Improvements to the External Corrosion Direct Assessment Process—Part 2

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The U.S. Department of Transportation Pipeline & Hazardous Materials Safety Administration sponsored a research project for the external corrosion direct assessment process for buried pipelines. Part 1 of this article (March 2011 MP) addressed methodologies for cased pipe. Part 2 covers severity ranking of indirect inspection indications and potential measurements in paved areas.

A study sponsored by the U.S. Department of Transportation Pipeline & Hazardous Materials Safety Administration (PHMSA) was conducted to determine the applicability of existing and emerging technologies to assess buried pipelines for external corrosion using external corrosion direct assessment (ECDA). This included examination of existing ECDA processes, best practices of pipeline operators, and emerging technologies. The project findings are significant for gas transmission pipeline operators in the United States because the integrity of all pipe in high-consequence areas (HCAs) must be assessed by December 17, 2012, including those segments of pipe in casings. There is an industry need for a methodology to assess cased pipe where in-line inspection (ILI) and pressure testing are either not possible or not practical.

Severity Ranking

The purpose of the severity ranking portion of the study was to enhance the existing Tables 3 and 4 in NACE SP0502-2010.[1] The existing tables in the standard are very general, which result in varying interpretations and inconsistencies in application under the current practice. The project goals were to identify improvements that could be made and develop an enhanced severity ranking methodology.

Data from five transmission and distribution system operators were compiled, sorted, and analyzed. This included the results of 400 direct examinations with complete, applicable data sets, including soil analysis. Fifty percent (200) of the data sets used in the study demonstrated measurable external corrosion. ILI data were also analyzed, which covered 14,000 joints of pipe where close interval potential surveys (CIPS) and alternating current attenuation (ACCA) surveys had been performed. These data included 4,000 joints of pipe with measurable corrosion and 100 excavations. To

TABLE 2

Typical Protective Coating Systems for Carbon Steels Under Thermal Insulation and Fireproofing

(Reprinted from NACE SP0198, pp. 25-26.)

System Number	Temperature Range[A],[B]	Surface Preparation	Surface Profile, µm (mil)[C]	Prime Coat, µm (mil)[D]	Finish Coat, µm (mil)[D]
CS-1	–45 to 60 °C (–50 to 140 °F)	NACE No. 2/ SSPC-SP 10	50–75 (2–3)	High-build epoxy, 130 (5)	Epoxy, 130 (5)
CS-2 (shop application only)	–45 to 60 °C (–50 to 140 °F)	NACE No. 2/ SSPC-SP 10	50–75 (2–3)	N/A	Fusion-bonded epoxy (FBE), 300 (12)
CS-3	–45 to 150 °C (–50 to 300 °F)	NACE No. 2/ SSPC-SP 10	50–75 (2–3)	Epoxy phenolic, 100–150 (4–6)	Epoxy phenolic, 100–150 (4–6)
CS-4	–45 to 205 °C (–50 to 400 °F)	NACE No. 2/ SSPC-SP 10	50–75 (2–3)	Epoxy novolac or silicone hybrid, 100–200 (4–8)	Epoxy novolac or silicone hybrid, 100–200 (4–8)
CS-5	–45 to 595 °C (–50 to 1,100 °F)	NACE No. 1/ SSPC-SP 5	50–100 (2–4)	TSA, 250–375 (10–15) with minimum of 99% aluminum	Optional: Sealer with either a thinned epoxy-based or silicone coating (depending on maximum service temperature) at approximately 40 (1.5) thickness
CS-6	–45 to 650 °C (–50 to 1,200 °F)	NACE No. 2/ SSPC-SP 10	40–65 (1.5–2.5)	Inorganic copolymer or coatings with an inert multipolymeric matrix, 100–150 (4–6)	Inorganic copolymer or coatings with an inert multipolymeric matrix, 100–150 (4–6)
CS-7	60 °C (140 °F) maximum	SSPC-SP 216 or SSPC-SP 317	N/A	Thin film of petrolatum or petroleum wax primer	Petrolatum or petroleum wax tape, 1–2 (40–80)
CS-8 Bulk or shop-primed pipe, coated with inorganic zinc	–45 to 400 °C (–50 to 750 °F)	Low-pressure water cleaning to 3,000 psi (20 MPa) if necessary	N/A	N/A	Epoxy novolac, epoxy phenolic, silicone, modified silicone, inorganic copolymer, or a coating with an inert multipolymeric matrix, is typically applied in the field. Consult coating manufacturer for thickness and service temperature limits[E]
CS-9 Carbon steel under fireproofing	Ambient	NACE No. 2/ SSPC-SP 10	50–75 (2–3)	Epoxy or epoxy phenolic, 100–150 (4–6)	Epoxy or epoxy phenolic, 100–150 (4–6)
CS-10 Galvanized steel under fireproofing	Ambient	Galvanizing: sweep blast with fine, nonmetallic grit	25 (1)	Epoxy or epoxy phenolic (for more information on coatings over galvanizing, see 4.3.3), 100–150 (4–6)	Epoxy or epoxy phenolic, 100–150 (4–6)

[A] The temperature range shown for a coating system (including thermal-cycling within this range) is that over which the coating system is designed to maintain its integrity and capability to perform as specified when correctly applied. However, the owner may determine whether any coating system is required, based on corrosion resistance of carbon steel at certain temperatures. Temperature ranges are typical for the coating system; however, not all coatings in a category are rated for the given minimum/maximum temperature. Specifications and coating manufacturer's recommendations should be followed for a particular coating system.

[B] Temperature range refers to the allowable temperature capabilities of the coating system, not service temperatures.

[C] Typical minimum and maximum surface profile is given for each substrate. Acceptable surface profile range may vary, depending on substrate and type of coating. The coating manufacturer's recommendations should be followed.

[D] Coating thicknesses are typical DFT values, but the user should always check the manufacturer's product data sheet for recommended coating thicknesses.

[E] If inorganic zinc-rich coating is applied in a shop and topcoat is applied in the field, proper cleaning of the inorganic zinc-rich coating is required. The use of inorganic zinc-rich coating under insulation is not a preferred system for service temperatures in the CUI range up to approximately 175 °C (350 °F). However, bulk piping is often coated with inorganic zinc-rich coating in the shop and some owners purchase this piping for use under insulation. In these cases, the inorganic zinc-rich coating should be topcoated to extend its life.

TABLE 1

Enhanced severity classification criteria of indirect inspections (IDI) (Modification of Table 3 in NACE SP0502-2010)

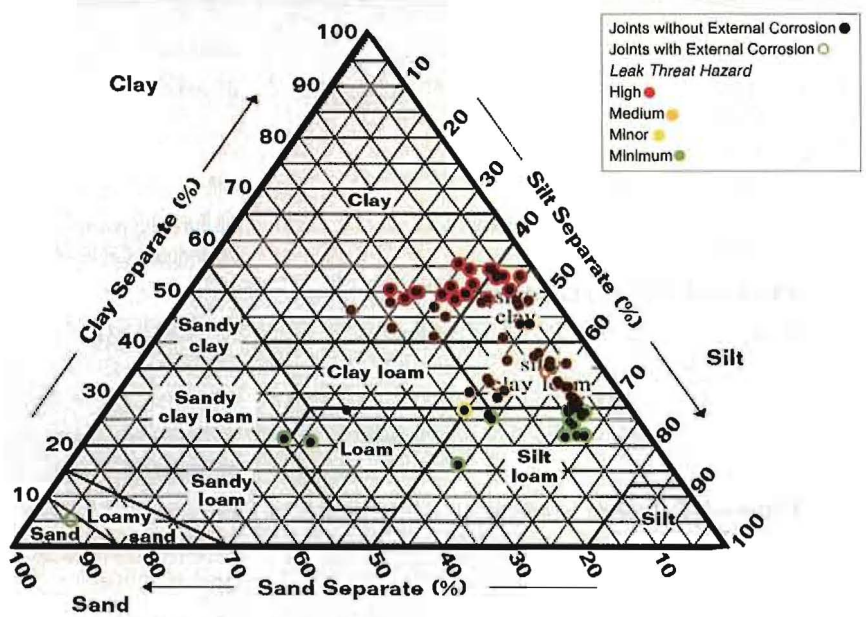
	IDI Classification		
Measure	Minor	Moderate	Severe
IDI Tool = Close Interval Potential Survey			
A = Off (polarized) potential (mV)	–950 mV < A < –850 mV	–850 mV < A < –650 mV	–650 mV < A
	OR	OR	AND
B = On potential (mV)	–1,000 mV < B < –950 mV	–950 mV < B < –850 mV	–850 mV < B
	AND	AND	AND
C = On/off convergence (mV)	50 mV < C < 70 mV	30 mV < C < 10 mV	10 mV < C
	OR	OR	AND
D = On and/or off profile depression within 100 ft (30.5 m) (mV/span)	50 mV/span < D < 100 mg/span	100 mV/span < D < 200 mV/span	200 mV/span < D
IDI Tool = AC Current Attenuation			
E = Current 98 Hz frequency signal loss (–) (mdB[mA]/ft)	7 mdb(mA)/ft < E < 3 mdb/ft	12 mdb(mA)/ft < E < 7 mdb(mA)/ft	12 mdb(mA)/ft < E
	AND/OR	AND/OR	AND/OR
F = Current 4 Hz frequency signal loss (–) (mdB[mA]/ft)	20 mdb(mA)/ft < F < 40 mdb(mA)/ft	40 mdb(mA)/ft < F < 60 mdb(mA)/ft	60 mdb(mA)/ft < F
	AND	AND	OR
CP level modifier	Adequate CP level	Adequate to marginal CP level	All indications with inadequate CP level
IDI Tool = AC Voltage Gradient			
G = Voltage signal loss (–) (dB[mV])	44 dB(mV) < G < 60 dB(mV)	60 dB(mV) < G < 78 dB(mV)	78 dB(mV) < G
	AND	AND	OR
CP level modifier	Adequate CP	Adequate to marginal CP level	All indications with inadequate CP
IDI Tool = DC Voltage Gradient			
H = coating defect size (%IR)	5%IR < H < 20%IR	20%IR < H < 50%IR	50%IR < H
	AND	OR	OR
I = Corrosion state assessment (normal operating conditions)	I = Cathodic/cathodic or cathodic/neutral	All indications 5%IR < H < 50%IR where I = cathodic/anodic	All indications where I = anodic/anodic
	AND	AND	OR
CP level modifier	Adequate CP level	Adequate to marginal CP level	All indications with inadequate CP level
IDI Tool Modifier—USDA Soils Data—Soil Texture Designation (Not an Independent Tool)			
J = USDA soil texture designation (12 types)	J = Sand, loamy sand, sandy loam, loam, silt loam, or silt	J = Sandy clay loam, sandy clay, clay loam, silty clay loam	J = Clay and silty clay
	AND	AND	OR
CP level modifier	Adequate CP	Adequate to marginal CP level	All area with inadequate CP

TABLE 2

Enhanced prioritization criteria for indirect inspection indications (Modification of Table 4 in NACE SP0502-2010)

Prioritization: Two Tools with Soil Modifier				
USDA Soil Texture Modifier	IDI Tool 2 Classification	IDI Tool 1 Classification		
		Severe	Moderate	Minor
Severe	Severe	Immediate	Immediate	Scheduled
Severe	Moderate	Immediate	Scheduled	Scheduled
Severe	Minor	Scheduled	Scheduled	Monitored
Moderate	Severe	Immediate	Scheduled	Scheduled
Moderate	Moderate	Scheduled	Scheduled	Monitored
Moderate	Minor	Monitored	Monitored	Monitored
Minor	Severe	Immediate	Scheduled	Monitored
Minor	Moderate	Scheduled	Monitored	Monitored
Minor	Minor	Monitored	Monitored	Monitored

FIGURE 1



Observed corrosion by soil texture.

capture best current industry practices, this phase of the project was discussed with 10 qualified and experienced operator and service provider professionals with a total of over 300 years of experience.

In developing improvements to Tables 3 and 4 in NACE SP0502-2010, specific, numerical criteria were developed, which covered a wide range of definable conditions. The work included analysis of rupture pressure ratio (RPR) and percent wall loss relative to abovegrade measurements at individual IDI indications. The enhancement of existing Tables 3 and 4 appear as Tables 1 and 2 herein.

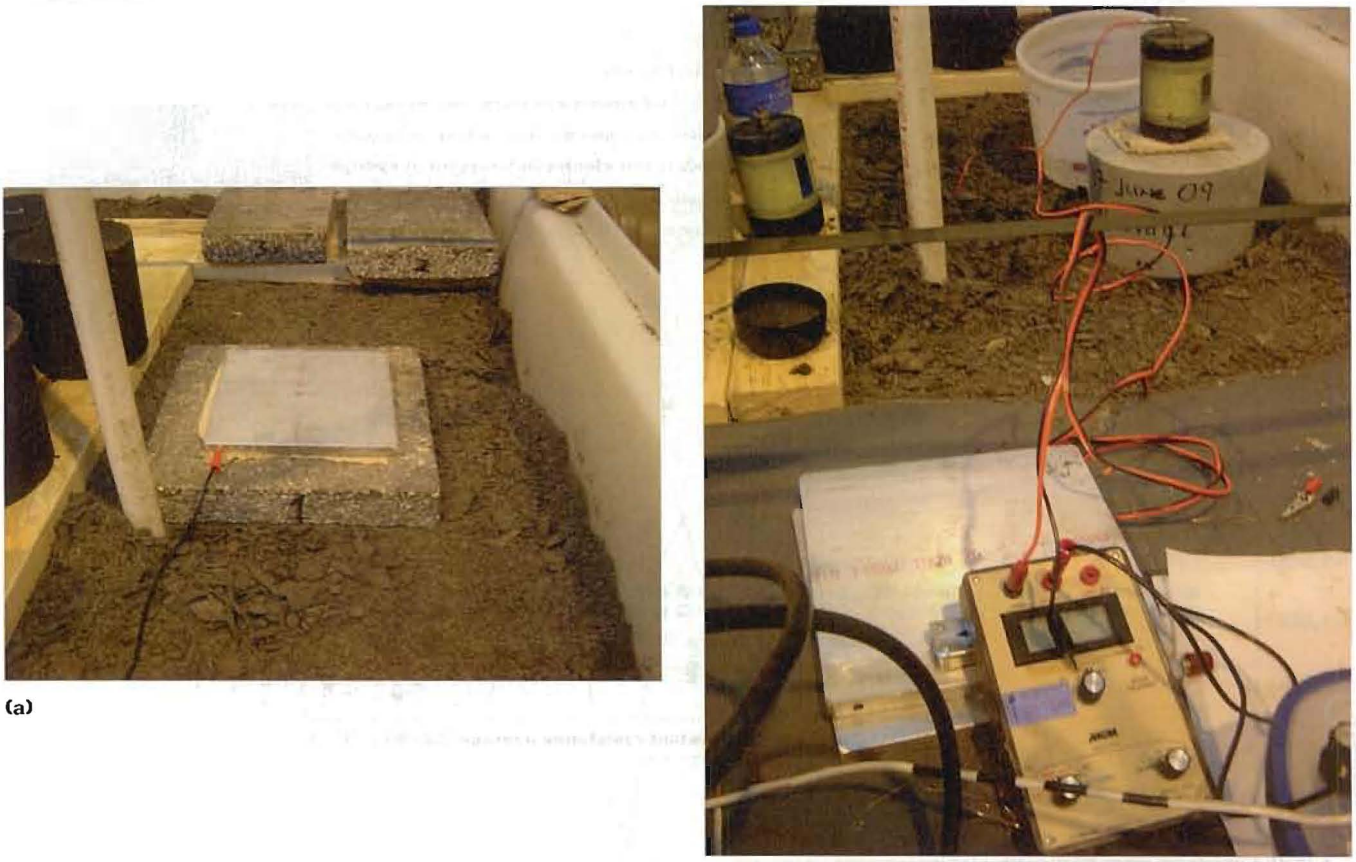
During the course of evaluating soil data at IDI indications, it was noticed that soil conditions appeared to correlate with the severity ranking as defined by the numerical ranges. This, of course, is consistent with what we have all observed, but have only been loosely able to tie to specific soil properties such as soil resistivity, pH, active ion concentration, and moisture content. A broader characterization of soil "texture" was postulated to provide a better indicator of corrosive conditions. This correlation was investigated using the U.S. Department of Agriculture (USDA) Web Soil Survey,[2] which provides significant detail regarding soil texture and physical/chemical properties across the United States. It has the additional advantage of being easily accessible on the Internet and free for anyone to use. The investigation concluded that percent clay content (expressed as a percentage of total composition) was a parameter that correlated with the presence of external pipeline corrosion. Data from the 14,000 joints of pipe (4,000 with measurable external corrosion) representing 188 soil types were plotted (Figure 1).

The data were then further analyzed by ranking the leak and rupture hazards as a percent of clay for the data set. The threat of leaks was indicated by wall loss while the threat of rupture was expressed as rupture pressure ratio. The data clearly illustrated that as the percent clay in the soil increases, so does the threat of both rupture and leak. A soil modifier was then applied to the Severity Classification Criteria of Indirect Inspections and the Prioritization Criteria for Indirect Inspection Indications as shown on the bottom of Table 1 and on the left side of Table 2, respectively.

Conclusions Concerning Severity Ranking

Improved tables for Severity Classification and Prioritization Criteria for Indirect Inspection Indications were developed, which provide a more consistent assessment of the external corrosion threat.

FIGURE 2



(a) (b)

Large-scale lab testing of potentials in paved areas: (a) steel plate electrode and (b) copper/copper sulfate ($Cu/CuSO_4$) electrode.

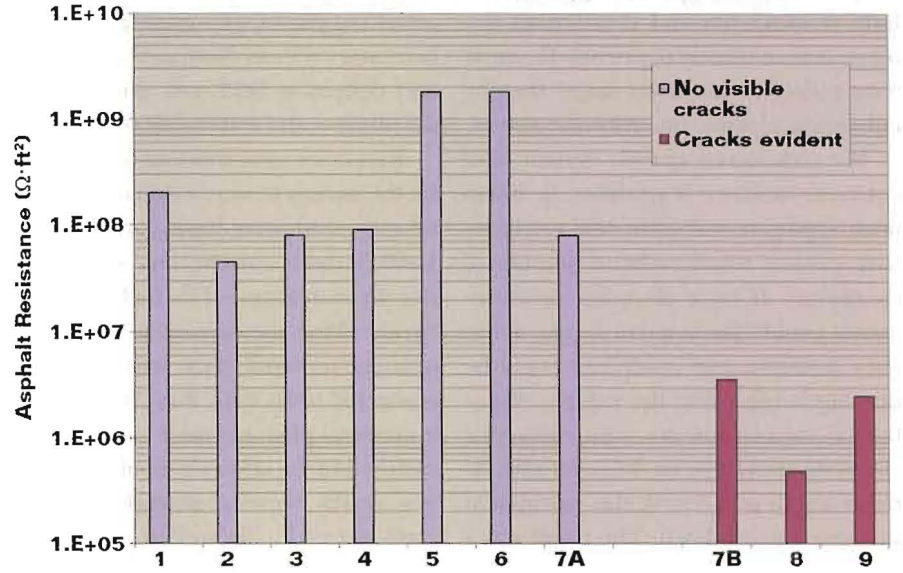
Methodologies developed represent an enhancement to NACE SP0502-2010 for quantification and qualification of IDI indications, effective use of available soils data, and introduction of a soil texture modifier.

The new methodologies quantified and verified both the project research data and industry knowledge and experience.

Potentials in Paved Areas

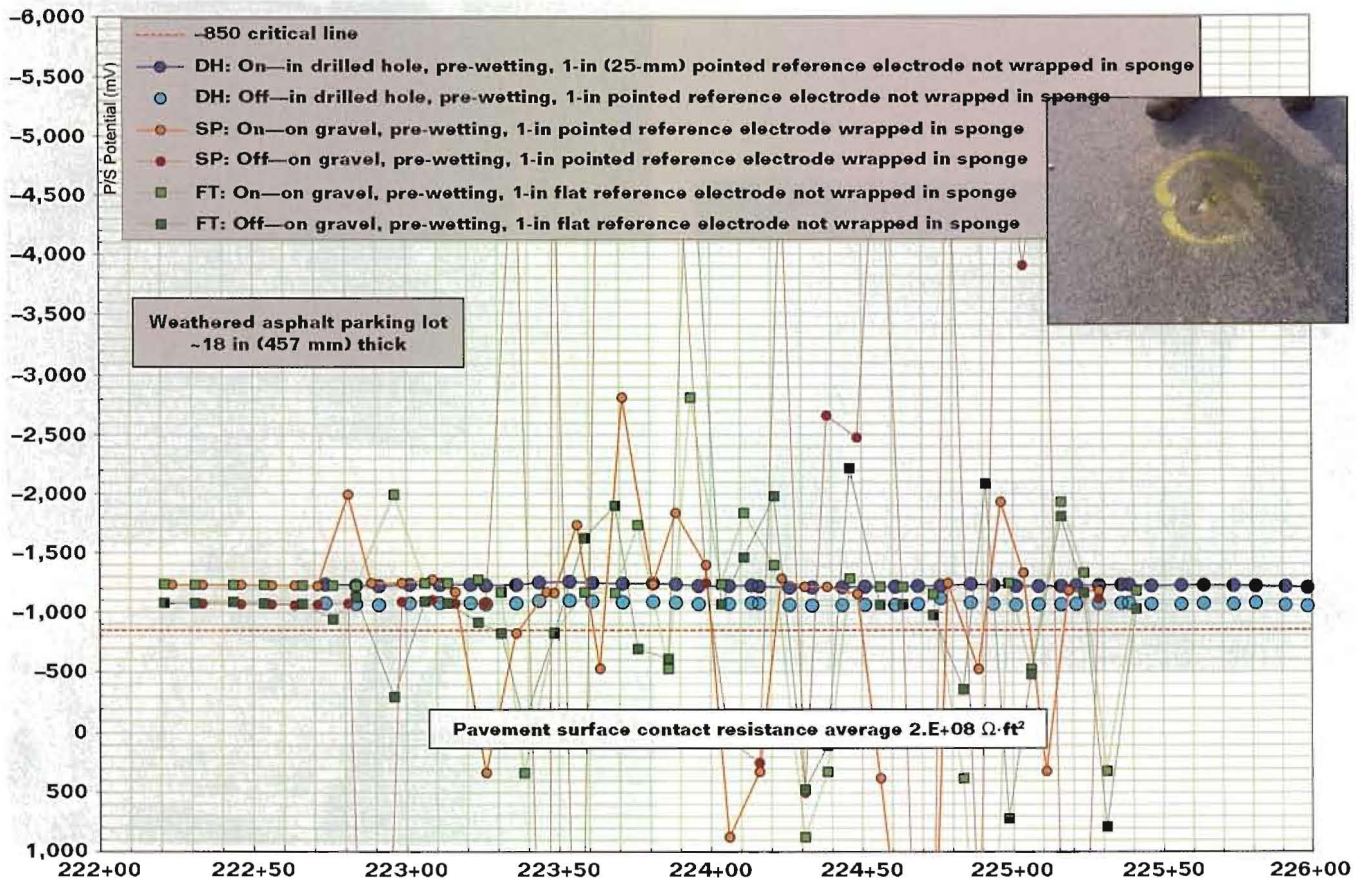
Current industry practices for collecting potential measurements in paved areas are to drill through the pavement, collect potentials offset from the location of the pipeline, surface wetting, or simply skipping data collection in paved areas. The purpose of the potentials in the paved areas portion of the project was to develop a methodology to collect more

FIGURE 3



Asphalt resistance measurements.

FIGURE 4



P/S potential measurements on weathered asphalt.

reliable data in a more user friendly, efficient, and safe manner. The goal was for the methodology to be applicable to both transmission and distribution systems, and ultimately to provide for more data collection in paved areas, thereby enhancing pipeline integrity assessment.

We considered gravel, asphalt, and concrete surfaces. Variability in thickness, aggregate, sub-base, and construction yields a nearly infinite number of conditions. If basic electrical measurements could characterize a pavement, then decisions and guidelines could be developed regarding the validity of potential measurements with reference electrode placement on the pavement. As the research progressed, this postulation was tested and refined. The result was a simple test procedure that can be used at the onset of a potential survey to determine if on-paving measurements can be made accurately.

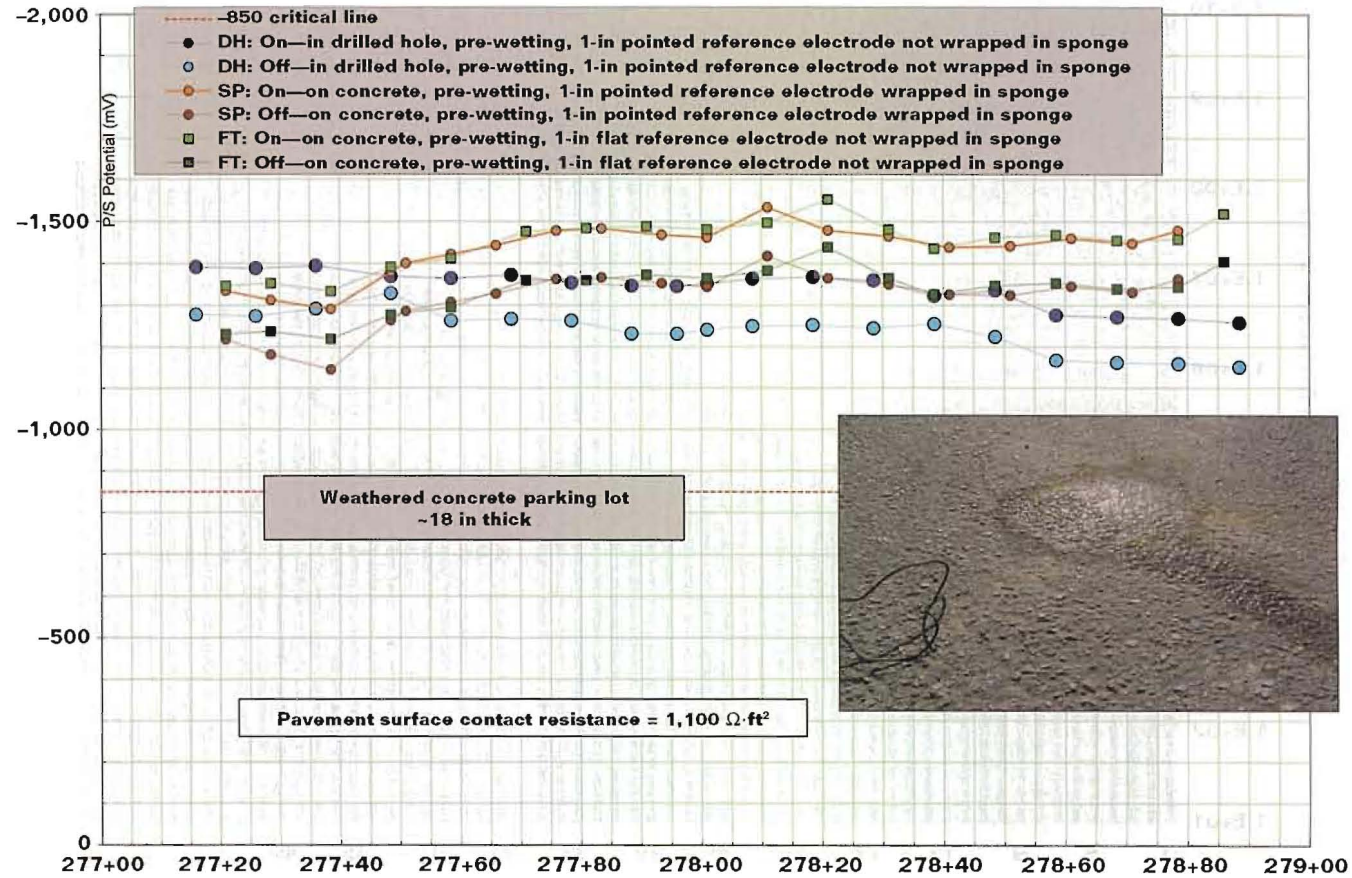
The research approach consisted of reviewing prior work, running large-scale laboratory tests as illustrated in Figure 2, and collecting field data on operating distribution and transmission pipelines.

Resistance measurements to characterize the pavement were made using a digital meg-ohmmeter having a maximum 1,000-V direct current (DC) source specifically manufactured for high-resistance circuits. Most measurements were made with one terminal of the meg-ohmmeter connected to an 8- by 8-in (203- by 203-mm) metal plate electrode on the paved surface and the other terminal connected to a nearby electrical ground used as an earth electrode. No surface wetting was done for these measurements, other than to use a damp towel directly under the metal plate electrode. Figure 3 shows surface resistance values for asphalt pavement with and without visible cracking.

Many CIS surveys were performed in the field that compared current on and instant-off pipe-to-soil (P/S) potential measurements with the cell placed on dry pavement, wet pavement, or in drilled holes through the pavement. Figure 4 contains results from a survey on weathered asphalt where the pavement contact resistance was 2×10^8 Ω·ft² measured as described above. The data on drilled holes are consistently accurate, whereas there are great inaccuracies in the data on the asphalt surface as evidenced by the extreme data scatter in both the positive and negative directions.

Figure 5 shows data collected on concrete pavement. Using the data from the drilled holes as the basis, potentials on

FIGURE 5



P/S potential measurements on weathered concrete.

pavement were first more positive and then became more negative as the survey progressed down the pipeline. This was the case even though the pavement contact resistance was a very low 100 Ω·ft².

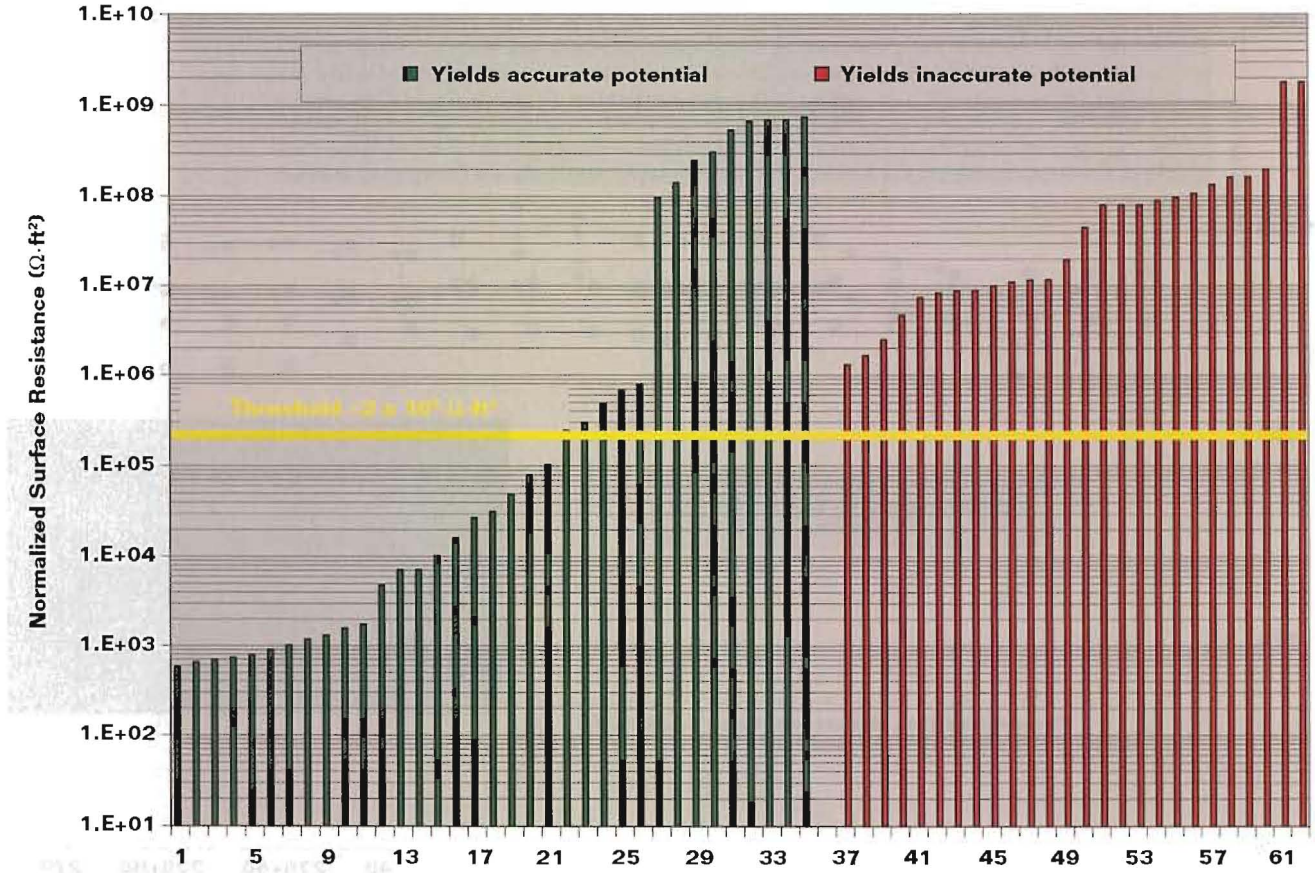
For gravel and asphalt, a procedure has been developed for measurement of the resistance through the pavement using a metallic electrode on the paved surface and a MΩ resistance meter. Figure 6 shows the correlation between accurate P/S potential data and the surface resistance measurement for 61 surveys on asphalt pavement. Based on analysis of the data collected, a threshold normalized resistance of 2×10^5 Ω·ft² has been established. That is, when gravel or asphalt paving exhibits a resistance of 200,000 Ω·ft² or less, a reliable potential measurement can be made with the reference electrode on the pavement.

For concrete pavement, the research concludes there is no clear, consistent method for making reliable P/S potential measurements without placing the reference electrode in direct contact with the underlying soil (e.g., by drilling holes through the pavement). P/S potentials with the reference electrode on a concrete surface are either more negative or more positive than when in contact with the underlying soil. While P/S potential measurements are not valid with a reference electrode on the concrete pavement, DCVG measurements may be.

Conclusions Concerning Potentials in Paved Areas

- For gravel and asphalt pavement:
  - A simple, straightforward, pre-survey surface resistance measurement can be used to determine if potentials recorded with the reference electrode placed on the pavement will provide accurate data.
  - A threshold of 200,000 Ω·ft² has been identified, below which potentials on pavement demonstrated accuracy.
  - A standard, 3-in (76-mm) diameter reference electrode with a wetted towel or sponge is adequate to minimize contact resistance.
- For concrete pavement:
  - No clear, consistent method for recording accurate potential measurements on concrete pavement was identified except by drilling holes through the pavement to facilitate reference electrode contact with the underlying soil.

FIGURE 6



Surface resistance threshold for asphalt.

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