Advanced Condition Assessment Using Pipe Penetrating Radar in Los Angeles County, California

Csaba Ékes, Ph.D.[1]

[1]SewerVUE Technology Corp., Coquitlam, BC, Canada. Email: info@sewervue.com

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 (>10 in./250 mm) non-ferrous (reinforced concrete, vitrified clay, PVC, HDPE, etc.) pipes. The key advantage of PPR is the unique ability to measure pipe wall thickness and deterioration including voids outside the pipe, enabling accurate predictability of needed rehabilitation, or the timing of replacement. This paper presents the recent advancements in PPR inspection technology and discusses one specific case study: the Los Angeles County Sanitation Districts (LACSD) in Los Angeles, California, USA. Two pipes were inspected: a 647.3 ft long, 25-in. NRCP (non-reinforced concrete pipe) sanitary sewer pipe (JOD-4) and a 22.6 ft, 48-in. RCP (reinforced concrete pipe) sanitary sewer pipe (JOH-9B). Both pipes had known issues of corrosion, erosion, and sedimentation. The objective of the PPR survey was to determine the condition and remaining service life of the pipes by mapping their wall thickness, and rebar cover, and detecting voids and/or other anomalies within or outside the pipe wall. The PPR results showed that JOD-4 had 28 deposits and 37 type 2 anomalies (voids), and JOH-9B had 6 deposits and encrustations. These findings were used by LACSD to make decisions about the necessary repairs and maintenance for these pipes to ensure their safe and efficient operation.

INTRODUCTION

This paper presents an overview of recent advancements in PPR (Pipe Penetrating Radar) inspection technology, highlighting the need for the technology. Particularly with the need to provide measurable data to establish the extent of rehabilitation or replacement required for critical linear infrastructure. The objective of the PPR survey was to determine the condition and remaining service life of two pipes with known issues of corrosion, erosion, and sedimentation.

With most of the underground pipe infrastructure reaching the end of its design life there is a need to provide measurable data to establish the extent of rehabilitation required or the timing of replacement for large-diameter critical pipelines.

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 provides a tool for the implementation of a preventative maintenance protocol for non-ferrous wastewater and water linear infrastructure. The combined application of PPR, CCTV and LiDAR provide a comprehensive inspection methodology to plan and schedule the rehabilitation of critical utilities before the occurrence of emergency scenarios.

This paper presents an overview of recent advancements in PPR inspection technology, with a specific focus on a case study conducted by the Los Angeles County Sanitation Districts (LACSD) in California, USA. The study aimed to determine the condition and remaining service life of two pipes: a 647.3 ft long, 25-inch NRCP (Non-Reinforced Concrete Pipe) sanitary sewer pipe (JOD-4) and a 22.6 ft, 48-inch RCP (Reinforced Concrete Pipe) sanitary sewer pipe (JOH-9B). Both pipes had known issues of corrosion, erosion, and sedimentation.

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. 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 the antenna frequency. Detectability of targets on 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 interference. 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 1mm to 1m 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 to enhance anomalies at deeper levels. Frequency filtering is used to remove noise. The 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).

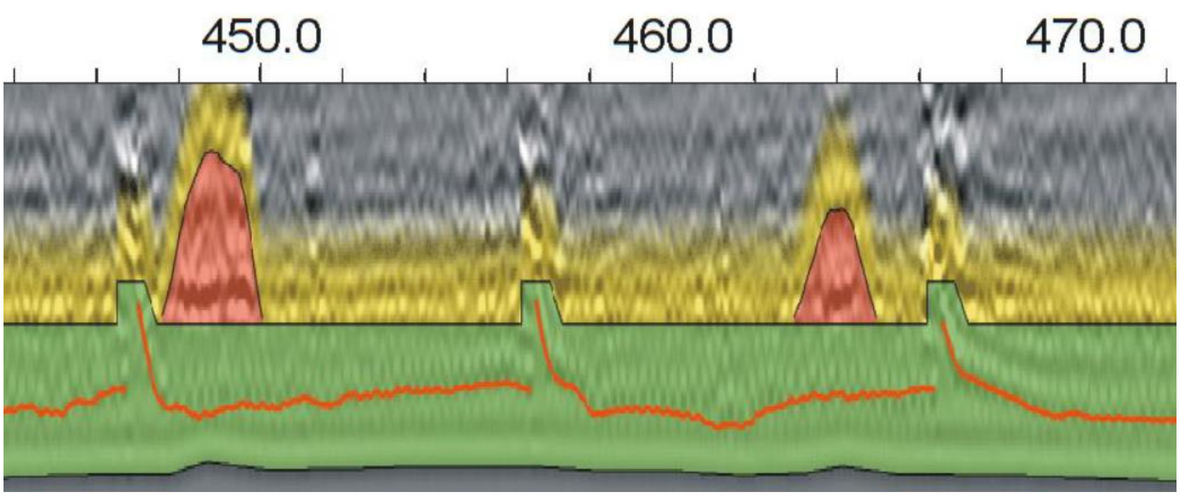

Figure 1. Robotic PPR data is displayed with the interpretation overlaid.

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 LACSD in California, USA can be adjusted for 21 to 60-inch diameter pipes, and 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.

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.

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

CASE STUDY

The County of Los Angeles, California, USA owns and manages a network of sanitary sewers. It is of interest to the County to measure the rate of deterioration and the structural condition of its sewers. It is of particular interest to know the remaining service life of these critical assets. A catastrophic failure would cause service disruption, and 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. We inspected the JOD-4 sewer pipe from MH703 to MH704 and the JOH-9B sewer pipe between D77 and D76.

Concrete sewers are prone to deterioration due to H2S in the airspace aggressively attacks and corrodes concrete and over time gradually eats away the pipe, the damage being most severe at the crown. 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 excellent structural condition, while a new one can experience failure due to excess H2S corrosion or material or installation defects. (A recent project involved the inspection of a 20,000 ft sewer pipe that was only seven years old and already experienced structural failure.)

The JOD-4 from MH703 to MH704 near the City of Industry is a 647.3 ft long concrete and asbestos cement pipe. JOD-4 has eroded pipe and there are known corrosion, erosion, sedimentation, and odor issues. The pipe has never been inspected. The County commissioned a high-frequency PPR survey to inspect sections of the JOD-4 from MH703 to MH704 Sewer. The objective of the PPR survey was to determine the condition and remaining service life of this critical pipe by mapping its wall thickness, and rebar cover and detecting voids and/or other anomalies within or outside the pipe wall.

The inspection of JOH-9B between D77 and D76 along Redondo Beach Boulevard.is made of reinforced concrete and is 22.6 ft long. Despite having encrustations, this pipe has never been inspected before. The known issues of corrosion, erosion, sedimentation, and odor have made it a critical pipe. The inspection was conducted using a high-frequency PPR antennae, and its goal was to evaluate the condition and predict the remaining service life of JOH-9B pipe by measuring wall thickness, rebar cover, and identifying any voids or anomalies within or outside the pipe wall.

This project's PPR survey was completed using a 2.3 GHz frequency antenna while the pipe remained in service with over 16" of flow. Narrow manhole frames, offset manholes and high flow conditions created deployment challenges (Figure 3).

Figure 3. Technicians preparing for deployment of the pipe inspection system at Los Angeles County, California, USA

PPR instrumentation and field survey design.

The inspection work was scheduled for the dry season for safety reasons and was completed in October 2022 (Figure 4). A total of 669.9 feet were inspected. The inspection was PPR and MSI.

Site JOD-4 the inspection was conducted over the lapse of 12 hours, 4 hours for setup, 7 hours for the survey and 1 hour for cleaning. The inspection truck was set up next to manhole MH H703 and the Surveyor ROV was inserted down this manhole and proceeded upstream for 647.3 ft towards MH H704, collecting CCTV, LiDAR, and PPR data.

On October 25th, 2022, data collection operations were conducted at JOD-4 from 8:00 am to 8:00 pm.

Figure 4. Workstation setup at MH H703.

Site JOH-9B The subject of this inspection site was the 48” inner diameter RCP sanitary sewer pipe. The outcome of the inspection was an MSI of the pipe, including CCTV video assessment of the pipe within the whole length, LiDAR 3D point cloud of the pipe, and PPR measuring the thickness of the pipe wall.

The inspection was conducted over 9.5 hours; 5.5 hours for setup, 2 hours for the survey and 2 hours for cleaning. The inspection truck was set up next to manhole MH D77 and the Surveyor ROV was inserted down this manhole and proceeded upstream for 220,6 ft towards MH D76, collecting CCTV, LiDAR, and PPR data. Upon reaching MH D76, the designated end point of the pipe segment to be inspected, the robot was pulled back via its electrical tether, collecting CCTV and LiDAR data in accordance with the upstream inspection.

On October 26th, 2022, data collection operations were carried out at JOH-9B from 8:00 am to 6:00 pm. Upon arrival at the site, a workstation was established for the Surveyor ROV and conducted a safety tailgate meeting with LACSD staff. However, at 9:00 am, it was determined that the height of the flow and hydrogen sulfide (H2S) levels within MH D77 were too high to conduct the inspection safely, so they requested support from LACSD staff to lower the water level and ventilate the pipe.

After LACSD lowered the water height and H2S levels to safe operational levels, the Surveyor ROV was deployed into MH D77 at 12:30 PM, but due to the size restrictions of the manhole, certain parts of the ROV had to be assembled within the pipe.

PPR data interpretation

The presentation of the PPR results is divided by site and by type of data. Wall thickness measurements are displayed with figures showing the wall thickness in inches along the length of the pipe, split into 1 ft sections showing the average thickness as well as maximum and minimum thickness per section.

The other major type of data displayed in this section is the detected anomalies (voids with a confidence weighting). The “Length” x-axis in the graphic refers to the length of the observed anomaly along the line of data. The “Depth” y-axis refers to the vertical length of the anomaly’s effect on the radiogram. This information will provide a clear understanding of the location and extent of the anomalies, allowing for accurate decisions to be made regarding repairs or maintenance.

Anomalies can be classified into two categories: Type 1 and Type 2. A Type 1 Anomaly is characterized by a higher frequency signal pattern compared to its surrounding areas. These patterns are typically spread over a longer. A Type 2 Anomaly is defined as a significant change in the signal's amplitude when compared to the surrounding area. This is typically identified as a sudden change in the signal's strength.

A point cloud is a collection of data points that are arranged in a 3D space and represents the surface of an object or environment (Figure 5). These data points are usually obtained using laser scanning technology or other 3D imaging methods. Point cloud data can be used to create digital 3D models of objects or environments, and it is commonly used in fields such as architecture, engineering, and construction. The point clouds for this assessment were created using LiDAR technology and rendered using Potree, which is a specialized software for handling and displaying large sets of point cloud data.

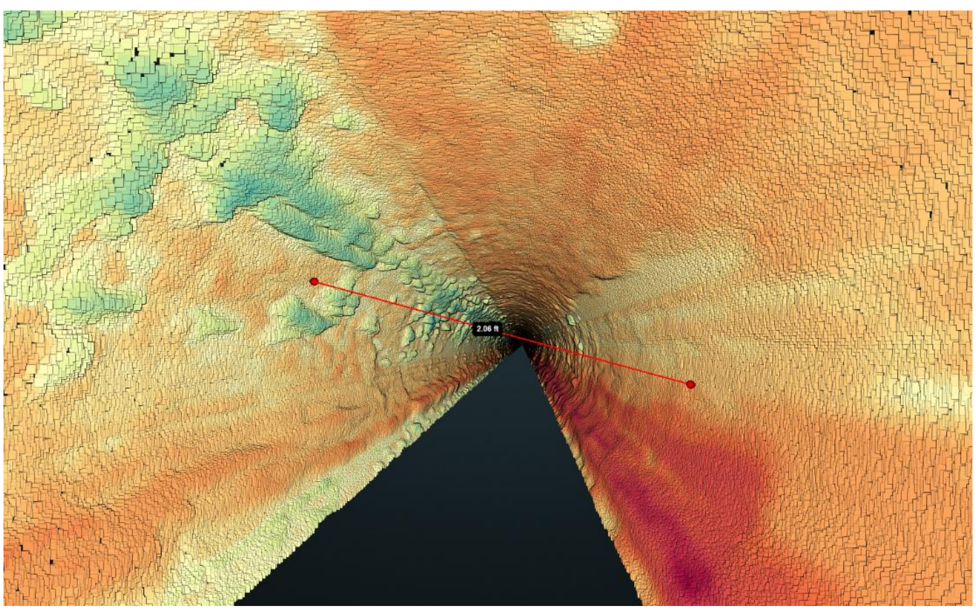

Figure 5. JOD-4 Point Cloud with measurement.

PPR results

The PPR measurements at the JOD-4 site revealed voids at the 12 o'clock position, with a range of 4 to 5 inches radially outward from the inner surface of the pipe. These voids were not found at the 10:30 o'clock and 1:30 o'clock positions. To provide a clear and concise summary of the anomaly results from the JOD-4 site, a table has been included below (Table 1).

Table 1. Voids Information, JOD-4 PPR Measurements

Clock Position	Start Distance (ft)	Length (ft)	Depth (in)	Anomaly Type
12	108.8	1.4	4.43	2
12	117.9	1.7	4.22	2
12	222.2	1	3.97	2
12	295.3	0.9	4.39	2
12	303.1	1.5	4.48	2

The table is organized in a manner that facilitates easy comprehension of the data. The voids are sorted by distance from manhole H703, and it is assumed that the nominal thickness of the NRCP wall is 2.5 inches. Additionally, the marked voids occur within a range of approximately 4 to 5 inches radially outward from the inner surface of the pipe. In the table, the "Length" column refers to the length of the observed void along the line of data (e.g.the first anomaly begins at 108.8 feet upstream from MH H703 and extends for 1.4 feet upstream). The "Depth" column refers to the vertical length of the void's effect on the radargram (in inches). This could be interpreted as the depth of the void from the inner surface of the pipe wall. The data provided in the table is comprehensive and detailed, and it is recommended that readers carefully review the information provided to gain a full understanding of the results of the inspection.

At the JOH-9B site, the analysis of the PPR data revealed that there were no voids detected in the wall thickness or in the material beyond the pipe. This means that the pipe has no defects or anomalies in its structure, which is a good indication that the pipe is in good condition. This is a positive outcome and it is important to keep monitoring and inspecting the pipe to ensure it remains in good condition.

PPR Measurements: JOD-4. The pipe wall thickness measurements were captured at four different positions along the pipe: 9 o'clock, 10:30 o'clock, 12 o'clock, and 1:30 o'clock. The graphic present the results of these measurements (Figure 6). Additionally, a summary table of the anomaly results from the JOD-4 site is provided. It is important to note that anomalies were only detected at the 12 o'clock position, and no such anomalies were discovered at the 10:30 o'clock and 1:30 o'clock positions. The data collected from these measurements will be crucial in determining the condition and remaining service life of the JOD-4 pipe.

JOH-9B. The pipe wall thickness measurements along the 10:30 o'clock, 12 o'clock, and 1:30 o'clock positions are captured in the figures on the following pages. According to the analysis of the PPR data, there are no anomalies detected in the wall thickness or the material beyond the pipe. (Figure 7).

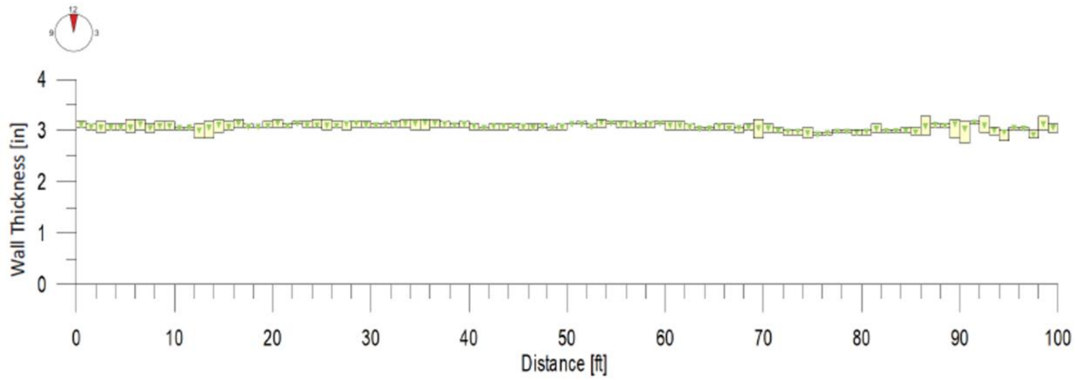

Figure 6. PPR Measurements: JOD-4, Los Angeles County, California, USA.

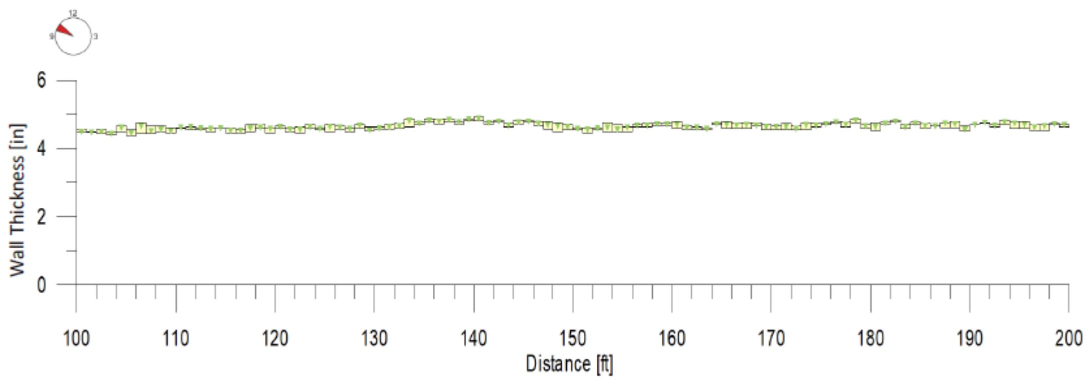

Figure 7. PPR Measurements: JOH-9B, Los Angeles County, California, USA.

SUMMARY

The objective of the pipe profiling and rating survey conducted was to determine the condition and remaining service life of the JOD-4 and JOH-9B pipes by mapping their wall thickness, rebar cover, and detecting voids and/or other anomalies within or outside the pipe wall.

The PPR results showed that JOD-4 had 28 deposits and 37 Type 2 anomalies, and JOH-9B had 6 deposits and encrustations. These findings were used by LACSD to make decisions about the necessary repairs and maintenance for these pipes to ensure their safe and efficient operation. The PPR survey was conducted using state-of-the-art equipment and techniques, which enabled the collection of high-resolution data on the condition of the pipes.

The results of the survey were presented in figures, graphics, and tables that showed the measurements taken on different positions of the pipes and the anomalies detected. Overall, the PPR data collected will be crucial in determining the condition and remaining service life of these pipes, and LACSD will use this information to plan the necessary repairs and maintenance.

CONCLUSIONS

The use of PPR technology in inspecting concrete pipes in LACSD, California has proven to be a valuable tool in determining the condition and remaining service life of these critical assets.

The PPR survey was able to map the wall thickness and rebar cover and detect voids and other anomalies within and outside the pipe wall, providing LACSD with crucial information to make decisions about necessary repairs and maintenance. The results of the survey found deposits and anomalies in both pipes, which will be used by LACSD to plan the necessary repairs and maintenance.

One of the key advantages of PPR technology is its ability to map pipe wall thickness and deterioration, including voids outside the pipe. This enables accurate predictability of needed rehabilitation or the timing of replacement. Concrete sewers are prone to deterioration due to H2S corrosion, which is a toxic gas that aggressively attacks and corrodes concrete and over time gradually eats away the pipe, the damage being most severe at the crown. Standard inspection methods such as CCTV are unable to detect the amount and rate of corrosion.

The age of the pipe is also of limited use, an old pipe can still be in excellent structural condition, while a new one can experience failure due to excess H2S corrosion or material or installation defects. PPR technology enables the collection of high-resolution data on the condition of the pipes, which is crucial in determining the condition and remaining service life of these pipes. This data will be used by LACSD to plan the necessary repairs and maintenance to ensure the safe and efficient operation of these pipes.

Overall, the use of PPR technology in inspecting concrete pipes in LACSD, California has proven to be a valuable tool.

REFERENCES

Ahmad, Z., and Arshad, A. (2019). Non-destructive testing of concrete pipes using ground-penetrating radar. *Arabian Journal for Science and Engineering*, 44(3), 2313-2323.

Daniels, D. J. (2004). *Ground penetrating radar*. 2nd ed. The Institution of Engineering and Technology.

Grasmueck, M., and Proctor, R. (2020). Advancements in pipe penetrating radar inspection technology. In *Proceedings of the Pipelines 2020 Conference: Sustainable Pipeline Infrastructure for a Changing World* (pp. V001T01A001-V001T01A008). American Society of Mechanical Engineers.

LACSD (Los Angeles County Sanitation Districts). (2021). About LACSD. Retrieved from https://www.lacsd.org/about.

Sato, M., Ikeda, T., and Konishi, K. (2011). Pipe penetrating radar system for non-destructive inspection of concrete pipe. *Journal of Nondestructive Evaluation*, 30(4), 202-207.

Song, H., Kim, J., and Park, J. (2019). Application of pipe penetrating radar for nondestructive testing of underground pipelines: A review. *Sensors*, 19(16), 3537.