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Technical Note: Field Study—Pitting Corrosion of Underground Pipelines Related to Local Soil and Pipe Characteristics

J.C. Velázquez, F. Caleyo,‡,* A. Valor,** and J.M. Hallen**

ABSTRACT

Recently, the authors proposed a new predictive model for pitting corrosion in underground pipelines. The model is based on field measurements of maximum pitting corrosion depth together with local soil and pipeline characteristics. The pitting corrosion data collection was conducted over a three-year period, for onshore buried pipelines operating in southern Mexico. This technical note contains a detailed description of the results of the field measurements, indicating the data entries classified as outlier observations and the textural soil class ascribed to each data entry.

KEY WORDS: corrosion, pipelines, pitting, soils

EXPERIMENTAL PROCEDURES AND RESULTS

The database used to produce the predictive model for pitting corrosion in underground pipelines published in the May 2009 edition of *Corrosion*[1] is presented in Table 1. A total of 259 samples of the soil and pipeline variables were obtained at dig sites over a three-year period, for onshore buried pipelines operating in southern Mexico for up to 50 years.

The maximum pit depth (d_{max}) of corrosion-caused metal losses with a diameter equal to or less than two times the pipe wall thickness in each exposed pipeline segment was measured in the field together with the following local soil properties: redox potential (rp), pH (ph), pipe-to-soil potential (pp), and soil resistivity (re). Soil samples taken from the pipeline ditch at dig sites were analyzed using standard laboratory methods to determine soil textural class (class), water content (wc), bulk density (bd) and dissolved chloride (cc), bicarbonate (bc), and sulfate (sc) ion concentrations. The pipeline age (t) and pipeline coating type (ct) were also recorded. Variable ct was treated as a discreet ordinal variable with its value assigned according to a scoring model described in detail in Reference 1 and summarized in a footnote in Table 1.

Based on the textural classes used by the U.S. Department of Agriculture (USDA, Washington, DC),[2] the collected soil samples were categorized into the following categories:

—clay (110 samples)
—sandy clay loam (79 samples)
—clay loam (61 samples)
—silty clay loam (6 samples)
—silty clay (2 samples)
—silt loam (1 sample)

The collected data sets were explored for outlier observations. Nine outliers were detected and the corresponding data sets were removed to produce the predictive model. The soil textural class of each data set is given in Table 1, where it is indicated which data entries classified as outlier. Further experimental details and statistical analyses of the in-field collected pitting corrosion data shown in Table 1 can be found elsewhere.[1]

The results shown in Table 1 indicate that the investigated pipeline population has suffered, on aver-

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age, from relatively long-term (~23 years) exposure to moderately corrosive environments characterized by weakly acidic soils with a relatively high resistivity (~5,000 Ω·cm), redox potential above 100 mV, and pipe-to-soil potential (natural or imposed) close to the optimum level of cathodic protection.

DATA APPLICATION

The purpose of this technical note is to make public the results of the field study given in Table 1. This is done with the goal of providing corrosion scientists and engineers with reliable data for modeling pitting corrosion in soil environments. Besides the predictive model reported earlier,[1] these data have been used by the authors to investigate the probability distribution of pitting corrosion depth and rate in underground pipelines using Monte Carlo simulation[3] and to stochastically model pitting corrosion using Markov chains.[4] Part of the data shown in Table 1 also has been used recently by other authors to develop a predictive model for steel corrosion damage in soil environment.[5] Upon request, the authors will be glad to provide the electronic version of Table 1 to any reader interested in soil pitting corrosion modeling.

ACKNOWLEDGMENTS

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TABLE 1

Field-Measured Soil Pitting Corrosion Data for Underground Pipelines[1]

Entry	d_{max} (mm)	t (years)	pH	pp[A] (V)	re (Ω·m)	wc (%)	bd (g/mL)	cc (ppm)	bc (ppm)	sc (ppm)	rp (mV)[B]	ct[C]	Class[D]
1	1.57	20	4.35	–0.71	62.1	23.9	1.21	12.41	16.65	172.20	342.0	WTC	C
2	3.05	20	4.79	–0.83	63.5	19.5	1.28	24.81	11.10	116.10	129.0	NC	C
3	2.08	20	5.78	–0.77	17.6	23.9	1.27	14.06	11.10	121.70	339.0	WTC	C
4	1.57	20	5.65	–0.83	19.3	27.0	1.25	15.44	11.10	34.30	340.0	WTC	C
5	0.79	19	6.84	–1.95	36.0	27.7	1.26	7.44	12.93	343.30	235.0	WTC	C
6	0.81	21	5.21	–0.91	65.8	12.8	1.30	12.13	11.10	84.17	313.0	WTC	C
7	1.17	21	5.27	–0.99	15.2	16.4	1.21	8.82	12.93	93.58	306.0	WTC	C
8	1.17	21	5.50	–1.08	20.8	15.3	1.24	9.10	13.87	47.40	279.0	WTC	C
9	1.57	20	4.33	–0.71	57.1	23.9	1.24	14.89	11.10	127.00	342.0	WTC	C
10	1.42	26	7.50	–0.65	15.7	20.3	1.28	8.27	12.65	136.40	235.0	CTC	C
11	1.89	26	7.11	–0.68	39.4	30.3	1.16	9.94	12.65	101.50	210.0	CTC	C
12	4.24	26	6.01	–0.67	13.3	29.4	1.30	69.05	5.55	40.43	96.0	CTC	C
13	2.59	26	7.04	–0.71	10.0	34.1	1.21	38.26	12.87	106.80	93.0	CTC	C
14	3.91	21	5.02	–0.81	44.0	19.5	1.27	49.30	11.10	28.00	104.0	NC	C
15	0.76	21	5.73	–0.79	81.1	12.5	1.29	9.93	19.42	173.00	272.0	WTC	C
16	2.51	25	5.80	–0.88	8.8	33.9	1.15	11.58	8.32	321.10	263.0	CTC	C
17	2.67	26	6.22	–0.77	10.8	27.4	1.17	27.99	5.10	143.20	92.0	CTC	C
18	0.94	25	6.37	–0.85	46.8	30.4	1.16	14.06	11.10	284.30	88.0	CTC	C
19	0.53	23	5.77	–0.97	104.7	28.0	1.20	8.82	12.94	170.80	305.0	CTC	C
20	1.07	25	5.73	–1.36	18.7	29.8	1.19	17.09	27.74	83.60	309.0	CTC	C
21	3.91	21	4.86	–0.80	89.6	16.1	1.26	56.32	5.55	34.80	189.0	NC	C
22	2.06	18	4.91	–1.16	124.2	22.3	1.24	10.75	11.10	39.81	348.0	NC	C
23	3.10	25	5.00	–0.88	16.2	31.0	1.11	26.62	5.55	133.20	220.0	CTC	C
24	0.43	20	7.50	–1.44	22.4	26.8	1.25	8.27	5.55	275.00	157.0	WTC	C
25	2.34	18	5.15	–1.36	183.1	25.5	1.22	15.72	5.55	57.66	218.0	NC	C
26	0.76	22	6.40	–0.88	30.9	18.8	1.24	8.27	5.55	129.80	202.0	WTC	C
27	1.17	25	5.29	–0.75	86.3	29.1	1.12	6.62	5.55	60.47	275.0	CTC	C
28	4.78	20	4.16	–1.09	6.8	28.9	1.20	86.30	8.32	129.80	108.0	NC	C
29	1.27	23	4.60	–0.80	129.3	20.8	1.27	8.80	9.71	98.10	130.0	CTC	C
30	1.57	20	5.51	–0.62	72.3	28.9	1.17	14.09	11.10	81.99	315.0	WTC	C
31	0.91	29	6.61	–1.11	9.1	30.8	1.28	18.49	5.55	30.97	59.0	CTC	C
32	1.40	19	5.50	–1.18	236.6	18.1	1.29	11.45	8.32	82.28	326.0	CTC	C
33	2.21	22	5.20	–0.87	98.5	21.0	1.29	12.33	16.65	184.80	255.0	NC	C
34	1.65	22	5.35	–0.88	87.4	23.1	1.19	7.92	19.42	59.19	288.0	WTC	C
35	1.17	20	5.29	–0.83	82.7	19.1	1.27	8.80	11.10	54.91	269.0	WTC	C
36	1.93	22	5.77	–0.96	79.3	17.0	1.19	7.92	11.10	71.59	233.0	WTC	C
37	0.94	20	6.01	–0.91	24.1	22.6	1.19	7.92	11.10	138.70	201.0	WTC	C
38	1.57	22	5.02	–0.96	72.0	20.3	1.25	12.49	16.55	172.30	180.0	WTC	C
39	1.57	19	6.96	–1.07	65.0	30.3	1.28	15.89	11.97	168.00	220.0	WTC	C
40	2.21	29	5.35	–1.05	34.5	21.7	1.26	13.33	13.87	308.40	190.0	CTC	C

continued on next page

TABLE 1 (continued)

Field-Measured Soil Pitting Corrosion Data for Underground Pipelines[1]

Entry	d_{max} (mm)	t (years)	pH	pp[A] (V)	re (Ω·m)	wc (%)	bd (g/mL)	cc (ppm)	bc (ppm)	sc (ppm)	rp (mV)[B]	ct[C]	Class[D]
41	1.17	18	5.99	–0.99	123.1	13.4	1.30	6.62	5.55	60.47	189.0	WTC	C
42	1.17	20	6.11	–0.80	87.8	20.1	1.22	12.33	16.65	54.85	150.0	CTC	C
43	1.57	19	5.43	–1.10	149.2	20.4	1.20	17.09	11.10	61.99	299.0	NC	C
44	0.41	20	5.57	–1.10	221.0	13.7	1.28	8.27	5.55	255.10	290.0	WTC	C
45	1.04	18	5.78	–1.10	65.0	21.6	1.25	17.09	17.74	53.56	133.0	WTC	C
46	1.57	15	5.93	–1.13	99.5	23.4	1.27	15.72	5.55	57.66	199.0	WTC	C
47	2.74	20	5.01	–0.81	43.6	25.3	1.19	27.75	5.55	27.81	74.0	WTC	C
48	0.41	15	6.48	–1.05	161.2	16.6	1.27	9.93	19.42	93.05	274.0	WTC	C
49	1.04	20	7.01	–0.98	15.1	34.0	1.19	14.06	11.10	184.30	85.0	WTC	C
50	0.41	15	6.84	–1.23	90.9	20.8	1.27	7.44	12.65	111.50	163.0	WTC	C
51	0.92	18	5.99	–0.94	104.0	13.4	1.30	9.72	5.55	66.47	189.0	WTC	C
52	0.94	20	6.01	–0.78	85.8	20.1	1.22	12.83	16.65	89.85	150.0	WTC	C
53	0.91	17	5.23	–1.02	139.2	20.4	1.20	17.86	11.10	128.00	209.0	WTC	C
54	0.91	20	5.70	–1.10	151.0	13.7	1.28	9.27	5.55	185.10	259.0	CTC	C
55	0.94	18	5.79	–1.10	65.0	21.6	1.25	17.94	15.74	148.60	233.0	WTC	C
56	0.91	16	5.56	–0.83	19.3	27.0	1.25	14.40	5.55	192.30	240.0	WTC	C
57	1.01	22	5.28	–0.77	17.6	23.9	1.25	19.06	8.32	158.00	339.0	CTC	C
58	1.93	15	4.69	–0.82	51.5	19.9	1.27	28.81	5.55	200.20	120.0	AEC	C
59	2.08	20	5.12	–1.03	11.6	29.1	1.28	26.81	5.55	159.50	101.0	AEC	C
60	1.58	13	5.02	–0.91	49.0	25.3	1.24	19.27	5.55	217.30	80.0	NC	C
61	2.50	20	6.01	–0.69	22.6	25.3	1.22	82.99	5.55	109.30	225.0	WTC	C
62	3.18	24	6.12	–0.63	11.6	29.1	1.26	96.81	5.55	115.50	11.0	WTC	C
63	1.31	21	6.21	–0.71	45.8	12.8	1.26	32.13	11.10	84.17	113.0	WTC	C
64	3.88	27	5.30	–0.62	36.5	25.3	1.23	109.80	10.65	374.30	17.3	CTC	C
65	2.65	13	5.08	–0.54	35.2	23.0	1.22	102.40	16.48	260.40	45.0	WTC	C
66	4.24	28	5.16	–0.79	60.0	23.9	1.36	109.80	11.87	95.57	108.0	CTC	C
67	1.17	21	6.27	–0.99	55.2	16.4	1.28	8.82	12.93	93.58	106.0	WTC	C
68	0.81	13	7.11	–0.60	25.0	19.4	1.27	48.12	9.24	232.20	90.0	WTC	C
69	0.94	18	6.09	–0.86	20.6	19.9	1.28	18.27	22.19	126.60	242.0	WTC	C
70	0.71	6	5.03	–0.52	43.0	23.1	1.28	18.41	5.55	152.30	102.0	FBE	C
71	8.56	42	6.12	–0.47	7.8	36.0	1.20	105.50	28.68	455.90	110.0	CTC	C
72	8.31	42	6.13	–0.47	6.8	32.4	1.21	104.00	15.01	379.10	117.0	CTC	C
73	8.41	42	6.50	–0.47	10.4	31.3	1.20	128.50	28.99	288.20	98.0	CTC	C
74	0.81	42	7.09	–0.48	107.1	16.8	1.34	30.96	29.65	101.20	138.0	CTC	C
75	8.26	42	6.20	–0.49	10.3	38.9	1.22	56.14	33.47	146.80	98.0	CTC	C
76[E]	0.41	42	7.79	–0.47	8.8	66.0	1.25	5.13	26.50	156.90	92.0	CTC	C
77	1.60	42	7.21	–0.49	8.1	30.3	1.30	22.17	19.55	256.70	92.0	CTC	C
78	1.57	42	7.79	–0.47	7.3	39.3	1.30	18.41	29.55	399.90	99.0	CTC	C
79	6.45	8	5.03	–0.42	6.3	23.7	1.22	49.17	8.32	16.28	130.0	NC	C
80	7.04	8	5.08	–0.45	3.8	27.3	1.22	47.57	8.32	14.90	95.0	NC	C
81[E]	10.41	22	5.02	–1.67	6.1	36.7	1.13	40.17	5.55	26.12	139.0	WTC	C
82	0.79	23	6.44	–1.13	30.0	19.4	1.18	117.00	78.10	14.53	44.0	CTC	C
83	1.17	23	8.18	–0.97	43.5	22.8	1.18	117.00	39.05	148.50	120.0	WTC	C
84	0.79	23	8.14	–0.97	42.6	23.3	1.19	292.50	91.12	24.10	146.0	WTC	C
85	0.41	23	8.09	–0.97	27.2	27.0	1.15	146.20	52.07	88.68	153.0	WTC	C
86	2.74	27	6.76	–0.87	10.5	21.6	1.24	175.50	65.09	38.45	108.0	WTC	C
87	0.79	23	6.55	–1.03	30.9	21.4	1.17	351.00	91.12	2.57	49.0	CTC	C
88	0.79	23	6.59	–1.03	30.0	21.0	1.22	146.20	117.20	69.54	51.0	CTC	C
89	1.57	50	9.88	–0.76	41.0	25.7	1.21	234.00	52.07	351.90	69.0	CTC	C
90	1.98	50	6.79	–0.75	41.0	26.9	1.17	21.06	65.09	9.75	65.0	CTC	C
91	1.98	40	7.01	–0.86	98.6	20.1	1.14	87.75	65.09	9.75	201.0	CTC	C
92	0.79	23	8.01	–0.96	44.9	24.2	1.25	263.20	78.10	48.02	163.0	WTC	C
93	1.57	16	5.99	–0.80	35.7	27.1	1.28	263.20	156.20	698.60	111.0	WTC	C
94	1.96	23	7.95	–0.98	44.3	29.3	1.16	11.70	65.09	146.10	125.0	WTC	C
95	4.83	27	4.14	–1.07	207.0	22.8	1.22	87.75	5.21	55.19	216.0	CTC	C
96	1.27	27	5.07	–1.15	72.6	25.0	1.12	87.75	6.51	69.54	285.0	CTC	C
97	5.00	35	5.13	–0.58	11.0	29.4	1.12	17.75	5.21	69.54	101.0	CTC	C
98	8.41	35	5.73	–0.58	8.4	23.1	1.11	234.00	5.21	43.23	178.0	CTC	C
99	7.59	35	6.33	–0.57	11.4	24.9	1.17	58.50	6.51	43.23	189.0	CTC	C
100	7.59	37	5.49	–0.82	22.3	31.8	1.23	117.00	7.81	21.71	144.0	CTC	C
101	5.00	37	5.41	–0.95	28.2	23.1	1.19	117.00	5.21	<1.00	146.0	CTC	C
102[E]	8.41	37	5.43	–0.99	78.3	22.4	1.10	672.70	5.21	28.88	173.0	CTC	C
103	5.00	37	5.33	–0.93	10.3	57.6	1.14	146.20	5.21	9.75	175.0	CTC	C
104	1.78	37	5.32	–0.87	8.9	19.7	1.18	11.70	3.91	45.63	232.0	CTC	C
105	1.14	33	5.04	–0.70	143.8	19.3	1.18	17.75	3.91	191.50	2.1	CTC	C
106	2.54	33	6.36	–0.70	12.2	32.1	1.19	75.50	10.41	2.57	242.0	CTC	C
107	2.36	33	5.80	–0.74	399.5	14.1	1.17	75.50	5.21	88.68	216.0	CTC	C
108	5.00	35	5.19	–0.58	11.2	29.7	1.28	27.75	5.21	53.66	107.0	CTC	C
109	4.83	27	4.64	–1.07	218.7	26.8	1.22	89.75	5.21	55.19	206.0	CTC	C
110	1.52	33	6.32	–0.76	276.7	8.8	1.23	46.25	5.21	189.10	256.0	CTC	C
111	0.99	21	6.16	–0.96	28.4	19.5	1.35	10.75	13.87	41.41	298.0	WTC	SCL
112	0.81	21	6.75	–0.91	34.1	15.2	1.45	8.27	8.32	16.85	262.0	CTC	SCL
113	0.79	19	6.98	–1.90	21.5	22.3	1.38	10.75	13.87	35.32	256.0	WTC	SCL
114	0.79	19	6.81	–1.97	33.7	21.9	1.40	11.58	13.87	37.37	256.0	WTC	SCL
115	1.65	26	6.47	–1.13	32.7	24.2	1.44	12.13	12.93	129.50	275.0	CTC	SCL

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TABLE 1 (continued)

Field-Measured Soil Pitting Corrosion Data for Underground Pipelines[1]

Entry	d_{max} (mm)	t (years)	pH	pp[A] (V)	re (Ω·m)	wc (%)	bd (g/mL)	cc (ppm)	bc (ppm)	sc (ppm)	rp (mV)[B]	ct[C]	Class[D]
116	1.17	21	5.94	–1.23	24.0	19.1	1.40	10.75	11.10	177.40	270.0	WTC	SCL
117	2.11	26	7.01	–1.10	34.1	24.7	1.43	17.72	12.93	115.00	72.0	CTC	SCL
118	1.25	26	6.80	–1.11	32.7	21.6	1.42	7.72	8.32	89.30	126.0	CTC	SCL
119	0.46	10	5.41	–0.90	25.0	19.4	1.46	28.12	9.24	332.20	90.0	WTC	SCL
120	0.79	21	5.68	–0.93	156.5	21.4	1.40	11.58	11.10	35.40	106.0	WTC	SCL
121	2.65	11	4.48	–0.84	35.2	27.0	1.44	32.43	16.48	160.40	45.0	NC	SCL
122	0.79	21	6.14	–0.92	25.8	16.1	1.43	18.20	16.65	126.90	312.0	CTC	SCL
123	0.76	21	6.68	–0.93	46.5	17.7	1.39	28.95	14.76	93.58	220.0	WTC	SCL
124	0.43	9	5.80	–0.68	243.6	11.4	1.47	32.53	16.65	243.40	192.0	NC	SCL
125	0.41	9	6.05	–0.84	16.1	23.6	1.48	33.58	16.65	263.80	211.0	AEC	SCL
126	1.68	10	5.23	–0.91	34.4	12.8	1.45	33.09	11.10	315.20	127.0	NC	SCL
127	0.79	21	7.62	–0.93	32.0	16.2	1.37	8.27	16.65	68.60	226.0	CTC	SCL
128	2.11	26	6.80	–0.79	30.9	23.1	1.36	14.89	11.10	90.16	162.0	CTC	SCL
129	0.41	9	6.04	–0.83	13.1	26.4	1.49	24.81	27.74	127.20	236.0	NC	SCL
130	0.41	21	6.89	–1.16	20.6	14.9	1.43	8.27	22.19	126.60	242.0	WTC	SCL
131	0.51	21	6.40	–0.88	30.9	18.8	1.43	8.27	14.76	80.10	202.0	WTC	SCL
132	0.99	11	6.50	–0.90	55.9	28.3	1.40	18.20	8.32	216.20	255.0	NC	SCL
133	0.79	26	7.80	–0.79	30.9	23.1	1.42	8.27	11.10	39.09	162.0	CTC	SCL
134	1.24	10	4.75	–0.91	113.1	15.6	1.34	10.75	8.32	77.33	240.0	NC	SCL
135	0.41	12	7.45	–0.86	149.1	14.3	1.41	54.58	8.32	36.28	50.0	FBE	SCL
136	0.91	20	5.50	–1.02	161.2	21.2	1.35	17.61	11.10	14.90	168.0	WTC	SCL
137	0.43	12	6.83	–1.04	100.8	16.9	1.42	9.68	5.55	129.50	87.0	FBE	SCL
138	0.66	19	7.55	–0.71	14.0	29.9	1.38	15.85	13.87	67.74	200.0	WTC	SCL
139	0.79	12	6.98	–1.05	41.0	16.0	1.37	16.73	5.55	169.60	23.0	FBE	SCL
140	1.68	19	5.30	–1.06	107.7	20.0	1.37	4.40	11.10	68.17	301.0	WTC	SCL
141	0.48	17	5.90	–0.67	105.3	18.6	1.37	8.80	11.10	44.22	322.0	WTC	SCL
142	0.91	11	6.18	–1.43	18.7	19.4	1.34	8.80	16.65	42.51	20.0	FBE	SCL
143	0.43	10	6.97	–1.07	48.4	17.5	1.45	7.04	8.32	114.40	44.0	NC	SCL
144	0.79	12	6.99	–1.05	41.1	26.0	1.45	76.59	16.65	63.04	23.0	WTC	SCL
145	3.76	20	5.16	–0.70	21.0	13.9	1.43	39.80	11.87	15.57	108.0	NC	SCL
146[E]	0.53	5	6.91	–0.81	6.0	19.6	1.56	237.70	30.52	905.30	92.0	NC	SCL
147[E]	1.57	5	7.12	–0.79	4.8	18.1	1.55	206.90	27.74	836.90	109.0	NC	SCL
148	1.04	20	5.52	–0.65	65.0	29.0	1.42	3.52	8.32	452.30	339.0	WTC	SCL
149	1.57	5	7.25	–0.86	4.5	25.0	1.55	184.90	30.07	344.40	85.0	NC	SCL
150	0.48	27	6.50	–0.88	19.0	20.9	1.30	16.73	12.93	114.80	215.0	CTC	SCL
151	1.17	19	6.02	–1.18	67.0	21.6	1.35	33.09	11.10	215.10	230.0	WTC	SCL
152	1.07	19	6.08	–1.08	93.4	22.5	1.37	10.75	8.32	77.33	205.0	WTC	SCL
153	0.41	12	7.31	–1.05	20.6	33.9	1.49	8.27	22.19	106.60	55.0	WTC	SCL
154	1.17	19	4.98	–0.90	118.9	17.4	1.37	31.43	18.48	280.40	302.0	NC	SCL
155	1.57	19	5.56	–0.99	161.2	16.4	1.38	14.40	7.10	68.17	328.0	NC	SCL
156	1.40	12	7.04	–0.81	31.6	27.1	1.48	18.20	16.65	126.90	88.0	WTC	SCL
157	1.25	19	5.53	–1.10	148.1	16.0	1.37	28.12	9.24	332.20	330.0	WTC	SCL
158	0.91	14	6.20	–1.01	60.0	21.6	1.35	32.09	18.10	205.10	230.0	WTC	SCL
159	0.91	19	6.18	–1.00	80.4	22.5	1.37	11.75	8.32	79.33	205.0	WTC	SCL
160	3.30	26	5.01	–0.67	12.3	28.6	1.30	34.85	5.55	33.43	102.0	CTC	SCL
161	0.90	25	4.91	–0.99	102.9	17.4	1.37	31.93	16.48	290.40	302.0	CTC	SCL
162	0.94	19	5.66	–1.08	141.2	16.4	1.38	14.49	7.10	57.17	328.0	WTC	SCL
163	1.91	15	5.32	–1.07	14.1	29.0	1.37	26.06	8.32	79.64	110.0	AEC	SCL
164	1.04	19	5.30	–1.06	107.7	20.0	1.37	8.27	9.24	106.60	301.0	WTC	SCL
165	1.91	13	5.08	–1.02	13.7	29.9	1.40	28.27	12.65	80.78	106.0	NC	SCL
166	1.87	15	5.14	–1.10	24.0	22.1	1.40	27.33	7.10	122.10	132.0	AEC	SCL
167	0.91	21	6.14	–1.00	25.8	16.1	1.43	16.62	11.10	94.26	312.0	CTC	SCL
168	1.17	17	6.68	–0.93	40.5	17.7	1.39	28.27	9.24	138.00	220.0	WTC	SCL
169	0.66	23	6.29	–1.06	20.6	14.9	1.39	8.27	22.19	126.60	142.0	CTC	SCL
170	2.34	19	5.64	–0.65	56.0	26.7	1.33	31.44	12.93	343.30	135.0	NC	SCL
171	1.17	23	6.48	–0.81	46.5	27.7	1.36	28.95	14.76	93.58	220.0	CTC	SCL
172	1.57	10	5.25	–0.81	70.1	21.6	1.35	63.58	12.65	163.80	111.0	FBE	SCL
173	0.79	39	7.79	–1.00	21.4	26.2	1.42	20.58	18.02	139.80	93.0	CTC	SCL
174	1.57	39	7.40	–0.91	40.4	20.5	1.36	32.01	12.05	158.90	132.0	CTC	SCL
175	1.19	39	7.80	–0.95	15.4	38.6	1.39	3.20	13.89	145.30	144.0	CTC	SCL
176	1.57	19	6.69	–0.83	15.9	30.3	1.39	17.57	11.10	146.20	99.0	CTC	SCL
177	1.19	19	6.29	–0.80	4.3	36.3	1.36	10.15	7.10	289.80	145.0	CTC	SCL
178	1.17	19	6.91	–0.77	4.8	22.0	1.35	3.90	20.99	206.60	86.0	WTC	SCL
179	0.79	19	5.89	–0.77	5.7	27.7	1.44	17.58	25.01	289.80	55.0	WTC	SCL
180	0.79	19	5.86	–0.77	10.4	27.0	1.44	3.20	25.01	259.30	25.0	WTC	SCL
181	0.79	19	6.75	–0.77	8.1	27.6	1.41	8.65	25.01	209.20	159.0	WTC	SCL
182	5.87	31	5.96	–0.74	16.2	29.1	1.32	36.06	5.10	16.57	63.0	CTC	SCL
183	5.87	31	5.85	–0.74	16.5	31.8	1.30	39.17	5.10	19.17	63.0	CTC	SCL
184[E]	3.30	23	7.99	–0.97	45.7	23.0	1.36	146.20	65.09	31.27	161.0	WTC	SCL
185[E]	1.57	16	5.98	–0.80	33.5	28.1	1.44	409.50	195.20	292.00	109.0	WTC	SCL
186	1.17	19	6.91	–0.77	4.8	22.0	1.35	3.90	20.99	206.60	86.0	WTC	SCL
187	0.79	19	5.89	–0.77	5.7	27.7	1.44	17.58	25.01	289.80	55.0	WTC	SCL
188	0.79	19	5.86	–0.77	10.4	27.0	1.44	3.20	25.01	259.30	25.0	WTC	SCL
189	0.79	19	6.75	–0.77	8.1	27.6	1.41	8.65	25.01	209.20	159.0	WTC	SCL
190	1.17	21	5.50	–1.23	21.1	19.1	1.33	9.10	8.32	138.00	240.0	WTC	CL

continued on next page

TABLE 1 (continued)

Field-Measured Soil Pitting Corrosion Data for Underground Pipelines[1]

Entry	d_{max} (mm)	t (years)	pH	pp[A] (V)	re (Ω·m)	wc (%)	bd (g/mL)	cc (ppm)	bc (ppm)	sc (ppm)	rp (mV)[B]	ct[C]	Class[D]
191	2.74	26	6.16	–0.69	16.9	27.1	1.31	28.20	10.87	125.20	149.0	CTC	CL
192	2.46	26	6.42	–0.75	14.5	22.3	1.32	31.93	16.65	179.10	252.7	CTC	CL
193	1.27	26	6.52	–0.83	17.8	28.4	1.32	20.40	19.42	77.33	261.4	CTC	CL
194	3.58	26	5.60	–0.62	16.5	29.3	1.31	34.81	12.65	74.26	217.3	CTC	CL
195	2.49	26	6.15	–0.72	15.6	26.9	1.32	28.74	13.87	128.00	219.1	CTC	CL
196	2.31	26	6.89	–0.80	15.6	23.9	1.33	25.31	18.48	35.42	271.3	CTC	CL
197	1.02	26	6.59	–0.76	16.4	26.3	1.33	25.31	16.65	56.80	241.5	CTC	CL
198	0.41	21	6.03	–1.13	30.0	19.4	1.32	8.27	20.34	109.80	44.0	WTC	CL
199	1.91	26	6.69	–1.10	19.6	23.5	1.33	7.11	22.19	71.16	147.0	CTC	CL
200	3.58	26	5.05	–1.01	21.2	21.1	1.34	29.93	11.65	88.70	170.0	CTC	CL
201	0.41	9	6.25	–0.81	10.1	23.6	1.34	8.27	24.03	50.64	189.0	WTC	CL
202	0.43	9	9.36	–0.79	1.9	30.7	1.33	289.50	46.22	1,370.20	19.0	AEC	CL
203	1.68	21	5.70	–0.89	24.3	15.5	1.38	4.96	9.71	82.71	120.0	WTC	CL
204	0.43	22	7.32	–0.88	54.0	16.5	1.32	8.27	11.10	123.50	154.0	CTC	CL
205	1.40	22	7.00	–0.61	14.8	29.2	1.33	14.09	11.10	219.30	70.0	WTC	CL
206	0.43	12	6.85	–1.08	45.1	17.2	1.33	4.40	11.10	100.70	78.0	FBE	CL
207	2.57	10	4.85	–0.82	113.1	15.8	1.31	59.87	11.10	11.30	240.0	NC	CL
208	0.58	20	5.89	–0.90	93.4	16.0	1.33	11.45	11.10	74.58	301.0	WTC	CL
209	0.48	21	7.02	–0.90	34.5	24.1	1.37	3.52	11.10	64.75	155.0	WTC	CL
210	1.96	29	6.40	–0.88	29.8	22.1	1.31	32.28	8.32	132.30	185.9	CTC	CL
211	1.96	25	6.67	–0.90	15.7	19.1	1.31	11.45	12.94	85.70	235.0	CTC	CL
212	1.19	5	5.90	–0.79	18.8	24.5	1.30	26.41	10.10	162.90	159.0	NC	CL
213	0.48	26	6.81	–0.80	10.8	22.1	1.33	19.37	11.10	99.56	233.0	CTC	CL
214	3.10	18	4.95	–1.00	19.7	27.4	1.31	62.28	8.32	132.30	213.0	NC	CL
215	0.94	22	5.79	–1.10	72.3	28.3	1.31	14.09	11.10	99.30	190.0	WTC	CL
216	0.41	12	6.98	–1.09	40.4	30.6	1.31	8.27	24.03	50.64	98.0	FBE	CL
217	1.59	18	4.90	–1.00	102.7	17.4	1.31	32.81	8.32	149.30	233.0	WTC	CL
218	1.96	22	5.69	–1.09	42.3	28.3	1.31	26.99	5.55	109.30	150.0	WTC	CL
219	1.04	26	6.89	–0.80	15.6	23.9	1.33	17.11	11.10	75.01	271.3	CTC	CL
220	2.10	26	5.09	–0.76	16.4	26.8	1.33	29.93	11.10	157.70	241.5	CTC	CL
221	1.17	21	5.50	–1.14	21.1	19.1	1.33	16.62	8.32	60.47	240.0	CTC	CL
222	1.59	26	6.59	–0.73	14.4	27.8	1.33	16.75	8.32	103.50	199.0	CTC	CL
223	1.17	5	5.07	–0.71	3.8	26.1	1.35	18.27	10.74	77.33	89.0	WTC	CL
224	0.91	9	8.01	–0.79	2.1	33.7	1.32	152.30	16.22	677.40	19.0	NC	CL
225	1.04	22	5.74	–1.03	44.0	25.1	1.32	29.75	11.10	177.40	70.0	WTC	CL
226	1.17	15	6.42	–0.90	34.5	24.1	1.30	33.52	11.10	64.75	155.0	NC	CL
227	1.40	21	7.12	–0.71	34.1	15.2	1.32	48.27	8.32	16.85	162.0	WTC	CL
228	4.15	16	4.99	–0.60	30.0	18.9	1.33	100.80	5.55	15.57	108.0	NC	CL
229	0.94	15	7.10	–0.56	34.5	24.1	1.38	33.52	11.10	64.75	150.0	NC	CL
230	2.21	30	5.65	–0.91	36.6	27.7	1.36	13.33	13.87	108.40	190.0	CTC	CL
231	0.79	17	5.84	–0.95	56.0	27.7	1.32	30.44	12.93	343.30	235.0	WTC	CL
232	0.81	42	7.26	–0.47	7.2	22.9	1.31	94.59	55.39	958.90	98.0	CTC	CL
233	8.13	42	6.30	–0.49	6.3	31.5	1.31	125.40	45.37	590.40	109.0	CTC	CL
234	7.70	42	6.58	–0.49	4.9	33.3	1.31	107.00	43.70	498.00	107.0	CTC	CL
235	0.81	42	7.09	–0.49	7.1	16.8	1.34	90.96	29.65	401.20	138.0	CTC	CL
236	1.19	42	6.81	–0.49	7.3	31.7	1.33	55.66	59.35	905.60	100.0	CTC	CL
237	0.41	42	7.36	–0.49	6.5	22.0	1.36	19.02	41.82	312.70	132.0	CTC	CL
238	7.65	42	6.22	–0.49	8.2	37.2	1.33	19.02	23.17	157.10	103.0	CTC	CL
239	1.60	42	7.52	–0.49	7.7	35.8	1.37	8.17	5.55	281.20	117.0	CTC	CL
240[E]	5.33	29	6.28	–1.57	306.1	21.7	1.31	20.16	5.10	50.36	167.0	CTC	CL
241	10.41	22	5.08	–1.53	20.1	27.7	1.31	21.17	<1.00	25.27	149.0	WTC	CL
242	1.17	50	6.81	–0.76	41.5	24.7	1.30	11.70	91.12	550.30	72.0	CTC	CL
243	4.75	27	5.98	–0.70	51.3	29.7	1.31	146.20	104.10	59.98	41.0	CTC	CL
244	3.18	23	8.02	–0.96	46.9	25.7	1.30	117.00	39.05	148.50	169.0	WTC	CL
245	0.81	27	6.91	–0.85	14.6	25.1	1.27	117.00	65.09	43.23	89.0	CTC	CL
246	1.17	20	6.50	–0.79	21.5	25.6	1.29	204.80	78.10	227.40	69.0	CTC	CL
247[E]	13.44	23	6.99	–1.00	45.7	30.1	1.26	146.20	169.20	115.00	125.0	WTC	CL
248	3.30	33	5.10	–0.66	20.8	25.1	1.25	14.25	5.21	69.54	151.0	CTC	CL
249	0.79	17	5.84	–0.95	56.0	27.7	1.32	30.44	12.93	343.30	235.0	WTC	CL
250	1.17	50	6.91	–0.77	42.0	24.8	1.30	21.70	91.12	385.80	75.0	CTC	CL
251	0.79	27	6.94	–0.84	13.3	24.8	1.26	<1.00	<1.00	<1.00	91.0	CTC	SYCL
252	1.57	21	7.41	–0.57	13.9	27.3	1.28	11.70	6.51	64.76	53.0	CTC	SYCL
253	2.79	33	5.30	–0.69	31.7	18.8	1.24	23.45	6.51	177.20	117.0	CTC	SYCL
254	1.78	33	5.42	–0.69	29.5	25.7	1.25	11.70	6.51	19.32	134.0	CTC	SYCL
255	1.78	33	5.04	–0.70	143.8	19.3	1.30	14.25	5.21	21.71	2.1	CTC	SYCL
256	1.14	33	6.24	–0.71	36.3	19.2	1.26	46.25	5.21	138.90	48.0	CTC	SYCL
257	2.36	33	4.56	–0.62	116.2	18.0	1.22	37.75	6.51	<1.00	260.0	CTC	SC
258	2.36	33	4.96	–0.62	169.2	17.4	1.22	30.75	6.51	9.75	255.0	CTC	SC
259	0.79	19	6.41	–0.85	7.2	34.4	1.33	351.00	78.10	16.92	119.0	CTC	SL

[A] Relative to a $Cu/CuSO_4$ (sat.) reference electrode.
[B] Relative to the standard hydrogen electrode.
[C] Coating conditions and assigned scores (in parenthesis): noncoated NC (1.0), asphalt-enamel-coated AEC (0.9), wrap-tape-coated WTC (0.8), coal-tar-coated CTC (0.7), and fusion-bonded-epoxy-coated FBE (0.3).[1]
[D] Clay (C), sandy clay loam (SCL), clay loam (CL), silty clay loam (SYCL), silty clay (SC) and silt loam (SL).
[E] Outlier observation.