RP329

SOIL-CORROSION STUDIES, 1930

RATES OF CORROSION AND PITTING OF BARE FERROUS SPECIMENS

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ABSTRACT

During 1930 the National Bureau of Standards removed from 70 test locations approximately 1,300 specimens of ferrous pipe materials. This paper reports the results of the examinations of these specimens. The extent of the corrosion is found to depend largely on the character of the soil. Rates of corrosion appear to vary somewhat from year to year, but the general tendency is for the rate to decrease as the time of exposure increases. The data do not indicate that there is a one best pipe material regardless of soil conditions. The material which appears best in one soil may appear inferior in another soil. It is too early to state whether this will hold true at the close of long-time tests. Supplementary tests indicate that at least a number of soils have characteristic corrosive properties which can be expected wherever those soils are found.

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I. INTRODUCTION

1. RELATION OF THIS REPORT TO PREVIOUS ONES

As a part of its investigation of stray-current electrolysis the National Bureau of Standards began in 1922 a study of the relation of soils to the deterioration of buried pipe. This study was planned to extend over 10 or more years and involved the cooperation of a large number of manufacturers and public-utility organizations. It seems wise to publish from time to time progress reports concerning the work in order that those cooperating may keep in touch with the results of their cooperation. The first report entitled "Bureau of Standards Soil-Corrosion Studies. I. Soils, Materials, and the Results of Early Observations" was published as Technologic Paper No. 368 in 1928. As the title indicates, it describes the soils and materials then under observation and records the rates of corrosion observed when specimens were removed in 1924 and 1926. This paper is neces-

sary for the complete understanding of the later reports. In August, 1929, the bureau published a second report known as Research Paper No. 95 entitled "Soil Corrosion Studies, 1927–28." That report gives the results of the examinations of ferrous specimens removed in 1928, together with a description of related field and laboratory studies.

The present report covers the results of the examinations of ferrous specimens removed in 1930 with such supplementary information as seems necessary for the interpretation of the data. The results of the examination of the nonferrous pipe specimens, the organic and metallic protective coatings, and the relation of soils to corrosion will be discussed in later papers. The investigation still has at least four years to run, and final conclusions can not be drawn until the data now available can be combined with those to be obtained later.

2. PURPOSE OF THE INVESTIGATION AND THE EFFECTS OF THE METHODS USED ON THE PRECISION OF THE RESULTS

The primary purpose of the investigation was to determine the extent to which soil conditions are responsible for the corrosion of underground pipes. This purpose determined the selection of the soils, the materials, and the method of testing. The results so far obtained indicate that the selections are quite satisfactory for the purpose for which they are intended but for some other purposes the data are not so well adapted, as will be pointed out.

The main objective in selecting the soils was to obtain soil representative of conditions encountered by underground pipes without regard to corrosiveness. For this reason the test locations are most numerous in those regions where underground pipe systems are extensive.

As is well known to all who have had extensive experience in the laying of gas or water mains, in most cities several varieties of soils are found, some of which are much more corrosive than others. For this reason it is necessary to avoid the association of the results of the tests with the cities in or near which they are conducted. This is illustrated by the fact that a rather corrosive soil, Susquehanna, is under test near Meridian, Miss. None of this soil is found within the boundaries of the city, and the rates of corrosion of buried pipes there are said to be much less than the rate found for Susquehanna clay. Likewise the rate of corrosion of specimens in Fairmount loam in Cincinnati, Ohio, is said to be considerably less than that experienced in one section of the city where a different soil is encountered. The data are indicative of corrosion under the described soil conditions, but not necessarily of the average corrosion of the pipes in the cities near the test locations.

In each test location an attempt was made to bury the specimens at approximately the depth at which pipes were laid in that locality. On this account, in the Southern States the specimens are at a depth of from 18 to 24 inches, while farther north their depth varies from 3 to 5 feet. Consequently, the specimens in the South frequently lie in the surface soil or upper subsoil, while those in the North may lie in the lower subsoil or parent material. Often in a given locality there is as much difference between the characteristics of the surface-soil and the subsoil as between two widely separated and different soils. While the method of burial adopted is quite satisfactory for indicating the soil corrosion in the locality of the test, it is not ade-

quate for correlating corrosion with soil types, because other things being equal the corrosion in any soil depends upon the soil horizon in which the pipe is buried. If a pipe is so laid that it passes from one soil horizon to another it may be expected to corrode at a different rate from that if laid wholly in either horizon.

The desire to make the tests in soils in which pipe systems are in service resulted in the selection of a number of soils which were found by the tests to be only slightly corrosive. Such soils are not suitable for the determination of the resistance of a material to corrosion.

An attempt was made to select typical representatives of the desired soil series, but in some instances the necessity of selecting an available site where assistance in burying specimens could be obtained resulted in placing the specimens in a trench, throughout

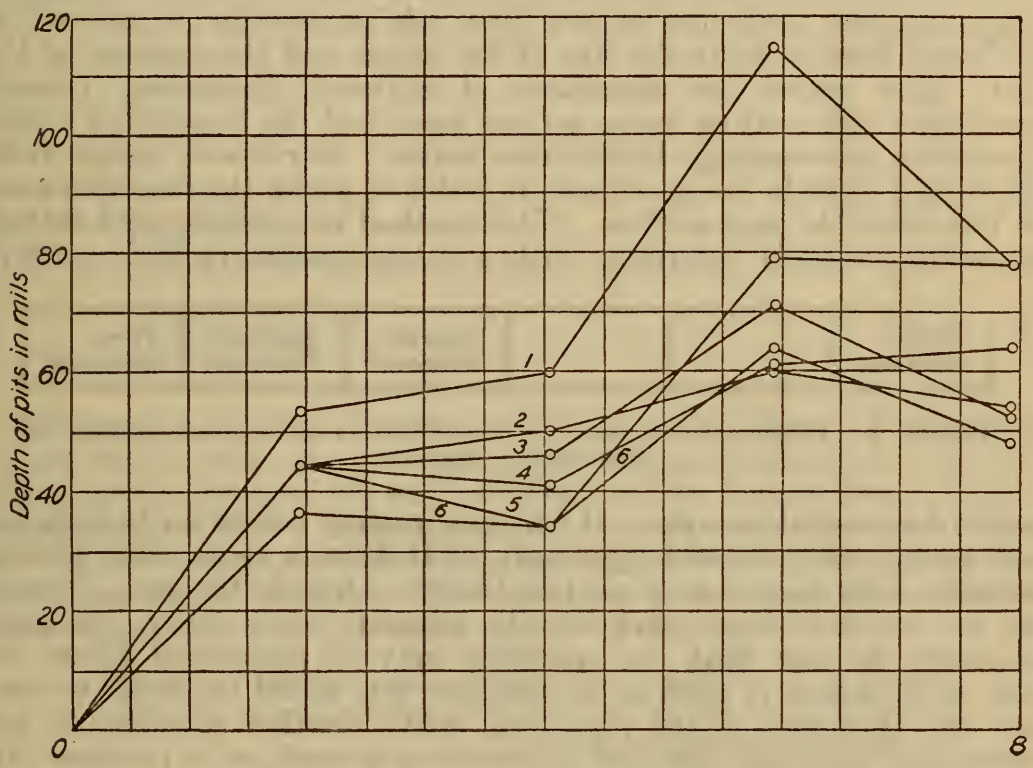

FIGURE 1.—*Variation in pitting soil No. 15*

the length of which the soil texture or moisture was not quite uniform. This lack of uniformity is responsible for some of the inconsistencies in rates of corrosion and pitting which are observed at some locations. This is illustrated by Figure 1 in which are plotted pitting data for a location where these variations are somewhat abnormal. The circles show the depth of the deepest pit on each of six materials at the end of four intervals of exposure. In order to compare equal amounts of exposed areas it is necessary to consider one 6-inch specimen of one material, two 3-inch specimens of another, and four 1½-inch specimens of a third material.

It will be noticed that the rates of pitting of all the materials are greatest for the first period. This is the case for most materials in most test locations and indicates that the initial rate of pitting is usually greater than subsequent rates. The specimens removed at the close of the 4-year period showed little or no greater depth of

pits over the specimens removed two years earlier. The specimens removed at the end of six years showed, with one exception, deeper pits than those removed two years later. Figure 2 shows the relative positions of the sets of specimens in the trench. The most logical way to account for the differences in depths of pitting is to conclude that the soil at one end of the trench where the third set was removed is not the same as at the other end of the trench. Several test locations give similar results for most specimens and a large number of the locations show erratic results for at least one material. Where the abnormal results apply to one material only, it is probable that irregularities in the material are responsible. Evidently, then, the results at the close of any one test period in a given soil can not safely be taken as a measure of the relative performance of materials in the soil or of the corrosiveness of the soil.

The selection of materials was governed by the desire to expose representative specimens of the materials commonly in use and at the same time to limit the size of the pieces and the expense of the test. This called for specimens of different diameters, 1½-inch specimens representing house service pipes and the 3-inch and 6-inch specimens representing distribution mains. Earth was placed both inside and outside the specimens in order to make the maximum use of the available pipe surface. This method of selecting and testing materials seriously interferes with a determination of their relative

FIGURE 2.—*Relative trench positions of specimens removed from soil No. 15 at different times*

merits for several reasons. If irregular pitting occurs on both inside and outside surfaces of a specimen, as it does in some soils, pits on opposite sides may or may not join to form a hole in the pipe, depending on whether they start exactly opposite each other. It may, therefore, happen that one specimen may be punctured where the rate of corrosion is such as to produce pits equal in depth to one-half the thickness of the pipe wall, while another specimen is not penetrated although the rate of corrosion is such as to produce pits equal in depth to two-thirds of the wall thickness. Again, the 1½-inch specimens, because of their thinner walls, will be punctured before the thicker walled 3-inch specimens.

The puncture of a specimen creates a problem with respect to the computation of rates of penetration, for which there appears to be no entirely satisfactory solution. In the absence of a better method, the rate of penetration for a material in a given soil for periods subsequent to the one in which a puncture from the outside only has been observed has been taken as the thickness of the pipe wall divided by the age of the specimen when the puncture was first discovered. Since rates of pitting decrease with time for most soils, this method yields a somewhat higher final rate of penetration than would be found if the specimen were thicker. It has been necessary to apply this treatment in this report only to the data for soil No. 23.

Different rolling mills and foundries finish their products differently, some being smoother than others. This difference in roughness may

have no effect on the rate of corrosion, but it affects the precision with which the depth of the pits can be determined.

This is illustrated in Table 1, which indicates the original roughness of the specimens. Eight measurements on each of two uncorroded specimens of several materials were made with the depth gage used for determining pit depths. The table shows the arithmetical average deviation of the individual measurements from the average of all the measurements on one kind and size of material. It will be seen that for two materials the deviation is about 5 mils, while for another it is about 30, or six times as great.

TABLE 1.—*Finish of representative specimens as furnished*

Identification letter	Material	Diameter	Average roughness
		Inches	*Mils*
a	Open-hearth iron	1½	5.0
b	Wrought iron	1½	8.1
d		1½	8.1
e	Bessemer steel	1½	4.9
y		1½	7.5
B	Wrought iron	3	11
D		3	8
K	Open-hearth iron	3	8
M	Bessemer steel	3	11.6
Y	Open-hearth steel+copper	3	12.3
C	de Lavaud cast iron	6	10.4
L	Northern pit cast iron	6	20.6
Z	Southern pit cast iron	6	29.9

Differences in size interfere with the comparison of materials. When small areas are concerned, other things being equal, it is probable that the deepest pit will be found on the largest area. This is illustrated in Table 2 which gives the average rates of penetration of the deepest pits on two materials for which both 1½-inch and 3-inch specimens were included. The averages cover specimens removed at the close of the 2, 4, 6, and 8 year periods, respectively.

TABLE 2.—*Effect of size of specimen on maximum rate of pitting*

Material	Maximum rate of pitting (mils per year)							
	2-year period		4-year period		6-year period		8-year period	
	Size of specimen (inches)							
	1½	3	1½	3	1½	3	1½	3
I	22.2	26.9	12.0	13.8	8.3	10.4	6.7	7.5
II	22.4	24.4	12.0	13.1	9.3	9.5	6.8	7.1

It will be noticed that in each case the 3-inch specimens showed deeper pits than the corresponding 1½-inch specimens. A study of the rates of loss of weight of the same materials indicates that for each period the 3-inch specimens show the lower rates of corrosion. Possible explanations for the greater corrosion of the smaller specimens are that they may have been subjected to greater internal strains due to quicker cooling, or to the additional rolling, to which the material from which they are formed is subjected, or that the

corroding solution may act more freely on the more curved surface of the smaller specimens. Whatever the explanation for the differences, it is evident that the rates of corrosion and pitting depend to some extent upon the size of the specimen, and that specimens of different sizes are not strictly comparable.

The differences in rates of loss of weight and rates of penetration of pits are frequently as great for two specimens of the same material as for two specimens of different materials. This is illustrated by Table 4, which shows the rates of loss of weight and rates of penetration of the deepest pits for individual specimens removed from soil No. 1 in 1930.

In order to get the necessary data on a single page in this and later tables it has been found necessary to refer to specimens by their identification letters. The significance of these letters is given in Table 3. The names of the soils, the locations of the tests and the ages of specimens removed in 1930 are given in Table 5.

TABLE 3.—*Identification of materials*

Identification letters	Material
1½-INCH SPECIMENS	
a	Pure open-hearth iron, lap-welded.
b, d	Hand-puddled wrought-iron, butt-welded.
e	Bessemer steel, butt-welded.
y	Scale-free Bessemer steel butt-welded.
3-INCH SPECIMENS, LAP-WELDED	
A [1]	Pure open-hearth iron.
B, D	Hand-puddled wrought iron.
K	Open-hearth steel.
M	Bessemer steel.
N [1]	Bessemer steel, scale-free, butt-welded.
Y	Open-hearth steel, 0.2 per cent copper.
6-INCH CAST-IRON SPECIMENS	
C	de Lavaud centrifugal process.
CC	de Lavaud centrifugal process, only outside exposed to soil.
I [1]	Monocast centrifugal process.
L	Vertically cast in sand molds, northern ore.
P [1]	"Pit" cast iron, southern ore.
Z	Vertically cast in sand molds, southern ore.

[1] Specimens buried in 1928 for special tests.

TABLE 4.—*Data on individual specimens removed from soil No. 1 in 1930*

Mark	Rate of loss	Rate of penetration	Mark	Rate of loss	Rate of penetration
	Ounces per square foot per year	*Mils per year*		*Ounces per square foot per year*	*Mils per year*
a	0.680	5.7	K	0.800	5.7
	.624	5.7		.665	8.5
b	.945	12.8	M	.970	8.7
d	.835	6.4		.948	7.4
e	.899	6.1	Y	.864	5.2
	.875	7.4		.862	6.5
y	.852	5.5	C	.708	7.2
	.855	7.8		.847	9.6
B	.882	7.0	L	.963	28.8
D	.848	6.8	Z	.942	27.2

TABLE 5.—*Ages of specimens buried in 1922*

Soil No.	Soil	Location	Age of specimens at close of period (years)—			
			First	Second	Third	Fourth
1	Allis silt loam	Cleveland, Ohio	0.98	3.58	5.50	7.68
2	Bell clay	Dallas, Tex	2.09	4.03	5.93	7.93
3	Cecil clay loam	Atlanta, Ga	2.01	4.09	6.04	7.98
4	Chester loam	Jenkintown, Pa	1.38	4.03	6.12	7.96
5	Dublin clay adobe	Oakland, Calif	1.93	4.13	6.16	8.06
6	Everett gravelly sandy loam	Seattle, Wash	1.93	4.13	6.17	8.05
7	Fairmount silt loam	Cincinnati, Ohio	1.04	3.50	--------	7.68
8	Fargo clay loam	Fargo, N. Dak	1.13	3.80	5.83	7.74
9	Genesee silt loam	Sidney, Ohio	1.03	3.48	5.47	7.67
10	Gloucester sandy loam	Middleboro, Mass	1.33	4.01	6.10	7.93
11	Hagerstown loam	Baltimore, Md	1.36	3.97	6.01	7.84
12	Hanford fine sandy loam	Los Angeles, Calif	1.94	4.14	6.17	8.05
13	Hanford very fine sandy loam	Bakersfield, Calif	1.93	4.22	5.89	--------
14	Hempstead silt loam	St. Paul, Minn	1.13	3.80	5.83	7.72
15	Houston black clay	San Antonio, Tex	1.96	4.04	5.93	7.95
16	Kalmia fine sandy loam	Mobile, Ala	1.97	4.04	5.97	7.94
17	Keyport loam	Alexandria, Va	1.21	3.83	5.89	7.71
18	Knox silt loam	Omaha, Nebr	1.19	3.74	5.78	7.67
19	Lindley silt loam	Des Moines, Iowa	1.12	3.66	5.70	7.58
20	Mahoning silt loam	Cleveland, Ohio	.98	3.57	5.50	7.68
21	Marshal silt loam	Kansas City, Mo	1.47	4.02	6.05	--------
22	Memphis silt loam	Memphis, Tenn	1.72	3.68	5.55	7.59
23	Merced silt loam	Buttonwillow, Calif	1.93	4.27	6.16	7.95
24	Merrimac gravelly sandy loam	Norwood, Mass	1.32	4.01	6.10	7.93
25	Miami clay loam	Milwaukee, Wis	1.03	3.71	5.74	7.62
26	Miami silt loam	Springfield, Ohio	1.04	3.49	5.48	7.67
27	Miller clay	Bunkie, La	1.95	4.05	5.96	7.95
28	Montezuma clay adobe	San Diego, Calif	1.64	--------	5.56	--------
29	Muck	New Orleans, La	1.96	4.07	5.99	7.96
30	Muscatine silt loam	Davenport, Iowa	1.11	3.65	5.69	7.58
31	Norfolk sand	Jacksonville, Fla	2.01	4.07	6.02	7.98
32	Ontario loam	Rochester, N. Y	.94	3.73	5.82	7.65
33	Peat	Milwaukee, Wis	1.03	3.71	5.75	7.63
34	Penn silt loam	Norristown, Pa	1.38	4.03	6.12	7.96
35	Ramona loam	Los Angeles, Calif	1.93	4.14	6.16	8.05
36	Ruston sandy loam	Meridian, Miss	1.99	4.07	5.97	8.00
37	St. Johns fine sand	Jacksonville, Fla	2.00	4.07	6.03	7.98
38	Sassafras gravelly sandy loam	Camden, N. J	1.40	4.04	6.13	7.97
39	Sassafras silt loam	Wilmington, Del	1.38	4.02	6.11	7.95
40	Sharkey clay	New Orleans, La	1.96	4.06	5.98	7.96
41	Summit silt loam	Kansas City, Mo	1.47	4.02	6.05	7.94
42	Susquehanna clay	Meridian, Miss	1.98	4.07	5.97	8.00
43	Tidal marsh	Elizabeth, N. J	1.29	4.06	6.16	8.02
44	Wabash silt loam	Omaha, Nebr	1.09	3.63	5.68	7.58
45	Unidentified alkali soil	Casper, Wyo	1.18	3.78	5.79	7.68
46	Unidentified sandy loam	Denver, Colo	1.46	4.05	6.07	7.96
47	Unidentified silt loam	Salt Lake City, Utah	1.48	4.08	6.09	7.99

Specimens b, d, B, and D are of the same material but specimens b and B were supplied by one mill and d and D furnished by another mill. No claim is made by either mill that one of these sets of material is superior to the other. It will be seen from Table 4 that in soil No. 1 the rates of loss of weight for the four specimens b, d, B, and D are quite similar, but that the maximum rate of pitting for specimen b is greater than for any of the other specimens except L and Z which are of quite different material.

Similar departures of a single specimen from the average behavior of its group will be found in the data for about one-third of the soils under observation. An abnormally low rate of pitting occurs about

as often as one that is abnormally high. Usually the variations in the apparent behavior of two similar specimens are not the result of errors in testing, but originate in abnormal conditions in the material, the soil, or the contact between the soil and the specimen. The variations are significant of what may be expected when pipe is placed underground, and indicate that the performance of one specimen or one section of working pipe line should not be taken as representative of the performance of the material from which the specimen or pipe is made.

Attention is called to these irregularities in corrosion data in order that those who attempt to compare data on different materials shall realize the character of the data with which they deal. There is a tendency among those unfamiliar with corrosion research in general, and especially with those unfamiliar with underground corrosion, to assume that for a given pipe material in a specified soil there is a definite rate of corrosion just as the material has a definite density. Such, however, is not the case. The most characteristic phenomenon of underground corrosion is its erratic nature. While a sufficient amount of data may indicate the average performance of the materials, it is to be expected that in any specific case the performance of a material may depart widely from the average. This appears to be true for all the commonly used ferrous pipe materials.

II. METHOD OF PRESENTING THE DATA

During 1930 approximately 1,300 specimens of ferrous pipe were removed from 70 locations. With a few exceptions two specimens of each material under observation were removed from each soil under investigation.

Determinations of the loss of weight and depth of the five deepest pits were made for each specimen and these data are available for those who have need for them. To reach any conclusion from these data requires a very considerable amount of time and effort, and an attempt has therefore been made to put their essential features in a form which can be more readily understood. The first step in this process was to combine the similar data for the two specimens of the same material and to determine the avarage rate of loss of weight per unit area for each pair of specimens.

When a study of the pitting of the specimens was made there was some doubt regarding the proper method of reporting the results. It has seemed desirable to continue in this report the form of table previously used in earlier reports on the soil-corrosion investigation. The rates of pitting in these tables have been derived from measurements of the deepest pit on each specimen. Thus for the six specimens of Bessemer steel removed from each soil, the rate of pitting is based on six pits, while for the two specimens of open-hearth steel, removed from a single soil the rate of pitting is computed from the depth of two pits.

It has been shown, however, that for a given material the depth of the deepest pit on a small specimen depends somewhat on the size of the specimen. In order to take account of this effect of the size of the specimen, other tables have been prepared in which the number of pits chosen for the determination of the rate of penetration is

proportional to the size of the specimen. As in former computations, the deepest pit on each 1½-inch specimen is used, but for the 3-inch specimens the two deepest pits on each specimen and for the 6-inch specimens the four deepest pits on each specimen have been made the bases for determining the rates of penetration.

It will be found that this method unduly favors one size of specimen or another, depending on the soil, but that for the average of all soils for all periods the weighted rates of pitting for the 1½-inch and 3-inch wrought-iron specimens are identical, as they should be since both sizes of specimens were furnished by the same mills at the same time. The weighted average results for the 1½-inch and 3-inch Bessemer steel specimens are nearly the same, the 3-inch material showing a somewhat higher rate of penetration. As all the specimens of gray cast iron were 6 inches in diameter, it is not possible to determine directly the fairness of the method with respect to these specimens. Since data are presented for both the maximum pit and the weighted maximum pit, the reader can use his discretion as to which he will accept.

It also appeared desirable to rearrange the data so as to show whether specimens of the same material from different sources behaved similarly, and to show the apparent relative performance of different sizes of the same material in each soil after the data had been adjusted to take account of the size of the specimen.

A further complication of some of the data originates from the fact that the outer surface of the de Lavaud specimens is quite different from the inner surface. This was not realized by those conducting the test at the time it was decided to fill the specimens with earth. An attempt was made later to take account of this difference by burying in 1924 additional specimens of de Lavaud cast iron which were coated on the inside. The ages of these specimens are consequently about two years less than those of the specimens first buried. Because fewer of these specimens were buried none were removed in 1928. In Table 6 the ages of these de Lavaud specimens are given. In Tables 11 to 16 these specimens are indicated by a footnote reference.

Whether the coating of the specimens will have the desired result is somewhat doubtful and it is probable that the decision as to the behavior of this material will have to be based largely on the rates of pitting. Since observation has indicated that the corrosion of the outer and inner surfaces of the other materials also differed on account of differences of the packing of the soil or for other reasons, and because pipe failures are usually caused by pit holes rather than by loss of material, rates of pitting may be the better criteria for corrosion of all materials.

TABLE 6.—*Age of De Lavaud specimens that were coated on the inside* [1]

Soil No.	Soil	Age of specimens removed— In 1926	Age of specimens removed— In 1930
		Years	*Years*
2	Bell clay	1.94	5.84
3	Cecil clay loam	2.07	5.97
5	Dublin clay adobe	2.20	6.13
6	Everett gravelly sandy loam	2.20	6.12
12	Hanford fine sandy loam	2.21	6.12
15	Houston black clay	2.08	5.99
16	Kalmia fine sandy loam	2.07	5.98
27	Miller clay	2.11	6.01
29	Muck	2.11	6.01
31	Norfolk sand	2.07	5.98
35	Ramona loam	2.20	6.12
36	Ruston sandy loam	2.08	6.02
37	St. Johns fine sand	2.07	5.98
40	Sharkey clay	2.10	6.01
42	Susquehanna clay	2.08	6.02

[1] Outer surface only exposed to soil. These specimens were buried in 1924. None were removed in 1928.

III. PRECISION OF MEASUREMENTS

The value of data depends upon the significance of the phenomena observed and upon the precision of the observations. The significance of the observed phenomena can be best understood after the data have been presented. The precision of the data depends on the care and thoroughness with which the corrosion products were removed and upon the errors in determining the losses and pit depths. The losses were determined by checking the weights of the 6-inch specimens to 0.2 g and the 3-inch and 1½-inch specimens to 0.02 g. The losses in weight are such as to make the maximum error due to weighing about 1 per cent for the heaviest specimens in the least corrosive soils, and 0.1 per cent for the specimens in the more corrosive soils.

It is not possible to determine exactly the maximum errors due to improper cleaning of the specimens. It is estimated that they are less than 1 per cent for the rolled materials. In most cases there is no sharp distinction between the corroded and uncorroded sections of the cast-iron specimens. Fortunately the difficulty in determining when all of the corrosion products have been removed is roughly proportional to the extent of the corrosion. It is doubtful whether the error caused by improper cleaning exceeds 1 per cent for the most difficult specimens.

The pit measurements for all specimens were checked to 3 mils, but the true depth of any one pit may differ from the measured depth by from two to five times this amount on account of the roughness of the finish of the specimens as shown in Table 1.

From the above statements it will be evident that the number of figures carried in the following tables indicate the precision of the measurements. It should not be understood, however, that the figures indicate the precision with which the performance of the soils and materials have been determined. The significance of the data will be discussed after their presentation.

IV. DATA OBTAINED IN 1930

Tables 7 to 10, inclusive, are given for the benefit of those who prefer the method of presenting data used in previous soil-corrosion reports. The data are comparable with similar data in Tables 4, 5, and 6 of Technologic Paper No. 368 and with Tables 5, 6, and 7 of Research Paper No. 95. The names of the soils and the approximate locations of the test plots are given in Table 5.

In these tables the Bessemer steel is represented by four 1½-inch and two 3-inch specimens, the wrought iron by two 1½-inch and two 3-inch specimens, the pure open-hearth iron by two 1½-inch specimens, the open-hearth and copper-bearing steels each by two 3-inch specimens, and the cast irons each by two 6-inch specimens.

In order to make the data for different sizes of materials more nearly comparable, the data presented in the earlier reports and those for the 1930 specimens have been recalculated and rearranged to form Tables 11 to 18. In these tables which show rates of penetration the rates have been weighted according to the size of the specimens by averaging the deepest pits on the 1½-inch specimens, the two deepest pits on the 3-inch specimens and the four deepest pits on the 6-inch specimens. There were two specimens of each material except materials *L* and *Z* (see Table 3), of which there was but one specimen removed at a time from each soil.

TABLE 7.—*Rates of loss of weight of 8-year-old specimens*

[In ounces per square foot per year]

Soil No.[1]	Time buried	Bessemer steel	Wrought iron	Pure open-hearth iron	Open-hearth steel	Copper-bearing steel	Sand-mold cast iron	De Lavaud cast iron
		Number of specimens considered						
		6	4	2	2	2	2	2
	Years							
1	7.68	0.90	0.88	0.65	0.73	0.86	0.95	0.78
2	7.93	.47	.47	.48	.39	.29	.37	(2)
3	7.98	.53	.51	.46	.51	.48	.54	(2)
4	7.96	.67	.68	.65	.69	.73	.62	.71
5	8.06	.67	.75	.73	.70	.67	.82	(2)
6	8.05	.11	.11	.10	.10	.12	.10	(2)
7	7.68	.54	.55	.52	.51	.55	.57	.61
8	7.74	.46	.48	.43	.46	.55	.81	.73
9	7.67	.41	.45	.42	.44	.40	.48	.52
10	7.93	.57	.57	.55	.58	.58	.50	.54
11	7.84	.21	.24	.13	.17	.18	.17	.19
12	8.05	.11	.14	.12	.10	.14	15	(2)
13	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
14	7.72	.35	.37	.26	.22	.30	.38	.35
15	7.95	.67	.66	.63	.71	.63	.55	(2)
16	7.94	.57	.61	.64	.58	.64	.60	(2)
17	7.71	.88	.94	.84	.90	.96	.82	.94
18	7.67	.31	.35	.23	.25	.27	.39	.27
19	7.58	.38	.36	.33	.32	.33	.39	.34
20	7.68	.38	.43	.36	.38	.37	.48	.46
21	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
22	7.59	.93	.83	.76	.82	.99	.69	.84
23	7.95	2.24	2.46	2.28	2.65	3.00	4.98	2.65
24	7.93	.12	.12	.12	.11	.10	.07	.09
25	7.62	.25	.27	.23	.23	.23	.31	.28

[1] See Table 5 for names and locations of soils.
[2] De Lavaud specimens buried late.
[3] No regular specimens.
[4] No specimens removed.

TABLE 7.—*Rates of loss of weight of 8-year-old specimens*—Continued

[In ounces per square foot per year]

Soil No.	Time buried	Bessemer steel	Wrought iron	Pure open-hearth iron	Open-hearth steel	Copper-bearing steel	Sand-mold cast iron	De Lavaud cast iron
		Number of specimens considered						
		6	4	2	2	2	2	2
	Years							
26	7.67	0.22	0.23	0.17	0.19	0.22	0.27	0.23
27	7.95	.56	.54	.57	.62	.55	.53	(2)
28	5.56	1.84	1.63	1.86	1.92	1.92	1.68	.77
29	7.96	1.61	1.50	1.80	2.07	2.01	1.72	(2)
30	8.17	.52	.57	.50	.49	.47	.62	.59
31	7.98	.31	.27	.23	.28	.28	.22	(2)
32	7.65	.32	.35	.26	.33	.35	.45	.34
33	7.63	1.18	1.16	1.10	1.16	1.03	1.11	1.18
34	7.96	.43	.43	.37	.40	.40	.50	.58
35	8.05	.23	.26	.30	.26	.29	.25	(2)
36	8.00	.29	.30	.25	.26	.26	.13	(2)
37	7.98	.67	.78	.73	.77	.81	.81	(2)
38	7.97	.26	.25	.25	.24	.26	.16	.17
39	7.95	.55	.59	.52	.61	.64	.67	.75
40	7.96	.85	.85	.80	.89	.96	1.15	(2)
41	7.94	.60	.60	.61	.53	.55	.47	.32
42	8.00	1.01	.88	.74	.86	.70	1.40	(2)
43	7.98	1.28	1.65	1.14	1.36	1.81	.92	1.32
44	7.58	.30	.28	.22	.28	.28	.26	.21
45	7.68	.51	.60	.45	.50	.55	.77	.51
46	7.96	.70	.71	.71	.75	.84	.74	.71
47	7.99	.23	.26	.27	.26	.20	.30	.38

[2] De Lavaud specimens buried late.

TABLE 8.—*Rates of maximum penetration of 8-year-old specimens*

[In mils per year]

Soil No.	Time buried	Bessemer steel	Wrought iron	Pure open-hearth iron	Open-hearth steel	Copper-bearing steel	Sand-mold cast iron	De Lavaud cast iron
		Number of specimens considered						
		6	4	2	2	2	2	2
	Years							
1	7.68	7	8	6	7	6	28	8
2	7.93	6	5	6	6	6	12	(1)
3	7.98	9	8	8	8	9	21	(1)
4	7.96	5	5	7	7	10	9	6
5	8.06	6	6	5	6	6	9	(1)
6	8.05	2	2	2	2	2	1	(1)
7	7.68	4	5	3	6	3	4	7
8	7.74	8	7	8	11	12	11	14
9	7.67	5	6	5	6	5	5	7
10	7.93	5	5	6	7	5	5	5
11	7.84	7	8	8	7	8	8	[2] 3
12	8.05	[2] 2	[2] 2	[2] 2	2	3	[2] 1	(1)
13	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
14	7.72	15	11	11	10	21	8	10
15	7.95	6	8	7	6	7	11	(1)
16	7.94	9	10	7	11	9	19	(1)
17	7.71	4	5	4	5	5	4	6
18	7.67	5	6	7	7	7	[2] 1	[2] 1
19	7.58	6	6	6	8	9	22	10
20	7.68	5	5	4	5	8	9	7

[1] De Lavaud specimens buried late.
[2] Pit depths assumed to be 10 mils for calculating purposes.
[3] No regular specimens.

TABLE 8.—*Rates of maximum penetration of 8-year-old specimens*—Continued

[In mils per year]

Soil No.	Time buried	Bessemer steel	Wrought iron	Pure open-hearth iron	Open-hearth steel	Copper-bearing steel	Sand-mold cast iron	De Lavaud cast iron
		Number of specimens considered						
		6	4	2	2	2	2	2
	Years							
21	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
22	7.59	8	7	7	8	9	17	15
23	7.95	17	19	27	20	27	51	22
24	7.93	2	2	3	3	4	[2] 1	[2] 1
25	7.62	5	6	6	5	5	13	[2] 1
26	7.67	6	6	5	6	8	10	5
27	7.95	5	5	4	9	5	18	(1)
28	5.56	10	10	9	14	13	31	8
29	7.96	13	10	13	11	22	27	(1)
30	8.17	5	6	6	4	4	8	9
31	7.98	5	5	5	6	5	7	(1)
32	7.65	5	5	4	6	6	22	7
33	7.63	11	10	17	15	12	21	17
34	7.96	6	6	5	8	9	7	7
35	8.05	[2] 2	3	4	3	7	4	(1)
36	8.00	5	6	6	[2] 7	[2] 6	[2] 22	(1)
37	7.98	7	7	7	8	12	6	(1)
38	7.97	3	4	7	3	3	[2] 1	[2] 1
39	7.95	6	7	5	10	10	6	7
40	7.96	10	11	11	12	12	11	(1)
41	7.94	7	8	8	7	7	6	6
42	8.00	13	11	10	12	11	19	(1)
43	7.98	9	14	11	17	11	6	13
44	7.58	8	7	9	7	12	6	5
45	7.68	7	7	7	8	9	11	9
46	7.96	15	9	8	8	17	11	6
47	7.99	[2] 1	[2] 1	[2] 1	[2] 1	[2] 1	[2] 1	[2] 4

[1] De Lavaud specimens buried late.
[2] Pit depths assumed to be 10 mils for calculating purposes.
[4] No specimens removed.

TABLE 9.—*Pitting factors of 8-year-old specimens*

Soil No.	Time buried	Bessemer steel	Wrought iron	Pure open-hearth iron	Open-hearth steel	Copper-bearing steel	Sand mold cast iron	De Lavaud cast iron
		Number of specimens considered						
		6	4	2	2	2	2	2
	Years							
1	7.68	5.2	6.0	5.9	6.5	4.4	17.2	6.3
2	7.93	8.2	7.1	8.3	9.5	13.5	19.8	(1)
3	7.98	10.9	9.7	11.0	10.8	11.7	23.6	(1)
4	7.96	5.3	4.3	7.7	6.7	8.6	8.6	4.7
5	8.06	5.6	4.8	4.1	5.9	5.3	6.6	(1)
6	8.05	11.5	11.0	14.4	13.1	9.9	7.1	(1)
7	7.68	4.8	5.3	3.9	7.4	3.5	3.3	6.4
8	7.74	11.9	9.8	12.2	16.1	14.4	8.0	11.2
9	7.67	8.1	8.3	7.5	9.1	8.5	6.3	8.1
10	7.93	5.5	5.6	7.3	7.9	6.0	6.3	5.0
11	7.84	23.9	23.6	41.0	27.8	29.6	26.9	[2] 8.5
12	8.05	[2] 10.5	[2] 11.2	[2] 11.8	15.1	14.8	[2] 6.5	(2)
13	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
14	7.72	28.4	22.3	27.0	30.0	45.6	15.3	16.5
15	7.95	5.9	8.2	7.9	5.2	6.8	11.4	(1)

[1] De Lavaud specimens buried late.
[2] Pit depths assumed to be 10 mils for calculating purposes.
[3] No regular specimens.

TABLE 9.—*Pitting factors of 8-year-old specimens*—Continued

Soil No.	Time buried	Bessemer steel	Wrought iron	Pure open-hearth iron	Open-hearth steel	Copper-bearing steel	Sand mold cast iron	De Lavaud cast iron
		Number of specimens considered						
		6	4	2	2	2	2	2
	Years							
16	7.94	9.7	10.2	7.6	11.9	10.0	19.1	(1)
17	7.71	3.3	3.4	3.3	3.7	3.4	3.0	3.8
18	7.67	11.9	12.0	20.7	19.3	17.3	[2] 2.0	[2] 2.8
19	7.58	10.7	11.9	12.5	15.6	17.6	33.8	17.0
20	7.68	9.5	6.8	7.3	7.8	14.8	10.9	9.4
21	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
22	7.59	5.6	5.7	6.1	6.1	6.1	14.7	10.5
23	7.95	5.0	5.0	(5)	5.0	6.0	(5)	4.9
24	7.93	9.9	12.5	15.3	18.6	25.5	[2] 11.9	[2] 8.4
25	7.62	13.3	13.8	15.8	14.5	16.6	27.2	[2] 2.8
26	7.67	17.2	17.2	20.1	21.0	22.1	21.3	13.7
27	7.95	5.4	5.6	4.5	9.7	6.2	20.5	(1)
28	5.56	3.7	4.1	3.2	4.7	4.6	10.8	6.2
29	7.96	5.6	4.7	4.9	3.6	7.3	9.3	(1)
30	8.17	5.9	6.7	7.5	5.8	5.4	7.3	9.3
31	7.98	9.6	12.8	13.3	13.2	10.6	20.7	(1)
32	7.65	11.4	9.6	11.0	12.4	11.2	28.7	13.8
33	7.63	6.3	6.0	10.5	8.7	7.9	11.1	8.4
34	7.96	8.7	8.3	9.4	14.2	13.9	7.6	6.9
35	8.05	[2] 7.0	6.7	9.1	[2] 6.9	[2] 12.9	[2] 9.3	(1)
36	8.00	11.7	14.3	16.2	18.6	15.8	110.1	(1)
37	7.98	7.0	5.8	6.4	7.2	9.9	4.4	(1)
38	7.97	7.8	10.1	18.2	8.6	7.6	[2] 4.6	[2] 4.4
39	7.95	7.1	7.8	7.4	10.3	10.1	5.6	5.8
40	7.96	7.6	8.2	8.9	9.1	7.9	5.7	(1)
41	7.94	8.1	8.3	8.4	8.9	8.4	7.4	10.3
42	8.00	8.4	7.8	8.8	8.8	10.6	7.8	(1)
43	7.98	4.8	5.7	6.0	8.2	4.2	3.8	5.4
44	7.58	18.7	16.3	27.9	15.9	27.0	15.2	13.1
45	7.68	9.2	7.9	9.7	10.3	10.3	9.4	10.9
46	7.96	14.2	8.7	7.8	7.4	13.0	8.2	5.3
47	7.99	[2] 3.6	[2] 3.1	[2] 3.2	[2] 3.1	[2] 4.1	[2] 2.6	[2] 6.6

[1] De Lavaud specimens buried late.
[2] Pit depths assumed to be 10 mils for calculating purposes.
[4] Not taken up.
[5] Specimen penetrated in 1928.

TABLE 10.—*Rates of loss of weight, maximum penetration, and pitting factors for De Lavaud specimens buried in 1924 and removed in 1930*

Soil No.	Time buried	Rates of loss of weight	Maximum rates of penetration	Pitting factor [1]
	Years	*Ounces per square foot per year*	*Mils per year*	
2	5.84	0.33	8	14.1
3	5.97	.22	[2] 2	[2] 4.4
5	6.13	1.58	[2] 12	[2] 4.3
6	6.12	.23	2	4.1
12	6.12	.39	[2] 4	[2] 5.4
15	5.99	.89	10	6.3
16	5.98	.62	15	14.4
27	6.01	1.18	16	7.9
29	6.01	1.39	15	6.4
31	5.98	.68	13	11.4
35	6.12	.22	[2] 2	[2] 4.7
36	6.02	.07	10	83.7
37	5.98	1.01	[2] 2	[2] 1.0
40	6.01	.98	14	8.1
42	6.02	.96	19	13.1

[1] The pitting factor is the ratio of the depth of the deepest pit to the average depth of corrosion.
[2] Pit depths assumed to be 10 mils for calculating purposes.

Comparisons of the data for the different years discloses the fact that the rates of corrosion differ from year to year. Part of this difference can be accounted for by variations in weather conditions, soil, and specimens. While there is a tendency for the rates to decrease, the most nearly representative values are probably those representing the average performance of all the specimens removed. Tables 19 and 20 give these average values as derived from Tables 11 to 18. In Research Paper No. 95 a table (Table 8) was given for the relative corrosiveness of soils. This table was derived by weighting the data according to the ages of the specimens. If changes in weather conditions were the controlling cause of the variations in the data for different periods, this weighting according to the ages of the specimens might be justified. A further study of the data discloses instances in which some other causes must control, and as the weighting referred to takes no account of these factors it seems best to abandon this method of weighting, at least until its value is better understood.

Table 21 goes one step further in averaging by combining all the similar data for all materials for any one soil. The purpose of the table is to furnish the best available data on soil corrosiveness. The rates of loss of weight for each soil for each period in Table 21 are based on exposed areas of approximately 14.4 square feet of pipe surface, and the average for all periods upon a total area of exposure of about 58 square feet. The pitting data for each soil for any one period are the results of measurements of 40 pits distributed over an area of approximately 7.5 square feet, while the data for the average of the four periods are derived from measurements of 160 pits distributed approximately uniformly over a total area of almost 30 square feet of pipe surface. The length of trench involved in the data for each soil is approximately 70 feet. These figures justify a very considerable degree of confidence that the data are representative of conditions under investigation. The authors know of very few sets of corrosion data representing so many determinations and none covering so wide a territory or in which individual determinations have been made with the same degree of precision.

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TABLE 11.—*Rates of loss of weight of 2-year-old specimens* [1]

[In ounces per square foot per year]

Soil No.	1½-inch specimens				3-inch specimens				6-inch specimens		
	a [2]	b	e	y	B	K	M	Y	C	L	Z
1	1.080	1.250	1.150	1.125	1.205	1.395	1.290	1.170	0.805	1.090	1.810
2	.900	.940	.860	1.170	.920	1.045	1.045	.875	[3] .430	.760	1.100
3	.730	.910	.865	1.005	.785	.980	1.055	.860	[3] .580	1.220	.740
4	1.055	.860	1.065	1.035	.980	1.015	1.010	1.120	.915	.880	1.100
5	.570	.470	.660	.700	.505	.515	.475	.495	[3] 1.175	.390	.540
6	.075	.080	.070	.110	.060	.075	.105	.080	[3] .121	.050	.080
7	.460	.665	.605	.580	.585	.510	.645	.595	.605	1.100	1.400
8	.640	.580	.645	.670	.590	.540	.700	.635	.695	.640	1.830
9	.540	1.175	.705	.880	.545	.610	.610	.525	.700	.610	.780
10	1.015	.930	.930	1.005	.860	.785	1.015	.880	.755	.590	.840
11	.200	.345	.280	.400	.265	.295	.325	.265	.075	.180	.170
12	.130	.130	.200	.165	.080	.110	.160	.130	[3] .035	.040	.220
13	1.285	1.550	1.900	2.735	2.015	2.335	1.715	2.110	1.410	1.980	1.820
14	.235	.325	.385	.480	.315	.415	.385	.400	.240	.120	.410
15	1.250	1.050	1.155	1.090	1.145	1.155	1.385	1.385	[3] 1.155	.670	1.270
16	.955	1.265	1.350	1.065	1.085	1.145	1.340	1.060	[3] .765	1.420	1.080
17	1.220	1.210	1.130	1.200	1.340	1.245	1.350	1.215	1.155	1.150	2.740
18	.355	.595	.375	.470	.340	.270	.400	.400	.210	--------	--------
19	.555	.755	.590	.605	.545	.565	.705	.750	.340	.500	.490
20	.950	.885	1.145	1.040	.920	1.050	.965	.950	.755	.900	1.320
21	1.370	1.410	1.440	1.445	1.500	1.355	1.395	1.440	1.090	1.670	1.400
22	.820	.920	1.170	1.100	.835	.890	.820	1.030	.625	.350	1.470
23	2.805	3.935	3.985	4.060	3.025	3.380	3.495	4.065	2.960	3.720	10.500
24	.150	.195	.200	.220	.155	.200	.215	.150	.135	.030	.190
25	.430	.580	.420	.430	.320	.355	.395	.400	.475	.580	.380
26	.765	.890	.800	.760	.790	.735	.865	.870	.765	.990	1.090
27	.205	.315	.250	.245	.305	.285	.300	.245	[3] 1.105	.220	.270
28	2.040	1.660	2.190	1.800	1.870	1.945	1.770	2.155	2.760	2.870	2.850
29	2.030	1.700	1.940	2.240	1.785	2.165	2.090	2.135	[3] 2.850	1.700	2.280
30	.810	.835	1.035	.805	.780	.965	.975	.915	1.040	1.070	1.180
31	.340	.625	.615	.755	.400	.620	.660	.525	[3] 1.090	.170	.580
32	.270	.510	.390	.395	.325	.420	.420	.340	.520	.650	.160
33	.420	.350	.400	.445	.430	.435	.390	.350	.420	.210	.490
34	.945	.925	.850	.780	.995	.985	1.055	.860	.910	.970	.940
35	.420	.450	.375	.370	.410	.470	.580	.485	[3] .515	.300	.900
36	.585	.615	.680	.575	.415	.420	.485	.475	[3] .360	.410	.540
37	1.155	1.130	1.190	1.175	1.210	1.200	1.265	1.215	[3] 1.955	.700	.950
38	.115	.135	.175	.170	.125	.185	.215	.200	.035	.040	.090
39	.755	.855	.840	.945	.845	.990	.850	.900	.865	.920	1.130
40	1.095	1.080	1.050	1.040	1.160	1.275	1.110	1.445	[3] 1.120	.990	1.350
41	.510	.370	.365	.675	.435	.430	.280	.270	.265	.840	.800
42	1.510	1.805	1.690	1.560	1.480	1.205	1.450	.970	[3] 1.145	3.120	1.780
43	1.050	1.345	1.455	2.200	1.580	1.705	1.760	1.870	.785	1.070	.760
44	.300	.595	.335	.475	.340	.320	.330	.385	.155	.250	.940
45	1.005	1.170	1.180	1.070	.930	.815	1.420	1.160	1.140	1.720	1.010
46	.535	.905	.830	.645	.695	.765	.820	.790	.355	1.730	1.220
47	.350	.250	.325	.255	.300	.395	.330	.255	.400	.310	.450

[1] See Table 4 for exact ages of specimens.
[2] See Table 3 for identification of specimens.
[3] C specimens exposed to soil on outside only. See Table 6 for ages of these specimens.

TABLE 12.—*Weighted maximum rates of pitting of 2-year-old specimens* [1]

[In mils per year]

Soil No.	1½-inch specimens				3-inch specimens				6-inch specimens		
	a [2]	b	e	y	B	K	M	Y	C	L	Z
1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	13.1	37.2	43.9
2	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	[2] 3.9	16.3	19.0
3	31.0	23.0	22.0	28.0	25.4	25.9	23.7	26.9	[3] 4.8	31.8	30.0
4	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	7.6	13.9
5	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	[3] 17.7	2.6	2.6
6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	[3] 4.5	2.6	2.6
7	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
8	39.0	27.0	34.0	27.0	25.6	38.7	41.1	50.7	4.4	49.1	58.2
9	44.0	30.0	24.0	22.0	31.1	30.6	26.7	32.0	4.9	17.0	18.2
10	19.0	11.0	14.0	12.0	17.9	16.0	15.6	17.1	11.4	3.8	3.8
11	36.0	28.0	24.0	21.0	27.2	23.5	27.6	27.0	21.1	3.7	23.0
12	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	[3] 4.5	2.6	2.6
13	18.5	16.5	25.0	19.0	23.1	31.6	27.7	32.5	13.2	2.6	31.0
14	30.0	33.0	23.0	24.0	26.3	27.2	32.1	51.8	4.4	10.4	18.6
15	16.0	17.0	20.0	18.0	19.5	17.2	20.5	19.9	[3] 6.1	24.5	33.2
16	22.0	18.0	19.0	21.0	20.7	17.9	19.4	22.5	[3] 13.8	20.9	19.5
17	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1	41.7	23.8
18	23.0	17.0	16.0	12.0	17.0	20.2	12.2	21.2	4.2	42.6	4.2
19	30.0	21.0	23.0	21.0	23.4	21.7	25.7	29.9	12.7	23.2	4.5
20	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
21	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4
22	26.0	20.0	25.0	25.0	21.5	21.9	27.8	26.5	2.9	31.8	26.0
23	27.0	25.0	25.0	26.0	23.4	40.8	26.6	32.1	16.4	28.4	82.0
24	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
25	23.5	19.0	18.0	25.0	20.4	24.0	26.9	24.5	11.4	4.9	36.7
26	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8	17.5	4.8
27	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	[3] 10.8	2.6	2.6
28	12.5	15.6	20.0	16.0	16.5	23.3	20.0	21.3	18.0	16.9	28.8
29	25.0	19.0	28.0	29.0	20.8	30.2	19.9	16.7	[3] 15.7	19.3	18.5
30	21.0	9.0	11.0	11.0	9.2	14.4	13.1	13.7	4.5	4.5	4.5
31	15.0	16.0	33.0	19.0	17.5	22.0	22.9	24.6	[3] 8.6	2.5	11.7
32	43.0	27.0	22.0	23.0	30.3	22.3	27.1	27.9	5.3	27.4	35.9
33	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
34	14.0	15.0	14.0	13.0	15.2	17.8	16.3	20.5	3.6	3.6	24.3
35	2.6	6.5	2.6	2.6	2.6	2.6	8.5	9.3	[3] 4.5	2.6	20.2
36	11.0	19.0	17.0	19.0	17.7	22.9	20.4	18.1	[3] 14.4	19.0	20.4
37	19.0	17.0	24.0	24.0	20.5	21.3	25.0	40.8	[3] 4.8	2.5	2.5
38	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
39	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
40	23.0	15.0	19.0	16.0	14.4	19.1	15.7	20.5	[3] 15.5	12.0	17.6
41	13.0	27.0	22.0	27.0	29.8	19.4	27.9	20.9	7.1	4.9	22.3
42	27.0	29.0	30.0	25.0	26.5	28.9	34.2	27.5	[3] 21.5	46.7	46.2
43	14.0	28.0	18.0	22.0	32.0	33.1	50.6	26.6	20.3	3.9	3.9
44	34.0	34.0	26.0	29.0	23.9	34.4	29.1	34.6	4.6	4.6	26.8
45	7.3	17.0	13.0	11.4	4.2	6.6	19.9	20.8	4.2	39.2	23.5
46	39.0	37.0	38.0	37.0	30.6	25.0	37.7	51.4	5.1	18.8	20.2
47	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4

[1] See Table 4 for exact age of specimens.
[2] See Table 3 for identification of specimens.
[3] See Table 6 for ages of these de Lavaud specimens.

TABLE 13.—*Rates of loss of weight of 4-year-old specimens* [1]

[In ounces per square foot per year]

Soil No.	1½-inch specimens				3-inch specimens				6-inch specimens		
	a [2]	b	e	y	B	K	M	Y	C	L	Z
1	0.925	1.125	1.075	1.080	1.190	1.170	1.200	0.960	0.965	1.070	1.040
2	.710	.735	.750	.745	.860	.680	.770	.625	(3)	.640	1.310
3	.705	.775	.805	.850	.885	.815	.875	.895	(3)	.840	1.220
4	.915	.875	.880	.865	.920	.915	.855	.925	.905	1.060	.970
5	.350	.520	.600	.595	.540	.510	.525	.500	(3)	.420	.420
6	.175	.170	.210	.190	.135	.175	.130	.130	(2)	.070	.090
7	.700	.700	690	680	765	.835	.725	.725	.765	.840	--------
8	.505	.500	.535	.515	.445	.450	.495	.485	.495	.710	1.420
9	.495	.665	.665	.580	.630	.350	.535	.495	410	.700	.630
10	.340	.520	.420	.290	.415	.305	.660	.390	.435	.600	.480
11	.230	.280	.265	.300	.245	.235	.255	.240	.165	.090	.350
12	.345	.470	.390	.475	.355	.370	.310	.390	(3)	.280	.480
13	.640	1.660	.930	.785	.710	.555	1.050	1.110	.685	1.430	2.550
14	.520	.650	.690	.645	.600	.590	.570	.515	.305	.500	.700
15	.895	.740	.745	.790	.770	.830	.955	.760	(3)	.660	1.000
16	.710	.955	.870	.760	.710	.745	.815	.855	(3)	.390	.780
17	.860	.840	.895	.850	.970	.900	.945	.950	.940	.850	1.080
18	.325	.495	.505	.435	.350	.305	.325	.445	.165	.290	.250
19	.540	.405	.600	.605	.625	.620	.495	.555	.375	.470	.230
20	.605	.660	.500	.645	.620	.605	.595	.565	.515	.660	.680
21	.630	.645	.730	.605	.695	.730	.710	.625	.620	.790	.800
22	.870	1.050	.940	1.000	.980	1.000	.955	.940	.675	1.170	1.060
23	2.620	3.105	3.205	2.465	2.800	2.790	2.805	2.260	2.890	5.250	8.240
24	.110	.160	.130	.085	.085	.090	.105	.080	.055	.060	.120
25	.190	.370	.290	.300	.195	.230	.255	.280	.305	.420	.480
26	.455	.640	.530	.530	.555	.550	.615	.540	.565	.780	1.120
27	.800	.775	.965	.885	.870	.865	.810	.665	(3)	.660	.800
28	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
29	1.785	1.900	1.800	1.670	1.775	1.790	1.710	1.940	(3)	1.910	2.190
30	.300	.325	.340	.315	.390	.355	.385	.340	.450	.460	.550
31	.500	.420	.525	.555	.510	.620	.510	.565	(3)	.360	.540
32	.310	.465	.435	.390	.380	.350	.360	.380	.425	.530	.530
33	.940	.890	.920	.935	1.005	.930	.975	1.020	.920	.880	.880
34	.400	.440	.440	.470	.465	.465	.455	.445	.435	.480	.420
35	.415	.490	.435	.340	.500	.475	.460	.435	(3)	.540	.870
36	.350	.500	.540	.515	.410	.420	.405	.365	(3)	.310	.330
37	1.035	1.075	1.080	1.045	1.100	1.090	1.115	1.215	(3)	1.000	1.010
38	.110	.185	.180	.145	.120	.105	.135	.135	.075	.070	.120
39	.780	.810	.730	.670	.795	.760	.790	.730	.710	.830	.660
40	.975	1.055	.960	.920	1.025	1.050	1.130	1.025	(3)	1.350	1.500
41	.685	.885	.750	.755	.665	.730	.610	.625	.460	.630	.670
42	1.095	1.800	1.395	1.440	1.190	.830	1.255	.840	(3)	1.850	2.720
43	.900	1.785	1.125	1.195	1.170	1.285	1.695	1.580	.775	1.170	.700
44	.380	.505	.560	.505	.395	.380	.345	.350	.275	.400	.250
45	.965	.790	.760	.880	.765	.855	.730	.865	2.065	1.200	1.030
46	.680	.790	.715	.640	.595	.635	.660	.795	.555	1.000	1.350
47	.315	.460	.540	.310	.315	.325	.385	.500	.460	.530	.650

[1] See Table 4 for exact age of specimens.
[2] See Table 3 for identification of specimens.
[3] C specimens not removed in 1928.
[4] No specimens.

TABLE 14.—*Weighted maximum rates of pitting of 4-year-old specimens* [1]

[In mils per year]

Soil No.	1½-inch specimens				3-inch specimens				6-inch specimens		
	a [2]	b	e	y	B	K	M	Y	C	L	Z
1	13.0	9.0	11.0	11.0	11.1	10.1	12.3	12.6	14.2	16.8	22.1
2	14.0	10.0	9.0	12.0	10.7	10.8	10.5	11.0	(3)	7.3	10.6
3	18.0	16.0	19.0	16.0	14.9	12.3	16.9	18.8	(3)	11.2	19.7
4	8.0	7.0	7.0	6.0	5.7	7.3	7.1	9.8	7.3	8.6	13.9
5	7.0	5.0	9.0	8.0	6.6	7.2	6.7	7.4	(3)	6.9	6.2
6	4.2	2.4	3.7	2.4	3.0	3.3	2.4	2.4	(3)	2.4	2.4
7	8.0	2.8	6.4	4.6	4.9	8.3	5.4	4.1	6.2	2.9	9.6
8	12.0	9.0	11.0	10.0	10.0	13.1	11.8	14.0	2.6	11.8	15.3
9	13.0	14.0	15 0	15.0	14.9	15.0	18.8	18.2	8.3	9.5	11.1
10	2.5	8.0	2.5	5.0	3.9	2.5	3.8	2.5	2.5	2.5	2.5
11	16.0	17.0	13.0	15.0	15.6	13.0	18.6	14.4	4.9	5.4	11.0
12	11.0	10.0	11.0	10.0	10.4	9.5	10.4	12.8	(3)	4.0	11.1
13	6.0	13.0	11.0	9.0	8.6	12.6	12.9	12.2	12.2	20.6	24.6
14	14.0	16.0	14.0	14.0	15.6	13.9	16.1	18.6	2.6	2.6	7.8
15	11.0	7.0	9.0	7.0	7.2	8.1	10.2	11.2	(3)	11.0	8.0
16	11.0	11.0	13.0	12.0	11.3	11.3	15.5	15.0	(3)	10.1	12.6
17	6.0	4.3	6.0	5.0	5.8	5.8	7.2	5.0	3.3	5.5	3.4
18	11.0	11.0	13.0	9.0	8.9	13.0	10.9	9.4	9.0	20.3	19.7
19	10.0	12.0	14.0	10.0	9.8	12.4	15.8	13.7	8.0	16.7	8.1
20	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
21	15.0	10.0	12.0	16.0	14.7	9.5	11.8	10.1	9.2	11.7	11.6
22	12.0	12.0	14.0	12.0	14.6	15.5	13.5	13.7	11.5	23.9	23.9
23	22.0	24.0	27.0	19.0	22.3	29.1	24.5	21.2	30.4	42.5	67.8
24	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
25	9.0	8.0	7.0	8.0	8.1	7.4	9.6	9.3	8.1	4.0	11.5
26	11.0	13.0	12.0	13.0	10.1	12.0	15.9	12.8	8.7	8.8	12.2
27	5.0	5.0	8.0	8.0	7.8	8.9	6.6	8.6	(3)	11.0	12.4
28	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
29	16.0	12.0	15.0	17.0	16.0	18.7	14.1	20.6	(3)	10.0	10.7
30	2.7	2.7	2.7	2.7	4.5	4.1	3.4	4.9	2.7	2.7	2.7
31	6.0	6.0	6.0	6.0	7.2	11.0	6.4	8.4	(3)	7.9	8.3
32	12.0	11.0	8.0	7.0	10.5	9.1	9.6	10.6	10.2	8.6	9.1
33	10.0	2.7	4.8	7.0	8.2	7.8	10.0	10.1	11.3	7.7	5.3
34	5.7	5.2	2.5	4.5	3.8	4.2	3.5	5.5	6.7	4.0	4.7
35	3.9	7.0	2.4	2.4	4.7	4.0	5.1	5.0	(3)	4.2	7.6
36	9.0	9.0	7.0	8.0	9.0	11.6	10.6	10.0	(3)	9.7	13.8
37	11.0	10.0	15.0	16.0	13.9	14.0	13.1	22.3	(3)	2.5	2.5
38	2.5	7.0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
39	11.0	6.1	9.0	6.0	3.3	4.2	7.2	10.5	8.1	8.5	7.2
40	15.0	13.0	10.0	9.0	9.9	11.1	10.2	10.3	(3)	9.6	15.5
41	8.0	9.0	10.0	11.0	10.2	9.0	10.3	8.6	2.5	6.3	4.5
42	16.0	18.0	18.0	19.0	19.2	19.8	19.3	17.7	(3)	38.5	26.7
43	10.0	11.0	9.0	11.0	20.6	17.9	18.5	13.6	8.9	3.8	33.3
44	21.0	12.0	15.0	15.0	12.3	11.5	12.1	13.4	11.2	15.4	15.0
45	9.0	7.0	6.0	6.0	7.5	8.7	7.7	12.4	11.5	14.6	10.6
46	20.0	16.0	19.0	20.0	15.7	13.4	25.3	26.7	2.5	11.7	11.6
47	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	7.0	2.5	3.5

[1] See Table 4 for exact age of specimens.
[2] See Table 3 for identification of specimens.
[3] C specimens not removed in 1928.
[4] No specimens.

TABLE 15.—*Rates of loss of weight of 6-year-old specimens* [1]

[In ounces per square foot per year]

Soil No.	1½-inch specimens				3-inch specimens				6-inch specimens		
	a [2]	b	e	y	B	K	M	Y	C	L	Z
1	0.810	1.000	1.010	0.855	0.985	0.975	0.930	0.845	0.855	0.950	1.160
2	.640	.705	.655	.575	.695	.680	.710	.715	[3] .335	.840	.940
3	.525	.695	.620	.580	.625	.585	.605	.695	[3] .221	.790	.600
4	.735	.715	.725	.755	.770	.755	.715	.800	.730	.710	.760
5	.790	.815	.735	.775	.805	.640	.785	.720	[3] 1.575	.680	.880
6	.105	.100	.135	.115	.100	.130	.155	.120	[3] .232	.070	.100
7	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
8	.540	.545	.500	.450	.505	.530	.575	.570	.585	.860	.980
9	.400	.420	.445	.425	.480	.490	.485	.470	.525	.460	.680
10	.560	.560	.570	.560	.560	.600	.560	.565	.500	.390	.520
11	.175	.235	.235	.210	.220	.230	.205	.260	.100	.160	.220
12	.520	.365	.550	.495	.540	.445	.440	.460	[3] .395	.350	.370
13	1.110	1.405	1.130	1.253	.935	1.037	1.330	1.453	1.120	2.163	2.163
14	.420	.635	.620	.530	.590	.550	.540	.505	.370	.740	.860
15	1.045	1.030	.950	.915	1.045	.955	.870	1.085	[3] .889	1.010	1.430
16	.880	.820	.735	.725	.930	.750	.840	.830	[3] .621	1.050	.920
17	.885	1.010	.955	.890	1.040	1.040	1.035	1.060	.830	1.140	.970
18	.390	.700	.560	.455	.500	.475	.545	.445	.395	.570	.880
19	.385	.520	.390	.410	.490	.405	.360	.370	.375	.400	.270
20	.445	.490	.445	.375	.420	.410	.515	.410	.575	.660	.710
21	.700	.735	.820	.775	.790	.840	.750	.765	.730	.830	1.040
22	.950	.975	.830	.975	.825	.830	.715	.645	.675	.710	.920
23	2.220	2.545	1.980	2.545	2.090	2.355	2.245	2.835	2.885	5.830	5.670
24	.145	.200	.220	.130	.185	.185	.180	.160	.140	.070	.190
25	.290	.290	.325	.330	.310	.290	.300	.260	.225	.310	.380
26	.265	.380	.305	.270	.225	.210	.245	.245	.335	.480	.340
27	.505	.635	.690	.505	.525	.515	.505	.530	[3] 1.177	.550	.760
28	1.855	1.667	1.711	1.911	1.602	1.921	1.894	1.917	.767	1.684	--------
29	1.670	1.485	1.580	1.645	1.545	1.610	1.485	1.560	[3] 1.393	1.810	1.800
30	.325	.400	.455	.350	.435	.470	.445	.410	.520	.360	.630
31	.255	.295	.305	.320	.245	.315	.380	.390	[3] .679	.310	.290
32	.300	.355	.395	.305	.390	.380	.445	.430	.400	.440	.530
33	.815	.795	.805	.975	.755	.975	.840	.525	.585	.250	.520
34	.500	.450	.450	.450	.455	.510	.465	.480	.460	.480	.460
35	.185	.190	.255	.165	.145	.110	.165	.220	[3] .220	.150	.260
36	.220	.285	.290	.295	.230	.310	.235	.265	[3] .071	.240	.310
37	.695	.760	.600	.765	.635	.690	.685	.625	[3] 1.011	.830	.940
38	.145	.135	.195	.135	.175	.215	.200	.200	.175	.120	.190
39	.390	.525	.430	.440	.530	.505	.520	.530	.585	.720	.810
40	.895	.920	.830	.880	1.015	1.105	1.040	.940	[3] .977	1.560	1.520
41	.760	.780	.750	.690	.540	.595	.685	.640	.355	.460	.630
42	1.180	1.330	1.290	1.225	.955	1.155	1.035	1.100	[3] .957	2.450	1.730
43	.935	1.290	1.570	1.205	1.160	1.005	1.245	1.350	.925	1.050	1.160
44	.395	.385	.395	.435	.370	.385	.360	.345	.175	.200	.390
45	.505	.545	.560	.540	.570	.535	.550	.520	.400	.420	.460
46	.475	.465	.510	.490	.465	.490	.425	.525	.365	.380	.600
47	.195	.240	.255	.190	.305	.265	.370	.240	.440	.440	.480

[1] See Table 4 for exact age of specimens.
[2] See Table 3 for identification of specimens.
[3] C specimens exposed to soil on outside only. See Table 6 for ages of these de Lavaud specimens.
[4] No specimens.

TABLE 16.—*Weighted maximum rates of pitting of 6-year-old specimens* [1]

[In mils per year]

Soil No.	1½-inch specimens				3-inch specimens				6-inch specimens		
	a [2]	b	e	y	B	K	M	Y	C	L	Z
1	10.0	8.0	7.0	10.0	13.6	9.4	9.0	8.7	11.4	12.5	17.8
2	7.0	7.0	8.0	7.0	6.1	6.8	8.6	9.7	[3] 6.0	8.9	7.4
3	11.0	10.0	11.0	12.0	10.5	12.4	9.6	10.1	[3] 1.7	15.3	22.3
4	13.0	8.0	7.0	8.0	7.7	8.9	7.4	14.2	8.1	6.6	6.9
5	7.0	6.0	8.0	5.0	6.5	9.9	9.3	6.0	[3] 8.9	8.8	11.9
6	4.0	1.6	1.6	1.6	2.1	2.3	3.0	2.9	[3] 1.6	1.6	1.6
7	([4])	([4])	([4])	([4])	([4])	([4])	([4])	([4])	([4])	([4])	([4])
8	11.0	9.0	9.0	9.0	11.1	12.0	9.6	12.0	10.3	13.3	11.6
9	3.3	6.0	5.0	5.0	5.6	7.5	6.4	5.6	6.4	1.8	6.3
10	7.0	6.0	6.0	7.0	7.5	6.1	6.4	8.2	5.8	5.3	7.5
11	11.0	12.0	10.0	12.0	10.2	9.4	13.3	11.4	3.4	2.6	7.6
12	9.0	10.0	11.0	9.0	10.4	8.7	9.8	9.6	[3] 1.6	3.5	9.3
13	8.0	16.0	11.0	14.0	9.6	13.4	12.0	8.4	2.2	30.0	30.0
14	15.0	14.0	14.0	14.0	16.6	13.4	15.7	25.2	3.2	6.3	6.3
15	11.0	10.0	9.0	9.0	10.1	10.7	9.9	9.4	[3] 6.7	13.5	15.8
16	15.0	14.0	16.0	20.0	13.3	9.9	15.7	14.6	[3] 12.9	21.4	10.0
17	5.0	4.0	4.0	5.0	5.2	5.5	5.0	5.6	6.8	10.5	7.7
18	12.0	12.0	12.0	12.0	10.3	10.8	10.3	13.1	12.2	15.2	15.2
19	8.0	9.0	8.0	8.0	9.7	10.2	9.5	8.6	6.4	16.6	15.4
20	2.9	5.0	3.9	6.0	4.5	3.8	5.8	4.1	10.3	9.0	6.3
21	12.0	9.0	10.0	10.0	9.9	9.0	10.1	9.3	8.5	14.1	8.6
22	12.0	10.0	10.0	10.0	10.5	10.9	10.9	10.5	11.0	24.2	24.2
23	27.0	20.0	15.0	16.0	14.4	17.0	15.8	20.3	23.3	31.7	41.8
24	1.6	1.8	1.6	2.6	3.1	2.8	2.3	3.6	1.6	1.6	1.6
25	8.0	7.0	7.0	6.0	7.8	7.9	9.5	8.6	6.1	7.6	10.7
26	13.0	12.0	12.0	12.0	12.6	11.7	14.0	13.6	4.9	7.5	8.7
27	3.5	5.0	5.0	7.0	4.6	8.3	5.3	7.3	[3] 15.4	9.4	10.8
28	9.0	10.6	10.7	9.9	9.8	12.7	9.9	12.7	7.0	30.0	--------
29	17.0	13.0	15.0	14.0	9.0	13.1	13.1	12.8	[3] 8.2	12.4	20.8
30	2.7	1.8	4.0	2.7	4.6	4.7	4.7	5.1	5.5	2.4	4.8
31	5.0	4.0	5.0	5.0	3.2	8.5	5.9	7.3	[3] 11.0	5.1	12.4
32	6.0	5.0	5.0	6.0	6.4	6.4	6.3	6.6	5.6	5.0	8.2
33	8.0	6.0	1.7	9.0	6.1	9.0	5.7	4.1	7.1	6.4	10.4
34	8.0	5.0	2.6	5.0	5.1	5.2	4.6	7.1	7.0	3.6	4.7
35	1.6	1.6	6.6	1.6	3.3	1.6	2.9	3.2	[3] 1.6	1.6	2.5
36	8.0	8.0	6.0	7.0	6.5	8.5	7.3	6.7	[3] 6.0	11.1	21.8
37	8.0	8.0	6.0	12.0	6.0	7.6	8.5	9.6	[3] 1.7	5.2	8.5
38	6.0	4.0	3.0	3.0	5.5	2.6	3.8	5.1	1.6	1.6	2.2
39	5.0	7.0	6.0	8.0	7.3	6.1	7.2	8.1	6.0	5.5	9.1
40	10.0	12.0	12.0	10.0	10.0	13.2	11.5	13.4	[3] 15.3	13.1	13.8
41	9.0	8.0	8.0	10.0	9.3	8.0	11.0	8.5	5.1	4.5	5.5
42	13.0	16.0	14.0	12.0	12.1	13.9	15.1	13.4	[3] 15.1	21.9	36.6
43	14.0	13.0	11.0	12.0	14.9	18.0	16.5	8.4	6.8	4.5	11.9
44	12.0	9.0	9.0	12.0	10.3	9.1	10.7	13.4	8.2	9.1	10.5
45	8.0	7.0	7.0	6.0	7.7	5.9	7.9	8.6	5.8	8.7	2.8
46	11.0	11.0	11.0	9.0	10.9	7.5	14.4	15.9	3.5	4.4	9.3
47	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	2.6	1.6	1.6

[1] See Table 4 for exact age of specimens.
[2] See Table 3 for identification of specimens.
[3] See Table 6 for ages of these de Lavaud specimens.
[4] No specimens.

TABLE 17.—*Rates of loss of weight of 8-year-old specimens* [1]

[In ounces per square foot per year]

Soil No.	1½-inch specimens				3-inch specimens				6-inch specimens		
	a [2]	b	e	y	B	K	M	Y	C	L	Z
1	0.652	0.890	0.887	0.853	0.865	0.732	0.959	0.863	0.777	0.963	0.942
2	.482	.464	.464	.455	.472	.390	.486	.284	(3)	.307	.425
3	.463	.546	.532	.494	.466	.514	.562	.477	(3)	.486	.601
4	.647	.674	.677	.662	.694	.693	.683	.729	.709	.613	.623
5	.730	.858	.625	.649	.649	.703	.726	.670	(3)	.822	.811
6	.097	.109	.125	.099	.113	.098	.113	.116	(3)	.090	.118
7	.516	.554	.571	.484	.541	.512	.542	.548	.613	.570	-------
8	.431	.432	.409	.417	.531	.457	.542	.551	.730	.649	.963
9	.417	.444	.414	.388	.451	.439	.412	.399	.516	.426	.535
10	.549	.547	.566	.570	.595	.577	.580	.583	.536	.496	.509
11	.132	.279	.243	.188	.196	.174	.203	.176	.191	.170	.162
12	.121	.171	.112	.126	.115	.103	.107	.138	(3)	.074	.231
13	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
14	.258	.482	.320	.285	.248	.218	.433	.299	.349	.491	.265
15	.628	.591	.685	.686	.733	.712	.641	.631	(3)	.605	.499
16	.644	.633	.585	.566	.576	.583	.566	.642	(3)	.526	.673
17	.835	.917	.833	.853	.964	.901	.962	.962	.936	.858	.771
18	.230	.424	.374	.255	.284	.248	.295	.271	.267	.418	.357
19	.326	.400	.358	.371	.313	.320	.401	.327	.337	.396	.374
20	.356	.440	.356	.326	.414	.382	.461	.371	.456	.475	.483
21	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)
22	.757	.817	.970	.791	.840	.817	1.024	.987	.838	.694	.682
23	2.283	2.574	1.952	2.343	2.340	2.649	2.413	3.000	2.647	4.223	5.737
24	.118	.122	.131	.107	.123	.112	.124	.100	.088	.049	.086
25	.232	.296	.261	.262	.250	.233	.238	.226	.275	.213	.402
26	.167	.268	.256	.203	.199	.192	.205	.222	.231	.241	2.96
27	.572	.535	.530	.676	.545	.616	.487	.548	(3)	.596	.454
28	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
29	1.800	1.633	1.726	1.760	1.368	2.065	1.395	2.008	(3)	1.617	1.821
30	.498	.571	.507	.517	.577	.487	.532	.467	.590	.573	.674
31	.232	.277	.298	.349	.267	.278	.287	.283	(3)	.225	.204
32	.255	.367	.351	.293	.327	.333	.302	.353	.336	.420	.484
33	1.098	1.204	1.209	1.148	1.116	1.156	1.167	1.025	1.184	1.220	.997
34	.370	.418	.432	.438	.442	.397	.418	.401	.582	.459	.535
35	.296	.260	.215	.209	.267	.261	.258	.286	(3)	.258	.237
36	.250	.369	.316	.293	.230	.255	.263	.257	(3)	.158	.102
37	.725	.767	.652	.646	.788	.766	.723	.813	(3)	.766	.853
38	.246	.244	.273	.231	.248	.244	.272	.263	.169	.157	.165
39	.520	.571	.583	.454	.616	.609	.620	.639	.753	.581	.762
40	.802	.817	.813	.691	.873	.893	1.033	.963	(3)	1.106	1.202
41	.605	.674	.631	.593	.533	.532	.583	.548	.320	.456	.477
42	.741	.962	1.029	1.161	.794	.856	.841	.698	(3)	1.409	1.397
43	1.137	2.041	1.290	1.426	1.265	1.359	1.123	1.806	1.317	.901	.943
44	.223	.305	.385	.267	.250	.278	.257	.281	.213	.191	.329
45	.449	.725	.541	.492	.533	.501	.494	.551	.513	.574	.968
46	.706	.785	.659	.717	.637	.746	.730	.838	.708	.663	.826
47	.269	.259	.213	.224	.266	.258	.252	.204	.383	.229	.370
Average	.542	.630	.576	.569	.566	.583	.584	.609	.606	.623	.706

[1] See Table 8 for exact age of specimens.
[2] See Table 4 for identification of specimens.
[3] Late.
[4] No specimens.

TABLE 18.—*Weighted maximum rates of pitting of 8-year-old specimens* [1]

]In mils per year]

Soil No.	1½-inch specimens				3-inch specimens				6-inch specimens		
	a [2]	b	e	y	B	K	M	Y	C	L	Z
1	5.7	9.6	6.8	6.6	6.8	6.7	7.5	5.4	7.0	27.3	24.9
2	6.1	4.6	5.2	6.3	5.4	4.9	5.7	5.4	--------	11.8	8.2
3	7.7	7.3	8.8	9.2	7.7	8.1	8.3	7.1	--------	14.4	15.3
4	7.5	4.5	5.6	5.5	4.5	6.4	5.0	8.4	5.4	4.6	9.6
5	4.5	6.7	5.4	4.7	4.3	5.8	6.5	5.0	--------	5.7	8.3
6	2.2	2.5	1.4	2.1	1.2	1.9	1.7	1.8	--------	1.2	1.2
7	3.0	4.4	3.3	3.3	4.5	5.2	4.8	2.8	5.3	2.9	3.1
8	7.9	6.8	8.5	6.7	7.8	10.7	9.0	10.9	13.1	9.2	9.2
9	4.7	6.0	4.9	4.2	5.5	5.6	5.6	4.9	6.1	3.0	5.1
10	6.2	4.0	4.8	4.7	5.7	6.0	4.8	5.0	4.1	3.8	5.8
11	8.2	8.2	7.2	5.9	8.2	7.0	8.9	7.5	2.3	3.7	9.9
12	2.2	1.7	2.2	1.2	2.4	2.1	1.7	3.0	--------	1.2	1.2
13	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
14	10.6	11.2	13.9	13.3	11.2	9.4	16.7	20.0	6.5	5.9	--------
15	7.4	8.3	7.7	4.8	6.9	5.6	5.3	6.3	--------	8.8	8.9
16	7.4	10.6	8.5	8.4	8.6	10.1	8.3	9.3	--------	14.4	16.1
17	4.1	4.7	4.7	3.8	4.7	4.8	4.4	4.6	5.1	2.8	4.3
18	7.2	4.8	5.3	5.5	9.1	9.5	8.2	8.6	1.3	1.3	1.3
19	5.7	5.3	6.0	5.2	6.5	7.5	6.9	8.0	6.6	18.0	20.8
20	5.6	4.6	4.7	4.5	4.0	4.6	5.4	6.6	6.5	5.8	7.8
21	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(3)
22	7.0	7.3	8.3	6.9	7.4	7.4	8.3	8.9	11.3	14.7	14.7
23	2.4	18.2	18.2	16.0	19.6	19.7	16.8	27.2	20.5	27.1	41.8
24	2.7	2.3	1.1	2.3	2.3	2.4	1.9	3.3	1.3	1.3	1.3
25	5.6	4.6	4.7	4.5	6.8	4.9	5.9	5.0	1.3	7.9	11.7
26	5.1	6.1	5.0	5.8	5.5	5.1	6.2	7.2	3.8	7.0	9.7
27	3.9	4.3	3.3	4.5	4.8	7.5	5.6	4.7	--------	14.9	12.5
28	Late.	Late.	Late.	Late.	Late.	Late.	Late.	Late.	Late.	Late.	Late.
29	13.1	8.5	11.3	11.4	10.2	11.1	12.5	22.3	--------	22.3	26.4
30	5.6	4.5	4.0	4.2	7.3	4.1	5.5	3.8	8.7	5.1	8.7
31	4.6	5.6	4.6	4.8	4.7	5.3	3.9	4.2	--------	4.0	7.4
32	4.2	5.4	5.4	5.1	4.8	6.0	5.5	5.7	6.5	17.3	20.0
33	17.0	7.9	8.7	12.7	12.7	14.9	12.4	12.0	15.0	20.4	16.8
34	5.3	5.8	5.7	6.5	5.3	7.7	4.7	8.0	5.8	3.9	7.0
35	4.0	3.0	2.9	1.2	2.1	3.0	3.1	6.7	--------	6.1	1.2
36	6.1	6.7	4.4	4.7	5.8	6.5	6.1	5.8	--------	15.8	20.2
37	7.2	6.1	6.5	6.8	7.6	7.9	7.5	12.1	--------	4.6	5.9
38	6.6	3.5	2.5	3.1	3.9	2.9	3.1	2.9	1.3	1.3	1.3
39	6.0	6.2	5.8	5.2	7.3	8.3	6.3	8.6	6.8	4.1	6.9
40	10.9	12.7	8.0	9.3	11.1	14.9	14.4	13.3	--------	12.7	13.6
41	7.7	8.2	6.9	7.5	7.2	7.1	7.6	6.7	4.4	4.1	6.0
42	9.5	11.1	14.1	13.8	10.0	10.7	10.8	10.8	--------	13.6	20.0
43	10.6	12.8	9.6	8.7	13.8	15.8	9.2	9.7	10.3	5.6	1.3
44	9.4	6.5	8.2	6.5	7.2	6.1	7.7	10.4	4.3	4.5	6.5
45	6.6	6.0	7.9	5.9	6.8	7.5	7.3	8.4	7.1	11.6	8.3
46	7.5	10.0	13.6	14.8	8.5	7.9	15.0	13.0	5.4	6.3	9.2
47	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	2.9	1.3	1.3
Average	6.8	6.6	6.5	6.3	6.8	7.2	7.2	8.0	6.4	8.7	10.2

[1] See Table 8 for exact age of specimens. [2] See Table 4 for identification of specimens. [3] No specimens.

TABLE 19.—*Average rates of loss of weight of all specimens of one kind removed from 1924 to 1930*

[In ounces per square foot per year]

Soil No.	1½-inch specimens				3-inch specimens				6-inch specimens		
	a	b	e	y	B	K	M	Y	C	L	Z
1	0.867	1.066	1.030	0.978	1.061	1.068	1.095	0.959	0.850	1.018	1.238
2	.683	.711	.682	.736	.737	.699	.753	.625	.382	.637	.944
3	.606	.731	.705	.732	.690	.723	.774	.732	.400	.834	.790
4	.838	.781	.837	.829	.841	.844	.816	.893	.815	.816	.863
5	.610	.666	.655	.680	.625	.592	.628	.596	1.375	.578	.663
6	.113	.115	.135	.128	.102	.119	.126	.111	.176	.070	.097
7	.559	.640	.622	.581	.630	.619	.637	.623	.661	.837	1.400
8	.529	.514	.522	.513	.518	.494	.578	.560	.626	.715	1.298
9	.463	.676	.557	.568	.526	.472	.510	.472	.538	.549	.656
10	.616	.639	.621	.606	.607	.567	.704	.604	.556	.519	.587
11	.184	.285	.256	.274	.231	.233	.247	.235	.133	.150	.225
12	.279	.284	.313	.315	.272	.257	.254	.279	.214	.186	.325
13	1.012	1.538	1.320	1.591	1.220	1.309	1.365	1.558	1.072	1.858	2.178
14	.358	.523	.454	.485	.438	.443	.482	.430	.316	.463	.559
15	.954	.853	.884	.870	.923	.913	.963	.965	1.022	.736	1.050
16	.797	.918	.885	.779	.825	.806	.890	.847	.693	.846	.863
17	.950	.994	.953	.948	1.078	1.021	1.073	1.047	.965	.999	1.390
18	.325	.553	.453	.404	.368	.324	.391	.390	.259	.426	.496
19	.451	.520	.484	.498	.471	.477	.490	.500	.357	.441	.341
20	.589	.619	.611	.596	.593	.612	.634	.574	.575	.674	.798
21	.900	.930	.997	.942	.995	.975	.952	.943	.813	1.097	1.080
22	.849	.940	.977	.966	.870	.884	.878	.900	.703	.731	1.033
23	2.482	3.040	2.780	2.853	2.564	2.793	2.739	3.040	2.845	4.756	7.537
24	.131	.169	.170	.135	.137	.147	.156	.122	.104	.052	.146
25	.285	.384	.324	.330	.269	.277	.297	.291	.320	.381	.410
26	.413	.544	.473	.441	.442	.422	.482	.469	.474	.623	.711
27	.520	.565	.609	.578	.561	.570	.525	.497	1.141	.506	.571
28	1.947	1.663	1.950	1.855	1.736	1.933	1.832	2.036	1.763	2.277	2.850
29	1.821	1.679	1.761	1.829	1.618	1.907	1.670	1.911	2.121	1.759	2.023
30	.483	.533	.584	.497	.545	.569	.584	.533	.650	.616	.758
31	.332	.404	.436	.495	.355	.458	.459	.441	.884	.266	.403
32	.284	.424	.393	.346	.355	.371	.382	.376	.420	.510	.426
33	.818	.810	.833	.876	.828	.874	.843	.730	.777	.640	.722
34	.554	.558	.543	.534	.589	.589	.598	.546	.597	.597	.589
35	.329	.347	.320	.271	.330	.329	.366	.356	.367	.312	.567
36	.351	.442	.456	.419	.321	.351	.347	.340	.215	.279	.320
37	.902	.933	.880	.908	.933	.936	.947	.967	1.483	.824	.938
38	.154	.175	.206	.170	.167	.187	.205	.199	.113	.097	.141
39	.611	.690	.646	.627	.696	.716	.695	.700	.728	.763	.840
40	.942	.968	.913	.885	1.018	1.081	1.078	1.093	1.048	1.251	1.393
41	.640	.677	.624	.678	.543	.572	.539	.521	.350	.596	.644
42	1.131	1.474	1.351	1.346	1.105	1.011	1.145	.902	1.051	2.207	1.907
43	1.005	1.615	1.360	1.506	1.294	1.338	1.456	1.651	.950	1.048	.891
44	.324	.447	.419	.420	.339	.341	.323	.340	.204	.260	.477
45	.731	.807	.760	.745	.699	.676	.798	.774	1.029	.978	.867
46	.599	.736	.678	.623	.598	.659	.659	.737	.496	.943	.999
47	.282	.302	.333	.245	.296	.311	.334	.300	.421	.377	.487
Average	.673	.763	.739	.737	.701	.721	.738	.738	.724	.811	.991

TABLE 20.—*Average weighted maximum rates of pitting—all specimens removed from 1924 to 1930*

[In mils per year]

Soil No.	1½-inch specimens				3-inch specimens				6-inch specimens		
	a	b	e	y	B	K	M	Y	C	L	Z
1	8.4	8.0	7.5	8.2	8.3	7.8	8.5	7.9	11.4	23.3	27.2
2	7.3	6.0	6.2	6.8	6.2	6.2	6.8	7.1	5.0	11.1	11.3
3	17.0	14.1	15.4	16.1	14.6	14.7	14.6	15.7	3.3	18.2	21.8
4	8.2	5.6	5.8	5.7	5.4	6.5	5.8	9.0	6.1	6.8	11.1
5	5.3	5.1	6.2	5.1	5.0	6.4	6.3	5.2	13.3	6.0	7.2
6	3.1	2.3	2.3	2.2	2.2	2.5	2.4	2.4	3.0	1.9	1.9
7	5.4	4.0	4.8	4.2	4.7	6.1	5.0	3.9	5.4	3.5	5.8
8	17.3	12.9	15.6	13.1	13.6	18.6	17.9	21.9	7.6	20.9	23.6
9	16.2	13.9	12.2	11.5	14.3	14.7	14.4	15.2	6.4	7.8	10.2
10	8.8	6.6	6.9	6.6	8.7	7.6	7.6	8.2	5.9	3.8	4.9
11	17.8	16.2	13.4	13.5	15.3	13.2	17.1	15.1	7.9	3.9	12.9
12	6.0	6.1	6.5	5.8	6.4	5.7	6.1	7.0	3.0	2.8	6.0
13	11.0	15.4	15.7	14.0	13.8	19.2	17.5	17.7	9.2	11.6	28.5
14	17.3	18.5	16.2	16.2	17.4	16.0	20.1	28.9	4.2	6.3	10.9
15	11.3	10.5	11.4	9.6	10.9	10.4	11.5	11.7	6.4	14.5	16.5
16	14.0	13.6	14.2	15.1	13.5	12.3	14.7	15.4	13.4	16.7	14.6
17	4.8	4.4	4.8	4.6	4.9	5.0	5.2	4.8	4.8	15.1	9.8
18	13.2	11.3	11.6	9.5	11.3	13.4	10.4	13.1	6.7	21.4	10.1
19	13.5	11.9	12.6	11.2	12.3	12.9	14.5	15.0	8.4	18.6	12.2
20	4.1	4.3	4.1	4.5	4.1	4.1	4.8	4.7	6.2	5.7	5.5
21	10.1	7.3	8.5	9.5	9.3	7.3	8.4	7.6	7.1	9.8	7.9
22	14.3	12.5	14.5	13.6	13.3	13.9	15.1	14.9	9.2	23.3	24.7
23	23.6	21.8	21.2	19.3	19.9	26.7	20.9	25.2	22.7	32.4	57.3
24	2.6	2.5	2.2	2.8	2.9	2.9	2.6	3.3	2.3	2.3	2.3
25	11.6	9.5	9.1	10.8	10.8	11.1	13.0	11.9	6.7	6.1	17.7
26	8.4	8.9	8.5	8.9	8.2	8.4	10.2	9.6	5.5	10.2	8.8
27	3.7	4.2	4.7	5.4	5.0	6.8	5.0	5.8	13.1	9.5	9.6
28	10.7	13.0	15.5	12.9	13.2	18.0	15.0	17.0	12.5	23.5	28.8
29	17.8	13.0	17.2	17.6	14.0	18.3	14.9	18.1	12.0	16.0	19.1
30	8.0	3.4	5.4	4.5	6.4	6.8	6.7	6.9	5.3	3.7	5.2
31	7.5	8.2	12.2	8.9	8.2	11.7	9.8	11.1	9.8	4.9	10.0
32	16.2	12.2	10.2	10.3	13.0	10.9	12.1	12.7	6.9	14.6	18.3
33	10.0	5.4	5.0	8.3	8.0	9.2	8.3	7.8	9.6	9.9	9.4
34	8.2	7.7	6.2	7.3	7.3	8.7	7.3	10.3	5.8	3.8	10.2
35	3.0	5.2	3.6	2.0	3.2	2.8	4.9	6.1	3.1	3.6	7.9
36	9.3	10.7	8.7	9.5	9.8	12.4	11.1	10.2	10.2	13.9	19.1
37	11.2	10.6	13.0	14.7	12.0	12.7	13.5	21.2	3.3	3.7	4.9
38	4.8	4.6	3.0	3.1	3.9	2.9	3.2	3.5	2.2	2.2	2.4
39	6.3	5.8	6.2	5.8	5.4	5.5	6.1	7.7	6.1	5.4	6.7
40	14.9	12.9	12.3	10.9	11.4	14.6	13.0	14.4	15.3	11.9	15.1
41	9.5	12.9	11.8	13.8	14.1	10.9	14.2	11.2	4.8	5.0	9.6
42	16.2	18.4	18.9	17.5	17.0	18.3	19.9	17.4	18.3	30.2	32.4
43	12.1	16.2	11.8	13.4	20.3	21.2	23.7	14.6	11.6	4.4	12.6
44	19.4	15.2	14.5	15.6	13.4	15.3	14.9	18.0	7.1	8.4	14.7
45	7.8	9.5	8.4	7.4	6.6	7.2	10.7	12.6	7.5	18.5	11.3
46	19.4	18.4	20.4	20.3	16.4	13.5	23.1	26.8	4.1	10.3	12.6
47	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	4.0	2.2	2.5
Average	10.6	9.9	10.0	9.8	9.9	10.7	11.1	11.9	7.6	10.8	13.5

TABLE 21.—*Weighted average rates of loss of weight and penetration of deepest pits for each test period for all materials*

Soil No.	Rates of loss of weight (ounces per square foot per year)					Rates of penetration (in mils per year)				
	2 years	4 years	6 years	8 years	Average	2 years	4 years	6 years	8 years	Average
1	1.187	1,066	0.939	0.852	1.011	12.3	13.0	10.7	10.4	11.5
2	.901	.794	.689	.412	.687	5.3	10.6	7.4	6.4	7.3
3	.886	.887	.592	.515	.703	24.8	16.3	11.5	9.4	15.0
4	.994	.922	.743	.678	.835	4.9	7.9	8.7	6.1	6.9
5	.588	.493	.849	.727	.707	4.0	7.0	8.0	5.7	6.5
6	.082	.138	.126	.108	.116	2.8	2.9	2.1	1.7	2.4
7	.720	.756	--------	.556	.727	4.8	5.8	--------	3.9	4.8
8	.759	.602	.621	.600	.645	35.8	11.0	10.7	9.1	16.6
9	.673	.536	.496	.452	.539	25.3	14.0	5.3	5.1	12.4
10	.842	.450	.532	.553	.594	12.9	3.0	6.7	5.0	6.9
11	.226	.228	.192	.188	.209	23.8	13.1	9.3	7.0	13.3
12	.121	.378	.440	.129	.265	2.8	10.0	8.3	1.9	5.6
13	1.853	1.078	1.377	--------	1.436	21.9	13.0	14.2	--------	15.8
14	.324	.534	.563	.332	.436	25.5	12.2	13.0	11.9	15.6
15	1.160	.820	1.028	.639	.928	19.2	8.9	10.4	7.0	11.3
16	1.135	.743	.836	.597	.829	19.5	12.4	14.8	10.2	14.3
17	1.373	.930	.981	.901	1.046	9.3	5.2	6.0	4.4	6.2
18	.341	.317	.526	.305	.378	17.2	12.2	12.4	5.6	12.0
19	.549	.482	.381	.353	.441	21.5	11.9	10.0	8.8	13.0
20	.963	.596	.515	.424	.624	5.1	2.8	5.6	5.5	4.7
21	1.377	.689	.799	--------	.955	3.4	12.0	9.9	--------	8.4
22	.865	.938	.786	.839	.857	23.2	15.2	13.1	9.3	15.4
23	4.150	3.562	3.144	3.023	3.470	32.1	30.0	22.0	21.7	26.5
24	.159	.089	.160	.101	.127	3.8	2.5	2.2	2.0	2.6
25	.433	.304	.292	.264	.323	21.1	8.3	7.9	5.7	10.8
26	.848	.637	.302	.226	.503	6.0	11.8	11.1	6.0	8.7
27	.360	.798	.637	.550	.612	3.3	8.1	7.4	6.6	6.6
28	2.282	--------	1.569	--------	1.990	19.0	--------	12.2	--------	16.4
29	2.107	1.862	1.599	1.717	1.839	21.9	14.9	13.5	14.9	16.2
30	.971	.402	.455	.554	.595	9.9	3.3	3.9	5.6	5.7
31	.579	.513	.355	.265	.456	17.6	7.4	6.6	4.9	9.3
32	.414	.418	.409	.352	.398	26.5	9.6	6.2	7.8	12.5
33	.395	.937	.673	1.138	.786	4.9	7.7	6.7	13.7	8.3
34	.937	.447	.469	.465	.580	14.3	4.6	5.2	6.0	7.5
35	.496	.515	.185	.257	.362	6.1	4.7	2.6	3.3	4.1
36	.481	.399	.245	.235	.334	18.3	9.8	8.8	8.2	11.4
37	1.202	1.081	.758	.763	.982	18.3	12.1	7.4	7.2	11.0
38	.122	.114	.175	.218	.157	3.6	2.9	3.6	2.9	3.3
39	.906	.748	.568	.640	.715	3.6	7.4	6.9	6.5	6.1
40	1.176	1.129	1.102	.954	1.091	17.1	11.3	12.2	12.1	13.3
41	.454	.639	.575	.502	.542	20.1	8.2	7.9	6.7	10.7
42	1.604	1.444	1.322	.993	1.331	31.1	21.2	16.6	12.4	20.4
43	1.334	1.165	1.132	1.298	1.232	23.0	14.2	12.0	9.8	14.7
44	.373	.364	.320	.260	.329	25.5	14.3	10.3	7.0	14.2
45	1.155	1.127	.493	.575	.837	15.2	9.3	6.9	7.6	9.8
46	.819	.756	.458	.729	.690	30.9	16.6	9.8	10.1	16.8
47	.343	.444	.342	.283	.353	3.4	3.0	1.7	1.4	2.4
Average	.895	.745	.690	.603	.726	15.4	10.1	8.9	7.4	10.5

Statistical studies indicate that for a given soil there may be significant differences between the performance of different materials, but until this is more definitely established it may be well to use data representing the average corrosiveness of the soils with respect to all the ferrous pipe materials. In Table 21 the average rates of loss of weight have been weighted in accordance with the exposed areas of the specimens; that is, the data on the two 6-inch "C" specimens have been given a weight of 4, the 6-inch "L" and "Z" specimens (of which there was but one of each removed from each soil for each test period) and the 3-inch specimens (of which two of each kind were removed each time) a weight of 2 and the data for the 1½-inch specimens a weight of 1. This gives equal weights to equal exposed areas, but it does not give equal weights to all materials; pure open-hearth iron being given less weight than the other materials.

V. SIGNIFICANCE OF THE DATA

The precision of the determination of the rates of loss of weight and penetration by pitting has already been discussed. There remain for consideration two questions—the precision with which the data represent the corrosion phenomena, and the extent to which the observed phenomena are indicative of the relation of soils to the behavior of pipe materials throughout the life of those materials.

While the rates of loss in weight and penetration for individual specimens have been determined with degrees of precision that may justify the number of significant figures carried in the tables, it should not be understood that the corrosive properties of the soils or the behavior of the materials in any soil can be so accurately expressed. Several students of corrosion have made statistical studies of the soil-corrosion data and have arrived at widely different conclusions because of the use of different methods of treating the data. If the precision of the data is computed from the data for a single material in a single soil a figure indicating a very low degree of precision will be obtained. If, however, all materials in one soil are considered or if one material in all soils is made the basis for computations, the results indicate a much higher degree of precision. Thus Dr. V. H. Gottschalk, a member of the underground corrosion section of the National Bureau of Standards has determined (by a statistical study of the data) that the average value of the 8-year data for the average rate of loss of weight of any one material in all soils as given at the bottom of Table 17 is correct to about 7.5 per cent and that the corresponding value for the average rate of penetration is correct to about 6 per cent. The standard error[1] for the average values at the bottom of Table 19 is about 10 per cent and that of the averages at the bottom of Table 20 about 7 per cent. The standard errors for the data in Table 21 are of similar magnitude. The precisions of the data for each period have not been calculated, but preliminary calculations indicate that they will not depart widely from the values for the 1930 data.

Having obtained a rough idea of the precision of the data, the reader is in a position to examine them for their significance. On account of the differences in materials and in soil conditions this is a rather difficult task and the character of some of the conclusions reached

[1] See R. A. Fisher, Statistical Methods for Research Workers, Oliver & Boyd, London. for a discussion of standard error.

will be tentative and will depend somewhat on the experience and purpose of the examiner. Perhaps the most positive conclusion that can be reached is that the rate of corrosion differs widely for different soils. This is illustrated by Figure 3 which shows the rates of loss and pitting for the average of all materials in the most corrosive and least corrosive soil under investigation. Table 20 indicates quite

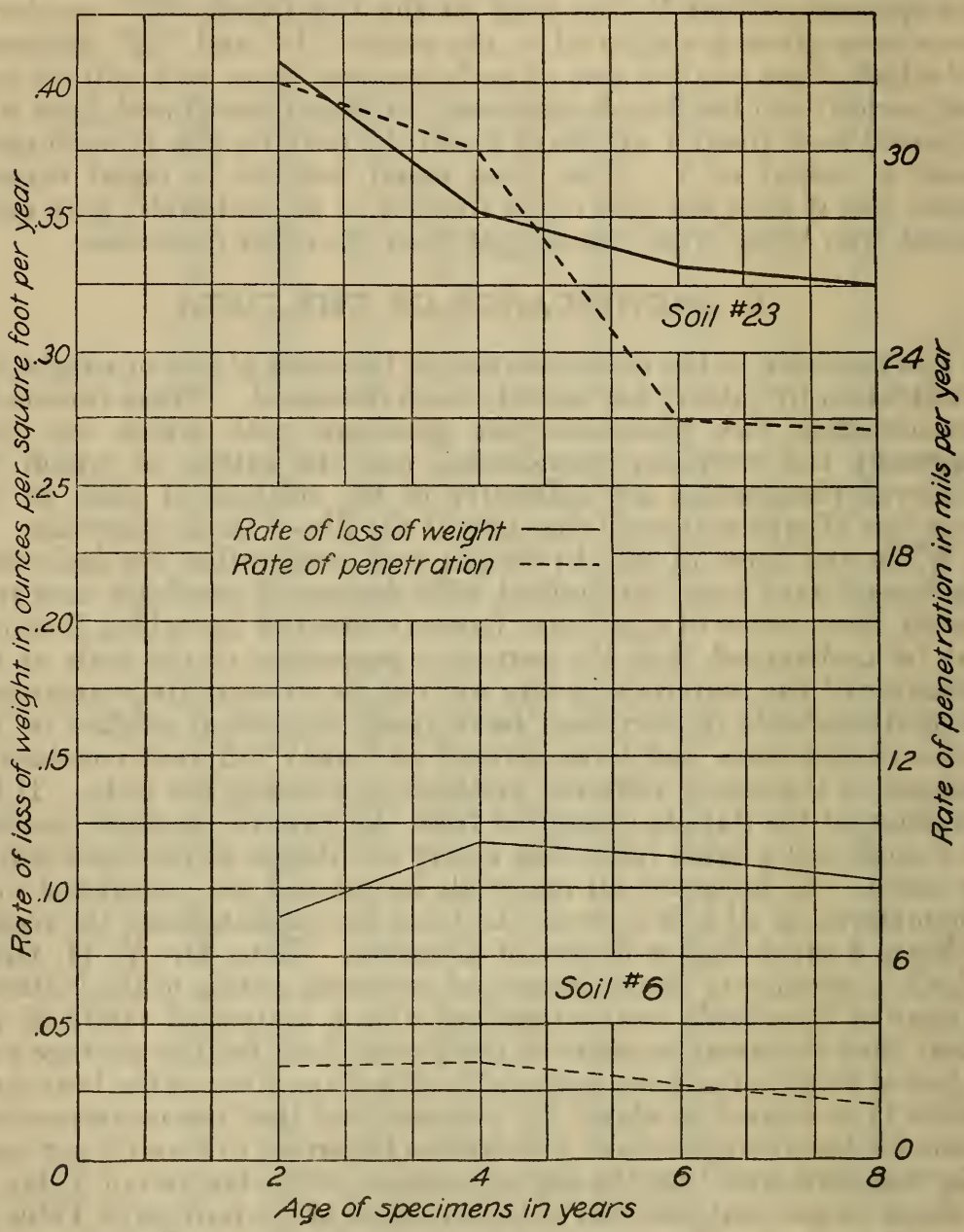

FIGURE 3.—*Rates of corrosion of all materials in worst and best soils*

definitely that if a soil is corrosive with respect to one ferrous material it is corrosive with respect to the others also.

It will be observed that both the weighted average rate of loss of weight, and the weighted average rate of penetration, for all materials in all soils (Table 21) decrease with the age of the specimens. This is shown graphically by the lines (— . —) in Figure 4, which shows also the average performance of three commonly used materials. It will be noticed that the average decrease in rate of pitting over the

8-year period is about 50 per cent, half of this decrease occurring prior to the removal of the 4-year-old specimens. The average rate of loss of weight has also decreased, but to a smaller extent. Comparing the average performances of materials 1, 2, and 3, it will be noted that though they behave nearly alike, their apparent relative merits depend upon the period of observation and upon whether rates of loss of weight or rates of penetration are the bases for comparison.

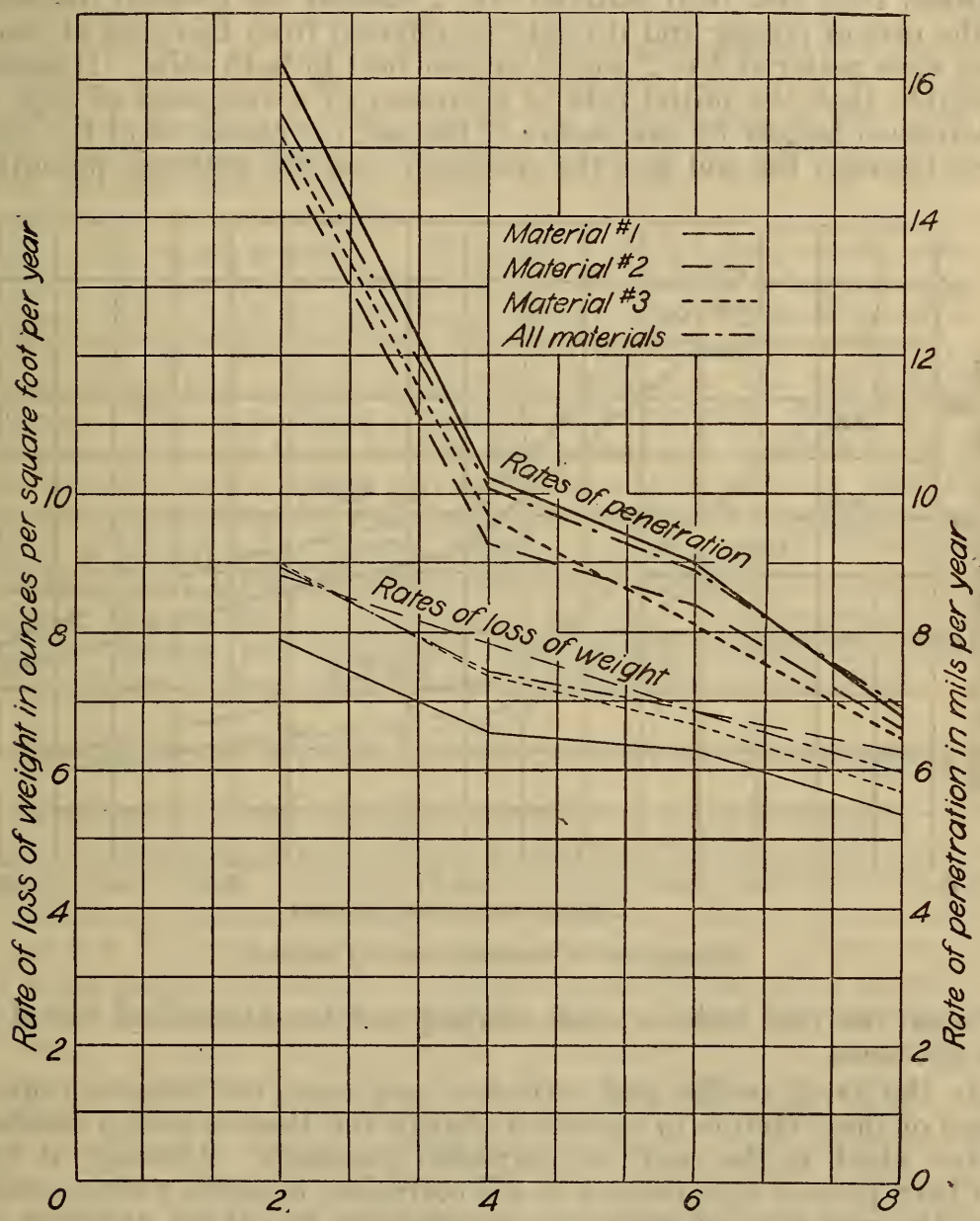

FIGURE 4.—*Change in rates of loss in weight and pitting*

Whether the differences indicated by the data are real or merely the result of lack of precision of the data will be more apparent at the close of the investigation. It is evident, however, that since the rate of corrosion decreases with time, other things being equal, the thicker the specimen the lower will be its rate of deterioration if the test is continued until the puncture of the specimen occurs. This observation has a very practical application to the selection of the wall thickness of pipes which are exposed without protection to corrosive soils.

When the behaviors of materials in a given soil are compared, it will be noticed that for most soils the differences between the ferrous materials is not large and their relative merits depend on the bases of comparison and on the soil chosen. This is illustrated in Figure 5, which shows the rates of penetration for three commonly used ferrous pipe materials in two quite different soils. Material No. 3, which is the worst of the three in soil No. 25, is the best in soil No. 42, but between 1928 and 1930 material No. 2 showed the greatest decrease in the rate of pitting and it might be inferred from this that at some later date material No. 2 would appear best in both soils. It seems probable that the initial rate of corrosion of a specimen of pipe is determined largely by the nature of the soil, the character of the contacts between the soil and the specimen, and the galvanic potential

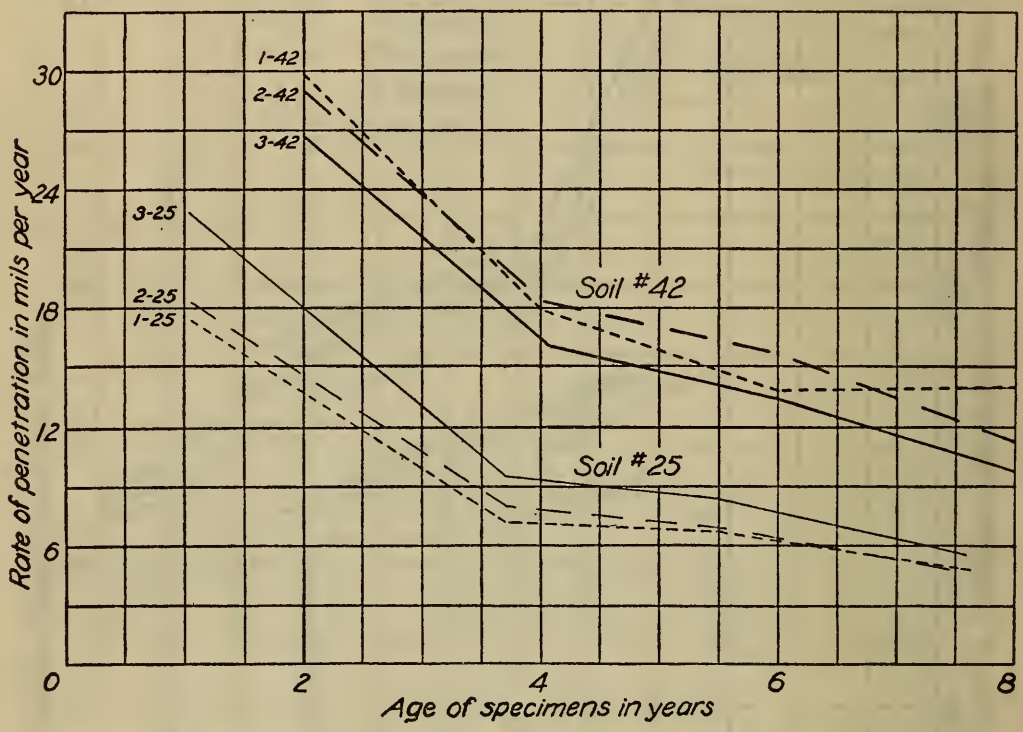

FIGURE 5.—*Changes in rate of pitting*

between the mill scale or oxide coating and the unoxidized metal of the specimen.

As the earth settles and corrosion progresses the relative importance of these factors in corrosion change and there is added another factor which is the result of corrosion processes. Although it has not been proven with respect to soil corrosion, it seems quite possible that the character of the corrosion products may have an effect on the sustained rate of corrosion and, hence, on the life of the material.

It is also possible that slight differences in the composition of the metal will result in marked differences in the character of the corrosion product and in the rate of corrosion. The American Society for Testing Materials has shown this to be the case with respect to the presence of small amounts of copper in sheet steel exposed to atmospheric corrosion.

At present the precision of the soil-corrosion data for individual materials in each soil has not been determined. Inspection of the

data on each specimen indicates that for a number of soils the standard error must be large and that significant differences in materials may be obscured because of the lack of precision of the data. Because of the uncertainties as to the significance of the data now available and because of possible changes in the apparent relative merits of materials which may appear in later data the authors believe that they should not attempt to compare materials at this time.[2]

The amount and variety of the data, while perhaps not justifying a comparison of materials at this time, serve to present a rather definite picture of some corrosion phenomena which will probably hold throughout the test. A great deal has been said by different authors from time to time about the importance of data derived from actual experience. The basis for belief in the superiority of data derived from actual service as compared with the results of experiments is undoubtedly sound in so far as the observations are made with equal precision. The data already cited should make it evident that corrosion underground is affected by a large number of factors, the individual importance of which it is difficult to estimate, and it has been shown that in the tests under discussion the life and apparent relative merits of materials depend on the soil conditions selected. The same thing is undoubtedly true with respect to working pipe lines, and there is little doubt that one material or another has actually given better service under one or another conditions, but the opportunity for determining accurately the conditions under which a material has proved superior are frequently very limited, and this limits the usefulness of the observations with respect to the value of the material for a proposed service. It is necessary, therefore, to examine data obtained in the field with considerable care and thoroughness if they are to be correctly applied to new work.

VI. DATA ON MISCELLANEOUS FERROUS MATERIALS

In addition to the materials reported on in the foregoing tables, several other ferrous materials of somewhat different natures are also under observation. Among these is high-silicon cast iron, the losses of which are shown in Table 22. It will be noticed that in all but three soils the rate of loss of weight is insignificant. There seems to be some general corrosion of the specimens in the tidal marsh (soil No. 43) and in Miller clay (soil No. 27), a heavy clay usually wet. Peculiar corrosion occurred on the specimens removed from Montezuma clay adobe (soil No. 28). One specimen was cracked, and marked softening of the metal was observed along the edges of the crack. There is reason to believe that the crack preceded the corrosion. The other specimen had on it one spot about the size of a dime at one edge where the material had softened much as in the case of the so-called graphitic corrosion of cast iron, although the corrosion product was even softer, being easily cut by the finger nail. With the exception of this specimen none of the specimens of high-silicon cast iron have shown definite evidence of pitting.

[2] At the advisory conference held on Jan. 30, 1931, for the purpose of criticizing the manuscript of this paper, the following resolution was adopted by the pipe manufacturers and users by a revised vote of 6 to 5 (several members of the conference not voting): "That the Bureau of Standards include in the next report the statement that it is the sense of this meeting that conclusions as to the relative merits of materials, based on these data by individuals, should not be published or used for sales purposes until the completion of the test."

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In 1924 specimens of malleable iron, high-tensile cast iron, and cast steel were added to the tests. These specimens were buried in only six or seven locations selected because of the wide differences in their characteristics. The soils are described in Technologic Paper No. 368.[3]

TABLE 22.—*Average rates of loss of weight of high-silicon cast-iron specimens*

Soil No.	Buried	Rate of loss of weight	Soil No.	Buried	Rate of loss of weight
	Years	*Ounces per square foot per year*		*Years*	*Ounces per square foot per year*
1	7.68	0.019	25	7.62	0.002
2	5.84	.002	26	7.67	.000
3	5.97	.004	27	7.95	.148
4	7.96	.007	28	5.56	[3] .211
5	8.06	.042	29	7.96	.068
6	8.05	.004	30	8.17	.091
7	7.68	.022	31	5.98	.004
8	7.74	.004	32	7.65	.006
9	7.67	.019	33	7.63	.041
10	7.93	.002	34	7.96	.034
11	7.84	.000	35	6.12	.041
12	(1)	(1)	36	8.00	.003
13	(1)	(1)	37	5.98	.007
14	7.72	.024	38	7.97	.001
15	5.99	.021	39	7.95	.022
16	5.98	.023	40	7.96	.007
17	7.71	.013	41	7.94	.004
18	7.67	.004	42	8.00	.007
19	7.58	.002	43	7.98	.545
20	7.68	.073	44	7.58	.003
21	(1)	(1)	45	7.68	.011
22	7.59	.004	46	7.96	.001
23	7.95	[2] .001	47	7.99	.086
24	7.93	[2] .005			

[1] Lost.
[2] One specimen only.
[3] Both specimens softened where chipped or cracked.

Table 23 gives the rates of loss of weight of these specimens. The malleable cast-iron and the cast-steel specimens were in the form of elbows, and on account of this, satisfactory measurement of pit depths could not be made with the apparatus at hand. Table 23 also indicates in a general way the condition of the specimens with respect to pitting. Generally speaking, the worst corrosion of the malleable iron and cast steel occurred near the ends of the specimens.

Chromium-iron-alloy specimens were buried in seven locations in 1926. The manufacturer supplying these specimens stated that they were tubes made by the Mannesman process from material containing approximately 26 to 28 per cent chromium, silicon and manganese about 0.5 per cent, and carbon about 0.2 per cent. Table 24 shows the rates of corrosion of these specimens. The behavior of the specimens was peculiar in that nearly all of the corrosion was in the form of pits which in most cases were confined to points under or adjacent to the asphalt used to protect the identification numbers on the ends of the specimens.

[3] B. S. Tech. Paper No. 368, Bureau of Standards Soil Corrosion Studies. I. Soils, Materials, and Results of Early Observations, p. 462.

TABLE 23.—*Corrosion of special cast specimens*

RATES OF LOSS OF WEIGHT

(Ounces per square foot per year)

Soil No.	Age, years	Specimens							
		P	CC	I	MD	MC	V	E	S
13	6.13	0.947	0.698	[1] 0.470	1.025	1.845	0.989	1.136	1.406
24	6.62	.173	.292	.269	.209	.224	.139	.146	.140
28	5.56	[1] 2.886	--------	[1] 1.045	--------	--------	--------	1.691	.976
29	6.01	1.144	[2] .875	.645	.915	.882	1.073	1.149	1.032
42	6.02	1.257	--------	.591	1.196	1.876	1.202	1.068	1.419
43	6.70	.738	1.830	.597	1.610	.991	.944	.790	1.076
45	6.50	2.105	2.545	1.137	2.176	2.204	1.489	[2] 1.176	.876

MAXIMUM RATES OF PITTING

(Mils per year)

13	6.13	26.5	13.4	[1] 18.9	6.7	24.5	24.6	S, a	S, w
24	6.62	U	U	U	2.4	U	U	U, a	U, a
28	5.56	[1] 34.2	--------	[1] 20.0	--------	--------	--------	P, w	S, a
29	6.01	10.6	8.8	7.1	13.1	16.8	14.6	P, b	P, b
42	6.02	32.4	--------	22.4	23.9	22.8	19.7	S, a	S, a
43	6.70	12.5	27.0	23.4	14.9	17.2	13.3	P, b	S, b
45	6.50	23.5	18.2	15.7	20.3	19.4	21.8	P*, w	P, a

[1] One specimen missing.
[2] No coating inside specimen.

P, 6-inch southern cast iron, 2 specimens.
CC, 6-inch de Lavaud cast iron coated inside, 2 specimens.
I, 6-inch monocast cast iron, 2 specimens.
MD, 6-inch de Lavaud cast iron, 1 specimen, both surfaces machined.
MC, 4-inch cast iron, 1 specimen, both surfaces machined.
V, High tensile cast iron, 2 specimens.
S, 2-inch malleable elbow.
E, 2-inch cast steel elbow.
U, no pitting.
S, slight pitting.
P, general pitting.
a, specimens about the same as others in the same soil.
b, specimens better than others in the same soil.
w, specimens worse than others in the same soil.

TABLE 24.—*Average* [1] *rates of loss of weight and maximum pitting for chromium iron alloy tubes*

Soil No.	Buried	Rate of loss	Average maximum rate of pitting	
			Under asphalt	Exposed
	Years	*Ounces per square foot per year*	*Mils per year*	*Mils per year*
23	3.90	0.029	9.3	N
24	3.92	.004	N	N
28	3.92	.193	28.2	VS
29	3.90	.049	3.4	VS
42	3.94	.051	10.7	N
43	3.92	.573	23.7	16.0(H)
45	3.91	.024	N	VS

[1] Average of 3 specimens in each soil.

N, no pitting.
VS, very slight pitting.
H, one hole through each of two specimens just outside asphalt protection.

On some specimens the rate of penetration of these pits was much greater than for ordinary steel pipe in the same soil. An explanation offered for this pitting is that the limitation or exclusion of oxygen under the asphalt prevented the formation of the film which usually protects this alloy from corrosion.

In cases where only one test was conducted in a given soil it is somewhat doubtful whether the data obtained are indicative of the corrosivity of that type of soil since they may be results of some accidental condition. It was deemed advisable, therefore, to start check tests in at least part of the soils under investigation, and specimens of pipe were buried in 25 additional locations in 1928.

Results of this test, as indicated by the examination of two specimens of each material removed from each of these locations in 1930 are given in Tables 25 and 26. The data are comparable with those in Tables 11 and 12 rather than with data on specimens buried for longer periods. In general, the indications are that soils have typical corrosion characteristics which are modified to some extent by local conditions. The discussion of the relation of soil characteristics to corrosion is reserved for a later paper to be prepared when more data on soil characteristics have been secured.

VI. SUMMARY

The data on the specimens removed in 1930 are, for the most part, in good agreement with those on specimens removed earlier, and confirm the tentative conclusions reached in previous reports. These may be summarized as follows:

The corrosion of ferrous materials buried in soils depends largely on the characteristics of the soils.

TABLE 25.—*Action of soils in special tests—average of all specimens removed*

Soil No.	Soil	Location	Age of specimens	Rate of loss of weight	Penetration of pits
			Years	*Ounces per square foot per year*	*Mils per year*
101	Billings silt loam [1]	Grand Junction, Colo	1.90	2.83	31
102	do.[2]	do	1.90	2.46	21
103	do.[3]	do	1.90	3.96	31
104	Cecil clay	Charlotte, N. C	1.93	1.33	32
105	Cecil clay loam	Macon, Ga	1.95	1.91	31
106	do	Salisbury, N. C	1.93	1.76	31
107	Cecil fine sandy loam	Raleigh, N. C	1.92	1.09	30
108	Cecil gravelly loam	Atlanta, Ga	1.94	1.68	29
109	Fresno fine sandy loam [1]	Fresno, Calif	1.90	3.22	38
110	do.[2]	do	1.90	2.31	38
111	do.[3]	Kernell, Calif	1.57	2.88	27
112	Imperial clay [2]	Niland, Calif	1.88	4.21	48
113	do.[3]	do	1.88	4.98	49
114	Lake Charles clay	El Vista, Tex	.93	1.60	17
115	Memphis silt loam	Vicksburg, Miss	2.02	.89	21
116	Merced clay	Los Banos, Colo	1.93	3.70	30
117	Merced clay loam adobe	Tranquility, Calif	1.92	3.91	49
118	Niland gravelly sand	Niland, Calif	1.88	3.58	43
119	Norfolk sandy loam	Macon, Ga	1.95	1.38	34
120	do	Pensacola, Fla	1.95	.42	8
121	Norfolk sand	Tampa, Fla	1.97	.27	5
122	Panoche clay loam	Mendota, Calif	1.92	1.01	12
123	Susquehanna clay	Shreveport, La	2.02	1.99	19
124	Susquehanna silt loam	Troop, Tex	.86	3.44	45
125	Susquehanna fine sandy loam	Shreveport, La	2.02	1.63	15

[1] Low alkali. [2] Moderate alkali. High alkali.

TABLE 26.—*Rates of loss of weight and pitting for specimens in special test*

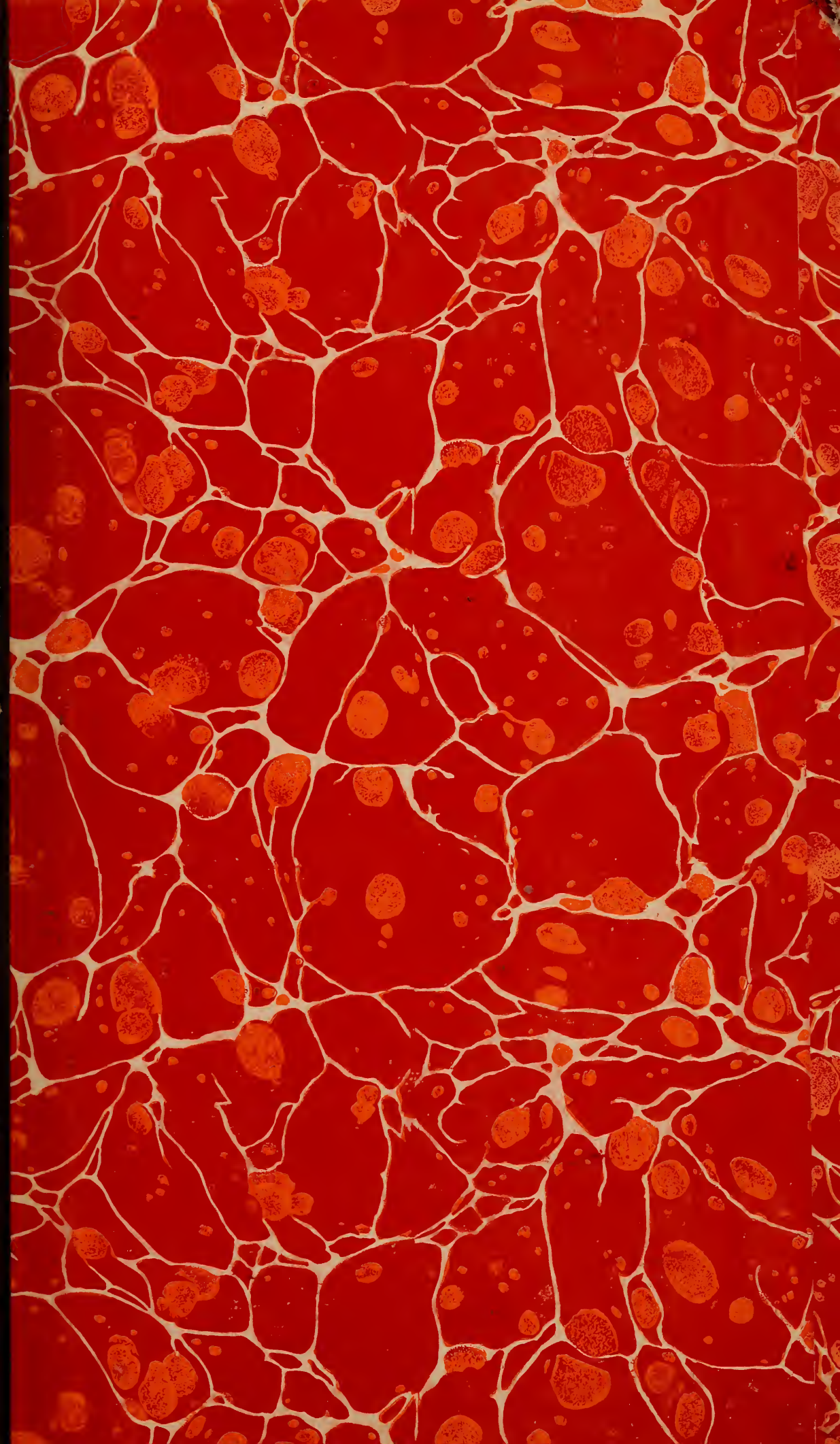
Soil No.	Buried	Rate of loss of weight (ounces per square foot per year)					Weighted maximum rate of penetration (mils per year)				
		A	B	N	P	C	A	B	N	P	C
	Years										
101	1.90	2.060	2.714	2.031	3.621	2.895	35.8	33.8	30.4	19.5	33.8
102	1.90	2.074	2.636	2.248	2.655	2.454	21.7	19.2	13.8	19.4	29.9
103	1.90	1.937	2.625	1.891	7.322	3.327	31.3	22.4	18.6	48.6	34.5
104	1.93	1.507	1.562	1.287	1.421	1.056	34.3	35.6	44.2	22.8	22.4
105	1.95	1.658	1.834	1.731	2.283	1.774	24.7	23.1	26.4	40.8	40.1
106	1.93	1.343	1.315	1.053	2.143	2.147	30.2	23.2	24.6	41.6	36.8
107	1.92	1.069	1.221	1.263	1,123	.912	28.0	30.7	32.8	28.6	29.5
108	1.94	1.427	1.720	1.766	1.960	1.446	32.7	19.6	27.2	34.0	33.3
109	1.90	2.484	3.088	2.731	3.893	3.209	35.5	34.5	37.6	53.3	30.8
110	1.90	2.073	2.358	2.163	2.683	2.097	37.5	30.0	21.3	55.5	43.8
111	1.57	2.761	2.851	3.318	2.876	2.738	33.3	27.9	20.2	31.1	23.2
112	1.88	3.792	3.858	3.868	4.522	4.452	39.8	29.3	35.2	79.7	53.6
113	1.88	4.377	4.307	4.395	5.331	5.572	47.9	28.5	28.1	72.8	67.8
114	.93	1.603	1.367	1.407	1.678	1.728	31.7	16.4	14.8	10.8	10.8
115	2.02	.906	.918	.850	1.040	.730	15.0	15.3	15.3	31.3	29.9
116	1.93	3.151	3.445	2.996	4.163	4.002	23.6	25.5	18.1	46.7	38.1
117	1.92	3.950	4.130	4.160	4.098	3.468	59.8	47.4	41.1	50.4	44.5
118	1.88	2.870	2.665	2.909	4.629	3.678	48.9	36.4	23.1	60.3	40.3
119	1.95	1.207	1.328	1.326	1.536	1.364	36.4	22.6	23.7	46.3	40.9
120	1.97	.564	.480	.411	.335	.413	10.2	9.9	9.5	5.1	5.1
121	1.95	.361	.290	.243	.211	.277	5.1	5.1	5.1	5.1	5.1
122	1.92	.998	1.169	1.000	1.011	.923	23.0	14.6	12.4	5.2	5.2
123	2.02	1.688	1.937	1.786	2.365	1.879	21.0	21.2	19.9	15.8	15.0
124	.86	2.779	3.033	3.131	4.533	3.038	51.2	51.5	54.4	32.8	32.6
125	2.02	1.484	1.564	1.560	1.981	1.423	13.7	13.9	14.0	17.5	15.5

A, open-hearth iron.
B, wrought iron.
C, sand-mold centrifugally-cast iron.
N, Bessemer steel.
P, pit-cast iron.

The data so far obtained do not indicate that any one of the commonly used pipe materials is markedly superior to the others for general use underground. In some locations one material or another appears slightly superior, but the precision of the data are insufficient to justify a comparison of materials. There is a possibility that subsequent results will indicate that over longer periods some material is better than others. This can only be determined at the close of the tests.

The corrosiveness of a soil can never be precisely expressed because of the variations in the soil, differences in the methods of back filling the trenches, the depth of burial of the pipes and the variations in moisture and temperature from year to year.

In most soils the rate of corrosion of buried pipe decreases with time. Several causes appear to be responsible for the corrosiveness of soils, and it is improbable that a single satisfactory method for determining soil corrosiveness can be developed.

The data on the materials examined are presented in tabular form in Tables 5 to 26.

WASHINGTON, January, 1931.