Applications of Pipe Penetrating Radar for Advanced Pipe Condition Assessments: the Clark Regional Wastewater District (WA) Case Study

Csaba Ékes, PhD, PGeo.[1], Boriszlav Neducza[1], Robin Krause, P.E.[2], and Robert Lee, P.E.[3]

[1]SewerVUE Technology Corp., 4650A Dawson St., Burnaby, BC, Canada V5C 4C3; Tel: 778 862 0707, email: info@sewervue.com

[2]District Engineer, Clark Regional Wastewater District, Vancouver, Washington

[3]Supervising Engineer, Brown and Caldwell, Portland, Oregon

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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 and outside mainline diameter non-metallic (reinforced concrete, vitrified clay, PVC, HDPE, etc.) underground 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. By having this information available, engineers and municipalities can better estimate the remaining life left in a pipeline, refine timing of repairs, and ultimately better allocate funding for asset management.

This paper presents recent advancement of PPR inspection technology together with the robotic, Vancouver, WA case study. Clark Regional Wastewater District, the owner of the Salmon Creek Interceptor and St Johns Trunk lines commissioned a condition assessment on the 21, 24 and 36 inch concrete lines. For the St. Johns Trunk, a 36-inch line, corrosion was suspected and evidence was observed visually by CCTV. Chemical dosing had been implemented to minimize continued corrosion due to vapor-phase H2S, but the District wanted to quantitatively determine the extent of corrosion and if/when future rehabilitation would be needed. PPR confirmed the upstream-most segment had corroding/missing reinforcement and reduced wall thickness.

For the Salmon Creek Interceptor, 21-inch and 24-inch lines, visual CCTV inspections revealed the inner cement layer had deteriorated. In these pipe sizes, the District was unsure if these pipes had reinforcement. PPR was used to determine changes in wall thickness and if reinforcement was present. The PPR results confirmed that the 21-inch concrete sewer was unreinforced and the observed corrosion had structural implications. The 24-inch segment was reinforced and had uniform pipe wall thickness with sufficient rebar cover. Subsequent coring improved the velocity calculations for the 21-inch and 24-inch pipe and confirmed and verified the PPR pipe wall thickness.

With limited available funding and budget constraints becoming more prevalent, timing of rehabilitation and overall intelligent asset management is more critical than ever. Advanced pipe condition assessment technologies, such as PPR show promise as a cost-effective, non-destructive method of condition assessment to help refine the estimated remaining life of a pipe, accurately determine pipe degradation, as well as provide a basis for improved cost allocation and timing of rehabilitation efforts.

Key words: pipe penetrating radar, PPR, condition assessment, non destructive testing, asset management, pipe inspection

1. INTRODUCTION

A high frequency pipe penetrating radar (PPR) survey to inspect sections of the Salmon Creek and St. Johns Trunk lines was carried out on behalf of Clack Regional Wastewater District (CRWD) in September 2013. The St Johns Trunk is 36 inch in diameter, the inspected sections were located between manholes 28-617 and 28-365 (Figure 1A). The total inspected length is 1562 feet. The Salmon Creek Trunk is 21 inch in diameter between MH 6-288 and 28-1 for a total length of 2174 ft and 24 inch between MH 28-1 and 9-508 for a total length of 351 feet (Figure 1B). Both pipes are concrete sewer pipe (CSP).

The objective of the PPR survey was to determine the condition of the RC pipes by mapping their wall thickness, rebar cover and detecting voids and/or other anomalies within or outside the pipe wall. This paper presents the methodology and results of the inspection.

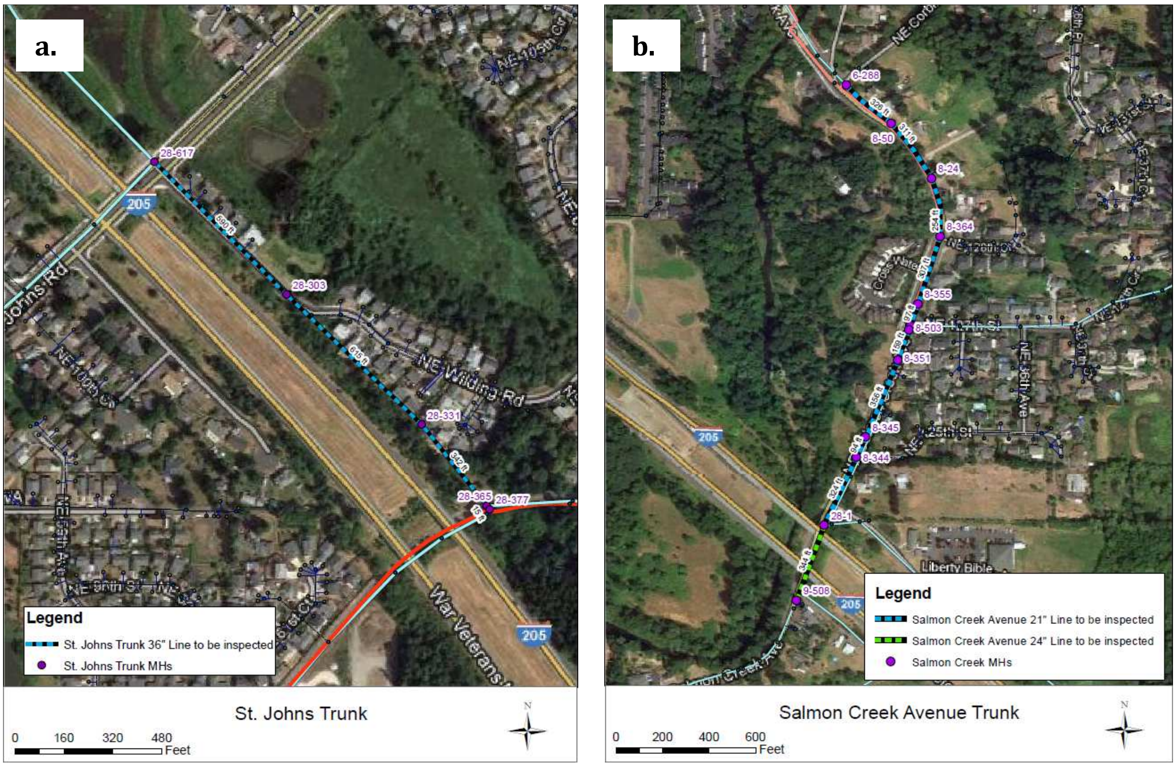

Figure 1: The inspection area at St. Johns Trunk (a.), and at Salmon Creek Avenue Trunk (b.) Vancouver, WA.

2. 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 Vancouver, WA can be adjusted for 21 to 36-inch diameter pipes, the PPR antennae were generally positioned between ten and two 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, rebar cover and locating voids outside the pipe. CCTV data is recorded simultaneously and is used for correlation with PPR data collection.

The robot has the capability to take quantitative measurements of inside pipe walls. LiDAR technology employs a rotating 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. LiDAR and x,y, and z data collection was not part of the scope for this project. The SewerVUE Surveyor is equipped with three cameras (front, antenna and back).

Figure 2: The SewerVUE Surveyor multi sensor inspection robot.

3. METHODOLOGY

3.1. PPR Theory

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 2.6 GHz) which are the most suitable for pipe investigations is on the order of 2 ft to 9 ft beyond the pipe wall. PPR can be used to detect pipe wall fractures, changes in material, reinforcement location and placement, and pipe wall thickness.

Resolution is primarily determined by the wavelength, but is also affected by other factors such as polarisation, dielectric contrast, signal attenuation, background noise, target geometry and target surface texture, all of which influence the reflected wave. 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.

3.2. Pipe Penetrating Radar Survey Layout and Data Processing

This project's PPR survey was completed using 1.6 and 2.3 GHz frequency antennas (Figure 3). 2D line data were collected on the crown of the pipe. The PPR lines were located along the 10:00, 11:00, 1:00, and 2:00 o'clock positions inside the pipe.

	diameter	inspected distance
St Johns Trunk	36"	1562 ft
Salmon Creek Trunk	21"	2174 ft
Salmon Creek Trunk	24"	351 ft

Figure 3: Insertion of the SewerVUE Surveyor robot at manhole 28-303.

Data processing was completed using SewerVUE's proprietary radar processing software: Pipe Penetrating Radar Data Interpretation Application (PP-RADIAN). By processing the data more information is extracted as the weak and closely spaced events are enhanced and better resolved by applying different correction, gain and filter functions.

4. PIPE PENETRATING RADAR RESULTS

The 2.6 GHz PPR data are of excellent quality. Signal penetration allowed analysis to a depth of 12 to 14 inches from the inside pipe wall surface. The objective of PPR data display is to present the processed data that closely approximates an image of the pipe and its bedding material with anomalies that are associated with the objects of interest in their proper spatial positions. The most commonly used data displays are the two dimensional cross sections or the two dimensional depth slice (Figure 4).

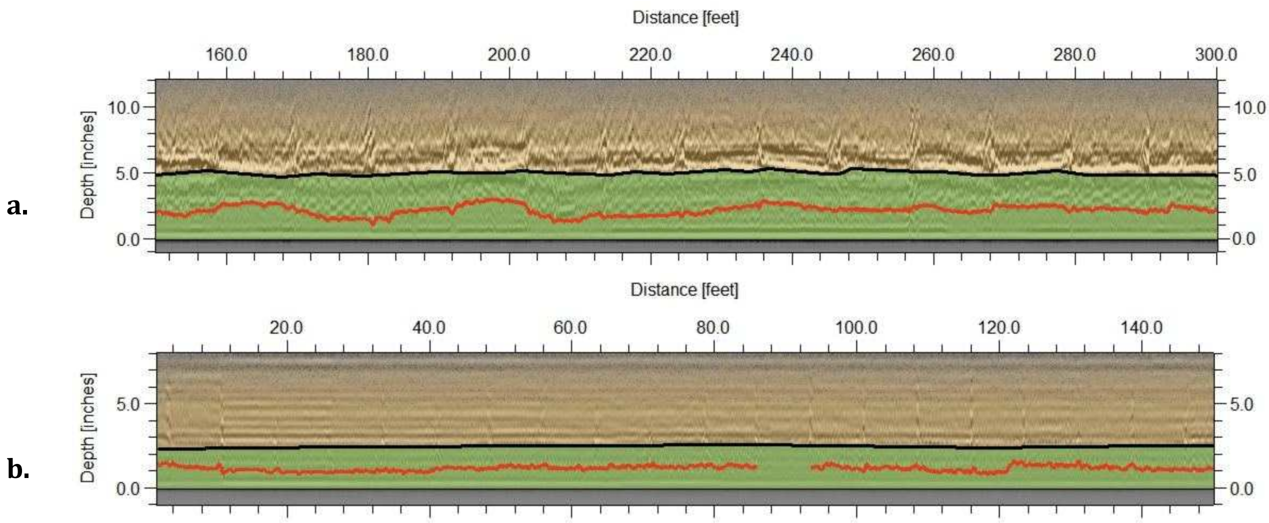

Figure 4: PPR inspection results showing wall thickness and rebar depth superimposed on the processed radar sections. Pipe wall thickness is marked by continuous black line, rebar shown as red lines (a. St Johns Trunk; b. Salmon Creek Avenue Trunk).

A more user friendly data presentation that is readily understood and is faster to review by lay audience was developed for this project. The PPR inspection results are summarized on distance (feet) vs. pipe wall thickness and rebar cover (inches) graphs (Figure 5 and 6). 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 3 ft interval. Red dots mark average rebar cover for the same 3 ft interval.

St Johns Trunk

From the CCTV results, approximately the entire 1,549 LF of 36-inch RCP showed concrete surface spalling and buildup above the water level. The CCTV results showed two locations with visible infiltration at joints located in the downstream end of the trunkline.

The graphed results show the summary results from the 10, 11, 1 and 2 o'clock positions. Most of the results were derived from the higher antenna frequency (2.6 GHz) but some locations contain readings from both antennas and from four depth profiles. PPR results for St Johns Trunk are summarized in Figure 5.

The PPR data show variations in pipe wall thickness, as well as location, depth and spacing of rebar. The results show that pipe wall thickness is around 5 and 5.25 inches, between 0 and 1085 ft. It is between 5 and 4.5 inches between and 1085 and 1460 ft, and between 4.5 and 3.75 inches between 1460 ft and 1545 ft at the upstream manhole MH 28-377 where corrosion appears most severe.

Rebar cover varies between 1 and 4 inch. Rebar signal is weak between 1475 and 1505 feet and very weak or appears to be absent between 1505 and 1545 feet. A minor void was detected at 27.5 ft at 10 o'clock position. This voids is approximately 4 feet long and 4 inches high.

Overall, the majority of the 36-inch trunkline is structurally in fair to poor condition. Inspection of the upstream-most pipe segment revealed evidence of severe corrosion. The PPR data indicated less concrete rebar cover at the upstream section of the trunkline and a loss of wall thickness as the robot moved upstream. Assuming the initial pipe design considered the railroad loading and appropriate dead loads, the loss of wall thickness and suspected corrosion in the reinforcement indicates that the existing pipe may be compromised structurally. PPR results for St Johns Trunk are summarized in Figure 5.

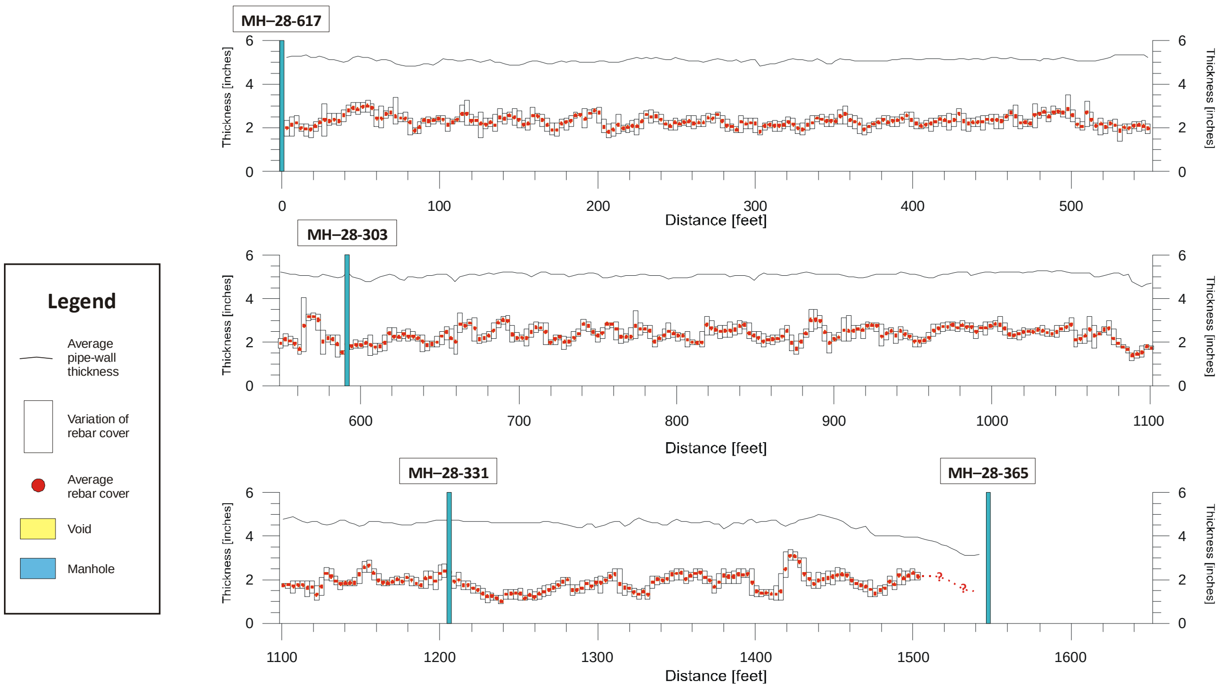

Figure 5: Summarized PPR results for St Johns Trunk.

Salmon Creek Avenue Trunk

Approximately the entire 2,400 LF showed concrete surface spalling and buildup above the water level. The CCTV and PPR results showed evidence of infiltration at four locations.

The PPR results are summarized in Figure 6. The PPR results are displayed as the summary results from the 2.6 GHz antennas at 11 and 1 o'clock positions. Pipe wall thickness is 3.25 inch with little variations. What is striking is the apparent lack of rebar. With the exception of 0 to 225 feet between MH 6-288 and MH 6-850 with the exception of 255 ft to 270 ft and 685 ft to 707 ft there appears to be no rebar reflection on the PPR profiles. Signal quality is otherwise very good. This leads us to the conclusion that there is no rebar in the majority of the pipe. Where rebar is present it appears to be uniform with adequate cover and little variation in depth. PPR scanning did not detect any voids in the fill material around the pipe.

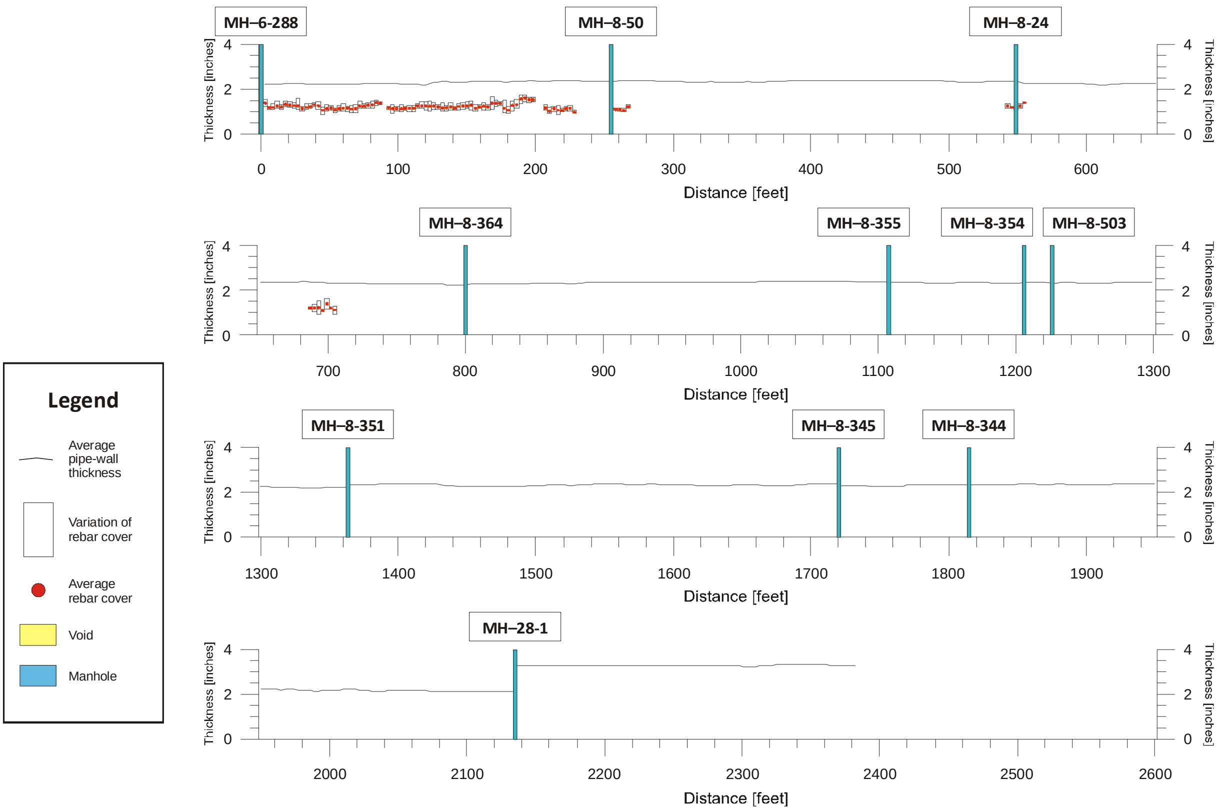

Figure 6: Summarized PPR results for Salmon Creek Avenue Trunk.

Structurally, the majority of the 21-inch-diameter portion of the pipe revealed evidence of concrete corrosion. The interior cement layer had either corroded or eroded, resulting in projecting aggregate.
On the recommendation of Brown and Caldwell the initial PPR results were recalibrated with data from a follow-up man-entry pipe wall thickness measurement.

The 24-inch segment that crosses underneath the Interstate 205 overpass revealed a uniform wall, a fairly smooth interior cement layer, and hardness commensurate with normal concrete. PPR also indicated that reinforcement is present in the pipe with adequate concrete cover. Overall, the 21-inch–diameter portion of the pipe is in poor structural condition and the 24-inch-diameter position of the pipe is in fair to good structural condition.

5. SUMMARY

1562 ft and 2525 ft of PPR data were collected for St Johns Trunk and for the Salmon Creek Trunk respectively with the multisensory SewerVUE Surveyor inspection robot.

The Salmon Creek Avenue 21” Trunk is a concrete line between MH 6-288 and MH 28-1. Pipe wall thickness is in the 2.25” and 2.50” range with no significant pipe wall loss for this 2060 LF section. Subsequent drilling data was used to recalibrate the PPR wave velocity and adjust the pipe wall thickness accordingly.

The pipe diameter is 24” between MH 28-1 and MH 9-508, pipe wall thickness is uniform and is in the 3.25” to 3.50” range with no significant pipe wall loss. Rebar, however, seems to be missing from approximately 336 ft of this pipe. Where rebar is present it appears to be uniform with adequate cover and little variation in depth.

Analysis of 1562 ft of PPR data for the St Johns Trunk show corrosion and pipe wall loss in the vicinity of MH 28-365. Between MH 28-331 and MH 28-365 pipe wall decreases from 4.75” to 3.25” and rebar signal appears to be weak or missing between 1475 ft and 1550 ft. Rebar cover shows a great variation between 1“ and 4” and appears to be adequate. No significant voids were detected outside either pipe. Subsequent coring confirmed and verified the PPR pipe wall thickness for the 24” RCP sections.

Overall, the use of PPR combined with man-entry coring and visual CCTV data provided the necessary information for the District to understand the condition of these critical trunk lines. For the St. Johns Trunk, the lack of rebar signal and the concrete material scraped off during the PPR inspections indicate poor structural condition. This condition can be addressed trenchlessly before further deterioration renders a trenchless solution infeasible. For the Salmon Creek Interceptor, knowing that the 21-inch portion does not contain reinforcement is important information. Follow-up man-entry inspections and localized visual observation of defects revealed that the pipe is in poor to fair condition; rehabilitation, while not immediately urgent, should be planned for in the near future.