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Estimation of different subsurface materials depth using Ground Penetrating Radar

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ABSTRACT

This paper present the technique to compare the depth of pipe measured with Ground Penetrating Radar (GPR) to the actual value determine during pipe installation. In this study six different subsurface materials were used to bury the pipes meant to evaluate the impact of these materials toward the depths obtained from reflected wave. Estimation of depth for buried object required an understanding of ground-penetrating radar (GPR) functioning that include the concept of pulse, wavelength, strength of the energy (amplitude), travelling time as well as reflection of electromagnetic wave. However, there is a considerable lack of the study on the accuracy depth using GPR. This study is attempted to address the knowledge deficit by buring pipe at specific depth and measure it with GPR to estimate depth. Despite increasing application, little consideration has been given to the accuracy of the depth. This study examines the accuracy of the depth by comparing the actual depth with what measured by GPR. Corresponding GPR and manual measurement of the depth were carried out at the site specially prepared for this study. There are two metals and two plastic pipes running through the material at the depth 0.5m and 1m respectively where a few pieces of plywood are used as the separator between them GPR utilises propagating electromagnetic (EM) that travel through subsurface material from the transmitter in form of pulse. When the energy faces a different dielectric constant on the journey it will reflect back up to the receiver at a specific time window. For this study the 250 MHz frequency is used to capture image of different six different samples of soils and one of it is a ready mix concrete. The 250 MHz GPR data set gives a vertical resolution (0.125 m) with an approximate penetration depth of about 3 m.

Key words: GPR, Depth measurement, Reflection intensity, Material composition, Construction.

1.INTRODUCTION

Ground Penetrating Radar (GPR) is a geophysical technique that utilize ground penetrating wave which can be used to semi continuously imaging the profile of subsurface material at construction site or developed area. It measured the depth of the submerge object based on the travel time at a specific wavelength [1-2]. GPR is a save electromagnetic wave like other radio wave used for communication or broadcasting [2-4]. The technique is capable of recording thousands of closely proximity tiny subsurface object at a very fast rate or only a portion of second in a specific time window allocated for capturing reflected wave [5]. A GPR consists of transmitting antenna which emits an electromagnetic wave (EM) that can travel into the ground surface at specific speed and reflected back up if it faces a dielectric contrast to be received by antenna or continue travelling with certain refraction factor to deeper depth until it lost all the energy.GPR reflections happened when dielectric permittivity (εr) of the current and the next medium have a different value, which is primarily determined by the nature of the material or outside factor such as moisture content. This study try to evaluate the impact of the selected material toward the reflected wave that passing through the material and how it influence the appearance of depth on image The abrupt changes of dielectric [6-7] face by the wave caused a reflection means a strong and continuous return of energy can be recorded by the receiver to display the profile which includes the depth.

GPR profiling is common this days as it proven to be faster to get information on object or utility with certain depth underground depending on the central frequency of the GPR but still little consideration has been given to the accuracy of these depth measurements as the emphasis more focus on the x and y location but not the depth (z) [8-9]. There are two important concept of GPR need to be master to conduct this study, the first one is vertical resolution and the other one is depth measurement penetration [10]. GPR resolution is determined by the wavelength of the central frequency that will determine the speed of the wave and the smallest detectable object can be sensed by the wave and captured in image [11-12]. The higher the frequency transmitted for imaging means it has a shorter wavelength then the better the resolution as have of the wavelength is the smallest object detectable [13-15]. The second one is the penetration depth of the GPR wave is depend on the energy of the wave generated in the system for example, instrument with central frequency of 300 MGh can penetrate deeper than instruments with 800 MGh central frequency because high frequency wave have lower energy compared to low frequency wave then it penetrate lesser as the energy is less.

The usage of GPR technology for shallow underground profiling is now growing in Malaysia in tandem with the growing infrastructure project development to cope the demand at current need, spur by economic development .With the availability of the underground feature mapping it will assist the construction industry by speeding up the detection process, reducing operation cost as GPR is not labour intensive also can avoid damages through GPR imaging by that any buried object can be determine earlier before major construction work taking place. The most appealing advantage of GPR surveys for utilities and construction work is that ground surfaces, footways or roads do not required to be excavated that can disturb the scene. Adopting GPR methods prevents the need for unnecessary digging that cause disturbance of land surface. For example a contractor in the process of installing electrical pipes down a main carriageway; a GPR survey work at an early stage of installation can identify other utilities or structures buried underground to ensure contractors only dig within an assigned area or line with direction which is determine and allocated for the stretch to be the safe from disturbing existing object but the depth must be accurate to a certain level. This study focus on the impact of underground material toward the depth appearance of buried pipe on different types of material based what is shown on the image.

2.OBJECTIVES

The main aim of this study is to determine whether the different type of underground material will affects the visibility and depth of submerge object on the image. The study includes scanning of metal and plastic pipe buried under different pre-determine subsurface material. The specific objectives are;

1) to establish the most suitable method for calibrating GPR surveys image of the underground pipe.
2) to compare the depth of pipe on the image with actual depth measured during fixing in the pipe.
3) to evaluate the impact of the materials submerging the pipe toward the depth shown on the image captured by GPR receiver.

GPR usually utilise electromagnetic wave in the VHF-UHF region of the electromagnetic spectrum where the frequency is easy to compromise [16-19]. For the purpose of penetrating deeper it is suggested to use the lowest possible frequency because low frequencies give reasonably high penetration depths into the earth with lesser resolution. But a sufficiently high frequency must be selected so that the radar wavelength is short, allowing better detection of object because short wave means higher resolution, then a small objects such as pipes . The 250 MHz GPR is a typical centre frequency for utility detection for object with diameter bigger than 2 cm, however 500 and 1000 MHz are sometimes used for shallow, high-resolution probing. Frequencies as low as 20 MHz are used for locating deep and big caves or mine tunnels. The penetration capability of GPR signal is strongly dependent on the soil electrical conductivity at the site that cause by soil moisture and the central frequency [20-22]. If the soil conductivity is high, attenuation of the radar signal in the soil can severely restrict the maximum penetration depth of the radar signal because conductor material reflect all the energy back to GPR and no further penetration

This study was conducted at Batu Kentomen Army Camp of Jalan Ipoh, Kuala Lumpur. Lack of vegetation and a flat surface, along the study area provides an ideal place to acquire GPR data. The other reason for selecting this area is it located near to the required heavy machinery storage such as a backhoe. Backhoe is required for this study to dig a one meter depth ditch and then bury four specifically selected pipes two of them metal and the other two is PVC pipe. Figures 1 give some idea about the location plan from map and the actual condition on the ground. The study area was designed to accommodate the proposed data acquisition using GPR Nogging Plus 250 MHz in order to capture image of the pipe embedded in six different types of material. The six (6) samples material are soil, sand, beach sand, rocks, concrete, and clay.

Figure 1: Study area at Batu Kentomen Army Camp of Jalan Ipoh, Kuala Lumpur

Each sample materials were placed in their personal segment divided by plywood as the retainer to avoid any encroachment by other material into the specific allocated space. The Metal and plastic pie (PVC) were buried in the ground to test how the content of the compartment can influence the depth of the pipe in the image. The pipes were planted at different depths of 0.5m and 1.0m respectively to evaluate the vertical resolution then analysis any possible correlation between type of material and the depth portray on the image. Each dimension of the segments determined based on the size of GPR equipment, depth of buried pipes, as well as construction costs. On the surface of the soils are plastered with cement to facilitate the movement of GPR through the samples during the works of data acquisition. The selection of potential location is based on the ground criteria that suit the intention of the study.

3.MATERIALS AND METHOD

Ground-penetrating radar (GPR) is a useful imaging tool for subsurface investigations such as utility survey, detecting unmarks grave, archaeology mapping etc. Selecting the optimum antenna frequency before GPR surveys is critical. As the impact of selecting the proper antenna frequency, survey time and cost can be reduced. Also, appropriate antenna frequency helps to achieve an acceptable accuracy in determining the depth of buried targets. In addition to the antenna frequency factor, GPR data acquisition success is also affected by the soil physical parameters such as the dielectric constant and conductivity. It is often that these parameters are unknown, highly variable, and depend on a specific site. The positive signals captured by receiver are displayed in black while negative signals are indicated in white. The velocity of GPR signal changes according to the medium as it passing through. In vacuum are 0.3 m/ns and in of saturated and compacted soil are 0.10 m/ns [23].

Preliminary study is the most important step in ground penetrating radar (GPR) survey work. The most important aspect should be considered are the depth penetration required for the targeted object and the resolution of the central frequency. This is achievable by selecting instrument with the right central frequency for the target depth, the deeper the target the lower frequency required to make sure it have enough energy to reach the target. The wave length of central frequency determine whether it vertical resolution can separate two different object vertically and small enough to catch the buried pipe, the shorter the wavelength the smaller detectable object and the resolution. Selecting suitable wavelength of the instrument is not unique to radar but common to all other geophysical techniques although but often overlooked in the urge to rush off and collect data.

The selected host material in this study that cover the pipe must be evaluated to make sure the energy from GPR to penetrate and reflect to acquire depth data or refract to precede the journey and reflect up again if it still has enough energy. First of all the electrical properties of the host material must be roughly estimated to make sure a possible reflection by the pipe. The relative permittivity and electrical conductivity of the material have to be considered to make sure the targeted depth and diameter of the pipe can be detected before conducting the experiment. It must be tallied with the capability of the instrument used to capture the data. Second, the degree and spatial scale of heterogeneity of the material in the compartment also required for initial estimation. For the purpose of this study the GPR instrument selected with the right central frequency has been chosen have properly the study will be a success.

Designing the compartment which includes the depth of the digging, the width and length is another important part of the study, the separation between two pipes must be wide enough to make sure it suitable with the horizontal resolution of the instrument that related with time window of it. Detail of the design with dimension is depicted in Figure 2. The configuration of the model on the ground is as in the Figure 3 before the space was filled up with the selected content. If any the amplitude of the signals returned by this material is relatively high which indicates that the underlying material is very different in electromagnetic terms so the material will reflect positive and negative energy based on the different in dielectric between two layers . The reality is that frequency and wavelength are entirely relevant; the size of grain or object to be detected must be bigger than the resolution of the central frequency. The aim of subsurface imaging is to obtain images of a scene which is buried underneath in order to reconstruct non-homogeneities perturbing the background medium.

Figure 2: Scanning site before filling up

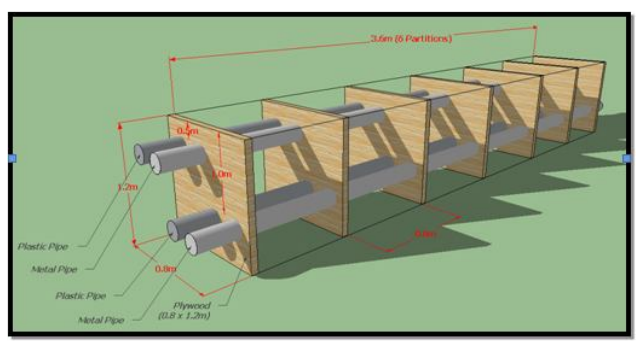

Figure 3: Configuration of the model

In these GPR surveying for depth measurement of pipe, the common-offset, single-fold reflection profiling was used to profile the model. This GPR system utilised a fixed antenna geometry that is transported along a survey line to capture profile of underground image versus distance along the surveying line which also known as B-scan. Normally there are seven main parameters need to determine before starting a scanning work using a common-offset, single-fold GPR reflection survey. It includes the frequency, the time window, the time sampling interval, the station spacing, the antenna spacing, the line location and spacing, and the antenna orientation to make sure the work become a success. Selection of the appropriate operating frequency for a radar survey is not simple as it must be suitable with the size of the targeted object. There is a trade-off between spatial resolution, depth of penetration and system portability; it must be related to the size of buried object and the depth of the object underground. Usually it is better to trade off resolution for better penetration. There is no use of having great resolution if the target cannot be detected because it located deeper than the capability of the energy to penetrate, it give a clear image but at shallower depth.

Locating the position and mark it, is the most common way of using GPR to trace existing utilities if the exact location of the pipe underground is not yet determine .It is very similar to the use of traditional current tracking utility detectors. The GPR sensor is moved along sweeps perpendicularly to the buried utility axis to make sure the image of pipe can be display on the screen. When the GPR unit crosses the utility line, the image shows a hyperbolic shape (inverted V) in the radar gram. The apex or top of the hyperbola is actually the position of the utility buried underground. The distance to the top of the hyperbola is an estimate of depth of the pipe. GPR profile was collected by manoeuvring the GPR antenna perpendicular to the pipe installed underground for a better quality image and it easier to identify the number of pipes that are under the ground. Before detection begins, chord line's ahead by GPR instrument must be marked on the ground first as guidance for operator to push forward the GPR instrument.

The proper number of scans varies depending on the size of the target and the soil or material one is working in. A smaller scan spacing (more scans per unit) will slows down the survey, so it is best to collect as many scans as possible while maintaining an acceptable survey speed. As the pipe is cylindrical objects like an old oil tank or buried drums, the bidirectional grid is used; these targets may look flat when scanned in one direction, so they can be easily missed or mistaken for a soil layer. Using a bidirectional grid would identify a cylindrical target

4.GPR DATA PROCESSING

Unprocessed GPR data often provide fairly good quality subsurface images, however the data may be difficult to interpret. Enhanced processing can improve image clarity as well as spatial and temporal resolution. a GPR survey is only part of the work. What follows is the GPR data analysis. There are a couple of data processing techniques that can and should be performed before proper conclusions can be drawn from the raw signals. One important step of utility detection is the post-processing of the ground penetrating radar (GPR) data collected. Detecting underground utilities with a GPR requires expertise on the field. That is why post-processing software is crucial for interpreting results. Data processing usually involve data preparation, dewow, background remover, frequency filtering, Automatic gain control, and migration.

Dew owing is performed meant to reduce the data to a mean zero level and allows positive–negative amplitude to be used in the recorded traces [24]. If dewow is applied incorrectly, the data will contain a decaying, low-frequency component which distorts the whole trace. Fortunately, most modern GPR systems now apply dewow to each trace automatically with the filter parameters set to the optimal conditions. Background removal was applied to all GPR profiles from site after performing the dewow to remove continuous flat reflections. With background removal, continuous flat reflections at top of the profile are attenuated and the profile is better imaged.

Bandpass filtering is the other processing implemented on the radargram captured at the site to remove unwanted frequencies in the raw radar grams. In this process the radar gram pulses was converted to the spectral domain. All recorded signals can be decomposed into a combination of individual pure frequencies which have different amplitudes and phases. The combination of the amplitudes at different frequencies and the phase that those frequency components arrive at the receiving antenna defines the unique radar signals that get recorded.

Background subtraction is a data processing steps conducted on the image for an average trace removal. The average trace removal aims at removing horizontal bandings from the profiles due to system noise, interference and reflections. It allows the subtle weaker signals to become better visible after processing by enhancing the dipping events while wiping out horizontal noise. It is necessary to apply background subtraction in areas of suspected horizontal events of interest.

Radar signals are rapidly attenuated during the propagation into the ground. Signals from greater depths are very small compared to signals from shallower depth [25]. Reflected GPR data present high amplitude only at shallow depth and it requires some treatment before visual display. Equalizing amplitudes can be achieved by applying a time dependent gain function compensates for the rapid fall of amplitude GPR data captured from deeper depths. Scale factor for a given window is calculated and applied to the sample at the centre of window. Then the window slide down one sample and the process is repeated. Automatic Gain Control was not applied to the GPR data from the study area because amplitude of multiples at the deeper part close to reflectors at the shallow part then AGC does not effect to the data.

Migration procedures essentially aim at reconstructing buried scattering objects from reflection collected above or just at the air/soil interface. It is a process that require to be done on the image to enhances the display of the reflections by moving the collapsed of diffraction hyperbolas and dipping reflections to the true geometrical position. As the travel time of a wave is longer it causes the reflections to be incorrect in term of depths or locations. Size and geometry of reflectors also can be distorted. The migration process can make some adjustment to the signal by collapsing hyperbola to its origin and moves reflectors to correct positions.

5.DEPTH OF PIPE ON GPR IMAGE

Generally Interpretation of GPR image of the acquired at the scanning site involved of the identification of the shape, position (spatial location and depth) and the orientation of the buried features. Changes in grain or shape can influence the level of connectivity of the material and influence the macroscopic electrical properties [26].Ground Penetrating Radar (GPR) is a geophysical method of underground imaging based on electromagnetic wave(EM) reflection which is sensitive to dielectric permittivity contrasts between two consecutive layers of material. The vertical resolution of the GPR instrument depends on the velocity and the frequency of the EM waves produce by the by the antenna which is $\lambda/10$ of the central frequency for vertical resolution , it varies from 14 cm to 20 cm for frequencies of 200–500 MHz and velocities of 0.1-0.18 m/ns [27].At the scale of vertical accuracy achievable by GPR, the dielectric constant of the effective medium is controlled by the volumetric fraction of each sub-material (concrete, beach sand, sand, rock, clay and soil). Therefore, one can say that the GPR response to subsurface grain depends principally on the nature of its matrix, its porosity and its fluid saturation.

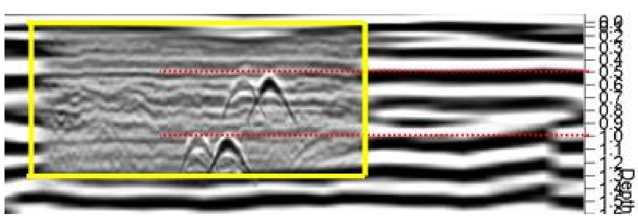

Figure 4.Depth of pipes buried in concrete

As can be seen on the image in figure 4, it shows layers of concrete on top of the others and the texture is a little bit rough as compare to sand or clay because of the grain size that mix up in the concrete. The size of granite in the concrete is bigger than 1cm which is the maximum vertical resolution of the 250MHz GPR instrument so the image appear like a distribution grain all over the space because the grain detected by the frequency. As the concrete dry the particle of material with the same electromagnetic property will appear as an object of bigger size in form of layer that the reason the object consist of a few pixel it appear bigger and longer than the other material used in this study. This is likely due to reflections from foreign objects mixed in the concrete like pebbles, small pores or small chunks. Buried within the concrete shows there is little wave reflections that occur around the pipe. The layers within concrete show the very of wetness which clearly portrayed a bit darker than the dryer surface seem lighter in greyness. Image also shows that the reflection wave of metal pipe is a little more contrast than the plastic pipe with darker grey it means the metal is a conductor so it reflects more positive as the permittivity of the concrete is lower than the permittivity metal. For the plastic pipe dielectric of concrete and plastic pipe is not much different so the gray colour is not much different. Around the both pipe there are spaces of air which seem white because of negative energy reflected as air space is lower in dielectric compared to concrete or concrete or the pipes. The sizes of granite cause the air space occur around the pipes.

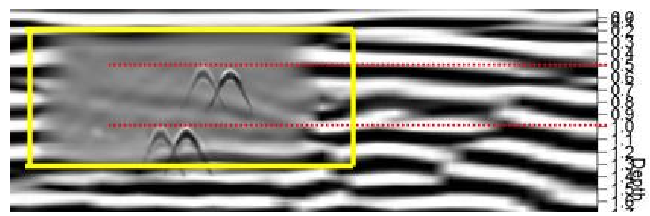

Figure 5: Depth of pipes buried in beach sand

Image in figure 5 shows the texture of beach sand is more event and not undulating compared to surrounding area. This is because beach sand physical texture is actually very tiny compared with soil texture that is around it mostly because the pulse from GPR detected a smooth texture of material not like the concrete it group to a bigger size with the same electromagnetic property . There is no existence of layers through the 1m X 1m compartment because the reflected wave has the same intensity of energy; there was no fluctuation of energy horizontally or vertically. This thing happen because of the size of particle is smaller than the resolution of the GPR so everything is look the same and event, layers can be seen if the central frequency of GPR is 6GHz that detect up to 1mm object [28] Beach sand can be uneven if there are foreign particles, mix soil or is not fully compressed. Salinity factors also contribute a bit of difference in this image. Metal pipe images reflect more energy (dielectric of 300) than plastic pipe (dielectric of 3.3) as has been mention earlier the conductor material reflect more energy but it is important to realise if the energy mostly reflected the possibility for the wave moving further is lesser then. The white space representing air pocket around the pipes and negative energy on the radar gram is smaller since the size of particle allows them to be more compact and reach closer to the pipes.

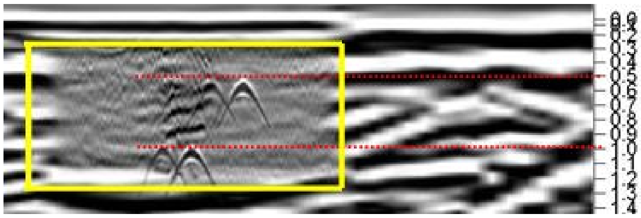

Figure 6:.Depth of pipes buried in sand

Comparing the size of material in figure 5 and figure 6 it show the sand form a combination larger number of pixel; this is because the sand particle size is relatively coarse and a little bigger than beach sand. This experiment show the GPR of 250MHz central frequency has vertical resolution of less than 1 cm; it is clearly in image of material beach sand with diameter of less than 1 cm [29]. There was a slight wave / uneven surfaces adjacent plastic pipe because the sand is not exactly properly compressed so the image some kind of layers wetter sand than the others. Image on plastic pipes is a little disturbed because it was a little wet sand around the plastic pipe. Water content and compaction cause the image to appear in layers of different greyness because the amplitude captured from reflected energy was not the same. The white image around the pipe is smaller compare to the concrete material but bigger than the beach sand as the compaction of sand is better compared to concrete but lesser than sand beach.

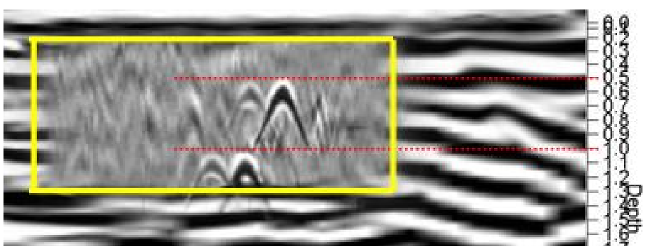

Figure 7: Depth of pipes buried in clay

Figure 7 is the radargram for clay compartment, Clay is known to have a frequency dependent permittivity and it range from 3-5 in dry condition and 20- 30 in wet condition. The clays permissibility is attributed to its fine particle size and therefore large reactive surface area (due to an excess of negative charge) which can absorb a significant amount of water. Image shows the texture of clay soil formed quite confusing because of uneven complexion and compaction, the existence of pipe lookalike hyperbolic is because of the big size of clay merge together that make it like a round object that confused with actual pipe. There is some difficulty to interpret because there are many hyperbolic images within the coverage from the particle of clay those forms as solid objects. The clay used in this study is a bit dry so it come inform of bigger size up to two cm in size, that cause the image look like many object other than pipe. The metal pipe seem darker as the relative dielectric between the two materials is big, the pipe reflect more positive energy relatively to the clay.

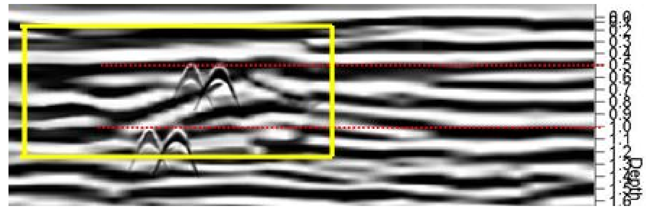

Figure 8: .Depth of pipes buried in rock

There are layers of undulating surface in the image it show the rock has form layers of material with different electromagnetic property. It shows a new material of almost the same feature with existing material can have almost the same image. In this case, the rock around the pipe reflected a wave with certain intensity but it is lower than the intensity of reflected signal from PVC pipe. This rock surface area similar to the surrounding surface it is because surface of the soil around this rock consisting of small rock and mixed soil. It is not difficult to interpret metal pipe based on the hyperbolic image but it a bit uncertain for the PVC pipe because the intensity of reflected signal look almost the same with material around the pipe. In these types of material the PVC pipe looks darker as relatively clear contras of dielectric between and rock. The formation of material of rock seem to have layers of air space between the rock

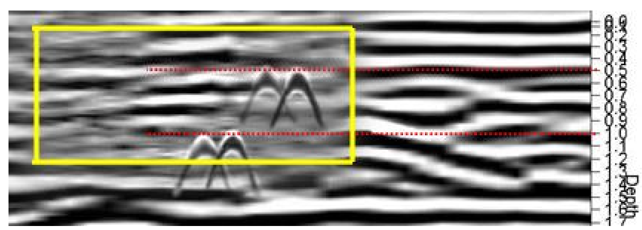

Figure 9: .Depth of pipes buried in local soil

The soil used in this study is composed of coarse sand, small chunks of rock and impurities. The area at the bottom of the pipe at the right side seems blurred because at the location filled with sand with tiny particle. There is clearer view of the image either metal or plastic pipe. This material is a mix of small grain and slightly bigger size. There are layers of local soil that structure like the permanent local material and some look blurry as the grain has been crunch during the excavation.

6.CONCLUSION

This study shows GPR with central frequency of 250 MHz.(11.99 cm wavelength) can actually detect 3cm diameter pipe with the accuracy of ± 1cm it means the horizontal resolution is 1/10 of wavelength. The use of 250 MHz antennas with 1cm resolution is not suitable for imaging of sand beach or clay as the grain size is smaller than the wavelength resolution capable to detect. The measurement of depth in clay is less accurate because of the attenuation is high in clay than other material in this study. The speed of wave is lower in clay because of the grain size that block the ray it make the time travel is longer than the depth position at deeper position in the image. The same thing appears in the sand beach compartment, where the pipe seems deeper because of the time travel before it receives back by the GPR.

The result highlights that antenna frequency selection is critical, as it determine the smallest grain size can be capture in the image and it is controlled by the specific objective of the survey. The study also suggests a criteria that can be established for selecting the most suitable antenna frequency to image buried pipe in the same or different soil conditions. As radar pulses passing through various materials on their way to the buried pipe, their velocity will change, depending on the electromagnetic properties of the material through which they are travelling. Each abrupt velocity change due to dielectric different between two adjacent materials it will generates a reflected wave, which travels back to the surface to be recorded as positive if the permissibility first material is lesser than the next be image as a different layer. Not all the energy reflected back, some of it will refract and keep moving in a different direction to be reflected or refract again until it lose all the energy. The Velocities of radar energy travelling the ground are very important to measure the wave travel times then calculate the estimated depth of any feature the wave came across. It demonstrates that GPR response varies significantly with typical variations in beach soil, clay, rock and soil saturation, porosity, and water content. Thus, interpretation of GPR data should either incorporate consideration of these variables. This study whatever type of earth material the pipe the parabolic shape always can be seem in the image as long as the vertical resolution of the central frequency smaller than the size of the pipe.

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