

Field Demonstration of Electro-Scan Defect Location Technology for Condition Assessment of Wastewater Collection Systems

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ABSTRACT

A USEPA-sponsored field demonstration program was conducted to gather technically reliable cost and performance information on the electro-scan (FELL -41) pipeline condition assessment technology. Electro-scan technology can be used to estimate the magnitude and location of potential leaks along a pipeline, helping utilities better understand and control sources of infiltration/exfiltration. It directly measures leak potential, independent of external conditions that are temporal in nature (e.g., seasonal, wet weather). Its use of direct measurements provides a quantitative analysis of leak potential without relying on visual observation.

The field demonstration was conducted in Kansas City, MO in August 2010 in areas of the collection system with known operational issues due to root intrusion and inflow/infiltration (I/I). The project was part of a USEPA research program "Innovation and Research for Water Infrastructure for the 21st Century." The program was implemented by the USEPA Office of Research and Development to generate science and engineering knowledge to help utilities reduce the cost and improve the effectiveness of operation, maintenance, and replacement of aging drinking water and wastewater treatment and conveyance systems.

This paper provides an overview of field demonstration results for the electro-scan (FELL-41) technology and compares them to observations obtained using traditional in-line closed-circuit television (CCTV) inspection. Electro-scan technology uses the variation of electric current flow through the pipe wall to identify pipe defects that are potential leaks. The standard practice is fully described in the ASTM standard F2550-06. It can be used in non-conductive (i.e., non-ferrous) gravity sanitary and combined sewer mains, and service laterals. The field demonstration was carried out in an area with small diameter (8-in. and 10-in.) vitrified clay pipe. Electro-scanning was performed under fully surcharged conditions, which was accomplished by using a sliding pipe plug in conjunction with a jet truck. Technology performance was measured in terms of versatility, accuracy, repeatability, and inspection time/production rate. Results were compared to a baseline condition assessment completed using traditional in-line CCTV inspection. The evaluation of the total cost included factors such as planning, mobilization, field inspection, and reporting.

Electro-scanning identified an average of 17 defects per pipe segment, although most were determined to be small defects (defined as anomalies with an amplitude of 1 to 4). It identified more leakage-related defects than CCTV and in some cases, detected different defects than CCTV. Electro-scanning technology did not detect all line breaks identified by CCTV, some of which may be stressed areas that may progress toward leakage. Electro-scanning can provide information on leak potential that is complementary to CCTV observations. While CCTV provided visual identification of pipe features, electro-scanning results were used to interpret defect severity and to better understand whether a defect poses a serious infiltration or exfiltration problem.

KEYWORDS

Condition assessment, asset management, inspection, sewer rehabilitation, demonstration.

INTRODUCTION

Condition assessment is an integral part of a utility's asset management program. Reliable information on pipe condition is needed to accurately estimate the remaining service life of each asset and to prioritize rehabilitation and replacement projects. These data needs are especially urgent given the current state of our nation's infrastructure. To help utilities improve their condition assessment programs, the U.S. Environmental Protection Agency (USEPA) is conducting research under the Aging Water Infrastructure program, which is part of the USEPA Office of Water's Sustainable Infrastructure Initiative. This paper presents results from a field demonstration program conducted as part of a three-year research project titled *Condition Assessment of Wastewater Collection Systems*.

Although inspections with conventional closed-circuit television (CCTV) have been the mainstay of pipeline condition assessment practice for decades, other technologies are now commercially available and may provide improved and/or complementary information to CCTV. As part of the overall program, five such innovative technologies were selected for field trials: zoom camera, electro-scanning, digital scanning, laser profiling, and sonar. This paper presents the results for the electro-scanning technology.

ELECTRO-SCANNING TECHNOLOGY

Electro-scanning technology uses electrical current to identify pipe defects that are potential leaks in non-ferrous pipes (e.g., clay, plastic, concrete, reinforced concrete, and brick). It can be used to estimate the magnitude and location of potential leaks, helping utilities to better understand and control sources of infiltration and exfiltration. Drawbacks to applying this technology include its inability to directly determine the cause of a pipe defect (e.g., misaligned joints, pipe cracks, defective service connections) or the defect's position around the pipe circumference. However, with the assistance of computer processing, the output can discriminate between defects that are due to faulty joints, service connections, manhole connections, and structural defects such as pipe cracks. The computer processing also provides information on defect size.

Electro-scanning is performed using a standardized testing protocol that is described in the American Society for Testing and Materials (ASTM) standard F2550-06 (ASTM, 2006). The electro-scan is carried out by applying an electric voltage between an electrode in the pipe, called a sonde, and an electrode on the surface, which is usually a metal stake pushed into the ground. The high electrical resistance of the pipe wall inhibits electrical current from flowing between the two electrodes unless there is a defect in the pipe, such as a crack, defective joint, or faulty service connection.

Electro-scanning registers only those defects that are covered by water in the pipe. If the pipe is partially filled, then the data represent the portion of the pipe circumference that is under water. To inspect the entire circumference of pipes that are typically not surcharged (e.g., gravity sewers), the pipe must first be filled with water at the location of the sonde using one of two methods. The more common method for pipe diameters of 12-in. or less, which was used in this project, employs a

sliding pipe plug. The sonde is attached to the upstream side of the plug (i.e., behind the plug). The upstream portion of the pipe is filled with water so that the sonde is submerged and the pipe surcharged. Then the plug and attached sonde are pulled through the pipe at a rate of 30 ft/min. Output from a pressure gauge in the sonde is monitored at the recording computer to ensure that the pipe remains surcharged at a level of 20% to 100% of the pipe diameter at the location of the sonde. The second method involves plugging the downstream manhole and filling the pipe with enough water such that the pipe is covered at the upstream manhole. This method can increase the set-up time by 20% to 50% and care must be taken to ensure that sewage does not back up to a hazardous degree into service laterals. Consequently, pipe plugging is usually only used in pipe diameters greater than 12-in. These larger diameter pipes usually have greater natural flow, reducing the time required to surcharge the pipe. .

Figure 1 is a photo of the electro-scanning components.

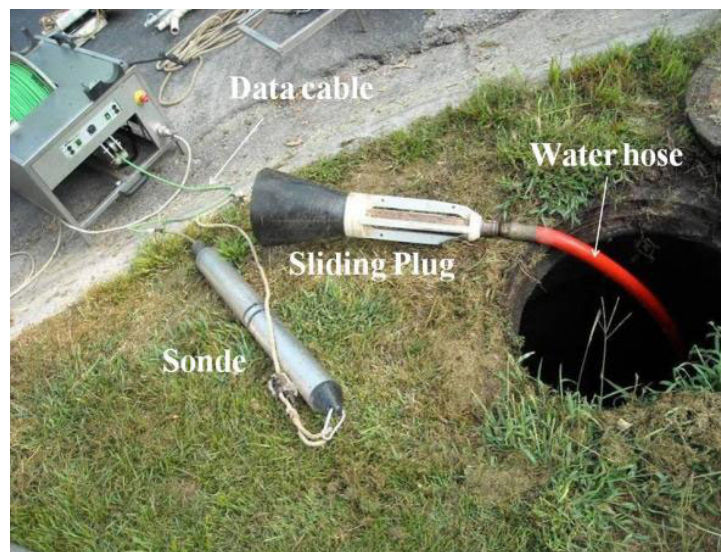


Figure 1. Electro-scan components.

As the sonde is pulled through the pipe, the electric current flow between the surface electrode and the sonde is measured and automatically recorded on a computer at approximately 0.5-in. intervals along the pipe. For sewer pipe materials that have high resistance to electrical current, there is only a small current flow except where there is a pipe defect. As the center of the sonde approaches within about an inch of a pipe defect, the current from the focused electrode increases, reaching a maximum when the center of the sonde is radially aligned with a defect.

Results of electro-scanning are graphed to show the electric current level (in units of 0.0001 Amp) plotted against the distance along the pipe. An example is shown in Figure 2. Levels of the measured electrical current greater than a threshold level are called anomalies and typically appear as spikes on the electro-scan. The shape and amplitude of these anomalies are interpreted to define the type and severity of each defect. Previous studies (e.g., Harris and Tasello, 2006) are used to distinguish between electrical currents that represent normal conditions (i.e., no defect) versus an anomaly (i.e., a potential pipe leak). For example, if pipe joint intervals are known and can be superimposed on the electrode current graph, anomalies that coincide with these joint locations would point to leaky joints. Anomalies that do not match joint locations may represent structural

defects (e.g., cracks in the pipe) or leaks at service connections. The categorization of the magnitude of the anomaly (e.g., small, medium, large) is based on a comparison of electro-scanning results with pressure testing results for pipe joints (Harris and Tasello, 2006). Anomalies with amplitude of 1 to 4 are classified as small defects while anomalies with amplitude of 4 to 7 and greater than 7 are classified as medium or large defects, respectively. Figure 2 shows the computer processed current trace for a pipe segment, with distance along the pipe on the horizontal axis and current level on the vertical axis. The line of crosses at the top represents joint locations. The graph displays numerous small joint defects (diamonds overlain on the crosses), as well as manhole entry defects, a faulty service connection at 73.2 ft, and a large pipe defect at 134.9 ft. The blue line shows total electric current.

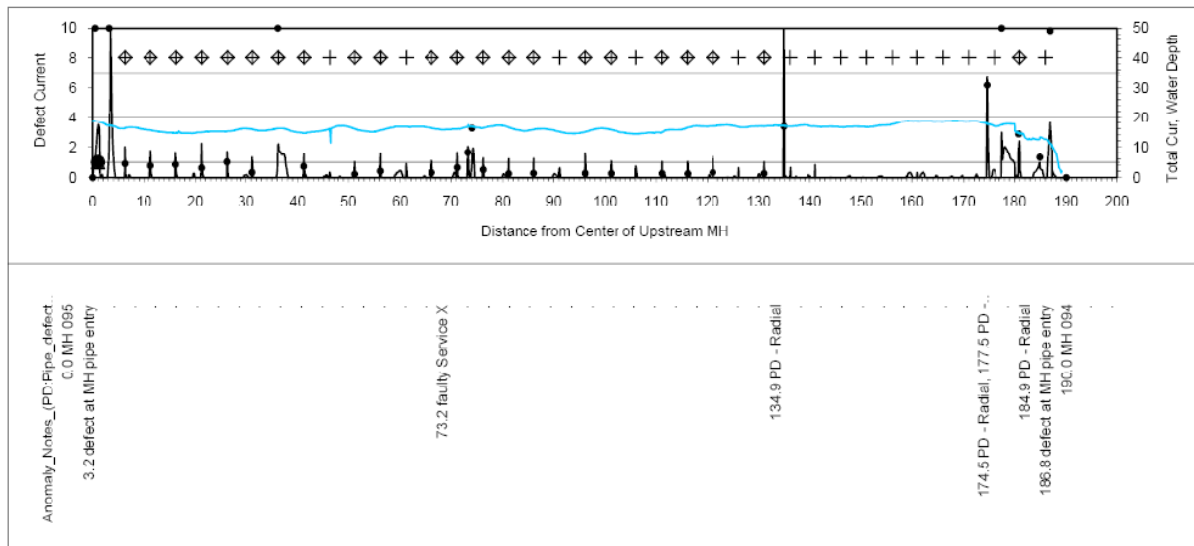


Figure 2. Electro-scanning results for the pipe segment MH 095 to MH 094.

FIELD DEMONSTRATION PROGRAM

The goal of the field demonstration was to evaluate the technical performance and cost of electro-scanning condition assessment technology as compared to conventional CCTV inspection. Specific objectives for the electro-scanning demonstration were to evaluate the capability of electro-scanning to discriminate among types of defects that can leak and to illustrate how the information collected by electro-scanning compares to the information obtained by CCTV.

The field demonstration was conducted during the week of August 23, 2010. The electro-scan demonstration was performed in the Gracemor area of the Kansas City, MO wastewater collection system. This is a residential area with predominantly 8-in. vitrified clay pipe (VCP). Traditional CCTV inspection was also performed as a baseline from which to compare other findings. During the demonstration, a total of 8,807 ft of pipe was inspected.

The contractor (Burgess and Niple, Inc. (B&N), Dallas Texas) used two electro-scanning models for this project: Focused Electrode Leak Locator (FELL-41) manufactured by Metrotech Corporation of Santa Clara, California and the MSI-1620 unit manufactured by Mount Sopris

Instruments of Denver, Colorado. The FELL-41 was the primary electro-scanning equipment being evaluated. The MSI-1620, a prototype instrument provided by Mount Sopris Instruments, was used in three pipe segments to compare results with the FELL-41. This paper only discusses results from the FELL-41 unit.

The only equipment calibration required was the daily setting of the atmospheric pressure to ensure accuracy of the sonde's pressure transducer. The distance between the manholes of the pipe segment being scanned was determined using a measuring wheel.

RESULTS

Defects Detected

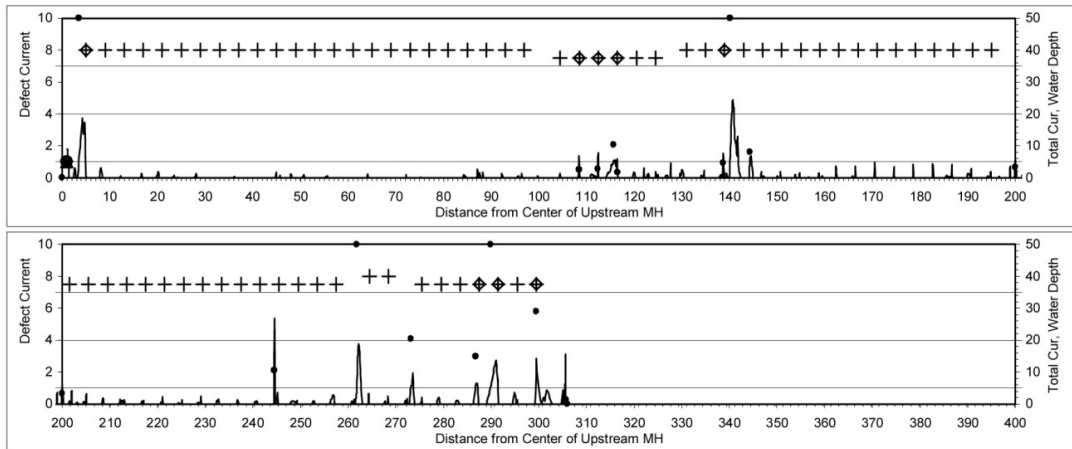
Electro-scanning identified an average of 17 defects per pipe segment, although most were determined to be minor defects. The electro-scanning results suggest that all of the pipe segments inspected for this project have defects that are potential sources of infiltration or exfiltration. Key results are as follows:

- **Overall:** About 87% of anomalies were considered to represent small defects as defined by their amplitude. When the anomalies were normalized as a percentage of pipe length, it was determined that an average of 3.7% of the pipe length consisted of areas of potential leakage.
- **Joint Defects:** 43% of all anomalies were interpreted to be caused by faulty pipe joints. Nine of the 36 pipe segments scanned (25%) showed more than 20% of their joints with defects. Most of these defects showed an amplitude level of less than 3. Consequently, the pipe joints were shown to be in generally good condition and are considered to be a minor potential source of infiltration/exfiltration.
- **Service Connections:** 87% of the service connections detected showed defects. The amplitude of the defect peaks ranged from small to medium. It was concluded that the service connections are in poor condition and considered to be a significant source of infiltration and exfiltration.
- **Manhole Connections:** 74% of the manhole pipe penetrations showed defects. The amplitude of the defects ranged from small to large. The manhole penetrations were shown to be in poor condition and are likely a major source of infiltration and exfiltration. It was also noted that the first and second pipe joint in the majority of segments showed defects. This may be attributed to settlement at the manholes.

Reproducibility

The reproducibility of the electro-scanning results was evaluated by duplicate inspections of the pipe segment from sanitary manhole (SMH) 101 to SMH 100, which was 306 ft long (Figure 3).

Scan A: Pipe segment 101 to 100 with ground stake 10 ft from manhole 101 on sewer line



Scan B: Pipe segment 101 to 100 with ground stake 30 ft from manhole perpendicular to sewer line

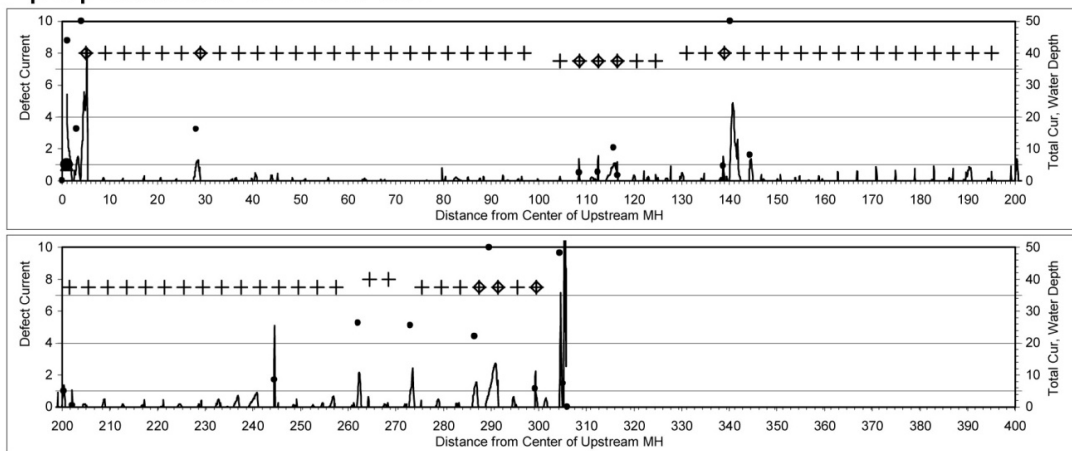


Figure 3. Duplicate electro-scans for pipe segment MH 101 to MH 100.

The two scans were very similar; scan B revealed only three more defects than scan A. The observed differences in results may be attributed to changes in the sonde's travel rate, which occurred at the start and end of the scan. The high current at the end of the second scan may have been caused by a steel pole used to move the probe into the middle of the downstream manhole. Although the ground stake placement varied between the two scans, it was not expected to affect the results.

Cost

The total cost of the electro-scanning inspection at Gracemor was \$28,900 including \$11,000 for planning and mobilization from Dallas, TX to Kansas City, MO; \$11,800 for field work, and \$6,000 for data analysis and reporting. The total cost (\$28,881) per total length of pipe assessed (9,784 ft) was \$2.95 per ft.

DISCUSSION AND COMPARISON TO CCTV

The number, type, and severity of defects found by CCTV and electro-scanning were compared for 17 pipe segments (Table 1). This table includes only CCTV defects that are potential sources of leakage (e.g., joints, taps, manholes, pipe defects). In this way, the table provides a direct comparison of how CCTV and electro-scanning performed in detecting sources of potential infiltration. The defects identified by CCTV are summarized by type (e.g., structural (S), maintenance (M)) and PACP (Pipeline Assessment Certification Program; NASSCO, 2001) grade, which indicates severity. PACP grades begin with “M” or “S” for maintenance or structural defect, respectively, followed by a numeric code (1 – 5) for severity, with 5 being most severe. The severity of pipe defects identified by electro-scanning are determined to be small, medium, or large depending on the electrical current level of the anomaly. Electro-scanning results explicitly identify anomalies near the ends of the segments and manhole entry defects. For the purposes of the comparison in Table 1, CCTV defects less than 5 ft from the starting and ending manholes are recorded as manhole defects. This is roughly within the range of distances of electro-scanning manhole defects from the manholes. The “miscellaneous” group shown for electro-scanning includes secondary peaks associated with defective taps or manhole entry defects.

Table 1. Number, Type, and Severity of Pipe Defects Identified by CCTV and Electro-Scanning that May Indicate Leakage

| Pipe Segment | CCTV | | | | | Electro-scanning | | | | | |
|---------------------------------|----------------------|--------------|--------------|----------|---------------|------------------|---------------|------------|-------------------|------------|---------------|
| | Joints | Taps | Pipe Defect | MH Entry | Total Defects | Joints | Miscellaneous | Taps | Pipe Defect | MH Entry | Total Defects |
| SMH 95-94 (No. 12) | M1-5 M3-1 M4-1 | | S4-1 | | 8 | S-22 | S-1 | S-1 | S-2 M-1 L-1 | L-1 S-1 | 30 |
| SMH 96-95 (No. 31) | M1-2 M3-1 | M2-8 M3-2 | S3-1 S4-1 | S2-2 | 17 | S-5 | S-2 | S-6 | S-5 | S-1 L-1 | 20 |
| SMH 102-101 (No. 15) | M2-1 | M2-1 | S4-1 | S4-1 | 4 | S-4 M-1 | S-1 | | S-1 L-1 | S-1 L-1 | 10 |
| 103-102 (No. 11) | | | | | 0 | S-5 | | S-5 | S-1 | S-2 | 13 |
| SMH 104-102 (No. 30) | M1-1 | M2-2 M3-3 | S2-1 | S2-1 | 8 | S-4 L-1 | S-1 | S-1 | S-1 M-2 | L-2 | 12 |
| SMH 106-105 (No. 29) | M1-2 | | S2-2 S5-1 | S3-1 | 6 | S-8 L-1 | | | S-1 | M-1 | 11 |
| SMH 107-106 (No. 28 cleaned) | | | S4-1 | | 1 | S-3 | | | S-5 L-2 | S-1 | 11 |
| 114-107 (No. 22 cleaned) | M1-1 | M2-3 | | S4-1 | 5 | S-14 | S-3 | S-2 | S-5 | M-1 S-1 | 26 |
| 115-114 (No. 23 cleaned) | | M2-1 M3-1 | S2-1 | | 3 | S-14 | S-4 | M-1 S-3 | S-3 | S-2 | 27 |
| SMH 116-115 (No. 25 cleaned) | M1-3 | M2-3 M3-3 | S2-1 S3-2 | S2-1 | 17 | S-7 | S-2 | S-2 | S-2 M-1 | S-2 | 17 |

| Pipe Segment | CCTV | | | | | Electro-scanning | | | | | |
|---------------------------------|--------------|--------------|------------------------------|--------------|---------------|------------------|---------------|------------|-------------|------------|---------------|
| | Joints | Taps | Pipe Defect | MH Entry | Total Defects | Joints | Miscellaneous | Taps | Pipe Defect | MH Entry | Total Defects |
| | | | S4-4 | | | | | | L-1 | | |
| SMH 117-116 (No. 24 cleaned) | M1-1 | M3-1 | S3-2 | S1-1 | 5 | S-1 | | S-2 | | S-1 | 4 |
| 118-117 (No. 19) | M1-3 | M2-3 | S2-1 S3-1 S4-1 | S2-1 S4-1 | 11 | S-1 M-1 | S-2 | S-4 | S-2 | M-1 S-1 | 12 |
| SMH 119-118 (No. 22 cleaned) | M1-1 | M2-2 M3-1 | S1-1 S2-1 S4-1 S5-1 | | 8 | S-2 M-1 | S-2 | S-1 M-1 | S-3 | S-1 M-1 | 12 |
| SMH 120-119 (No. 21 cleaned) | M1-2 | M2-1 M3-2 | S3-1 S4-2 S5-1 | | 9 | L-1 S-7 | S-5 M-1 | L-1 S-3 | L-1 | S-1 | 20 |
| SMH 125-116 (No. 20 cleaned) | | M2-2 M3-1 | S4-1 S5-1 | | 5 | S-17 | S-2 | S-2 M-1 | S-2 L-1 | S-1 M-1 | 27 |
| 127-125 (No. 15) | M1-1 M4-1 | M2-1 M3-2 | S1-1 S2-1 S4-1 | | 8 | L-1 S-6 | S-6 | S-4 | S-4 | S-2 | 23 |
| 128-127 (No. 13) | M4-1 | M2-1 M3-1 | S5-1 | M2-1 | 5 | S-4 | S-1 | S-2 | S-4 | L-1 S-1 | 13 |
| Total | 28 | 45 | 36 | 11 | 120 | 131 | 33 | 42 | 52 | 30 | 288 |

SMH = sanitary manhole; No. = number; MH = manhole.

For CCTV results, S = structural; M = maintenance. Each code is assigned a severity grade from 1 to 5 based on PACP grading system. The number after the dash represents the number of defects of that type and severity. For electro-scanning results, S = small; M = medium; L = large. Numbers after dashes represent number of defects of that type. MH entry indicates a defect at the entry of the pipe into the manhole.

For individual pipe runs, electro-scanning frequently registered more leakage-related defects than CCTV. Overall, the total number of electro-scanning defects was more than twice the number of CCTV defects. This is due in part to electro-scanning detecting small defects at more joints (28 for CCTV vs. 131 for electro-scanning). Because CCTV cannot “see” into the joint, joint defects are identified visually by the presence of roots; if a pipe is not in the vicinity of trees or has been cleaned prior to inspection, the ability of CCTV to identify joint defects is diminished. At this field site, there were abundant trees close to the pipes. Some pipe segments, as noted in Table 1, were cleaned prior to inspection to cut roots and remove sediment. Electro-scanning also identified more manhole defects than CCTV. Because these defects are difficult to identify visually by CCTV, this result is not surprising.

The tap and pipe defects identified by both CCTV and electro-scanning show similar totals, and values for individual pipes are roughly similar. This suggests that both technologies are effective at identifying certain types of defects. Electro-scanning can also detect leakage at taps that do not appear defective by CCTV, as discussed below.

Figures 4 – 9 provide a qualitative side-by-side visual comparison of the correspondence between leakage-related data obtained by CCTV and electro-scanning for six of the 17 segments for which data were acquired using both technologies. These segments were chosen to provide representative examples, with varying quantities of defects. These comparisons are made with the understanding that the distances along the pipe segment shown by CCTV and electro-scan may not exactly

correspond. Each diagram shows electro-scanning results. Superimposed on the electro-scan are triangle symbols (Δ) that are at the tap locations shown by the CCTV inspection, open diamonds (\diamond) that are at the locations of the CCTV maintenance defects that indicate potential leakage, and filled diamonds (\blacklozenge) that represent CCTV structural observations. These are plotted on the horizontal axis according to the severity grade. Data labels to the right note the description of the electro-scanning anomalies and the PACP codes (e.g., TBD; RFJ) and severity ratings for CCTV defects. For the PACP codes, “T” represents a tap, “R” represents roots, “J” indicates a joint, and “C”, “F”, and “B” indicate cracks, fractures, and breaks. Other letters in the PACP codes provide additional description. For electro-scanning descriptions, “PD” denotes a pipe defect such as a crack.

Pipe Segment: MH 096 to 095

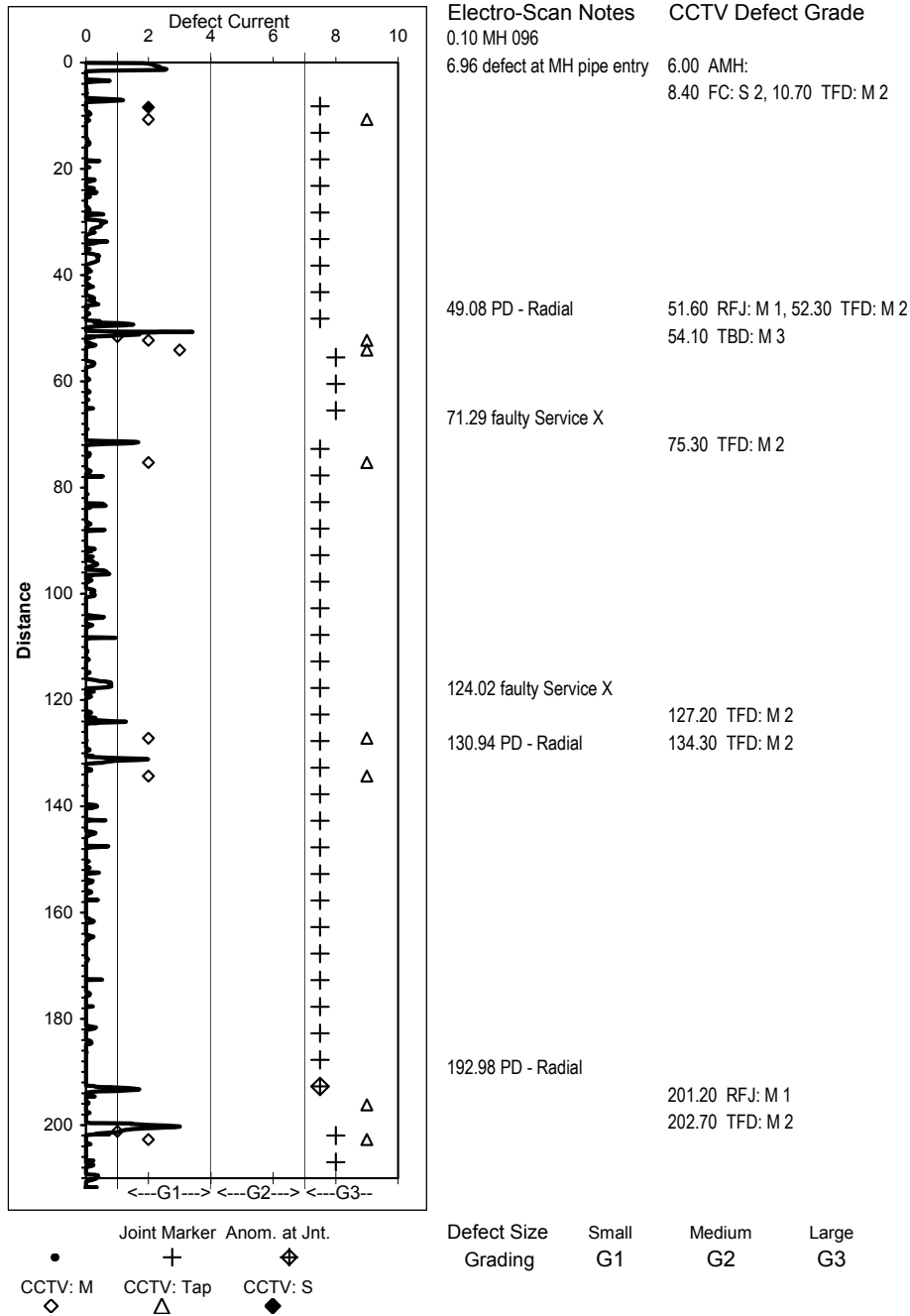


Figure 4. Comparison of CCTV and electro-scanning for pipe segment 96-95

Pipe Segment: MH 104 to 102

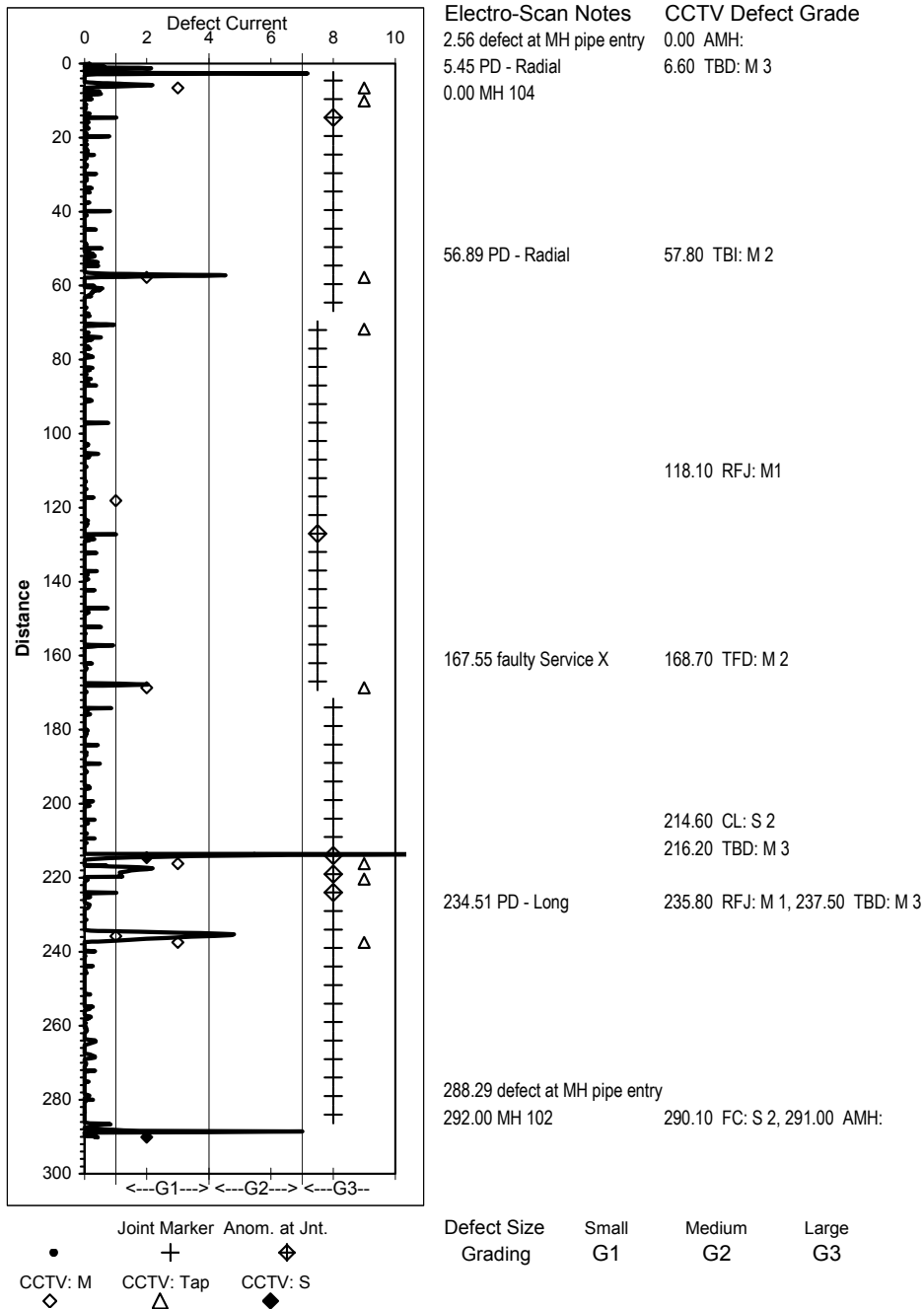


Figure 5. Comparison of CCTV and electro-scanning for pipe segment 104-102

Pipe Segment: MH 116 to 115

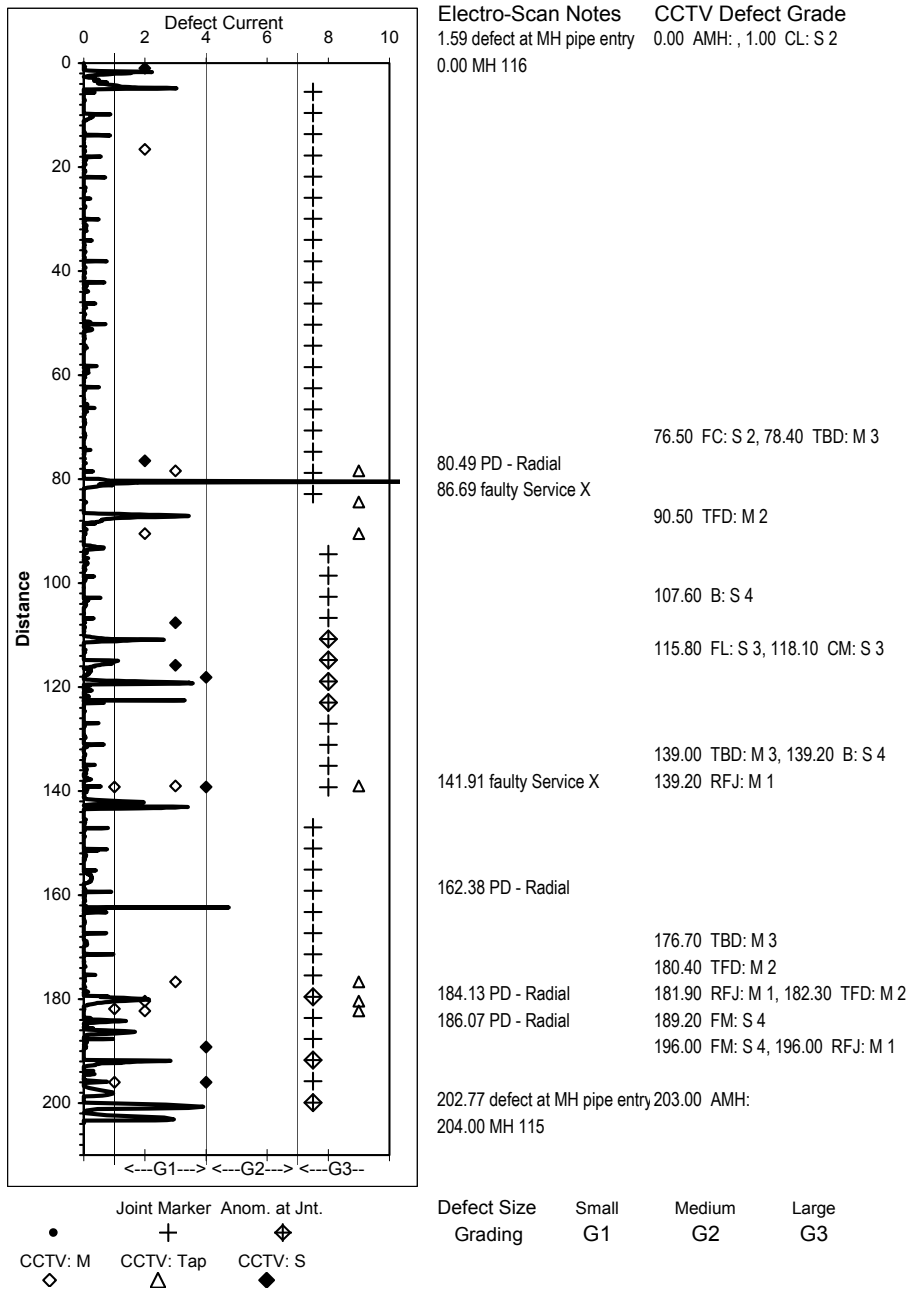


Figure 6. Comparison of CCTV and electro-scanning for pipe segment 116-115

Pipe Segment: MH 117 to 116

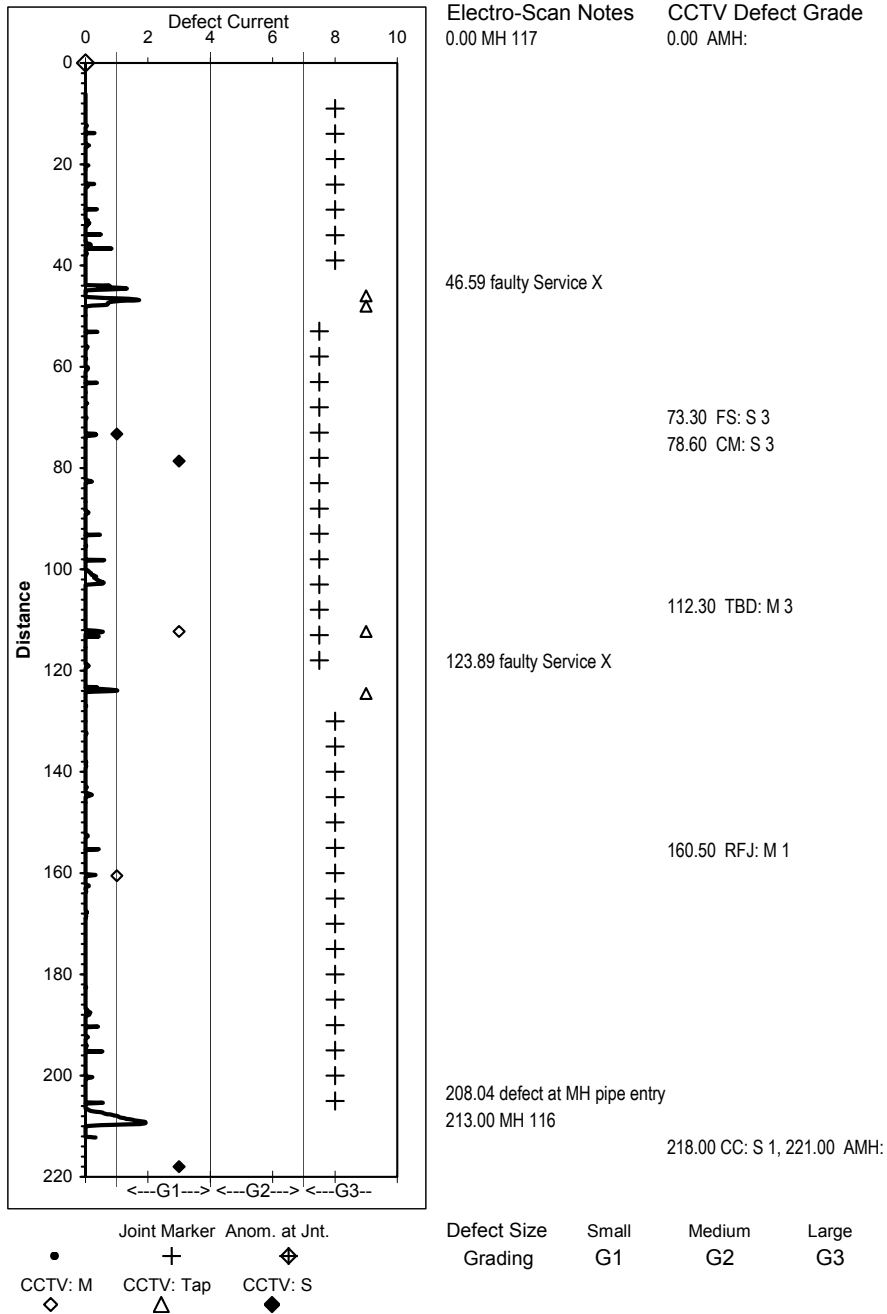


Figure 7. Comparison of CCTV and electro-scanning for pipe segment 117-116

Pipe Segment: MH 119 to 118

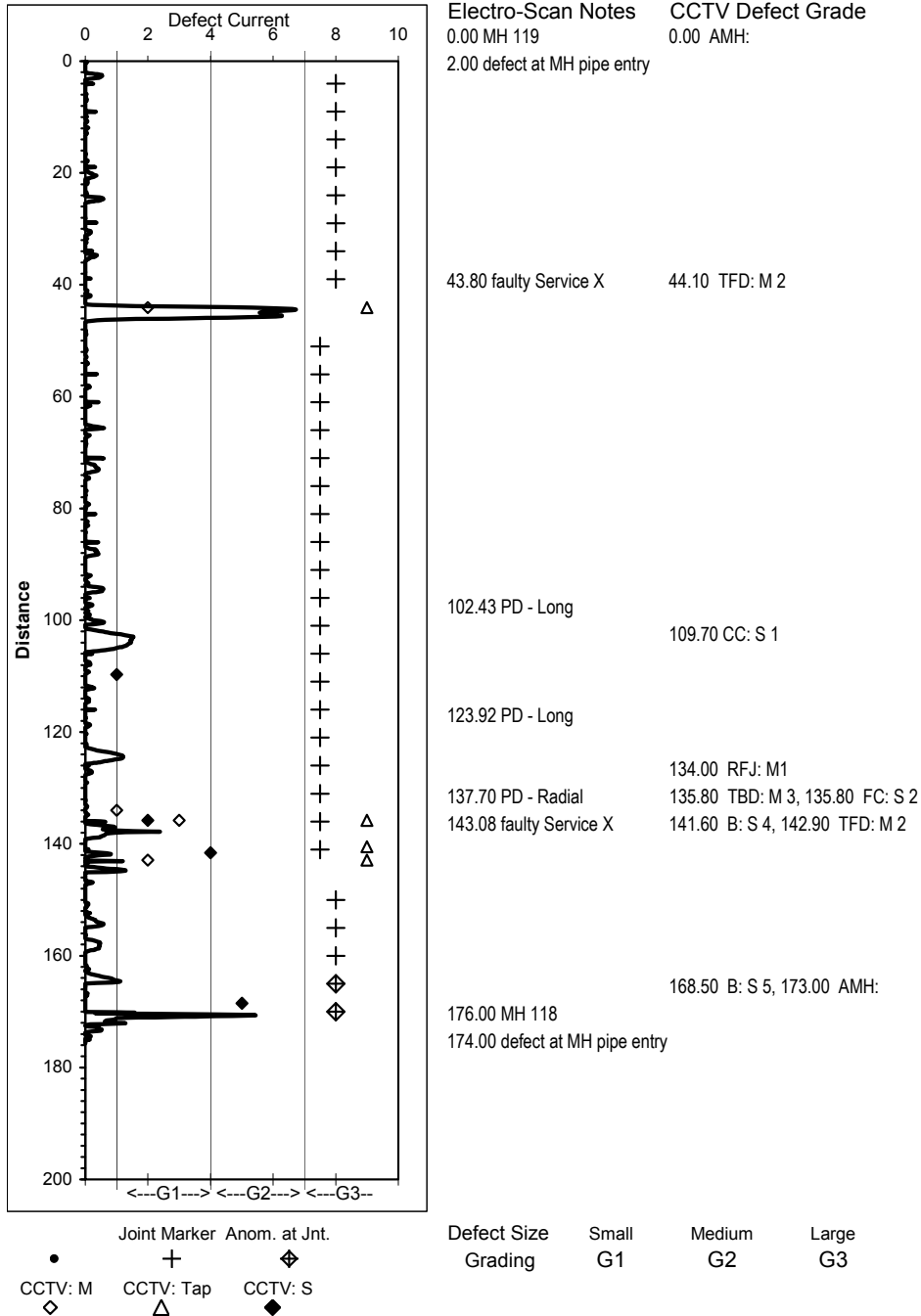


Figure 8. Comparison of CCTV and electro-scanning for pipe segment 119-118

Pipe Segment: MH 120 to 119

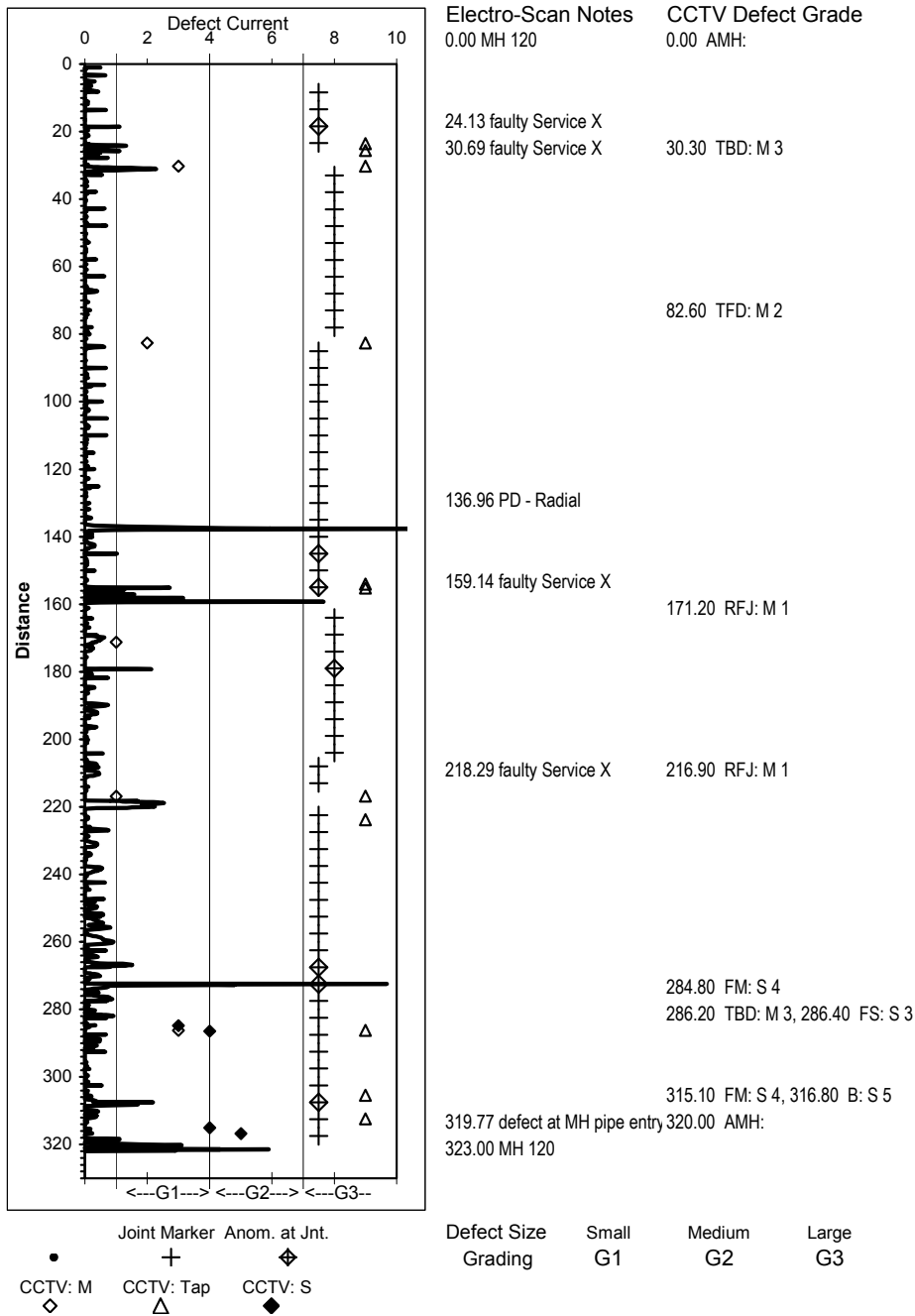


Figure 9. Comparison of CCTV and electro-scanning for pipe segment 120-119

Figures 4-9 show that electro-scanning anomalies generally coincide with CCTV defects and that electro-scanning is effective at detecting pipe locations with leak-related defects. These graphs also illustrate the ability of electro-scanning to find leakage potential that is not observed by CCTV. For example, anomalies occur at some taps that do not appear defective by CCTV (e.g., Figure 7, 47 ft and 124 ft; Figure 9, 24 ft). Among the 17 segments with data for both CCTV and electro-scanning, electro-scanning results showed 42 defective taps, and CCTV identified 45 defective taps (Table 1). If the total number of tap-related anomalies is expanded to include anomalies interpreted as pipe defects (PD) but that occur where CCTV identified a tap, then electro-scanning identified leak potential at 75 of 97 taps. In addition, some electro-scanning anomalies interpreted as pipe defects did not have corresponding CCTV crack defects (e.g., Figure 6, 162 ft; Figure 9, 137 ft).

The description of defect type based on electro-scanning results did not always agree with CCTV observations. Defects such as cracks can be readily identified visually by CCTV, while electro-scanning relies upon the spacing and locations of joints and service connections to aid in interpreting defect type. Figures 4-9 illustrate cases where electro-scanning anomalies were assigned different type descriptions than the CCTV defects with which they coincided (e.g., Figure 5, ~56 ft; Figure 9, 285 ft). As noted above, some pipe defect anomalies may actually represent defective taps (Figure 4, ~50 ft, ~131 ft). Anomalies that are assigned as defective joints may co-occur with other CCTV defects. Thus, the electro-scan description of the anomaly type can be refined by comparison with CCTV.

Some pipe fractures identified by CCTV were not associated with electro-scanning anomalies (e.g., Figure 7, ~73-79 ft; Figure 6, 108 ft). These defects may represent areas where the pipe has deteriorated but is not yet leaking. In such cases, CCTV data are valuable for identifying emerging pipe defects that may become sources of leakage.

CONCLUSIONS

The total cost of electro-scanning was \$28,881 for 9,784 ft, yielding a unit cost of \$2.95 per ft. This technology identified an average of 17 defects per pipe segment, although many were small joint defects. It identified more leakage-related defects than CCTV, in some cases identifying leakage at taps that did not appear visually defective. Interpretation of coinciding anomalies and CCTV defects sometimes differed, suggesting that interpretation of electro-scanning results may benefit from being compared with CCTV data. The electro-scanning provides information on leak potential that is complementary to CCTV. While CCTV provides visual identification of pipe features, electro-scanning results can be used to interpret defect severity and to better understand whether a pipe segment poses a serious infiltration or exfiltration problem.

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