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Soil Characterisation and Its Effect on Depth Accuracy Using Ground Penetrating Radar

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ABSTRACT

Assessing depth of utility in different soil moisture conditions require good research. Moreover, different soil moisture conditions produce depths that are not the same as one another. The information of underground utility such as depth is very important to avoid damage towards utility during excavation process. Therefore, this study was conducted to assess the depth recorded by the (GPR) equipment in different soil condition in terms of soil moisture. The first objective of this study was to determine the soil moisture level for three different soil conditions. Next, this study evaluated the depth accuracy produced by the GPR equipment with the different soil moisture level such as dry, semi-dry and wet. Different soil moisture conditions were determined by the sampling of the three soil conditions. These samples were taken and tested using speedy soil moisture tester equipment that provided the percentage of soil moisture content. Next, the depth of utility was taken at the three soil moisture conditions and an assessment was made. The shape of hyperbolic on the radargram was generated from the equipment and was used to assess the accuracy of the depth. The information from this study is very useful to underground utility users which can help the development of the country in general. It also benefits the improvement of the preparation quality of underground utility mapping.

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1. Introduction

1.1 Background of Study

Therefore, applications of GPR in scanning the subsurface area give the opportunity in making research on different soil moisture level. GPR is used for detection and determining the depth of utilities buried underground. It produces a utility mapping which is the process of determining locations and marking underground utility routes. Utility mapping can prevent service disruption due to accidents during excavation and maintenance work can be carried out efficiently.

Most of technologies used to get the depth of underground utilities such as satellite images. Many researchers from different field, method and application have study the depth on soil moisture. Such as method in satellite images based on rectified satellite's surface temperature (Ts) to enhance the spatial estimation of Soil Moisture (Hassaballa et al., 2014) and many other fields.

Utility mapping can prevent service disruption due to accidents during excavation and maintenance work can be carried out efficiently. The risk of accidentally damaging this buried utility also increases due to the lack of information the depth of utility in the field accurately. Much of this problem stems from the facts that were installed more than several years ago when drawing (if existed) referred to surface features that are no longer present. In addition, these utilities typically consist various depths in a variety of soil moisture condition (e.g., dry, semi-dry and wet). Traditionally, utility was buried to depth ranging from 2 to 4 feet (or less). Accidentally damaging this utility can cause serious damage or loss of life to employees or other individuals near the work area. Essential public services (such as water, electricity, telecommunications, etc.) for houses, education, businesses, hospitals, air traffic control operations and emergency service providers may be temporarily unavailable or out of service.

Therefore, applications of GPR in scanning the subsurface area give the opportunity in making research on different soil moisture level. GPR is used for detection and determining the depth of utilities buried underground. It produces a utility mapping, which is the process of determining locations and marking underground utility routes. These pipelines may include pipelines for telecommunications, power distribution, natural gas, water mains, and wastewater pipelines. To know the exact location, an accurate survey of the underground utility is important. In addition, any kind of accidental destruction related to excavation of other projects can be prevented. In this country, changing weather and climate conditions is vary causing the condition of the soil in several of conditions such as dry, semi-moist and wet. Soil laboratory with using speedy soil moisture tester will be performed on all three types of soil conditions to get the result that can prove the condition of the soil.

Several research questions in this study can support the following objective such as how a speedy soil moisture tester gives the percentage of soil moisture in a certain area. Implementation of the second objective is supported by the following research question such as under various soil moisture conditions, will the wave emitted by GPR affect the depth and if ignore the depth precision, what happens to other utility objects. Therefore, an alternative to solve these problems, application GPR was conducted to assess the depth recorded by the GPR in different soil moisture level such as dry, semi-moist and wet. The results will be evaluated whether the depth recorded is same or not in all different soil moisture level. According from the result, it provides to help utilities user to ensure that the result from the observation is appropriate with the different level of the soil during survey work.

1.2 Objective of study

a) To determine the percentage of moisture in soils from the site study
b) To assess the depth accuracy with the different soil moisture level such as dry, semi-dry and wet

1.3 Significant of Study

The significant of the study is to determine soil moisture level and the capability of ground penetrating radar equipment to get the depth in different level of soil moisture condition. This information is useful and beneficial for local authorities and utility user in this country. With the development related to telecommunications, drainage, and others, it can provide knowledge and help them to get the accurate depth in underground utility mapping. It is indirectly possible to avoid any desired things during construction or after completed construction.

2. Literature Review

The literature of this research focuses on soil moisture conditions (dry, semi-dry and wet), underground surveying and GPR as equipment for detecting different soil moisture depths. This chapter reviews the related studies of impact soil moisture towards depth on underground utility mapping. This chapter features corresponding fields elaborated to show their respective significance as background knowledge. In this chapter is cover related topic about the soil moisture and underground utility mapping. It covers the equipment used such as speedy soil moisture tester and GPR. The last part of this chapter explains the research gap that needs to fulfil along this study.

Soil moisture is the water stored in the soil and is affected by precipitation, temperature, soil characteristic, and more. Another definition states that soil moisture indicates the amount of water stored between the pores of the soil (Saputro et al., 2017). Over the past few decades this challenge has become increasingly serious as soil moisture is an important part of water estimates. As our country climate changes, moisture availability is becoming more variable. Climate change can be defined as the changes in the average conditions such as temperature, rainfall, and soil moisture. Malaysia also expects more rainfall extremes intense rainfall in the wet period and a lack of rainfall in the dry period (Abdul Rahman, 2018). In some cases, data are collected from corresponding department or organizations to anticipate the changes (Shahid et al., 2017**).** Thus, a moisture content of 100 mm/m corresponds to a moisture content of 10 volume percent. Where the 25% - above soil moisture content, the condition is wet, 20% - 24% soil moisture content, the condition is moderate and 0 – 20% soil moisture content, the soil condition is Dry. (Source Malaysia Meteorology Department).

Underground utility mapping can be defined as the process of identifying, tracking, locating, and labelling underground public facilities. Determination, position tracking and identification of cables and pipes buried underground refers to the mapping of underground utilities (Jamil, 2015). The use of data acquisition and post-processing software makes it possible to determine the path of buried objects or telecommunication lines, the position of power cables, metal and non-metallic pipes and buried objects such as underground oil storage tanks. Every construction project has the potential to become a disaster site without utility mapping of underground infrastructure. Mapping of underground utility pipeline is a "hit-and-miss" for urban areas, and this has resulted in many catastrophic damages. Therefore, this study was conducted to extract locational information of the urban underground utility pipeline using trenchless measuring tool, namely GPR (Jaw & Hashim, 2014).

Previous research of the GPR study of (Ammer et al., 2019), their study is the effect of soil conditions on depth accuracy of underground utility detection. Their study had come to conclusion the soil properties which are dry and wet soil will affect the accuracy of depth underground utility. The issue is the method to determine soil moisture. There are various methods that can be used in determining the percentage of soil moisture level. In this study, it did not use any method to determine soil moisture. It just looks at the soil conditions in wet or dry conditions. The result of the depth can process the interpretation data on Ekko_Project software. Soil moisture being a one the influences factors will affect the result of image interpretation. To produce good interpretation, resolution of GPR image must be good (Ammer et al., 2019).

The next issue is the technique to get depth of Utility object. Most of the previous study generated depth using Electromagnetic Locator. Use electromagnetic locator method to generate depth of buried utility. Typically, these active electromagnetic induction devices simply employ a single electric current with a single frequency. The issues are electromagnetic locator can detect only smaller diameter and metallic cables compare to GPR which can provides its own transmitter and is able to detect underground features without a power source. However, GPR able to detect most types of utilities including plastic and other non-metallic services, as well as metal. Although the service will be determined in the EM survey results, the drawing will lack other detailed information of GPR recovery and will not be able to detect any non-metal services or services that cannot be accessed through manholes.

3. Method

The Method Methodology must be arranged according to the priority of the process research to get the correct data and information to complete the research. The methodology consists of the five phases whereas the first phase is preliminary study, and a second phase is literature study related to the research. After that, the third phase is data collection, and the fourth phase discusses the results of data analysis research. The final phase discusses the conclusion and recommendations. The aim for this research study is to determine soil moisture level and assess the depth accuracy with the different soil moisture level such as dry, semi-dry and wet. In addition, understanding and explore how to process the sample of soil moisture using speedy soil moisture tester and the whole operation of GPR in performing detection of utilities underground in three different soil moisture condition.

3.1 Preliminary Study

Before starting any research or project, planning is the most important thing. Therefore, the first thing is to understand and exploring the information of underground utility mapping and soil moisture. To get more information on case studies, equipment, use of software and techniques, ideas from several journals and articles need to be taken and studied. Additionally, the process planning also discussed with the Civil Engineer and freelance surveyor to get information about the process has good result until the end.

3.3.1 Site Reconnaissance

Firstly, reconnaissance is important before starting the survey work to make sure the suitable place to fulfil this research. The chosen site location based on the requirement of the case study. Then, to ensure the location have a buried utility such as pipe or cable to do the detection and have soil moisture in three different conditions. This research has two locations where for location A at Semambu Water Pump House, Kuantan and location B at Gebeng Industrial Area, Kuantan.

3.3.2 The Equipment

Noggin SmartCart System ground penetrating radar equipment using on the underground utility survey. The equipment of GPR consists of four main elements which is the transmitting unit, the receiving unit, the control unit and the display unit. The instrument chosen must be in accordance with the type of study research. Besides that, GPR has been chosen in this research suitable for investigate soil moisture content (water) to get the depth. The frequency that used is medium frequency (250MHz) and suitable for deep target and providing high resolution images.

The frequency of the antenna determines the depth of penetration and the resolution depend on the frequency. The power supplies range small rechargeable batteries to vehicle batteries. The suitable software used to manage the radar signal and review the data acquired directly on the fieldwork

The speedy soil moisture tester is a portable system for measuring the moisture content of a wide range of material including soils. The system consists of a rugged plastic case containing a low-pressure vessel fitted with a pressure gauge and an electronic scale and accessories.
Speedy soil moisture tester it is particularly useful for field determinations of soil moisture content immediately. The procedure is simple to follow and takes just a few minutes for most materials.

3.2 Data Collection

Observation of the real work survey on the fieldwork using Speedy Soil Moisture Tester and Noggin Smart Cart GPR equipment. On the field many methods that is used to make sure this project complete, working well and get collect the data in project that get a perfect result. The procedure to use speedy moisture test are first, clean the speedy vessel to make sure that the inside of the speedy empty and clean. Then, Select and prepare the sample. Weigh the sample. Add the sample to the speedy vessel and add the reagent to the speedy cap. Seal the speedy and mix the sample with the reagent. Lastly, hold the speedy horizontally and at eye level and take the moisture content reading directly from the pressure gauge.

The procedure to start the survey GPR scanner process is by setting the instrument, instrument calibration and data collection. Calibrate the instrument is first important step before start any survey work to make sure the instrument in good condition to do the survey work. The procedure to start the survey GPR scanner process is by setting the instrument, instrument calibration and data collection.

3.2.1 Data Calibration

Calibration instrument is first important step before starting any survey work. The calibration of the instrument is to make sure the instrument in good condition to do the survey work. Besides that, to determine the accurate the depth recorded by GPR. On this calibration, method measured directly on the surface used meter tape and measure used equipment of GPR.

3.2.2 Data Acquisition

On the field many methods that is used to make sure this project complete, working well and get collect the data in project that a perfect result. The method must carry out to collected data are line survey method. This study uses line survey method. In this study, the desired data is the underground utility image of subsurface recorded by GPR. The scanning starting from the straight line that been planned. The scanning line should be covered all the previous detected points (using EML). Then, start the scanning from the grid line that has been created.

Start Scan button in the New Acquisition window. In preparation stage, we should check the method to be carried out whether it is a one-way direction or 'go and back' direction. After finish scanning, click on the Stop button and save the image. Then, repeat the step for next grid interval until finish. The data is automatically saved and can be preview back finish site work.

3.3 Data Processing

This phase gives details of the processing steps available in the software to improve the raw data quality before further processing and techniques developed in this work are applied. The scanned data from data acquisition then is processed to enhance raw data. The raw data GPR from the field could be process using suitable software an import, display, processing, and interpretation of 2-dimensional. The software also can process included all necessary filter and edit functions starting.

3.3.1 Ekko_View Software

This Ekko_View software is simple and intuitive allows being quickly display and analyzing data from Noggin Smart Cart GPR. The data show on the screen in 2 Dimensional. The output can be export variety format such as BMP and JPE. Figure 3.8 showed the data on Ekko_View software in radargram image, on the screen vertical axes displayed the time, depth and elevation and other axes is horizontal displayed line position.

3.4 Data Analysis

The result of the Speedy moisture tester and Noggin Smart Cart GPR data produced after data processing phase and data process to access the accuracy of the depth between difference conditions of the soil of the underground utility. The analysis makes to compare the result of the depth from the condition of the soil which is dry, semi-dry and wet soil. The results from the software result of radar image and value to the depth. The analyses are made after processing the radar images data at the software. Based on the result, the analyses are made included to evaluate the accuracy of the data and difference of the image of the underground utility by detected using GPR. In additional, to know the properties of the data detected such as the depth and type of the utility underground.

4. Results and Discussion

The results and analysis of this research are explained and discussed. The main idea is to determine the soil moisture level between three conditions such as dry, semi-dry and wet. To determine the soil moisture percentage content, Speedy Soil Moisture tester has been used. From the result, it assesses to detect and record the accuracy depth of public utility mains which are located underground and presented in 2-dimensional as a result. To conduct the GPR survey, the survey line method was conducted. The results of analysis and interpretation can achieve the objective of this study.

4.1 Soil moisture percentage content (water)

From the collected soil samples, use a speedy soil moisture tester to determine the percentage of soil moisture content. The test is very simple, each sample only takes a few minutes. First, clean the speedy vessel to make sure that the inside of the speedy empty and clean. Then, from the sample must ensure to be weighed. Then, add the sample to the speedy vessel with carefully. Make sure all samples have been included to the speedy vessel. After that, add the moisture reagent calcium carbide to the speedy cap of two full scoops. The calcium carbide reagent is a hazardous product that must be handled with care by the user. Sample of soil mixed together with a calcium carbide reagent in the sealed pressure vessel. The calcium carbide reagent reacts chemically with water in the soil sample producing acetylene gas that in turn increases the pressure within the vessel. In the speedy vessel, the pressure is increase proportional to the amount of water in the sample and the moisture content can be read directly from the pressure gauge meter.

Then, seal the speedy soil moisture tester and hold the speedy horizontally and shake the speedy vessel for 5 seconds. Rotate the speedy through 180º so that the pressure gauge faces the sky, tap the sides of the speedy to ensure the sample falls into the cap and hold the speedy soil moisture tester in this position for 1 – 2 minutes. The percentage of the soil moisture content has been read directly from the pressure gauge meter. For test the next sample, release the pressure. Hold the speedy vessel vertically with the pressure gauge facing the ground. Release the screw on op cap slowly to vent the gas reagent that may have been produced within the speedy. Remove the mixed of soil sample and reagent calcium carbide from the speedy. Clean with already bristle brush to remove any residues from previous tests and dry open container. This cleaning to ensure the next sample moisture tester runs smoothly. Table 4.1 shows the meter readings of the three types of soil moisture form the speedy vessel and the percentage of soil moisture calculated using the formula.

Table 4.1: Soil moisture percentage content for each sample

Location Water Pump House Semambu

Number of Test	Soil Condition	Meter Reading (x)	Soil Moisture (w)
1	Dry	10%	11.111%
2	Dry	10.5%	11.731%
3	Dry	10%	11.111%
1	Semi-Dry	18%	21.951%
2	Semi-Dry	17.5%	21.212%
3	Semi-Dry	18%	21.951%
1	Wet	25.5%	34.228%
2	Wet	26%	35.135%
3	Wet	25%	33.333%

Location Gebeng Industrial Park

Number of Test	Soil Condition	Meter Reading (x)	Soil Moisture (w)
1	Dry	8.5%	9.289%
2	Dry	8.5%	9.289%
3	Dry	8.5%	9.289%
1	Semi-Dry	17.5%	21.212%
2	Semi-Dry	17%	20.482%
3	Semi-Dry	17.8%	21.655%
1	Wet	25%	33.333%
2	Wet	26%	35.135%
3	Wet	25.7%	34.589%

4.2 Data Calibration

This calibration is required to ensure that the instrument is under standard conditions with higher accuracy and accurately determine the reflection depth recorded by the GPR, and to understand the speed of signal propagation in the measured material. Each calibration instrument on survey should be performed to specified accuracy. Before performing calibration, please refer to JUPEM for the accuracy value of underground survey. According on standard guideline for underground utility mapping from JUPEM, calibrated survey equipment and surface geophysical detection equipment will be used to acquire quality level A data to ensure that the expected accuracy of measurement is achieved. These accuracies are at 10 cm or better in vertical as well as in horizontal.

This calibration a used the method survey which is survey on the surface and survey with the instrument GPR detection, then calculated the difference between the method and the result as the accuracy of the calibration of instrument. The data collected through the measuring tape, calculated the difference the depth of underground utility. After done, continue with detection underground utility using Ground Penetrate Radar. This method using software to identify the depth of underground utility after collected the data on the field. Transfer the data to the computer and export the data to the Ekko_View software. On the radargram, placing the top of the model over the top of the hyperbolas, the model needs to be adjusted until it matches with the targeted hyperbolic and the velocity wave will be extracted.

4.3 2D Ground Penetrating Radar result

The application of modern visualization technique has been beneficial for the 2D presentation of GPR data image results. Digital Video Logger displayed on the screen when scanning process of the GPR instrument on the ground. The screen showed what the scanned in a greyscale figure. While in the research area at Semambu Water Pump House and Gebeng Industrial Area in Kuantan, everything that see through the display board is recorded and saved as a raw data. Then, the processing the raw data from GPR field of scanning the underground utility produced the result in radargram. Radargram is a figure that GPR produced during the process of scanning the underground utility (Daniels, 2000). Data radargram is largely dependent on surface topography, soil moisture, clay contents and various more. If less of experience, knowledge and skills of the person interpreting the data, will cause the problems of interpreting the obtained 2-D profiles because is not such an easy task. Radargram contain the properties of the subsurface that have been scan at the research area.

According to the assessment, the increase of soil moisture (water) in the soil will lead to stronger underground utility characteristics. If the water content in the soil is excessive or moist soil, the image of radargram will be blur and shape of hyperbolas difficult to prediction. It is because wave energy is emitted absorbed and weakened. As such, energy is difficult reflect to the surface. The depth to which GPR waves can reach beneath the ground surface is mainly dependent on the soil properties and frequency of the antenna used. Table 4.2 showed the list of depth measurement between dry, semi-dry and wet soil. The comparisons of the differences in each soil moisture condition are not much different.

Table 4.2 comparison of depth between dry, semi-dry and wet soil

Number of Test	Soil Moisture Condition	Calibration (+/-)	Depth (m)	Depth after (+/-) calibration
T1	Dry	+/- 0.007m	0.920	0.927m
T1	Semi-Dry	+/- 0.007m	0.860	0.867m
T1	Wet	+/- 0.007m	0.850	0.857m
T2	Dry	+/- 0.007m	0.700	0.707m
T2	Semi-Dry	+/- 0.007m	0.650	0.657m
T2	Wet	+/- 0.007m	0.630	0.637m

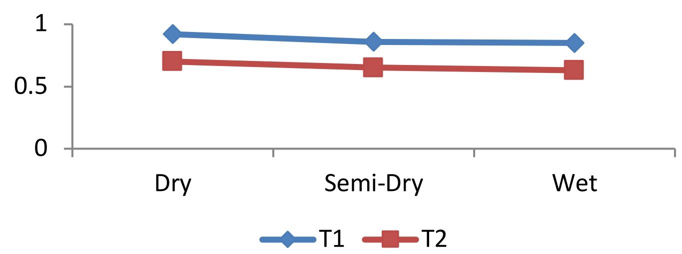

Figure 4.3 Graf comparison of depth between dry, semi-dry and wet soil

Based on the analysis in figure 4.3, it showed that dry soil still shows the deepest depth compared to semi-dry and wet soil. These graphs are easier to see and analyze in terms of depth for the three types of soil moisture used. The blue color on graph line shows the first location which is Semambu water pump (T1) while the red line on the graph shows the second location which is Gebeng Industrial in Kuantan (T2). Based on this graph, it is clear that the effect of water on the soil will have an impact on the depth of the GPR application. The physical nature of this soil plays a role in terms of its ability to store water, for example in sandy soils the capacity to store water is very low. Therefore, to wait until the soil is dry is very quick to do underground utility mapping work.

5. Conclusuion

As the conclusion, the project performed of the ground penetrate radar survey to assess the depth accuracy with the different soil moisture level such as dry, semi-dry and wet. This research investigates about the accuracy of the depth affected with the different soil moisture condition such as dry, semi-dry and wet soil. Before the study was conducted using the GPR equipment, the soil moisture research was conducted using the speedy soil moisture tester method. The first objective is to determine the soil moisture level between three conditions such as dry, semi-dry and wet soil. To determine the soil moisture (water) percentage content, Speedy Soil Moisture tester has been used. To determine the percentage of soil moisture content were conducted using the speedy soil moisture tester. The tests are simple and take just a few minutes for each sample. From the test of *T1* and *T2* sample, it proved the resulting percentage is indicative of three conditions of soil moisture which dry 0 - 20%, semi-dry 21% - 25% and wet soil 25% and above. For *T1* result of soil moisture percentage, it found 11.918% for dry, 21.705% semi-dry and 34.232% for wet soil. For T2 result, it has got 9.289% dry, 21.116% semi-dry and 34.352% for wet soil. The advantage of using speedy soil moisture tester in test soil moisture (water) is making testing more practically especially in study/site area. Besides that, speedy moisture tester does not use electrical power or batteries to conduct studies. Result from speedy moisture tester also fast and accurate in just 3 minutes compared to the oven method which results in after 24 hours. That's why it is very suitable for using in the field.

Next the second objective was to assess the depth accuracy with the different soil moisture level such as dry, semi-dry and wet. The GPR has an ability to detect the depth of buried utility in different condition of soil moisture and provide the internal information in form of radargram image. All utility data interpretation scanned will be display at the Digital Video Logger. The signal transmitted into the subsurface and reflected signal as a radargram image. From the radargram image, is represent the reflectance of the material scanned that has unique identity based on hyperbolic, velocity, time and distance of reflection. Hyperbolic image will view on the screen DVL during scanning. All data scanned has been collected and recorded and transfer to the laptop for next processing using Ekko_View software. Radargram and hyperbolic image studied to determine their depth and in assisting interpretation in the study area.

Based on the result, the soil moisture which is dry, semi-dry and wet soil was affect the accuracy of the depth underground utility. According to the results, the difference between the depths into dry soil is deeper than semi-dry and wet soil. Image from radargram also showed which dry soil radargram image more clearly than others. The analyse that result can conclude related with the water content in soil moisture in underground. Soil moisture content (water) can produce the physical changes in density, it can make the weak of radar reflection or electromagnetic wave travel to antenna weak. Based on effect on the dielectric constant, in three soil moisture the real part of the dielectric constant increases more than one order of magnitude when soil moisture content (water) increases. According on the assessment, the increase of soil moisture (water) in the soil will lead to stronger underground utility characteristics. If the water content in the soil is excessive or moist soil, the image of radargram will be blur and shape of hyperbolas difficult to prediction. It is because wave energy is emitted absorbed and weakened. As such, energy is difficult reflect to the surface. The depth to which GPR waves can reach beneath the ground surface is mainly dependent on the soil properties and frequency of the antenna used.

The idea of this research is used GPR to study effect of accuracy of depth at different soil moisture caused received attention from the minister of natural resources and environmental Malaysia who stated that underground utility mapping needs to be managed efficiently for the planning and development of the country in the future. Utility mapping can prevent services disruption due to accidents during excavation work and maintenance work can be carried out efficiently.

The advantage of using ground penetrating radar in detecting buried utility in different soil moisture (water) is non-destructive measurement technique and more efficient rather than other methods like remote sensing. Besides that, GPR is real-time data collection, and no health hazards will produce. It also consumes time because GPR measurement is user friendly.

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