Use of Acoustic Inspection for Prioritizing Renewal and Replacement Projects at Ft. Jackson, South Carolina

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ABSTRACT

Current useful life estimation techniques rely heavily on professional judgment based on a wide range of available information including asset age, physical condition, maintenance history, prior operational issues, and other data. Inspection of collection system assets is often limited to visual inspection of the manhole and not direct inspection of the pipe with technology such as CCTV. Even though direct inspection with CCTV would significantly enhance the useful life estimation, the scope and cost associated with collecting these data for each pipe segment within a collection system can be difficult to justify. InfoSense, Inc. has developed the Sewer Line Rapid Assessment Tool (SL-RAT) to provide utility operators with a new capability to inspect pipe segments. The SL-RAT was designed specifically to act as a cost effective tool for prioritizing maintenance operations based on rapidly assessing the degree of blockage within sewer line pipe segments. It has proven an effective tool in prioritizing cleaning operations. The objective of this study is to evaluate the cost effectiveness of using the SL-RAT to enhance asset useful life estimations and the subsequent use of that information to prioritize R&R projects. An inspection of 2,600m (8,500ft) of 45.7cm (18-inch) and 61cm (24-inch) pipe was performed using CCTV at Ft Jackson, near Columbia South Carolina. The CCTV inspection campaign took 45 hours. This run of pipe was also inspected acoustically using the SL-RAT device. The SL-RAT inspection was performed in under 5 hours using a two person crew. Overall the SL-RAT proved to be effective in identifying major issues, but it was found that using the device on larger diameter pipes required a more conservative scoring approach when evaluating acoustic scores.

KEYWORDS

Pipeline rehabilitation, condition assessment, acoustic inspection.

INTRODUCTION

Wastewater utilities struggle to maintain the vast underground network of pipes that handle transportation of raw sewage through our nation's cities and towns. System operators must constantly balance a variety of competing challenges including how to properly maintain their aging infrastructure against often severe operating and capital cost constraints. Maintaining the collection system's operational integrity involves prioritizing renewal and replacement (R&R) projects based on evaluating the useful life of the systems' assets. An asset's useful life is the anticipated amount of time that the asset will serve its intended purpose prior to failure. Failure can be considered either when the asset is unable to perform its intended function or when the cost of operations exceeds an acceptable level. Both approaches are based on physical deterioration of assets. For collection systems, pipe assets serve a critical function and replacement is frequently justified before physical failure occurs. Generally, if failure occurs, replacement costs will be much greater due to emergency design and the expedited procurement of contracting services required. Failure of these assets can also cause collateral property and economic losses as adjacent facilities and watersheds may be unusable during sewer backups and damage to surrounding property is likely. Ideally, a utility asset will be replaced just prior to failure. Due to the high cost of current inspection technologies, predicting failure of an asset is a complex exercise relying on indirect assessment. Incorrect estimates of an asset's useful life can result in errors and omissions in prioritizing R&R projects consequently leading to misdirected resources and possible unanticipated asset failure.

Ft. Jackson water and wastewater utilities were constructed sporadically since the early 1920s when the post was established. Recent intense development of the post has put added pressure on the utilities to provide capacity for these new projects while continuing to meet more and more stringent regulatory requirements. These utilities were operated by the U.S. Army until 2006 when Palmetto State Utility Services (PSUS) was awarded the utility privatization contract. Under this contract, PSUS and Brady Engineering were tasked with creating a utilities master plan to determine how to improve the existing level of service and to provide capacity for future expansion. In developing the master plan, the Ft. Jackson collection system assets were catalogued and the useful life of each asset was estimated. Sewer pipe useful life estimates run from a high of 100 years to a low of 50 years. These lengths of time are based upon multiple variables including materials, quality of installation, sewage characteristics, maintenance and exterior impacts (such as root intrusion, structural loading and soils conditions). The timeframes associated with the wastewater system sewer pipes on Ft. Jackson are based upon physical inspection of a limited number of manholes, review of the most recent system study material available (1995), and through discussions with system operators. The quantity of piping has been categorized by a range of construction dates to reflect estimated installation dates. The master plan provides an excellent resource for comparing and contrasting the efficacy of acoustic inspection data with standard industry practices in estimating remaining useful life.

The Sewer Line Rapid Assessment Tool (SL-RAT™) utilizes acoustic technology to quickly assess the degree of blockage in a sewer line (Howitt, 2012). Using this assessment tool to estimate pipe segments' useful life could provide a breakthrough enhancement for prioritizing R&R projects. The SL-RAT exploits the similarities between water and sound transmission through a sewer line segment in order to diagnose the extent of the pipe's blockage. This novel, patented methodology is based on measuring the signal received from an active acoustic transmission through a segment. Figure 1 depicts the general configuration of the SL-RAT device. The acoustic transmitter generates sound waves just below the entrance to the manhole which naturally couple into connecting sewer line segments, whether the depth of the manhole is 1 meter or greater than 10 meters. The sound wave propagates in the air gap above the wastewater flow from the speaker to the receiving microphone located at the adjacent manhole. Segment lengths exceeding 250 meters have been successfully evaluated. The acoustic receiver measures the acoustic plane wave from the transmitted signal in order to evaluate the condition of an entire segment and provides an onsite assessment in less than three minutes. An important practical aspect of the SL-RAT is that both the speaker and the microphone are placed just within the opening of the manhole and never come in contact with the wastewater flow and the operators have no requirement for confined space entry.

Figure 1. Operation of the Acoustic Inspection System

An initial inspection of 2,600 meters (8,500ft) of 45.7cm (18-inch) and 61cm (24-inch) pipe was performed using CCTV at Ft Jackson, SC. This run of pipe was also inspected using the SL-RAT device. The SL-RAT inspection was performed in less than 5 hours, compared to the several weeks required to complete the CCTV inspection.

METHODOLOGY

SL-RAT acoustic inspection measurements were conducted on May 16, 2012. Figure 2 shows a typical configuration for an SL-RAT transmitter unit (speaker). The receiving unit (microphone) was set on an open manhole (in a similar fashion) at the other end of the sewer line segment. Typical acoustic inspection time was between 1.5 to 3 minutes once the manhole lids were removed. CCTV video was taken in the six months prior to the acoustic inspection.

Figure 2. SL-RAT Transmitter Unit Deployed on a Manhole

RESULTS

Results are presented in Tables 1 and 2, and maps of the acoustic assessments are shown in Figures 2 through 4. Sewer line segment classification (i.e., color code) is based on the SL-RAT measurements and is based on the default classification scheme as defined in the legend. These classifications were based algorithms developed for 15-30cm (6-12 inch) pipe. Note that all pipes for this inspection campaign were larger (45.7-61cm, or 18-24 inch).

Table 1: Sewer Line Assessment Results Fort Jackson
SL-RAT Measurements Conducted from May 16, 2012 to May 16, 2012
(RX: Receiver Unit; TX: Transmitter Unit)

Meas. ID	RX Oper. ID	RX HW ID	TX Oper. ID	TX HW ID	Date & Time	Meas. Duration (sec)	Oper. Pipe Length (ft)	Eval. Pipe Length (ft)	Meas. Status	Assessment (0-Blocked; 10-Clean)	RX Latitude (dec. deg.)	RX Longitude (dec. deg.)	TX Latitude (dec. deg.)	TX Longitude (dec. deg.)
23	1	16	1	17	5/16/2012 9:31	79	250	267	Valid	10	33.99813	-80.95884	33.99882	-80.95856
24	1	16	1	17	5/16/2012 9:37	80	150	117	Valid	8	33.99892	-80.95820	33.99885	-80.95858
25	1	16	1	17	5/16/2012 9:44	80	250	269	Valid	9	33.99891	-80.95814	33.99964	-80.95803
26	1	16	1	17	5/16/2012 9:52	80	50	42	Valid	9	33.99973	-80.95812	33.99964	-80.95803
27	1	16	1	17	5/16/2012 10:03	79	450	435	Valid	9	33.99973	-80.95812	34.00087	-80.95771
28	1	16	1	17	5/16/2012 10:10	127	250	159	Valid	0	34.00130	-80.95760	34.00087	-80.95771
29	1	16	1	17	5/16/2012 10:18	159	250	166	Valid	0	34.00130	-80.95760	34.00085	-80.95768
30	1	16	1	17	5/16/2012 10:27	79	350	373	Valid	4	34.00130	-80.95760	34.00230	-80.95782
31	1	16	1	17	5/16/2012 10:39	80	250	279	Valid	7	34.00155	-80.95730	34.00086	-80.95770
32	1	16	1	17	5/16/2012 10:44	79	350	407	Valid	6	34.00155	-80.95730	34.00265	-80.95706
33	1	16	1	17	5/16/2012 10:53	79	550	513	Valid	9	34.00372	-80.95596	34.00265	-80.95706
34	1	16	1	17	5/16/2012 11:05	80	550	532	Valid	10	34.00374	-80.95600	34.00507	-80.95528
35	1	16	1	17	5/16/2012 11:15	79	150	81	Valid	7	34.00507	-80.95502	34.00507	-80.95528
36	1	16	1	17	5/16/2012 11:26	79	250	261	Valid	6	34.00507	-80.95500	34.00576	-80.95479
37	1	16	1	17	5/16/2012 11:36	80	50	20	Close	7	34.00579	-80.95485	34.00576	-80.95479
38	1	16	1	17	5/16/2012 11:51	159	350	401	Valid	0	34.00567	-80.95493	34.00670	-80.95448

Table 1 (cont.): Sewer Line Assessment Results Fort Jackson
SL-RAT Measurements Conducted from May 16, 2012 to May 16, 2012
(RX: Receiver Unit; TX: Transmitter Unit)

Meas. ID	RX Oper. ID	RX HW ID	TX Oper. ID	TX HW ID	Date & Time	Meas. Duration (sec)	Oper. Pipe Length (ft)	Eval. Pipe Length (ft)	Meas. Status	Assessment (0-Blocked; 10-Clean)	RX Latitude (dec. deg.)	RX Longitude (dec. deg.)	TX Latitude (dec. deg.)	TX Longitude (dec. deg.)
39	1	16	1	17	5/16/2012 11:53	80	350	411	Valid	10	34.00567	-80.95493	34.00673	-80.95447
40	1	16	1	17	5/16/2012 12:04	79	450	416	Valid	8	34.00774	-80.95383	34.00673	-80.95447
41	1	16	1	17	5/16/2012 12:27	79	250	251	Valid	10	34.00774	-80.95383	34.00842	-80.95396
42	1	16	1	17	5/16/2012 12:36	80	350	334	Valid	7	34.00923	-80.95344	34.00842	-80.95396
43	1	16	1	17	5/16/2012 12:42	79	250	248	Valid	10	34.00923	-80.95344	34.00962	-80.95277
44	1	16	1	17	5/16/2012 12:51	79	250	201	Valid	9	34.01017	-80.95280	34.00962	-80.95277
45	1	16	1	17	5/16/2012 13:06	80	250	311	Valid	9	34.01017	-80.95280	34.01091	-80.95229
46	1	16	1	17	5/16/2012 13:14	79	350	308	Valid	6	34.01128	-80.95138	34.01091	-80.95229
47	1	16	1	17	5/16/2012 13:26	79	550	575	Valid	3	34.01128	-80.95138	34.01283	-80.95107
48	1	16	1	17	5/16/2012 13:29	80	550	575	Valid	3	34.01128	-80.95138	34.01283	-80.95107
49	1	16	1	17	5/16/2012 13:37	79	450	432	Valid	6	34.01358	-80.94997	34.01283	-80.95107
50	1	16	1	17	5/16/2012 13:46	111	350	389	Valid	0	34.01358	-80.94997	34.01465	-80.94997
51	1	16	1	17	5/16/2012 13:50	159	350	389	Valid	0	34.01358	-80.94997	34.01465	-80.94997
52	1	16	1	17	5/16/2012 13:58	80	150	46	Valid	9	34.01477	-80.94996	34.01465	-80.94997
53	1	16	1	17	5/16/2012 14:11	79	450	457	Valid	4	34.01477	-80.94996	34.01542	-80.94867
54	1	16	1	17	5/16/2012 14:22	79	250	298	Valid	3	34.01624	-80.94867	34.01542	-80.94867

<u>Definitions for Table 1 columns:</u>

Meas. ID - (Measurement ID) Unique identification number for each SL-RAT receiving unit (RX).

RX Oper. ID – (Receiver Operator ID) Operator ID assigned to the operator by the SL-DOG system administrator and entered by the operator when login into the SL-RAT receiving unit (RX).

RX HW ID – (Receiver Hardware ID) Unique serial number assigned by InfoSense to the SL-RAT receiving unit (RX); RX serial numbers are even.

TX Oper. ID - (Transmitter Operator ID) Operator ID assigned to the operator by the SL-DOG system administrator and entered by the operator when login into the SL-RAT transmitting unit (TX).

TX HW ID - (Transmitter Hardware ID) Unique serial number assigned by InfoSense to the SL-RAT transmit unit (TX); TX serial numbers are odd.

Date & Time – Date and time of the SL-RAT measurement. Time is based on SL-RAT local time setting.

Meas. Duration – (Measurement Duration) Duration of the measurement as recorded by the SL-RAT receiver (RX). Measurement duration is in seconds.

Oper. Pipe Length – (Operator Pipe Length) Pipe length as entered by the SL-RAT receiver operator. This value is used in the pipe segment assessment. Pipe length is in feet.

Eval. Pipe Length – (Evaluated Pipe Length) Pipe length estimated by the SL-RAT unit.

Definitions for Table 1 columns (cont):

Meas. Status –(Measurement Status) the SL-RAT receiving unit (RX) evaluates the conditions under which the pipe assessment is conducted and provides a warning concerning possible limitations in the measurement as follows:

Measurement Status	Condition
Valid	No anomalies in the measurement conditions were detected
Early	The SL-RAT transmitter unit (TX) was stopped prior to the SL-RAT receiving unit (RX) completed its processing. The Pipe assessment maybe corrupted.
Late	The SL-RAT transmitter unit (TX) was started after the SL-RAT receiving unit (RX). The Pipe assessment maybe corrupted.
No TX	The SL-RAT transmitter unit (TX) was not turned on during SL-RAT receiving unit (RX) measurement. **The Pipe assessment is corrupted.**
Close	The SL-RAT transmitter unit (TX) and the SL-RAT receiving unit (RX) were too close during the measurement. The Pipe assessment maybe corrupted.
Noise	The SL-RAT receiver (RX) detected noise conditions which may impact the measurement. The Pipe assessment maybe corrupted.

Definitions for Table 1 columns (cont):

Assessment – Pipe assessment scaled from 0 to 10 with the following general interpretation:

Assessment	Typical Condition / Interpretation
10	No significant obstructions within the pipe
7-9	Minor impediments within the pipe such as joint offsets, partial sags, protruding laterals, debris, minor grease, and/or minor root fibers.
4-6	Impediments within the pipe such as joint offsets, partial sags, protruding laterals, debris, grease, and/or root fibers. Single or multiple occurrences.
1-3	Significant impediments within the pipe such as multiple joint offsets, near full pipe sag, multiple protruding laterals, significant debris, significant grease, significant root fibers and/or root balls. Single or multiple occurrences.
0	Full pipe sag; single or multiple obstructions within the pipe reaching or nearly reaching the flow.

RX Latitude – Global position system (GPS) latitude at the SL-RAT receiver (RX) unit at the time of the measurement; GPS RX measurement is in decimal degrees.

RX Longitude - Global position system (GPS) longitude at the SL-RAT receiver (RX) unit at the time of the measurement; GPS RX measurement is in decimal degrees.

TX Latitude - Global position system (GPS) latitude at the SL-RAT transmitter (TX) unit at the time of the measurement; GPS TX measurement is in decimal degrees.

TX Longitude - Global position system (GPS) longitude at the SL-RAT transmitter (TX) unit at the time of the measurement; GPS TX measurement is in decimal degrees.

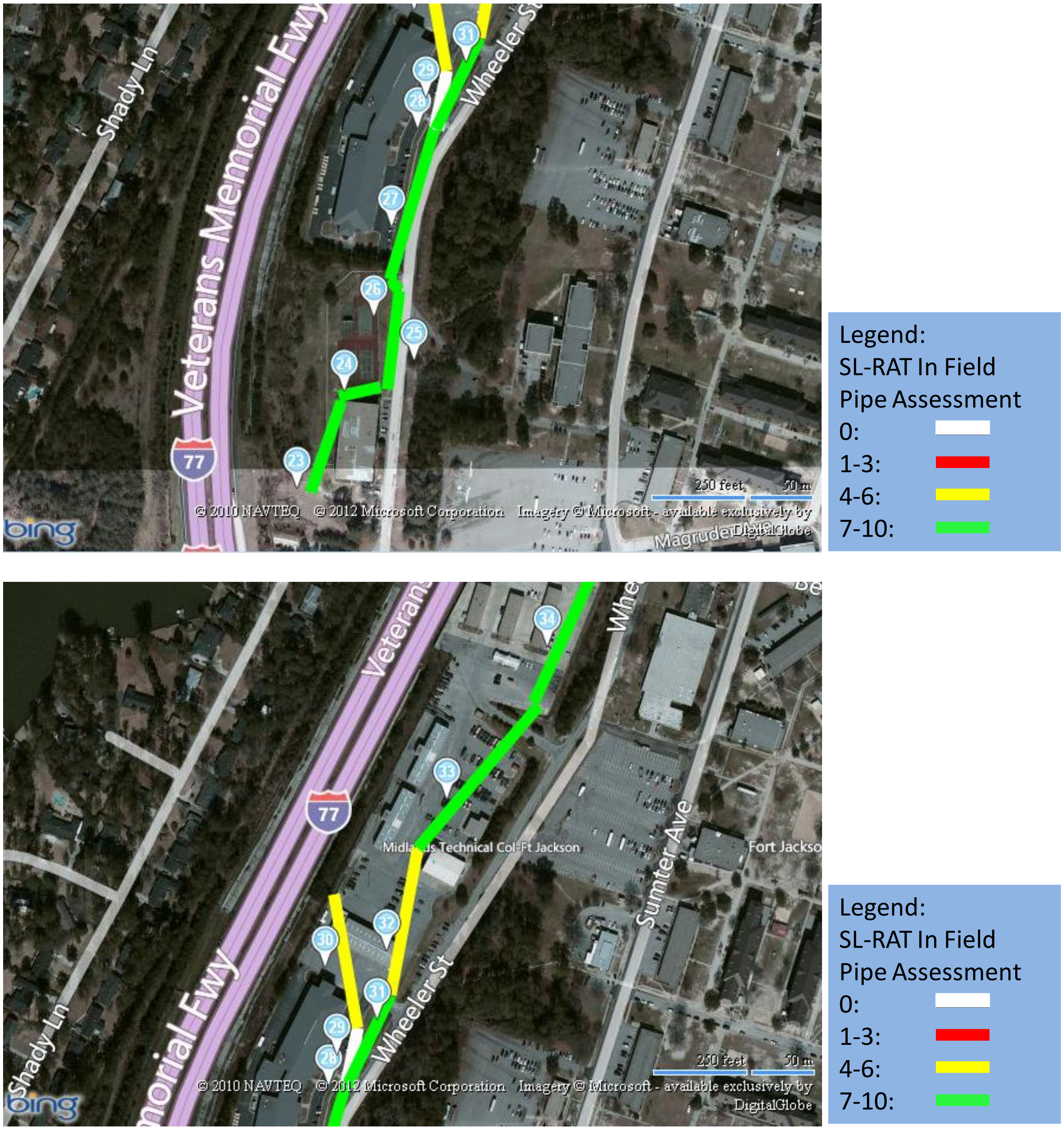

Figure 3. SL-RAT acoustic classification results overlaid on GIS map.

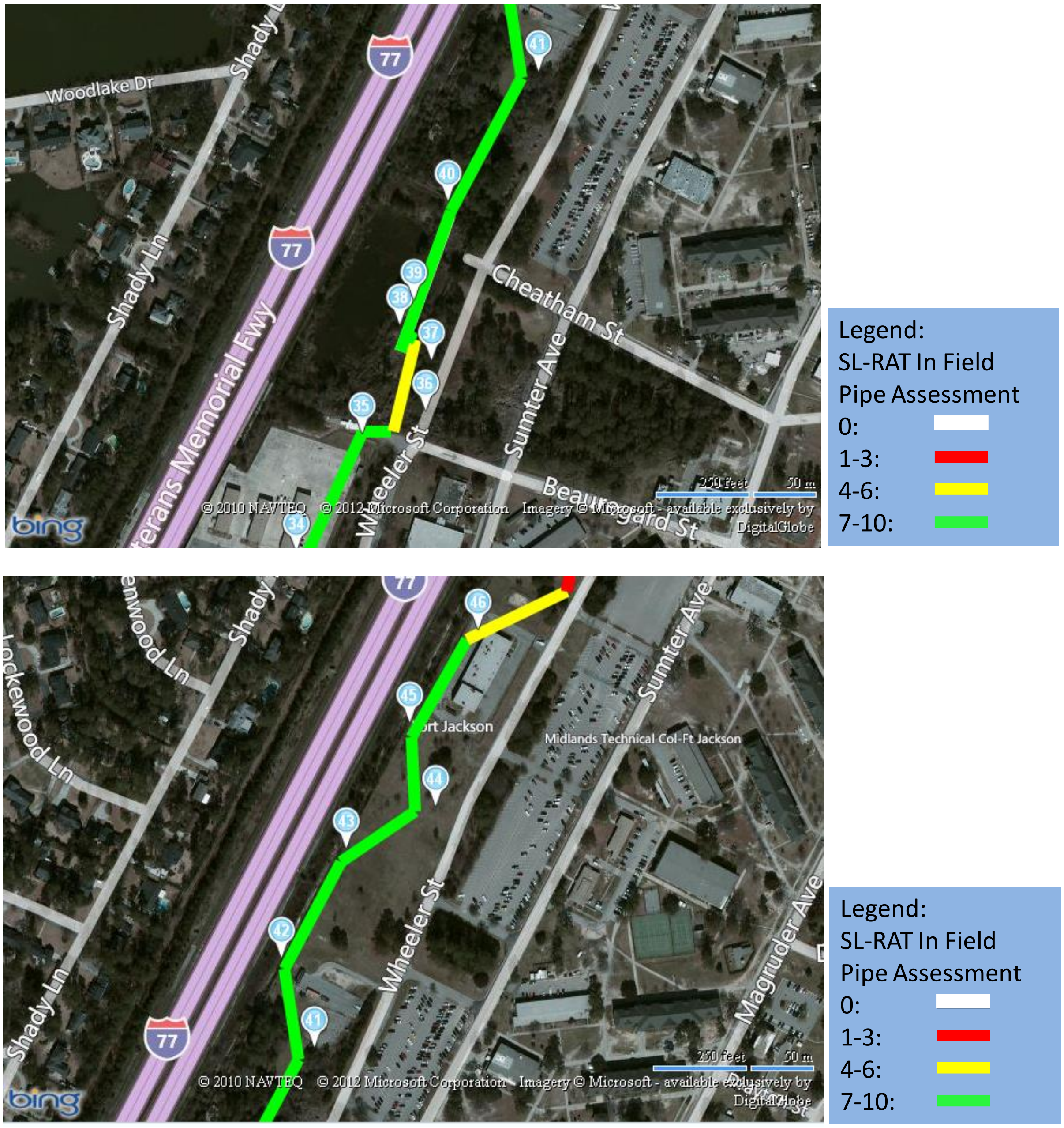

Figure 4. SL-RAT acoustic classification results overlaid on GIS map.

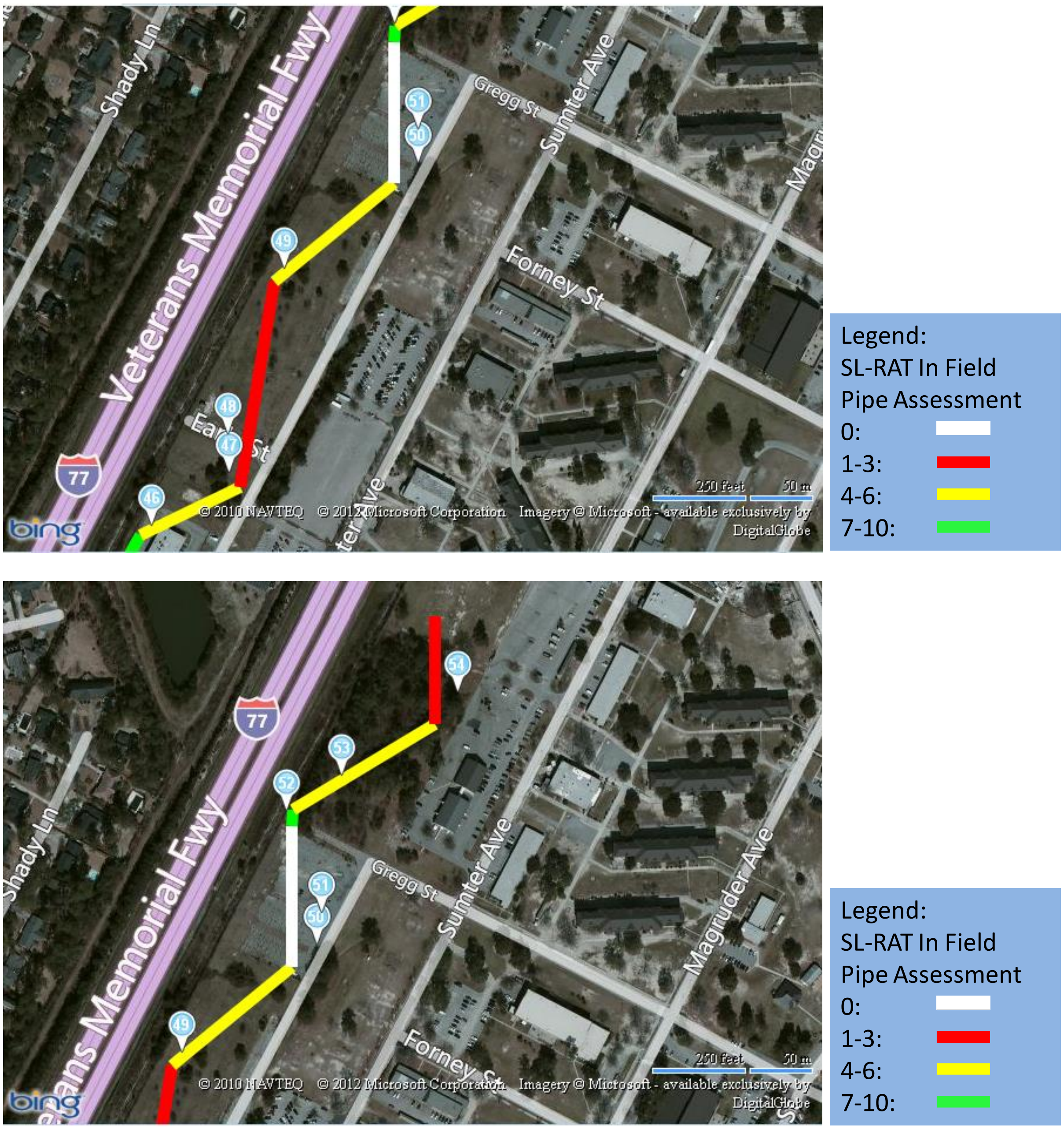

Figure 5. SL-RAT acoustic classification results overlaid on GIS map.

Table 2. Summary of CCTV and Acoustic Inspection Data

Sewer Line Segment (MH TO MH)	Pipe Condition and Notes	Pipe Length (m)	Pipe Diameter (cm)	SL-RAT Acoustic Score
31-21 TO 25-144	No issues	85	61	10
25-144 TO 25-143	No issues	38	61	8
25-143 TO 25-20	Grease buildup	79	61	9
25-20 TO 25-142	No issues	16	61	9
25-142 TO 25-19	No issues	127	61	9
25-19 TO 25-18	Cracks	90	61	7
25-18 TO 25-17	Cracks w/water infiltration, collapsing pipe, pipe shift	121	61	6
25-17 TO 25-264	Cracks	157	61	9
25-264 TO 25-15	Cracks	159	61	10
25-15 TO 25-14	Cracks, Grease buildup	31	61	7
25-14 TO 25-14A (INCL. JB-1)	No pipe issues. Verify depth of JB-1.	64	61	6
25-14A TO 19-139	No video	3	61	7
19-139 TO 19-138	No video	114	61	10
19-138 TO 20-137	To be video inspected. Replacement/refurbishment method TBD	126	61	8
20-137 TO 19-0	No issues	85	61	10
19-0 TO 20-136	To be video inspected only	107	61	7
20-136 TO 20-135	No issues	71	61	10
20-135 TO 20-1628	Cracks, negative/flat slope	71	61	9
20-1628 TO 20-134	To be video inspected only	88	61	9
20-134 TO 20-1627	Cracks, broken pipe pieces, root intrusion	105	61	6
20-1627 TO 20-1648	Cracks, root infiltration/growth, broken pipe pieces, pipe collapse (top)	168	61	3
20-1648 TO 14-130	Steel pipe inserted	136	61	6
14-130 TO 14-1626	Cracks, broken pipe pieces, pipe shift, steel pipe inserted, grease buildup/clog	108	61	0
14-1626 TO 14-129	To be video inspected only	36	61	9
14-129 TO 14-120A	Cracks, pipe shifts, major root intrusion	123	45.7	4
14-945 TO 14-120A	Cracks, major root intrusion	89	45.7	3

DISCUSSION

Figure 6 shows some video snapshots and the corresponding acoustic segment scores.

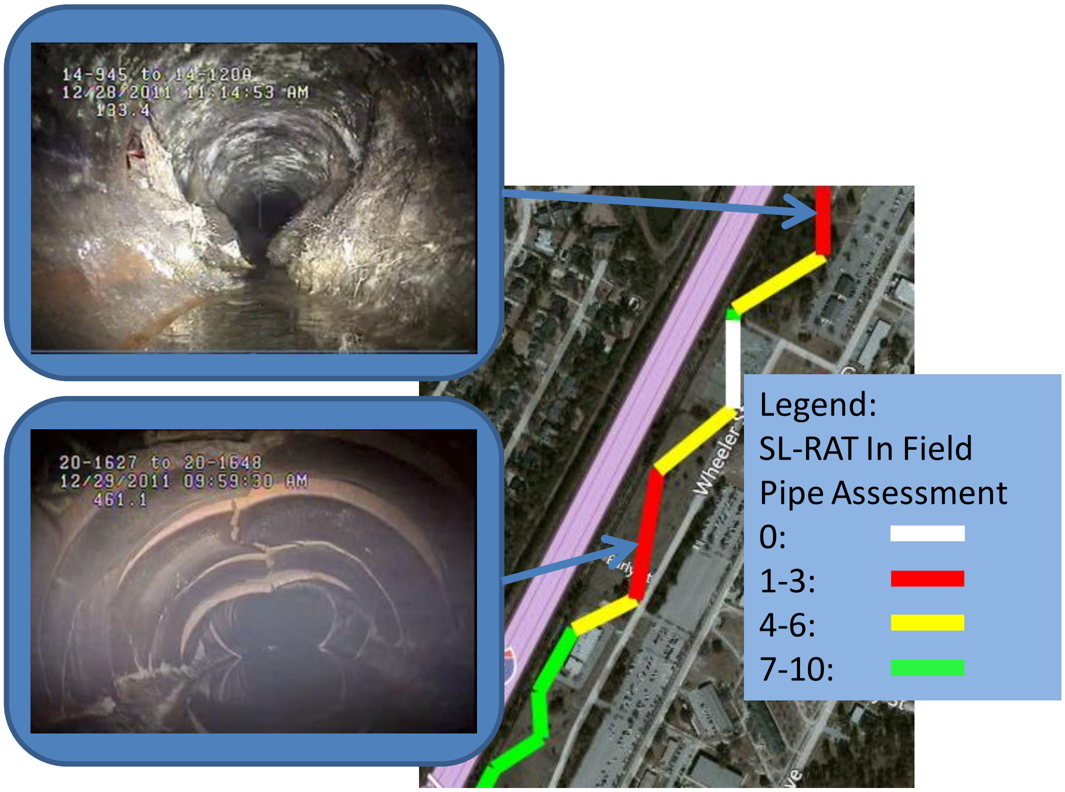

Figure 6. Correlation of SL-RAT and CCTV Results

The SL-RAT condition assessment is affected by the available cross-sectional area throughout the pipe segment. As seen in the snapshots in Figure 6, when the cross-sectional area is obstructed by either a grease blockage or structural failure, the assessment score is reduced. For pipes with major issues (collapsed pipe or major obstructions to flow), the SL-RAT device proved to be an effective prioritization tool. Any pipes with low acoustic scores were confirmed by CCTV inspection to need immediate attention.

The Ft. Jackson acoustic inspection campaign provided the opportunity to assess the SL-RAT's assessment performance in larger diameter pipes, 46 to 61cm. Prior acoustic inspection campaigns were predominantly in 15-30cm (6-12 inch) pipes. The following observation was made and provides insight into interoperating the results for larger diameter pipes. As indicated above the acoustic assessment is influenced by the pipes available cross sectional area throughout the pipe segment. Since the cross sectional area is proportional to the square of the pipe's radius, increasing the diameter from a 20.3cm (8 inch) to 61cm (24 inch) provides a nine fold increase in area. In addition, as the pipe radius increases, to achieve the same degree of blockage requires a proportional increase in the observed blockage. To illustrate, within a 20.3cm pipe a 25% reduction in cross sectional area occurs with a 1.3cm (0.5 inch) radial blockage uniformly distributed from the circumference of the pipe. Correspondingly, in a 61cm pipe the blockage required is 4cm (1.5 inch) or 3 times the blockage. Therefore, when evaluating the CCTV, medium priority issues such as partial obstructions due to grease or other debris, the acoustic scores for this inspection campaign could be interpreted as being higher than would be typically obtained for 15-30cm (6-12 inch) pipes. Therefore, when inspecting pipes with a larger diameter than 30cm (12 inches), a more conservative (higher) threshold should be used to identify pipes that need more detailed inspection. As an example, when inspecting 15-30cm pipes, the cleaning/CCTV threshold might be a “3” (clean pipes with an acoustic score of 3 or lower), whereas in a 61cm (24 in) diameter pipe, this threshold should be closer to an acoustic score of “6” or “7”.

CONCLUSION

Acoustic inspection data matched up well with the corresponding CCTV inspection results, including the identification of significant structural problems. Overall, acoustic inspection proved to be a valuable tool for performing preliminary inspection of sanitary sewer lines, and the inspection results can be used to help prioritize renewal and replacement projects. The SL-RAT device was effective at identifying major issues in the medium diameter pipes (45.7-60cm, 18-24in). It is recommended that a more conservative (higher) threshold be used for acoustic scores in larger pipes, since there is more area for sound to travel around obstructions in these pipes.

REFERENCES

Ivan Howitt, John Fishburne, “Rethinking collection system cleaning using acoustic inspection,” WEFTEC 2012.