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Use of an Integrated CIPS/DCVG Survey in the ECDA Process

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ABSTRACT

The paper describes the theoretical and practical aspects of merging two indirect inspection tools (i.e. Close Interval Potential Survey and DC Voltage Gradient) in one integrated survey, as used in 2004 during an ECDA project covering more than 21 Km of gas pipelines in Southern Ontario.

A method was developed and verified in the field to calculate the %IR at coating defects using the recorded data, with no need to interrupt the survey or to return to the defect location in order to measure the total gradient to remote earth.

The data processing was improved by deriving the longitudinal gradient profile from the Close Interval Potential Survey data. This enhancement will be used in future surveys to validate indications, in conjunction with the measured lateral gradient data.

INTRODUCTION

The Direct Assessment (DA) was formally listed as an acceptable integrity assessment technique in Subpart O of the 49 CFR 192 regulations, as modified on December 15, 2003 by the Office of Pipeline Safety, part of the Research and Special Programs Administration (RSPA) of the US Department of Transportation.

The External Corrosion Direct Assessment (ECDA) as described in NACE Standard RP0502-2002[1] is a continuous improvement process using existing data and the results of indirect inspection techniques, validated by a series of direct examinations, to identify and address locations where external "corrosion activity has occurred, is occurring, or may occur". As such, the technique relies heavily on the accuracy of the data acquired by indirect inspection tools, such as close interval potential survey (CIPS), DC voltage gradient survey (DCVG), AC attenuation survey, etc.

CIPS appears to be the only reasonable tool for estimating the cathodic protection level of the pipe and subsequently the risk of corrosion activity. The DCVG survey was successfully used to detect, locate and estimate the size of coating holidays in almost every area, except where limited by high contact resistance or significant dynamic stray current activity.

In many applications, these two complimentary indirect tools are used independently, with the CIPS followed by a fast-paced DCVG survey, often using different instrumentation. The main problem in this approach is aligning the indications from the two surveys, although flagging the suspect locations and using sub-meter GPS co-ordinates can minimize or even eliminate this problem. A second disadvantage of separate surveys is the possibility of errors when calculating the percentage IR to classify the severity of the holiday. The percentage IR is defined as the ratio between the lateral gradient measured to a reference located at remote earth and the total potential shift of the pipeline (i.e. the difference between the "on" and "off" potentials measured with respect to a reference electrode installed at remote earth). Since the pipe-to-soil potentials are not measured during the DCVG survey, they are typically interpolated from potential measurement records at adjacent test posts. When the soil resistivity varies significantly, the error introduced by this interpolation becomes appreciable.

A number of authors[2],[3] reported successful application of an integrated survey where the CIPS and the DCVG are performed simultaneously (i.e. "intensive measurement survey", according to German Standard DIN 50 925[6]). The main advantages of this approach are the ease with which the survey data is aligned and the instant access of the operator to two different sets of data that facilitates the identification of an indication (i.e. coating holiday or protection level). Developments in instrumentation, such as multi-channel data loggers[4] give the integrated method additional technical facility.

Corrosion Service Company Limited (CSCL) was retained by Union Gas Limited (UGL) to conduct an ECDA process on three pipelines in southern Ontario. Based on the information gathered during the pre-assessment, the CIPS and the DCVG were selected as complementary indirect inspection tools and merged in one integrated survey. The results of the ECDA process and a number of significant issues were discussed in a previous paper[5]. This paper describes the developments in data processing introduced as part of this project.

INTEGRATED CIPS/DCVG SURVEYS

The integrated CIPS/DCVG surveys were conducted using a lateral reference arrangement, as shown in Figure 1.

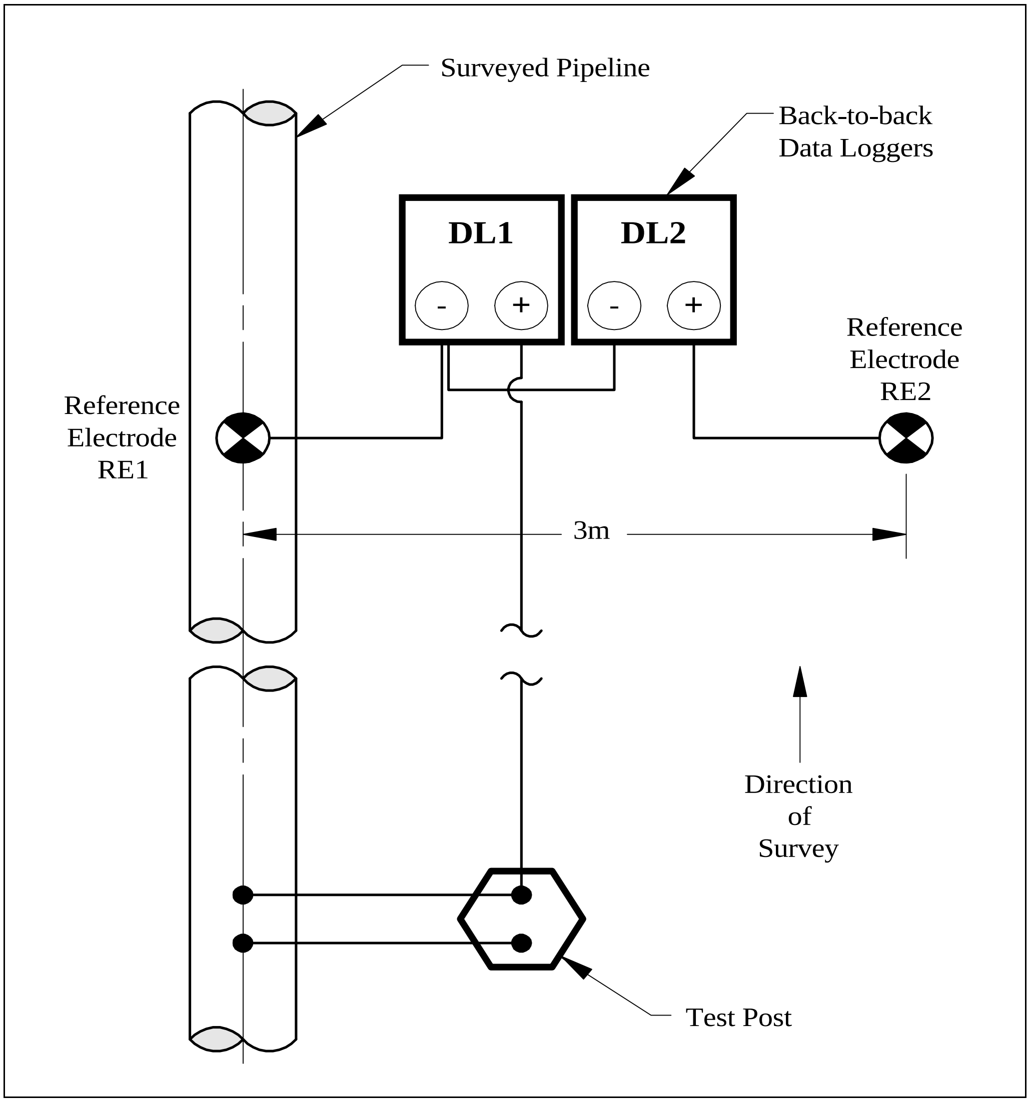

Figure 1. Integrated CIPS/DCVG Arrangement

All the influencing current sources, such as rectifiers and sacrificial anode groups were interrupted simultaneously using GPS synchronized equipment. Waveforms were recorded during the off-cycle and analyzed to confirm that the line was "clean" and that true off-potentials were measured. The pipe-to-soil potential and the 3m lateral voltage gradient* were recorded at 1m spacing. Sub-meter GPS co-ordinates were recorded at suspected indications and at landmarks. All the data was automatically time-stamped to facilitate telluric compensation or further analysis of potential profile anomalies. Typical field data are shown in Table 1.

* Measured with one reference located above the pipe and the second reference located at 3m distance, perpendicular on the pipeline.

Chainage (m)	VON (mV)	VOFF (mV)	Lateral Gradient @ 3m		GMT Time	Remarks	GPS Co-ordinates	
			ON	OFF			Longitude	Latitude
81128.25	-2091	-1272	-13	-3	185502	END OF ROAD	-82.8200066	42.2868330
81130.22	-2030	-1240	-30	-1	212957	DRILLED HOLES		
81132.18	-2060	-1260	-15	4	212917	DRILLED HOLES		
81134.15	-2050	-1250	-25	-8	212905	DRILLED HOLES		
81136.11	-2110	-1260	-10	-6	185630	END OF ROAD	-82.8201022	42.2868352
81138.22	-2090	-1240	-13	-3	185710			
81138.71	-2110	-1230	-8	2	185734			
81139.74	-2100	-1270	-15	-3	185814			
81139.95	-2090	-1260	-35	-10	185906			
81140.81	-2080	-1120	-37	-6	185934	TS 661	-82.8201596	42.2868322
81141.62	-2040	-1270	-80	-6	190854			
81143.25	-1750	-1270	-368	4	190930		-82.8201894	42.2868294
81144.14	-1830	-1270	-273	7	191058	CL DITCH	-82.8202002	42.2868300
81145.50	-2030	-1270	-97	-1	191226			
81146.62	-2110	-1260	-45	-3	191314			
81147.71	-2120	-1260	-37	-10	191346			
81148.78	-2140	-1260	-32	-10	191410	START FARMER FIELD	-82.8202562	42.2868364

Table 1. Typical Field Data (16" Pipeline)

Although the quality of data was high, the survey speed was slow (2-3 km per day), even compared with integrated CIPS/DCVG surveys measuring longitudinal gradients[3].

Returning to the location of an indication to measure the total gradient to remote earth as part of %IR or holiday size calculations would have resulted in additional survey time.

Accordingly, it was decided to try and use the existing data to accurately locate and classify the coating holidays, with no need for additional measurements.

LOCATING COATING HOLIDAYS FROM RECORDED DATA

The location of a coating holiday was determined by the characteristic shape of the lateral voltage gradient versus distance curve (i.e. increasing, reaching a maximum value at the epicenter of the holiday and then decreasing), as shown in Figure 2.

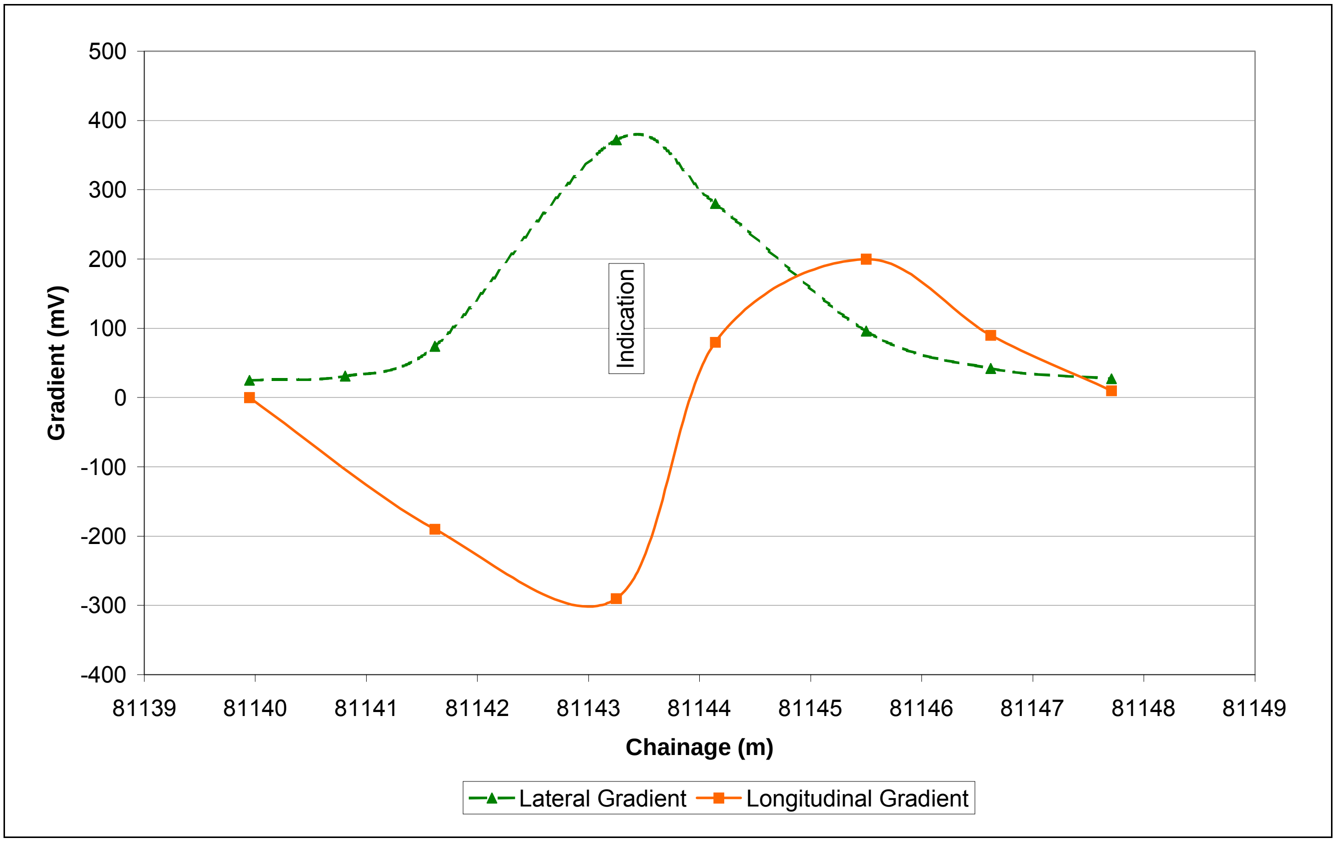

Figure 2. 16" Pipeline. Chainage 81143.25m. Voltage Gradients at DCVG Indication

In comparison, the longitudinal gradient versus distance curve has a different shape (i.e. increasing, reaching a maximum, changing sign to reach a minimum and returning to zero, with the epicenter at the null point between the maximum and minimum value).

The indications can be easily identified, either from the graph or from the calculated %IR column in the data sheet containing the field data, see Table 2.

Chainage (m)	Lateral Gradient @ 3m		ΔG (mV)	ΔV (mV)	% IR	GMT Time	Remarks	GPS Co-ordinates	
	ON	OFF						Longitude	Latitude
81136.11	-10	-6	4	850	0.7%	185630	EOR	-82.8201022	42.2868352
81138.22	-13	-3	10	850	1.8%	185710			
81138.71	-8	2	10	880	1.8%	185734			
81139.74	-15	-3	12	830	2.2%	185814			
81139.95	-35	-10	25	830	4.6%	185906			
81140.81	-37	-6	31	960	4.9%	185934	TS661	-82.8201596	42.2868322
81141.62	-80	-6	74	770	13.3%	190854			
81143.25	-368	4	372	480	**55.2%**	190930		-82.8201894	42.2868294
81144.14	-273	7	280	560	**44.3%**	191058	CL DITCH	-82.8202002	42.2868300
81145.50	-97	-1	96	759	*16.7%*	191226			
81146.62	-45	-3	42	849	7.3%	191314			
81147.71	-37	-10	27	859	4.8%	191346			
81148.78	-32	-10	22	879	3.8%	191410	ST FARMER FIELD	-82.8202562	42.2868364

Table 2. 16" Pipeline. Identification of Indications Based on %IR

For convenience, the cells were formatted to automatically display the %IR in color; (bold) red for values exceeding 35% and (italic) blue for values between 15% and 35%.

Additional information was provided by the pipe-to-soil potentials measured with the rectifier in operation (i.e. V_{ON}), as shown in Figure 3.

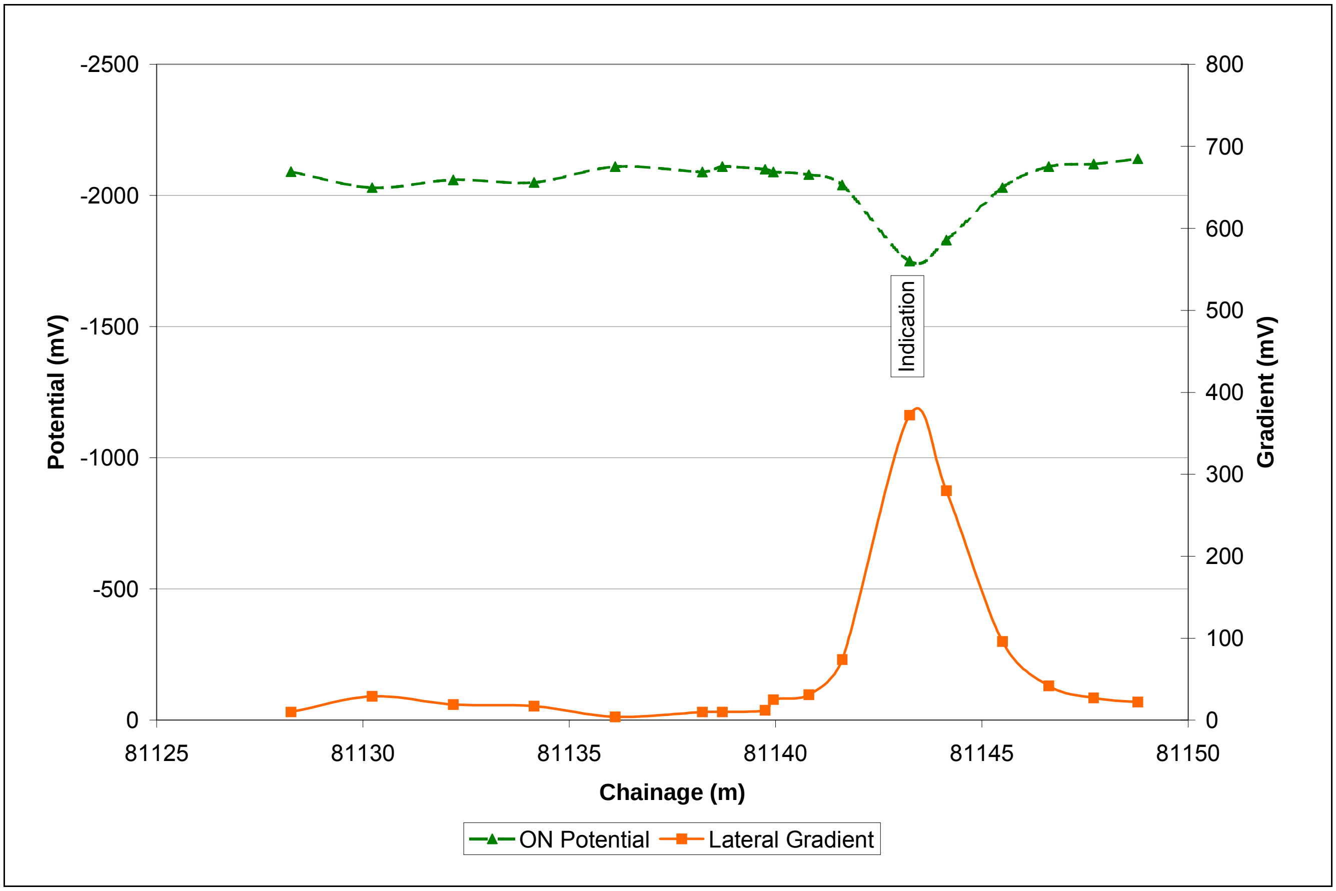

Figure 3. 16" Pipeline. Identification of Indications Based on Potential and Gradient Profile

As the surveyor approaches the holiday, the IR drop diminishes, reaching a minimum at the epicenter of the holiday. Therefore, it would be expected that the on-potential would display a minimum at an isolated holiday.

The identification of indications using the integrated CIPS/DCVG graphs on an entire section of line is shown in Figure 4, reproduced from a previous presentation[5].

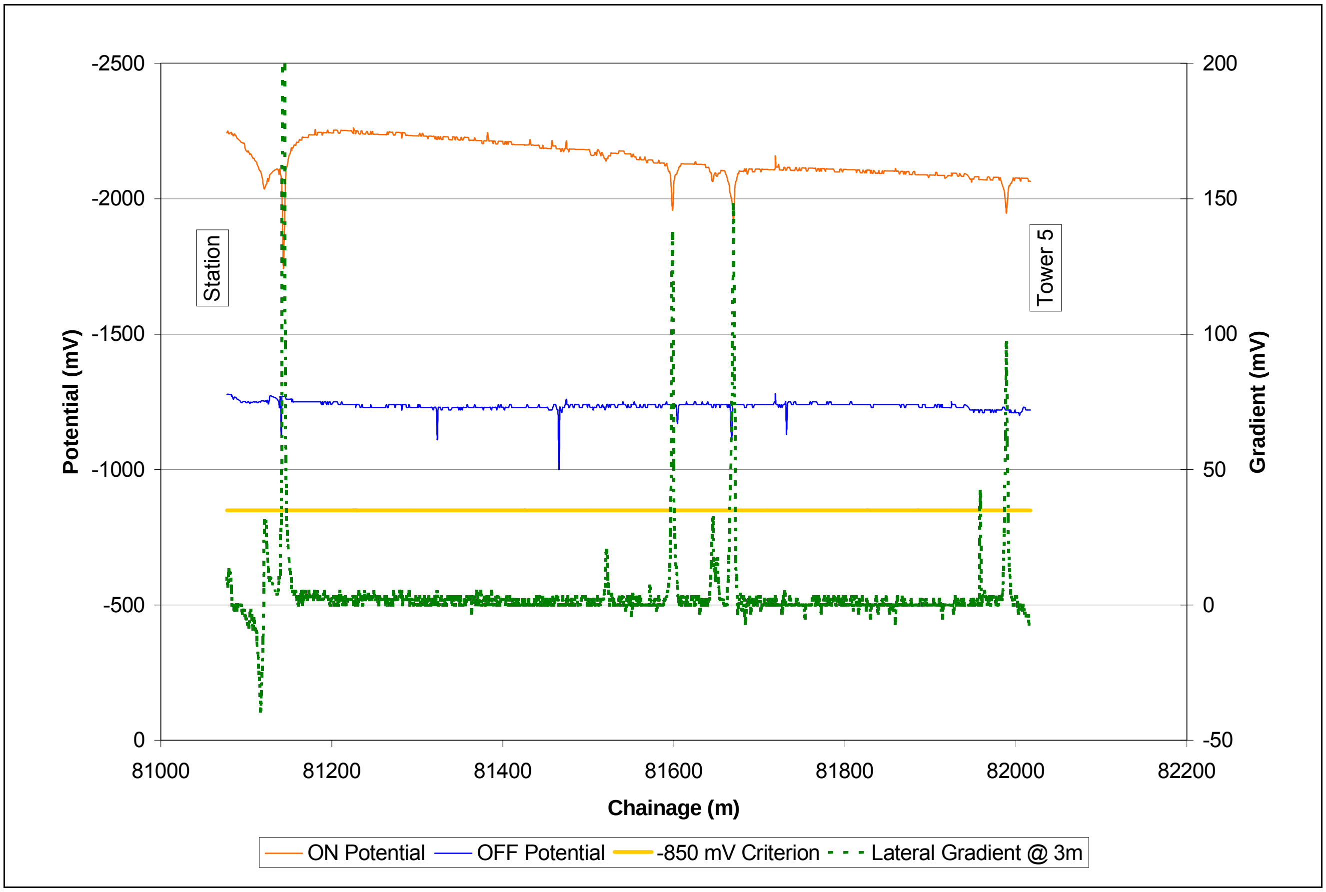

Figure 4. 16" Pipeline. CIPS/DCVG Survey. (1.1 Km Sample)

The alignment between the maximum lateral gradient and the drop in the ON potentials points clearly to the location of the coating holidays.

CALCULATING %IR FROM RECORDED DATA

When the source of the DCVG signal is the interrupted CP current, the %IR is defined as the ratio between the total lateral gradient shift measured to remote earth (ΔG_{OL-RE}) and the total pipe-to-soil potential shift measured to remote earth (ΔV_{RE}).

$$\%IR = \frac{\Delta G_{OL-RE}}{\Delta V_{RE}} \qquad [1]$$

In the integrated CIPS/DCVG survey, both the lateral gradient and the pipe-to-soil potential are recorded at every location, however they are not measured with respect to remote earth. The challenge was to develop an equation relating the %IR to the available data, without the need to conduct a second survey to obtain the gradient to remote earth.

A first step in solving this problem was the observation that the ratio between the 3m gradient and the total gradient measured to remote earth is the same for all type and size of holidays, when the pipe depth does not change, as shown in Figure 5. For a pipe buried at a depth of 1.2 m, this ratio is approximately 63%.

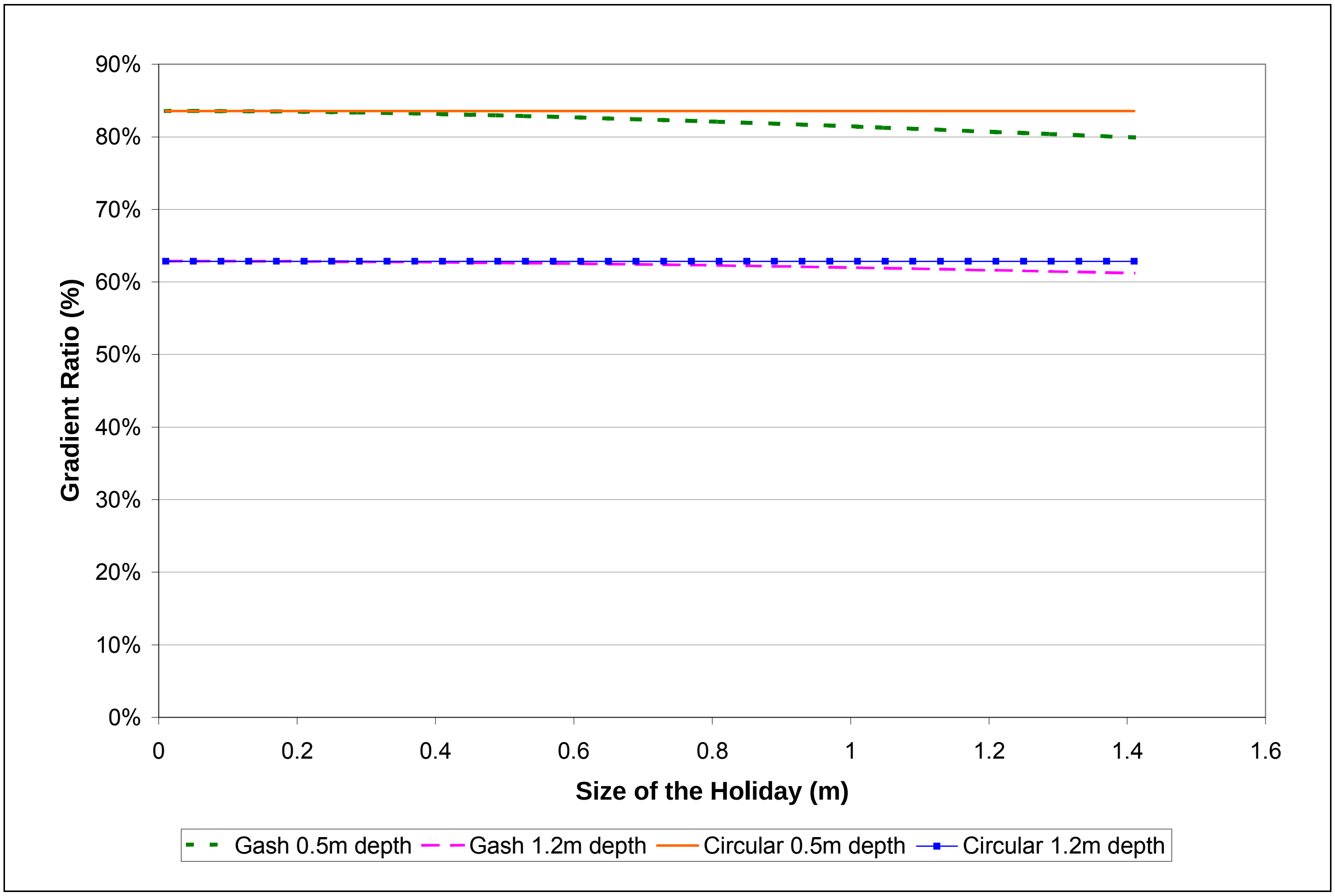

Figure 5. Variation of the Gradient Ratio $\left(\frac{\Delta G_{OL-3m}}{\Delta G_{OL-RE}}\right)$ with the Size of the Holiday

The actual formulas were developed for both circular holidays and long gashes and were used to draw Figure 5.

Considering that the total potential shift with respect to remote earth is the sum of the pipe-to-soil potential measured with respect to close earth (i.e. reference electrode RE1 in Figure 1) plus the total gradient to remote earth, equation [1] becomes:

$$\%IR = \frac{k(t,d) \times \Delta G_{OL-d}}{\Delta V_{OL} + k(t,d) \times \Delta G_{OL-d}} \qquad [2]$$

where:

ΔG_{OL-d} = lateral gradient shift as measured between a reference electrode installed over the line (RE1) and a reference electrode (RE2) installed at a distance (d) perpendicular to the line.

ΔV_{OL} = potential shift between the pipe and a reference electrode (RE1) installed over the line.

$k(t,d)$ = function depending on the pipe depth (t) and the distance (d) between the two reference electrodes used to measure the gradient (i.e. d=3m for the 3m gradient). The values of $k(t,d)$ are plotted in Figure 6.

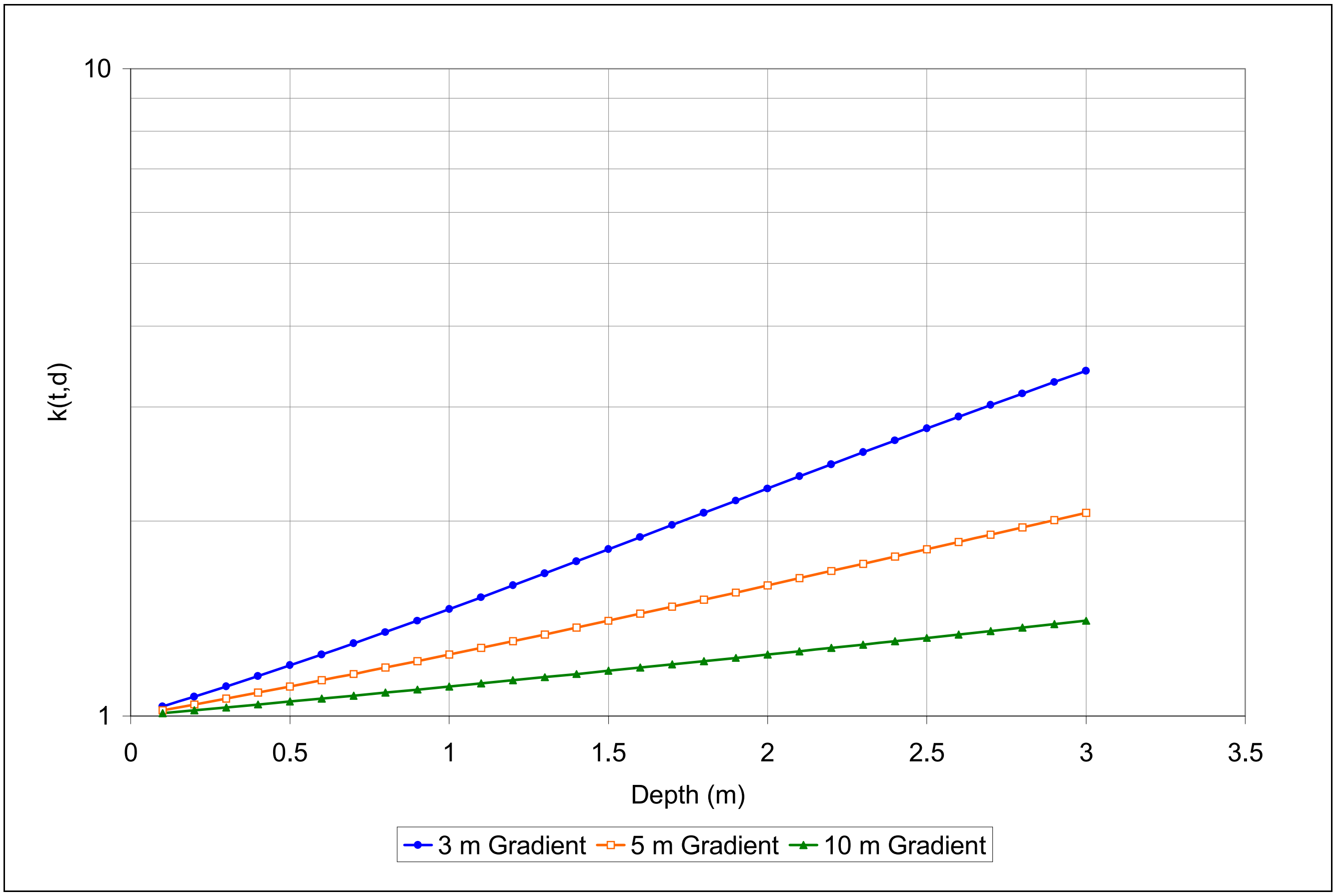

Figure 6. Function $k(t)$ for Calculating %IR

For a pipe installed at 1.2m depth, and a gradient measured at 3m lateral distance $k(t,d) = 1.59$.

Equation [2] therefore can be used to calculate the severity of a holiday (i.e. %IR) using the data collected in an integrated CIPS/DCVG survey.

The accuracy of equation [2] was verified by actually measuring the lateral gradient and the total potential shift with respect to remote earth at five indications on a 16" dia. pipeline, calculating the exact value of %IR using the fundamental equation [1] and comparing with the value calculated using the proposed equation [2].

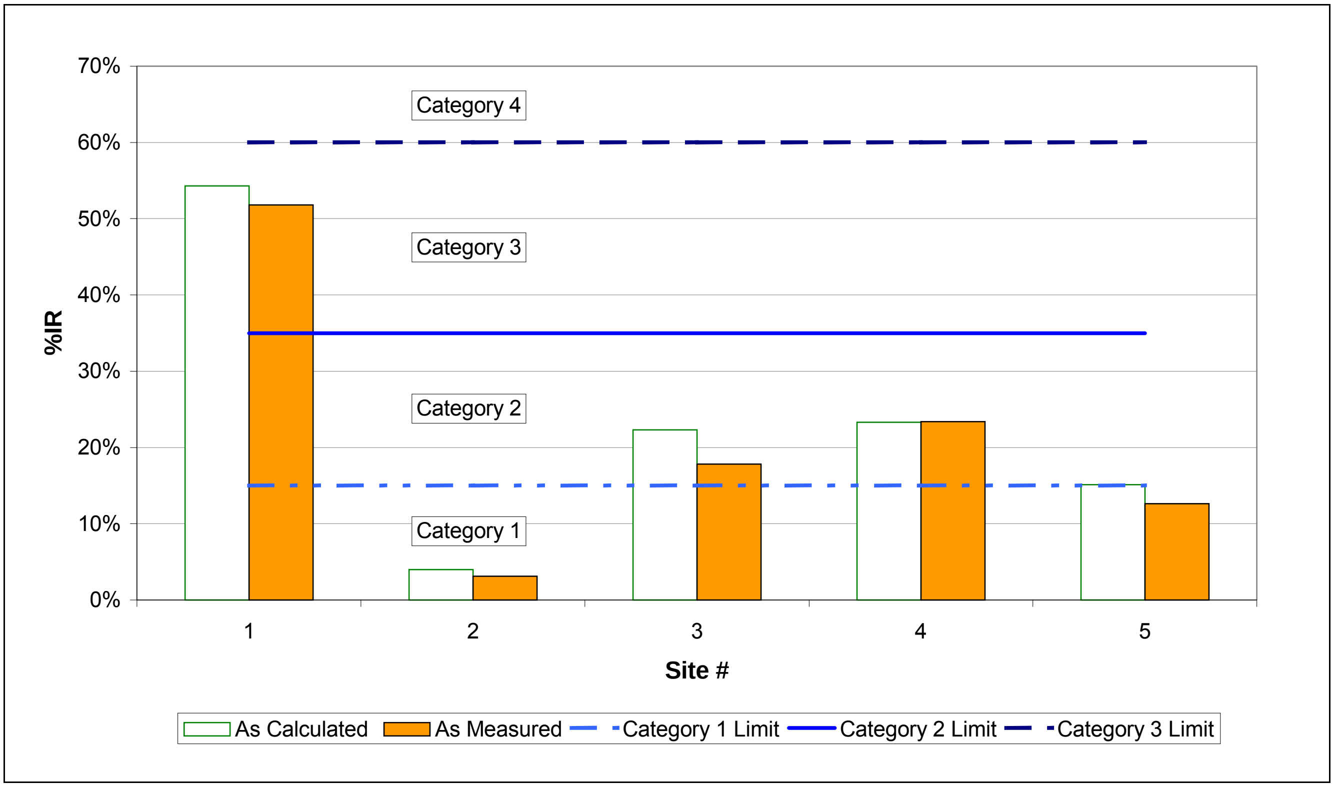

Figure 7. Comparison between "As Measured" and "As Calculated" %IR

The results are shown in Figure 7 and indicate that the proposed equation is accurate and slightly more conservative throughout various severity categories.

ESTIMATING THE LONGITUDINAL GRADIENT FROM RECORDED DATA

The longitudinal gradient shift (ΔG^{L}_{A-B}) measured between two points A and B located at a spacing "s" along the line is by definition the difference between the soil potential shifts at the two locations:

$$\Delta G^{L}_{A-B} = \Delta V_{soil-A} - \Delta V_{soil-B} \quad [3]$$

In a close interval potential survey, only the location of the reference electrode changes, as the trailing wire is connected at the test station. In other words, in the absence of dynamic stray currents and assuming that there is no change in the pipe polarized potential within the short interval A-B, the longitudinal gradient can be calculated as the difference between the pipe-to-soil potential shifts recorded at the two points.

$$\Delta G^{L}_{A-B} = \Delta V_{P/S-A} - \Delta V_{P/S-B} \quad [4]$$

where:

$$\Delta V_{P-S} = V_{ON} - V_{OFF} \quad [5]$$

In practical terms, the CIPS data can be used to calculate the longitudinal gradient at any spacing equal to or greater than the spacing of the survey.

The longitudinal gradient shown in Figure 2 was derived using this procedure. An additional example is shown in Figure 8, reproduced from a previous presentation[5].

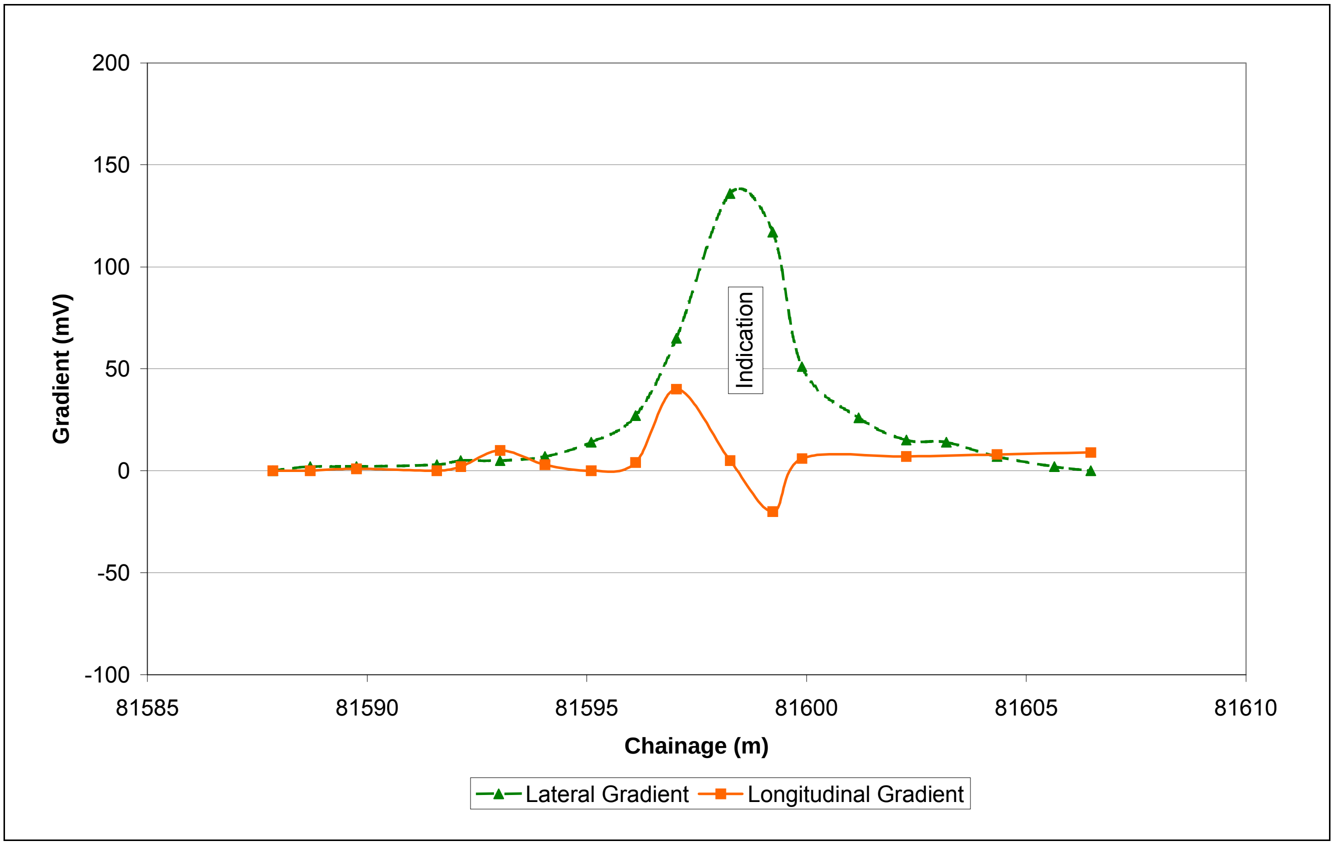

Figure 8. 16" Pipeline. Chainage 81598m. Voltage Gradients at DCVG Indication

Since the calculated longitudinal gradient is based on four different measured parameters (i.e. ON and OFF potentials at two different locations), the possibility of measurement error increases accordingly, especially in very dry soils. As such, this parameter was used only as an additional tool to validate coating holidays identified using the lateral gradient. Additional applications of the calculated longitudinal gradient may include analysis of previous CIPS data to detect holiday locations, when no other information is available, and validation of the results of AC attenuation surveys conducted in conjunction with CIPS.

CONCLUSIONS

The results of the ECDA process performed on more than 21 km of pipelines in southern Ontario indicated that the data collected during an integrated CIPS/DCVG lateral survey could be used to accurately locate a coating holiday as well as to quantify the severity of the defect in terms of %IR.

The coating defects were successfully located by measuring the lateral gradient curve. Additional information provided by the on-potential profile and the derived longitudinal gradient graph was used to validate the results.

An equation was proposed for calculating the %IR from the lateral gradient data measured at 3m and the CIPS data. Field testing performed during the ECDA process demonstrated the accuracy of this formula.

A simple procedure was proposed for deriving the longitudinal gradient profile from the CIPS data. Possible applications may include: validation of the lateral DCVG results, analysis of previous CIPS survey conducted with no associated DCVG and validation of the results of AC attenuation surveys conducted in conjunction with CIPS.

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