Non-Destruction Method for Detecting Corroded Underground Pipe Using Ground Penetrating Radar

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Abstract. Ground-penetrating radar (GPR) is a geophysical method that can accurately map the spatial extent of near-surface objects or changes in soil. It also produce radargram of those features. The demand for underground utility mapping in Malaysia is increasing rapidly for construction and non-construction activities. However, implementation of GPR in detecting corroded underground pipe in Malaysia can considered unpopular due to less exposure and exploration. Over the time, underground utility pipe will undergo corrosion process. Thus, is it relevant to detect old corroded pipe using GPR? On this basis, the aim of this experimental study was to validate the condition of corroded pipe by comparing its radagram profiles and to evaluate the significant signal reflectivity which were tested on three different pipe condition, namely new, average and old corroded pipe. The result of GPR calibration and data on GPR were processed using Reflex 2D software. In this study, with the aid of Time-Domain Reflectometry (TDR) sensor was used to obtain the soil moisture as it is one of the biggest in fluent to corrosion activity. In the GPR method, radar antennas moved along the ground in transects (B-scan), and two-dimensional profiles of a large number of periodic reflections (A-scan) were obtained. As conclusion, these GPR datasets and soil moisture from TDR reading are evaluated and been analysed thoroughly. At the end of this paper, it is suggested that GPR is efficiently can be used to detect corroded pipe.

Keywords: GPR, soil moisture, corroded underground pipe

1. Introduction

Corrosion is a common form of degradation in pipelines that reduces both the static and cyclic strength of the pipeline. Failure due the internal and external corrosion defects has been a major concern in maintaining pipeline integrity. As a pipelines ages, it can affected by a range of corrosion mechanism, which lead to a reduction in its structural integrity and eventual failure [1].

There are several types of utilities such as electric power supply, water supply or internet connection by using underground pipeline as a structure which associate for a better living. All iron-based metals can, and do corrode if their environment causes particular material to deteriorate. Besides that, it is common to bury pipelines for mechanical protection. Buried pipelines or underground pipes are tend to undergo degradation in the long period. This is because high exposure to aggressive environment of soil can lead to unexpected high rate of failures. Risk of failures for underground pipe works will give major impact in every aspects which include social, economic loss, flood, water crisis and many others [2].

Nowadays, underground pipelines are often damaged due to surrounding and third-party accidents, especially the most common defects in the pipelines is corrosion. Hence, it increases the probability for the pipe to bust. The aging pipelines also known as underground time bomb cause fatal destruction. Thus, a traditional way to determine any defects for underground pipes is by sending out surveyors to scout or monitor the area where it may have the potential problem for pipe busting or others. By implementing this method, it is highly effective in revealing the external condition and providing certain clues, however it only can be practiced in the area where there is actually defected pipe underneath. It will be more effective if users are able to detect the exact problem beforehand. By using Ground Penetrating Radar, its ability to identify buried utilities and utilized fundamentally to detect imperfections of pipes condition [3]. Thus, surveyors are able to detect the condition pipes on the earth surface without digging for it.

Figure 1. Old sewerage after the excavation in Puchong. (Source: The Star newspaper)

Therefore, with this non-destructive approach or method provided sufficient information in detecting underground pipe condition beforehand and helps to prevent failures or errors during the excavation. In this study, a study completed in order to determine the detection of corroded pipe by using the RIS HI-MOD GPR. The result was analyzed and compared in three pipe condition between new, average and corroded pipe. The analysis also includes element of proving either the GPR is relevant to use in assess the corroded condition of pipes situation in the underground pipes.

2. Methodology

The methodology for this study divided into three stages. The first stage is the planning stage which involving the preparation of works including determination of study area and equipment calibration. This is to ensure the quality of the survey data be more understandable and reliable. The second stage is implementing stage where the data acquisition works such as GPR used to generate GPR radagram profiles (B-scan) with its signal reflectivity (A-scan) and TDR for soil moisture measurement. Next, the final stage is analyzing the result involving software to do comparison on their radagram for corroded and normal pipe.

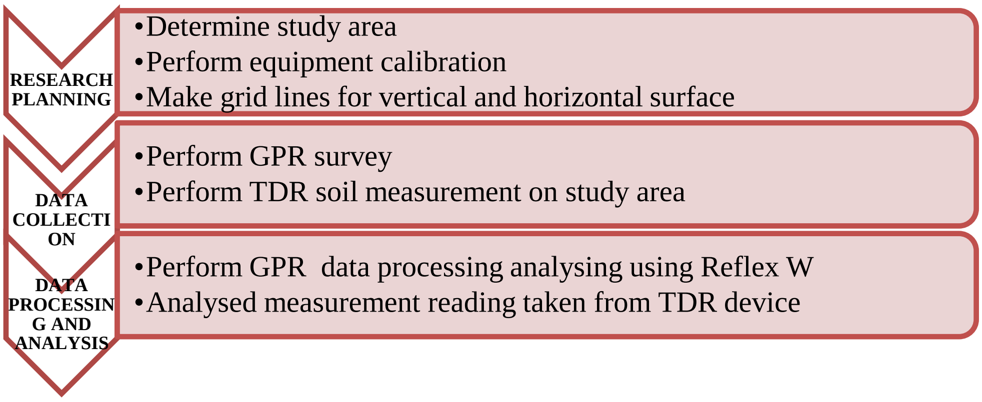

Figure 2. Simple flowchart of work planning.

2.1 Study Area

This study area was conducted at three places which three pipe conditions were tested. The estimated coordinates were obtained from Google Maps, which are:

i) 1°28’ 28.9”N, 103°45’1.5”E (Figure 3)
ii) 1°31’ 08.0”N, 103°42’9.0”E (Figure 4)
iii) 1°30’56.2”N, 103°42’9.1”E (Figure 5)

Figure 3. Study area for new condition pipe.
(Source: Google Maps)

Figure 4. Study area for average condition pipe.
(Source: Google Maps)

Figure 5. Study area for old corroded condition pipe.
(Source: Google Maps)

The GPR survey were using transversal movement which was perpendicular to the pipe alignment. 8.0 m by 3.0 m survey grid with a common offset at an equal spacing of 1.0 m for each study areas.

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2.2 Pipe Conditions
Three types of underground pipe conditions were taken in this study which were new, normal and several corroded pipes. The age of the underground pipes help to differentiate its condition. One years old pipe for new pipe condition, ten years old for normal pipe condition and 34 years old pipe for severe corroded pipe condition is also included for this study. As a constant variable, all these pipes were acknowledged and have the same properties such as its diameter and product which is Mild Steel (MS) with a diameter of 150 cm each.

2.3 Data Acquisition
For this study, the RIS HI-MOD GPR is used. This equipment used with its dual frequency 400 MHz and 900 MHz antenna systems. Time domain reflectometry sensor (TDR 100) with rods from FieldScout Company was used to perform soil moisture measurement in research area.

Figure 6. RIS HI-MOD GPR with dual frequencies 400 MHz and 900 MHz antenna systems.

Figure 7. TDR sensor.

Data processing involves the GPR raw data which were obtained by the use of GPR. In this study, Reflex 2D Quick was used. Reflex 2D Quick was used to process the raw data captured by K2 FastWave GPR software. Briefly, Reflex 2D Quick software acts as ground vision with radar. The function is it enables instant viewing of the data acquisitions. It's adapted for data processing, originating for the GPR. It's also the tools proposes with five analysis modules and offers a diverse range of treatments [4]. Basic steps that involved to process based on certain techniques, such as subtract mean (dewow), static correction, gain functions and background removal to remove the unnecessary signals.

3. Results and Discussion

3.1. Qualitative Observation of GPR Radargram Profiles
These B-scans from each underground pipe condition are shown as below. The first (figure 8 a-b), second (figure 9 c-d) and the third (figure 10 d-e) rows illustrate results with Tx antenna frequencies of 400 MHz and 900 MHz respectively for different type of underground pipe conditions. The direct waves from Tx to Rx and its time travel were kept constant and evident for all scans. Besides that, it also noted that the X-axis and Y-axis of the radagram profile represent 'Traversal' in meter and 'Depth' in meter respectively for all B-scans in this section.

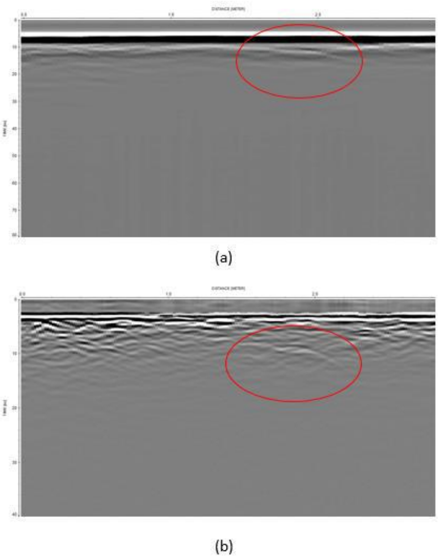


Figure 8. B-scans acquired using (a) 900 MHz and (b) 400 MHz for new pipe condition.

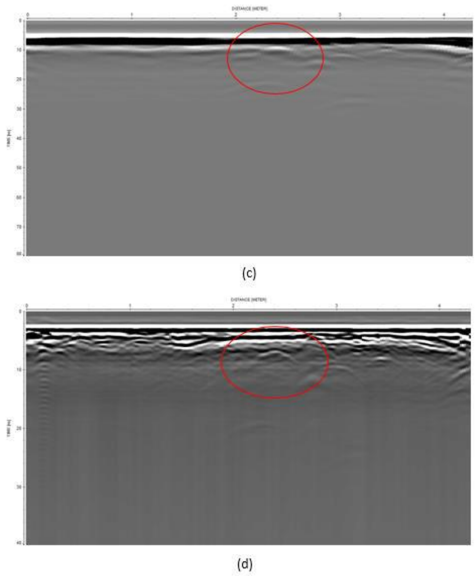


Figure 9. B-scans acquired using (c) 900 MHz and (d) 400 MHz for average pipe condition.

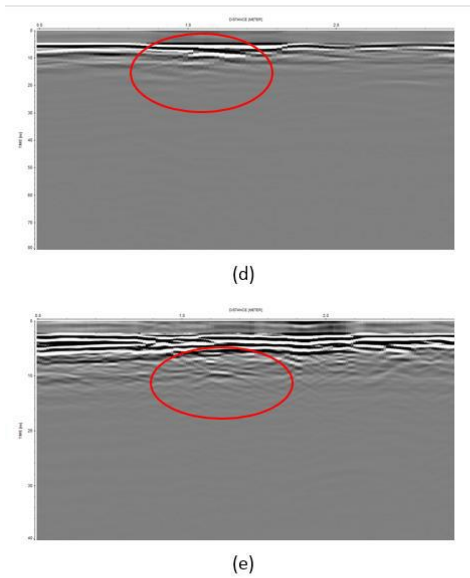


Figure 10. B-scans acquired using (d) 900 MHz and (e) 400 MHz for old pipe condition.

Based on all figures above, it is clearly shows that resolution with 400 MHz Tx is obviously seen and radagram profile with 900 MHz Tx demonstrates good resolution while simultaneously resolving the location of the pipe with high accuracy. From the results, it is suggested that GPR systems with centre frequency of 900 MHz is suitable for providing indirect assessment of pipes.

The qualitative comparison of radagram profiles between new, average and old corroded pipe also can be made through observation of its intensity. Low intensity or hyperbola feature decreases show there is corrosion activity occurred in the underground pipe [5]. Based on all radargram profiles with 900 MHz Tx, it can be seen more visible to differentiate its pipe condition. Figure 8 (a) resulting pipe absent of corrosion damage, while for Figure 9 (c) shows slightly decreasing contrasts in hyperbola intensity. However, for Figure 10 (e), it shows that a bit sharp contrasts in hyperbola intensity which means there is a presence of corrosion activity on the underground pipe [2]. This is because variable layer of thickness around the pipe. This is because variable layer of thickness around the pipe may have undergone higher levels of material loss due to corrosion within a very long period of time [5]. Note that all scans above are constructed at same colour scale.

3.2. Processed Backscattered Radargrams of Underground Pipes

These GPR radargram profiles from three types of underground pipe conditions were shown with the same dimension of area which was 8.0 x 3.0 m. It was taken with the same dimension in order to keep it as a constant variable. Three B-scans from each pipe conditions were best-picked due to its better resolution with 400 MHz Tx, which helps to make analysis of this study more realistic and understandable.

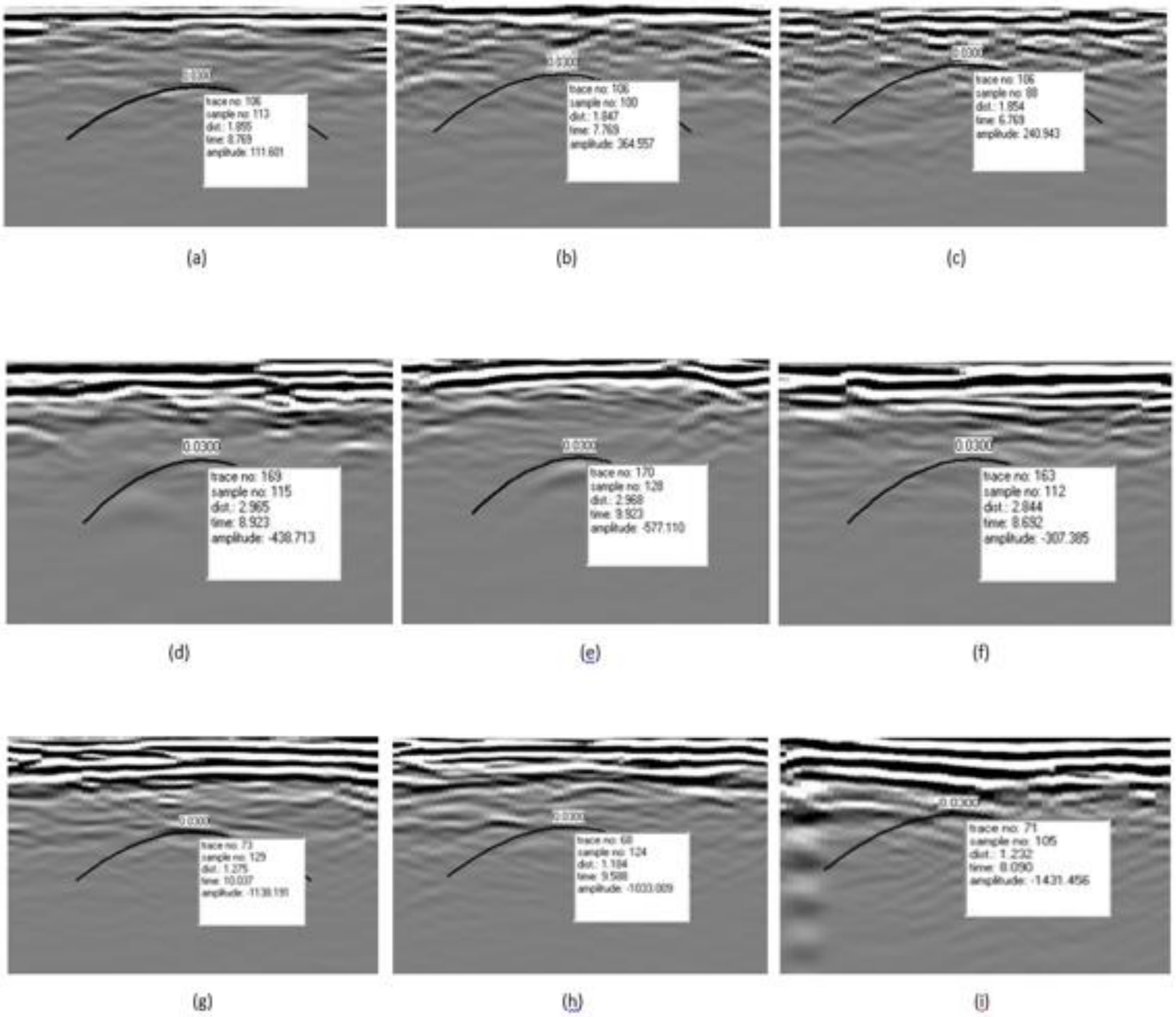


Figure 11. B-scans for three types of underground pipes conditions which are (a)-(c) for new pipe, while (d)-(f) for average pipe and B-scans (g)-(i) is the corroded pipe.

Based on figure 11, after each radargram profiles form different conditions have been processed, the quantitative comparison can be made for each pipes condition. It is noted that once the signal travelled underneath, hit or meet the initial part of the pipes, it gives value of signal reflectivity. In other words, with appropriate GPR formula, user can determine the actual depth of the pipe from its signal reflectivity.

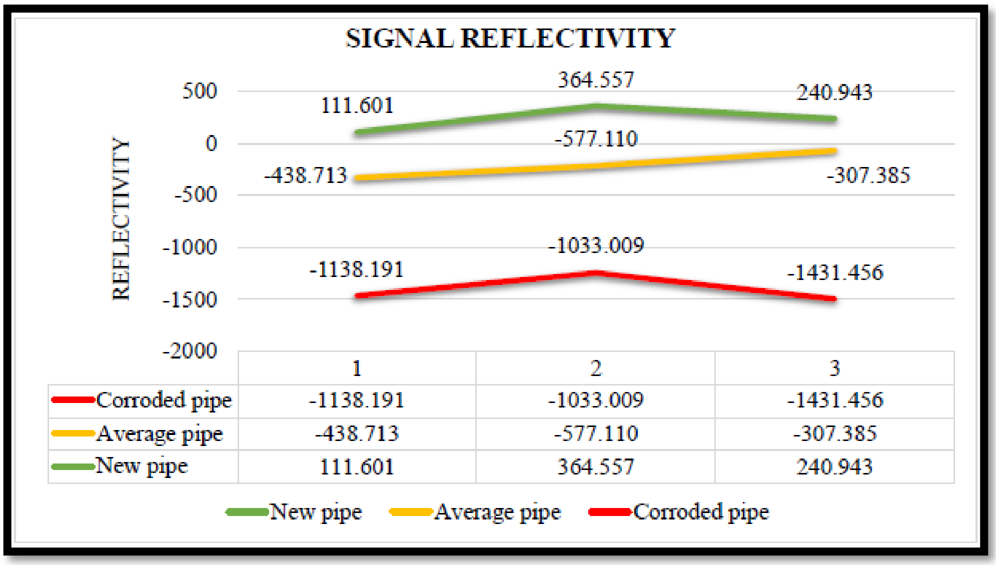
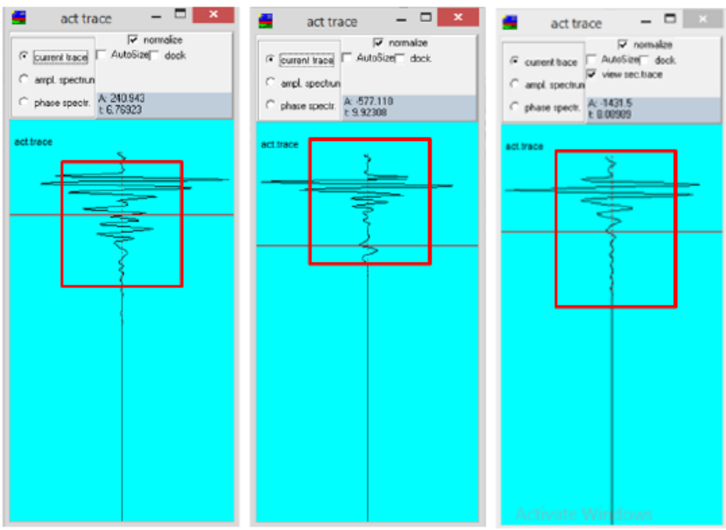


Figure 12. Graph of signal reflectivity of three B-scans from different type of underground pipe conditions. Note that reflectivity is unit less.

From line chart shown in figure 12, it is a graph that shows GPR signal reflectivity for different underground pipe conditions. For new condition pipe (green line) shows positive value of reflectivity of signal as compared to those two pipe conditions which it was ranged between 100 to 250. Average and old corroded condition pipe shows negative value of reflectivity which were range between -300 to -600 and -1110 to -1450 respectively.



(a) (b) (c)

Figure 13. Amplitude of reflected signal with 400 MHz Tx for (a) new condition pipe, (b) average condition pipe and (c) old corroded condition pipe.

Based on figure 13, the highest signal reflectivity from each pipe conditions were shown, in order to evaluate its significant attenuation of the reflected signal in the soil. Figure 13 (c) shows stronger attenuation compared to figure 13 (a) and (b). This is because there was a corrosion activity occurred within a period of time, which leads to stronger attenuation of the reflected signal underneath. The surface of metal pipe may have undergone major material loss and deterioration. Therefore, it is proven that by using GPR technique, it able to detect corroded pipe based on its reflectivity of the signal.

3.3. Results on Soil Water Content from TDR Device

Soil water content (SWC) or soil moisture is generally considered as the mostly influent parameter. The result of volume of soil water content (VWC) in the percentage form which depends on its pipe condition. Two zones with three readings of TDR device were taken for each pipe conditions to obtain its average.

Table 1. TDR reading for new pipe condition.

	Standard VWC%			
	Reading 1	Reading 2	Reading 3	Average
Zone 1	13.1	13.1	13.1	13.10
Zone 2	14.9	15.2	15.2	15.1
Average	14	14.15	14.15	14.10

Table 2. TDR readings for average pipe condition.

	Standard VWC%			
	Reading 1	Reading 2	Reading 3	Average
Zone 1	29	29	29.3	29.10
Zone 2	2.6	2.9	2.6	2.7
Average	15.8	15.95	15.95	15.90

Table 3. TDR readings for old corroded pipe condition.

	Standard VWC%			
	Reading 1	Reading 2	Reading 3	Average
Zone 1	20.7	21.4	20.7	20.93
Zone 2	31.5	31.5	31.5	31.5
Average	26.1	26.45	26.1	26.22

Based on all tables above, the average readings for each pipe condition were ranged between 14 to 27 percent. The highest average reading for new, average and old corroded pipe condition obtained were 14.10, 15.90 and 26.22 respectively. From table 3, soil for old corroded pipe condition obtained the highest percentage of SWC due to high soil moisture.

It can be concluded that higher soil moisture resulting increase in soluble salt content, which leads to lower electrical resistivity [6]. The electrical resistivity of a soil is a measure of its resistance to the flow of electrical current due to presence of soluble salt, which it is unable to conduct electricity in the soil. Therefore, topically, the high the resistivity, the higher the corrosively in the soil. This supports analysis that were made in the previous section that the presence of corrosion damage underneath the ground can be determined and proven by using GPR technique.

4. Conclusion

From all the result obtained, it shows that GPR is efficiently can be used to detect corroded pipe. It is also helped to differentiate the pipe conditions based on the GPR datasets obtained. Through some research findings, validation and evaluation on analysis from GPR datasets are achieved.

Old corroded pipe condition was efficiently detected by using GPR, the reflectivity signal shown leads to the objectives. GPR radagram profiles helps to differentiate its intensity for all pipe conditions in this study which based on the frequency used. There was significant reflection in the radargram profile shown though corroded pipe. The corroded pipe are detectable through its intense evaluation of the radargram profile and with the aid of the amplitude trace of reflected signal. Thus, it is resulted that corroded pipe has the strongest attenuation of reflected signal due to corrosion activity occurred underneath because of metal loss distributed into soil. In the other word, the response was related to higher GPR waves lost in the deteriorated soil environment near the corroded pipe.

However, by relying solely on GPR B-scan data for corroded pipe assessment under practical cases may lead to correct identification of corrosion interest point of locations. It is to be noted that the scan needs to be conducted perpendicular to the pipe alignment. Weak hyperbolic reflections collected over a pipe length, with the lower soil electricity resistivity, it can be used to isolate possible regions of corrosion activities. With the help of reading of soil water content by using TDR device, element of soil moisture can be obtained. Thus, the corroded pipe condition has the highest reading of soil moisture which leads to lower electrical resistivity of soil due to high presence of soluble salt content that able to conduct electricity. This shown that corrosive soil environment is the one of the factor that leads to corrosion activity.

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