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Monitoring underground water leakage pattern by ground penetrating radar (GPR) using 800 MHz antenna frequency

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Abstract. Water is the most treasure natural resources, however, a huge amount of water are lost during its distribution that leads to water leakage problem. The leaks meant the waste of money and created more economic loss to treat and fix the damaged pipe. Researchers and engineers have put tremendous attempts and effort, to solve the water leakage problem especially in water leakage of buried pipeline. An advanced technology of ground penetrating radar (GPR) has been established as one of the non-destructive testing (NDT) method to detect the underground water pipe leaking. This paper focuses on the ability of GPR in water utility field especially on detection of water leaks in the underground pipeline distribution. A series of laboratory experiments were carried out using 800-MHz antenna, where the performance of GPR on detecting underground pipeline and locating water leakage was investigated and validated. A prototype to recreate water-leaking system was constructed using a 4-inch PVC pipe. Different diameter of holes, i.e. ¼ inch, ½ inch, and ¾ inch, were drilled into the pipe to simulate the water leaking. The PVC pipe was buried at the depth of 60 cm into the test bed that was filled with dry sand. 15 litres of water was injected into the PVC pipe. The water leakage patterns in term of radargram data were gathered. The effectiveness of the GPR in locating the underground water leakage was ascertained, after the results were collected and verified.

1. Introduction

Water is precious natural resource to human being and plant. Unfortunately, a very large amount of water goes wasted as the potential water leaking in most water-distribution systems (WDSs) is getting higher year by year, thus cause most urban and developing areas face acute water problems. The WDSs is one of the most critical and treasured utilities and infrastructure systems. According to the World Bank database report, more than 32 billion cubic meter of treated water and non-revenue water (NRW) suffered from physical leak in WDSs, each year around the world. Unaccounted water loss reportedly by International Water Supply Association (IWSA) is 20-30 percent for WDSs [1]. The result is common, however for older WDSs, the percentage can reach up to 50 percent. The reports are quite dreadful and staggering, since the actual losses is more than reported losses. Smart solution is implemented in order to solve the acute water leaking in WDSs, notably underground water pipeline system.

The technique included is smart sensor in detecting water leaking named ground penetrating radar (GPR) technology. Locating and discovering the element of WDSs such as water leaks are one of the applications of GPR [2]. The basic GPR technology had aided the development of non-destructive testing (NDT) methods. This can be proved by the growth of GPR production since 1970's [3] and GPR application in various fields. Approved physical theories and discoveries that are associated with the occurrence of frequency energy transmitter of GPR, leads to the improvement of WDSs.

2. Experimental works

Analyzing the effectiveness of ground penetrating radar (GPR) is the main goal of this study by recreating a physical laboratory experiment to detect water leaking from underground pipes. An experiment was carried out to stimulate leaks in a 4-inch PVC pipe. A 4-inch PVC pipe was chosen in this laboratory water leakage simulation because PVC is the frequently used in industrial underground pipeline of water distribution system [4]. The 4-inch PVC pipe with three different holes diameter of ¼ inch, ½ inch, and ¾ inch, was buried in a test bed with 6 tons of dry sand as shown in figure 1, which ½ inch and ¾ inch were sealed with silicone sealant. The dimensions of test bed were 2.5 m long, 1.5 m high, and 1.5 m wide as shown in figure 2. The PVC pipe was buried at depth of 0.60 m in dry sand as depicted in figure 3 (a) and the hole faced downward to simulate leaks. The test bed was constructed using wooden box without the usage of metals such as screws and nails [5]. The present of metals will cause interference with radar signal during GPR scanning. 15 liters of water was injected for the water leakage laboratory experiment. RAMAC/GPR 800 MHz shielded antenna was used for the GPR scanning. For the antenna polarization in the experiment, the long axis of the antenna was perpendicular along the PVC pipe as presented in figure 3 (b). Table 1 summarized the antenna setting employed throughout the study. Testing parameters are listed as following:

- Number of samples is 502
- Sampling frequency is 8800 MHz
- Time window is 57 ns
- Antenna separation is 0.14 m

Table 1: Antenna setting

Parameter	Value
Antenna	800 MHz shielded
Trigger	Distance
Trig int	0.005 m
Measuring wheel	Meas.wheel 300-800 MHz

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Figure 1. Six tons of dry sand used for the entire experiment.

Figure 2. Real photograph of test bed for the laboratory experiment.

Figure 3. (a) Photograph of PVC pipe buried at the depth of 0.60 m, and the PVC pipe is in L-shape to inject water for water leaks simulation, (b) 800 MHz shielded antenna is perpendicular along the PVC pipe.

3. Result and analysis

3.1. *Detecting water leakage*

Several attempts of experiments were carried out to stimulate leaks in PVC pipe, in which the pipe was buried at the depth of 0.60 m in the test bed. Three different holes were drilled at different hole diameters, i.e. ¼ inch, ½ inch and ¾ inch hole diameter. 15 liter of water was injected into PVC pipe to simulate water leakage. The first section of result and discussion emphasis on comparison between time interval of water leakage at the smallest hole, i.e. ¼ inch hole diameter, the next section focus on ½ inch hole diameter for comparison between time interval of water leakage, the following section discuss on comparison at ¾ inch hole diameter, and the last section details on the comparison between ¼ inch, ½ inch and ¾ inch during water leaking.

3.1.1. Comparison between time interval of water leakage at ¼ inch hole diameter. Three different diameter of holes, ¼ inch, ½ inch and ¾ inch were chosen as variable for the water leakage simulation, to observe the variation of water pressure during water leaking. 800 MHz exhibits strong signal and provides sufficient penetration to detect the water leakage. Hyperbola pattern was exhibited as shown in figure 4 (a), (b), (c), (d), and (e), with the center is located approximately at 0.60 cm as proven in red circle. This illustrate that the position of the buried PVC pipe at approximately 0.60 m, almost 100% accurate as presented in Figure 4 (a). Generally, the hyperbolic pattern projected downward was generated to represent the buried pipe [6]. It can be seen from figure 4 (b), during water leaking at ¼ inch hole, the reflection pattern was totally clear and seems massive below the PVC reflection line, where the hyperbola intensity increased. The change in hyperbola pattern was influenced significantly

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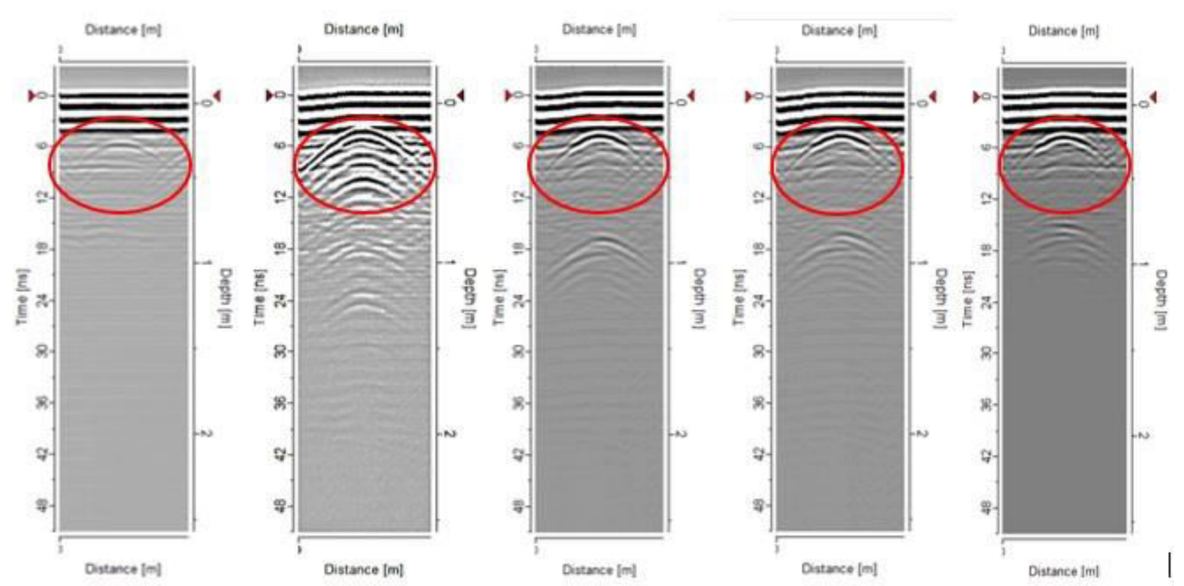
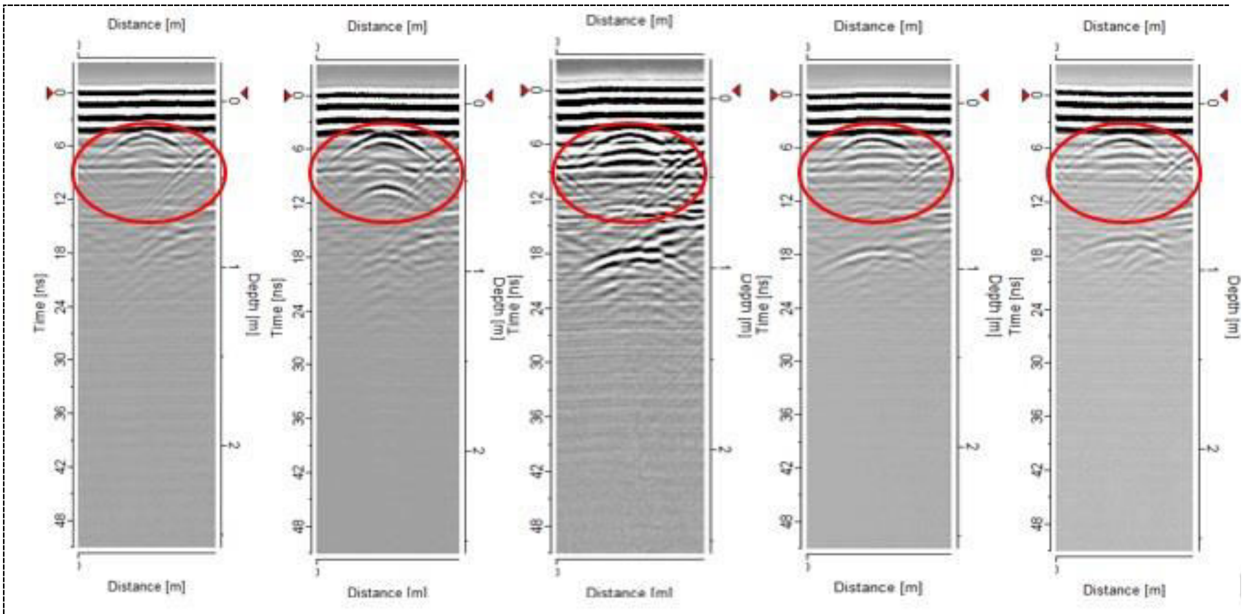
by changes in dielectric medium [7]. The changes in dielectric medium were caused by the presence of water leaks. Due to highest water pressure, the water flow rate is the fastest. The hypothesis on the smaller the pipe diameter, the higher the pressure was justified. That was perhaps, the water leakage already reached at the bottom of the sand in the short period of time due to fastest water flow rate. There is no significant difference in figure 4 (c) and (d), since the water runs to the bottom at similar rate. However, the reflection of water leakage getting blurry after 24 hours as depicted in figure 4 (e). The purpose of GPR scanning after 24 hour was to analyze the water dissipation in the dry sand. The result indicates that the saturation water was already dissipated into the dry sand. The GPR scanning profiles for time interval illustrate the depth of water leakage can reach up to more than 1 m, even after 24 hours of water leaks simulation.



(a) (b) (c) (d) (e)

Figure 4. Radar profile of water leakage ¼ inch when (a) before water leakage, (b) during water leakage, (c) 30 minutes after water leakage, (d) 1 hour after water leakage, (e) 24 hour after water leakage.

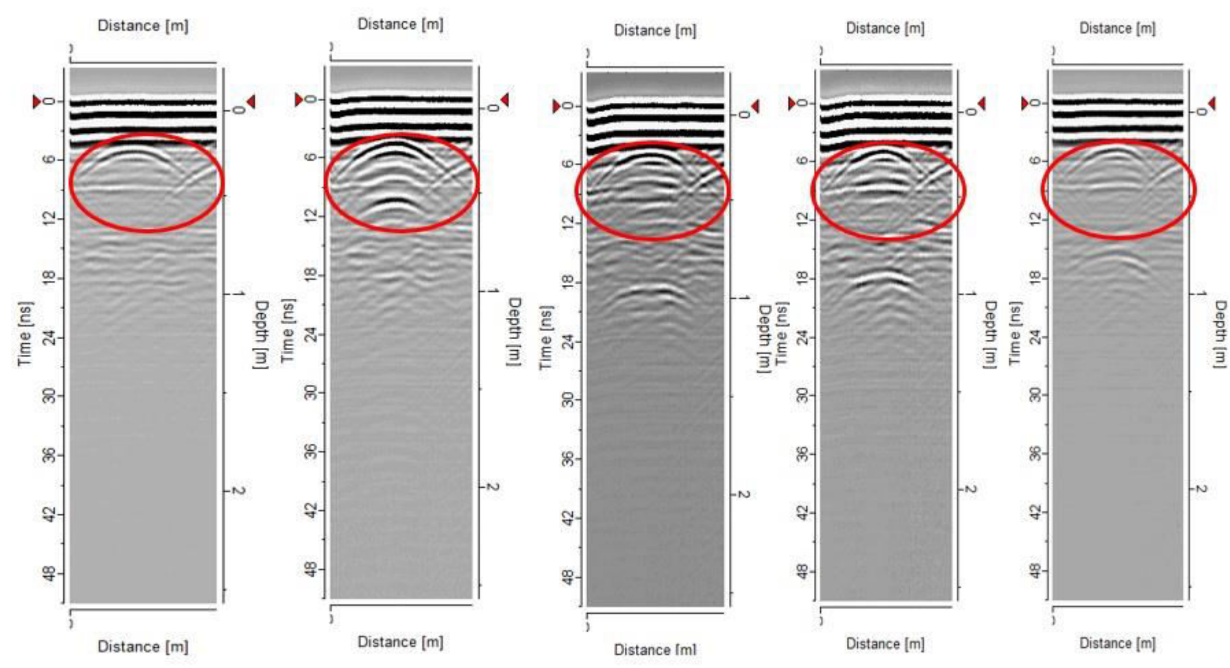
3.1.2. Comparison between time interval of water leakage at ½ inch hole diameter. Figure 5 represents the radargram profile of water leakage simulation for hole diameter of ½ inch. The differentiating factor between the radargram profile in figure 5 (a) and other figures 5 (b), (c), (d), and (e) is the presence of water as marked with red circle. The presence of water created new hyperbolic reflection pattern in figure 5 (b). The water has substantially changed the dielectric properties of the dry sand. The pattern showed increased in intensity and the range of hyperbolic pattern started to extent after 30 minutes of water leakage as depicted in figure 5 (c). The low water pressure was caused by bigger hole diameter as compared to ¼ inch diameter. That was the reason on why the great difference in water leakage can only be seen after 30 minutes. The anomalous change then started to disappear as the phenomena demonstrates that the water leaks low started to move downward and dissolve into the dry sand as presented in figure 5 (d) and 5 (e). Figure 5 (e) illustrated that resemble to radargram in figure 5 (a), as the anomalies pattern was not notably detectable, where indicating that most of the saturation water has moved downward to the bottom of the test bed.



(a) (b) (c) (d) (e)

Figure 5. Radar profile of water leakage at ½ inch when (a) before water leakage, (b) during water leakage, (c) 30 minutes after water leakage, (d) 1 hour after water leakage, (e) 24 hour after water leakage.

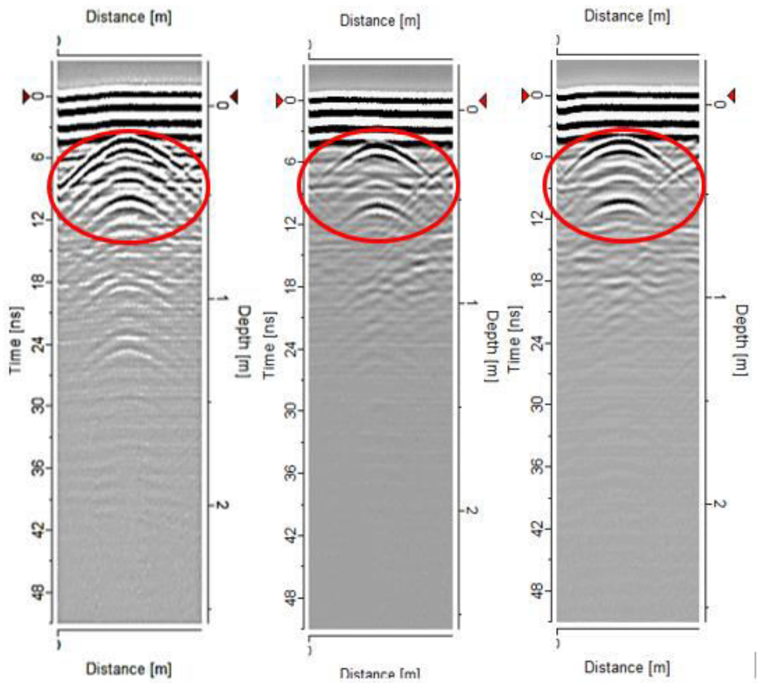
3.1.3. Comparison between time interval of water leakage at ¾ inch hole diameter. Figure 6 illustrates the radargram images for water leakage simulation for ¾ inch hole diameter, the biggest hole for the experiment. The GPR scanning was conducted right after the injection of 15 litres of water. The radar profile during the water injection showed that more than one hyperbola were observed due to the presence of water in figure 6 (b). The reflection pattern through the GPR scanning was marked in red circle as shown in figure 6. The large amount of dielectric constant of water with the value of 80, is clearly make a huge difference between before and during of water injection. Low water velocity was caused by smallest water pressure, where only little water leaks detected through GPR scanning in figure 6 (b). The intensity of hyperbola reflection pattern increased and the water anomalous feature was sharp as illustrated in figure 6 (c), and still remain the same after 1 hour of water leakage as presented in figure 6 (d). Due to lowest water velocity, the water reflection pattern is clearly visible in figure 6 (d). The sharpness of water leaks anomalous features slightly lost after 24 hour in figure 6 (e), because the water leaks already dissipated in the dry sand and already shifted downward toward the bottom of the test bed.



(a) (b) (c) (d) (e)

Figure 6. Radar profile of water leakage at ¾ inch when (a) before water leakage (b) during water leakage, (c) 30 minutes after water leakage, (d) 1 hour after water leakage, (e) 24 hour after water leakage.

3.1.4. Comparison between ¼ inch, ½ inch and ¾ inch during water leaking. The radargram profiles during water leakage for the three different hole-diameter were portrayed in figure 7. Significant differences of hyperbolic reflection pattern were observed during water leakage between ¼ inch hole diameter and other two holes, ½ inch hole diameter, and ¾ inch hole diameter as illustrated in red mark position. The great differences show that, at highest water pressure, the water flow rate is fastest compared to others. More hyperbolic reflection patterns were observed in figure 7 (a) compared to figure 7 (b) and figure 7 (c). One of the factors that can be weighed into the discussion was the presence of high dielectric constant of water as can be observed through the anomalies features. The dielectric constant of PVC pipe, dry sand, wet sand, and water is 3, 3-5, 30-60 and 80 respectively [8]. The intensity of hyperbolic reflection pattern is highest in figure 7 (a), as comparing to figure 7 (b) and figure 7 (c). Greatest water pressure leads to highest water velocity, hence the water flow rate is the fastest through smallest hole diameter. The phenomena then leads more hyperbola pattern can be produced during water leaking. Penetration water reaches up to 1.5 m as depicted in figure 7 (a), (b) and (c) through the GPR scanning. Hence, the argument that suggested GPR is capable on detecting water leakage was validated.



(a) (b) (c)

Figure 7. GPR radar profile of (a) ¼ inch hole diameter, (b) ½ inch hole diameter, (c) ¾ inch hole diameter.

4. Conclusion

The performance of ground penetrating radar on detecting water leaking was ascertained through the various water leakage experiments. It was revealed that the water leaks reflections was generated as similar with hyperbolic anomalies. Greatest water pressure was occurred in small hole diameter which is the ¼ inch hole diameter. The radargram pattern of underground water leakage using ¼, ½ and ¾ inch hole diameter results was clearly observed. The goal of the experiment has achieved its objective. It proves that the GPR is one of the best equipment to detect water pipe leakage without having to dig the ground and causing damages to the surrounding structures.

5. References

[1] Hunaidi O 2000 Detecting Leaks in Water Distribution Pipes *Construc. Tech. Update* **40** pp 1-6

[2] Crocco L, Soldovieri F, Millington T and Cassidy N J 2010 Bistatic Tomographic GPR Imaging for Incipient Pipeline Leakage Evaluation *Progress In Electromagnetics Research PIER* **101** pp 307-321

[3] Conyers L B 2013 *Ground Penetrating Radar for Archaeology* Rowman and Littlefield Publishers Inc.

[4] Lai W W L, Ho M L Y, Chang R K W, Sham J F C and Poon C-S 2017 Tracing and Imaging Minor Water Seepage of Concealed PVC Pipe in a Reinforced Concrete Wall by High-Frequency Ground Penetrating Radar *Construction and Building Materials* **151** pp 840-847

[5] Eyuboglu S, Mahdi H and Shukri H A 2003 Detection of Water Leaks Using Ground Penetrating Radar *Geophysics 2003 : Conf. on Appl.Geophysics* pp 8-12

[6] Yelf R J 2007 Application of Ground Penetrating Radar to Civil and Geotechnical Engineering *Electromagnetic Phenomena* **7 1** pp 102-117

[7] Hunaidi O, Chu W, Wang A, and Guan W 2000 Detecting Leaks in Plastic Water Distribution Pipes *J. AWWA* **92(2)** pp 88-94

[8] Davis J L and Annan A P 1989 Ground Penetrating Radar for High Resolution Mapping of Soil and Rock Stratigraphy *Geophysical Prospecting* **37** pp 531-551

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