IN-PIPE GROUND PENETRATING RADAR FOR NON-DESTRUCTIVE EVALUATION OF PVC LINED CONCRETE PIPE

Samuel T. Ariaratnam[1] and Noel Guercio[2]

[1] *DEWSC, Ira A. Fulton School of Engineering, Arizona State Univ., P.O. Box 870204, Tempe, AZ, 85287-0204, USA; E-mail: ariaratnam@asu.edu*
[2] *Project Engineering Consultants, 2310 W. Mission Lane, Suite 4, Phoenix, AZ, 85021, USA; E-mail: noel@pecaz.com*

Abstract

Underground utility services play an essential role in sustaining urban life. The majority of these utility services are delivered through pipeline networks, which are mostly buried underground and are interconnected through other urban systems to distribute or collect basic sustainable needs such as treated water, waste water, gas, communication, and power. Deterioration of underground infrastructure systems occurs due to ineffective maintenance management practices. Because new installation can be very costly and disruptive, the best course of action is to maintain the present infrastructure in a more effective way to maximize life span and prevent catastrophic failures. The accurate evaluation of current underground infrastructure must be done before any crucial decisions including lifecycle, rehabilitation and replacement intervals, and appropriate remedial methods can be made. Unfortunately, traditional technologies and management approaches have been limited by the use of insufficient data in the evaluation of the structural integrity of an aged infrastructure. This paper describes the testing, development, and application of a novel assessment technology, which combines in-pipe Ground Penetrating Radar (GPR) with Digital Scanning and Evaluation Technology (DSET) robotics to collect accurate information about the condition of the inside wall of concrete sewer pipes. A case study applying this innovative technology to sections of large diameter PVC-lined concrete pipe in the City of Phoenix is presented. The study and adoption of innovative pipeline assessment methods provide better information to improve the decision-making process, thereby making economical decisions to optimize resources in more efficient ways.

Introduction

The recent Infrastructure Report Card produced by the American Society of Civil Engineers (ASCE) assigned the U.S. infrastructure an overall average grade of D (ASCE, 2005). Within the overall infrastructure, both water and wastewater systems were giving grades of D-. This is alarming as the nation struggles to maintain the integrity of its buried network. The project cost for fixing this problem is estimated to be in the trillions of dollars. Municipalities are trying adopting fiscally responsible strategies for minimizing the impact of their failing water and wastewater systems. A situation analysis must first be performed through the review and assessment of Closed Circuit Television (CCTV) records of the current state.

Back in the 1950's the City of Phoenix, Arizona searched for a feasible solution to the problem of hydrogen-sulfide attacks on reinforced concrete sewer lines. Due to elevated temperatures in the Southwestern United States, Phoenix, along with other cities such as Los Angeles, Las Vegas, and Sacramento, turned to adopting a PVC liner to provide a protective barrier inside concrete pipe. The lined concrete pipe of choice for the City of Phoenix was Ameron's T-Lock™ pipe. T-Lock pipe is a

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reinforced concrete pipe lined with a polyethylene sheet. As illustrated in Figure 1, the liner is fixed to the concrete with imbedded “Tees” that run the length of the pipe section. This prevents the liner from detaching itself from the pipe. The degree of lining varies depending on what has been specified and is intended to protect the concrete from harmful sewer gases including hydrogen-sulfide.

The City of Phoenix wastewater collection system is comprised of approximately 6,400 km (4,000 miles) of pipeline ranging in diameter from 200 mm (8 in) to 2,250 mm (90 in) and including over 72,000 manholes. Of the Phoenix system, approximately 98 km (61.4 miles) are composed of lined concrete pipe. In addition to its own system, the City operates and maintains two systems from the Sub-Regional Operating Group (SROG). These systems convey wastewater from the Cities of Phoenix, Mesa, Tempe, Scottsdale, Glendale, Peoria and Tolleson to the 91st Avenue Wastewater Treatment Plant located at 91st Avenue and Southern Avenue. These two SROG-owned systems include the Southern Avenue Interceptor (SAI) and the 99th Avenue Interceptor. The SAI includes approximately 30 km (19.1 miles) of PVC lined concrete pipe and 99th Avenue system includes approximately 10 km (6.5 miles) of PVC lined concrete pipe.

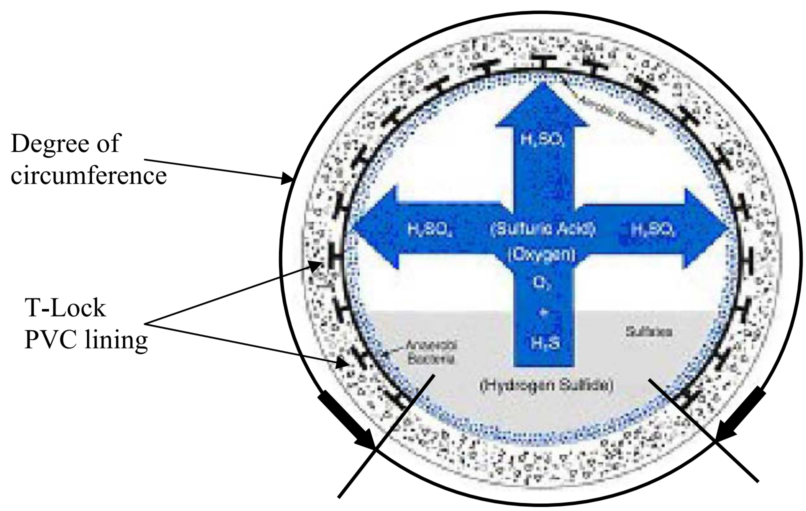

Figure 1. Cross-sectional view of reinforced concrete sewer pipe with T-Lock liner (Ameron 2001)

The City of Phoenix was the first municipality to initiate a major assessment program on the lined-concrete system. The program consists of a condition assessment of all lined concrete sewer pipe 750mm (30 in) in diameter and larger that are maintained and operated by the City, including those portions owned by the SROG. This also included the condition assessment of the associated manholes. The project was divided into two phases. Phase 1 included a condition assessment of all lined concrete sewer pipe constructed prior to 1990. Phase 2 included a condition assessment of all lined concrete sewer pipe constructed after 1989. Phase 2 also included an evaluation of the pipe erosion due to sediment and debris transportation within the sewage flow.

Sewer Inspection Methodology

The entire lined-concrete pipe system was assessed using a Closed Circuit Television (CCTV) for each manhole-to-manhole run. Each CCTV inspection was documented with a written field report and a viewable recording placed on electronic media. The inspection operations were normally completed during periods of relatively low system flow, which generally occurred during night time hours. As inspections were completed, the information was reviewed for entirety and clarity with additional field information requested as necessary. Each defect type found within a pipe run was quantified and assigned a rating based on the National Association of Sanitary Sewer Companies (NASSCO) Pipeline Assessment and Certification Program (PACP) standards and ratings to the resultant defect data. Table 1 presents the NASSCO grading system. It should be noted that the similar rating system used in Canada is through the North American Association of Pipeline Inspectors (NAAPI).

Table 1. NASSCO grading system

Defect Grade	Defect Condition	Rate of Pipeline Deterioration
5	Immediate Attention	Pipe has failed or will fail within the next 5 years
4	Poor	Pipe will probably fail in 5 to 10 years
3	Fair	Pipe may fail in 10 to 20 years
2	Good	Pipe is unlikely to fail in at least 20 years
1	Excellent	Failure is unlikely in the foreseeable future

By applying standardized defect codes to this assessment project, each similar defect will have comparable ratings to help in generating the condition assessment results. The codes also help to standardize the condition assessment procedure and convert the inspector's defect data into meaningful condition grading information.

Inspection Results

Various defects were observed during the CCTV visualization inspection. Condition assessment of the results found that a total of 537 out of 2,451 total defects (22%) were considered to be minor and given a condition grade of 1. Subsequently, these were omitted from the pipe segment ratings and the subsequent tables and figures. Common defects observed during the CCTV inspection included pinholes in the liner, blisters in the liner, detached weld strips, and holes in the liner. Several of these defects are illustrated in Figure 2. A breakdown of the Grade 2 through 5 defects is presented in Table 2.

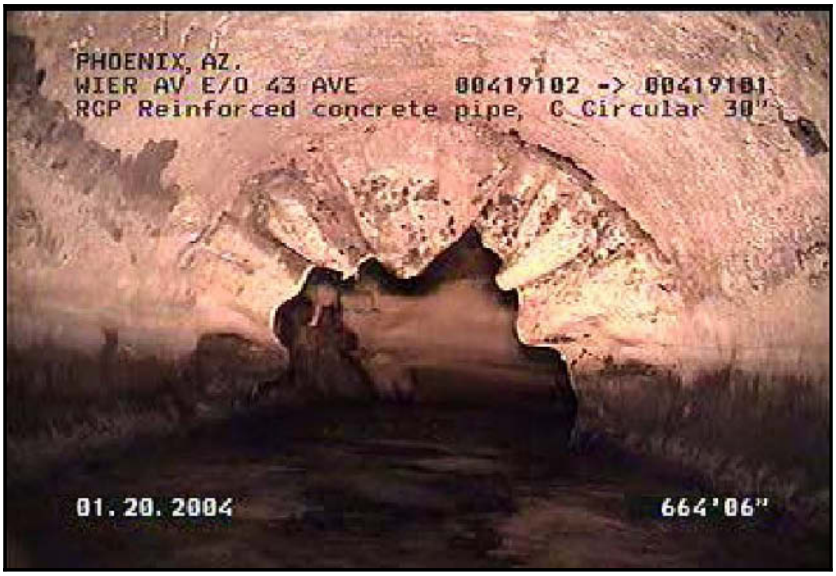

Figure 2. Detached liner

Figure 3. Detached weldstrip

Figure 4. Blister in liner

Table 2. Breakdown of Phoenix defects

Defect Descriptions	Defect Code	Total # Found	% of Defects
Pinhole in Liner	LFPH	1038	54.2
Blister in Liner	LFB	278	14.5
Weld Strip Detached	LFWS	169	8.8
Hole in Liner	LFHR	127	6.6
	LFHL	99	5.2
	LFHC	31	1.6
Detached Liner	LFD	72	3.7
Wrinkled Liner	LFW	54	2.8
Grease Deposits	DAGS	23	1.2
Settled Deposits	DS	12	0.6
Obstructions	OBZ	5	0.3
Deposits, Attached	DAE	2	0.1
Visible Reinforcement	SRVC	1	0.1
Object Protruding	OBI	1	0.1
Construction Debris	OBN	1	0.1
Defective Tap	TFD	1	0.1
Total		**1914**	**100%**

Evolution of In-Pipe Ground Penetrating Radar

The defects discovered by the CCTV inspection were of the liner and not the actual concrete pipe. There was concern raised about the condition of the concrete pipe and reinforcements "behind" the liner. Subsequently, a need was recognized for utilizing a form of non-destructive method testing for evaluating the condition behind the liner. Morrison (2004) recommended the use of secondary assessment technologies during a pipe assessment program.

Several non-destructive evaluation methods were examined for suitability including: sonar; thermography; X-ray; laser profilometry; and ground penetrating radar. It was determined that ground penetrating radar (or GPR) was the most promising of the applications for looking behind the liner and into the concrete pipe. Furthermore, it was decided that it would be best if the GPR unit were placed on the CCTV robot and transported within the sewer line providing close contact with the lined pipe.

Field testing of a prototype unit was conducted in Tskuba, Japan in the fall of 2003 to determine whether readings could be made. Defects were manually created in the concrete behind sections of lined pipe. The first prototype, illustrated in Figure 5, performed well in the trials and was brought to Phoenix for a pilot project.

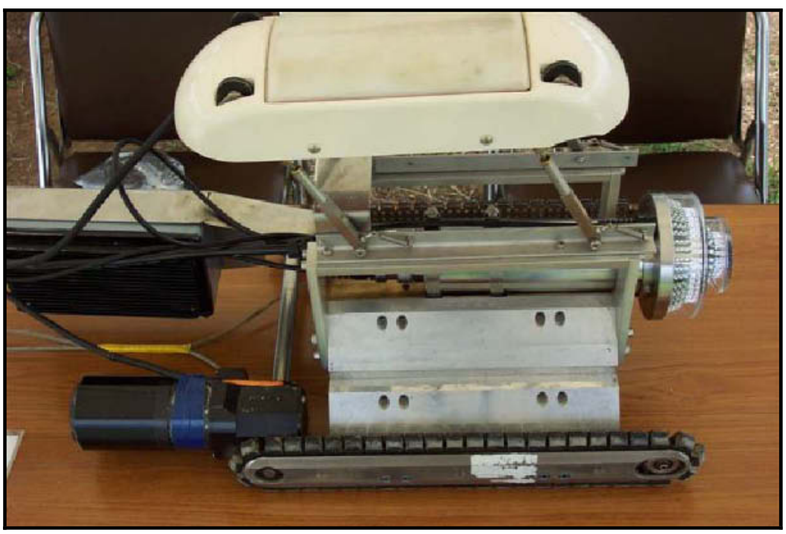

Figure 5. Prototype inspection robot with gpr unit

Due to the pipe size and potential flow conditions, it was determined to use a wheel robotic body rather than the track body used in the Japanese field tests. The second generation robot, illustrated in Figure 6, capture data behind the liner at pre-positioned liner defect positions along several pipeline sections. Unfortunately, a limitation was the fact that information could only be captured at the 12 o'clock position due to the fixed GPR unit.

The third generation robot, illustrated in Figure 7, solved any problems associated with clock face positioning through the use of multiple gpr units attached to two arms. This enables the unit to capture defect information anywhere along the 9 o'clock to 3 o'clock positions of a pipe section. An example of the corresponding ground penetration radar results is shown in Figure 8. The top results show the defect areas in relation to a folded view of the pipe, while the bottom results show a front view of the liner tears.

Figure 6. Second generation wheeled inspection robot with gpr

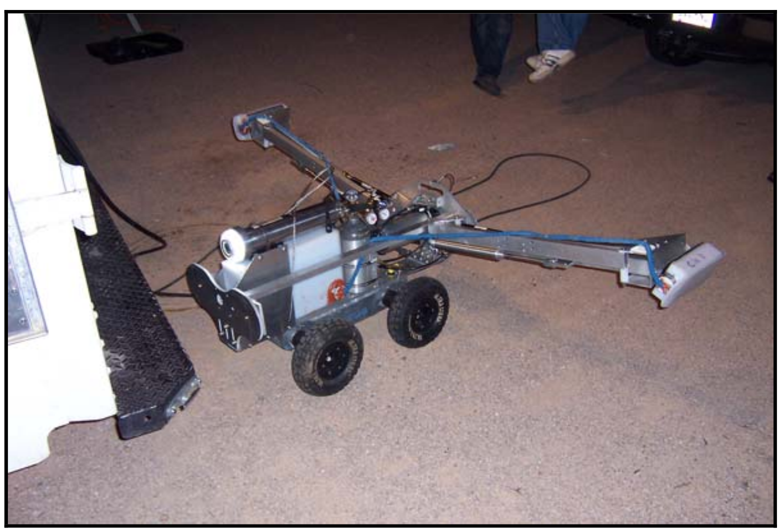

Figure 7. Third generation wheeled inspection robot is multiple gpr units

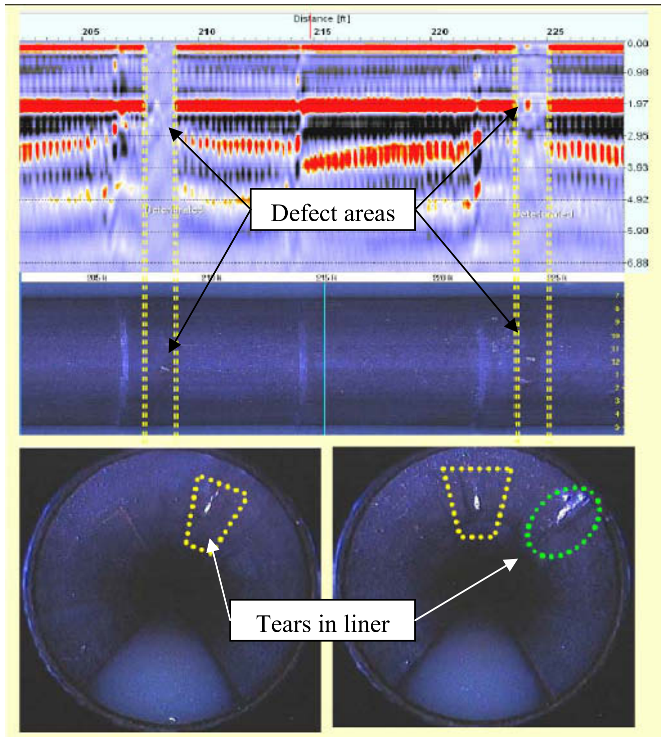

Figure 8. In-pipe ground penetrating radar results

Ground Penetrating Radar Technology

Ground penetrating radar is a wave-based electromagnetic geophysical method that fundamentally detects interfaces between materials possessing varying electrical (dielectric) characteristics. A typical digital GPR system consists of transmitting and receiving antenna elements, which emit outgoing electromagnetic pulses into the media being investigated and receive incoming reflections from this media; a central control unit which governs the characteristics of the transmitted electromagnetic waves, processes the received signal by amplifying and recording it and converting it to a digital format; and a color computer video display unit that receives the digital information from the control unit and, after processing the information through the GPR acquisition software, produces a graphical representation of the acquired data as a real-time two-dimensional continuous depth profile, which includes horizontal antenna position and vertical target depth and amplitude information. GPR operates by emitting electromagnetic radar impulses into a media (pipe) at a high repetition rate, from an antenna array towed through the pipeline. Reflections occur at interfaces of materials with differing electrical characteristics (dielectric permittivity). Reflections of various amplitudes (Figure 8) are produced at these interfaces and are detected by the receiving antenna element, depending on the incoming signal frequency, the magnitude of the difference in dielectric constants of the two materials. Additional information on GPR may be found in Holmes (2004).

Current state-of-the-art GPR systems have evolved into compact, reliable, user-friendly instruments able to be operated from start to finish by a well trained, technically experienced individual. Today's systems allow a single user to acquire and interpret large amounts of project data in a relatively short amount of time as well as the ability to transfer the information in real time.

Along with technological advancements in recent GPR systems comes an increase in available situations to apply the technology. Beyond the historically scientific applications in the geological, archaeological, or research realms, GPR has recently been increasingly applied for utilitarian purposes in the environmental and trenchless technology industries to locate and assess subsurface objects.

Destructive Verification through Core Samples

Core samples of pipe walls were obtained from two different locations to provide a visual verification of suspected problem areas detected by the ground penetrating radar. In both locations, a 5 m deep, 2.4 m wide, 7.6 m long trench was excavated at predetermined locations with a box shoring used for stabilization. A GPR survey was performed on the exterior surface of the top of the reinforced concrete pipe to determine the exact location to extract the coring sample. Two 75 mm diameter samples were recovered at each of the two locations and preserved for laboratory testing of compressive strength (Edwards and Nowaczyk, 2005). One sample was at a suspected defect location, while the other was in an unaffected section of the concrete pipe wall for comparison. Table 3 presents the results of the compressive strength tests performed to ASTM C39-01 standards.

The cores samples (Figure 9) verified the results found using the non-disruptive in-pipe ground penetrating radar unit transported on a robotic platform. Discoloration of the core samples and diminished compressive strength measures further demonstrate the problems that could occur if hydrogen-sulfide gases were to penetrate the liner and attack the concrete wall.

Table 3. Laboratory testing of concrete core compressive strength (ASTM C39-01)

Core Sample #	Measured Average Length of Recovered Concrete Core (mm)	Compressive Strength (psi)	Notes
1 (a)	102.87	9,770	Core recovered from relatively non-corroded 750mm pipe section
1 (b)	85.09	8,840	Core recovered from suspected corroded 750mm pipe section
2 (a)	106.81	8,020	Core recovered from relatively non-corroded 900mm pipe section
2 (b)	93.17	7,810	Core recovered from suspected corroded 900mm pipe section

Figure 9. Core samples from 750 mm concrete pipe section

Conclusions and Recommendations

As municipalities that previously adopted lined concrete sewer pipe engage in their respective inspection programs, it is critical that secondary inspection technologies be utilized to provide validation of the pipe wall condition "behind" the liner. This paper provides a description of the development and use of in-pipe ground penetrating radar (GPR) deployed on a robotic unit for the evaluation of PVC lined concrete pipe. The third generation unit employs multiple GPR units on two arms to facilitate the capture of data from any location above the pipe's spring line. This improved on the limitations of previous generation, which were restricted to only capturing information at the 12 o'clock position within a pipe.

Furthermore, coring samples were conducted to validate the results obtained from the GPR unit. Samples were extracted from two different pipe locations. For each location, two 75 mm diameter core samples were taken. One sample was at a suspected defect location, while the other was in an unaffected section of the concrete pipe wall for comparison. The samples from the defect section had lower compressive strength measures compared to the unaffected samples.

References

ASCE (2005). *Infrastructure Report Card 2005*. American Society of Civil Engineers, Reston, VA.

Ameron International (2001). *Amer-Plate® T-Lock® Price List [Brochure]*. Brea, CA.

Edwards, Mark D., and Nowaczyk, S.D. (2005). *Existing Sewer Line Geophysical Evaluation 41st Avenue and Peoria Avenue, Phoenix, Arizona Pecos Road and 40th Street, Phoenix, Arizona Report*. Prepared by Ninyo & Moore Consultants, Phoenix, AZ.

Holmes, Patrick (2004). "Emerging Methods for Utility Locates." *Proceedings of the No-Dig 2004 Conference*, New Orleans, LA, March 22-24, Paper B-4-01, pp. 1−7.

Morrison, Robert (2004). "Condition Assessment: Back to Basics." *Underground Infrastructure Management,* November/December, Peninsula, OH, pp. 51−55.