SOIL EVALUATION AND CORROSION CONTROL PROCEDURES FOR DUCTILE AND GRAY IRON PIPELINES

by

Edward C. Sears
Research Superintendent, American Cast Iron Pipe Company
Birmingham, Alabama

INTRODUCTION

One essential benefit of our water resources is a supply of quality water delivered to our homes and businesses. This water moves over a vast transportation system of underground piping, most of which is cast ductile or gray iron pipe. A recent survey showed that cast iron pipe make up more than 90% of the water mains servicing the 100 largest cities in the United States. Each year about 10,000 miles of ductile and gray iron pressure pipe are added to the underground piping system.

The Cast Iron Pipe Research Association has for some 40 years studied various aspects of the service performance of these pipe in the soil environment. These studies have developed a substantial amount of information for designers and users of pipe including data on the soil corrosion resistance of gray and ductile iron pipe, procedures for testing and evaluating soils for corrosiveness and means of protecting pipe in corrosive soils. This paper will review these aspects of the Association's research work.

CORROSION RESISTANCE OF GRAY AND DUCTILE IRON PIPE

The use of gray cast iron pipe in pressurized water systems began in Europe over 300 years ago and in the United States over 150 years ago. At least 130 of the largest utilities in the United States have cast iron pipe in operation after more than 100 years. Many other water systems contain cast iron pipe in service for 50 to 100 years. This excellent durability record has been achieved without the use of heavy duty coatings or other special protection.

Ductile iron, introduced in 1948, is similar in chemical composition to gray iron but differs in the shape of the graphite in the microstructure. Ductile iron pipe has about twice the tensile strength and more than ten times the impact strength of gray iron pipe. Ductile iron pipe is furnished in sizes up through 54-inch and has developed into a major material for underground piping.

The soil corrosion characteristics of ductile iron pipe were studied by the Cast Iron Pipe Research Association in a 14 year research program which began in 1950. Several hundred samples of ductile and gray iron pipe were installed in test sites which were selected in very corrosive soils in order to obtain accelerated corrosion rates and develop data as quickly as possible. One site consisted of cinders of 400 ohm-cm resistivity and another site was in a western alkali soil of 200 ohm-cm. At 2 to 3 year intervals samples were removed, sand blasted to remove corrosion products and tested for depth of pitting and weight loss. Results are shown in Figure 1 and Figure 2. These data show that the soil corrosion resistance of ductile iron pipe is equal to or somewhat better than that of gray iron pipe. Consequently, from a corrosion engineering standpoint, the two types of pipe may be treated alike.

SOIL EVALUATION

Most soils in the United States are not corrosive to ductile or gray iron pipe. A study made in 1960 by a committee of the American Standards Association (now USA Standards Institute), covering 83,000 miles of cast iron pipe in 110 utilities, showed that less than 2% of this pipe was in areas where corrosion had been experienced. In most cases the corrosive areas were of such types as cinder fills, peat bogs, salt marshes, areas where stray current was present, and similar abnormal conditions.

In most areas of proposed new installations local service experience with gray iron pipe will show that ductile or gray iron pipe may be installed without special protection. In questionable areas a soil survey will determine whether potentially corrosive soils are present. The Cast Iron Pipe Research Association (CIPRA) has developed a standard procedure for soil survey tests and interpretation which is based on correlation of soil tests with actual service experience in many different types of soil. The essential features of the CIPRA soil survey procedures are described below.

Representative test points are selected along the route of the proposed pipeline and recorded on the survey map. At each point a small diameter hole is bored to proposed pipe depth by means of a portable power auger. Soil samples are removed from pipe depth for analyses to determine redox potential, pH, sulfides, and soil description. Resistivity is measured in the test hole. The results are evaluated by the point system shown in Table 1.

Earth resistivity is a measure of the ability of the soil to serve as an electrolyte which is significant in the development of local cell corrosion as well as in transmission of stray currents. Resistivity is measured by means of a Vibroground meter connected to a single probe which is inserted into subsoil at the bottom of the test hole. Direct contact with the soil at pipe depth is an essential requirement of the CIPRA resistivity test. The four-pin technique with ground surface contact is considered unsatisfactory because it yields an average value of resistivity for the soil between the surface and a depth equal to pin spacing. The result may be a very misleading indication of conditions at pipe depth.

If the subsoil is relatively dry, the resistivity is also measured with a Miller soil box under laboratory conditions using a soil sample from pipe depth saturated with distilled water. This places all of the soluble salts into solution yielding the lowest resistivity which the soil can reach during the local wet season. Soil box measurement is also used whenever the subsoil temperature is at or near freezing, a condition which yields false high resistivity values. In any case, the measurements are aimed at providing accurate information as to the lowest resistivity value that may occur at the test point and this value is used in evaluating the soil in accordance with Table 1.

The redox or oxidation-reduction potential is an indication of the oxygen content of the soil and is significant because the most common sulfate reducing bacteria can live only under anaerobic (oxygen deficient) condition. A positive redox potential greater than 100 millivolts shows that the soil is sufficiently well aerated that it will not support sulfate reducing bacteria. Positive redox values between 100 millivolts and zero may be anaerobic with the likelihood increasing with decreasing redox. Negative redox potentials definitely indicate anaerobic soil which favors sulfate reducing bacteria. Redox is measured with a Beckman Model N portable pH meter using platinum and calomel electrodes inserted into the soil sample.

The pH value indicates the balance between acid and alkaline constituents in the soil. The acid range from 0 to 4.0 is significant because hydrogen evolution from iron in this range accelerates the corrosion rate and also because the acid constituents responsible for the low pH cause the soil to act as a good electrolyte. Similarly, the alkaline range from 8.5 to 14.0 is significant because the high pH is the result of a large amount of soluble salts which cause the soil to act as an electrolyte when sufficient moisture is present. Values of pH in the intermediate range from 4.0 to 8.5 are not significant except when sulfides are detected and low redox values are obtained. In such cases the neutral pH range from 6.5 to 7.5 does become significant because this is the optimum range for sulfate reducing bacteria if other conditions are suitable. Measurement of pH is made with the Beckman Model N pH meter.

The sulfide test is an indirect qualitative indication as to whether sulfate reducing bacteria may be present. Under anaerobic and neutral pH conditions these bacteria can convert soil sulfates by metabolic action into sulfide compounds. Sulfides serve as corrosive electrolyte material and also as depolarizing agents which accelerate corrosion activity. The qualitative test is made by treating the soil sample in a test tube with a solution of sodium azide and iodine. If sulfides are present they catalyze a reaction between the sodium azide and iodine producing nitrogen gas. The results are rated in three catagories as shown in Table 1 reflecting the degree of nitrogen gas foaming and bubbling which is a relative indication of the sulfide content of the soil.

Prevailing moisture content is a significant factor in soil corrosion. Two soils with similar resistivities and other characteristics may differ substantially in corrosive action if one is in a very dry area while the other is continually saturated. Since moisture content at a given point usually varies during the year, information is gathered from local sources concerning the average moisture condition in the area and the drainage condition at each test point is observed. These factors are used to rate the prevailing moisture condition in accordance with Table 1.

At each test point the subsoil is described as to color and general type. Experience has shown that in a given area isolated corrosive conditions may be associated with certain colors and types of soil. This is valuable information for determining the extent of the corrosive soil and for possible future investigations in the general area.

Observations are also made for possible stray current sources, the most common of which are cathodically protected steel transmission pipelines for gas and oil products. The locations where such pipelines cross or run close to the proposed pipeline are noted on the survey map.

In evaluating the survey findings the results of each of the five basic tests, resistivity, redox, pH, sulfides, and moisture, are assigned points from 0 to 10 as shown in Table 1. Soils receiving a total of 10 points or more are rated potentially corrosive to gray iron and ductile iron pipe. Table 2 shows examples of actual survey test results and evaluations taken from surveys in two separate areas. The moist dark red clay at test point S3 received a total of 5.5 points and was rated non-corrosive with no protection required. The wet blue-gray clay at test point T7 received a total of 20.5 points and was rated potentially corrosive to gray and ductile iron pipe. Protection was recommended for pipe to be laid in this soil.

The CIPRA soil survey standards emphasize evaluation of a number of factors which affect soil corrosiveness and require that no single factor be the basis of a complete judgment. Other systems of evaluating soil corrosiveness have usually taken an oversimplified approach and have attempted to rate soils entirely by one characteristic such as resistivity or pH. Frequently, such systems have established very unrealistic guidelines, for example, rating all soils which have resistivities less than 5000 ohm-cm as being corrosive to all ferrous pipe. This guideline has no factual basis for application to gray and ductile iron pipe as evidenced by the excellent service record of thousands of miles of cast iron pipe in soils with much lower resistivities.

The CIPRA standard procedures have been widely applied in soil surveys made in areas of proposed pipe projects. These surveys, usually requested by the project consulting engineer, have been made in more than 110 localities in 37 states during the past two years.

PROTECTION IN CORROSIVE SOILS

If the soil survey indicates potentially corrosive conditions, it becomes necessary to provide adequate protection for the pipe to be installed. Several protective measures have been considered and determined to be uneconomical or of doubtful effectiveness in their application to gray or ductile iron pipe. For example, increasing the pipe thickness is not justified because other methods give more positive protection at lower cost. Heavy duty factory applied coatings also are undesirable due to high initial cost and the probability of incomplete protection as the result of coating damage in shipment and handling. Cathodic protection of gray and ductile iron pipe is not economical due to high cost of installation, operation and continued maintenance and technical service.

A very effective and low cost protection system for gray and ductile iron pipe has been developed by the Cast Iron Pipe Research Association. The method consists of encasing the pipe with a loose sleeve of 8 mil thick polyethylene during installation. CIPRA has tested this method for 15 years in several very corrosive test sites such as cinders and coastal salt marsh and has determined that it gives excellent protection. British research worker, D. R. Whitchurch, reporting at the 1968 London Conference on Corrosion and Protection of Pipe and Pipelines, confirmed the CIPRA work with data on a series of tests in corrosive English soils. Installations of polyethylene sleeve protection on operating pipelines began in 1958 and the method has subsequently gained wide acceptance.

CIPRA tests have also shown that polyethylene sleeve is effective in preventing corrosion by stray electric currents. Proposed gray or ductile pipelines which will cross cathodically protected steel pipelines should be protected with polyethylene sleeve for one pipe length either side of the crossing to prevent stray current pickup.

The installation of polyethylene sleeve protection is relatively simple and inexpensive. The sleeve has sufficient diameter to pass readily over the belled end of the pipe and is about 2 feet longer than the pipe length. While the pipe is suspended by a center sling, the sleeve is slipped over the spigot end of the pipe and bunched up between the spigot and sling. After the pipe is lowered into the trench and jointed to the previous pipe, the sling is removed. The polyethylene sleeve is then slipped to cover the full length of the pipe and overlap the sleeve on the preceding pipe. The overlap joint is sealed with tape to prevent entry of backfill soil. A water tight seal is not required. The CIPRA tests have shown that ground water intrusion between the sleeve and pipe does not cause significant corrosion.

TABLE 1
EVALUATION OF SOIL SURVEY TESTS

Soils receiving a total of 10 points or more are rated as corrosive to gray iron or ductile iron pipe and protection is indicated.

TYPE TEST	TEST VALUE	POINTS
Resistivity, ohm-cm	over 2000	0
	1500-2000	1
	1200-1500	2
	1000-1200	5
	700-1000	8
	under 700	10
Redox, millivolts	over 100	0
	50-100	3.5
	0- 50	4
	negative	5
pH	0- 2	5
	2- 4	3
	4- 6.5	0
	6.5- 7.5	0 (Note)
	7.5- 8.5	0
	8.5-14.0	3
Sulfides	None	0
	Trace	2
	High	3.5
Moisture	Generally dry, good drainage	0
	Generally moist, fair drainage	1
	Continuously wet, poor drainage	2

Note: If sulfides are detected and low or negative redox values are obtained, pH values in the range of 6.5 to 7.5 are assigned 3 points.

TABLE 2
EXAMPLES OF SOIL SURVEY RESULTS

	S3 DARK RED CLAY		T7 BLUE-GRAY CLAY	
	VALUE	POINTS	VALUE	POINTS
Resistivity, ohm-cm	1815	1	908	8
Redox, millivolts	+60	3.5	+48	4
pH	6.0	0	7.0	3
Sulfides	None	0	High	3.5
Moisture	Moist	1	Wet	2
		5.5		20.5
Rating	Non-Corrosive		Corrosive	

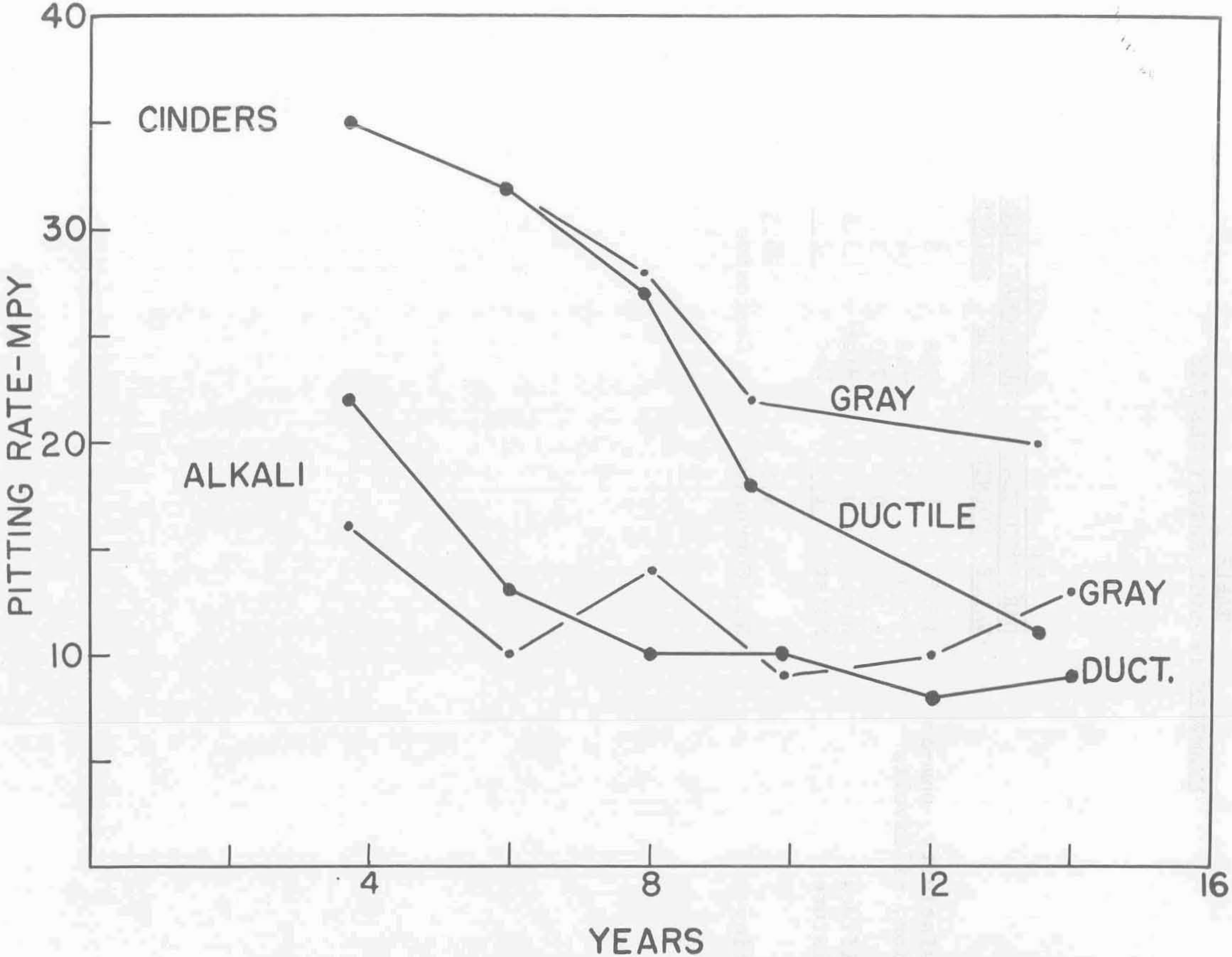

FIG. I PITTING OF DUCTILE AND GRAY IRON PIPE IN CORROSIVE SOILS

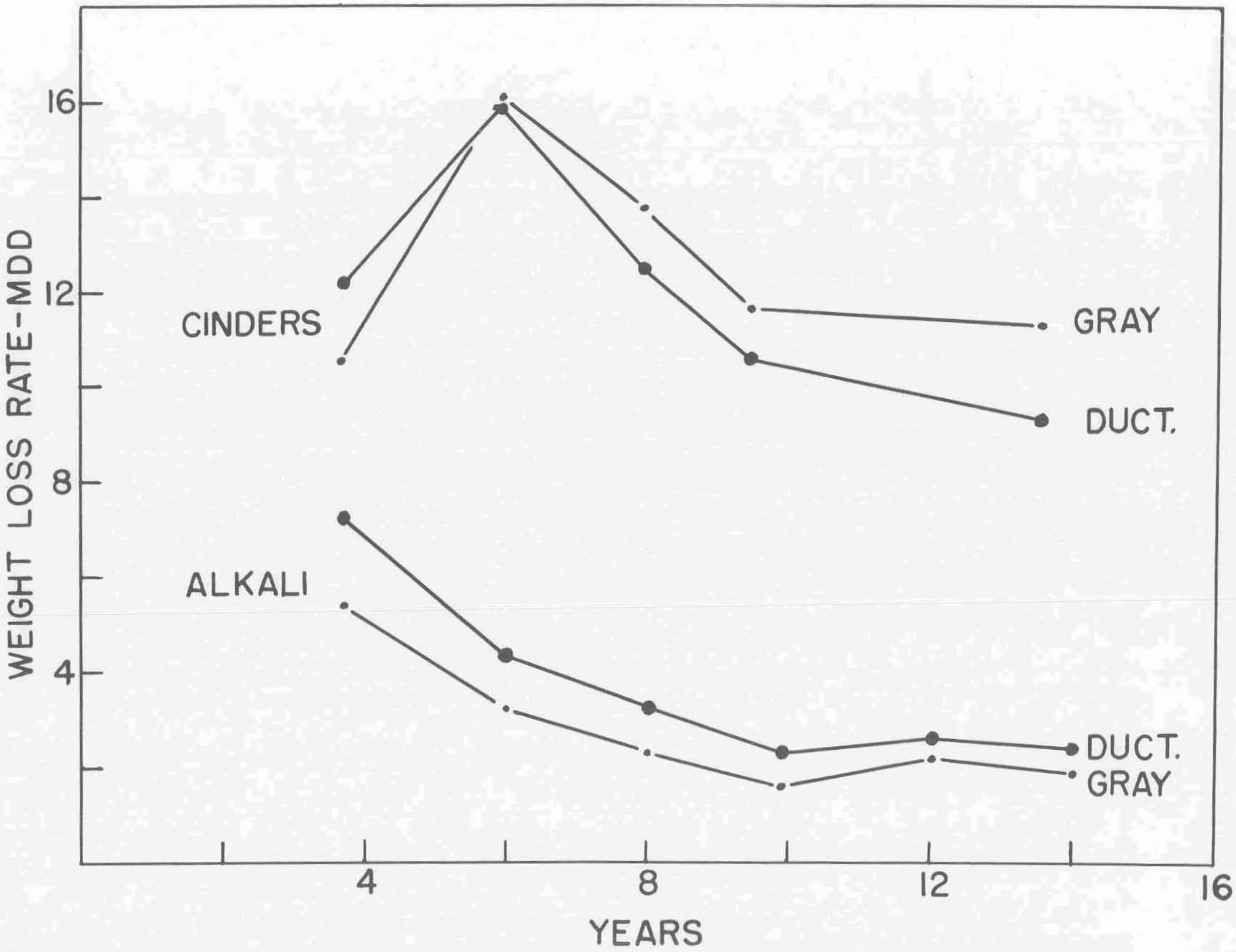

FIG.2 WEIGHT LOSS OF DUCTILE AND GRAY IRON PIPE IN CORROSIVE SOILS