GROUND-PENETRATING RADAR FOR DETECTION OF LEAKS IN BURIED PLASTIC WATER DISTRIBUTION PIPES

Osama Hunaidi
National Research Council, Institute for Research in Construction, Ottawa, Canada K1A 0R6
osama.hunaidi@nrc.ca

and

Peter Giamou
multiVIEW Geoservices Inc., 1091 Brevik Place, Mississauga, ON, Canada, L4W 3R7

ABSTRACT

Ground-penetrating radar (GPR) could in principle identify leaks in buried water pipes either by detecting underground voids created by the leaking water as it circulates near the pipe or by detecting anomalies in the depth of the pipe as the radar propagation velocity changes due to soil saturation with leaking water. The potential of ground-penetrating radar for leak detection is independent of the pipe type, e.g., metallic or plastic. Therefore, GPR could help in avoiding difficulties encountered with commonly used acoustic leak detection methods in the case of plastic pipes or it could be used as a supplement to these methods. An extensive survey using ground-penetrating radar was carried out at a specially constructed experimental leak detection site to evaluate the radar's potential for leak detection. In this paper, the results of this survey will be reported and discussed.

INTRODUCTION

In many water distribution systems, a significant percentage of water is lost due to leakage from distribution pipes. To reduce water loss, distribution system operators conduct systematic programs to locate and repair leaks. Leaks are normally located by using acoustic leak-detection equipment, e.g., simple listening devices such as acquaphones and geophones or computer-based leak noise correlators. Acoustic equipment is generally considered to be satisfactory for metallic pipes. For plastic pipes, however, the effectiveness of this equipment is not well understood or documented. The lack of information on the effectiveness of leak detection methods for plastic pipes is alarming in view of the increasing use of these pipes in water distribution systems. This has prompted an extensive investigation of the effectiveness of acoustic methods and the potential of alternative non-acoustic ones for leak detection in plastic pipes. Ground-penetrating radar has been identified as a promising method in this investigation.

GPR could in principle identify leak areas by either detecting underground voids created by the leaking water as it circulates near the pipe or by detecting anomalies in the depth of the pipe as measured by radar. Saturation of soil by water leaking from a pipe slows down radar waves – thus making a leaking water pipe appear deeper than what it should be.

An extensive leak detection survey using ground-penetrating radar was carried out in this investigation to evaluate the potential of GPR for leak detection. The survey was performed at a specially constructed leak detection facility where several types of leaks could be simulated under controlled conditions (see Figure 1). In this paper, the results of the GPR survey will be reported and discussed. Also, details of the survey procedure, GPR instrumentation, and image processing and analysis will be presented.

INSTRUMENTATION

Tests were performed using the pulseEKKO radar system manufactured by Sensors and Software Inc. of Mississauga (Canada). Two different models of this system were used for the tests: (i) pulseEKKO 1000 system equipped with only a 450 MHz antenna (antennas at lower centre frequencies are available for this system but could not be obtained during the study), and (ii) pulseEKKO 100 system equipped with 200, 100, and 50 MHz antennas. The pulseEKKO 1000 system is of the shielded type which makes it ideal for use in "electromagnetically noisy" urban environments. However, preliminary tests of this system indicated that

Figure 1 Simulated leak at test site as seen before ground reinstatement

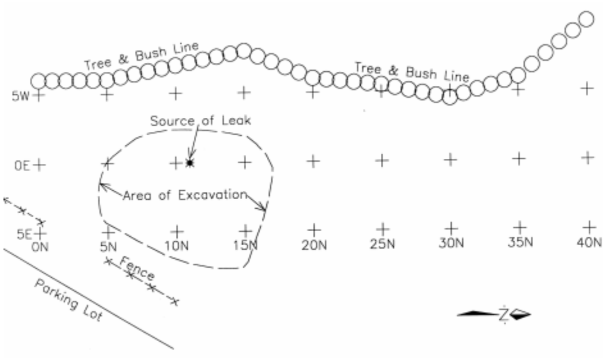

Figure 2 GPR survey grid

Figure 3 GPR antennas perpendicular to survey line

the penetration depth was not sufficient and therefore the pulseEKKO 100 system was used for the survey.

Data acquisition and processing parameters were as follows: antenna separation equal to 0.5, 1 and 2 m for antennas having 200, 100 and 50 MHz centre frequencies, respectively; nominal step size equal to 0.2 m; number of stacks equal to 64; reflection survey mode; DEWOW filtering; 5-point stacking; spreading and exponential compensation (SEC) with maximum gain of 200, radar wave attenuation of 3 dB/m, and start value at 5.

DESCRIPTION OF TESTS

GPR tests were performed at a specially constructed leak detection facility at the National Research Council campus in Ottawa (Canada). The facility has a 200 m long PVC pipe, 150 mm in diameter, that is buried in soft silty clay soil at a depth of 2.4 m. Several types of leaks could be simulated in the pipe including those from service connections, faulty joints and cracks. All leaks were buried but they could be opened using valves accessible from the surface.

A leak from a ¼ inch underground nozzle was opened about 4 hours prior to the GPR survey and was left open during the survey. The flow rate of the leak was approximately 20 litres/min. A photo of the leak before ground reinstatement is shown in Figure 1.

In order to facilitate the GPR survey, a 10 m by 40 m survey grid was marked over the leak site as shown in Figure 2. The grid covered a large area above the leak and further away from it. Grid lines were spaced at 5 m intervals in both the east-west and south-north directions which are perpendicular and parallel to the pipe, respectively. The grid's main axis was centered directly above the water pipe. The east-west boundaries of the grid were located at ±5 m east and west from the grid's main axis; and the south and north boundaries were located at 11 and 29 m from the leak location. Radar data were acquired along the 3 grid lines parallel to the pipe (5W, 0E, and 5E) and along the 8 grid lines perpendicular to the pipe (0N, 5N, 10N, 15N, 20N, 25N, 30N, and 35N).

The radar survey was performed with antennas having centre frequencies at 50, 100, 200, and 450 MHz. The axis of the transmitting and receiving antennas were oriented perpendicular to the survey line direction as seen in Figure 3 for the 50 MHz antennas. The antennas were moved manually across the ground and data was acquired at a nominal 0.2 m interval.

All antennas exhibited strong signal attenuation with depth. On-site review of radar images, indicated that the 100 MHz antennas provided both sufficient penetration and resolution of features in the top 2 to 3 m. The 50 MHz antennas did not provide sufficient resolution and the 200 and 450 MHz antennas did not provide sufficient ground penetration. Only results obtained with the 100 MHz antennas are presented in this paper.

RADAR WAVE VELOCITY

A common-mid-point (CMP) survey was also carried out to determine the radar wave velocity for the site. The CMP survey was carried out along line 5E with its centre point at line 30N. Interpretation of the CMP radar images was difficult; nonetheless, it revealed a velocity of 0.09 m/ns which is typical for silty clay soils.

RESULTS

Radar profiles obtained using the 100 MHz antennas are shown in Figures 4 and 5 for survey lines perpendicular to the pipe (only lines 10N and 20 N are shown), and in Figures 6 to 8 for survey lines parallel to the pipe. The maximum penetration of the radar signals was between 2 to 3 m. At deeper levels the radar data is not reliable because it is dominated by noise. In interpreting the radar data one usually searches for anomalies such as hyperbolic reflections, irregularities in largely uniform reflection patterns, and changes in the frequency of the signals. Hyperbolic reflections are caused by point reflectors in the ground such as pipes, rocks, voids etc. Irregularities in largely uniform reflection patterns are usually caused by disturbances to the natural sedimentation of soils as a result of construction activities. Changes in the frequency of radar signals are caused by changes in the dielectric properties of the transmitting medium, e.g., due to saturation by water. Water saturation lowers the frequency and focuses the beam width of the radar signal. Radar images presented in Figures 4 to 8 display the above three anomaly types.

The point reflector seen near the centre of the images in Figures 4 and 5 is believed to be the water pipe. It appears at a depth of about 2 m rather than the pipe's actual 2.4 m depth (perhaps due to an inaccuracy of the measured radar velocity). It should be noted, however, that the pipe appears slightly deeper in the radar image taken above the leak area than in the one taken away from it. This perhaps could be taken as indication of a slow-down in the radar wave due to the saturation of the soil near the leak.

The radar images in Figures 6 to 8 reveal changes in both reflection pattern and signal frequency. This also indicates that the radar wave is slowing down over the leak area likely due to saturation of the soil by the leaking water. However, it might be argued that the anomalies are caused by soil disturbance from construction activities undertaken to create the leaks. At the test site, soil type is mainly soft clay. Therefore, this uncertainty may not be resolved as the clay soil has a high natural moisture content. A velocity decrease due to water saturation would perhaps be more apparent in sand. The usually well-defined boundary of the water table in sandy soils (as opposed to clayey ones) would give rise to a definite dielectric contrast between the soil above and below the water table level which in turn would produce a strong radar signal reflection. This has yet to be demonstrated.

Finally, careful inspection of the radar images did not reveal any anomalies that indicate the presence of voids due to the turbulent circulation of leaking water. An explanation for this might be that the soft clay soil at the test site is not conducive to the formation of such voids.

CONCLUSION

Based on the GPR survey performed in this study, no definite conclusion can be made regarding the potential of ground-penetrating radar for leak detection but it still appears to be promising. This is due to several factors. First, the soft clay soil at the NRC site is highly conductive and therefore had greatly attenuated the radar signals. Second, the clay soil had a high natural moisture content which hindered the detection of the water table boundary. Finally, the soft soil at the NRC site was not conducive to the formation of voids. These difficulties might not be encountered at sites with other soil types, especially sandy ones. This remains to be demonstrated in the future.

ACKNOWLEDGEMENT

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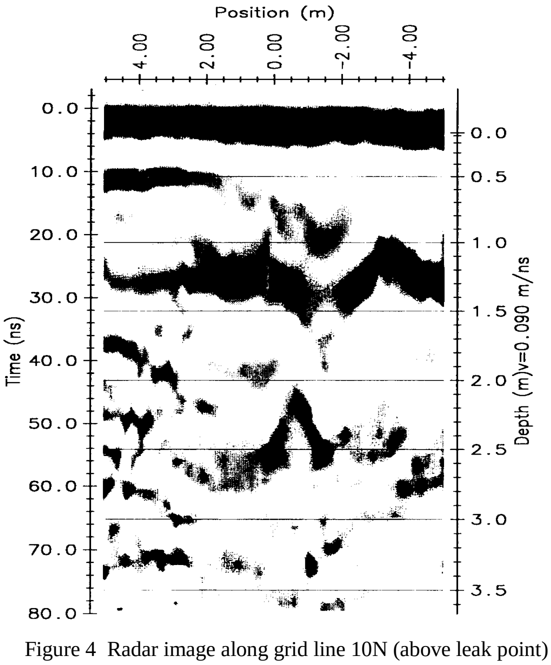

Figure 4 Radar image along grid line 10N (above leak point) obtained using 100 MHz antennas

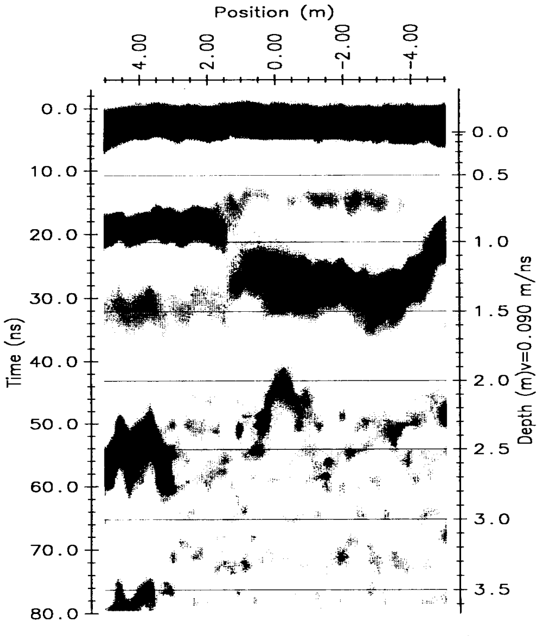

Figure 5 Radar image along grid line 20N (10 m north of leak point) obtained using 100 MHz antennas

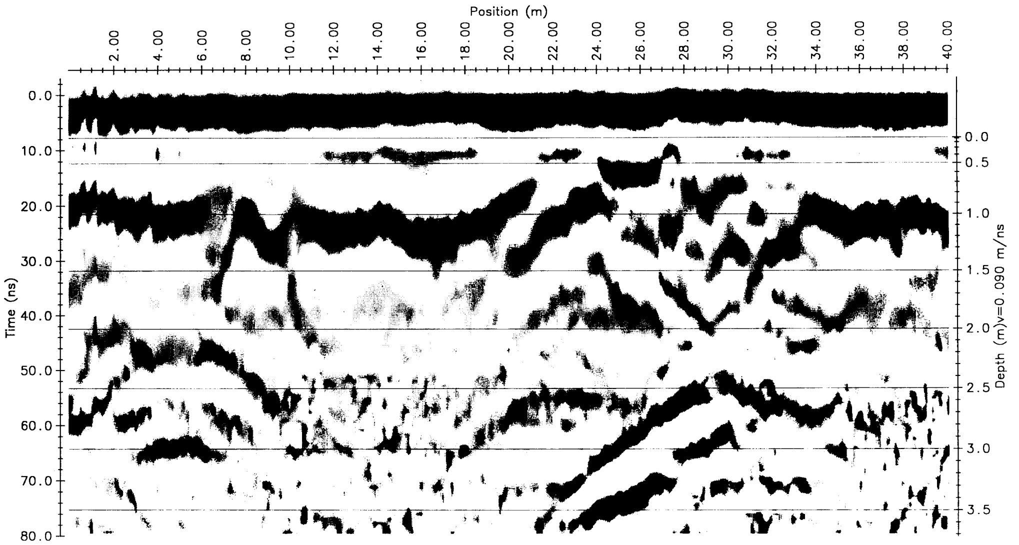

Figure 6 Radar image along grid line 5W (parallel to test pipe) obtained using 100 MHz antennas

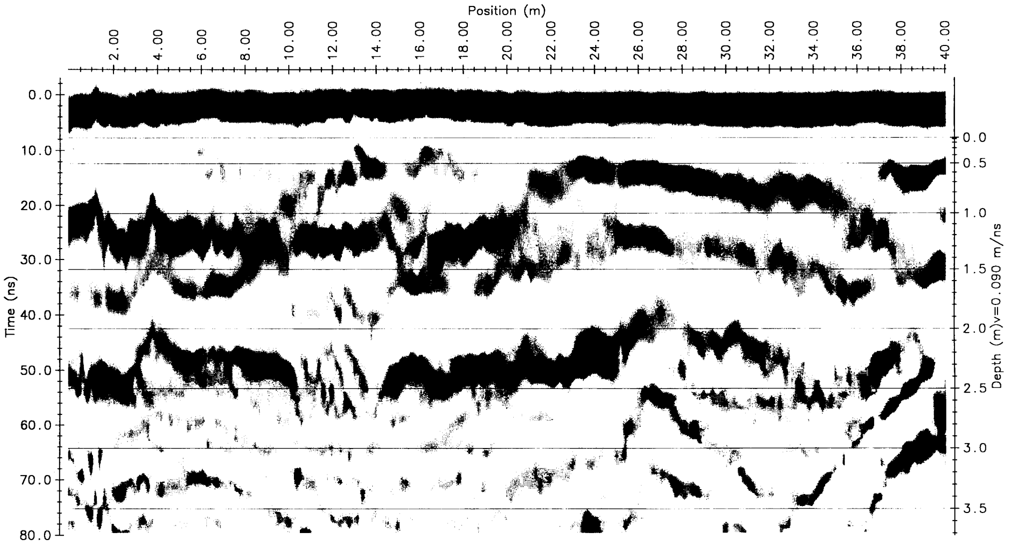

Figure 7 Radar image along grid line 0E (directly above test pipe) obtained using 100 MHz antennas

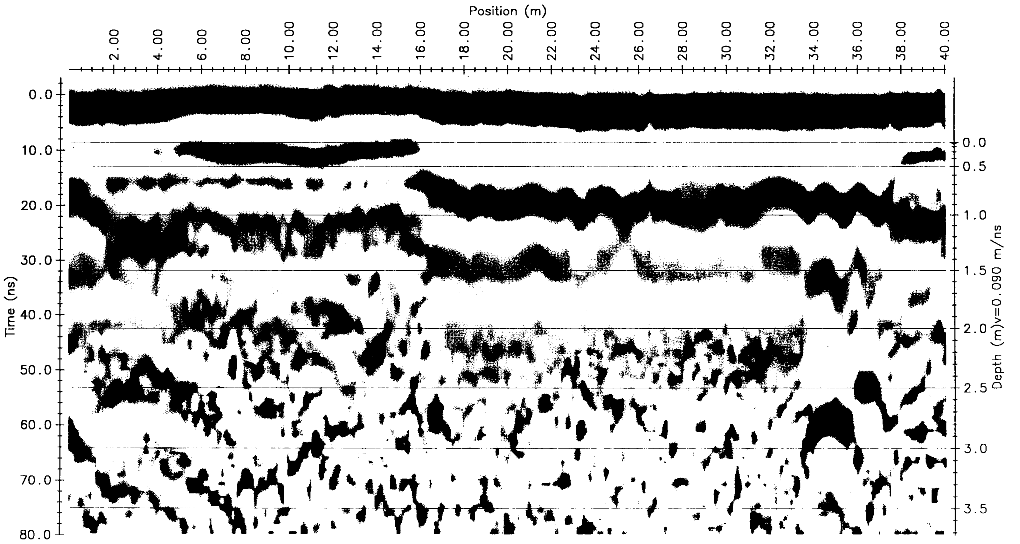

Figure 8 Radar image along grid line 5E (parallel to pipe) obtained using 100 MHz antennas