Pipe Penetrating Radar: Performing Advanced Condition Assessment On Gravity Sewers

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ABSTRACT

Pipe penetrating radar is a condition assessment technology that uses high-frequency ground-penetrating radar from inside non-ferrous pipes. It sees past the pipe's inner surface, measures the pipe wall's thickness, and detects voids. With millimeter accuracy, pipe-penetrating radar can detect voids while still small and well before they develop into sinkholes. This paper will look at how Pipe penetrating radar is used as part of effective asset management plans through a case study on a recent project.
Milwaukee Metropolitan Sewerage District chose SewerVUE Technology Corp. to determine the concrete thickness and map reinforcing rebar for some linear assets. A complex manned-entry pipe-penetrating radar survey was undertaken to assess the conditions of two sections of a reinforced concrete force main with different diameters running through the Jones Island peninsula in Milwaukee, Wisconsin. More than 1,110 feet of line data was collected. The survey detected no significant variance in the inside and the outside surfaces of the pipe walls; however, a few sections were found to be delaminating.

We completed the inspections in a single day and delivered the Pipe penetrating radar data, reporting anomalies, wall thickness, and reinforcement positioning.

Pipe penetrating radar is a valuable tool for effective asset management plans. By measuring wall thickness and detecting voids early, owners and managers can prioritize rehabilitation for pipes where it is needed most.

INTRODUCTION

Pipe penetrating radar applies high-frequency radar pulses from within a pipe to assess the condition of the pipe's wall. Pipe penetrating radar is a development of ground-penetrating radar (GPR) that relies solely on high-frequency pulses. Pipe penetrating radar penetrates the pipe's inner wall, measuring the wall thickness and locating rebar in reinforced concrete. It can also detect voids in the soil outside the pipe wall while those voids are still relatively small (Ékes, et al., 2011). PPR is effective in any non-ferrous pipe (RCP, AC, RP, PVC, HDPE, etc.).

- RCP: Reinforced Concrete Pipe
- AC: Asbestos-cement pipe
- RP: Reinforced Pipe
- PVC: Polyvinyl chloride pipe
- HDPE: High-density polyethylene pipe

Pipe penetrating radar is used for the condition assessment of wastewater pipes. The case study presented will describe how the manned-entry Pipe penetrating radar method gave the municipal owner of the pipe detailed information about its wall thickness and voids developing in the soil surrounding it.

WHAT IS PPR

Pipe-penetrating radar is the underground in-pipe application of GPR (Ékes et al., 2011). GPR has been used extensively to inspect the condition of concrete and brick-lined tunnels and sewers. One of its most common applications is detecting and locating voids, air-filled spaces between pipes' outer walls and their surrounding environments (Annan et al. 2002). To better understand the application of PPR, familiarity with some basic concepts of GPR is essential.

RADAR BASIC CONCEPTS

GPR is a non-destructive, high-resolution electromagnetic technique primarily designed to investigate volumes of solid material to shallow depths beneath the earth, building materials, roads, and bridges. A GPR system is typically comprised of two antennae: a transmitter antenna (Tx) and a receiver antenna (Rx). The Tx transmits pulses of electromagnetic radiation that penetrate through the volume. If a portion of a pulse is reflected by some component of the volume being examined, the reflected waves are received by the Rx and the time difference between that pulse's emission and reception is measured. This is known as two-way travel time (TWT). The system records TWT and the amplitude of the signal, which together, the returned signal can be used to provide data on properties of features within volumes that cause the waves to be reflected and the location of these features. A skilled geophysicist can then use this information to determine and explain the nature of these anomalies.

When the electromagnetic waves encounter an interface between materials with different dielectric permittivity and electric conductivity, portions of the waves' energies are transmitted or reflected depending on the electromagnetic properties of the materials on each side of the boundary.

Electromagnetic radiation travels at different speeds through different media and is slowed down by an amount called the *dielectric constant* K

$$c' = \frac{c}{\sqrt{K}},$$

Where c is the speed of light in a vacuum, The dielectric constant of a material depends on its chemical and physical composition. The more significant the difference in the dielectric constants between materials is, the greater the strength of the reflected signal at the interface between them. The receiving antenna detects these reflected waves and records them as a single trace (A-scan). This process is repeated continuously as the antenna is moved along a survey line to build up a composite profile (B-scan) along this line. A radargram image displays TWT vs. distance along the survey line, with amplitude displayed either as a wiggle trace or colour scale.

Measurement of dielectric properties is essential to resolve the depth of targets or layers accurately. In order to convert two-way travel time to a respective depth, the velocity of the pulse must be set. This wave velocity is determined by the dielectric permittivity of the material and is most calculated from hyperbola fitting. Migration collapses the reflected waveforms (hyperbolae) into dots representing the actual targets and helps build a pseudo image for interpretation purposes. This can be helpful for successful target identification.

The received pulse is affected by antenna transfer functions, mutual coupling between the antennae, and scattering from the target and nearby objects. In order to obtain the target information, other effects have to be eliminated from the received pulse, Sr(t). By measuring the mutual coupling and removing it from the received pulse, we can decouple the information about the target (Oloumi et al., 2015).

$$Sc(t)=SR(t)-Sco(t)$$

Where Sc(t), Sr(t), and Sco(t) are calibrated pulse, received pulse and the mutual antenna coupling, respectively (Oloumi et al., 2015).

Mutual antenna coupling is measured by transmitting and receiving the pulse into the air with no object in front of the antennae. For illustration purposes, the pulses are offset along the vertical axis; the received pulse and mutual antenna coupling resemble each other up to 1.4 ns, where the target signal has not appeared yet. The decoupled pulse, called the calibrated pulse, is the reflection from only the concrete pipe (Oloumi et al., 2015).

DATA VALIDATING

The accuracy of actual field measurements is controlled by several factors, including environmental factors, instrument accuracy, and the data collection process. The most significant contributor to uncertainty in the final measurements is the variability in environmental factors. In particular, the electrical properties of the inspected material vary based on several factors (concrete composition, water content, porosity, etc.). This produces a±10% uncertainty on depth measurements that have not been calibrated relative to a known depth. This error is non-random, preventing its reduction using statistical techniques. However, errors can be reduced by taking samples of the pipe material and measuring their electrical properties. Antenna manufacturers will frequently cite this number when asked for accuracy, as this tends to be the primary driver of uncertainty for radar measurement.

The other factor that influences data quality is the survey design. In particular, the importance of having good contact between the antennae and the pipe wall cannot be overstated. When antennae are off the wall, the data from that section is generally non-interpretable.

The recorded raw data were processed in order to enhance anomalies. Frequency filtering was used to remove noise. More information is extracted as the weak and closely spaced events are enhanced by processing the data. SewerVUE's proprietary RadART software package applied different correction, gain and filter functions.

METHODS TO SURVEY

There are presently two practical methods for Pipe penetrating radar surveying: remotely operated vehicles (ROVs) or manned entry. remotely operated vehicle-mounted antennae to reach deployment is preferable where possible, as it does not require the safety considerations that manned entry does, and it tends to lead to more precise results. Manned entry is done only in cases where the pipe is too large for the remotely operated vehicle or where access points do not allow for the remotely operated vehicle inserted.

Currently, two different remotely operated vehicles are used for PPR inspections: the 4th Generation SewerVUE Surveyor and the Asbestos Cement Pipe Scanner (ACPS). The Surveyor is used for pipes with diameters between 20.6 inches and 59 inches. It is equipped with 3-D LiDAR imaging devices. LiDAR scanners to gather point cloud data. Accurate pipe profiles are generated that can detail crack depth, width, and length to industry precision. Combined with sonar profiles below the flow, SewerVUE will generate a 360-degree profile of the inside of the pipe. This profile is used to determine the inner diameter of the pipe and help assess wall loss and measure ovality.

In addition to two PPR units. The Surveyor was the first commercially available multi-sensor ROV to use both visual and quantitative technologies for pipeline condition assessment. The ACPS is a prototype design for small-diameter asbestos cement or other non-ferrous pipes. It is designed to inspect pipes with diameters as small as 7.8 inches

PROJECT OVERVIEW

This project looked at a sizeable reinforced-concrete pipe feeding into the city's primary water reclamation facility. The pipe portions that were inspected totalled 1,110 linear feet (LF). Of that length, 260 LF measured 78 inches in nominal diameter, with the remaining 850 LF measuring 72 inches. Because of the size of the pipe, it was determined that remotely operated vehicle-mounted scans would be infeasible, but a PPR technician could safely enter the pipe and scan it directly with a hand-held Pipe penetrating radar scanner. Line data for each clock position could only be collected one at a time. The clock positions chosen for this survey were 2 o'clock and 12 o'clock. Example of what the data looks like all together seen in Figure 2.

The purpose of this inspection was to ascertain the current thickness of the concrete pipe walls and the remaining rebar coverage, making Pipe penetrating radar the technology of choice. The wide diameter of the pipe made remotely operated vehicle-mounted scans infeasible but meant that a Pipe penetrating radar technician could safely enter the pipe and scan it directly with a hand-held Pipe penetrating radar scanner; as seen in Figure 1.

With the pipe briefly shut down, the survey was completed quickly and safely within a 12-hour window.

Analysis of the Pipe penetrating radar data revealed pipe that the pipe was in a primarily serviceable condition. There was no concerning variation in wall thickness; the wall thickness measured an average of 8.67 inches through the 78-inch section and an average of 7.48 inches through the 72-inch section. Pipe penetrating radar scans did not detect any notable voids developing outside the pipe walls.

Figure 1. SV Technician during inspection

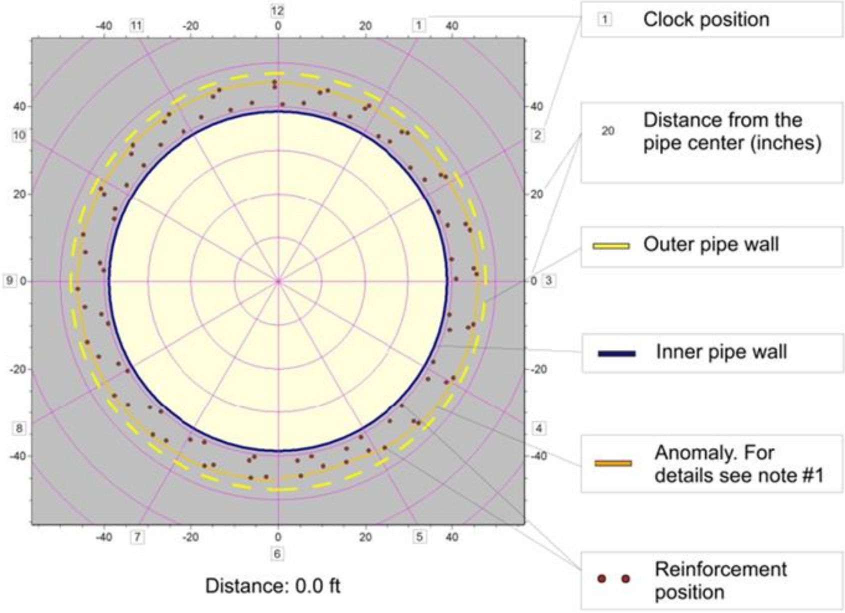

Figure 2. Example of PPR Cross-Section data.

CONCLUSION

In the 72-inch section, SewerVUE Technology Corp. identified two locations where the pipe wall was delaminating. Additionally, the survey detected an anomalous signal at one location: radar detected a notable change in the pipe's properties that did not correspond to known profiles of delamination or rebar coverage. SewerVUE Technology Corp. recommended the pipe's owner take a core sample at the anomaly's location to discover the cause.

Overall, the Pipe penetrating radar survey showed a pipe in generally good condition aside from a small number of localized defects. The owner can prioritize the pipe's maintenance budget accordingly with this information. When used as part of an ongoing condition assessment program, Pipe penetrating radar surveying can provide quantitative benchmarks that accurately track the pipe's deterioration over time.

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