters and settings [3].

The system of GPR consists of four main elements which are transmitting, receiving, control and display units. The transmitter produces a short duration, high voltage pulse. This pulse is applied to the transmitting antenna (Tx), which radiates it into the ground. The receiving antenna (Rx) collects the signals coming from the material under investigation, which are amplified and formatted for display, by the control unit [4].
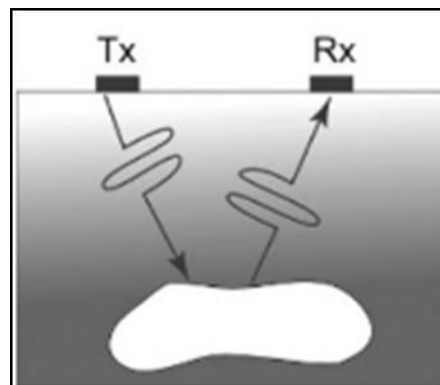

Figure 1. The detection of reflected or scattered energy [6].

In GPR techniques capitalizes on the reflection of high-frequency EM pulses produced and conveyed to the ground. This course of action will enable one to detect dielectric disruption occurring into the material through which the pulse travels. The contrast in the dielectric permittivity at the layer border between the bulk medium and buried objects that causes the reflections: the greater the difference in dielectric permittivity, the greater the coefficient of reflectivity [3]. These differences are related with alternation occurs in textural, lithology, porosity and density of materials, but mainly with water content. Water content specifically dominates the energy of signal, causing a wave energy loss and any water content changes may result in sudden increase in relative dielectric permittivity [3].

1.2 Depth Penetration

GPR uses EM waves within the frequency range 10-2000 MHZ to probe shallow subsurface. In this study, multi band of GPR dataset are used, which are 250 MHz, 400 MHz, 700 MHz and 900MHz. Every frequency has their own depth penetration limit [5].

There is proportional relationship between frequency of the transmitter (to determine the wavelength) and the resolution obtained. On the contrary, there is an inversely proportional relationship between frequency and penetration depth. High frequencies are usually for small, shallow targets. Meanwhile, lower frequencies are for those larger, deeper objects.

The depth penetration and resolution depend mainly on antenna transmitting frequency, earth's electrical properties and the contrasting electrical properties of the target. The important physical properties are of course dielectric constant as well as electrical conductivity. The higher the frequency of transmitter used, the higher the resolution, but the shallower the depth penetration [7].

1.3 Soil Electromagnetic Properties

Physical parameters of soil consist of permeability value, electrical conductivity as well as dielectric permittivity. They play important roles in GPR data scanning process [5].

GPR is a geophysical mechanism that implements an electromagnetic technique. Analysis emphasized the frequency-dependent, complex nature of electromagnetic parameters and associated effective soil properties.

Dielectric permittivity or dielectric constant is a measure of the signal energy that can be stored in a material, through separation of charges in a material.

There is a formula that can be used to determine dielectric permittivity;

$$\varepsilon = \left(\frac{c}{v}\right)^2 \qquad (1)$$

where,

c: speed of light (3.00 x 108 m/s)
v: velocity of travelled signal
ε_r: dielectric constant

The main purpose of this study is to determine the best frequency used based on the soil textures and different types of pipes. Thus, in order to fulfill the purpose, there are two objectives that need to be done. First, there will be an examination on the reflectivity of EM wave of GPR based on simulation on two different types of pipes buried in all two different types of soil. Then, a frequency will be determined that fix the best based on that particular pipe at the particular type of soil in order to gain the most effective signal reflection. Accuracy in determining the position while detecting the underground objects is essential for a valid data. It is also important to have a solid guideline to simplify the surveyors' responsibilities in identifying the best frequency for different types of pipes based on types of soil while using GPR. There are various categories of soil with different contents of solid matrix, pore fluid, and gaseous pore filing. The physical parameters of soil must not be taken for granted as well as GPR relies on EM wave principle.

2.   Methodology

In this study, multiple frequencies of antenna were used in which there will be trial and error in order to determine the most suitable frequency to gain the reflectivity of the EM wave from GPR. There were total of two testbeds; PVC, and iron pipes, both were buried in two holes of different types of soil; sand and clay. Then, all testbeds were observed by using GPR of different frequencies. The fastest and the most efficient frequency responding to the observation will be determined as the best frequency for that particular condition of testbed. The information from the observation would be extracted by processing the raw data using Reflex2DQuick software. Basically, the main scope of the process was about image filtering in order to gain clearer image of radargram for better data interpretation.

2.1 Study Area

The most suitable study area selected to do the simulation was at T05, Faculty of Science, Universiti Teknologi Malaysia (UTM) (Figure 2).

Figure 2. Test site at T05, Faculty of Science, UTM.

2.2 Testbed Simulations

In this study, there were two testbed simulations to collect the data. The testbeds were for sand and clay soil. All of the testbed dimensions were the same which wqs 2m in length, 1m in width and about 1m in depth.

   After the hole had been dug about 1m deep, one PVC pipe and one iron pipe which about the same length with the hole which is 1m length were placed into it. Then, the hole was filled with clay soil until it reached the surface level. The same procedure was applied to the second testbed but fill them with sand soil.

   Then, both testbeds were compacted by using a compactor machine. It was so that the soil would be well compressed and to reduce the porosity or air spaces between soil particles.

2.3 Instrumentations

The only instrument used in this data collection was Ground Penetrating Radar (GPR), but with different frequencies. They were IDS DuoDetector GPR (250 MHz and 700MHz) and RIS Hi-Mod V.1.0 (400MHz and 900MHz), both of multi-frequency function.

Figure 3. Observation on testbed of sand soil by using GPR RIS Hi-Mod.

Figure 4. Observation on testbed of clay soil by using GPR IDS DuoDetector.

GPR is used to detect underground utility as well as geophysical features by using reflected signals as the linker to obtain the data. GPR shows the depth penetration of the targets in the form of image which is shown on its monitor, known as the toughbook.

2.4 Data Processing

Reflex2DQuick software was used to filter the image of data observed for clearer image in term of brightness and contrast as well as eliminating any noise that happened to be in the data. By using this software, it is easier to interpret the data; convert the raw data into 2-dimensional form of data. The frequency of the best GPR that give the best result of data interpretation will be chosen as the best frequency used on that particular pipe in that particular soil. Figure 5 shows the complete process of image filtering of radargram.
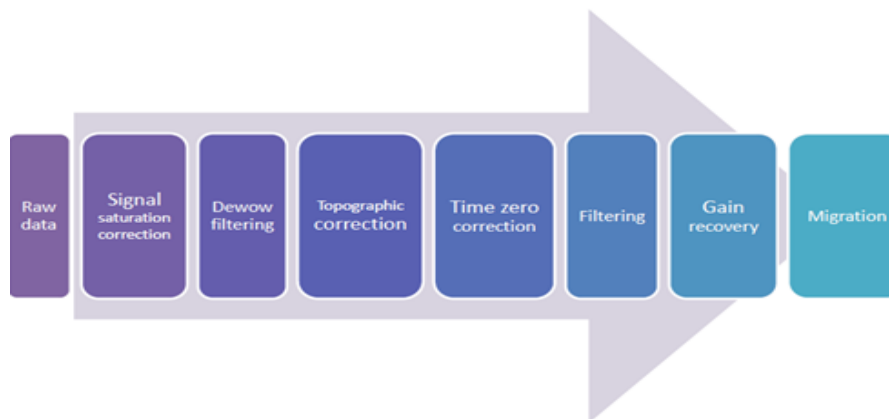

Figure 5. Flowchart of GPR processing.

3. Results and Discussion

Data interpretation were done after it has been processed in order to extract other information such as velocity of GPR, depth penetration of GPR and amplitude of EM waves.

3.1 Results on Power of Reflectivity

Table 1 shows the value of power of reflectivity at sand for both iron and PVC pipe with different frequencies. Meanwhile, Table 2 shows the reflectivity power value for both pipes at clay soil. The value of power of reflectivity was based on the value of amplitude shown in radargram after the processing.

Figure 6 and 7 show the strength of reflection at sand and clay respectively. Figure 8 shows the comparison of resolution of radargram for iron pipe at both types of soils. Meanwhile, Figure 9 shows the comparison of resolution of radargram for iron pipe at both types of soils. This is based on the formula;

$$v = \lambda f \qquad\qquad (2)$$

Where,

v: velocity of travelled signal

λ: center frequency wavelength of antenna (resolution)

f: frequency of antenna

Table 1. Value of Power Reflectivity at sand

Type of Pipe	Frequency of GPR (MHz)	Power of Reflectivity
Iron	250	-77.876
	400	-50.340
	700	-358.539
	900	-57.526
PVC	250	-131.967
	400	-165.614
	700	-225.144
	900	-119.062

Table 2. Value of Power Reflectivity at clay

Type of Pipe	Frequency of GPR (MHz)	Power of Reflectivity
Iron	250	-106.609
	400	-27.136
	700	-286.034
	900	-67.598
PVC	250	-102.233
	400	-64.801
	700	-173.402
	900	-32.712

The highest reflectivity value for all types of pipes in both soils is at 700MHz frequency. It can be seen that the value of power of reflectivity is much higher for iron pipe compared to PVC pipe.

Table 3. Comparison of velocity and dielectric constant of iron pipe at clay and sand soil.

Pipe	Soil	Frequency (MHz)	Velocity (m/ns)	Dielectric Constant (x 10^{19})
Iron	Clay	250	0.02500020	14.39977
		400	0.02500000	14.40000
		700	0.02500020	14.39977
		900	0.02500023	14.39973
	Sand	250	0.04999911	3.60013
		400	0.04999903	3.60014
		700	0.05000000	3.60000
		900	0.04999906	3.60014

Table 4 Comparison of velocity and dielectric constant of PVC pipe at clay and sand soil.

Pipe	Soil	Frequency (MHz)	Velocity (m/ns)	Dielectric Constant (x 10^{19})
PVC	Clay	250	0.02500018	14.39979
		400	0.02499977	14.40026
		700	0.02500000	14.40000
		900	0.02499977	14.40026
	Sand	250	0.05000000	3.60000
		400	0.04999891	3.60016
		700	0.05000000	3.60000
		900	0.04999944	3.60008

Based on Table 3 and 4, it was proven that the value of dielectric permittivity for sand was around 3.6 and 14.4 for clay. The computed value of dielectric constant for both soils were within the typical theoretical dielectric constant value, in which the typical dielectric constant value for sand is within range 3 - 5 for sand and 5 – 40 for clay. High dielectric permittivity indicates lower velocity propagation.
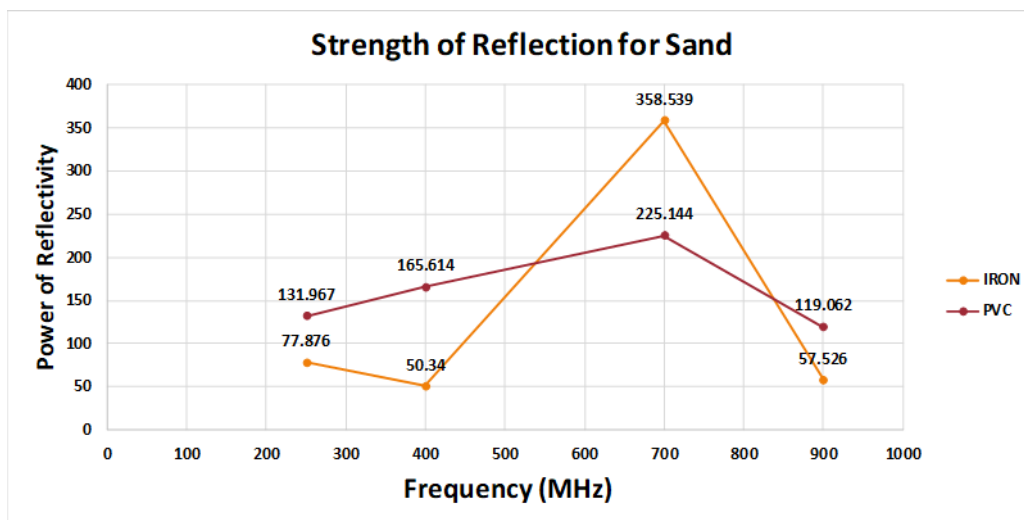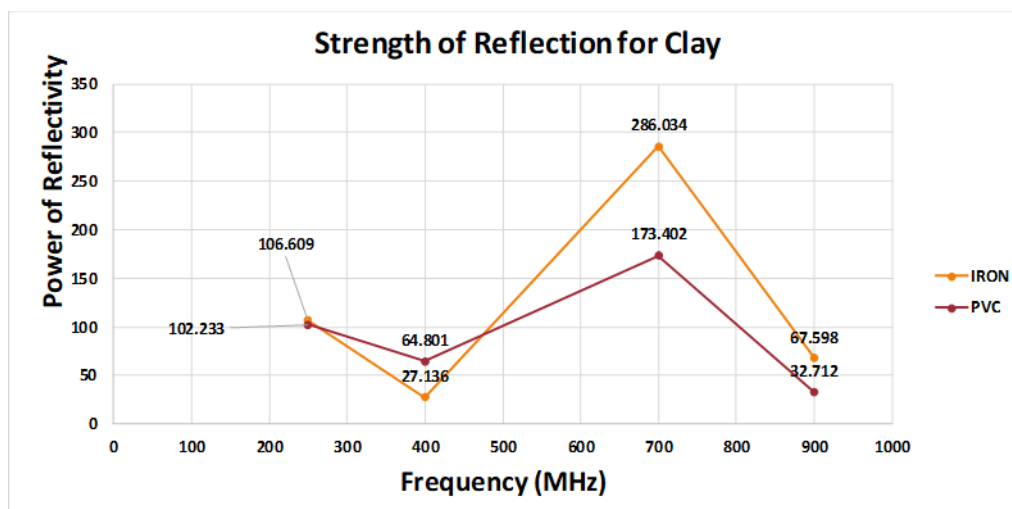

Figure 6. Strength of reflection for sand.

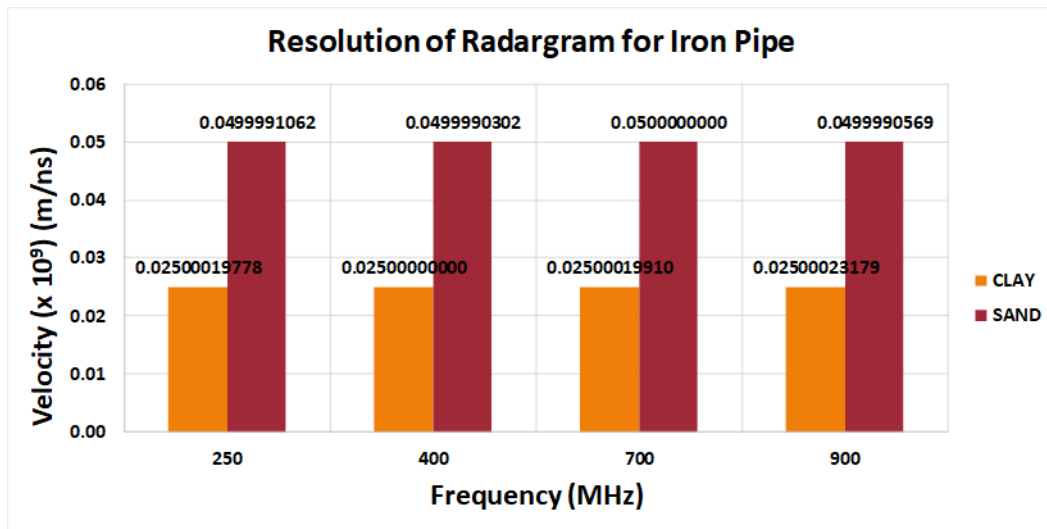**Figure 7.** Strength of reflection for clay.

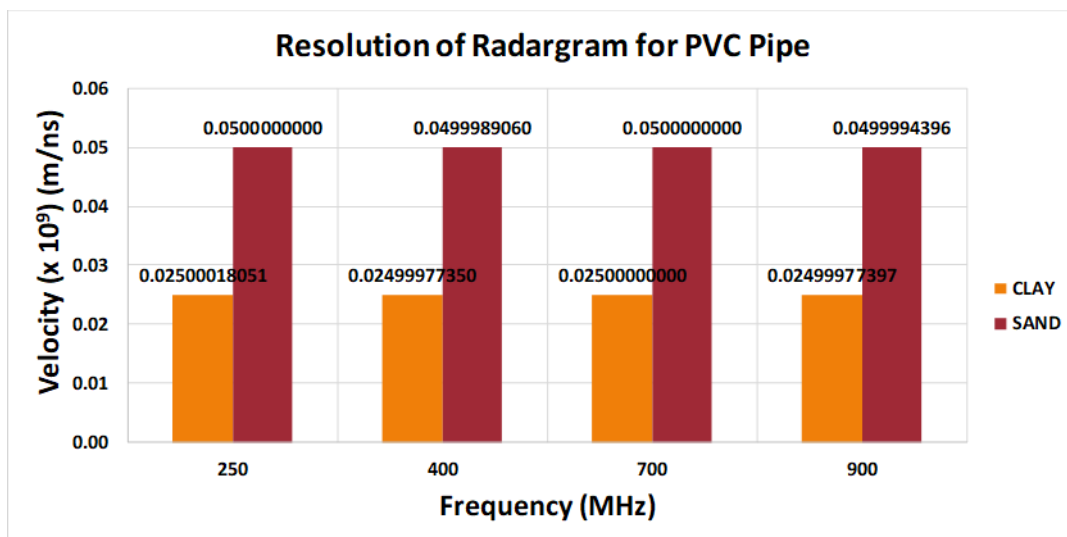**Figure 8.** Resolution of radargram for iron pipe.

Figure 9. Resolution of radargram for PVC pipe.

3.2 Discussion

Based on the results above, at sand soil, the highest value of reflectivity of iron pipe is at frequency of 700MHz. Meanwhile, the lowest reflectivity power is at 400MHz. for PVC pipe, the highest reflectivity is at 700MHz as well and its lowest reflectivity is at 900MHz.

At clay soil, the highest power of reflectivity of iron pipe is at 700MHz. its lowest value of reflectivity power is at 400MHz. On the other side, PVC pipe shows the highest reflectivity value at 700MHz. meanwhile, its lowest reflectivity is at 900MHz.

The negative or positive symbol of power of reflectivity does not affect the quality of the value of reflectivity power. It still shows that the reflection is valuable. The power of reflectivity represents the value of amplitude of electromagnetic waves. [9]

For both soils, the value of reflectivity power of iron pipe was higher compared to PVC pipe. This is due to the conductivity of the iron pipe that makes it easier to reflect back the EM wave.

The value of power of reflectivity at 400MHz frequency is at the lowest for iron pipe at both soils because the depth preference according to theory for this frequency is at approximately 4 meters. Plus,

the resolution is directly proportional to the frequency value used. From the hyperbolic images, it shows that the lower the frequency, the deeper the penetration, but the lower the resolution.

For PVC pipe, the lowest value of reflectivity power is at 900MHz. Even though the value of frequency is high, thus, gives high resolution, but the suitable depth penetration value is not parallel with this study condition, which is at approximately 1metre depth. The preferred depth penetration value for 900MHz frequency is 0.5metre and below.

As it can be seen from the table, it shows that the most suitable frequency that can be used for both types of soils and both pipes is 700MHz. the high value of reflectivity power for all condition of testbeds clearly shows that this study meets the depth penetration preference which is at approximately at 1metre depth.

The highest value of reflectivity power or amplitude for iron pipe in sand is 358.539 whilst the value of amplitude of the pipe at clay is 286.034. for PVC pipe, the highest reflectivity power value is 225.144 at sand and 173.402. it can be concluded that for both pipes, the value of reflectivity power is higher at sand. The gap difference at sand soil is 72.505 for iron pipe, while for PVC pipe the difference of reflectivity value is 51.742. This is due to different textures of the soil itself that give different reflection strength.

First of all, the observation of the simulation testbeds was done right after the pipes were buried in the holes of testbeds. Even though the soil for both testbeds were compacted by using compactor machine right after that, there is still quite a big porosity or void left in between the particle of soil. Thus, it affected the resolution of image on the radargram as well as the signal penetration. Next, clay soil has higher moisture level than sand due to smaller particles the clay that makes it easier to absorb moisture compared to sand. The clay particles can only be seen through the aid of microscope which is at <0.002 mm in diameter. Meanwhile, sand particles are big enough to be seen by naked eye at $2.0 - 0.050$ mm in diameter. Typical relative dielectric permittivity of clay is 5–40ε and 3-5ε for sand. Thus, it affects the signal penetration of EM wave as well. As clay soil has higher tendency to absorb moisture, the reflected back signal might appear weaker at clay as compared to sand.

4. Conclusion

In this study, testbed simulations were prepared and being observed in which there were two types of pipes; iron and PVC pipe that were buried in two holes of different soil types; sand and clay soil. Both testbeds were set up at 1metre depth. This study demonstrated that metal utilities have better reflections than that those made from non-metallic [10]. This difference is caused by various reflective capabilities of metals and non-metals. Metals tend to reflect most of the EM waves, while PVC is transparent to EM waves.

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