Pipe Penetrating Radar: Developing Predictive Models for Effective Asset Management

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Subject

Advanced pipeline condition assessment

Abstract

Pipe penetrating radar (PPR) is the in-pipe application of GPR, a non-destructive testing method that can detect defects and cavities within and outside non-ferrous pipes. The advantage of PPR is the ability to map pipe wall thickness and deterioration, including voids outside the pipe, enabling accurate predictability of needed rehabilitation.

This paper presents recent advancement of PPR technology through selected case studies. The first includes the deployment of a recently developed robotic PPR crawler for small-diameter pipes in Canada. The Asbestos Cement Pipe Scanner (ACPS) was deployed in a 10” sewer main in Surrey, British Columbia. Analysis of the data revealed localized wall thinning that provided engineers with critical information to proceed with their rehabilitation plan.

The second case study took place in Melbourne, Australia and involved the deployment of the Surveyor ROV. A variety of large diameter pipes ranging from 24”, to 37.4” were surveyed, the total inspected length was over 11,500 ft.

PPR allows utility owners to accurately estimate the remaining lifetime of pipelines, and refine the timing of repairs.

Introduction

Pipe penetrating radar (PPR) is the high-frequency application of ground penetrating radar technology that is deployed from inside a pipe. PPR is an advanced pipeline condition assessment method for non-ferrous water and wastewater pipelines. Compared to qualitative inspection methods such as CCTV, PPR provides comprehensive, quantitative data. PPR measures wall corrosion and degradation, as well as rebar cover in reinforced concrete pipes. PPR can also detect voids developing outside the pipe.

This paper outlines the benefits of PPR as a condition assessment method and asset management tool. Two recent projects will be used to illustrate these benefits. The first project involves the deployment of PPR sensors on the newly-designed ACPS, surveying a length of 10” sewer main in Surrey, British Columbia, Canada. The second project was a PPR survey of a number of large diameter pipelines with sizes between 24” and 37.4” in Melbourne, Australia.

Overview of Pipe Penetrating Radar

PPR is the use of high-frequency ground penetrating radar from the inside of a pipe (Figure 1). GPR systems transmit EM waves at different frequencies based on the desired outcome. Lower frequencies will achieve deeper subsurface penetration, while higher frequencies will not penetrate as far, but can create a higher resolution image. (Daniels, 2004) High resolution GPR antennas (2.6 GHz – 500 MHz) typically achieve 23” – 118” penetration.

Figure 1 – The Surveyor robot conducting a PPR survey of a concrete pipe.

PPR uses this technology to gather detailed data on the present condition of water and wastewater pipelines. By collecting GPR data from inside the pipe, PPR can provide information on remaining pipe wall thickness, rebar cover, or the presence and locations of voids developing on the outside of the pipe (Ékes, et al., 2011). PPR is presently deployed on either of two platforms: the Surveyor robot, or the ACPS. Where it is safe and feasible to do so, manned entry is an additional option. In the case of the Surveyor, two lines of PPR data are collected in one run, from any two clock positions between 9 o’clock and 3 o’clock. The Surveyor’s current PPR antennae transmit at 1.6 GHz or 2.3 GHz. This setup results in signal penetration of up to 36”, with accuracy to 0.3”. The robot also collects CCTV and LiDAR data to correlate with the PPR scans. The ACPS carries one or more PPR antennae, and is used to inspect smaller diameter pipelines (8 – 18”).

PPR data interpretation is a critical step if meaningful information is to be drawn from the survey. Proprietary software is used to apply different correction, filter, and gain functions to the PPR data. This processing enhances anomalies and allows for clearer interpretation of the results. Proper interpretation of PPR data is enhanced by the construction of a good three-dimensional display. Anomalies or points of interest are far easier to locate on a three-dimensional data set compared to a two-dimensional set. The final PPR data interpretation is superimposed over actual depth profiles versus distance.

To collect data for pipeline condition assessment, PPR sensors must be carried along the length of the pipe section that is to be surveyed, with the sensors remaining coupled to the walls for the duration of the survey. In very large-diameter pipes it is possible to collect PPR data via a man-entry operation. In smaller pipes, or in pipes where man-entry methods would be too unsafe, PPR sensors are mounted to one of two remotely operated vehicles: The ACPS, or the Surveyor.

The ACPS is a remote operated vehicle used in AC pipes with diameters as small as 8 inches (Figure 2). The ACPS also features a CCTV camera, for visual correlation with the PPR results. The Surveyor is a tracked ROV. It is the first commercially available multi-sensor inspection robot to use both visual and quantitative technologies in underground pipeline condition assessment. It can be adjusted to scan pipes with diameters between 21” and 60”. In addition to carrying two PPR sensors, the Surveyor also carries LiDAR and a CCTV camera that collects visuals for correlation with the sensor data.

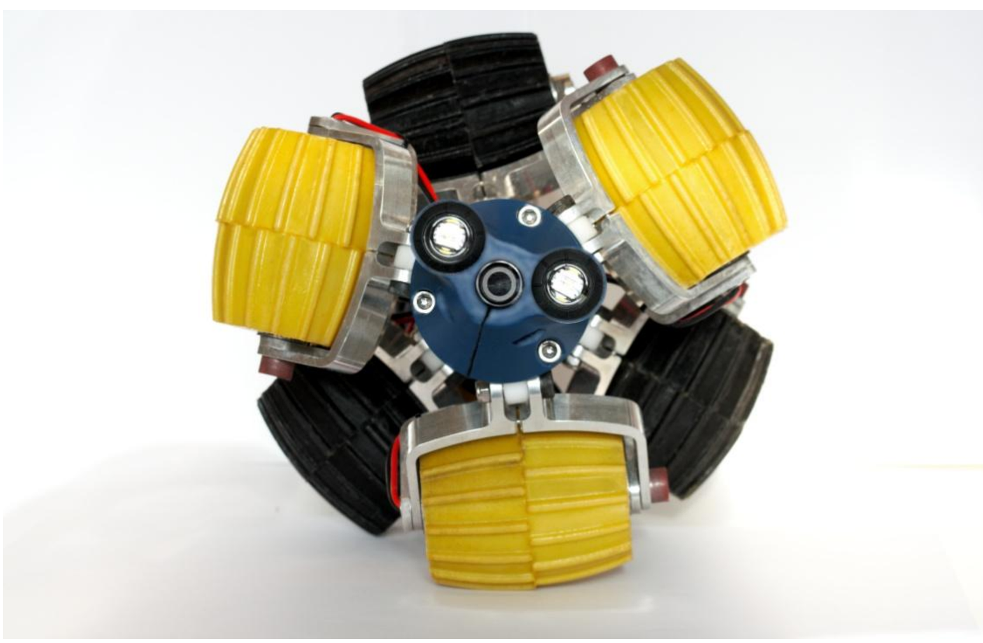

Figure 2 – The Asbestos Cement Pipe Scanner.

Asbestos Cement Pipe Scanner – Surrey, British Columbia

Much of North America’s water and wastewater infrastructure exists in the form of asbestos cement (AC) pipes. Between 1940 and 1970, over 600,000 miles of AC pipe was laid in North American municipalities. Data has shown that AC pipe has a lifetime of 60-70 years on average. As a result, tens of thousands of miles of AC pipe in North America is nearing the end of their expected life (Hu, et al., 2013).

With such a large volume of AC pipe nearing the end of their useful life, predictive asset management becomes essential for municipalities. Waiting for catastrophic failure is neither desirable nor economical. Such failures can cause service disruption, environmental damage, and can be extremely costly to fix. However, replacing pipes too early is an inefficient use of resources.

AC pipes are vulnerable to deterioration by acidic, sulphate, and microbiological attack. They can also suffer deterioration due to corrosive groundwater. In the case of groundwater corrosion, traditional inspection methods such as CCTV cannot detect the presence of corrosion. To address this, more comprehensive measurements are required. The ACPS was developed with this challenge in mind.

The Harbourgreene line in Surrey, BC, Canada is an AC pipe that was installed in 1972. Currently there are no known corrosion issues; the initial inspection will serve as a baseline. The pipe is inspected regularly using traditional CCTV. The City has partnered with SewerVUE Technology to conduct a high-frequency PPR survey to inspect sections of the Harbourgreene Line in order to obtain structural condition information (Figure 3). This project's PPR survey was completed using high-frequency antennae while the pipe remained in service. 2D line data were collected on the invert of the pipe. The high antenna frequency provided good quality data and signal penetration to allow analysis to a depth of 12" from the inside pipe wall surface. In Phase 1 of the project, 196.9 ft. of PPR data were collected from the Harbourgreene line with supplementary CCTV.

Figure 3 – The ACPS on-site in Surrey, BC.

Wall thickness was interpreted to be in the 1.77” range with little variation over the inspected length (Figure 4). Interpreted results at the end of Phase 1 concluded no significant structural issues on the inspected sections of the pipe.

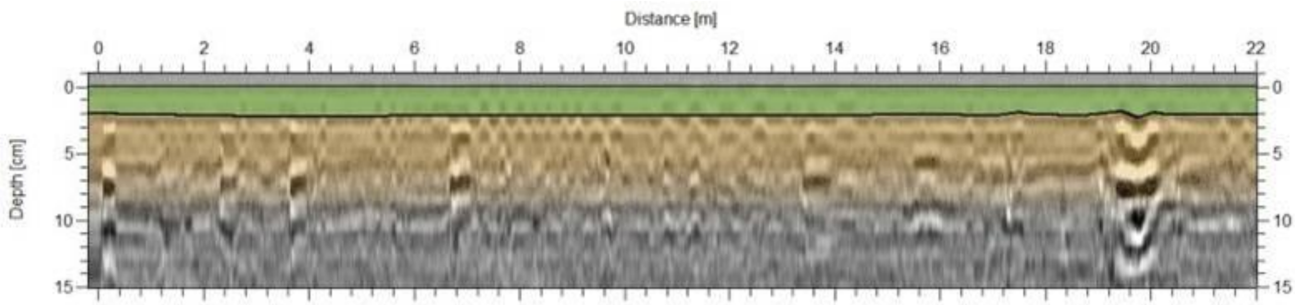

Figure 4 – PPR data from the Harbourgreene Line. Wall thickness is represented by the green-shaded area.

SewerVUE 4th Generation Surveyor – Melbourne, Australia

PPR can be used to gather quantitative data from any pipe made of non-ferrous material (concrete, RCP, AC, RP, PVC, HDPE, brick, etc.). In this case study, PPR was used to inspect a number of pipelines in Melbourne, Australia. Four lines were surveyed, with CCTV, LiDAR, and PPR data being collected. The Surveyor robot was deployed for this project (Figure 5). The utility owner had very little knowledge about the construction or current condition of these pipes.

Figure 5 – The Surveyor on-site in Melbourne, Australia.

A 4,255.3 ft. section of the Mordialloc Main Sewer was inspected first. This section was reinforced concrete pipe, with a diameter of 30”. Access was from a single deployment point near the middle of the surveyed section. CCTV footage showed widespread surface damage that was consistent with chemical attack on the inner surfaces of the pipe wall. A small hole was located 109.6 ft downstream from the access point. Some circumferential fracturing was also seen 136.2 ft downstream. LiDAR results showed a small but consistent degree of deformation along the crown of the pipe. PPR data revealed average rebar cover in the line to be between 1.38” and 2.36” (Figure 6).

Figure 6 – PPR data from Mordialloc Main showing wall thickness (green line) and rebar cover (blue line).

A section of the Hobsons Bay Main 24” line was surveyed next. From one access point, 1,876.6 ft was inspected in the upstream direction. The survey began 45.3 ft from the access point, where the RCP section of the pipe started. This pipe also showed damage that appeared to be the result of chemical attack. PPR data showed the areas with thinner rebar cover, however rebar cover always exceeded 0.59”.

The Caulfield Intercepting Sewer is a 37.5” RCP line. The survey inspected a 3920.6 ft section, using a single access point near the centre of the section. Generally, the survey showed the line to be in good condition. The most significant discovery from the inspection was a section where the pipe increased in diameter to 43.3”, which was unknown to the utility owner. PPR data revealed an area 262.5 ft downstream of the deployment site where the rebar was quite close to the pipe wall.

The Maribyrnong Main Sewer was the final inspected line. This line was built from RCP, and had a diameter of 29.9”. Two different sections of the line were inspected, in each case using an access point near the middle of the section. The inner pipe walls were covered in attached deposits, and the invert of the pipe had frequent patches of gravel and other sediment. CCTV footage from the survey showed significant surface damage, with sections of visible reinforcement. Much of the pipe wall was not visible due to the attached deposits. The PPR data from this section showed little rebar cover along the whole length of the survey.

Summary and Conclusion

Examples from the two projects outlined in this paper demonstrate the benefits of PPR in condition assessment projects. The nature of PPR data allows for the creation of accurate predictive models about the remaining useful life of pipes. This is especially true when PPR is supplemented with data from other condition assessment techniques, such as CCTV or LiDAR.

Data gathered from the ACPS survey in Surrey, BC, demonstrates that PPR is very useful in the assessment of small-diameter AC pipes. PPR has already been shown to be effective at surveying larger AC pipes, but this survey demonstrated that the technology could be adapted for smaller pipes, which represent a significant portion of the decaying AC pipe infrastructure in North America.

Information collected from the four sewer lines in Melbourne is a prime example of PPR as an effective asset management tool. In these cases, the utility owner had very little information about the current condition of the lines. Following the PPR survey, they could make informed decisions about which of the lines needed immediate attention, and which lines could afford to have maintenance deferred to a later date.

PPR is an invaluable tool for assessing the current condition of non-ferrous pipelines. Supplemented with data from other survey methods such as LiDAR and CCTV, PPR can be used to generate comprehensive data about the current conditions of pipe. This information forms a strong basis for creation of accurate predictive models that allow utility owners to make efficient asset management plans. The cost of a PPR survey pales in comparison to the costs that could be incurred if a line suffers catastrophic failure, or if a serviceable line is replaced too soon. Funding is often limited, so cost-effective asset management methods are essential for municipalities and other owners of underground pipeline infrastructure.

References

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