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Dealing with Severe Corrosion on a Recently Installed Pipeline

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ABSTRACT

Two leaks were found on a recently installed (1999) pipeline which was coated with extruded polyethylene and protected with directly connected magnesium anodes.

This paper describes the use of external corrosion direct assessment (ECDA) principles to identify locations where corrosion could pose a threat to pipeline integrity, and describes the challenges encountered in developing a mitigation program.

The reliability of indirect inspection tools along directionally bored sections of pipe, in correlation with special soil conditions, is also discussed.

Key words: ECDA, CIPS, DCVG, Directional Boring, Current Requirement Test, DC Coupons.

INTRODUCTION

An NPS6/NPS4 gas line, 61.8 km long, 4.8 mm wall thickness, was installed in 1999 in Ontario. The line was coated with extruded polyethylene (“yellow jacket”) and the joints were coated with 58 mil thick coal tar coating (heat applied).

The soil consists mostly of sand with relatively large sections of rock and relatively short sections of clay.

The pipeline is protected by distributed magnesium anodes, typically installed every 300 meters and directly connected to the pipe, except at designated test posts.

The annual recorded potentials at test posts indicated that the pipeline was fully protected, according to the company’s -1,000 mV_{CSE} ON potential criterion.

Major highways were crossed using directional boring and the use of this technique was extended to other crossings, to minimize traffic disruption and environmental impact.

No ILI facilities were provided for this pipeline.

A leak occurred in the summer of 2009, followed by a second leak in the spring of 2010.

This paper will describe how the ECDA principles were used to identify the locations under imminent threat of new corrosion leaks and the technical approach employed to develop a remedial program.

IDENTIFICATION OF LOCATIONS UNDER HIGH RISK OF CORROSION

Immediately following the first leak, a close interval potential survey (CIPS) was conducted along the entire length of the pipeline. Direct current voltage gradient (DCVG) surveys were then conducted at seven selected locations that displayed sub-criterion or marginal potentials, according to the -1,000 mV_{CSE} ON criterion.(1)

The data were then aligned using GPS coordinates. Close-interval potential survey (CIPS) and DCVG indications were identified and classified using ECDA methodology. Twenty-eight areas displayed CIPS indications, of which two areas displayed severe indications, with potentials as electropositive as -411 mV_{CSE} – see Figure 1.

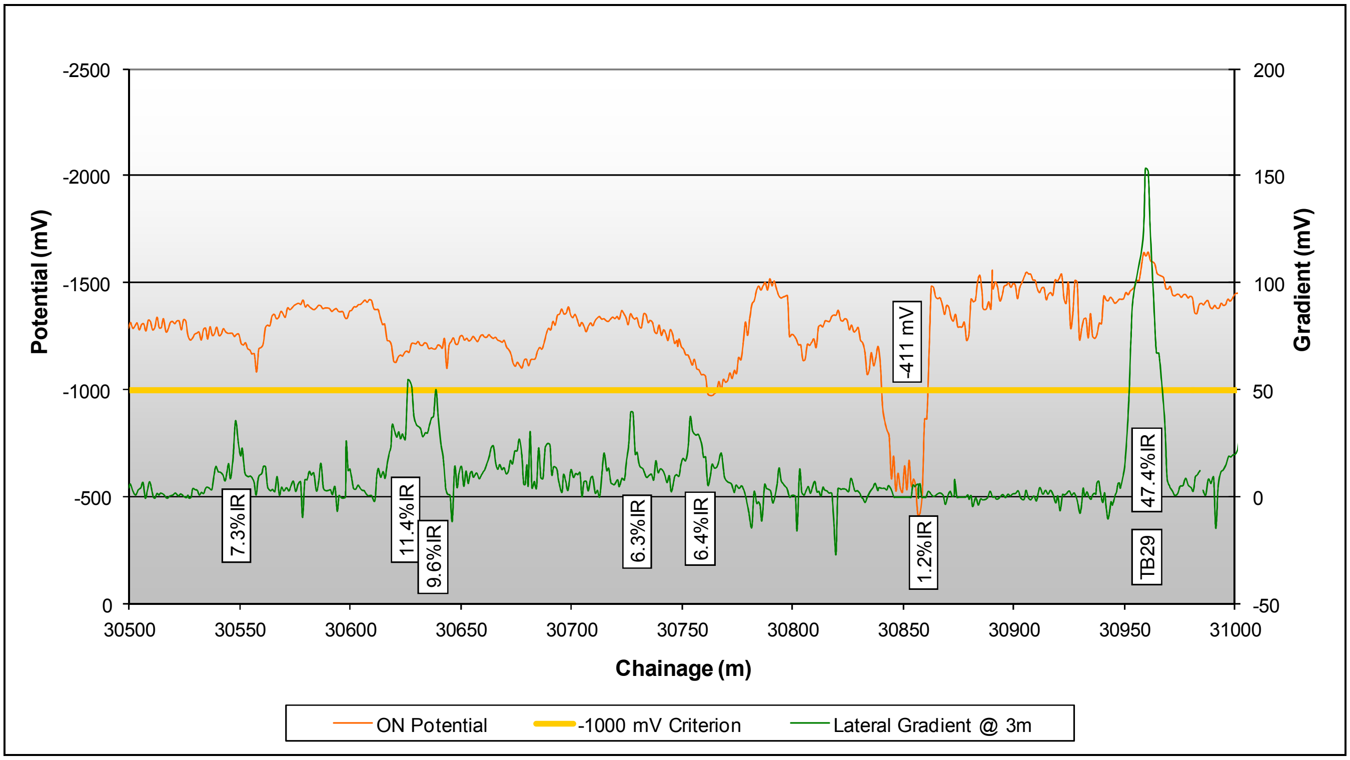

Figure 1: NPS6 Line. Ch. 30500 m to 31000 m. CIPS/DCVG Aligned Data

Thirty-five DCVG indications were identified along the surveyed sections, of which four were severe and 27 were moderate indications, as shown in Figure 2.

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(1) With the magnesium anodes solidly connected to the pipe, only ON potentials were measured.

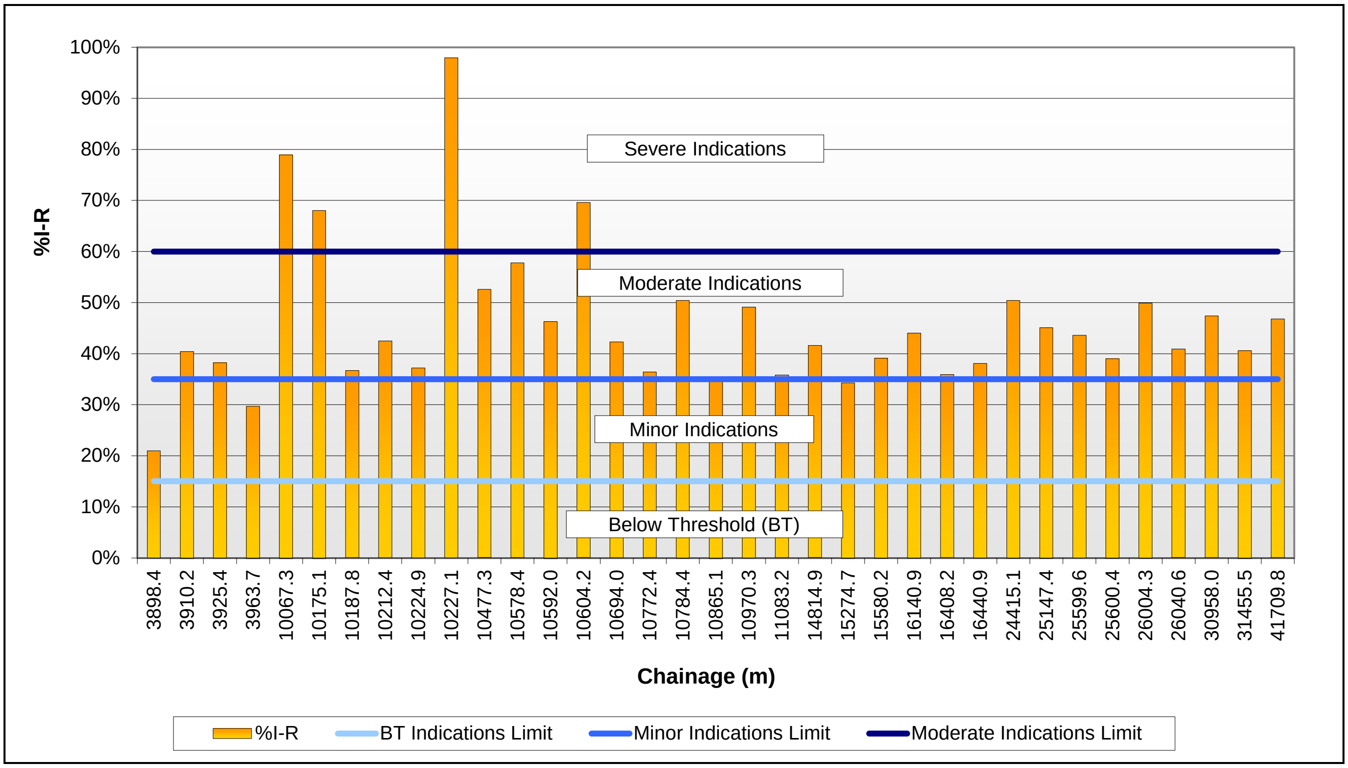

Figure 2: NPS6 Line. Summary of DCVG Indications along Surveyed Sections

However, the most important information in processing the survey data was provided by the investigation at the excavation at the second leak site (chainage 10604 m).

The leak occurred in April 2010 and the dig findings were analyzed with respect to the results of the survey performed in December 2009, shown in Figure 3.

Figure 3: NPS6 Line. Ch. 10500m to 11000m. CIPS/DCVG Aligned Data

At chainage 10604 m, the line displayed a severe DCVG indication (i.e. 69.6%IR), however the pipe-to-soil potential measured on grade was -1,071 mV_{CSE}, which satisfied the -1,000 mV_{CSE} protection criterion.

The dig examination indicated that the field coating was in extremely poor condition (i.e., approximately 80% bare), matching the severe DCVG indication. However, the potential measured with the reference in the trench at pipe level was only -581 mV_{CSE}, indicating that the -1,000 mV_{CSE} criterion cannot compensate for the very high IR drop affecting the CIPS data. The sand resistivity in the upper layer exceeded 75,000 Ω-cm and dropped to 21,000 Ω-cm at pipe level.

It was also noted that both leaks occurred at directionally bored locations.

Subsequently, it was decided to upgrade the CIPS identification criterion to -1,250 mV_{CSE} and to identify **all CIPS and DCVG indications located along directionally bored sections**. Furthermore, DCVG surveys were scheduled to be completed as soon as possible at all 129 directionally bored sections that were identified from the drawings. The “as built” chainages were aligned with the survey chainages and the more electropositive potentials, as well as the DCVG indications, were reported at each bore section. An excerpt of the 129 row matrix is shown in Table 1.

Table 1
Excerpt of Directionally Bored Sections Information Matrix

Bore Number	Chainage (m)				CIPS Data		DCVG Data		Survey Report Page No.
	As Built		As Surveyed		Min. Potential (mV)	Chainage (m)	%IR	Chainage (m)	
	Start	End	Start	End					
14	9107.6	9706.1	9206.4	9809.4	-1339	9306	-	-	-
15	10004.8	10329.1	10110.3	10437.3	-986	10175	68.0%	10174	A35
					-1187	10212	42.5%	10212	
					-1138	10226	97.9%	10226	
16	10329.1	10342.7	10437.3	10450.3	-1280	10441	NI	-	
17	10429.9	10513.0	10538.3	10622.4	-1015	10579	57.8%	10579	A36
					-1021	10591	46.3%	10591	
					-1071	10603	69.6%	10604	
18	10686.5	10765.0	10796.4	10875.4	-950	10784*	50.4%	10786*	

*Location within 10 m of bore crossing edge

The data were then filtered using the new -1,250 mV_{CSE} CIPS identification criterion and a new matrix containing all CIPS and DCVG indications was generated. An excerpt of this matrix is shown in Table 2.

Table 2
Excerpt of CIPS/DCVG Indications Matrix

Bore Number	Chainage (m)		CIPS Data		DCVG Data	
	Start	End	Min. Potential (mV)	Chainage (m)	%IR	Chainage (m)
9	3630.3	3836.3	-998	3824	19.5%	3824
10	3876.2	4052.7	-963	3909	40.4%	3913
			-1090	3923	38.2%	3925
			-1167	3964	29.7%	3964
15	10110.3	10437.3	-986	10175	68.0%	10174
			-1187	10212	42.5%	10212
			-1138	10226	97.9%	10226
17	10538.3	10622.4	-1015	10579	57.8%	10579
			-1021	10591 Leak	46.3%	10591
			-1071	10603	69.6%	10604
18	10796.4	10875.4	-950	10784*	50.4%	10786*
20	11238.8	11254.8	-1005	11252	21.0%	11251
21	11254.8	11563.8	-1013	11265	21.3%	11264
			-1050	11277	20.4%	11277
			-1160	11499	28.1%	11495
30	14434.6	14759.6	-769	14764*	0.7%	14764*
35	16095.2	16443.2	-1038	16410	35.9%	16408
			-981	16446*	33.0%	16446*
36	16458.2	16801.2	-1031	16460	32.0%	16460
48	21604.6	21881.6	-960	21788	-	-
57	24430.2	24459.2	-978	24417**	50.4%	24412**
63	25724.4	25995.4	-1048	25731	NI	-
66	27348.4	27389.4	-1130	27362	-	-
70	28609.3	28727.2	-1135	28635	-	-
74	30831.5	30952.5	-411	30856	NI	-

*Location within 10m of bore crossing edge
** Location within 25m of bore crossing edge

The data were prioritized and a first group of nine digs were scheduled to be performed in 2010, as shown in Table 3.

Table 3
List of 2010 Scheduled Digs

Dig Number	Bore Number	Chainage (m)		CIPS Data		DCVG Data	
		Start	End	Min. Potential (mV)	Chainage (m)	%IR	Chainage (m)
1	10	3876.2	4052.7	-963	3909	40.4%	3913
2	15	10110.3	10437.3	-986	10175	68.0%	10174
3				-1138	10226	97.9%	10226
4	18	10796.4	10875.4	-950	10784*	50.4%	10786*
5	30	14434.6	14759.6	-769	14764*	0.7%	14764*
6	35	16095.2	16443.2	-981	16446*	33.0%	16446*
7	57	24430.2	24459.2	-978	24417**	50.4%	24412**
8	63	25724.4	25995.4	-1048	25731	NI	-
9	74	30831.5	30952.5	-411	30856	NI	-

*Location within 10m of bore crossing edge
** Location within 25m of bore crossing edge

The field crew had the authority to conduct additional digs along directionally bored sections displaying severe corrosion.

RESULTS OF 2010 DIGS

Pitting (up to 53% through wall) was found at digs #1, #4 and #6, as shown in Figure 4 to 6.

Figure 4: Pitting at Dig Site #1

Figure 5: Pitting at Dig Site #4

Figure 6: Pitting at Dig Site #6

The factory applied coating was typically found in excellent condition, however at three dig sites, the field coating was either completely missing (Site 6) or almost entirely ripped off (Sites #1 and #4), as shown in Figure 7 to 9.

Figure 7: Dig Site #1. Bare Areas at Weld

Figure 8: Dig Site #4. Bare Areas at Weld

Figure 9: Dig Site #6. Bare Areas at Weld

At Site 6, a double-layer of extruded polyethylene coating had been applied, but the outside layer had rolled back for 30 cm during pipe installation, as shown in Figure 10. It appears that the same mechanical stresses that damaged the factory coating completely ripped away the field coating.

Figure 10: Dig Site #6. Damaged Factory Coating in Vicinity of Weld

Subsequently, the field crew conducted seven additional digs at welds (1A, 4A and 6A to 6E), until no more bare welds were found.

The pipe-to-soil potentials measured at pipe depth were up to 630 mV more electropositive than the potentials measured at grade, at locations displaying large bare areas (i.e. dig sites #1, #4, #4A and #6 to #6D). Significantly lower IR drops, up to 250 mV, were measured at areas displaying only minor holidays.

At dig #9, the potential measured at grade was -411 mV_{CSE} during the 2009 survey, changed slightly to -556 mV_{CSE} during the pre-dig survey and increased to -1,306 mV_{CSE} at pipe depth. All the measurements were taken under wet conditions. The pipe coating was in excellent condition. The erroneous surface reading was attributed to the presence of an intermediate thin sandy layer, with very high resistivity (i.e. 177,000 Ω-cm), which acted as an isolating membrane for at-grade measurements.

The special configuration of the soil, with clay or bentonite around the pipe(2) and a high resistivity membrane as an intermediate layer, also resulted in false DCVG indications, such as at dig sites #2 and #3, where only minor holidays were found.

Remedial action was performed, including installation of clock-spring repair sleeves at selected locations, recoating, and installation of magnesium anodes in selected areas.

2011 and 2012 DIGS

Additional DCVG surveys were performed in 2011 at the directionally bored sections displaying CIPS indications and not included in the 2009 survey. The indications were subsequently reprioritized and six new digs were scheduled, as indicated in Table 4.

Table 4
List of 2011-2012 Scheduled Digs

Dig Number	Bore Number	Chainage (m)		CIPS Data		DCVG Data	
		Start	End	Min. Potential (mV)	Chainage (m)	%IR	Chainage (m)
1 - 2011	41	19277.6	19459.1	-1155	19384	27.8%	19337
2 - 2011	66	27348.4	27389.4	-1130	27362	47.2%	27375
3 - 2011	67	27698.4	27772.4	-1271	27710	30.2%	28709
1 - 2012	1	98.4	378.9	-1120	102	51.0%	99
2 - 2012	9	3630.3	3836.3	-998	3824	19.5%	3824
3 - 2012	21	11254.8	11563.8	-1013	11265	21.3%	11264

Pitting up to 56% with poor field applied coating and significant IR drops were found at three digs (3 - 2011, 1 – 2012 and 3 – 2012).

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(2) The low resistivity clay or bentonite layer around the pipe acted as an electrolytic tube, offsetting the location of the various indications towards the start or end of the bore.

MITIGATION PROGRAM

The dig results, particularly the low potentials measured close to the pipe, indicated that magnesium anodes could not protect the pipeline in areas where the coating was damaged during the directional boring. Subsequently, it was decided that an impressed current system should be installed and a current requirement test (CRT) be conducted in order to determine the number and size of groundbeds.

The main challenge in conducting a CRT was how to rely on pipe-to-soil potentials measured on-grade, when the IR drops could reach hundreds of millivolts.

To deal with this challenge, cathodic protection coupons were installed at dig sites and selected test posts. Furthermore, a modified version of the step-wise current reduction technique was developed in-house and will help in analyzing the testing results. The CRT is scheduled for October 2012 and the results will be presented in a future paper.

CONCLUSIONS

An ECDA based technical approach was used to prevent additional leaks on a 1999 pipeline, that had displayed corrosion rates of up to 19 mpy at two leak sites.

The proposed protocol successfully assumed that all critical sites were located at directionally bored sections. It also took into consideration that on a line protected by magnesium anodes solidly connected to the pipe, the results of the CIPS survey could be significantly affected by I-R drop errors. Subsequent digs have established that the IR drop error in areas where the coating was missing could exceed 600 mV.

The reliability of the DCVG survey was also affected at several locations by special soil configurations (i.e. a thin intermediate layer of very high resistivity sand acting as a membrane). The use of bentonite at several bores also contributed to offsetting the location of various indications.

Despite the limitations of each tool under these special conditions, the integration of all available data contributed to the identification of eleven locations displaying through wall pitting of up to 56%. More importantly, no additional leaks occurred.

A remedial program was developed using current requirement testing to determine the size of the impressed current system. Cathodic protection coupons were installed at dig sites and are being installed at selected test posts in order to provide reliable data during testing.

The project also indicated the importance of conducting coating quality testing at directionally bored sections, to avoid future leaks.

Extreme caution is recommended when using ON potential based criteria on pipelines protected by directly connected magnesium anodes in high resistivity soils, as the IR drop error could be hundreds of millivolts.