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SOIL-CORROSION STUDIES, 1934. FIELD TESTS OF NONBITUMINOUS COATINGS FOR UNDERGROUND USE

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ABSTRACT

The National Bureau of Standards has conducted a series of tests of metallic and other nonbituminous coatings to determine their suitability for the protection of structures exposed to corrosive soils. Tests of calorized pipe in a few soils indicate that this type of coating affords only partial protection. Lead corrodes sufficiently in many soils to render thin lead coating unsatisfactory. Of the metallic coatings tested, zinc was the best. However, zinc coatings gradually deteriorate in many soils.

Several new coatings have been under observation for 2 years. For this period of exposure, the best of these were a vitreous enamel and two rather thick rubber compounds.

CONTENTS

I. INTRODUCTION

In 1922 the National Bureau of Standards began its study of metallic coatings for underground use by the burial of specimens of galvanized pipe. Two years later, studies of the effects of the weight or thickness of the coating and of the type of base material to which the coating was applied were undertaken. Some other metallic coatings have also been investigated. In 1932 there were included in the investigation of corrosion-resistant materials several types of recently developed coatings. This report gives the results of the tests of all of the above-mentioned coatings. With a few exceptions, the coatings have been applied to sections of steel pipe. The descriptions of the coatings buried prior to 1932 are given in Technologic Paper 368,[1] which gives also descriptions of the soils in which the tests were conducted.

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[1] K. H. Logan, S. P. Ewing, and C. D. Yeomans, *Bureau of Standards soil-corrosion studies: I. Soils, materials, and results of early observations.* Tech. Pap. BS **22,** 447 (1928) T368, 50¢.

II. PROPERTIES OF SOILS AT TEST SITES

Table 1 gives the names and locations of the soils to which the specimens were exposed. Some of the physical and chemical properties of these soils are given in table 2. The drainage was estimated by an examination of the soil and topography at the test site. The moisture equivalent is the percentage of moisture the soil will retain against a centrifugal force of 1,000 gravity. It is a measure of the moisture content of a soil which after saturation has reached equilibrium with gravitational and capillary forces. The methods used to determine the moisture equivalent, pH, and the chemical composition of the soil extract, are given in Research Paper 918.[2] Methods for measuring total acidity are given in Research Paper 539.[3]

TABLE 1.—*Identification of soils*

Soil	Soil type	Location	Cooperating organization
1	Allis silt loam	Cleveland, Ohio	East Ohio Gas Co.
2	Bell clay	Dallas, Tex	Dallas Gas Co.
3	Cecil clay loam	Atlanta, Ga	Department of Public Works.
4	Chester loam	Jenkintown, Pa	Philadelphia Electric Co.
5	Dublin clay adobe	Oakland, Calif	East Bay Municipal Utility District.
6	Everett gravelly, sandy loam.	Seattle, Wash	Department of Public Works.
7	Silt loam	Cincinnati, Ohio	Union Gas and Electric Co.
8	Fargo clay loam	Fargo, N. Dak	Union Light, Heat and Power Co.
9	Genesee silt loam	Sidney, Ohio	Tide Water Pipe Line Co., Ltd.
10	Gloucester sandy loam	Middleboro, Mass	Town of Middleboro.
11	Hagerstown loam	Baltimore, Md	Department of Public Works.
12	Hanford fine sandy loam.	Los Angeles, Calif	Southern Calif. Gas Co.
13	Hanford very fine sandy loam.	Bakersfield, Calif	San Joaquin Light and Power Corp.
14	Hemstead silt loam	St. Paul, Minn	Northern States Power Co.
15	Houston black clay	San Antonio, Tex	San Antonio Public Service Co.
16	Kalmia fine sandy loam	Mobile, Ala	City of Mobile.
17	Keyport loam	Alexandria, Va	Alexandria Water Co.
18	Knox silt loam	Omaha, Nebr	Omaha and Council Bluffs Electrolysis Committee.
19	Lindley silt loam	Des Moines, Iowa	Des Moines Gas Co.
20	Mahoning silt loam	Cleveland, Ohio	Department of Public Utilities.
22	Memphis silt loam	Memphis, Tenn	Board of Water Commissioners.
23	Merced silt loam	Buttonwillow, Calif	San Joaquin Light and Power Corp.
24	Merrimac gravelly sandy loam.	Norwood, Mass	Boston Consolidated Gas Co.
25	Miami clay loam	Milwaukee, Wis	Department of Public Works.
26	Miami silt loam	Springfield, Ohio	City of Springfield.
27	Miller clay	Bunkie, La	Standard Pipe Line Co.
28	Montezuma clay adobe	San Diego, Calif	San Diego Consolidated Gas and Electric Co.
29	Muck	New Orleans, La	Sewerage and Water Board.
30	Muscatine silt loam	Davenport, Iowa	United Light and Power Engineering and Construction Co.
31	Norfolk sand	Jacksonville, Fla	City Commission of Jacksonville.
32	Ontario loam	Rochester, N. Y	Department of Public Works.
33	Peat	Milwaukee, Wis	Milwaukee Gas Light Co.
34	Penn silt loam	Norristown, Pa	Philadelphia Electric Co.
35	Ramona loam	Los Angeles, Calif	Los Angeles Gas & Electric Co.
36	Ruston sandy loam	Meridian, Miss	Peoples Water and Gas Co.
37	St. Johns fine sand	Jacksonville, Fla	Jacksonville Gas Co.
38	Sassafras gravelly sandy loam.	Camden, N. J	Camden Water Dept.
39	Sassafras silt loam	Wilmington, Del	Delaware Power and Light Co.
40	Sharkey clay	New Orleans, La	New Orleans Public Service Co.
41	Summit silt loam	Kansas City, Mo	Kansas City Gas Co.

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[2] I. A. Denison, *Electrolytic measurement of the corrosiveness of soils.* J. Research NBS **17,** 363 (1936) RP918, 5¢.

[3] I. A. Denison, *Methods for determining the total acidity of soils.* BS J. Research **10,** 413 (1933) RP539, 5¢.

TABLE 1.—*Identification of soils*—Continued

Soil	Soil type	Location	Cooperating organization
42	Susquehanna clay	Meridian, Miss	City of Meridian.
43	Tidal marsh	Elizabeth, N. J	Standard Oil Development Co.
44	Wabash silt loam	Omaha, Nebr	Omaha and Council Bluffs Electrolysis Committee.
45	Unidentified alkali soil	Casper, Wyo	Stanolind Oil and Gas Co.
46	Unidentified sandy loam	Denver, Colo	Public Service Co. of Colo.
47	Unidentified silt loam	Salt Lake City, Utah	Mountain Fuel Supply Co.
51	Acadia clay	Spindletop, Tex	Sinclair Prairie Pipe Line Co. of Tex.
53	Cecil clay loam	Atlanta, Ga	Department of Public Works.
54	Fairmount silt loam	Cincinnati, Ohio	Union Gas and Electric Co.
55	Hagerstown loam	Baltimore, Md	Bureau of Water Supply.
56	Lake Charles clay	El Vista, Tex	Gulf Pipe Line Co.
57	Merced clay adobe	Tranquillity, Calif	Standard Oil Co. of California.
58	Muck	New Orleans, La	Sewerage and Water Board.
59	Peat	Kalamazoo, Mich	Department of Public Utilities.
60	do	Plymouth, Ohio	Ohio Fuel Gas Co.
61	Sharkey clay	New Orleans, La	New Orleans Public Service Co.
62	Susquehanna clay	Meridian, Miss	City of Meridian.
63	Tidal marsh	Charleston, S. C	Commissioners of Public Works.
64	Unidentified alkali soil	Cholame Flats, Calif	Shell Oil Co.
65	do	Wilmington, Calif	Do.
66	Mohave sandy loam	Phoenix, Ariz	City Water Department.
67	Cinders	Milwaukee, Wis	Milwaukee Gas Light Co.

TABLE 2.—*Properties of soils* [a] *in the National Bureau of Standards soil-corrosion investigation*

(mg-eq=milligram equivalent)

A=Alkaline.
C=Not determined.
G=Good; *F*=Fair; *P*=Poor; *VP*= Very poor.

Soil [b]	Soil type	Mean temperature [c]	Annual precipitation [c]	Internal drainage of test site	Moisture equivalent	pH	Total acidity mg-eq per 100 g of soil	Resistivity at 60° F	Composition of water extract mg-eq per 100 g of soil						
									Na+K as Na	Ca	Mg	CO_3	HCO_3	Cl	SO_4
		°F	*Inches*		%			ohm-cm							
51	Acadia clay	69	49	*P*	47.1	6.2	13.2	190	10.27	15.55	5.03	0.00	0.56	5.75	22.00
52	Alkali knoll	69	47	*P*	54.8	8.8	*A*	234	4.20	.33	.18	.52	1.36	1.33	1.26
1	Allis silt loam	49.2	33.8	*P*	28.6	7.0	11.4	1,215	.72	.25	.43	.00	.09	.09	.83
2	Bell clay	65.5	36.2	*P*	37.6	7.3	3.5	684	.28	1.09	.13	.00	1.18	.04	.18
101	Billings silt loam	52.0	8.8	*F*	30.0	7.3	*A*	261	5.21	19.24	1.43	.00	.66	1.56	22.48
102	do	52.0	8.8	*F*	20.4	7.3	*A*	103	22.63	16.56	3.85	.00	.56	4.67	36.82
103	do	52.0	8.8	*F*	30.6	7.3	*A*	81	22.01	13.32	2.00	.00	.18	11.09	25.70
104	Cecil clay	60.2	46.1	*G*	34.1	4.6	11.0	8,500	--------	--------	--------	--------	--------	--------	--------
3	Cecil clay loam	61.2	48.3	*G*	29.1	5.2	11.5	30,000	--------	--------	--------	--------	--------	--------	--------
53	do	61.2	48.3	*G*	33.7	4.6	9.6	17,794	--------	--------	--------	--------	--------	--------	--------
105	do	64.2	44.5	*G*	34.2	4.8	12.9	28,000	--------	--------	--------	--------	--------	--------	--------
106	do	60	46	*G*	38.8	4.8	12.8	25,000	--------	--------	--------	--------	--------	--------	--------
107	Cecil fine sandy loam	60.1	46.3	*G*	29.6	4.8	11.8	54,400	--------	--------	--------	--------	--------	--------	--------
108	Cecil gravelly loam	61.2	48.3	*G*	34.3	4.9	11.2	44,400	--------	--------	--------	--------	--------	--------	--------
4	Chester loam	54	40	*F*	22.2	5.6	7.6	6,670	--------	--------	--------	--------	--------	--------	--------
67	Cinders	46.1	30.1	*VP*	11.1	8.0	*A*	455	.77	3.03	.53	.00	.55	.08	2.89
5	Dublin clay adobe	56.4	23.4	*P*	28.8	7.0	6.5	1,346	.93	.48	.10	.00	.69	.03	.25
6	Everett gravelly sandy loam	51.0	34.0	*G*	12.2	5.9	12.8	45,100	--------	--------	--------	--------	--------	--------	--------
54	Fairmount silt loam	53.2	38.6	*P*	26.1	7.0	3.5	886	.59	10.10	.59	.00	.70	.08	9.05
8	Fargo clay loam	39	21	*P*	37.0	7.6	*A*	350	1.42	1.72	2.55	.00	.71	.01	4.43
109	Fresno fine sandy loam	63	9	*P*	18.6	8.4	*A*	497	2.62	.07	.10	.31	.59	1.56	.48
110	do	63	9	*P*	18.4	10.2	*A*	531	3.53	.07	.12	1.49	1.07	.79	.25
111	do	63	9	*P*	22.1	7.3	*A*	51	41.55	16.21	.44	.00	.58	34.58	23.41
9	Genesee silt loam	51.2	39.0	*P*	24.8	6.8	7.2	2,820	--------	--------	--------	--------	--------	--------	--------
10	Gloucester sandy loam	50	41	*F*	13.0	6.6	3.6	7,460	--------	--------	--------	--------	--------	--------	--------
11	Hagerstown loam	55.4	42.6	*G*	32.0	5.3	10.8	11,000	--------	--------	--------	--------	--------	--------	--------
55	do	55.4	42.6	*G*	32.0	5.8	10.9	5,213	--------	--------	--------	--------	--------	--------	--------
12	Hanford fine sandy loam	62.4	15.2	*F*	12.4	7.1	2.5	3,190	.39	.50	.16	.00	.40	.00	.14
13	Hanford very fine sandy loam	64.6	5.6	*F*	21.7	9.5	*A*	290	6.23	.09	.13	.00	1.12	1.64	3.76
14	Hempstead silt loam	44.2	27.2	*F*	17.2	6.2	5.6	3,520	--------	--------	--------	--------	--------	--------	--------

15	Houston black clay	68.9	27.2	*P*	51.4	7.5	5.0	489	2.18	.88	.20	.00	2.00	.13	.73
113	Imperial clay	71	2	*F*	30.2	7.4	*A*	176	22.18	14.09	1.29	.00	.36	10.94	25.98
112	do	71	2	*F*	34.6	7.4	*A*	92	9.56	.84	.51	.00	.63	6.26	4.06
16	Kalmia fine sandy loam	67.3	61.6	*F*	22.2	4.4	11.8	8,290	--------	--------	--------	--------	--------	--------	--------
17	Keyport loam	55	42	*P*	30.8	4.5	19.1	5,980	--------	--------	--------	--------	--------	--------	--------
18	Knox silt loam	50.6	27.8	*G*	28.4	7.3	1.4	1,410	.27	.63	.20	.00	.94	.00	.25
56	Lake Charles clay	69	49	*P*	28.7	7.1	4.5	406	3.12	.69	.47	.00	.80	1.59	3.04
114	do	69	49	*P*	35.8	7.1	*C*	320	2.65	.68	.26	.00	.77	1.84	.93
19	Lindley silt loam	49.5	32.0	*G*	28.4	4.6	10.9	1,970	.38	.32	.41	.00	.16	.03	.46
20	Mahoning silt loam	49.2	33.8	*P*	22.4	7.5	1.5	2,870	.25	.48	.20	.00	.51	.00	.15
21	Marshall silt loam	54.4	37.1	*F*	31.2	6.2	9.5	2,370	--------	--------	--------	--------	--------	--------	--------
22	Memphis silt loam	61.6	47.7	*G*	28.4	4.9	9.7	5,150	--------	--------	--------	--------	--------	--------	--------
115	do	65.6	51.9	*G*	25.7	6.9	4.7	3,450	--------	--------	--------	--------	--------	--------	--------
116	Merced clay	63.4	8.1	*F*	39.7	9.2	*A*	320	9.30	.33	.18	4.60	2.10	1.17	1.57
57	Merced clay adobe	63	8	*P*	40.9	7.7	*A*	128	23.40	13.50	4.51	.00	.34	1.15	37.50
117	Merced clay loam adobe	63	8	*P*	51.8	8.5	*A*	106	36.19	14.66	.83	.00	1.55	2.89	46.53
23	Merced silt loam	65	6	*P*	24.7	9.4	*A*	278	8.38	.38	.22	.02	1.87	1.12	5.57
24	Merrimac gravelly, sandy loam	50	41	*G*	13.0	4.5	12.6	11,400	--------	--------	--------	--------	--------	--------	--------
25	Miami clay loam	46.1	30.1	*F*	25.8	7.2	4.7	1,780	.23	.70	.41	.00	1.01	.03	.10
26	Miami silt loam	53	37	*G*	16.4	7.3	2.6	2,980	.27	.50	.31	.00	.70	.03	.12
27	Miller clay	67	56	*P*	42.6	6.6	3.7	570	.53	1.86	1.12	.00	2.00	.08	1.54
66	Mohave sandy loam	69.7	7.8	*G*	16.5	8.7	*A*	232	6.55	.51	.18	.00	.73	2.77	2.97
28	Montezuma clay adobe	61.0	10.3	*P*	24.6	6.8	*C*	408	1.50	.06	.18	.00	.12	.99	.89
29	Muck	69.3	57.4	*VP*	34.5	4.2	28.1	1,270	2.15	1.92	1.55	.00	.00	1.69	2.30
58	do	69.3	57.4	*VP*	57.8	4.0	79.3	712	2.03	2.23	1.29	.00	.00	.47	2.54
30	Muscatine silt loam	49.9	32.1	*P*	29.4	7.0	2.6	1,300	.32	.65	.40	.00	.71	.09	.24
118	Niland gravelly sand	71	2	*F*	6.1	7.3	*A*	273	4.30	1.03	.64	.00	.20	5.01	.86
31	Norfolk sand	69.3	47.4	*G*	2.8	4.7	1.8	20,500	--------	--------	--------	--------	--------	--------	--------
120	do	67.7	57.9	*G*	4.4	5.7	1.3	34,400	--------	--------	--------	--------	--------	--------	--------
121	do	71.8	49.4	*G*	3.0	4.8	1.2	16,400	--------	--------	--------	--------	--------	--------	--------
119	Norfolk sandy loam	64.2	44.5	*G*	24.1	4.7	9.7	10,800	--------	--------	--------	--------	--------	--------	--------
32	Ontario loam	47.6	32.8	*G*	17.8	7.3	0.5	5,700	.23	.70	.12	.00	.73	.01	.42
122	Panoche clay loam	63	6.4	*F*	30.0	7.4	*A*	552	2.32	.05	.26	.00	.70	.07	1.40
53	Peat	46.1	30.1	*VP*	72.8	6.8	36.0	800	1.52	7.30	4.06	.00	*C*	2.27	2.13
59	do	49	31	*VP*	43.6	5.5	33.3	1,659	1.03	3.08	2.70	.00	.00	3.47	1.04
60	do	49	37	*VP*	43.4	2.6	297.4	218	2.91	10.95	2.86	.00	.00	.00	56.70
34	Penn silt loam	54	40	*F*	23.4	6.7	7.0	4,900	--------	--------	--------	--------	--------	--------	--------
35	Ramona loam	62.4	15.2	*G*	18.0	7.3	5.7	2,060	.68	.68	.49	.00	1.10	.06	.35
36	Ruston sandy loam	64.0	53.0	*G*	13.8	4.5	4.6	11,200	--------	--------	--------	--------	--------	--------	--------
37	St. Johns fine sand	69.3	47.4	*P*	7.0	3.8	15.3	11,200	--------	--------	--------	--------	--------	--------	--------

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[a] Measurements and determinations by I. A. Denison and R. B. Hobbs.

[b] For locations of soils see table 1.

[c] Data furnished by U. S. Weather Bureau. Values with no figures to the right of the decimal point are for some nearby city.

TABLE 2.—*Properties of soils in the National Bureau of Standards soil-corrosion investigation*—Continued

Soil [b]	Soil type	Mean temperature	Annual precipitation	Internal drainage of test site	Moisture equivalent	pH	Total acidity mg-eq per 100 g of soil	Resistivity at 60° F	Composition of water extract mg-eq per 100 g of soil						
									Na+K as Na	Ca	Mg	CO_3	HCO_3	Cl	SO_4
		° F			%			ohm-cm							
38	Sassafras gravelly sandy loam	54	40	*G*	3.0	4.5	1.7	38,600	------	------	------	------	------	------	------
39	Sassafras silt loam	54	40	*P*	24.2	5.6	6.6	7,440	------	------	------	------	------	------	------
40	Sharkey clay	69.3	57.4	*P*	33.0	6.0	9.4	970	0.56	0.58	0.44	0.00	0.93	0.07	0.28
61	do	69.3	57.4	*P*	30.8	5.9	8.6	943	.73	.68	.33	.00	.71	.10	.91
41	Summit silt loam	54.4	37.1	*F*	33.1	5.5	11.0	1,320	.30	.54	.36	.00	.78	.04	.46
42	Susquehanna clay	64.0	53.0	*P*	34.8	4.7	28.2	13,700	------	------	------	------	------	------	------
62	do	64.0	53.0	*P*	34.6	4.1	24.2	6,922	------	------	------	------	------	------	------
123	do	65.8	43.4	*P*	37.6	4.1	21.9	6,840	------	------	------	------	------	------	------
124	Susquehanna silt loam	66.0	42.7	*P*	36.0	4.4	28.1	1,160	------	------	------	------	------	------	------
125	Susquehanna fine sandy loam	65.8	43.4	*P*	37.2	3.9	28.3	5,770	------	------	------	------	------	------	------
43	Tidal marsh	52	43	*VP*	55.4	3.1	36.8	60	45.10	5.17	9.45	.00	.00	43.30	37.00
63	do	66.0	45.2	*VP*	46.7	2.9	100.2	84	33.60	6.85	4.00	.00	.00	12.70	36.60
44	Wabash silt loam	50.6	27.8	*G*	31.2	5.8	8.8	1,000	1.05	1.08	.66	.00	1.97	.82	.41
	UNIDENTIFIED SOILS														
45	Alkali soil	47.2	15.3	*P*	14.8	7.4	*A*	263	8.15	3.70	.70	.00	.24	.18	11.98
46	Sandy loam	50.0	14.1	*G*	7.6	7.0	*C*	1,500	------	------	------	------	------	------	------
7	Silt loam [d]	53.2	38.6	*P*	34.3	4.4	29.8	2,120	------	------	------	------	------	------	------
47	do	51.6	16.1	*P*	25.7	7.6	3.0	1,770	.67	.72	.39	.00	.88	.06	.48
64	Alkali soil	58	16	*VP*	41.1	8.3	*A*	62	28.10	2.29	.76	.00	.89	28.80	.26
65	do	62.4	15.2	*F*	26.4	7.2	*A*	148	7.65	12.40	2.20	.00	1.30	6.05	16.90

[d] Previously classified erroneously as Fairmount silt loam.

III. METALLIC COATINGS

1. LEAD-COATED PIPE

Lead-coated pipe was exposed to corrosion at various test sites on three occasions. The first of these was in 1924 when specimens of 1½-inch lead-coated steel pipe 6 inches long were placed in 47 soils.

Two years after the first lead-coated specimens were buried, specimens of steel pipe coated by a hot-dip process by another manufacturer were placed in seven soils.

A third test of lead-coated steel pipe was begun in 1932. The specimens were prepared by the manufacturer of the specimens buried in 1924. This coating consists of approximately 98 percent of lead and 2 percent of tin, bonded to the base metal by a third element or bonding agent.

The thickness of the lead coatings was determined using the chord method.[4] The results of these measurements are given in table 3. The three lead coatings all have about the same average thickness (1 to 1.5 mils), and they all show wide variations in thickness from point to point.

TABLE 3.—*Dimensions of and thickness of coating on lead-coated pipe specimens*

Dimensions of specimens (in.)	1½ by 6	2 by 17	1½ by 13
Date of burial	1924	1926	1932
Number of measurements	8	9	12
Average thickness (mils)	1. 05	1. 18	1. 44
Minimum thickness (mils)	2. 50 0. 30	1. 96 0. 82	2. 97 0. 50

Table 4 gives the average rates of loss of weight and of maximum penetration for 10-year-old specimens buried in 1924. The table also shows the corresponding rates of corrosion for unprotected steel pipe and lead cable sheath.

Only in Ramona loam were the specimens free from pits. In Dublin clay adobe, the coated specimens were worse than the uncoated both with respect to loss of weight and penetration. In 13 of the 34 soils for which comparisons can be made, the rates of maximum penetration were greater for the coated specimens. Severe pitting of lead-coated specimens occurred in several soils in which commercial lead cable sheath was attacked but little.

The data on rates of corrosion of lead cable sheath show that, in general, corrosion is most severe in the absence of oxygen and salts (especially sulphates) either of which would precipitate a protective layer of corrosion products on the lead. However, in all soils the rate of corrosion is great enough to penetrate the lead coating somewhere, even if the coating were originally free of pinholes. After it is exposed, the rate of penetration of the steel depends largely upon the rate at which bare steel is attacked. In soils of low resistance, the lead accelerates the rate of corrosion if the coating is punctured. The places where the lead coating seems to be most effective in reducing the rates of corrosion and pitting are well-drained soils of very high resistivity. In such soils the penetration of the bare ferrous pipe wall practically stops after a few years.

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[4] W. Blum and A. Brenner, *Mesle's chord method for measuring the thickness of metallic coatings.* J. Research NBS **16,** 171 (1936) RP866, 5¢.

TABLE 4.—*Corrosion of 1½- by 6-inch lead-coated pipe exposed for approximately 10 years*

Soil	Soil type	Rates of loss (oz/ft²/yr)			Rates of maximum penetration (mils/yr)		
		Lead-coated steel	Bare steel [1]	Lead cable sheath [1]	Lead-coated steel	Bare steel	Lead cable sheath
1	Allis silt loam	0.529	0.80	0.173	11.9	5.8	8.1
2	Bell clay	.102	.49	.067	4.0	6.7	1.8
3	Cecil clay loam	.066	.43	.059	3.6	4.5	1.4
4	Chester loam	.239	.52	.177	7.0	6.8	4.0
5	Dublin clay adobe	.597	.45	.135	6.9	3.1	3.8
6	Everett gravelly, sandy loam	.096	.08	.025	2.0	1.4	0.8
7	Unidentified silt loam	.207	.37	--------	7.0	2.5	--------
9	Genesee silt loam	.080	.43	--------	5.0	4.5	--------
10	Gloucester sandy loam	.163	.36	.088	6.5	3.2	1.2
11	Hagerstown loam	.071	.16	.034	3.4	4.9	1.2
13	Hanford very fine sandy loam	.064	--------	--------	5.4	--------	--------
14	Hempstead silt loam	.036	.39	.049	4.2	7.1	1.7
15	Houston black clay	.052	.65	.036	3.2	4.4	2.2
17	Keyport loam	.379	.77	.028	4.7	3.3	1.7
18	Knox silt loam	.046	.23	.016	4.6	3.2	1.1
20	Mahoning silt loam	.224	.52	.268	5.3	5.5	4.1
22	Memphis silt loam	.192	.61	.085	7.3	6.6	1.2
24	Merrimac gravelly, sandy loam	.033	.12	.015	2.2	2.1	1.5
27	Miller clay	.231	.63	.067	5.6	4.9	2.4
28	Montezuma clay adobe	.314	1.75	.069	7.8	15.1	0.9
29	Muck	.689	1.61	.343	6.3	12.0	.9
31	Norfolk sand	.028	.22	.022	1.5	2.5	.5
32	Ontario loam	.072	.32	.028	5.2	4.3	1.5
33	Peat	.537	1.22	--------	7.7	8.9	--------
35	Ramona loam	.011	.09	.017	(2)	0.4	2.3
36	Ruston sandy loam	.032	.24	.032	1.8	3.9	1.1
37	St. Johns fine sand	.202	.58	--------	6.4	5.6	--------
38	Sassafras gravelly, sandy loam	.053	.22	.025	3.4	2.5	1.7
40	Sharkey clay	.191	.56	--------	6.2	6.6	--------
41	Summit silt loam	.051	.45	.039	5.8	7.6	1.5
42	Susquehanna clay	.092	.95	--------	4.6	7.1	--------
43	Tidal marsh	.726	1.47	.019	18.8	8.7	1.0
45	Unidentified alkali soil	.198	.79	.021	9.2	6.9	1.7
46	Unidentified sandy loam	.033	.37	.015	4.5	8.8	1.0
47	Unidentified silt loam	.184	.23	.122	6.1	2.4	5.7

[1] Bessemer steel pipe 1½ by 6 inches and commercial lead cable sheath in sheets 20¾ by 3½ by 0.112 inch removed from sites at the same time the lead-coated specimens were removed, were buried, in most cases, 1 or 2 years longer. The figures given are the averages from 2 specimens in the case of the steel and 1 specimen in the case of the lead sheath. The penetration of the sheath was determined by averaging 2 pits, each of which was the deepest on 1 side of the specimen. These pits were, of course, somewhat deeper than would be expected on specimens of the same exposed area as that of the pipe.

[2] No pits.

Table 5 shows the rates of corrosion of the lead-coated specimens buried in 1926, together with the corresponding rates for steel specimens of the same dimensions.

Table 6 gives the data on the specimens buried in 1932 and removed in 1934. It will be noted that in 5 of the 14 soils the lead-coated specimens developed deeper pits in 2 years than did the bare specimens. All of the specimens developed measurable pits, and large holes were found in the specimens exposed to cinders.

TABLE 5.—*Corrosion of 2 by 17 inches lead-coated steel pipe exposed approximately 8 years*

Soil	Soil type	Rate of loss (oz/ft.^{2}/yr)		Rate of penetration (mils/yr)	
		Lead-coated steel	Bare steel [a]	Lead-coated steel	Bare steel
13	Hanford very fine sandy loam	0.18	1.70	6.5	19.3
24	Merrimac gravelly, sandy loam	.08	0.21	3.3	3.7
28	Montezuma clay adobe	1.09	----------	9.1	----------
29	Muck	0.61	1.21	7.8	10.5
42	Susquehanna clay	.44	0.89	7.4	8.8
43	Tidal marsh	[b] .77	.86	[b] 18.0	10.8
45	Unidentified alkali (Casper, Wyo.)	1.27	2.64	10.1	16.6

[a] The data in this column are from specimens of bare Bessemer steel of the same dimensions as the lead-coated specimens and which were buried and removed at the same times. Those in soil *24* were of copper-bearing steel.

[b] Of the 4 lead-coated specimens in soil *43*, 3 were punctured, and since the ends of the specimens were closed, it was impossible to clean them in order to determine the weight lost. The figures given with respect to both rate of loss of weight and penetration are for the remaining specimen. These specimens were of 0.154-inch wall thickness.

TABLE 6.—*Corrosion of 1½- by 13-inch lead-coated steel pipe exposed approximately 2 years*

Soil	Soil type	Rates of loss (oz/ft^2/yr)		Rates of maximum penetration (mils/yr)	
		Lead-coated steel	Bare steel [1]	Lead-coated steel	Bare steel [1]
51	Acadia clay	2.72	3.75	27.3	41.4
53	Cecil clay loam	0.40	1.37	18.4	18.9
55	Hagerstown loam	.25	1.28	11.9	21.7
56	Lake Charles clay	.53	2.03	28.7	9.8
57	Merced clay adobe	.24	2.33	11.3	16.8
58	Muck	.87	1.85	14.8	9.0
60	Peat	1.59	3.24	20.8	19.3
61	Sharkey clay	0.38	0.86	21.6	11.1
62	Susquehanna clay	.41	2.12	17.9	32.1
63	Tidal marsh	.01	1.88	7.8	7.4
64	Salinas loamy sand	.19	6.62	18.6	68.3
65	Alkali soil (Wilmington, Calif.)	.20	3.87	14.7	20.7
66	Mohave sandy loam	.41	4.02	19.0	34.4
67	Cinders	16.66	10.65	65.3	76.2

[1] Low-carbon steel tube 2 by 10 inches buried and removed at the same times as the lead-coated pipe.

It is of interest to compare the corrosion-resisting properties of the three coatings developed at different times in three types of soil. Such a comparison is shown in table 7.

Figure 1 shows the appearance of the specimens after exposures of 2, 6, and 8 years. It is evident that no marked improvement in the resistance to soil corrosion of this type of coating has been made since the first specimens were buried.

It is believed that these data justify the conclusion that lead coatings in general are not suitable for protecting steel pipe against soil corrosion. In the early stages, lead coating reduces corrosion. However, after the coating is penetrated, the rate of penetration of the steel is often accelerated, so that in many cases the pipe wall will be penetrated earlier on the lead-coated than on the bare steel pipe.

TABLE 7.—*Comparison of corrodibility of three varieties of lead-coated pipe exposed 2 to 4 years to three soils*

Type	Lead-coated Bessemer steel			
	No. 1 [a]	No. 2 [b]	No. 3 [c]	Bare Bessemer steel [d]
RATES OF LOSS OF WEIGHT (oz/ft²/yr)				
Muck	0.88	0.85	0.87	1.85
Susquehanna clay	.14	.81	.41	2.12
Tidal marsh	.41	.69	.01	1.88
RATES OF MAXIMUM PENETRATION (mils/yr)				
Muck	[e]21.3	[f]8.7	[f]14.8	[f]9.0
Susquehanna clay	19.7	14.0	17.9	32.1
Tidal marsh	52.2	24.2	7.8	7.4

[a] 1½- by 6-inch coated steel pipe exposed 2 to 2½ years to soils *29*, *42*, and *43*.
[b] 2- by 17-inch coated steel pipe exposed about 4 years to soils *29*, *42*, and *43*.
[c] 1½- by 13-inch coated steel pipe exposed 2 years to soils *58*, *62*, and *63*.
[d] 2- by 10-inch bare steel tube exposed 2 years to soils *58*, *62*, and *63*.
[e] Single deepest pit on 2 specimens having combined exposed area equal to that of 1 pipe 1½ by 10 inches.
[f] Average of the 2 deepest pits, 1 from each specimen.

2. ALUMINUM (CALORIZED)

A calorized coating is an alloy of aluminum with the base metal. It was developed primarily for the purpose of preventing scaling when the metal is subjected to high temperatures. The aluminum oxide, which develops on the surface of calorized materials, was considered as a possible protection against soil corrosion. There are two processes of calorizing, one known as the powder or dry process, and the other as the dip or wet process. Specimens of pipe calorized by each process were placed in seven soils in 1924. Since it seemed inadvisable to stamp numbers on these specimens or to attach tags by wires which might cause galvanic corrosion, the specimens were identified by their positions in the trenches. This has resulted in the loss of identification of some of the specimens. Table 8 gives the rates of corrosion of the calorized specimens, together with the corresponding data for unprotected steel.

TABLE 8.—*Corrosion of calorized steel pipe exposed approximately 10 years*

Soil	Soil type	Rates of loss of weight [1] (oz/ft²/yr)			Rates of maximum penetration [1] (mils/yr)		
		Dry calorized	Wet calorized	Bare steel [2]	Dry calorized	Wet calorized	Bare steel [2]
13	Hanford very fine sandy loam	0.137	0.087	1.24	3.4	4.4	13.0
24	Merrimac gravelly, sandy loam	.019	.013	0.12	2.4	3.2	2.1
28	Montezuma clay adobe	.437	----------	1.75	5.5	----------	15.1
29	Muck	.250	.458	1.39	3.4	7.8	9.2
42	Susquehanna clay	.452	.088	1.25	7.0	4.2	9.2
43	Tidal marsh	.861	.434	1.72	3.1	3.4	7.4
45	Alkali soil (Casper, Wyo.)	.712	.184	1.23	3.4	4.4	11.9

[1] Average of 2 specimens.
[2] Rates for unprotected Bessemer steel specimens of similar area which were exposed, except in the case of soil *13*, for a similar period. The data presented for bare steel in soil *13* are for specimens exposed only 6 years, there being no data available for a longer period.

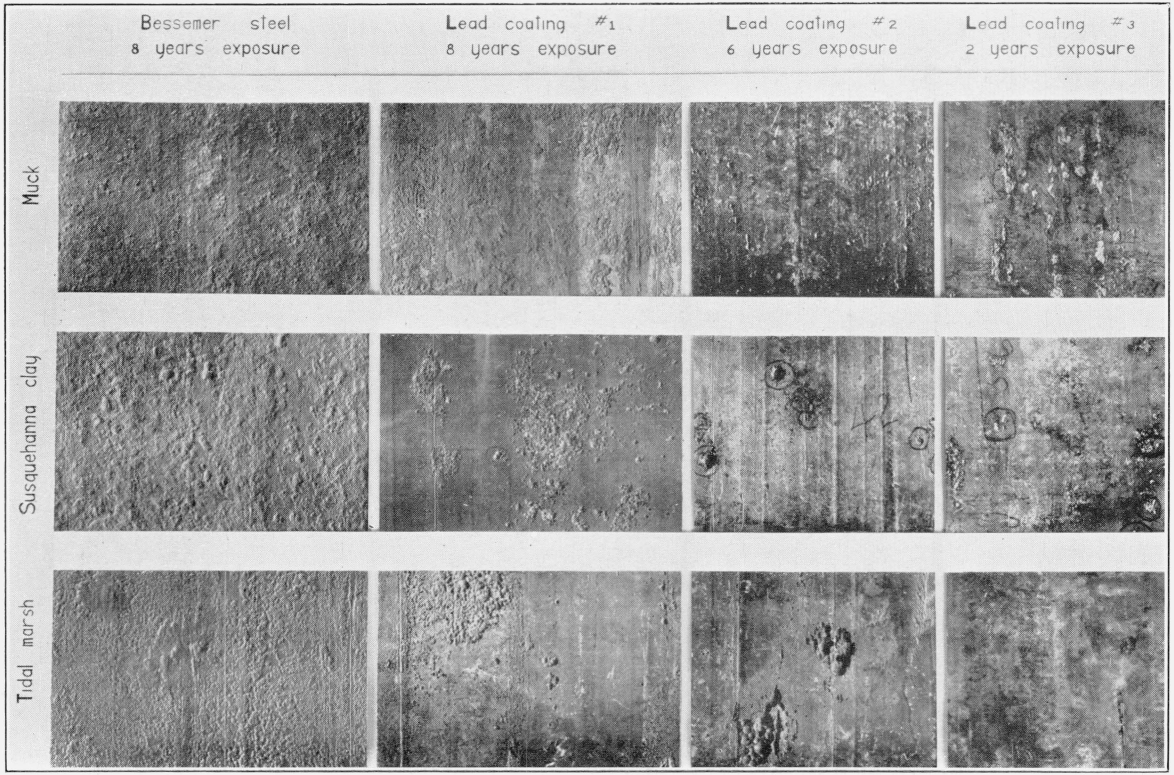

FIGURE 1.—*Steel pipe and three varieties of lead coatings removed from three soils in 1934.*

The specimens are 5 inches high.

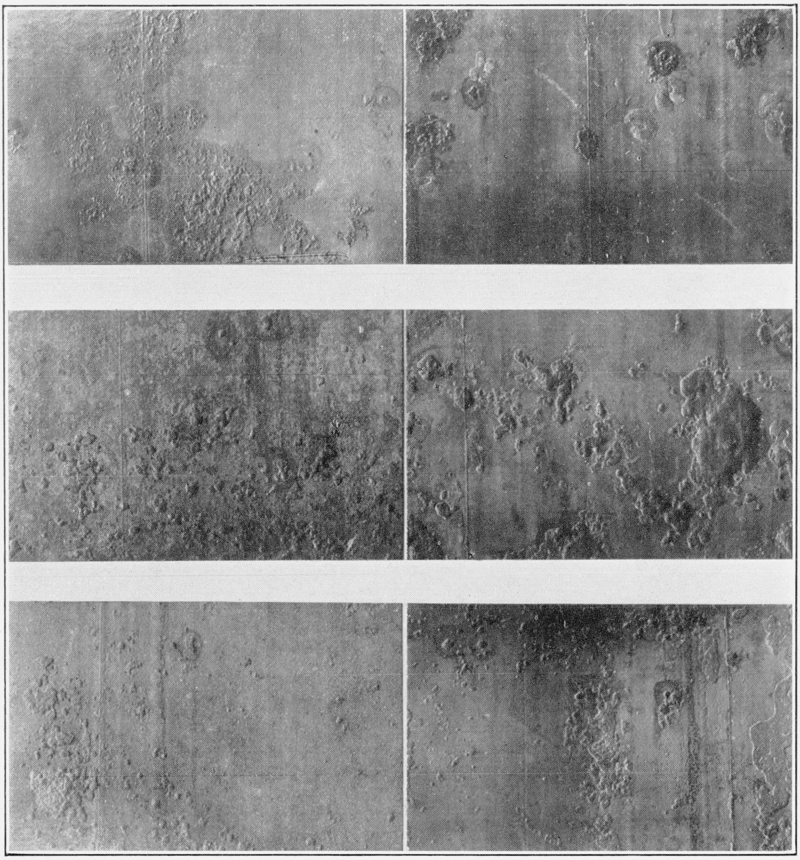

FIGURE 2.—*Powder- (on the left) and dip- (on the right) calorized specimens exposed for 10 years to Hanford very fine sandy loam containing black alkali (carbonates) at top; muck (center); and Susquehanna clay (bottom).*

The specimens are 5 inches high.

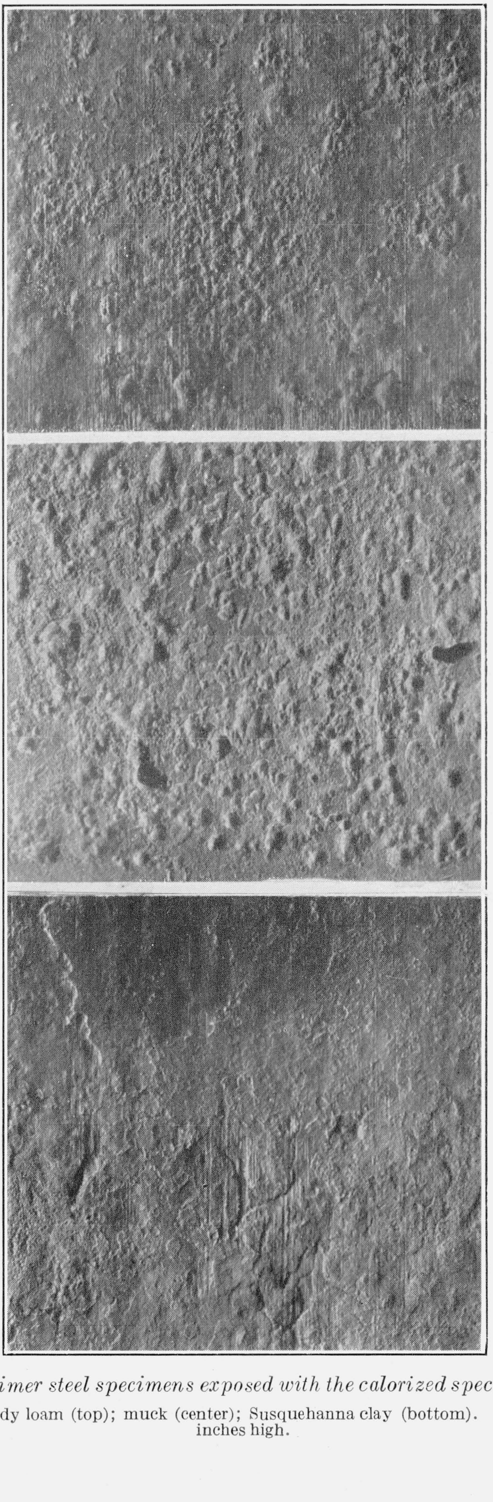

FIGURE 3.—*Bessimer steel specimens exposed with the calorized specimens in figure 2.*

Hanford very fine sandy loam (top); muck (center); Susquehanna clay (bottom). The specimens are 5 inches high.

In all cases the calorized specimens lost weight and, with one exception, were pitted at a lower rate than the unprotected pipe in the same soils. In five of the six soils the powder-calorized pipe was pitted at a lower maximum rate than the dip-calorized pipe, while in five of six soils the dip-calorized pipe lost less weight than the powder-calorized pipe. It is thus apparent that the powder-calorized coating was more effective in reducing pitting, although it allowed a greater loss of weight than the dip-calorized coating.[5]

The thickness of the coating on both types of calorized pipes was measured in several places, using the chord method,[6] potassium ferrocyanide and copper sulphate being applied to distinguish the alloy boundary. The thickness of the coating on both kinds of calorized pipe was found to be reasonably uniform. The thickness of the powder-calorized coating was 2 mils and that of the dip-calorized was 11 mils.

It is evident from table 8 that although, on the whole, calorizing made the pipe more resistant to soil corrosion, the process as applied to the specimens did not prevent pitting in any soil. The rate of pitting and loss of weight are usually high in poorly drained, corrosive soils where the use of a good coating would be economical. The appearance of the calorized specimens from three widely different soils is shown in figure 2. Unprotected steel specimens exposed to the same soils for the same times are shown in figure 3. While these photographs have been selected to show the appearance of more or less typical specimens, they are not presented as the basis for general conclusions.

3. ZINC (GALVANIZED)

The tests of galvanized ferrous pipe and sheet were undertaken in order to determine the effectiveness of various thicknesses of this type of coating in withstanding soil action, and to ascertain whether or not one base material was superior to another when the same weight of zinc was applied to each.

Galvanized iron prepared by the hot-dip process includes an outer layer of nearly pure zinc, a middle zone of one or more alloys of zinc and iron, and finally, the metal to which the zinc was applied. The thickness of the alloy layer depends upon the methods used in galvanizing, and to some extent on the character of the base metal. It is not practicable to apply an exact amount of zinc or to apply the zinc as a perfectly uniform coating by the hot-dip process as used commercially [7] [8]. For these reasons, and because of nonuniform soil conditions, some dispersion of the data for what is nominally the same weight of coating is to be expected.

It is evident from the statements above that the determination of the effect of each factor in the corrosion of galvanized specimens under field conditions would be very difficult, if not impossible, even with a very large number of specimens. From the available data, it is possible to draw general conclusions only. These conclusions are valid only for the period covered by the experiments.

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[5] For a description of calorizing processes, see H. S. Rawdon, Protective Metallic Coatings. (The Chemical Catalog Co., New York, N. Y.)

[6] See footnote 5.

[7] H. S. Rawdon, Protective Metallic Coatings. (The Chemical Catalog Co., New York, N. Y., 1928.)

[8] E. C. Groesbeck and Wm. A. Tucker, *Accelerated laboratory corrosion test methods for zinc-coated steel.* BS J. Research 1, 255 (1928) RP10.

The first test of galvanized pipe was started in 1922 when two 24-inch specimens of 2-inch galvanized steel pipe were placed in 30 soils. One of these specimens was removed from each soil in 1926, and the other specimens were removed in 1934. The specimens were not weighed.

In 1924, specimens of galvanized pipe and sheet were placed in 46 soils. In seven of these soils specimens having different weights of coatings were also buried.

Table 9 gives the corrosion data on pipe and sheets carrying nominal 2-ounce coatings. In the case of pipes, this is the nominal weight of the coating on 1 square foot of the outside surface of the pipe, while in the case of sheet metal it refers to the weight of coating per square foot of sheet and is, therefore, twice the weight of the coating on 1 square foot of surface. To avoid confusion, the weights of coating given near the top of the table are all expressed in ounces of zinc per square foot of surface. Although all specimens listed in table 9 carried the same nominal weight of coating, the actual weights differed considerably, and the uniformity of the coating on the same kind of specimens also varied.[9]

Table 9 shows also the rates of corrosion of steel pipe for those soils for which data on this material for the same period of exposure are available. To make the comparison of the galvanized and bare materials easier, the ratio of the rates of corrosion of the two materials is also shown. A low ratio indicates that the coating was relatively effective.

The composition of the steel to which the coating was applied has been given in Technologic Paper 368.[10] Results of early examinations of coatings will be found in that paper, as well as in Research Papers 359 [11] and 638.[12]

The specimens were cleaned with warm water and a stiff fiber brush, and, in some cases, not all of the corrosion products were removed. The rates of loss of weight given in tables 9, 10, 11 are, therefore, somewhat less than they should be. They are, however, comparable with earlier data on specimens cleaned in the same way and give a good indication of the condition of the specimens.

In order to show the correlation between weight losses and the results of the 10-year inspections, the data in table 9 are given graphically in figure 4. The rates of loss of weight for each of the four materials are plotted on a logarithmic scale on separate lines, each point representing one specimen. The thick lines indicate the thickness of the coatings. The condition of each specimen, as judged by inspection and the weight of the coating, is shown in the figure. It can be seen that the various visual classifications are well grouped, with some overlapping. However, the weight losses do not arrange the specimens in exactly the same order as the inspection results and pit measurements. This lack of correlation is not due entirely to chance. In figure 5 the average rate of loss of weight of the three galvanized sheets is plotted against the average maxi-

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[9] See footnotes 7 and 8, p. 371.

[10] K. H. Logan, S. P. Ewing, and C. D. Yoeman, *Bureau of Standards soil-corrosion studies: I. Soils, materials, and results of early observations.* Tech. Pap. BS **22,** 447 (1928) T368, 50c.

[11] K. H. Logan. *Soil-corrosion studies. Nonferrous metals and alloys, metallic coatings, and specially prepared ferrous pipes removed in 1930.* BS J. Research **7**, 585 (1931) RP359.

[12] K. H. Logan and R. H. Taylor. *Soil-corrosion studies, 1932. Rates of loss of weight and pitting of ferrous and nonferrous specimens and metallic protective coatings.* BS J. Research **12**, 112 (1934) RP638.

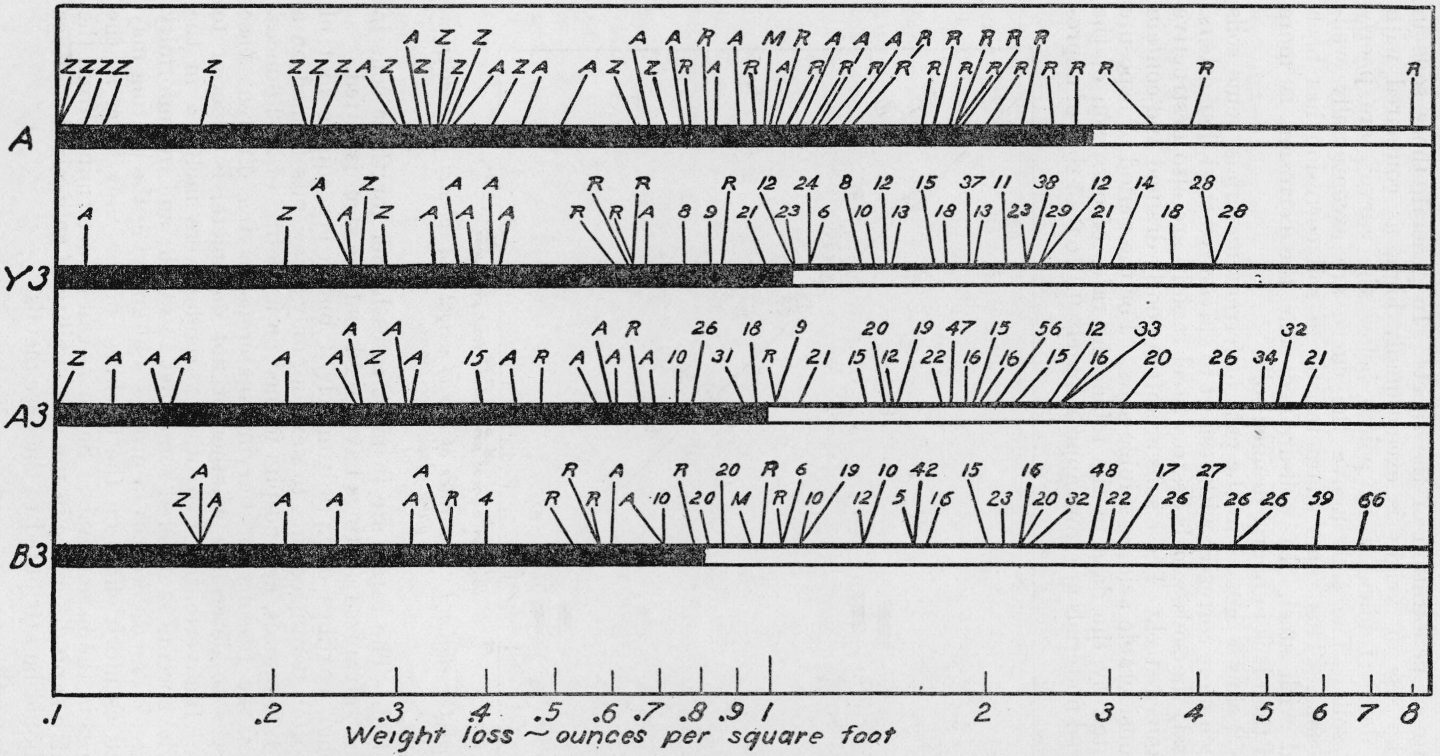

FIGURE 4.—*Correlation between losses of weight and condition of galvanized specimens as determined by inspection.*

The specimens were 10 years old. When figures appear they are the rates of penetration of the maximum pit, in mils per year. When letters appear they have the following meanings:

Z=Zinc continuous over specimen.
A=Blue or black alloy layer exposed over at least part of specimen.
R=Rusted or bare steel exposed.
M=Shallow metal attack; no pit as great as 10 mils total depth.

mum rate of penetration of the sheets. In general, those soils in which the loss of weight is exceptionally high, as compared with the pit depth (indicated by points below the curve), are poorly drained soils. The soils above the curve are exceptionally well-drained soils. This same characteristic of soil corrosion has been observed with steel. In well-drained soils the corrosion is more localized than it is in poorly drained soils.

Table 9 shows that as in the case of ferrous materials, some soils were much more corrosive with respect to galvanized steel than others. In general, the soils which destroy steel rapidly are also destructive to galvanized steel. These soils are often poorly drained and contain either considerable acid or soluble salts. For the period of exposure represented by the data in the table, the rates of corrosion of the galvanized materials are from approximately 0.1 to 0.45 that of unprotected steel. The ratios are in most cases higher for those soils in which the galvanized coatings have failed and the steel is pitted.

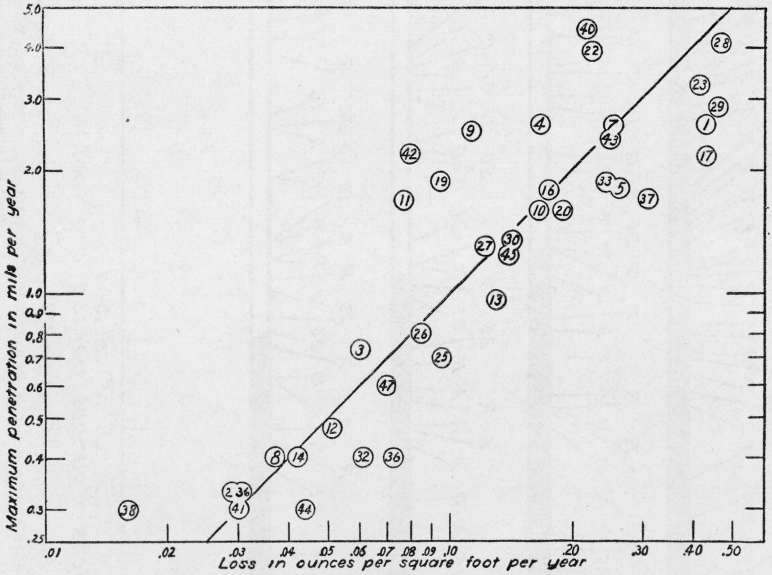

FIGURE 5.—*Correlation between rates of loss of weight and rates of penetration on galvanized specimens.*

Although coatings of approximately 1 ounce per square foot of surface often permitted pits to develop, only a few pits formed on a coating 1.81 ounces, and no pits formed on a coating of 2.82 ounces.

One of the reasons for burying materials having different base metals was to determine whether or not one metal is superior to another. Inadvertently, two other variables were included in the test. The specimens differed somewhat in weight and in uniformity of coating. The differences in processes of applying the coating may have had as much effect on the thickness of the alloy layer as the differences in the base metals. So far as can be determined from the data, there is no difference in the corrodibility of galvanized coatings which should be attributed to the base metals.

TABLE 9.—*Corrosion of galvanized pipe and 16-gage steel sheet with nominal 2-ounce coatings*

[Average time buried 10 years]

The numbers in parentheses are the weights (oz/ft^2) of the coatings.
Z=Zinc continuous over specimen.
A=Blue or black alloy layer exposed over at least a portion of specimen.
R=Rusted or bare steel exposed.
M=Shallow metal attack; no pit as great as 10 mils total depth.

Soil	Soil type	Rates of loss of weight (oz/ft^2/yr)					Ratio [c]	Condition or rates of maximum penetration (mils/yr)				
		Pipe	Sheet			Bare [b]		Pipe *B* [d] (1.81)	Sheet			
		A (2.82) [a]	*A3* (0.99)	*B* (0.81)	*Y3* (1.07)				*A*	*A3*	*B*	*Y3*
1	Allis silt loam	0.274	0.433	0.449	0.418	0.957	0.41	2.5	*R*	2.6	2.6	2.8
2	Bell clay	.035	.044	.058	.029	------	------	*M*	*Z*	*A*	*R*	*Z*
3	Cecil clay loam	.041	.048	.071	.061	.393	.14	*M*	*Z*	*R*	1.0	*R*
4	Chester loam	.183	.174	.166	.193	------	------	*R*	*R*	2.2	1.6	1.3
5	Dublin clay adobe	.179	.246	.298	.241	------	------	------	*R*	1.2	2.2	1.2
6	Everett gravelly, sandy loam	.012	.027	.025	.009	------	------	------	*Z*	*A*	*A*	*Z*
7	Unidentified silt loam	.250	.257	.225	.290	------	------	*R*	*R*	1.6	1.6	2.1
8	Fargo clay loam	.073	.061	.053	.037	.522	.11	*R*	*Z*	*A*	*R*	*A*
9	Genesee silt loam	.116	.092	.082	.114	------	------	*R*	*A*	3.1	2.0	2.4
10	Gloucester sandy loam [e]	.121	.164	.161	.165	------	------	*A*	*R*	1.5	2.3	1.1
11	Hagerstown loam	.085	.040	.086	.109	.170	.47	------	*A*	1.5	2.0	1.2
12	Hanford fine sandy loam	------	.032	.094	.026	------	------	*A*	------	*A*	*M*	*A*
13	Hanford very fine sandy loam	[f].086	.219	.036	.135	------	------	------	*R*	1.5	*R*	0.8
14	Hempstead silt loam	.024	.031	.032	.064	.470	.08	*A*	*Z*	*A*	*A*	*R*
15	Houston black clay	.035	.029	.060	.021	------	------	------	*Z*	*Z*	*A*	*Z*
16	Kalmia fine sandy loam	.099	.145	.203	.177	.641	.24	*Z*	*M*	2.0	1.5	1.8
17	Keyport loam	.344	.558	.371	.368	------	------	*R*	*R*	2.1	2.6	1.8
19	Lindley silt loam	.065	.078	.110	.099	.314	.28	*A*	*Z*	2.6	1.9	2.1
20	Mahoning silt loam	.114	.197	.225	.146	.470	.36	*R*	*R*	1.6	2.0	1.2
22	Memphis silt loam	.120	.205	.230	.239	.721	.28	------	*R*	5.6	3.2	2.9
23	Merced silt loam [e]	.945	.358	.260	.628	2.526	.22	------	6.7	3.6	2.1	4.0
24	Merrimac gravelly, sandy loam	[f].024	.012	.016	.004	------	------	*Z*	*Z*	*A*	*A*	*Z*
25	Miami clay loam	.034	.102	.097	.086	------	------	------	*Z*	0.9	*R*	*R*
26	Miami silt loam	.068	.074	.104	.076	------	------	*A*	*A*	1.0	0.6	0.8
27	Miller clay	.091	.148	.136	.083	------	------	------	*A*	1.2	1.0	.9

See footnotes at end of table.

TABLE 9.—*Corrosion of galvanized pipe and 16-gage steel sheet with nominal 2-ounce coatings*—Continued

Soil	Soil type	Rates of loss of weight (oz/ft^2/yr)					Ratio [c]	Condition or rates of maximum penetration (mils/yr)				
		Pipe	Sheet			Bare [b]		Pipe *B*[d] (1.81)	Sheet			
		A (2.82) [a]	*A3* (0.99)	*B* (0.01)	*Y3* (1.07)				*A*	*A3*	*B*	*Y3*
28	Montezuma clay adobe	[f] 0.204	0.493	0.668	0.231	1.700	0.21	------	*R*	3.4	6.6	2.3
29	Muck	[f] .593	.515	.444	.421	1.467	.34	3.0	*R*	3.2	2.6	2.8
30	Muscatine silt loam	.045	.150	.135	.141	------	------	1.1	*A*	1.9	1.2	1.0
31	Norfolk sand	[f] .016	.005	.017	.005	------	------	------	*Z*	*Z*	*A*	*Z*
32	Ontario loam	[f] .056	.057	.058	.067	.284	.21	*R*	*R*	*A*	*R*	*A*
33	Peat	.172	.188	.401	.148	1.123	.20	------	*R*	1.6	2.7	1.3
35	Ramona loam	.030	.069	.105	.042	------	------	*A*	*A*	*A*	*R*	*A*
36	Ruston sandy loam	.023	.014	.043	.034	------	------	------	*Z*	*A*	0.4	*A*
37	St. Johns fine sand	.202	.314	.305	.301	.851	.35	------	*R*	2.0	1.7	1.4
38	Sassafras gravelly, sandy loam	[f] .020	.015	.021	.011	------	------	------	*Z*	*A*	*A*	*A*
40	Sharkey clay [e]	.092	.218	.220	.212	.742	.25	*R*	*R*	4.7	4.8	3.8
41	Summit silt loam	.051	.026	.036	.026	------	------	*M*	*A*	*A*	*A*	*A*
42	Susquehanna clay [e]	.071	.086	------	.074	1.059	.07	------	*R*	2.1	------	2.3
43	Tidal marsh	[f] .129	.102	.584	.064	1.185	.19	2.3	*A*	*R*	5.9	*R*
44	Wabash silt loam	------	.021	.071	.041	------	------	------	------	*A*	*A*	*A*
45	Unidentified alkali soil	[f] .174	.096	.160	.170	1.282	.12	3.6	*R*	1.8	0.5	1.5
46	Unidentified sandy loam	.016	.010	.016	.027	.416	.04	*A*	*Z*	*Z*	*Z*	*Z*
47	Unidentified silt loam	.100	.066	.078	.065	------	------	*A*	*A*	*R*	*R*	*R*

---

[a] The weight of coating given here is in ounces per square foot of exposed area. It is the average obtained from at least 10 measurements of thickness by the stripping method.

[b] In the column headed "Bare" are presented the average weight losses of rolled iron and steel specimens buried a similar length of time, i. e., approximately 10 years. These were not available for all soils.

[c] The column headed "Ratio" presents the ratio of the average of the first 4 columns of data to the bare-metal column, a low figure indicating that the galvanizing was effective in reducing weight loss.

[d] The B pipes were buried 12 years. They were not weighed before burial so weight losses are not known.

[e] In this soil there were 2 specimens. The condition or penetration is for the worst corroded specimen.

[f] There were 2 specimens of this material. The condition is for the worst of these specimens.

[g] No specimens 10 years old were removed from soil *25*. The data given are for specimens exposed for 8 years.

In order to make the comparison of the materials simpler, data on the average rates of loss of weight for each material for three periods of exposure have been assembled in table 10. For the shortest period of exposure there seems to be no difference in the rates which can be attributed to differences in the weights of the coatings, probably because in most soils the losses were of zinc only. The open-hearth iron sheet showed the lowest average rate of loss. This is true also for the 8-year period of exposure, although the open-hearth iron pipe which carried a heavy coating showed the highest rate of corrosion. A possible explanation for this is that, in the case of the pipe, the zinc only was exposed, whereas the alloy layer was exposed on the sheets. The data for the 10-year period of exposure indicate that the rate of loss for galvanized materials decreases with increasing weight of coating within the range for which data are given. Beyond this range, the weight of coating has on the average no effect on the loss of weight, as shown in figure 6.

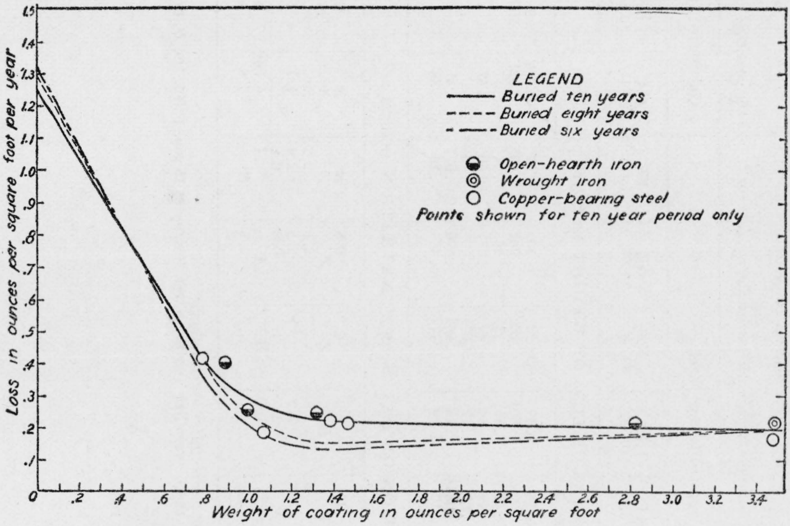

FIGURE 6.—*Correlation between rates of loss of weight and the weight of zinc on galvanized pipe and sheets exposed to six soils*

TABLE 10.—*Summary of data on specimens with nominal 2-ounce coatings*

Symbol	Material	Weight of coating [1]	Average rate of loss of weight (oz/ft²/yr)		
			6 years of exposure in 38 soils	8 years of exposure in 19 soils [2]	10 years of exposure in 39 soils
B	Bessemer steel sheet	0.81	0.091	0.145	0.169
A3	Open-hearth iron sheet	.99	.081	.128	.147
Y3	Copper-bearing steel sheet	1.07	.095	.133	.132
A	Open-hearth iron pipe	2.82	.091	.185	.113

[1] In ounces of coating per square foot of exposed area.

[2] The soils in this group are, on the average, more corrosive than those in the other groups.

TABLE 11.—*Effect of weight of zinc coating and character of base metal on rates of corrosion of galvanized pipe and sheet metal exposed for approximately 10 years*

[NOTE.—The numbers in parentheses are the weights (oz/ft ²) of the coatings]

Soil	Galvanized pipe			Galvanized 16-gage sheet							Galvanized 18-gage sheet			Ungalvanized 18-gage sheet		
	A[1] (2.82)	*D* (3.48)	*Y* (3.47)	*A2* (0.90)	*A3* (0.99)	*A4* (1.33)	*Y2* (0.79)	*Y3* (1.08)	*Y4* (1.38)	*Y5* (1.46)	*CA* (0.94)	*CB* (0.83)	*CY* (1.06)	*CA–B* (0)	*CB–B* (0)	*CY–B* (0)
	RATES OF LOSS OF WEIGHT (oz/ft²/yr)															
13	0.086	0.10	0.12	0.34	0.22	0.18	0.27	0.14	0.10	0.17	0.076	0.057	0.075	0.57	0.53	*D*[2]
24	.024	.010	.004	.04	.012	.008	.004	.004	.004	.005	.021	.012	.009	.18	.17	0.17
28	.20	.28	.21	.20	.49	.52	.19	.23	.25	.34	.11	.10	*D*[2]	*D*	*D*	*D*
29	.59	.42	.30	.51	.51	.48	.44	.42	.37	.40	.47	.54	.35	*D*	.99	1.06
42	.071	.068	.054	.098	.086	.077	.12	.074	.10	.10	----------	----------	----------	----------	----------	----------
43	.13	.17	.13	.44	.10	.086	.14	.064	.090	.077	.41	.57	.44	*D*	*D*	.88
45	.17	.20	.13	.81	.096	.12	1.29	.17	.40	.16	.38	.61	.31	*D*	*D*	*D*
	CONDITION OR RATES OF PENETRATION (mil/yr)															
13	*R*	*Z*	*A*	2.7	1.5	1.1	3.0	0.8	0.8	*R*	*R*	*R*	*R*	4.9+	4.9+	*H*
24	*Z*	*Z*	*Z*	*A*	*A*	*Z*	*R*	*Z*	*Z*	*Z*	*A*	*A*	*A*	2.3	2.7	2.7
28	*R*	*Z*	*A*	4.3	3.4	3.2	1.5	2.3	2.5	2.2	*R*	.4	*H*	*H*	*H*	*H*
29	*R*	*R*	*R*	4.1	3.2	2.5	3.9	2.8	2.5	2.4	1.7	5.0+	2.8	*H*	5.0+	5.0+
42	*R*	*A*	*R*	1.9	1.1	*A*	2.5	1.2	0.6	0.8	----------	----------	----------	----------	----------	----------
43	*A*	----------	*A*	5.5	*R*	*R*	1.5	*R*	*A*	.4	4.7+	4.7+	4.7+	*H*	*H*	4.7+
45	*R*	*Z*	*R*	6.0	1.8	2.0	*H*	1.5	2.1	*R*	2.8	4.7+	4.7+	*H*	*H*	*H*

[1] The meanings of the material designation symbols at the tops of the columns are as follows:
A=open-hearth iron; *D*=wrought iron; *Y*=copper-bearing steel; the *C* preceding another letter designates 18-gage sheet, the *B*, preceded by a dash, indicates that the specimen was not galvanized.

[2] The meanings of the condition symbols are as follows:
Z=Zinc still visible over entire surface of specimen.
A=Alloy layer exposed over at least a part of specimen but no rust.
R=Specimen rusty over at least a part of surface.
H=Hole entirely through specimen.
D=Specimen destroyed; impossible to determine weight loss.

Further light on the effects of the weight of the coating and of the base materials is afforded by table 11, which gives data on a variety of galvanized materials from seven soils. The data from this table are plotted in figure 6. The rates for the different base materials are differentiated by different symbols. Curves showing the trend of the data for other periods of exposure but without the points for the individual observations are shown by broken lines. The curves lie quite close together, and the differences between them probably lie within the standard errors of the tests. The point on the left end of the curve represents the average rate of loss for all ferrous pipe materials exposed to the same soils. This value was used because of the destruction of some of the thin sheet steel specimens. The figure indicates that the 10-year average rate of loss of weight of the galvanized specimens in the six corrosive soils was about one-fifth of that for ungalvanized specimens and that, during this period of exposure, the lightest weight of coating was almost as effective as the heaviest. It is to be expected, however, that as the period of exposure is lengthened the advantage of the heavier coating will become more evident. This is indicated by the data on rates of maximum penetration given in table 11. These show that the pipes which carried much more zinc than the sheets had no measurable pits, although most of the latter were pitted to a depth of at least 10 mils. The second part of table 11 also indicates that the heavy coating on the pipes afforded better protection to the base metal than did the lighter coating on the sheets.

The data for the 18-gage galvanized and black sheet show very definitely the superiority of the former. This illustrates a principle applicable to protective coatings in general, namely, that the life of unprotected material is short either because of the thinness of the material or the corrosiveness of the soil; a protective coating will probably increase the life of the structure sufficiently to justify its use. If, however, the life of the structure is long, the desirability of a coating is more questionable. Thus the use of galvanized rather than black corrugated iron culverts might be economical, although the use of large-diameter galvanized water pipes might not be advisable.

Galvanizing is extensively used on pipes up to about 4 inches in diameter. Many gas and water companies use galvanized pipe for house services. This coating is especially well adapted to this use because the pipe is installed by a few men in small and widely scattered jobs where the use of any coating equipment would be inconvenient and expensive. In a distribution system where all pipes are unprotected, most of the leaks will occur on services and small pipes because the pipe wall is relatively thin. The use of galvanizing on these pipes will tend to equalize the average life of large and small pipes. If electrolysis is the principal cause of leaks, galvanized coatings will be of little or no value. However, in small distribution systems where there are no street railways, and hence no electrolysis, and where the soils are moderately but not severely corrosive, galvanized coatings are perhaps the most economical means for reducing maintenance costs. Galvanized coatings for underground use should have a weight of at least 2 ounces of zinc per square foot of pipe surface.

The relative rates of corrosion of zinc, steel, and galvanized steel exposed to five soils for approximately 10 years are shown in table 12. These are the only soils in which zinc was placed. The table indicates that for the period of exposure involved and for the soils for which comparisons can be made, zinc corroded less rapidly than iron or steel and that the galvanized steel corroded least of all.

TABLE 12.—*Rates of loss of weight and maximum pitting of miscellaneous metals and alloys buried for approximately 10 years*

Material	Soil									
	Hanford very fine sandy loam (*13*)		Muck (*29*)		Susquehanna clay (*42*)		Tidal marsh (*43*)		Alkali (*45*)	
	Loss[1]	Pits[2]	Loss	Pits	Loss	Pits	Loss	Pits	Loss	Pits
Zinc (thin)	0.35	4.0	0.46	3.9	0.085	1.7	0.23	3.3	*f*[3]	*f*
Do	.19	5.2	.38	*f*	.11	2.0	.45	3.7	*f*	*f*
Zinc (thick)	.34	7.0	.53	5.5	.078	1.8	.22	6.8	0.94	9.8
Open-hearth iron	.98	13.+	.58	6.2	.56	7.0	*f*	13.+	*f*	13.+
Copper-bearing steel	*f*	6.+	.69	6.+	.54	5.9	*f*	6.+	*f*	6.+
Galvanized steel sheet[4]	.14	.8	.42	2.8	.07	2.3	.06	*R*[6]	.17	1.5
Galvanized iron pipe[5]	.09	*R*	.59	*R*	.07	*R*	.13	*A*[7]	.17	*R*

[1] Loss is given in ounces per square foot per year.
[2] Rate of maximum penetration in mils per year.
[3] Failure, 1 or more holes (*f*). If this symbol appears in the loss column the specimens were corroded so badly it was not possible to weigh them.
[4] 16-gage copper-bearing steel sheet, 6 by 12 inches, coated with 2.15 oz of zinc per square foot of sheet.
[5] Open-hearth iron pipe, 2 by 17 in., coated with 2.82 oz of zinc per square foot of surface.
[6] Rusted, but no measurable pits; (*R*).
[7] Alloy layer exposed but not rusted: (*A*).

IV. MILL AND FOUNDRY SCALE AS PROTECTIVE COATINGS

Ferrous pipes as made at the foundry or mill are covered with an oxide coating commonly called foundry or mill scale. Various opinions have been expressed as to the effect of this scale on the corrosion of the pipe. Some believe that the scale acts as a protective coating, while others think that because the iron has been found to be anodic to mill-scale corrosion is accelerated at points where the scale is discontinuous. In 1926, specimens of several materials in their original condition and similar materials with the mill scale removed were buried in seven soils. Table 13 shows the rates of corrosion of these specimens after approximately 8 years of exposure. To facilitate the comparison of the materials with and without mill scale, the ratio of the number of cases in which the scale-free material was superior to the scale-coated specimens is given at the bottom of each part of the table. It is evident from the table that, on the whole, the specimens from which the scale had been removed corroded somewhat less than those having a coating of mill scale, i. e., that mill and foundry scale did not afford any protection to the specimens. In most instances there was so little difference between the rates of corrosion of the specimens with and without mill scale that the difference might be attributed to chance.

TABLE 13.—*Effect of mill and foundry scale on corrosion*

[Period of exposure was approximately 8 years]

Soil	Soil type	Pit cast iron		Delavaud cast iron		Steel		Wrought iron	
		A Normal	*MC* Machined	*C* Normal	*MD* Machined	*P* Normal	*M* Ground and polished	*K* Normal	*D* Rough ground
	RATE OF LOSS OF WEIGHT (oz/ft²/yr)								
3	Hanford very fine sandy loam	1.12	1.29	0.05	1.10	1.70	1.51	1.12	1.01
24	Merrimac gravelly sandy loam	.11	.13	.17	.16	------	------	.22	.18
28	Montezuma clay adobe	3.94	------	1.14	------	------	------	------	------
29	Muck	2.31	.99	5.28	1.27	1.21	1.06	1.18	1.22
42	Susquehanna clay	.70	.43	.59	.47	.89	.94	.88	.80
43	Tidal marsh	1.08	1.00	3.08	1.20	.86	1.14	.67	.67
45	Unidentified alkali	3.50	------	3.55	2.59	2.64	2.26	2.51	2.17
	Ratio[1]	------	3:5	------	5:6	------	3:5	------	4:6
	RATE OF PENETRATION (mils/yr)								
13		17.8	12.8	7.8	9.1	19.3	15.3	11.9	11.1
24		3.6	3.2	3.8	2.4	------	------	4.7	3.8
28		20.4	------	6.8	------	------	------	------	------
29		11.4	5.0	10.7	8.9	10.5	9.8	6.3	7.3
42		17.9	15.9	7.0	8.9	8.8	10.0	10.3	9.4
43		14.1	5.2	27.5	11.5	10.8	8.1	15.3	9.7
45		22.3	------	14.3	15.7	16.6	13.0	12.9	18.2
	Ratio[1]	------	5:5	------	3:6	------	4:5	------	4:6

[1] Ratio of cases of superiority to total number of cases of comparison.

V. PARKWAY CABLE

Specimens of parkway cable consisting of an insulated copper wire covered by a lead sheath followed by a wrapping of treated jute, two spiral wrappings of zinc-coated steel strip, and another covering of bitumen-impregnated jute, were buried in 47 test sites in 1922 and 1924.

This cable is usually laid in direct contact with the earth in rather shallow trenches. The coverings outside the lead sheath are largely for the purpose of protecting the cable against mechanical injury. The impregnation of the outer covering delays its decay but does not prevent the moisture reaching the metal beneath. The steel tapes are coated with zinc.

Table 14 indicates the conditions of the several components of the cable after approximately 12 years of exposure. It will be seen that although in many soils there was slight corrosion of the lead sheath no serious corrosion of the sheath occurred at any of the test sites.

TABLE 14.—*Condition of parkway cable buried from 10 to 12 years*

Ratings: *G*, good; *F*, fair; *B*, bad; *D*, destroyed; *P*, pitted; *R*, rusted; *SR*, slightly rusted; *BR*, badly rusted; *TW*, thin white corrosion product on lead sheath.

[All steel is zinc-coated]

Soil	Soil type	Outer fabric	Inner fabric	Outer steel[1] wrapper	Inner steel wrapper	Lead sheath
1	Allis silt loam	*F*	*G*	*R*	*G*	*G*
2	Bell clay	*D*	*G*	*BR*	*R*	*TW*
3	Cecil clay loam	*D*	*F*	*P*	*R*	*G*
5	Dublin clay adobe	*B*	*G*	*SR*	*G*	*G*
10	Gloucester sandy loam	*D*	*G*	*P*	*R*	*TW*
16	Kalmia fine sandy loam	*D*	*G*	*P*	*SR*	*TW*
17	Keyport loam	*D*	*F*	*P*	*R*	*TW*
18	Knox silt loam	*B*	*G*	*R*	*SR*	*TW*
19	Lindley silt loam	*F*	*G*	*R*	*G*	*TW*
24	Merrimac gravelly sandy loam	*F*	*G*	*G*	*G*	*G*
25	Miami clay loam	*F*	*G*	*SR*	*G*	*TW*
26	Miami silt loam	*D*	*G*	*P*	*R*	*TW*
28	Montezuma clay adobe	*D*	*G*	*P*	*P*	*TW*
29	Muck	*B*	*F*	*P*	*G*	*TW*
30	Muscatine silt loam	*F*	*G*	*G*	*G*	*TW*
31	Norfolk sand	*D*	*G*	*BR*	*SR*	*TW*
32	Ontario loam	*D*	*G*	*R*	*G*	*TW*
34	Penn silt loam	*F*	*G*	*SR*	*SR*	*TW*
35	Ramona loam	*F*	*G*	*P*	*G*	*TW*
36	Ruston sandy loam	*B*	*G*	*P*	*R*	*TW*
37	St. Johns fine sand	*B*	*G*	*SR*	*SR*	*TW*
38	Sassafras gravelly sandy loam	*B*	*G*	*SR*	*G*	*TW*
39	Sassafras silt loam	*F*	*G*	*SR*	*G*	*TW*
41	Summit silt loam	*D*	*G*	*P*	*G*	*TW*
43	Tidal marsh	*B*	*G*	*R*	*SR*	*G*
45	Unidentified alkali soil	*B*	*F*	*R*	*R*	*G*
46	Unidentified sandy loam	*D*	*G*	*BR*	*R*	*TW*
47	Unidentified silt loam	*F*	*G*	*SR*	*SR*	*G*

[1] All steel is zinc coated.

VI. MISCELLANEOUS NONMETALLIC COATINGS

Since the burial of specimens of protective coatings by the National Bureau of Standards in 1922, 1924, and 1926, and by the research associates of the American Gas Association and the American Petroleum Institute in 1929 and 1930, a number of quite different protective coatings have been developed. It was thought advisable, therefore, to give the manufacturers of these coatings an opportunity to have them tested under conditions which were severely corrosive with respect to steel pipe.

Ten kinds of nonmetallic coatings were submitted by manufacturers and buried in 15 corrosive soils, which differed greatly in their physical and chemical properties. Several of these coatings are experimental in nature and have not been offered to the public as protective coatings. The object of their manufacturers is to obtain data useful in the development of a satisfactory coating. The results of the tests are of interest to the public also because they show the ways in which soils affect protective coatings and indicate, therefore, some of the requirements for satisfactory coatings. A soil which rapidly corrodes steel is not necessarily destructive to protective coatings, and one that destroys certain kinds of coatings may not be corrosive. Since coatings are required only in corrosive soils, such soils should be used for testing coatings, and, to be helpful, reports on the performance of coatings should be accompanied by data on the corrosion of unprotected steel exposed to similar conditions.

The soil types in which the coatings were exposed and their locations are given in table 1. Some of the physical and chemical properties of these soils are given in table 2. Table 15 shows the identification letters for the coatings, together with a descriptive name for each. A more detailed description of the coatings follows. These descriptions were furnished by the manufacturers but in some cases are quite inadequate.

The following manufacturers furnished coatings for the tests:

American Machine and Foundry Co., Brooklyn, N. Y.
Ball Chemical Co., Pittsburgh, Pa.
Chadeloid Chemical Co., New York, N. Y.
Ferro Enamel Corp., Cleveland, Ohio.
P. D. George Co., St. Louis, Mo.
B. F. Goodrich Rubber Co., Akron, Ohio.
Goodyear Tire and Rubber Co., Akron, Ohio.
Harpoon Paint Products Inc., Long Island City, N. Y.
Irvington Varnish and Insulator Co., Irvington, N. J.
Thiokol Corp., Yardville, N. J.

TABLE 15.—*Nonmetallic coatings*

Identification letter	Descriptive name	Identification letter	Descriptive name
B	Synthetic rubber.	*G*	Hard rubber.
C	Vitreous enamel.	*H*	Loaded hard rubber.
D	Rubber paint.	*J*	Synthetic resin varnish.
E	Paint, unidentified.	*K*	Chlorinated rubber paint.
F	Cashew-nut oil-asbestos-fiber paint.	*W*	China wood oil-mica plastic.

The coatings listed in table 15 have been described by their makers as follows:

B.—A product described as an olefin-polysulfide reaction product. The specimens under observation were made by the addition to this product of small quantities of nine other materials to form a rubber-like substance. The dimensions of the specimens of this material are 10 by 5 by ¼ inch. They were placed on edge in the trench.

C.—A vitreous enamel coating described by the manufacturer as an acid-resisting enamel, free from pinholes. The thickness of the coating is approximately 14 mils.

D.—The manufacturer describes the coating as follows: first coat, 23-percent solution of rubber derivative in xylene; second and third coats, 30-percent solution of rubber derivative in xylene; fourth coat, 20-percent solution of rubber derivative in a mixture of turpentine and mineral spirits, plus 5 percent of carbon black as percentage of the total solids. The thickness of the coating was approximately 0.010 inch.

E.—Two applications of paint which differ in color. Neither the kind of pigment nor the kind of vehicle was specified. The thickness of the coating was approximately 0.005 inch.

F.—A semiplastic compound, which may be applied cold with a brush, consisting of 4½ parts of treated cashew-nutshell oil, 3 parts of fiber asbestos, and 3½ parts of mineral turpentine substitute. The thickness of the coating was approximately 0.006 inch.

Twelve of the specimens of coating *F* were placed in water for 1 week. Pattern tests[13] were then made. All tests indicated pinholes in the coating.

G.—A hard-rubber compound comprising rubber, sulfur, and an accelerator cured to a bone-hard condition. The thickness of the coating is about 0.09 inch. The bond between the pipe and the coating is not strong.

H.—Highly loaded hard-rubber stock containing 30 percent of magnesium carbonate and approximately 15 percent of "white substitute." The thickness of this coating is about 0.1 inch.

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[13] S. P. Ewing and G. N. Scott, *An electrolytic method for determining the condition of nonmetallic pipe coatings.* Am. Gas Assn. Monthly **16**, 140 (1934).

J.—A modified synthetic resin applied to the pipe in the same manner as a paint or varnish. The pipe is then subjected to a baking operation at 425° F for 30 minutes. The thickness of this coating was about 0.002 inch.

K.—A paint coating containing imported highly chlorinated rubber which may be dissolved in solvents to which may be added drying oils, pigments, quartz meal, or carborundum. The exact ingredients of the coating, which was applied to the pipe 1 inch in outside diameter, were not stated. The coating was applied in Germany. Its thickness was approximately 0.006 inch.

W.—An experimental coating prepared as follows. The pipe was primed with a china wood oil varnish containing considerable lead and manganese drier as the vehicle. The pigment portion consisted of a mixture of equal parts zinc chromate, basic lead chromate, small proportion of oxide of zinc, and about 10 percent of inerts in the form of asbestine. This primer was baked at a temperature of about 200° F for ½ hour.

The coating consists of thoroughly dehydrated china wood oil to which was added powdered mica and a catalyst. This mixture was molded on the pipe and heated to 200° F for 3 hours. The thickness of this coating was about 0.17 inch.

Coatings G, H, J, and K were received after a part of the other specimens had been buried. The first two specimens were placed in eight soils and the last two, because of the limited number of specimens furnished, in only four soils. The results of all of the field tests on corrosion conducted by the National Bureau of Standards indicate that because of uncontrolled factors the data are likely to be erratic, and on this account a considerable number of observations are required, if reliable information is to be secured. Moreover, because of the wide differences in soils, a material suitable for one soil condition may be unsatisfactory in another. The results of observations on a few specimens in a few soils may, therefore, be misleading as to the general usefulness of the material tested.

The nonmetallic coatings differ so greatly in character that it is difficult to tabulate their conditions when removed from the test sites. The condition of the pipe to which the coating was applied is probably the best indication of the usefulness of the coating although the relative conditions of the specimens may differ for different periods of exposure.

Table 16 shows the conditions of the pipes after approximately 2 years of exposure. In most cases the conditions of two specimens of the same coating exposed to the same soil did not differ greatly. For this reason, and the fact that this report deals with a relatively short period of exposure of a small area, the condition of the worse of the two specimens is recorded in cases where differences occurred. It will be seen that, with two exceptions, the coated pipes were in better condition than the bare pipes in the same soil. On the other hand, no coating entirely prevented corrosion in all soils for 2 years, and on several specimens rather serious pits were found.

The last column of table 16 shows the condition of somewhat larger specimens of steel pipe protected for approximately 2½ years by an asbestos-fabric reinforced coal-tar enamel coating. This coating which is among the best of the bituminous coatings, can be obtained at reasonable cost and can be applied to any size pipe. The performance of better and worse bituminous coatings can be compared with the coatings in table 16 by reference to Technological Paper 368 and the reports of Scott[14] and Ewing.[15]

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[14] G. N. Scott, *API coating tests—Progress report III.* Proc. Am. Petroleum Inst. **13**, sec. 4, 114 (1932).

[15] S. Ewing, *AGA studies of coatings for pipe lines.* Proc. Am. Gas Assn. p. 741 (1933).

TABLE 16.—*Condition of pipe protected by nonmetallic coatings, after 2 years of exposure*

[The worse of the 2 specimens in each case is recorded]

The following symbols have been used to indicate the condition of the pipe. *U*=no corrosion; *R*=rusted; *M*=metal attack; pipe roughened by corrosion. The figures represent the depth of the deepest pit in mils (thousandths of an inch).

Soil	Soil type	Identification of coating										
		C	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*W*	*N*	
		Vitreous enamel	Rubber paint	Paint	Cashew-nut oil-asbestos fiber	Hard rubber	Loaded hard rubber	Synthetic resin	Chlorinated rubber paint	China-wood oil-mica compound	Low-carbon steel tube	Asbestos felt and coal-tar enamel
51	Acadia clay	14	20	*M*	*R*	------	------	------	------	*R*	101	------
53	Cecil clay loam	*U*	*R*	*M*	*R*	------	------	*R*	16	*U*	37	*U*
55	Hagerstown loam	*U*	*R*	*M*	*R*	------	------	------	------	*R*	42	------
56	Lake Charles clay	*U*	40	------	*R*	------	------	------	------	*R*	26	------
57	Merced clay adobe	------	*M*	*M*	*R*	*U*	*U*	*M*	*M*	*U*	34	------
58	Muck	------	*M*	*M*	*R*	------	------	------	------	*R*	20	*U*
60	Peat	*U*	45	*M*	*R*	*U*	*U*	------	------	*U*	55	------
61	Sharkey clay	*U*	*U*	*R*	*R*	------	------	------	------	*U*	13	------
62	Susquehanna clay	*U*	*R*	*M*	*R*	------	------	------	------	*R*	68	*U*
63	Tidal marsh	*U*	*M*	------	*M*	------	------	------	------	*M*	21	*U*
64	Salinas clay	*U*	63	40	*R*	*R*	*U*	22	*M*	*U*	138	------
65	Alkali soil	*U*	*M*	45	*R*	*U*	*U*	------	------	*U*	43	*U*
66	Mohave sandy loam	*U*	*M*	28	*R*	*U*	*U*	------	------	*R*	71	------
67	Cinders	*U*	76	32	*R*	*U*	------	------	21	*U*	154+	*U*

In general, the thin coatings employing a volatile solvent were not as satisfactory as the thicker coatings. In the past, such coatings have been found to contain pinholes. It required four applications of the thin rubber solution to eliminate pinholes in coating *D*, and these applications proved ineffective in eliminating corrosion in more than one soil.

Since the strip *B* was not applied to a pipe its effectiveness as a coating can only be judged from the condition of the material. Seventeen specimens appeared to be unchanged by 2 years of exposure to soils. Eight specimens appeared to have become somewhat stiffer. In the tidal marsh, both specimens had hardened and showed minute surface cracks. Several specimens showed distortion resulting from unequal clod pressure on the two sides of the specimens.

Of the vitreous-enamel specimens, *C*, two pits were found on one specimen from Acadia clay, and one pit was observed on one specimen from muck. It is probable that these pits were the result of pinholes. All other specimens of enamel were unaffected.

Coating *D*, made from a solution of rubber, blistered badly in several soils, became quite brittle, and showed little adhesion to the pipe. Most of the specimens were rusted to some extent. Eight specimens showed pits 10 mils in depth or deeper. The coating material appeared to be in better condition than several others, which suggests the possibility that a satisfactory rubber-base coating could be developed.

Paint coating *E* gave results similar to paints that have been tested on other occasions. The color of many of the specimens changed.

A large percentage of the specimens developed a large number of small blisters beneath which rust was found.

Coating *F*, which is a cold application of cashew-nut shell oil and asbestos fiber, became brittle and rust formed beneath the coating. As a result the bond between the pipe and the coating was destroyed. Table 16 indicates that although the specimens rusted at all test sites no measurable pits developed within 2 years. Experience with other types of coatings indicates that thinly coated specimens which rust will develop pits on longer exposure.

Coatings *G* and *H*, which are hard-rubber compounds about 0.1 inch in thickness, behaved similarly. Several specimens showed rust near the ends of the specimens but no rust was observed elsewhere. The indications are that moisture entered at the ends of the specimens because of imperfect bond between the coating and the metal rather than through the coating. The continuity of the bond between the coating and the pipe is important. Experience has shown that it is very difficult to maintain a coating entirely free from voids and injuries until it has been placed underground. The adhesion of the coating to the pipe should, therefore, be such as to prevent moisture from spreading beneath the coating. Rusting which follows the entrance of moisture may crack the coating and allow more moisture to reach the pipe.

Coating *J*, a synthetic resin, was removed from only three soils. The coating exposed to Cecil clay loam (*53*) was only slightly affected. In the two alkali soils (*57* and *64*) to which the coating was exposed, it became brittle and rust formed on the pipe. In the Salinas clay (*64*) both pipes were pitted.

Specimens of the chlorinated rubber coating *K* were removed from four soils, but from two of the soils only one specimen was removed. The specimen removed from Cecil clay loam *53* was unaffected, except for two small pits about ½ inch apart, which may have been the result of imperfections or injury to the coating. The single specimen exposed to cinders (*67*) showed rust stains through the coating and rust in spots on the pipe. In the other soils, *57* and *64*, each of the specimens showed some small blisters.

Coating *W*, which is a compound of china wood oil and powdered mica, was the thickest coating tested. Seven of the coatings cracked longitudinally. As a few specimens were cracked when received it is possible that the cracking was the result of the aging of the material rather than an effect of the soil. The primer beneath the coating on most of the specimens was blistered. Since some of the blistered primers were covered by apparently perfect coatings, it is possible that the blistering of the primer was caused by the baking of the coating rather than by corrosion. Nine specimens showed rust spots but no measurable pits were found. The bond between the primer and the coating is poor. The rust inhibitor in the primer was not altogether effective.

In considering the significance of the data on nonmetallic coatings presented herewith, the reader should keep two facts in mind: (1) The data represent the condition of approximately ½ square foot of pipe surface, whereas the pipe-line operator is interested in the worst condition on thousands of square feet. As we are dealing with maxima, we should expect a section of pipe coated for test to show fewer rust spots and shallower maximum pits than would a whole pipe line to which the same coating has been applied; (2) although protective coatings generally do not entirely prevent corrosion, they usually reduce the annual maintenance charges on the pipe line. It is possible that the use of an inexpensive coating may be more economical than the use of a more effective coating which costs more.

The final decision as to whether or not one or more of the coatings for which data have been presented can be used to advantage under a given soil condition depends not only upon the corrosiveness of the soil and the corrosion-inhibiting value of the coatings, but also upon the cost of the pipe, the cost of the coating and the cost of making repairs. It can be shown that in cases where the soil is very corrosive, almost any coating affords sufficient protection to pay for its cost. Between this condition and the one in which bare pipe will last indefinitely is a wide range of soil conditions for which corrosiveness, protective properties of coatings, and costs must be known before the engineer can determine whether or not any coating should be applied. For most of these cases sufficient data are not available.

VII. SUMMARY

1. With the exception of the lead-coated specimens, all of the coatings treated in this report appear to have reduced the rate of corrosion of steel during the period of the test.

2. None of the coatings have a perfect record for all specimens removed, although in some cases of short-time exposures the rusting of the protected pipe was probably caused by moisture entering through the ends of the specimens and not through the coating.

3. Specimens calorized by the powder process showed somewhat higher rates of loss of weight and somewhat lower rates of maximum penetration than those calorized by the dip process.

4. Lead is sufficiently corrodible in most soils to result in the perforation of lead coatings of the thickness used in these tests within 10 years. After the lead has been punctured, accelerated corrosion may occur because of differences of potential between lead and steel.

5. Over a 10-year period, the rates of loss of weight of galvanized steel were from one-half to one-fifth the rates for bare steel.

6. Galvanized steel corrodes most rapidly in poorly drained acid soils and in those high in salts.

7. For long periods of exposure, thick zinc coatings are superior to thin ones. A coating of 2.8 ounces per square foot of exposed surface prevented the formation of measurable pits in all but one soil for a period of 10 years.

8. The type of ferrous material to which the zinc is applied does not have an appreciable effect on the rate of corrosion of galvanized materials during the first 10 years of exposure.

9. The rate of corrosion of galvanized steel is lower than that of either zinc or steel alone.

10. Foundry and mill scale do not protect ferrous materials against underground corrosion.

11. The coverings over the lead sheath in parkway cable prevent serious corrosion of the sheath for a period of 12 years at least.

12. Of a group of nonmetallic and nonbituminous coatings, vitreous-enamel and hard-rubber coatings afforded the best protection over a 2-year period of exposure.

Thin coatings in this group permitted moisture to reach the pipe and rusting followed.

13. It is not possible to determine from the data presented whether or not any of the coatings would be advisable under any of the soil conditions studied because this is an economic problem depending largely on the cost of the coating and other factors.

The cleaning, weighing, and measuring of the specimens have been done mostly by A. L. Lewis and L. M. Martin. The inspection of the galvanized sheet and pipe was made by R. F. Passano of the American Rolling Mill Co., and C. P. Larrabee of the Carnegie-Illinois Steel Corporation. The inspection of the nonmetallic coatings was made by S. P. Ewing. Tables and drawings were prepared by L. M. Martin and R. W. Mattoon. From all of these men, and from I. A. Denison, many helpful suggestions as to the significance of the data have been received.

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