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Application of High Frequency Pipe Penetrating Radar in Asbestos Cement Pipes

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1. ABSTRACT

Pipe Penetrating Radar (PPR) is the underground in-pipe application of GPR, a non-destructive testing method that can detect defects and cavities within non-ferrous (reinforced concrete, vitrified clay, PVC, HDPE, etc.) pipes. The key advantage of PPR is the unique ability to map pipe wall thickness and deterioration including voids outside the pipe, enabling accurate predictability of needed rehabilitation or the timing of replacement. This paper presents recent advancement of PPR inspection technology together with selected case studies.

The century old Broadway sewer main in Everett, WA is a combination of a 30" RCP pipe and a 36" brick lined pipe. Little information is known about the condition of these pipes and the owners needed structural information beyond the usual CCTV in order to plan long term management of these critical assets. Over 16,000 ft of high resolution PPR line data were collected via robotic inspection. Due to the highly complex nature of the geophysical data, data processing and interpretation was a critical component of this project. The PPR results revealed that there are variations in the rebar cover in segments of the RCP pipe. Although the average minimum rebar cover (depth of the first layer of rebar measured from the inner surface of the pipe wall) in almost every pipe segment appears to be sufficient (more than 0.75"), local anomalies occur along the pipe. No voids were detected outside the concrete pipe.

PPR technology is currently proven and has been deployed in large diameter (>21 inch) gravity sanitary sewer and water pipes. While several miles of large diameter sewer pipes have been surveyed to date. A prototype antenna resolution was limited to pipe walls thicker than 3". A new, high resolution AC Pipe Scanner (ACPS) was built and tested successfully in a live 10" AC pipe in March 2016. Using new, high frequency antennae, the PPR survey was able to accurately resolve the relatively thin 38 mm wall.

With limited available funding and budget constraints becoming more prevalent, timing of rehabilitation and overall intelligent asset management is more critical than ever. PPR provides engineers and utility owners the information to accurately estimate the remaining life left in a pipeline, refine timing of repairs, and ultimately better allocate funding for asset management.

2. INTRODUCTION

Pipe penetrating radar (PPR), the in-pipe application of ground penetrating radar (GPR) is one of the most promising quantitative pipe condition assessment technologies to emerge in recent years. With most of the underground pipe infrastructure reaching the end of their design life there is a need to provide measurable data in order to establish the extent of rehabilitation required or the timing of replacement for large diameter critical pipe lines.

Although Closed Circuit Television (CCTV) inspection methods are effective and widely available tools for identifying visible defects on the internal wall of pipes, CCTV cannot see behind the pipe's inner surface, nor can it quantitatively determine the extent of corrosion. PPR technology allows the implementation of proactive preventative maintenance procedures for non-ferrous wastewater and water underground infrastructure. The combined application of PPR, CCTV and LiDAR provides the most complete and state of the art inspection technology to enable proactive asset management and allow utility owners to plan and schedule the inspection and rehabilitation of critical utilities prior to the occurrence of emergency scenarios.

This paper highlights the benefits of using PPR. Examples to illustrate the key benefits are drawn from two projects: one conducted with the fourth generation SewerVUE Surveyor robot, the second with the high resolution AC Pipe Scanner (ACPS).

3. OVERVIEW OF PPR IMAGING TECHNIQUE

Ground penetrating radar is the general term applied to techniques that employ radio waves to profile structures and features in the subsurface. Pipe penetrating radar (PPR) is the in-pipe application of GPR.

Signal penetration depth is dependent on the dielectric properties of the pipe and the host material, and on the antenna frequency. Detectability of targets in the ground depends on their size, shape and orientation relative to the antennas, contrast with the host medium as well as external radio frequency noise and interferences. The penetration depth of high frequency antennas (1.0 GHz to 3.0 GHz) which are the most suitable for pipe investigations is on the order of 1 ft to 5 ft beyond the pipe wall, depending on the material of the pipe inspected. PPR can be used to detect pipe wall fractures, changes in material, reinforcement location and placement, and pipe wall thickness. Since the primary factor determining signal penetration is the conductivity of the soil, it is important to point out that PPR works where traditional “above ground” GPR does not.

The recorded raw data is processed in order to enhance anomalies at deeper levels. Frequency filtering is used to remove noise. SewerVUE’s proprietary RadART software package was used for applying different correction, gain and filter functions. The interpretation is then superimposed on the processed PPR profiles (Figure 1).

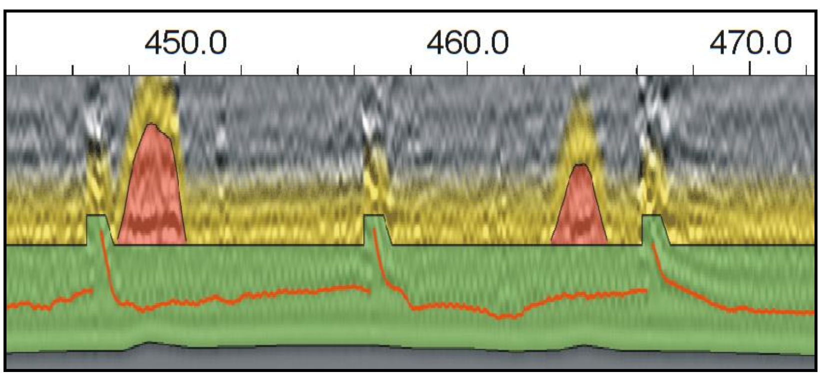

Figure 1. Robotic PPR data is displayed with the interpretation overlaid.

4. SURVEY EQUIPMENT

The SewerVUE Surveyor is the first commercially available multi sensor inspection (MSI) robot that uses visual and quantitative technologies (CCTV, LIDAR, and PPR) to inspect underground pipes (Figure 2). This fourth generation PPR pipe inspection system is mounted on a rubber tracked robot and equipped with two high-frequency PPR antennae. The system used in Everett, WA can be adjusted for 21 to 60-inch diameter pipes, the PPR antennae can be rotated between the nine and three o’clock positions. Radar data collection is obtained via two independent channels in both in and out directions, providing a continuous reading on pipe wall thickness and locating voids outside the pipe. CCTV data is recorded simultaneously and is used for correlation with PPR data collection.

Figure 2. The fourth generation SewerVUE Surveyor multi sensor inspection robot equipped with HD pan tilt zoom CCTV, PPR and LIDAR.

The sensors mounted on the robot take quantitative measurements of inside pipe walls. LIDAR technology employs a scanning laser to collect inside pipe geometric data which is then used to determine pipe wall variances from a manufactured pipe specification. LIDAR data is correlated with an onboard inertial navigation system (INS) that can accurately map the x, y, and z coordinates of the pipe without the need for external references.

5. CASE STUDY #1: PPR Inspection of a 36 inch diameter brick lined sewer in Everett, WA

The first case study took place in a 100 year old 36 inch diameter brick lined sewer in Everett, WA. The pipe is a combined sewer that, during carries sewage and runoff under the city's main thoroughfare (Figure 3).

Figure 3. Deployment of the SewerVUE Surveyor robot at the Broadway Sewer main, Everett, WA.

All pipe materials and structural members deteriorate with age and exposure to corrosive agents such as H2S. However, in most cases, damages cannot be detected by visual inspection. Hence, the application of non-destructive testing methodologies are increasing in condition assessment and further repair and rehabilitation, their information being crucial in the structural evaluation. Understanding the interior of the structures is the first stage to evaluate their state and to design potential repairs.

Bricks were commonly used liners for large diameter sewers in the late nineteenths and early twentieth century. However, it is difficult to obtain accurate information about their inner structure. Non-destructive testing (NDT) methodologies such as PPR provide a unique insight into the hidden structure of these pipes.

PPR data interpretation

The overlapping arrangement of bricks created complex signal reflection and refraction patterns, thus data processing and interpretation proved particularly challenging. The main difficulty of PPR surveys lies in the interpretation of complex structures such as brick lined pipes. Irregular brick arrangement, the existence of different materials and objects generated numerous anomalies.

The interpretation was based on the careful analysis of certain reflections that show the expected brick liner/fill interface in all of the depth slices in all directions. A given reflection was compared to the surrounding signal strength. PPR inspection results are summarized on distance (feet) vs. pipe wall thickness graphs in (Figure 4).

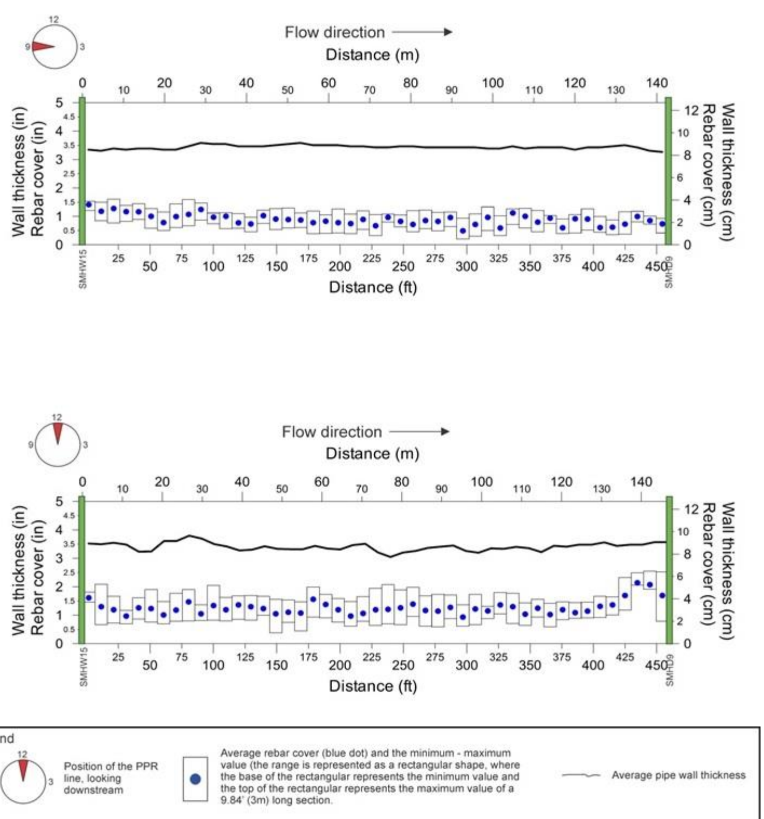

Figure 4A. PPR results from the 30” RCP Broadway Sewer Main.

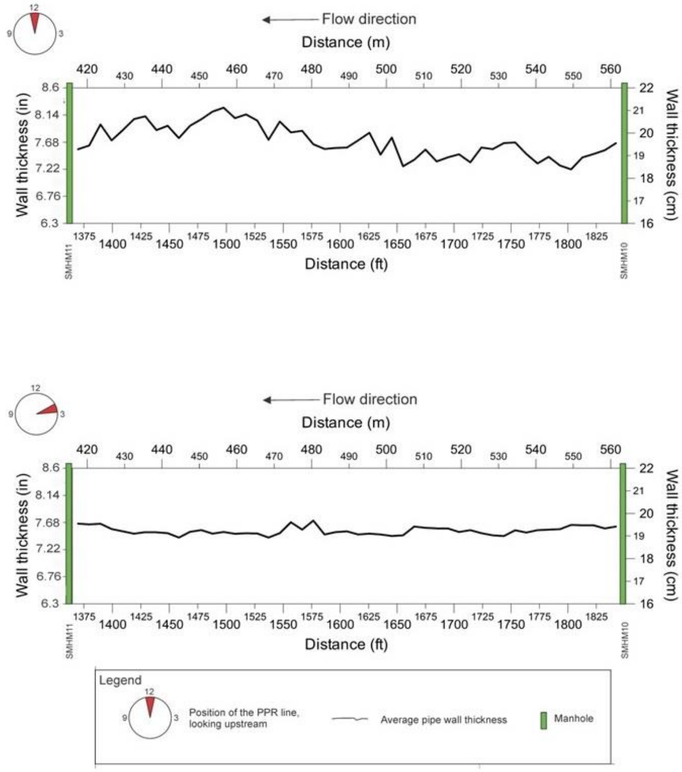

Figure 4B. PPR results from the 36” brick lined Broadway Sewer Main.

Results

A total of 4223.8 feet of pipe was inspected with the SewerVUE Surveyor multi-sensor robot. The pipe penetrating radar (PPR) data were of good quality. Signal penetration allowed analysis to a depth of 10 and 12 inches respectively in the reinforced concrete and brick lined pipe measured from the inside pipe wall.

PPR inspection results are summarized on distance (feet) vs. pipe wall thickness and rebar cover (inches) graphs (PPR Results). These summary graphs are based on data extracted from the processed and interpreted individual PPR depth sections. Pipe wall thickness is represented by a continuous black line. Change in rebar cover is represented by bar graphs showing rebar cover variations (min-max) for every 10 ft interval. Blue dots mark average rebar cover for the same 10 ft interval (PPR Results).

Pipe wall thickness is in the 3 to 4 inch range in the concrete pipe with no significant corrosion. The PPR results revealed that there are variations in the rebar cover in segments of the RCP pipe. Although the average minimum rebar cover (depth of the first layer of rebar measured from the inner surface of the pipe wall) in almost every pipe segment appears to be sufficient (more than 0.75"), local anomalies occur along the pipe. No voids were detected outside the concrete pipe.

“Wall thickness” in the brick lined pipe is in the 7.125 and 8.25 inch range. Although “wall thickness” appears to be more varied at the 11 and 12 o’clock positions this is a construction artifact and not a sign of corrosion. A 6” deep and 9” wide void type anomaly was detected at 997 feet at 12 o’clock. The actual diameter of the brick pipe appears to be 34.5" based on the LiDAR results.

The CCTV inspection showed that the reinforced concrete pipe has suffered some surface damage, with the aggregate in the concrete visible in the most eroded segments. This pipe also has a number of gravel deposits. The video from the brick pipe also shows a number of attached encrustations on the walls of the pipe. Both surveyed sections display small (<10%) obstacles and other localized defects (the occasional root, intruding tap etc.).

In summary, both the inspected reinforced concrete pipe and the brick pipe appear to be in good overall condition. Monitoring the condition of the brick pipe, however, is highly recommended due to its age and the variation in its wall thickness.

6. CASE STUDY #2: Harbourgreene Trunk Line, Surrey, BC, Canada

The City of Surrey (City), BC, Canada owns and manages a network of sanitary sewers. It is of interest to the City to measure the rate of deterioration and the structural condition of its sewers, especially the small diameter (<300mm) Asbestos Cement (AC) lines. It is of particular interest to know the remaining service life of these critical assets. A catastrophic failure would cause service disruption, serious environmental damage such as sanitary sewer overflows (SSO) and would be very costly to repair. A too early rehabilitation or replacement on the other hand, would be a wasteful use of limited resources.

Asbestos Cement pipes are prone to deterioration due to corrosive ground water, that aggressively attacks and corrodes these assets and over time gradually eats away the pipe, the damage being most severe at the invert. Since the attack occurs from the outside standard inspection methods such as CCTV are unable to detect the amount and rate of corrosion. The age of the pipe (a common proxy used for timing of rehabilitation) is also of limited use, an old pipe can still be in an excellent structural condition, while a new one can experience failure due to excess corrosion or material or installation defects. (One of our recent projects involved the inspection of 20,000 ft of sewer pipe that was only seven years old and already experienced structural failure.)

Harbourgreene line is a short segment of asbestos cement pipe that was installed in 1972. This pipe has no known corrosion issues; it serves as a baseline. The pipe is inspected regularly using traditional CCTV. The City has partnered with SewerVUE to conduct a high-frequency pipe penetrating radar (PPR) survey to inspect sections of the Harbourgreene line in order to obtain structural condition information. The secondary objective of the PPR survey was to field test the new, high resolution antennae.

Figure 5. Deployment of the AC Pipe Scanner at the Harbourgreene drive sewer in Surrey, BC, Canada.

This project's PPR survey was completed using 3.0 GHz frequency antennae while the pipe remained in service. Shallow flows, made for some inspection challenges. 2D line data were collected on the invert of the pipe.

The 3.0 GHz antenna frequency provided good quality data and signal penetration to allow analysis to a depth of 20 to 30 centimeters from the inside pipe wall surface (figure 6).

PPR inspection results are presented in “classic view” form with the interpretation is overlaid on the processed PPR data (Figure 6). The distance shown on each profile is measured from the center of the manhole of deployment. Pipe wall thickness is represented by a continuous black line (Figure 7).

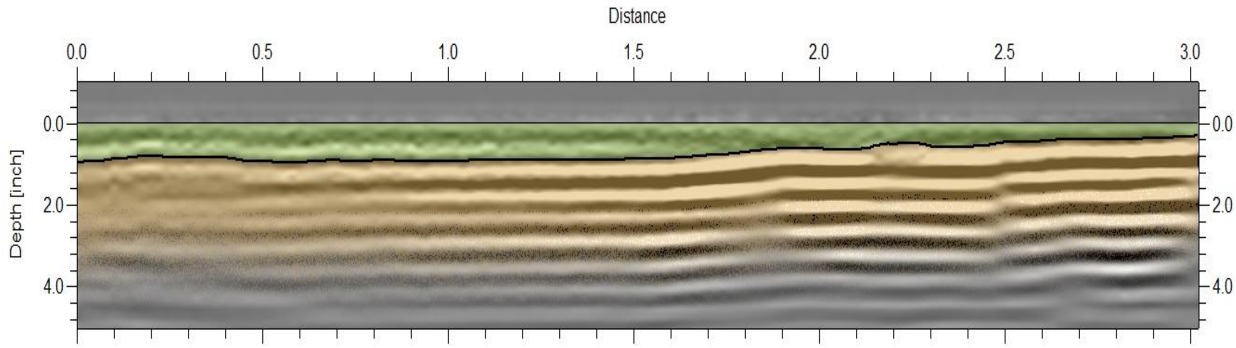

Figure 6. “Classic view” PPR bench test results for a 3 ft section AC. Antenna resolution is sufficient to map wall loss from 1 inch to 0.35 inch.

In Phase 1 of the project 60m of PPR data were collected for the Harbourgreene line with supplementary CCTV using the SewerVUE AC Pipe Scanner. Wall thickness was interpreted to be in the 38 mm range with little variation over the inspected length. There appears to be an anomaly between 19 and 21m and between 37 and 41 m (Figure 7). The anomaly can be caused by possible ground disturbance or variations in the physical properties of the soil behind the pipe wall. Preliminary results at the conclusion of Phase 1 concluded no significant structural issues on the inspected sections of the pipe.

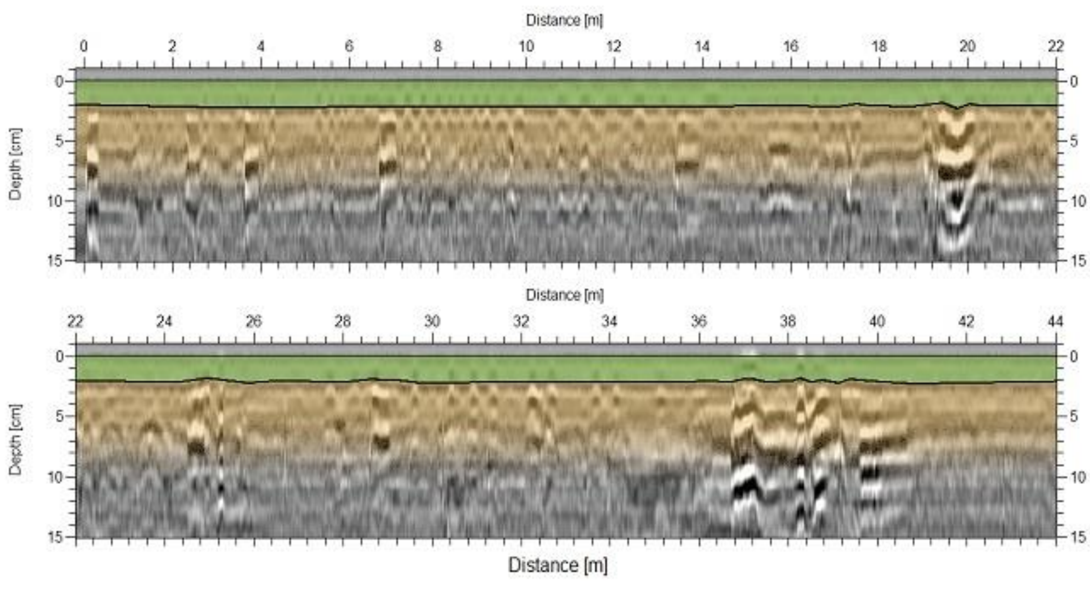

Figure 7. PPR results for the Harbourgreene Drive, Surrey, BC. Pipe wall thickness is represented by a continuous black line.

7. SUMMARY AND CONCLUSIONS

PPR has the unique ability to map pipe wall thickness and deterioration including voids outside the pipe, enabling accurate predictability of needed rehabilitation or the timing of replacement. Examples from two projects were used to illustrate how PPR can map remaining pipe wall thickness, rebar cover and voids outside the pipe.

A total of 4223.8 feet of the Broadway Street Main was inspected with the SewerVUE Surveyor multi-sensor robot in Everett, WA . The PPR data were of good quality allowing analysis to a depth of 10 and 12 inches respectively in the reinforced concrete and brick lined pipe measured from the inside pipe wall. Pipe wall thickness is in the 3 to 4 inch range in the concrete pipe with no significant corrosion. The PPR results revealed that there are variations in the rebar cover in segments of the RCP pipe. Although the average minimum rebar cover (depth of the first layer of rebar measured from the inner surface of the pipe wall) in almost every pipe segment appears to be sufficient (more than 0.75"), local anomalies occur along the pipe. No voids were detected outside the concrete pipe.

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In summary, both the inspected reinforced concrete pipe and the brick pipe appear to be in good overall condition. Monitoring the condition of the brick pipe, however, is highly recommended due to its age and the variation in its wall thickness.

A new, high resolution PPR system, the ACPS was successfully used for the condition assessment of a 10" diameter AC pipe in Surrey, BC, Canada. The high frequency antennae successfully and accurately mapped the pipe wall thickness and provided base line data for further condition assessment.

With limited available funding and budget constraints becoming more prevalent, timing of rehabilitation and overall intelligent asset management is more critical than ever for municipalities and asset owners. Advanced pipe condition assessment technologies, including the SewerVUE PPR system, have demonstrated to be cost-effective, non-destructive methods that are able to help better refine structural condition and estimated remaining life of an interceptor, accurately determine overall severity of pipe degradation, as well as provide a basis for improved cost allocation and timing of rehabilitation efforts.