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## Performance of Ductile-Iron Pipe in Soils

—Melvin Romanoff—

*A paper presented on Jun. 8, 1967, at the Annual Conference, Atlantic City, N.J., by Melvin Romanoff, Research Chemist, National Bureau of Standards, Institute for Materials Research, Washington, D.C.*

THE field investigations on underground corrosion, conducted for many years by the National Bureau of Standards, have contributed significantly to our present understanding of the behavior of metals in soils. During the 30 years preceding 1952 data were obtained on 37,000 specimens, representing many varieties of metals, alloys, and protective coatings, some of which had been exposed up to 17 years at the 128 test locations throughout the United States. These data, reported in part in many different publications, were all assembled in National Bureau of Standards Circular 579.<sup>1</sup>

In 1958, new specimens were buried at six test sites to obtain additional information on metals and alloys not completely investigated in the earlier tests. Included were specimens of ductile cast-iron pipe. Carbon steel pipe was used as a reference material to correlate the corrosiveness of the soils at the six test sites with that of the soils at the 128 locations at which corrosion investigations were previously conducted.<sup>1</sup>

A progress report was made on the performance of ductile iron after exposure of 4 years.<sup>2</sup> The data presented in this progress report indicated that ductile cast iron corrodes at nearly the same rate, with respect to weight

loss and pitting, as gray cast iron in the same soil environment, and that the graphite corrosion products of ductile-iron specimens have the same general characteristics and adhesive properties as those of gray cast iron. It was concluded, therefore, that in the same soil ductile iron and gray iron not only corrode at about the same rate, but that the pattern of corrosion and the nature of the corrosion products are also similar.

In this article data are presented giving another point on the corrosion-time curves, after exposure for 8 years, in soils at five of the six test sites where specimens of ductile iron were exposed. There are additional specimens, still exposed, awaiting later removal.

Before discussing the results obtained on the specimens of ductile iron in the field tests, it is advisable to review briefly the data on the performance of gray iron in the earlier tests.

Present at the 128 NBS test locations are 95 different types of soils. The chemical and physical properties of these soils cover a wide range. Extreme acidity (pH 2.6), as well as high alkalinity (pH 10.2), is represented. Electrical resistivity ranges from 51 ohm-cm, approximately that of sea water, to 54,000 ohm-cm, indicating the absence of soluble salts. In

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one soil the soluble material is almost entirely in the form of sulfates, while in other soils it is in the form of chlorides or carbonates. Wide differences in aeration are exhibited. Some of the environments are highly oxidizing. Others are definitely reducing.

### Gray-Iron Data

The gray cast-iron materials, buried at 47 test sites in 1922, consisted of several varieties of pipe specimens manufactured by both the centrifugal and pit cast processes. Data obtained on these materials after exposure for 12 years in the more corrosive soils and 17 years in the less corrosive soils show that in the same soil environment there is no appreciable difference with respect to both weight loss and

pitting in the corrosion of the cast-irons manufactured by the different methods. The data also show that the corrosion of gray iron is determined essentially by soil conditions, not by the composition of the material, and, fortified by supplementary data obtained at 48 additional sites in subsequent years, they show that soils differ radically in their corrosive action on cast iron and other commonly used ferrous metals. In one soil the corrosion rate, as indicated by weight loss and maximum depth of pits, may be constant. In another, it may decrease with time. This is illustrated in Fig. 1, which shows the changes in weight losses and maximum pit depths relative to exposure time for gray iron in four different soils.

In general, the rate of weight loss or depth of pitting in well drained soils with high electrical resistivities, such as Hagerstown loam and Susquehanna clay, is high initially, but becomes insignificant after a few years. In soils of this type, an increase in wall thickness will substantially increase the service life of a pipe. On the other hand, in poorly drained soils with low resistivities, such as Acadia clay and Lake Charles clay, the rate of corrosion is nearly linear after 1 or 2 years. In these soils heavier-wall pipe may not be justified economically, because it is more practical to apply protective coatings, cathodic protection, or both.

### Cast-Iron Corrosion

Corrosion of cast iron is characterized by conversion of the metal into an adherent layer consisting chiefly of iron oxides and graphite, which increases in thickness as corrosion progresses. Corrosion by this process is called graphitization, or graphitic corrosion, and is caused in part by electrochemical action between the ferritic and

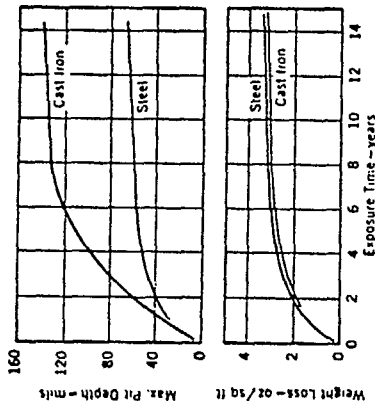


Fig. 2. Corrosion-time Curves for Gray Cast Iron and Carbon Steel Buried in Hagerstown Loam for 14 Years

graphitic constituents of cast iron and also, perhaps, by differences in potential produced by contact of the metal with the soil. An example of this would be differential aeration.

The graphitized layer often can be detected by its dull black appearance and by the lack of a metallic ring when the metal is struck by another metallic object. Nonetheless, because the original shape of the metal is retained, visual observation prior to thorough cleaning and removal of the graphitized corrosion products gives no indication of the extent of corrosion.

For the purpose of corrosion studies, graphitization is considered to be corrosion, although it is generally recognized that the strength of the graphitized corrosion products is often sufficient to permit a severely corroded pipe to provide many years of service if low or moderate pressures are maintained, and the pipe is not subjected to mechanical disturbances in the surrounding soil.

To evaluate the residual strength of graphitized cast iron, specimens of 2-in. OD pipe with a wall thickness of  $\frac{1}{4}$  in.,

that had been removed from five corrosive soils after exposures of up to 11 years, were subjected to hydraulic pressure tests.<sup>1</sup>

After the application of hydraulic pressures, the corrosion products were removed, and the specimens were examined for weight loss and pitting. The data show that most of the specimens withstood a maximum pressure of 500 psi, although removal of the corrosion products revealed numerous perforations of various diameters.

Gray cast iron is a heterogeneous alloy, chiefly because the carbon that it contains is predominantly present as graphite flakes. The graphite flakes tend to disrupt the continuity of the metal, causing brittleness and low strength.

### Ductile Iron

By contrast ductile iron is manufactured by a process that converts the graphite flake to nodules more or less uniformly distributed throughout the metal matrix. This ductile cast iron, also known as nodular or spheroidal cast iron, is considerably tougher and more ductile than gray iron.

In 1958, specimens of 2-in. ductile iron pipe, 12 in. long with a wall thickness of  $\frac{1}{4}$  in., were buried in six different soil environments. Twenty specimens were buried approximately 3-4 ft below the ground line at each test site to allow for removal of one set consisting of four specimens after 1, 2, 4, and 8 years, with one set to be removed still later, depending upon the results of the prior removals.

The progress report mentioned above gives data for specimens exposed 1, 2, and 4 years in the six soils.<sup>2</sup> The present article adds 8-year data in five of the soils. The sixth site, coastal sand (site E), was washed out by a

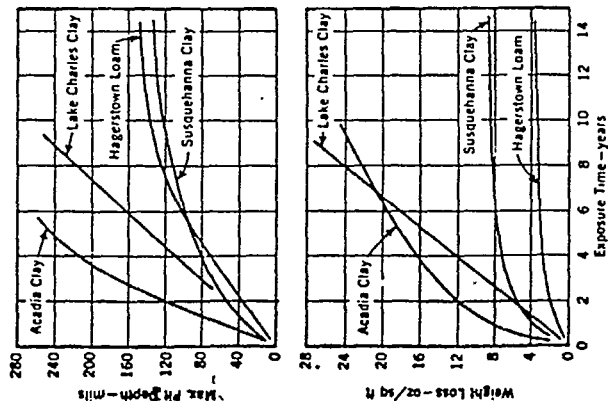


Fig. 1. Weight Loss and Maximum Pit Depth of Gray Cast Iron Plotted Against Exposure Time

tidal flood prior to the scheduled removal of the 4-year specimens. Therefore, only 1- and 2-year data are presently available for the specimens from this site. Additional specimens were exposed in a nearby site of similar soil characteristics from which data will be available in the future.

#### Test Sites

The physical and chemical properties of the soils are given in Table 1. Descriptions of the soils at the six test sites follow:

1. *Site A.* Sagemoor sandy loam is a well-drained alkaline soil with a resistivity of 400 ohm-cm and a pH of 8.8. It is typical of soils found in vast

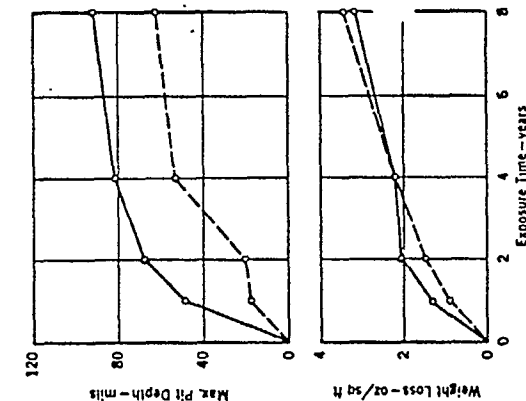


Fig. 4. Hagerstown Loam

weight loss and maximum pit depth are plotted as a function of time for ductile cast-iron (solid lines) and carbon-steel (dashed lines) pipe buried in Hagerstown loam (Site B) at Loch Raven, Md.

areas of eastern Washington and Oregon. The site is located on the Yakima Indian Reservation near Toppenish, Wash. The soil is consistent in composition to a depth of at least 7 ft and supports an abundant growth of sage brush.

2. *Site B.* Hagerstown loam is a well drained soil representative of the well-developed soils found in the eastern United States. The site is located at the Loch Raven Reservoir of the Baltimore water department. The soil consists of a brown loam about 1 ft deep, underlain by a reddish-brown clay extending down 5 ft or more a rock base. The soil has a resistivity of 5,200 ohm-cm and a pH of 5.8. Almost all the materials investigated since 1922 in NBS soil corrosion tests

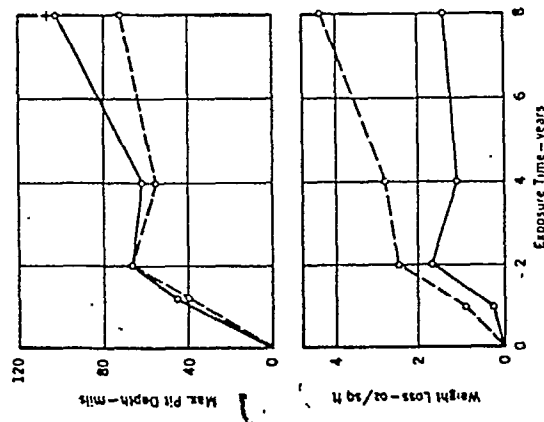


Fig. 3. Sagemoor Sandy Loam

Weight loss and maximum pit depth are plotted as a function of time for ductile cast-iron (solid lines) and carbon-steel (dashed lines) pipe buried in Sagemoor sandy loam (Site A) at Toppenish, Wash.

have been exposed at this site. Therefore, it can serve usefully as a reference site for correlating data obtained during the present program with that of earlier tests.

3. *Site C.* Clay soil is located in a large clay pit on level land at Cape May, N.J. The soil consists of plastic gray clay to a depth of 6 in. This is underlain by gray clay mixed with patches of brown clay to a depth of 12 in. Underneath this is a poorly drained, very heavy plastic clay in which the specimens are exposed. The soil has a resistivity of 300 ohm-cm and a pH of 4.0.

4. *Site D.* Lakewood sand is a white, loose sand with black streaks in some places. The site is located in a well drained, rolling area at Wildwood, N.J., which is not subject to overflow from the ocean except under unusual flood conditions. The sand, which supports the growth of beach grasses abundantly, has a pH of 7.3 and a resistivity of 30,000 ohm-cm.

5. *Site E.* Coastal sand is a typical white beach sand with a high content of black sand streaks. It is similar to the Lakewood sand, except that at this site, on the Two-Mile Beach at Wildwood, N.J., the sand is saturated

TABLE 1  
Properties of Soils at Test Sites

| Site | Soil                | Location         | Internal Drainage of Test Site | Resistivity* ohm-cm | pH  |
|------|---------------------|------------------|--------------------------------|---------------------|-----|
| A    | Sagemoor sandy loam | Toppenish, Wash. | Good                           | 400                 | 8.8 |
| B    | Hagerstown loam     | Loch Raven, Md.  | Good                           | 5,200               | 5.8 |
| C    | Clay                | Cape May, N. J.  | Poor                           | 300                 | 4.0 |
| D    | Lakewood sand       | Wildwood, N. J.  | Good                           | 30,000              | 7.3 |
| E    | Coastal sand        | Wildwood, N. J.  | Poor                           | 55                  | 7.1 |
| G    | Tidal marsh         | Patuxent, Md.    | Poor                           | 300                 | 7.1 |

| Composition of water extract—ppm |        |     |     |                |                 |                  |                 |       |                 |
|----------------------------------|--------|-----|-----|----------------|-----------------|------------------|-----------------|-------|-----------------|
|                                  | TDS†   | Ca  | Mg  | Na + K (as Na) | CO <sub>2</sub> | HCO <sub>3</sub> | SO <sub>4</sub> | Cl    | NO <sub>3</sub> |
| A                                | 7,080  | 108 | 23  | 1,960          | 0.0             | 5,002            | 216             | 330   | 6               |
| B                                | —      | —   | —   | —              | —               | —                | —               | —     | —               |
| C                                | 14,640 | 540 | 754 | 2,242          | 0.0             | 0.0              | 6,768           | 3,529 | 118             |
| D                                | —      | —   | —   | —              | —               | —                | —               | —     | —               |
| E                                | 11,020 | 302 | 329 | 3,230          | 0.0             | 55               | 1,133           | 5,765 | 31              |
| G                                | 11,580 | 140 | 165 | 2,392          | 0.0             | 0.0              | 1,709           | 3,259 | 37              |

| Mg equivalents/100g of soil |   |      |      |      |     |      |      |      |      |
|-----------------------------|---|------|------|------|-----|------|------|------|------|
|                             | — | —    | —    | —    | —   | —    | —    | —    | —    |
| A                           | — | 0.54 | 0.19 | 8.50 | 0.0 | 8.20 | 0.45 | 0.93 | 0.01 |
| B                           | — | —    | —    | —    | —   | —    | —    | —    | —    |
| C                           | — | 2.70 | 6.18 | 9.51 | 0.0 | 0.0  | 14.0 | 9.94 | 0.19 |
| D                           | — | —    | —    | —    | —   | —    | —    | —    | —    |
| E                           | — | 1.51 | 2.70 | 13.9 | 0.0 | 0.09 | 2.36 | 16.2 | 0.05 |
| G                           | — | 0.70 | 1.35 | 10.2 | 0.0 | 0.0  | 3.56 | 9.18 | 0.06 |

\* Resistivity determinations made at the test site with Shepard Canes.

† Total dissolved solids, residue dried at 103°C.

continuously with salt water. It has a pH of 7.1 and a resistivity of 55 ohm-cm.

6. *Site G.* Tidal marsh is typical of the poorly drained soils found along the Atlantic and Gulf coasts. The site is located along a creek that empties into the Chesapeake Bay at Patuxent, Md. The soil is charged with hydrogen sulfide and has a resistivity of 300 ohm-cm and a pH of 7.1.

#### Gray Iron Not Exposed

Because gray iron was not exposed in these tests, no direct comparison



Fig. 5. Clay. Weight loss and maximum pit depth are plotted as a function of time for ductile cast-iron (solid lines) and carbon-steel (dashed lines) pipe buried in clay (*Site C*) at Cape May, N.J.

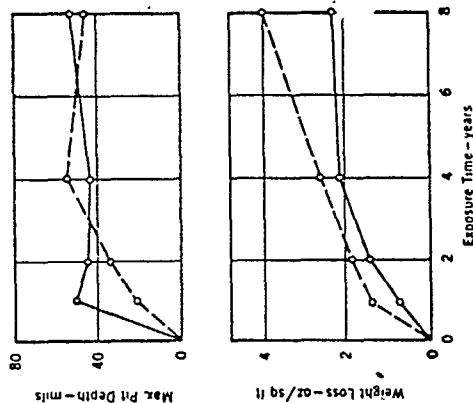


Fig. 6. Lakewood Sand. Weight loss and maximum pit depth are plotted as a function of time for ductile cast-iron (solid lines) and carbon-steel (dashed lines) pipe buried in Lakewood sand at Wildwood, N.J.

could be made between it and ductile iron. Comparisons between specimens of ductile-iron and carbon-steel pipe (1.9 in. OD, 12 in. long, 0.145 in. wall thickness), which were exposed to the same sites, were made to evaluate the behavior of the ductile-iron specimens. A statistical comparison of earlier data obtained for specimens of gray iron and steel after exposure for 14 years in the fifteen soils, showed that no significant differences between the weight losses of the two materials could be detected.<sup>1</sup> It is reasonable to assume, therefore, that the same situation exists when gray cast iron and ductile cast iron are compared. With respect to maximum penetration, in ten soils, no significant differences between the two materials could be detected. In five soils pit depth was sig-

nificantly greater for the specimens of gray cast-iron.

It is also worth noting that data obtained for the many corrosive soils to which both gray cast iron and steel were exposed in the earlier tests<sup>1</sup> show that, despite the greater wall thickness of cast-iron pipe, the first perforations on both materials, caused by corrosion, generally were detected after the same exposure period.

The curves for weight loss and maximum pit depth plotted against ex-

posure time for specimens of gray-iron and steel pipe exposed in the earlier tests to the moderately corrosive Hagerstown loam (*site B*) are shown in Fig. 2. The curves show that with respect to weight loss both materials corroded at about the same rate, and that the rate of pitting on the cast iron was greater than that of steel.

The weight losses and maximum pit depths plotted against the exposure time for the specimens of ductile-iron and carbon-steel pipe in five soils are

TABLE 2  
Average<sup>a</sup> Loss in Weight and Maximum Pit Depth of Carbon Steel and Ductile Cast Iron in Different Soils

| Ident. | Soil               |                  | Exposure Time—years | Carbon               |                     | Steel                |                     | Ductile              |                     | Iron |
|--------|--------------------|------------------|---------------------|----------------------|---------------------|----------------------|---------------------|----------------------|---------------------|------|
|        | Type               | Location         |                     | Weight Loss—oz/sq ft | Max. Pit Depth—mils | Weight Loss—oz/sq ft | Max. Pit Depth—mils | Weight Loss—oz/sq ft | Max. Pit Depth—mils |      |
| A      | Sagehen sandy loam | Toppenish, Wash. | 1.0                 | 0.9                  | 39                  | 0.9                  | 39                  | 0.3                  | 45                  | 45   |
|        |                    |                  | 2.0                 | 2.5                  | 66                  | 1.7                  | 66                  | 1.7                  | 66                  | 66   |
|        |                    |                  | 4.0                 | 3.0                  | 55                  | 3.0                  | 55                  | 1.1                  | 60                  | 60   |
|        |                    |                  | 8.0                 | 4.4                  | 71                  | 4.4                  | 71                  | 1.4                  | 102†                | 102† |
| B      | Hagerstown loam    | Loch Raven, Md.  | 1.0                 | 0.9                  | 18                  | 0.9                  | 18                  | 1.3                  | 49                  | 49   |
|        |                    |                  | 2.1                 | 1.5                  | 20                  | 2.0                  | 20                  | 2.0                  | 68                  | 68   |
|        |                    |                  | 4.1                 | 2.2                  | 53                  | 2.2                  | 53                  | 2.2                  | 81                  | 81   |
|        |                    |                  | 8.1                 | 3.4                  | 60                  | 3.4                  | 60                  | 3.1                  | 97                  | 97   |
| C      | Clay               | Cape May, N. J.  | 1.0                 | 1.0                  | 12                  | 1.0                  | 12                  | 2.4                  | 61                  | 61   |
|        |                    |                  | 2.0                 | 3.3                  | 12                  | 4.7                  | 108                 | 4.7                  | 108                 | 108  |
|        |                    |                  | 5.0                 | 7.6                  | 30                  | 5.9                  | 114†                | 5.9                  | 114†                | 114† |
|        |                    |                  | 8.0                 | 42.7                 | 121†                | 13.8†                | 231†                | 13.8†                | 231†                | 231† |
| D      | Lakewood sand      | Wildwood, N. J.  | 1.0                 | 1.4                  | 19                  | 0.7                  | 50                  | 0.7                  | 50                  | 50   |
|        |                    |                  | 2.0                 | 1.8                  | 33                  | 1.4                  | 44                  | 1.4                  | 44                  | 44   |
|        |                    |                  | 4.0                 | 2.6                  | 54                  | 2.1                  | 43                  | 2.1                  | 43                  | 43   |
|        |                    |                  | 8.0                 | 4.0                  | 45                  | 2.3                  | 52                  | 2.3                  | 52                  | 52   |
| E      | Coastal sand       | Wildwood, N. J.  | 1.0                 | 0.3                  | 13                  | 1.8                  | 35                  | 1.8                  | 35                  | 35   |
|        |                    |                  | 2.0                 | 0.6                  | 8                   | 3.8                  | 49                  | 3.8                  | 49                  | 49   |
| G      | Tidal marsh        | Patuxent, Md.    | 0.9                 | 1.1                  | 12                  | 2.7                  | 63                  | 2.7                  | 63                  | 63   |
|        |                    |                  | 1.8                 | 2.0                  | 14                  | 3.4                  | 56                  | 3.4                  | 56                  | 56   |
|        |                    |                  | 3.9                 | 34.3                 | 136†                | 10.3                 | 142†                | 10.3                 | 142†                | 142† |
|        |                    |                  | 7.8                 | 40.0                 | 128†                | 17.6                 | 190†                | 17.6                 | 190†                | 190† |

<sup>a</sup> Average of four specimens.  
† One specimen perforated by corrosion.  
‡ Pipe wall thickness: carbon steel, 145 mils; ductile iron, 250 mils.  
§ Average of three specimens. One specimen not recovered.

shown in Fig. 3-7. Each point represents an average of the weight losses and maximum pit depths of four specimens. The weight loss and pit depth data from which the curves were plotted are given in Table 2.

The condition of the specimens of ductile cast-iron pipe and carbon-steel pipe after exposure for 8 years at the test sites are shown in Fig. 8 and 9.

The curves for both weight loss and pit depth of the ductile iron and carbon

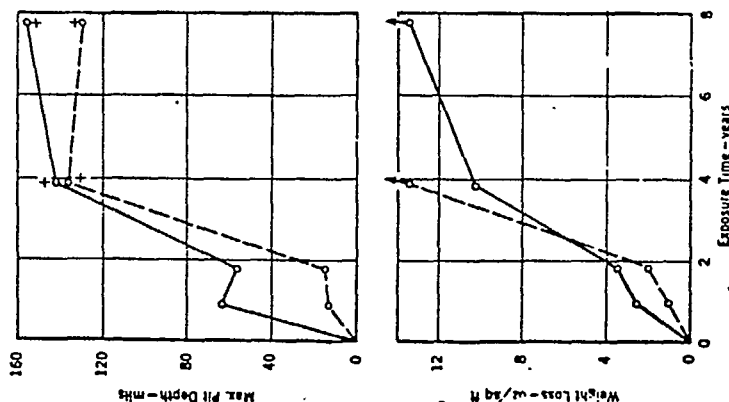


Fig. 7. Tidal Marsh

Weight loss and maximum pit depth are plotted as a function of time for ductile cast-iron (solid lines) and carbon-steel (dashed lines) pipe buried in the tidal marsh at Patuxent, Md.

the ductile iron corrodes at a greater rate.

The differences in weight loss or pitting shown by the specimens of ductile iron and carbon steel may be shown to be significant in some of the soils by statistical analyses. But for practical purposes, as far as the corrosion engineer is concerned, the differences are of such small magnitude that the two materials can be considered, in general, to behave essentially alike in the same environments. Hence, it can be concluded, after 8 years of exposure in the five soils where the specimens have been ex-

posed, that ductile iron and carbon steel corrode at nearly the same rate.

Because one of the major conclusions drawn on the basis of the long-range studies from the earlier NBS corrosion studies<sup>1</sup> was that the commonly-used ferrous metals, including gray cast iron and carbon steel, corrode at nearly the same rate in the same soil environment, it also can be concluded that gray iron and ductile iron corrode at nearly the same rate in the same soil environment. It is also obvious from the data in Table 2 and Fig. 3-7, that the materials corrode at different rates in different soils.

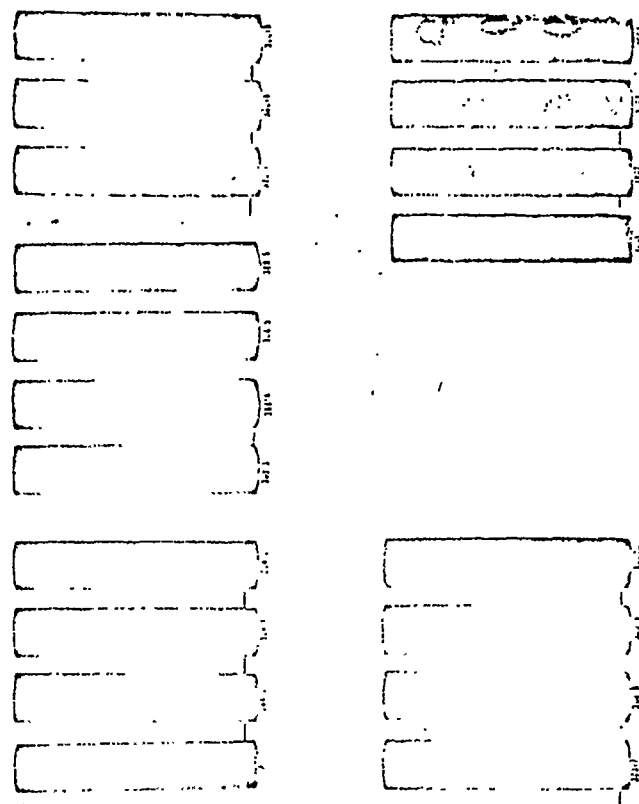


Fig. 8. Specimens of Ductile Cast-Iron Pipe Exposed 8 Years at Five Test Sites

The top row shows pipe exposed in Sagemoor sandy loam (Site A), Hagerstown loam (Site B), and clay (Site C). The bottom row shows pipe exposed in Lakewood sand (Site D) and Tidal marsh (Site G).

With respect to pitting, the data

show that the ductile iron and carbon steel corroded at about the same rate in the moderately corrosive Lakewood sand and in the highly corrosive clay and tidal marsh soils. In the latter two soils, specimens of both materials were perforated by corrosion within the 8-year exposure period. In the Hagerstown loam and Sagemoor sandy loam the maximum pit depths for the ductile iron were significantly greater than for the carbon steel.

### Summary

In summary, the corrosion-time curves for specimens in these five soils show that with respect to weight loss, the ductile-iron specimens show the same general rates of corrosion for the 8-year exposure period in three of the soils as do the steel specimens. In the other two soils, ductile iron shows lower weight losses.

The pit-depth-time curves show that in three soils the rate of corrosion of ductile iron is about the same as that of steel, and in the other two soils,

This is the same conclusion made in the 4-year progress report.<sup>2</sup>

It has been noted with respect to the 8-year specimens, as was reported in the 4-year report, that the graphitic corrosion products of ductile iron had the same general characteristics and adhesive properties as were observed on specimens of gray iron in previous exposures.

Therefore, after 8 years of exposure to five different soils, it can be con-

cluded that ductile cast iron and gray cast iron corrode at nearly the same rate in the same soil, and that the pattern of corrosion and the nature of the corrosion products are also similar in the same soil environments.

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#### PIPE PERFORMANCE

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