

Detection of Leaks in Water Distribution System using Non-Destructive Techniques

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Abstract. Water is scarce and needs to be conserved. A considerable amount of water which flows in the water distribution systems was found to be lost due to pipe leaks. Consequently, innovations in methods of pipe leakage detections for early recognition and repair of these leaks is vital to ensure minimum wastage of water in distribution systems. A major component of detection of pipe leaks is the ability to accurately locate the leak location in pipes through minimum invasion. Therefore, this paper studies the leak detection abilities of the three NDT's: Ground Penetration Radar (GPR) and spectrometer and aims at determining whether these instruments are effective in identifying the leak. An experimental setup was constructed to simulate the underground conditions of water distribution systems. After analysing the experimental data, it was concluded that both the GPR and the spectrometer were effective in detecting leaks in the pipes. However, the results obtained from the spectrometer were not very differentiating in terms of observing the leaks in comparison to the results obtained from the GPR. In addition to this, it was concluded that both instruments could not be used if the water from the leaks had reached on the surface, resulting in surface ponding.

1. Introduction

A water distribution system is a reliable set of infrastructure used for transportation of safe, potable and good quality water to the consumers. It generally comprises of pipes, pumps, valves, storage tanks, reservoirs, meters, fittings, and other hydraulic accessories that provides a link between treatment plants or the source of the water to houses of the consumers. The loss of water during the distribution process can be quite significant for any utilities. Water loss due to leakage contributes the most significant part of the water loss. Water leakage is defined as loss of water from an opening in the supply system. The leakage could occur in different parts of the distribution system such as, transmission pipes, distribution pipes, service connection pipes, joints, valves [1]. The amount of water that is leaked at a given time in a distribution network depends on the structure of the network, material of the network, the pipe flows, the age of the network and the length of the work cycle [1]. There are several factors that contribute to the leakage of the pipes. Pipe material, surrounding soil properties, and water quality in the distribution system are some of these factors. Pipe material plays a significant role in the leakage behaviour of pipes since pipes of different materials, due to the material properties, will fail in certain characteristic ways. In addition to this, the pressure exerted on the pipes by the surrounding soil and corrosivity of the soil that surrounds the pipe are contributing factors which could potentially lead to leaks in pipes. Additionally, the water flowing in the pipes might contain high chlorine content or other chemicals which could corrode the pipes leading to pipe leakages. Other factors which could lead to leaks in the water distribution system are: faulty



installation, excessive water pressure, material defects, water hammer, ground movement due to drought or freezing, excessive loads and vibration from road traffic and stray electric current [1].

Different methods are used for the detection of leaks in pipes in the water distribution system. Non-Destructive Techniques (NDT) have certain advantages to detect leaks because they allow to evaluate the condition of the leak without changing the structure of the water distribution network, excavations of the soil above the water pipes, or disrupting the serviceability of the system. This not only helps in maintaining the services provided by the distribution system, but also save a lot of costs associated with the leak detection.

Ground Penetrating Radar (GPR) is non-invasive, geophysical method, which employs short electromagnetic pulses in the microwave range to produce an image of the subsurface. In a study conducted a laboratory on Plastic and Metallic pipes surrounded by silt and clay, it was concluded that the GPR technique are good at detecting the location of the leak; however, these results are negatively influenced by the presence of foreign buried objects [2]. Additionally, a study conducted in a laboratory on Polyvinyl chloride (PVC) pipes surrounded by dry sand concluded that GPR probing technique might be applicable to detect leaks in real soil [3].

The basic function of a spectrometer is to disperse the light emitted by an object into its spectral components and digitize the signal as a function of wavelength; thus, the physical and chemical properties of the object emitting the light can be inferred by analyzing its spectral components. The spectral reflectance obtained by soil is affected by the moisture content of the soil. In event of a leak in the distribution system, the moisture content of the soil surrounding the pipes increases. Therefore, the soil moisture content is the soil property of interest when dealing with spectrometers. Studies have successfully proven that as that moisture content of soil increases the reflectance obtained from the sand decreases and vice-versa [4], [5]. However, literature shows that the reflectance decreased non-linearly with the increase in moisture content of soils and this effect was not noticed in saturated soils [6]. Also, studies have shown that the decrease in the reflectance with the increase in moisture content is more noticeable in the infrared bands [7]. Even though soil moisture content is measured using spectrometer, it has never been used for detection of leaks in water distribution system.

This research intends to determine and compare the abilities of the chosen NDT's (GPR and Spectrometer) in detecting leaks in water distribution systems. In this research, laboratory based experiments were conducted to assess the effectiveness of these NDTs.

2. Research Methodology

To achieve the objective of this study, laboratory scale experimental approach was taken. An experimental setup was designed to replicate the existing conditions of the underground leaking pipes in water distribution systems.

2.1. Experimental Setup

The experimental setup designed for experimentation is a soil filled wooden box with four pipes placed at a depth of two-third from the top edge of the box as shown in Figure 1. The box is made of wood because it has minimum signal reflection, which makes it suitable for using GPR. Plastic and concrete were not chosen as the material for the box because these materials give strong signal reflections whenever the signal strikes the material surface. The bottom surface of the wooden box will have a layer of metal to calibrate the GPR. The designed dimensions of the box (L x B x H) in inches are 66 x 40 x 24. The pipes were fitted at a height 16 inches from the top surface of the wooden box According to the user's manual published by the manufacturer, the minimum distance between the pipes should be greater than 3 inches for a 1.6 GHz GPR to avoid any interferences in the images generated by the GPR. Hence, the distance between the pipes was chosen to be 12 inches.

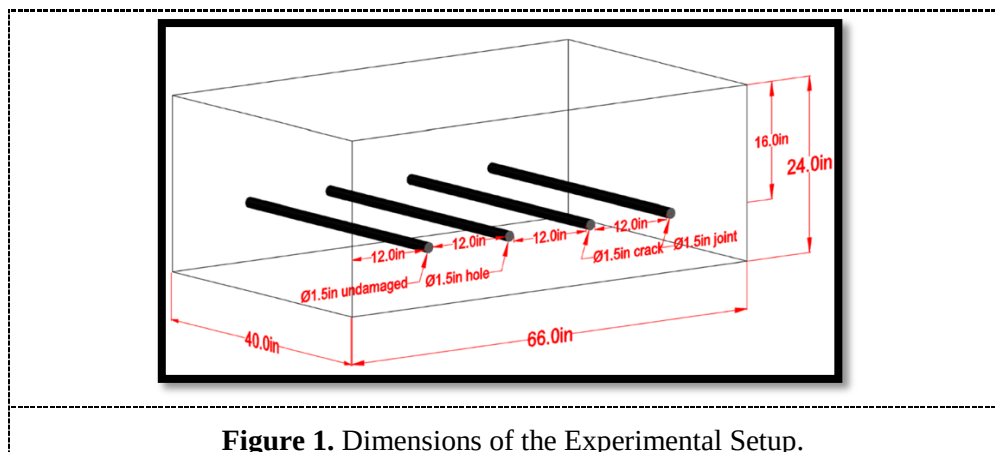


Figure 1. Dimensions of the Experimental Setup.

2.2. Pipes Used

The pipe materials used in our experiments is Polyvinyl Chloride (PVC). The diameter of these pipes is 1.5 inches. Also, the experimental setup consists of four pipes in which three pipes are damaged to simulate a leak and one pipe is an undamaged pipe. The first pipe in the experimental setup is a reference pipe with no damage to simulate no water leak scenario. In the second pipe, a hole was drilled to damage the pipe and stimulate a water leak due to defects in the pipe. In the third pipe, a crack (vertical cut) was created to damage the pipe. The last pipe consisted of a faulty joint to stimulate a leak. The sequence and type of damages stimulated in the pipes have been shown in Figure 1.

2.3. Fill Material for the Experimental Setup

Soil characteristics as low-electrical-loss materials, low relative dielectric constant and low absorption coefficient are suitable soils to obtain ideal GPR readings. Hence, taking all these factors into consideration the fill material chosen for experimentation is dune sand. In addition to this, the dune sand was compacted uniformly to imitate the real conditions of underground pipes. If compaction was not performed the damages stimulated in the pipes would leak faster because of lack of pressure from the surrounding soil. In addition to this, the water would spread faster because when the degree of compaction is less, the pore space is more and water can seep through these pores in the soil affecting the readings from other pipes. In this research, a compaction level of 85% was achieved to replicate the compaction level achieved in the road and pavement constructions as these pipes are usually under the pavements. A moisture content of approximately 5% was achieved.

2.4. Description of Instruments Used

The GPR used for experimentation is the Geophysical Survey Systems, Inc. (GSSI) Structure Scan Mini GPR with an antennae frequency of 1.6 GHz and penetration depth of about 20 inches. RADAN software was used to process and analyse the scans obtained from the GPR. Whereas the Spectrometer used in during experimentation was the Exemplar LS Spectrometer. The Exemplar LS Spectrometer displays real-time data and requires the use of BW Spec software to display the data obtained by the spectrometer.

2.5. Locations for Data Collection

During the experiments, the data was collected along the entire length of the pipe and not only at the location of damage because this experiment aims to observe how effective the instruments are at identifying the leak.

2.5.1. Locations of Data Collection points for the GPR

A grid was drawn on plywood to take readings for the GPR. For each pipe, three readings were taken which are: 6 inches right of the pipe, centre of the pipe and 6 inches left of the pipe.

2.5.2. Locations of Data Collection Points for the Spectrometer

Spectrometer readings were taken at three locations along the pipes which are the right side of pipe, middle of the pipe and left side of the pipe.

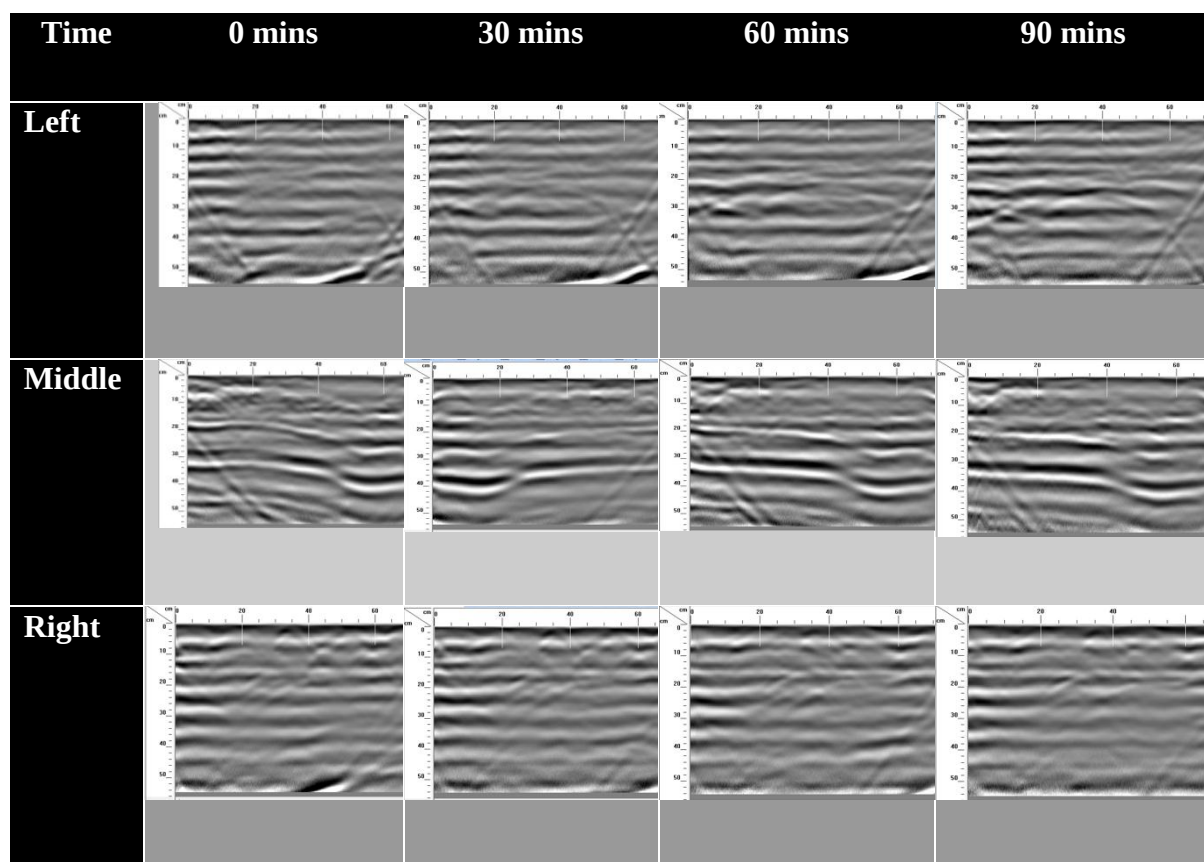
3. Results and Discussions

The GPR and the spectrometer were used on each of the four pipes to detect the leaks. The readings were taken at intervals of 30 minutes and a total of four readings were obtained. The total experimental time was 2 hours.

3.1. Results obtained for GPR

A dielectric constant of 6.4 was used to detect the depth of the calibration sheet. The calibration sheet is shown in a bright white tone in the images. The results obtained for pipe 3 (which is the pipe with crack) for the PVC setup are shown in Table 1. It can be seen from the images that there has been a significant drop in the depth of the calibration sheet with time as the moisture content level of the sand increased due to the leaks produced from the cracks in pipe 3. In addition to this, it is observed that the readings taken by running the GPR along the center of the pipe are not clear and the calibration sheet is not visible in the images. This is because the radiation emitted by the GPR reflects to the detector of the GPR on hitting the PVC pipe. Hence, the radiation does not reach the calibration sheet because of which it is not visible in the images obtained by running the GPR along the center of the pipes.

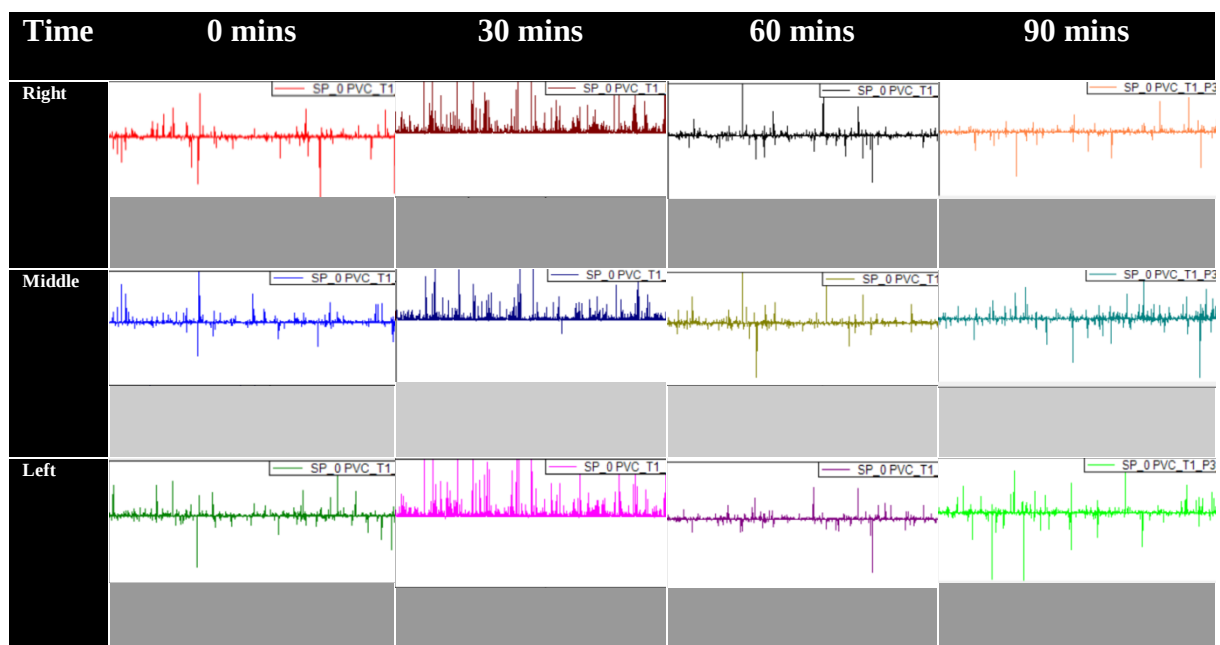
Table 1. Data Obtained on Pipe 3 Using the GPR



3.2. Results obtained for Exemplar Spectrometer

As observed in Table 2, the reflectance at all the three locations has slightly reduced at reading 3 (60 mins) when compared to reading 1 (0 mins). Furthermore, the reflectance reduces even further at the last reading, reading 4 (90 mins). Thus, this indicates an increase in the moisture content of the soil, which is caused by the leaks in the pipe 3 (i.e. pipe with a crack). However, the readings obtained after 30 minutes show an unusual pattern in comparison to the other three readings. Hence, this reading was not considered when analyzing the data. Also, the reduction in spectral reflectance is the highest in the readings obtained in the left side of the pipe, indicating that the leak was in the right side of the pipe.

Table 2. Data Obtained on Pipe 3 Using the Spectrometer.



After conducting the experiments for all four pipes using the two devices and analyzing the data, the observations have been summarized in Table 3. Both the instruments could identify leaks in pipe 2 and pipe 3 which are the pipe with the crack and the pipe with the hole respectively. However, both instruments were unable to detect the leak on the fourth pipe which is the pipe with the joint due to the accumulation of water on the surface of the soil in 30 minutes which resulted in ponding, as a result it was not possible to use both the instruments. This is coherent with the findings in literature which suggested that the spectral reflectance did not show any variation in saturated soils [6]. Nevertheless, the leak in the fourth pipe could be detected by just visual inspection as the water from the faulty joint had reached the surface.

Table 3. Summary of Leak Detection Potential of NDT's.

	GPR	Exemplar LS Spectrometer
Crack	Able to identify	Able to identify
Hole	Able to identify	Able to identify
Faulty Joint	Not able to identify	Not able to identify

4. Conclusion

Both the instruments were able to detect leakage in the pipes with the hole and the crack. In these pipes the water from the leaks did not cause ponding on the surface of the soil. However, in the fourth pipe which consisted of a faulty joint, water from the surface caused ponding on the surface of the soil because of which the GPR and the spectrometer could not be used. Nonetheless, in the case of surface ponding, these instruments will not be required as visual inspection itself will be enough to understand that there is a leak at that location. The results obtained from the GPR were easier to analyze. However, the initial calibration of the GPR was a time-consuming process which is necessary to determine the dielectric constant for the soil. On the other hand, the results obtained from the spectrometer showed very little deviation from the initial reading; making data analysis less accurate. However, the instrument was very easy to use during experimentation. This is valid for the soil type which is used in the current investigation. It is recommended to investigate other type of soils to determine the effectiveness of both instruments.

5. References

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