Detection and Localization of Water Leaks Using Ground Penetrating Radar (GPR)

Pengesanan dan Pemusatan Kebocoran Air
Menggunakan Ground Penetrating Radar (GPR)

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Abstract

Water leakages can frequently happen and can impact on the user and provider itself. The quality of water is getting worse and the leakage that happened can cost the provider to detect and fix it. Ground Penetrating Radar (GPR) could in principle identify leaks in buried pipes either by detecting underground void created by the leaking water as it circulates near the pipe. In this study, the potential of GPR as a non-destructive method to detect fluid leakage has been examined. Besides, this study intended to obtain 3D models for an upgraded visualization of radargram mainly focused on the user that has poor knowledge about GPR and radargram analysis. The survey has been conducted at UTM Skudai. The simulation situation has been designed and constructed. This study was conducted by simulating the water leaks in the pipe, which were buried underground. The water was injected into the pipe before the survey was performed. A vision of fluid leakage and contaminated soil was observed with the post processing using Reflex2DQuick in order to get the result. The radargram shows the leakage cumulated around the buried pipe. Several experiments were designed and conducted to prove that GPR can be a tool to detect fluid leakage. The radargram images were sorted and a 3D model has been generated. The 3D model was used in interpretation of water leakage. The result of this study will elaborate on the capabilities and effectiveness of the GPR in detecting fluid leakage which could help in other leak detection methods.

Keywords: Water leaks, GPR

Abstrak

Kebocoran air kerap berlaku dan kekerapan ini memberi impak kepada pengguna dan pemilik itu sendiri. Kualiti air semakin teruk dan kebocoran yang berlaku akan menyebabkan lebih banyak kos untuk dibelanjakan sama ada untuk mencari kerosakan ini dan juga membaikinya. GPR mungkin boleh digunakan untuk mengesan lompong di bawah tanah yang dihasilkan oleh kebocoran air. Menerusi kajian ini, potensi GPR sebagai kaedah bukan pemusnah untuk mengesan kebocoran air telah dikaji. Selain itu, kajian ini bertujuan untuk mendapatkan visual 3D model daripada radargram bagi membantu pengguna yang mempunyai kurang pengetahuan dalam analisis radargram. Kajian ini telah dilakukan di UTM Skudai. Tapak simulasi telah direka untuk menggambarkan keadaan sebenar di kawasan kajian. Paip yang bocor telah ditanam sebelum kerja pengesanan dilakukan. Hasilnya, terdapat beberapa kenampakan kebocoran dan juga tanah yang basah di sekeliling paip tersebut setelah data pengesanan diproses selepas aktiviti pengesanan dilakukan dan ini membuktikan yang GPR boleh menjadi salah satu peralatan untuk mendapatkan kebocoran air yang berlaku di bawah tanah. Imej radargram telah disusun dan imej 3D dapat diperoleh. 3D model yang terhasil sangat membantu dalam pengesanan kebocoran air di bawah tanah. Keputusan kajian ini akan dapat menerangkan kemampuan dan keberkesanan penggunaan GPR dalam mengesan kebocoran bawah tanah yang boleh membantu kaedah pengesanan yang lain.

Kata kunci: Kebocoran air, GPR

INTRODUCTION

The current development in the country is notably raised in many aspects especially in construction. The installation of new underground utilities has been used frequently in the construction industry. Some installation and maintenance may affect the current services of the power source of electricity or water distribution system to the public. National Water Services Commission (SPAN) used Non-Revenue Water (NRW) as an indicator to reflect the performance of water supply in Malaysia. Malaysiakini.com stated that NRW is the water that is lost between the water distributor and the consumer. Somewhere along the way to your house, that precious, treated water is lost either through leaking or burst pipes, malfunctioned water meters or even water theft.

Back on February 15 in 2014, The Star Online on their website mentioned the Petaling Jaya residence had experienced a dry tap due to the broken pipe within the area. Deputy Minister of Energy, Green Technology and Water, Datuk Mahdzir Khalid stated that the incident was caused when the sheet pile used to support the 900mm pipe was removed which lead to soil erosion and caused the pipe to be damaged (The Star,2014). Thus, local authorities made fast move by repairing the damages and provided the precautionary steps to minimize the damages for the other following cases. Furthermore, Malaysia is a country that experienced 2 seasons of monsoon in one year period (MOSTI, 2002). Within this period, there are unlikely more damages can occur because of rainfall that can cause a landslide which can affect the buried utilities for the general public.

Other than that, the latest development of new public transport, known as the Mass Rapid Transit (MRT) project has reported increase of costs up by another million due to utility damages only (The Edge Market, 2014). This is a serious problem that will not only affect water supply but also telecommunication, electricity and most importantly transportation. This destructive damage generated a wave and swept everything along its path as our countrys development problem. Roughly the cost estimated for the damaged utility is nearly RM172 million which affected the Selangor area (The Edge Market, 2014).

This study emphasizes the use of GPR in the detection of water leakage with the model (IDS-DUO 250MHz-750MHz.). GPR is one of the most effective tools for the characterization of ground conditions in urban areas (Hong et al., 2018), thus, in particular, making it easier for water network inspection by demarking in GPR images (radargrams) contrasts between leaked water and the surrounding ground derived from their dielectric characteristics (Crocco et al., 2010).

Also, the main product of this study is to model Three - Dimension of the whole part of piping system that involved around the leakage. The outcome from this study will be the result of the reliability of GPR detecting the leakage, along with the 3-D mapping of the pipe around the area of survey. Time domain reflectometry (TDR) and electrical resistivity methods are geophysical approaches that have also demonstrated a good ability in assessing the possible presence of water leaks (Lee & Oh, 2017; Cataldo et al., 2012a).

Water leakages are the common problem nowadays. As we know, every country has their own system to distribute the water to public for daily uses. Without a doubt, water is indeed an important resource that we need to survive. That is why the local authorities need to arrange the facilities strategically to provide a good system to transport and distribute the water to housing area without polluting it. However, these facilities can break crack and malfunction even with extra precaution from the authorities itself. This problem has actually occurred for a long time ago and yet, the authorities seem to fail to come out with the best sollution to stop it in a short period of time to minimize the leaked water. Malaysia experience many rainfall period in a year. So, we can say that this weather can possibly cause the landslide, or crack on the road and soil thus, causing to harm on the underground pipes.

There are different types of leaks, including service line and valve leaks but most cases are due to service line leaks. There are many possible causes of leaks and often combination of issue leads to their occurrence. For example, the material, composition, age and joining methods of the distribution system components can influence leaks occurrence. Another related issue is the quality of the early installation of distribution system components.

METHODOLOGY

Planning Process

Previous study on water leakage detection using GPR has been performed by Amalina Yusup (2015) and, she successfully found a leakage by performing a 2D processing using Reflex2D. For this study, the same technique is used. However this study is more focused on generating 3D modeling for the leakage and the contaminated soil around it. This study was also carried out by creating a simulation fieldwork because it is difficult to get the real case study from the local utilities' authorities.

The cracked pipe was buried underground on purpose. The pipe was buried horizontally below the ground and the tank was placed above the ground to inject in the fluid to the pipe while the detection is performed later. The pipe was placed 1 meter vertically under the ground. The 3x3 meter grid will be formed to perform this detection as shown in Figure 1.

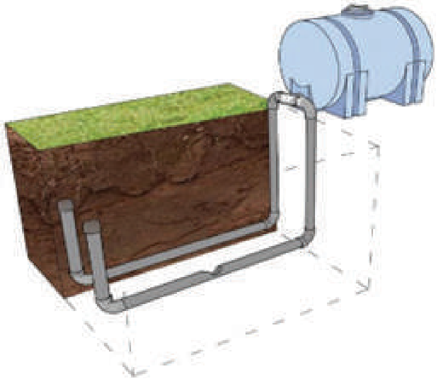

Figure 1 Perspective drawing for simulation

Instruments and Software

In this study, only one instrument is needed for the underground scanning which is Ground Penetrating Radar. For post-processing, there are 2 softwares that will be used for analysis. These are the example of the that instruments and softwares used for this study:

i. GPR IDS DUO Detector (250-750MHz)
ii. Reflex2DQuick Software
iii. Reflex3D Software

Site Selection

The selected site is at the field nearby the UTM Exit Gate (1°33'48.8" N, 103°39'17.7" E). The simulation was performed at that respected place. The pipe was installed following the illustration in Figure 1. The survey was conducted few days after the soil compacted. Figure 2 shows the selected site for this study.

Figure 2 Selected site (Google Map,2020)

Acquisition Plan

For this study, the grid line was set up around the area. We created two lines to perform longitudinal and transversal scans. The rope was used to indicate lines that need to be scanned. Figure 3 illustrated the longitudinal and transversal lines pattern for the detection works.

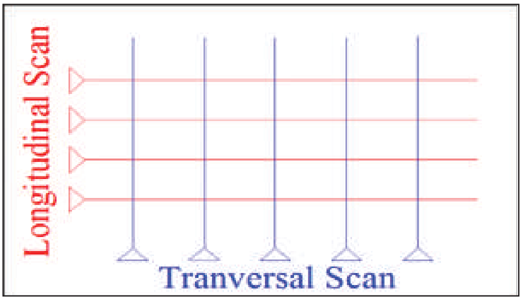

Figure 3 Detection Pattern

Data Acquisition

The simulation was set up at the field beside the main road. For this simulation, the crew need to dig the soil out and put the assembled pipe into the ground. Figure 4 shows the setup that has been done.

Figure 4 Buried process

The detection was conducted using Ground Penetrating Radar (GPR) IDS DUO Detector. This model is the only GPR model that provides two different antenna in the same transmitter which is 250MHz and 750MHz. The differences between two frequencies can affect the reading on the radargram and provides a different analysis based on the frequency respectively. This easy-to-use radar tool immediately locates utilities, simultaneously displaying on the same screen deep and shallow buried metallic and non-metallic pipes and cables.

Data Processing

The purpose of GPR data processing is to improve the raw data quality by manipulating the acquired data into image that can be used to infer the subsurface structure. Basic processing is required to make a perfect image of radargram.

Reflex 2DQuick

The program Reflex2D allows user to import, display, process and interpret two dimensional GPR data. The Reflex 2D are able to display image in 2 dimensional (2D) views for the scanned subsurface either in longitudinal or transversal respectively. Analysis can be done by referring to the amplitude on the images. In order to generate the three-dimensional GPR image, the x scan and they scan need to be combined to create a new c scan which can be used by Reflex 3D.

Reflex 3D Scan

3-dimensional (3D) data interpretation on Reflex3D software is described including the generation of a 3D dataset, the processing of 3D data files and also the interpretation of 3D data files. The software allows to import and analyses the 3D GPR data using both longitudinal and transversal scans. Before the processing begin, user need to ensure that the data have been acquired along equidistant parallel 2D lines on a regular rectangular grid.

Numerical Analysis: Dielectric Permittivity

The underneath material can be classified by dielectrics based on its properties (parameter permittivity and conductivity). Dielectric is defined as the accommodation propagating of a non-conducting material to alternate electromagnetic field while permittivity is to measure signal energy that can be stored in a material through separation of charges in a material. Next, conductivity is defined as a measure of the degree to which soil allows the passage of electrical charge through it. The dielectric permittivity can be estimated by calculating it using the standard permittivity formula as shown in Equation 1. (Halimshah.N,2015).

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

Er= electric permittivity
v = velocity
c = speed of light 3.0 x 108

The c in the formula indicated as the speed of light that constant in vacuum as 3.0 x 108 m/s. The v is referred to the velocity of reflectance value that has been extracted from the radargram image by doing the hyperbola fitting technique. The hyperbola fitting technique was carried out in Reflex 2D Quick software. The velocity and signal time travel was extracted. The fitted velocity value was used in dielectric permittivity calculation.

RESULTS AND DISCUSSION

The data was collected with increment for every 0.5 meter to allow better generation of three-dimensional modeling views of radar data, greatly improving the ability to interpret subsurface condition.

Two-Dimensional (2D) Interpretation

The study was performed for 2 sessions. The first was for the normal condition pipe and the second survey was performed after the water was injected into the pipes. Figure 5, 6 and 7 shows the unprocessed image, good condition pipe, and leaked condition pipe respectively.

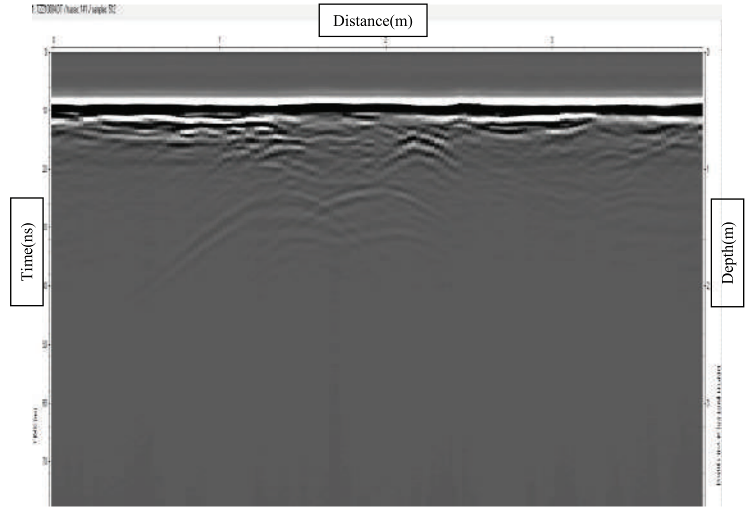

Figure 5 Unprocessed Radargram

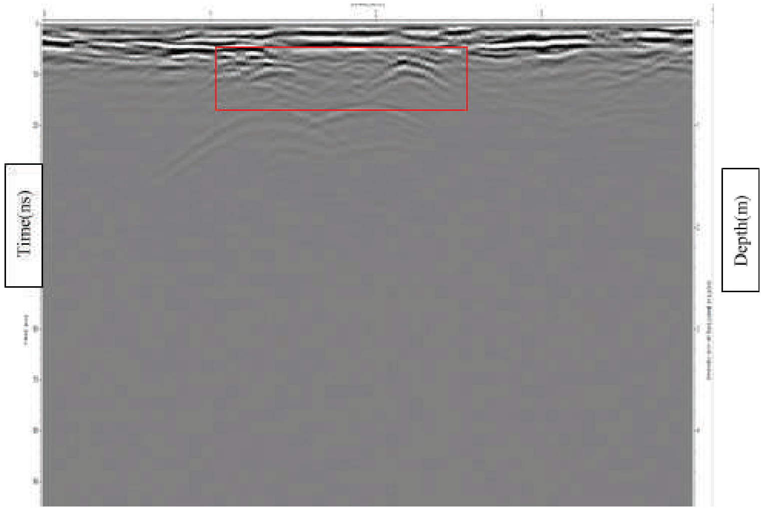

Figure 6 Good condition pipe

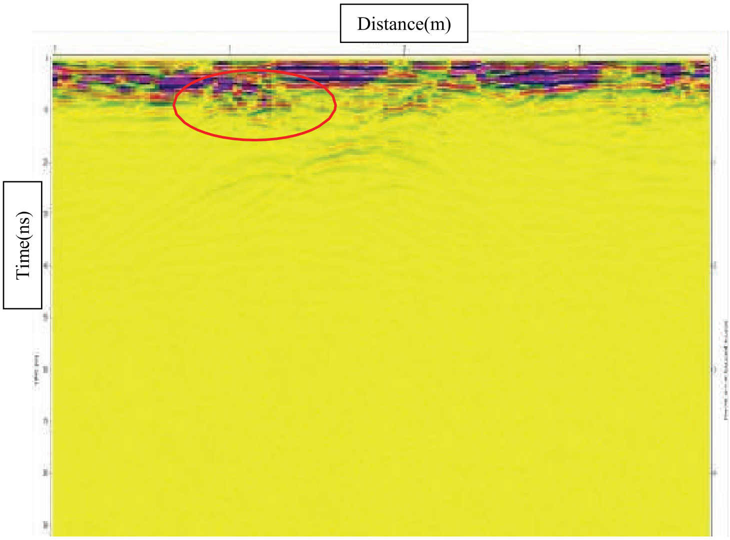

Figure 7 Water leaked condition pipe

Figure 6 and 7 show that there is a slight difference in the parabola pattern. The parabolas in Figure 6 are at even position. But in Figure 7, the leakage affects the scanned data. The parabola on the left side shows various unidentified parabolas. It depicts that there is leakage detected and the water is cumulated around the pipe and thus, disturbing the signal from the transmitter.

Three-Dimensional (3D) Visualization

Reflex3D is the software improved from Reflex2D for 3-dimensional processing and interpretation of GPR data, reflection and refraction seismic. Equidistant or non-equidistant 2D lines can be constructed by using 3D data during the data import step.

The Reflex3D can generate the image following our requirements and needs for the interpretation as shown in Figure 8.

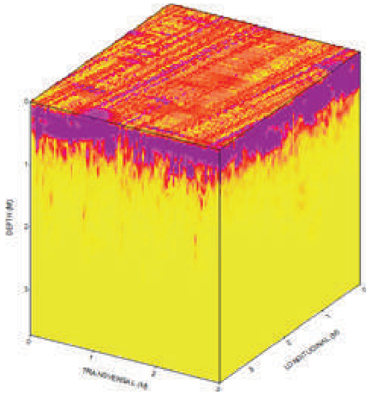

Figure 8 Full generation of 3D image

Figure 8 shows the full image of 3D generation of transversal and longitudinal scans that has been combined together. The 3D model is generated to 3x3 cube model for longitudinal and transversal as same as the grid that has been created before the detection work was performed. The figure shown is the data of the buried pipe underground with 100% clay around it.

The image might be different if the pipe is buried with the sand or other soil because different soil carries a different dielectric value and texture. In this study, the aim was to obtain 3D data visualization which was a critical part of interpreting the GPR data set.

By multiple scan collection over a regular grid in the x and y plane, a 3D data set which contain *(x, y, t)* can be recorded. This sets of data will be called, C scan data. Finally, C-Scan data were presented as 2D image by plotting the amplitudes of the recorded data by given time, *ti.*

Water Leak Interpretation

Water leakage interpretation an important part of this study in order to understand the occurrence of the leakage. In this data interpretation part, the depth of the pipe buried is the main point to make the water interpretation successful. The depth of the pipe buried is 0.8~0.9m underground. Figure 9 shows the 3D model of the area.

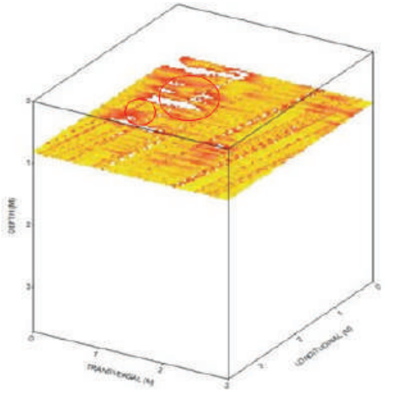

Figure 9 Fluid Detection Interpretation

The red circles from the figure show that there were some differences between them and the other iso-surface that has been generated. Based on Figure 9, irregular data was detected around that area and it maybe effected by the hole and caused the leakage around it.

However, the generation of the model of the pipe cannot be made. This is maybe because of the limitation of the GPR itself to detect the reflected signal from the PVC pipe. The second reason might be the surrounding. Based on the previous study by Amalina Yusup, the view of the PVC pipe buried in the sand is clear enough to be interpreted. With clay in the surrounding, the interpretation of the pipe was unclear from a 2D image radargram view. But, somehow the generation of the 3D model can show the leakage happened at the depth of 0.8~0.9m exactly where the pipes were buried.

Numerical Analysis

The soil in the site study area is classified as clay. The identification of soil properties reflectance based on the amplitude value, time of reflectance and the velocity is needed to get the dielectric permittivity of soil around the pipe buried. Dielectric permittivity is known as the energy stored and released by the material when electromagnetic energy is applied to the material. Significantly by using GPR that used electromagnetic energy to transmit the signal on the subsurface material, dielectric permittivity become a unique identity for the material. Each type of material has a different dielectric and permittivity. (Dong L, 2012).

GPR velocity was extracted with the parabola fitting technique that has been provided in Reflex2D. The dielectric permittivity is calculated by using the formula Equation 1 as stated in the previous sub-topic. The values of Dielectric Permittivity are shown in Table 1.

Table 1 Calculated Dielectric Value

Condition	GPR Velocity (m/ns)	Dielectric Permittivity (Er) $x10^{18}$
1. Wet Clays around burst pipe	0.07	18.37
2. Normal Clay	0.15	4.01

The differences in numerical can also be part of the analysis to differentiate between water-contaminated clay and the fine clay around the buried pipe. The value shows that the dielectric value of the wet clay was higher than the normal clay. Hence, the wet clay can store more electric energy than normal clay.

CONCLUSION

The general aim of the work described in this study is to analyze the potential of GPR for detecting underground leakage to generate 3D view using 3D scans and to improve GPR data visualization by using Reflex3D software. Through this study, the strength and limitation of GPR to detect water leakage was identified.

An experienced operator is needed to visualize the 3D image of the radargram. The process of analyzing those images can be very difficult and become very costly and time consuming. For this reason, this study is intended to improve and understand the measured radargram image.

Through this study, we can study the potential of GPR to detect underground leakage. The use of GPR could improve the time period to monitor and detect fluid leakage in real time through GPR radargram. It is very practical and effective to locate the utility position without digging the ground. GPR now would be proven as the non- destructive method that helps to locate early leaks and avoid additional damages by providing precaution and awareness to the community. The effectiveness of GPR as a tool for detecting water leakage is examined in this study.

The on-site simulation has been carefully designed and constructed. The pipe is perforated to visualize the real situation. The data collection has been performed when the water was injected in to the pipe. The grid was set up for a better sortation while processing. The main conclusion of this study is GPR may easily be adapted to detect water leaks in distribution systems whether the subject is a metal or PVC.

Despite the high price of GPR in the market, the usage of GPR is very easy besides that, the duration of the project can be shortened because it is simple. It does not require a lot of man power to operate and perform the scans. The data also can be interpreted faster on the site.

Based on this study, there a are few suggestions and approaches to improvise future study:

i. Perform the comparison of the pipe leakage using a different type of soil. (Past study used sand and clay as the soil)
ii. Use the real pressure equipment or pump system to create the real rate flow of the water injected into the pipe.
iii. Comparison between GPR with the different types of water leakage detection.
iv. Use different kind of GPR other than the IDS model to enable the result and output more in detail such as precise 3D modeling and others.

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