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Advanced Condition Assessments: The Benefits of Using Pipe Penetrating Radar

Csaba Ékes, Ph.D., P.Geo.[1] , Boriszlav Neducza[1], Michael Fleury, P.E., BCEE[2], and Darren Hess, P.E.[3]

[1]SewerVUE Technology Corp.
[2]Carollo Engineers, Inc.
[3]Weber Basin Water Conservancy District

ANBTRACT: 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 (>18 in/450 mm) 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, and/or the timing of replacement. By having this information available, engineers and owners can better estimate the remaining life left in a pipeline, refine timing of rehabilitation, and ultimately better allocate funding for asset management. This paper presents recent advancement of PPR inspection technology together with two selected case studies from the U.S. The Weber Basin Water Conservancy District (WBWCD) Layton, UT and the Denver, CO case studies are discussed in detail. Carollo Engineers and WBWCD conducted a large condition assessment project on the Weber and Davis Aqueducts. The 26-mile aqueduct system (21 to 84-inches in diameter) was constructed in the early 1950s to convey raw water to several water treatment plants and irrigation providers. The aqueducts supply 250 MGD and serve as the primary water source for over 600,000 people. As part of the investigation, the team identified three leaky 60-inch reinforced concrete joints previously fixed with mechanical joint seals along with a "non-leaky" control joint to be assessed with PPR. PPR identified pipe wall thickness and confirmed the rebar configuration in the surveyed joints. Radar data mapped voids outside several of the joints. Small cracks in the bell of the joints were identified on all three of the joints. The "non-leaky" control joint did not exhibit any radar anomalies. 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 pipe life, accurately determine pipe degradation, as well as provide a basis for improved cost allocation and timing of rehabilitation efforts.

1. 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 current 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 laser (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 a robotic platform the other via manned entry.

2. KEY BENEFITS OF USING PPR

PPR provides quantitative repeatable information on pipe wall thickness, rebar depth, and voids within or outside the pipe. Key benefits of using PPR are illustrated with examples from the Metro Wastewater Reclamation District (MWRD) Denver, CO pipe inspection project conducted in October 2011.

2.1 Background: The Harvard Gulch Interceptor

The Harvard Gulch Interceptor (Figure 1), a sewer pipeline owned and operated by the Metro Wastewater Reclamation District (MWRD) in Denver, CO was originally constructed in the early 1950s by the City and County of Denver. Because of rapid growth in the Metro Denver area and problems with the original vitrified clay pipe (VCP) joints, approximately 80 percent of the interceptor was replaced in the late 1970s with larger diameter reinforced concrete pipe. The interceptor ranges in size from 8 to 48 inches, consisting mostly of reinforced concrete pipe (RCP) with the remainder consisting of original VCP. The main problems on the Harvard Gulch interceptor include significant levels of corrosion in the concrete pipe segments, cracking issues, as well as faulty joints and root penetration problems. A portion of the interceptor was rehabilitated in 2008 with CIPP lining. Future rehabilitation efforts using CIPP or sliplining are planned on this interceptor in the next 10-15 years, with timing based on corrosion severity and budgeting for this rehabilitation work being the primary challenges.

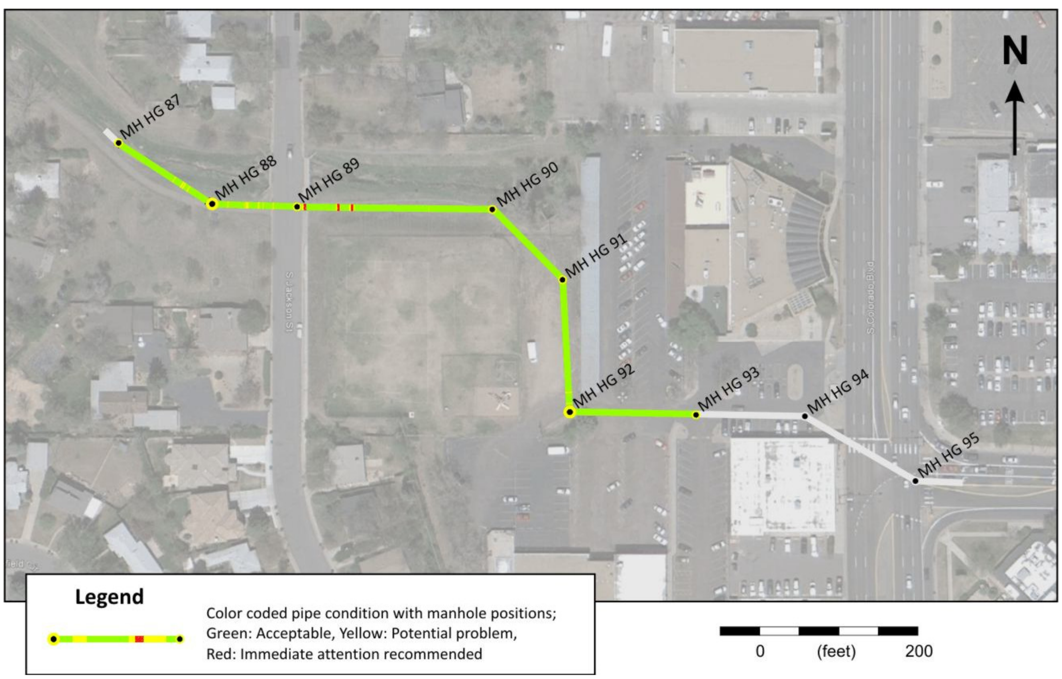

Figure 1. Aerial Photo of Inspected Section (green) of the Harvard Gulch Interceptor (Yellow and Red Indicate Areas of Concern).

2.2 Measuring pipe wall thickness

One way to test remaining pipe wall thickness is via a coupon through coring. This destructive method requires excavation, coring, patching, and pipe reburial. This is not always feasible, it is limited to areas of no or low traffic or if traffic control is involved may involve permitting issues. The number of coupons are generally limited to a few randomly located samples which do no guarantee statistical results, and the sampling is invariable expensive.

Mapping concrete thickness with GPR is an established technique Ékes et al. (2011), Donazzolo and Yelf (2009), Annan et al. (2002), and is particularly accurate if the wave velocity can be established through calibration. In the case of the Harvard Gulch Interceptor, 0.11 m/ns wave velocity was used for the pipe thickness conversion, and this velocity provided 98% accuracy in wall thickness measurement when compared to the core sample (Figure 2).

PPR results are displayed with the interpretation superimposed on the actual depth profiles. The horizontal scales are in feet, while the vertical scales are in inches. The location of the scan lines are marked on the foldout view of the pipe at the bottom of each pipe segment with the corresponding clock positions on the vertical axis. Anomalies and other notable features are color coded. Pipe wall thickness is marked by a continuous black line and reinforcement is marked by red dots which are then connected by a red line.

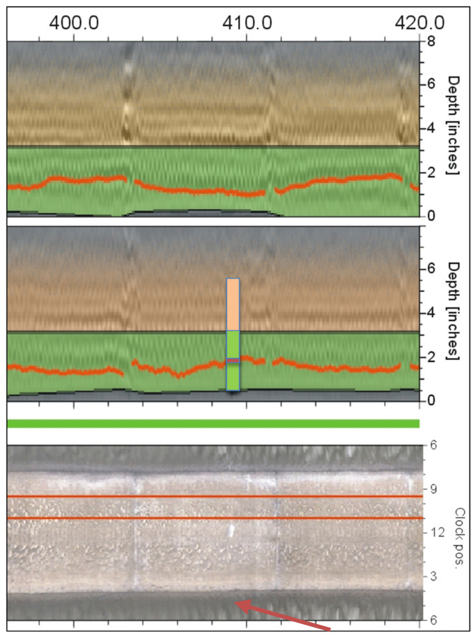

Figure 2. Pipe Wall Thickness Verification (Red Arrow Shows Borehole Location on CCTV image and PPR Shows the Same Rebar Cover and Pipe Wall Thickness at this Location).

<u>2.3 Locating voids and preventing sinkhole collapses</u>

With the exception of Superman's X-ray vision, currently there is no other technology to locate and map voids outside non-ferrous pipes. PPR void mapping is based on the dramatically different wave propagation velocities in concrete (vitrified clay, brick, HDPE, etc.), air and/or water. The PPR signal encountering a void outside the pipe is usually associated with a polarity reversal (Figure 3) making the characteristic signal pattern relatively easy to identify. CCTV may or may not provide indication of the void outside the pipe. Even if it does as is the case illustrated on Figure 3 the operator is very unlikely to identify the cause of the leakage as a void.

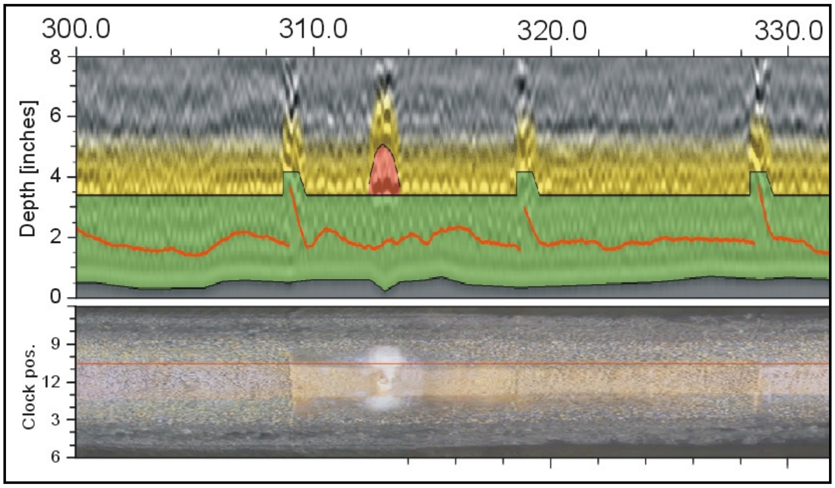

Figure 3. Visible Leakage (CCTV Flat View) and Strong Void Type Anomaly (PPR) at 313 linear feet.

Taking this to the logical next step, if voids are identified on a PPR profile they can be monitored over time and preventative maintenance can take place (Figure 4) before a sinkhole develops and/or an existing one collapses.

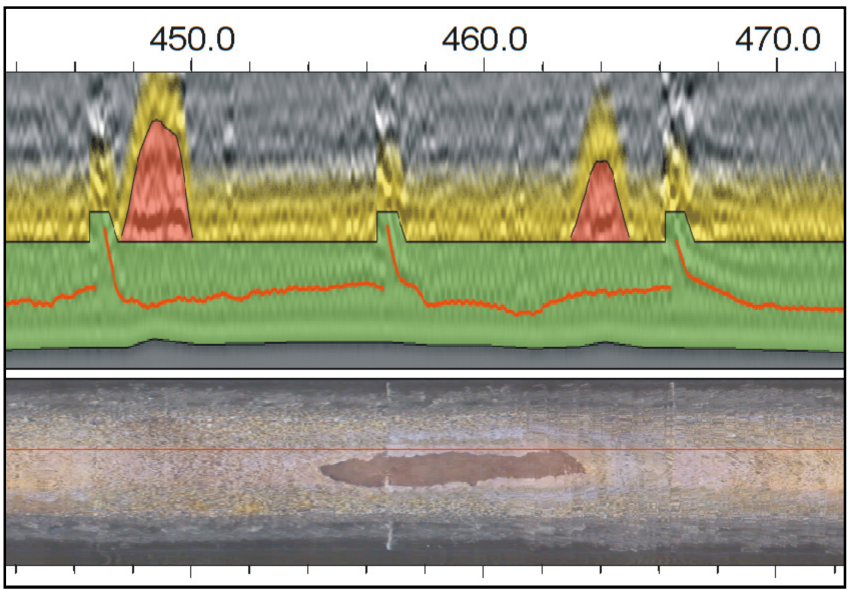

Figure 4. Predictive Void Location: 2 Void Type Anomalies Seen at 449 and 464 linear feet Where no Visible Defects Can be Seen on the CCTV Image.

<u>2.4 Mapping grout thickness</u>

Confirming grout volume and thickness and quality control of a grouting job is problematic. Generally, it is based on assumptions: X cubic feet of grout was delivered to the site and pumped into the casing or around the pipe. PPR provides qualitative means to verify grout placement and if any voids are left unfilled (Figure 5).

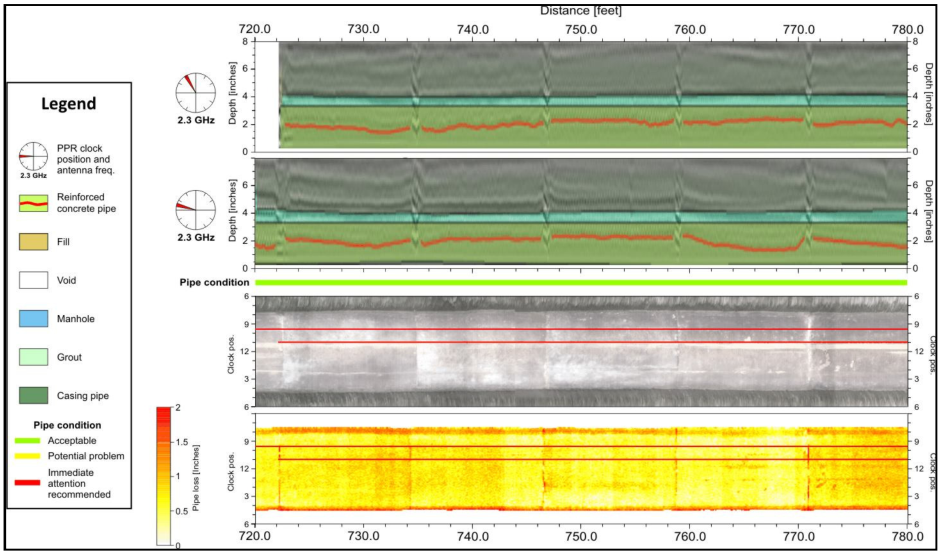

Figure 5. PPR Results with CCTV and LIDAR Foldout Views (Grout Shown in Lighter Green).

2.5 Harvard Gulch Interceptor: PPR results

The PPR data show variations in pipe wall thickness, as well as location, depth, and spacing of rebar. Pipe wall thickness appears to be uniform with no significant pipe wall loss. The remaining pipe wall thickness is between 2.5 to 3.3-in. with an average of 3.0-in. The measured minimum pipe wall thickness is 2.5-in. between MH-HG 89 and MH-HG 88 (at 195.2 ft and 11:30 o'clock).

Rebar cover, while showing variations along the surveyed clock positions appears to be in the 0.25 to 3.2-in. range. Notable exceptions where rebar cover appears to be less than 0.73-in. are shown in Figure 1. This loss of rebar cover, however, appears to be mostly due to the pipe manufacturing process and not the result of pipe wall loss.

The PPR data show the presence of a casing and grouting between the casing and the sewer pipe between MH HG92 and HG93. The grout appears to be uniform with a 0.75 to 1-in. thickness (Figure 5).

The interpreted PPR anomalies are summarized on the pipe location map (Figure 1). No significant voids were detected along the inspected line. Hence the yellow and red sections indicate areas where rebar cover is less than that recommended by ASTM C76M-08.

3. WBWCD CASE STUDY: BACKGROUND

The U.S. Bureau of Reclamation (BOR) began planning the Weber Basin Project in 1942, and Congressional authorization was received in 1949. The Weber Basin Water Conservancy District (WBWCD) was created on June 26, 1950, by a decree of the Second District Court of Utah, under the guidelines of the Utah Water Conservancy Act. The District was formed to act as the local sponsor of the federal project and to supply water resources to the population within its boundaries. The original project, including reservoirs, canals, aqueducts, irrigation and drainage system and power plants were constructed by the BOR from 1952 to 1969. The WBWCD covers over 2,500 square miles within five counties near Salt Lake City, UT: Davis, Weber, Morgan, Summit, and part of Box Elder. In total, WBWCD delivers approximately 220,000 acre-feet of water annually. The project included two aqueducts (Weber and Davis) consisting of 26 miles of 21 to 84-in. reinforced concrete pipe, mortar coated and lined steel pipe, and modified prestressed concrete cylinder or bar wrapped pipe all of which were constructed in the early 1950s. See Figure 6.

Figure 6: WBWCD's Raw Water Aqueduct System.

The aqueducts are the District's most critical water supply pipeline and cannot be taken out of service for extended periods of time. Due to these restraints, the system has had limited shut downs since the aqueducts were commissioned with minimal draining structures to allow access for inspection and maintenance. The raw water aqueducts are a lifeline to more than 600,000 people and supply up to 250 MGD to three water treatment plants, agriculture, and industrial users. As the solitary water supply to the community, planned shut downs are limited to four days in the fall during low flow conditions.

Carollo Engineers and WBWCD staff conducted a large condition assessment project on the Weber and Davis Aqueducts. As part of the investigation, the team identified three leaky 60-inch reinforced concrete joints previously fixed with mechanical joint seals along with a "non-leaky" control joint to be assessed with PPR.

4. WBWCD FIELD INSPECTION AND RESULTS

4.1 PPR instrumentation and field survey design

The PPR survey was completed using high resolution PPR systems. The applied antenna frequencies were 1.0, 1.6, and 2.6 GHz. Linear (2D) and spatial three-dimensional (3D) data were measured during the inspection on each joint for the best results. During 2D data acquisition the PPR data are collected along variable lines and during data processing they are usually processed separately. During 3D data collection, PPR data are acquired in a given geometrical grid. The acquisition is usually slower, but more accurate (especially using a template grid) and provides better detail and resolution of the target area. The subtle anomalies are spatially correlated and enhanced during data processing.

The effective 2D data acquisition is illustrated in Figure 7. The red lines show the circumferential lines that were collected every 2-in. (5 cm) from the joint in both directions. The green lines show the horizontal lines collected at 3, 6, 9, and 12 o'clock positions. During data processing the circumferential lines were merged with the longitudinal lines and were processed as grid data.

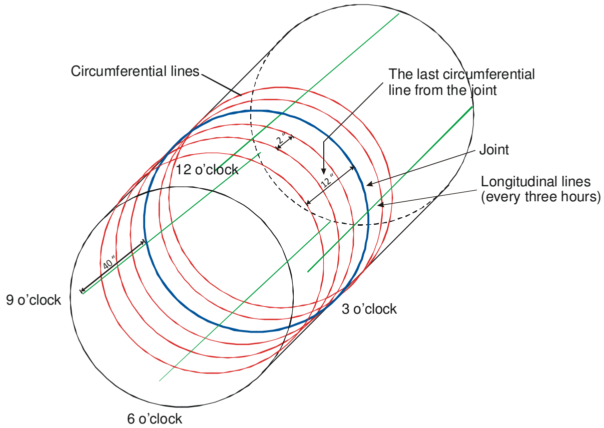

Figure 7. Circumferential and Longitudinal Lines at a Joint (left) and Scanning Longitudinal Lines (right).

A securely fixed 48” by 48” PPR grid covering approximately one quadrant of the pipe was placed at the bottom of the pipe. Line spacing was 2” in each direction. The effective 3D data acquisition is illustrated in Figure 8.

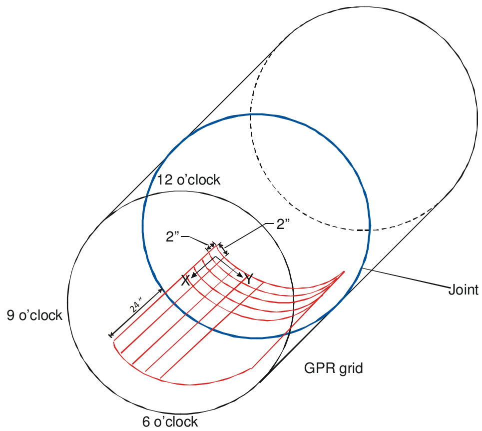

Figure 8. Position of High-Resolution Grid Measurements (left) and High-Resolution Grid Scanning (right).

4.2 PPR Data Processing and interpretation

By processing the data, more information is extracted as the weak and closely spaced events are enhanced. SewerVUE’s proprietary RadART software package was used for applying different correction, gain, and filter functions. Manual processing of individual radar profiles can enhance the data significantly, however, it is very time consuming. Sophisticated processing programs such as RadART allow merging the individual radar lines and can generate depth plots at selected depth intervals. The depth plots (amplitude maps) show the relative amplitude change (potential anomalies) within the surveyed grids.

The various shades of gray on the processed GPR profiles (Figure 9) represent subtle variations of the reflected signal amplitude. Lighter colors represent higher amplitudes. When the higher amplitudes form a spatial extent then they are flagged as anomalies. These anomalies were color coded and superimposed on the processed radar depth plots.

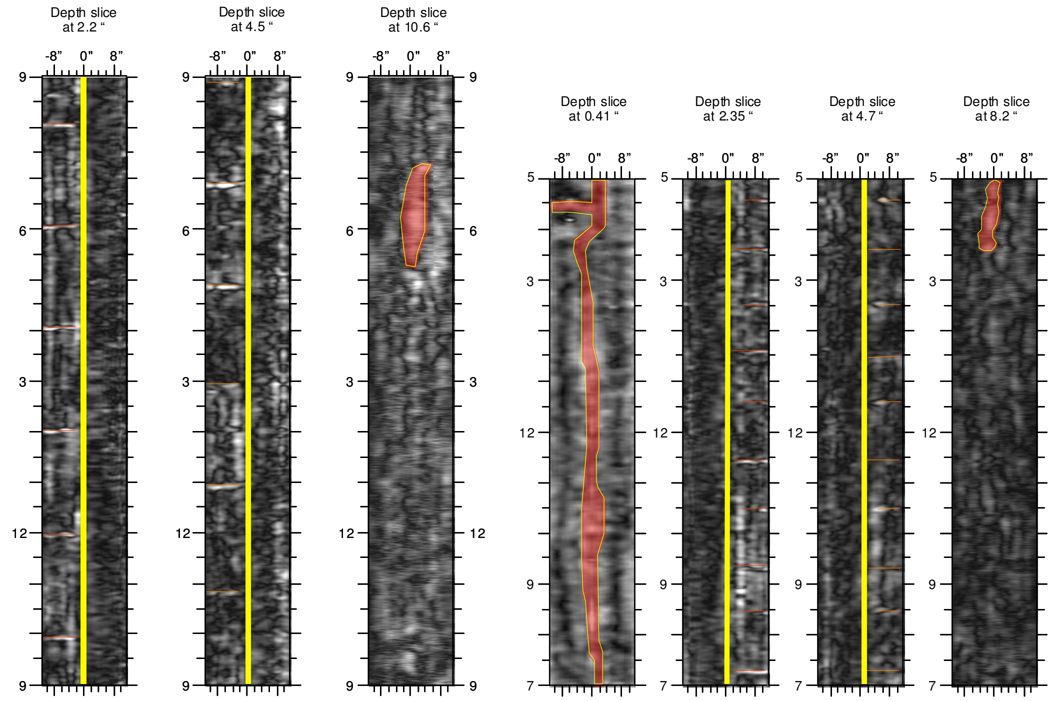

Figure 9. Selected Depth Sections of 2 Leaky Joints (Void Type Anomalies are Marked in Orange).

Processed data show an x-z slice of a pipe joint. The amplitude plot represents the reflectivity strength around individual points. Black area shows low, while white areas mean high reflectivity from the given point.

5. PIPE PENETRATING RADAR RESULTS

Longitudinal distance is displayed on the X-axis, while circumferential distance (as clock position) is displayed on the Y-axis. The pipe joints are marked with a yellow line. All the collected GPR data are of high quality and rich in detail. Signal penetration was 10-inches with the 2.6 GHz antennae and 18-inches with the 1 GHz antennae.

Since steel reflects high amplitude signal reinforcement is readily apparent on all the radar data. There are two layers of reinforcement running parallel to the (longitudinal) pipe axis. All surveyed pipe joints appear to be bell and spigot type joints. The interpreted pipe wall thickness is 6 inches. The interpreted joint configuration is illustrated in Figure 10. All four surveyed joints appear to be the same type. The presence of the gaskets cannot be confirmed since stronger reflections from overlaying rebar overshadow the weaker reflection from the gasket.

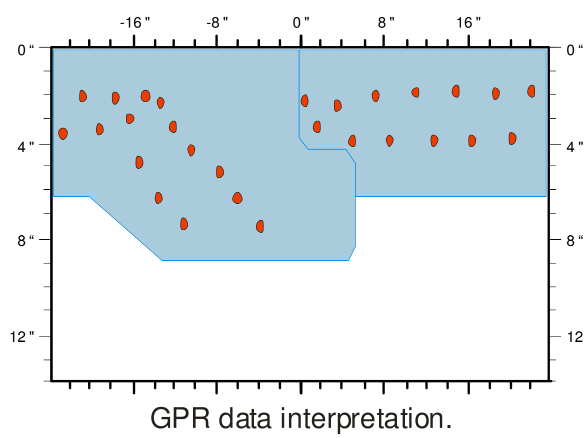

Figure 10. Interpreted Joint Configuration for Joint 896+24 (Red Dots Represent Rebar).

5.1 Joint 924+36

Depth slices at 2.15" and at 5.5" show the two layers of rebar. The two pipes appear to be the same design according to pitch spacing and placement of the reinforcing steel. The configuration is revealed as a bell and spigot joint. The upper layer rebar positioning is equidistant offset from the lower layer of longitudinal rebar. An anomaly was detected along the 6:00 to 6:30 clocking position from the inner pipe wall through the spigot pipe. This is confirmed on high resolution grid where it can be seen at 2.25 inches to connect the two layers of rebar. This anomaly can be interpreted as a crack. The reflections from the inner layer of rebar on the spigot pipe shield the location of the gasket, therefore, radar data cannot confirm the presence of the gasket.

5.2 Joint 923+46

The two pipes at this joint appear to be of different design. The spigot pipe is of the same design as the pipe at Joint 924+36, based on evidence of rebar pitch spacing. The bell end pipe displays tighter rebar pitch, indicating a higher strength designed pipe. The circumferential pitch is measured at 3 inches. An anomaly was detected at 5:15 to 7:15 clocking position, and at depth of 10 inches. Based on an assumed pipe wall thickness of 6-inches, this anomaly is therefore located outside the bell portion of the joint and can be interpreted as a void. Its approximate size is 30 inches long (circumferentially) and 4-inches wide.

5.3 Joint 896+73

These two pipes are of the same design, similar to the greater strength pipe identified at joint 923+46. The pitch is also similar, at a 3 inch pitch spacing. This joint exhibits a separation of an average 1.5 inch width and 0.4 inch depth along the entire joint circumference. At the 4:30 position, there is evidence of a fracture along the length of the longitudinal rebar displaying a similar depth. This fracture extended past the surveyed zone longitudinally. A circumferential anomaly between 3:30 and 5:00 is evident at the depth of 8 inches, coincidentally at the similar location of the aforementioned fracture.

5.4 Joint 896+24

The previously surveyed three joints were known to be leaky. Joint 896+24 had no apparent problems and was selected as a "non-leaky" control joint. These two pipes are of the same design specifications, and exhibit a bell and spigot joint. There are no anomalies, no uncharacteristic design changes, and no exhibited areas of concern. The applied methodology of collecting closely spaced line and grid data with multiple frequencies allowed the identification of the joint types and the detection of two types of anomalies. The interpreted pipe wall thickness is 6 inches. GPR data confirmed the rebar configuration in all four surveyed joints. All four joints are the bell and spigot type, however, the exact type cannot be ascertained. Radar data of all the three leaky joints show anomalies. Crack type anomalies were identified on two of the joints (896+73 and 924+36) while external void type anomalies on joints 896+73 and 923+46. The "non-leaky" control joint (896+24) did not exhibit any radar anomalies.

6. SUMMARY AND CONCLUSIONS

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. Examples from a robotic and a manned entry project were used to illustrate how PPR can map remaining pipe wall thickness, rebar cover, grout placement, and voids outside the pipe.

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. 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 estimated remaining life of an interceptor or water conveyance facility, accurately determine overall severity of pipe degradation, as well as provide a basis for improved cost allocation, and timing of rehabilitation efforts.

7. REFERENCES

Annan, A.P., Cosway, S.W., and De Souza, T. (2002). Application of GPR to map concrete to delineate embedded structural elements and defects. Proceedings of the Ninth International Conference on Ground Penetrating Radar, (IEEE, Santa Barbara, 2002) 358-354.

Donazzolo, V., and Yelf, R. (2009). Determination of Wall Thickness and Condition of Asbestos Cement Pipes in Sewer Rising Mains using Surface Penetrating Radar, Proceedings of the Fourteenth International Conference on Ground Penetrating Radar, (IEEE, Lecce, 2010) 234-238.

Ékes, C., Neducza, B., and Henrich, R. G. (2011). GPR Goes Underground: Pipe Penetrating Radar, Proceedings of North American Society for Trenchless Technology (NASTT), No Dig Show 2011, Washington, D.C., Mar 27-31, 2011.

Jaganathan, A., Allouche, E., and Simicevic, N. (2006). Pipeline Scanning: Novel Technology for Detection of Voids and Internal Defects in Non-Conductive Buried Pipes, Proceedings of the No Dig Down Under 2006, Brisbane, Australia Oct 29-Nov. 2, 2006.

Koo, D. H., and Ariaratnam, S.T. (2006). Innovative Method for Assessment of Underground Sewer Pipe Condition. Automation in Construction.15 (4): 479-488.

Parkinson, G., and Ékes, C. (2008). Ground Penetrating Radar Evaluation of Concrete Tunnel Linings, Proceedings of Twelfth International Conference on Ground Penetrating Radar, Birmingham, UK June 16-19, 2008.