CORROSION CONTROL BY CATHODIC PROTECTION

CORROSION CONTROL BY CATHODIC PROTECTION (Subsurface Metal Structures)

ENGINEERING
DESIGN AND CONSTRUCTION
OPERATION AND MAINTENANCE

NAVDOCKS MO-307

DEPARTMENT OF THE NAVY
BUREAU OF YARDS AND DOCKS
WASHINGTON, D. C. 20390

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FOREWORD

This publication prescribes the preferred maintenance standards, practices, and procedures for the control of corrosion on subsurface structures, and is an effective field manual for enabling personnel to meet the standards established.

The procedures described were derived from extensive field tests and observations at various shore activities, and from knowledge and practices adopted from other pertinent sources. Special recognition is given to the Maintenance Division of the Office of the Director, Southwest Division, Bureau of Yards and Docks for obtaining and compiling the technical information contained in this publication.

The standards prescribed in this publication are in consonance with Bureau of Yards and Docks Technical Publication NAVDOCKS MO-306, formerly Part M of TP-PW-30, and are established to protect Government property, with an economical and effective expenditure of maintenance funds commensurate with the functional requirements and the planned future use of the facilities. This publication is also a guide for maintenance forces in the field who will do the work, and is designed for their use in the performance of this work.

Recommendations or suggestions for modification, or additional information and instructions that will improve the publication and motivate its use, are invited and should be submitted through appropriate channels to the Chief, Bureau of Yards and Docks, Washington, D.C., 20390.

This publication is certified as an official publication of the Bureau and, in accordance with Secretary of the Navy Instruction 5600.16, has been reviewed and approved.

P. Corradi

P. CORRADI,
Rear Admiral, CEC, USN,
Chief, Bureau of Yards and Docks.

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CHAPTER 1. CORROSION CONTROL

1.1 PURPOSE. This manual is primarily intended to be used by public works department shop personnel as a guide for the control of corrosion at naval activities. The information presented includes the types of corrosion, corrosion control, survey methods, installation of protective anodes and graphite rods, and the maintenance of cathodic protection installations.

1.2 TYPES OF CORROSION. Metals corrode when buried in moist soil or when placed in water (see pages 3–14 of DM–4, *Electrical Engineering*). This corrosion is caused by electric current which flows away from the metal and into the adjacent soil or water. The current may be produced at the surface of the metal by a chemical action between the metal and the chemicals in the soil, or by water coming into contact with the metal. This type of corrosion is referred to as "galvanic corrosion" (see figs. 1, 2, and 3). Other sources of current may be an electrical railway system or a current-generating source; in this case, the corrosion is referred to as "electrolysis" (see par. 1.8).

1.3 CONTROL OF GALVANIC CORROSION. The galvanic corrosion of underground metallic structures can be controlled through cathodic protection. Cathodic protection is a method of protecting metal surfaces, through the use of a direct current voltage, from corrosion. The voltage is applied so that the current tends to flow from the direct current source through the soil or water to the metal surface to be protected. This flow of current applies electrical energy that reverses the natural process of corrosion.

1.4 CATHODIC PROTECTION. The underlying purpose of cathodic protection installations is to stop the flow of direct electrical current from a metal structure (bare or coated) through the soil in which it is buried. There are two well-known methods of cathodic protection.

(1) Galvanic Anode System. The galvanic anode system, which requires no external power supply, incorporates the use of metallic anodes. The anode metal generates sufficient voltage in the soil or water which acts as an electrolyte. The electrical current flows from one piece of metal to the other because of a natural voltage difference between them (see appendix A, "Electromotive Series"). The current flows from the anode through the soil to the pipe, thus protecting the pipe. Such metals as magnesium, zinc, or aluminum may be used as the anode.

(2) Impressed Current System. The impressed current system requires graphite rods and an external power source to establish a

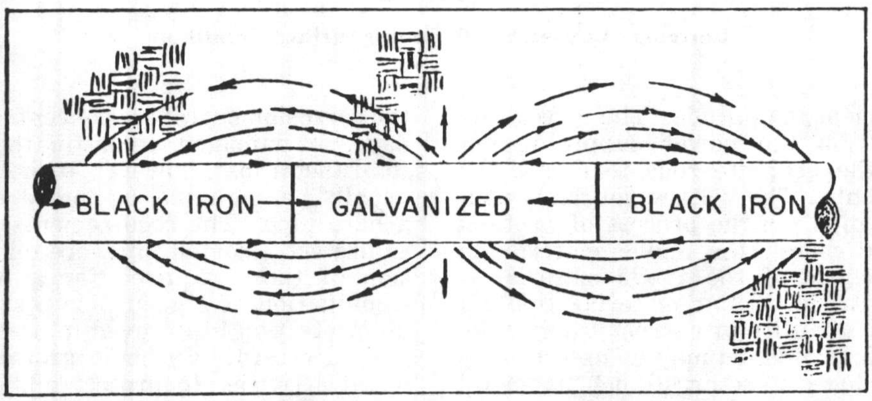


FIGURE 1

Corrosion Caused by Dissimilar Metals

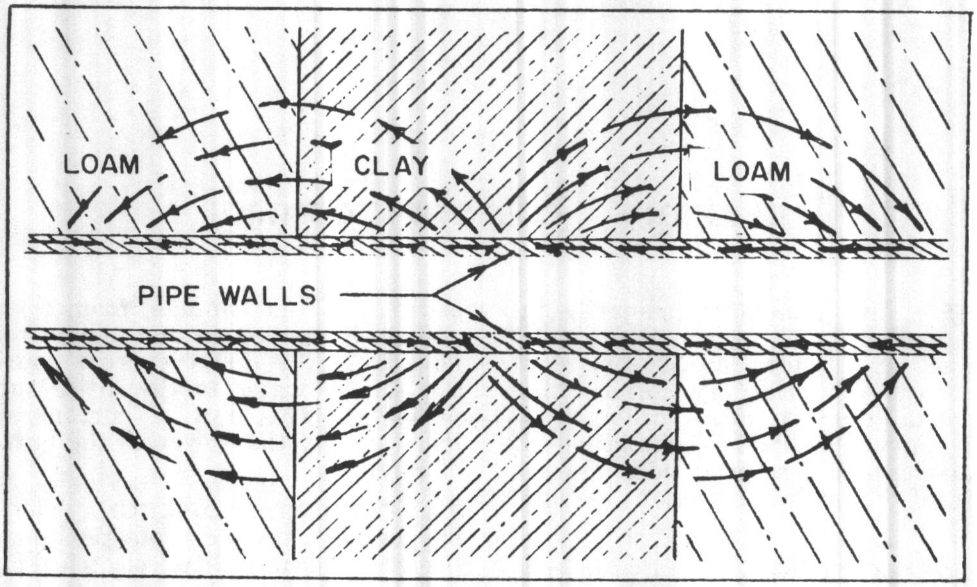


FIGURE 2

Corrosion Caused by Dissimilar Soils

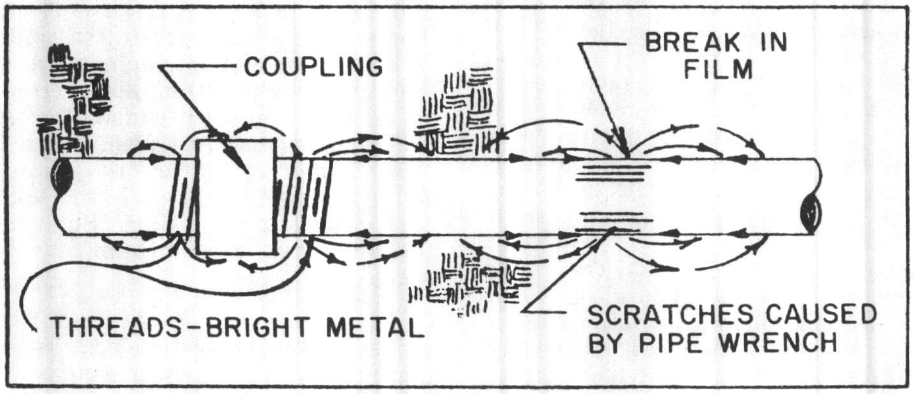


FIGURE 3

Corrosion Caused by Dissimilar Surface Conditions

voltage of sufficient magnitude. The direct current voltage from the power supply is impressed upon the graphite rods to create the necessary currents. The voltage source is usually a rectifier unit. In the process of protecting the desired metal, the anode material is consumed. The life of the anode material is determined by the particular material used, its weight, and the quantity of current leaving the anode. Cathodic protection may be used to protect coated or bare structures, such as metal pipes and tanks. The perforations of a pipe, as a result of corrosion, may occur more rapidly on a well-coated pipe than on a bare pipe, since the corrosion current is concentrated at the holidays, or damaged areas, in the coating. The total metal loss, however, of a coated pipe will usually be negligible as compared with that of a bare pipe. The requirements of the current, to protect a coated pipe, are only a small fraction of those required for a bare pipe. The combination of a good pipe coating plus cathodic protection has proved to be both economical and successful. Cathodic protection is used at naval activities to protect oil, water, and gas lines; various types of buried metal structures; the interiors of elevated water tanks; and both the exterior and interior surfaces of buried and

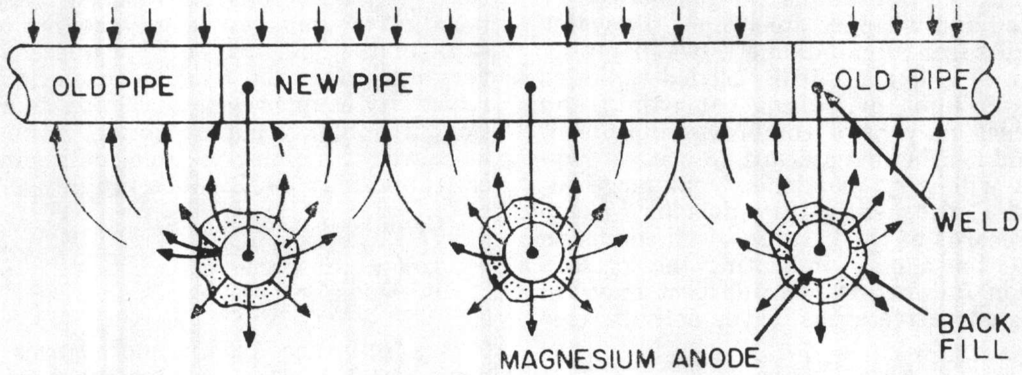


FIGURE 4

Galvanic Anode System

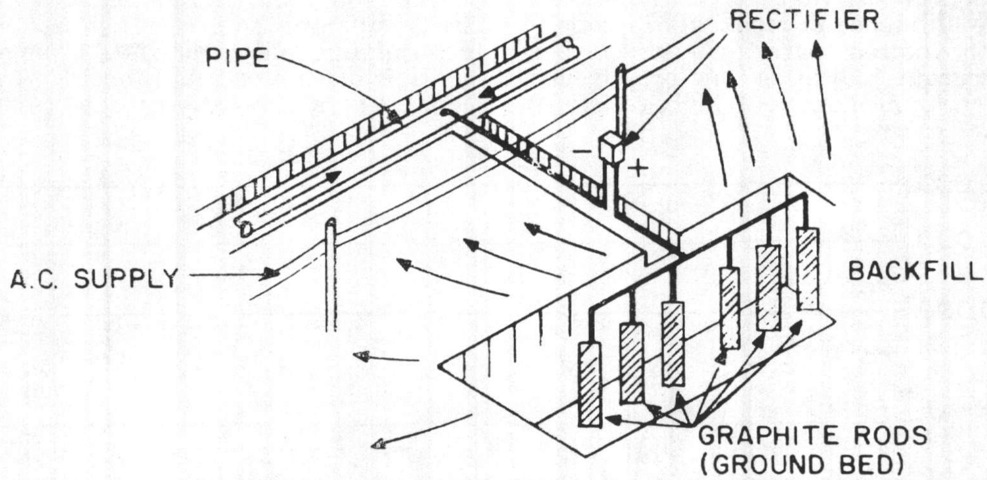


FIGURE 5

Impressed Current System

partially buried tanks. Important applications are the protection of lead-covered cables of telephone, signal, and power systems installed in underground ducts, and the protection of the subway type of equipment, which is subject to frequent immersion in water in manholes.

1.5 CORROSION INVESTIGATIONS. The broad classifications into which the bulk of corrosion field investigations fall may be listed as follows:

(1) visual and physical inspections,
(2) study of maintenance records,
(3) soil resistivity measurements,
(4) potential (voltage) of structure-to-soil (pipe-to-soil potential) measurements, and
(5) cathodic protection current requirement tests.

1.5.1 Visual and Physical Inspections. A visual inspection of a metal structure yields much information. If a structure is found to be corroded, physical measurements on the structure are of great value. Inspections of both aboveground and below-ground structures are valuable. When measurements of buried structures are made, the inspection locations are selected partially by availability, and partially by expected soil conditions as the result of other tests.

1.5.2 Study of Maintenance (Inspection) Records. Properly compiled inspection and maintenance records and graphs contribute much information on the progress of corrosion damage. Since different structures at a naval activity are subjected to varying degrees of corrosion damage, records should be kept separately, by services, for each buried structure. The severity of corrosion damage varies partially because of the different types of construction used over a period of time. For example, the gas mains may be of coated and wrapped steel pipe; the water mains of cast iron; small diameter water piping of galvanized and black iron; buried tanks of steel with a light prime coat of paint; and power cables may be a combination of lead-covered and synthetic materials. Moreover, soil conditions will vary, particularly at large installations. Consequently, it is advisable to keep accurate records of the location of all corrosion failures. Often a map, indicating the location of corrosion failures, is helpful, as it may aid in locating corrosive areas of the activity (see par. 4.4).

1.5.3 Soil Resistivity. Low resistivity soils are corrosive. Although medium and high resistivity soils were once thought of as not being particularly corrosive, much corrosion has been found in high resistivity soil areas. Consequently, the difference in resistivity of soils in contact with different parts of a structure is a more accurate indication of corrosiveness with respect to medium and high resistivity soils. Alkaline soils are usually very low in resistivity because of large amounts of soluble salts in the soil, and are considered as being very corrosive (fig. 6). Because of this, a low resistivity coupled with alkalinity is an indication of a highly corrosive soil. Resistivity is measured in ohm-per-cubic-centimeter (ohm-cm.), and may be classified roughly as follows:

Up to 1,000 ohm-cm	Very low
1,000 to 3,000 ohm-cm	Low
3,000 to 10,000 ohm-cm	Medium
10,000 to 30,000 ohm-cm	High
Above 30,000 ohm-cm	Very high

Wet soils are usually more corrosive than dry soils. Dry, clean sand without salt content is noncorrosive; however, there are some very moist soils, where rainfall is extremely heavy, which are noncorrosive.

1.5.3.1 **Soil resistivity test methods.** Soil resistivity tests are the most often used methods of determining soil corrosivity. Change in resistivity is often a critical property. Information concerning soil resistivity is necessary for the

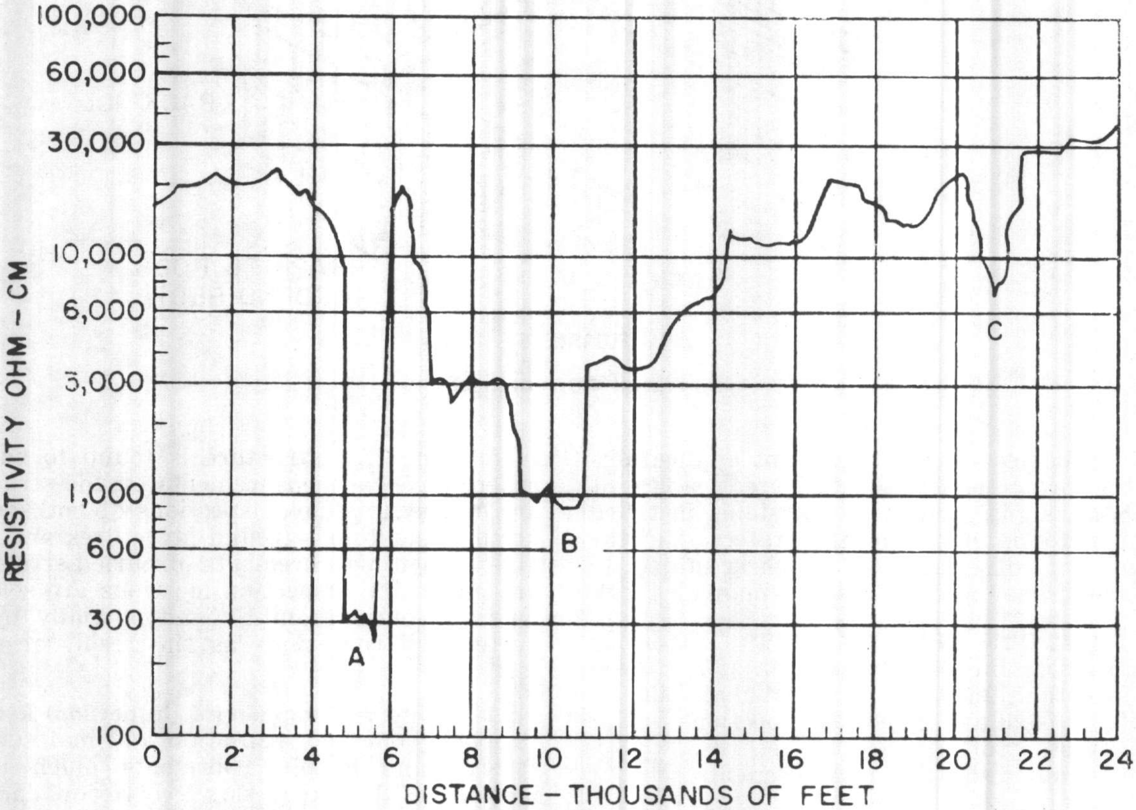


FIGURE 6

Soil Resistivity Profile. Showing Location of Three "Hot Spots": (A) a steam crossing, (B) a slag backfill, (C) a cinder backfill

layout of cathodic protection systems. Resistivity tests combined with a knowledge of the types of soil in an area, from the standpoint of texture, aeration, and alkalinity or acidity, present the most accurate available method of predicting the corrosiveness of the soil in the area.

1.5.3.1.1 **Shepard cane method of measuring resistivity.** Suitable locations for anode or ground bed installations may be quickly determined by making preliminary tests of soil resistivity at and near the surface by means of "shepard canes." At several spots throughout the area to be cathodically protected, these tests will indicate the more desirable areas of low resistivity at which more detailed tests for layout purposes should be made. The shepard canes indicate the average soil resistivity directly in ohm-centimeters, but only to a depth of approximately 8 inches below the steel contact surfaces at the ends of the rods. Resistivity values within 10 percent are obtained at the point at which the tip of the probe is placed in the soil or liquid. It is useful for obtaining resistivity of liquids or soil resistivity in excavations and trenches. Earth resistivity meters are usually calibrated to give results directly in ohm-centimeters. These meters are usually manufactured with one or two ranges on the meter, and read from zero to 30,000 or 50,000 ohm-cm.

1.5.3.1.2 **Four-Pin method of measuring resistivity.** The average resistivity of a large volume of earth can be determined from the surface of the ground by a method developed by Wenner. With this method (fig. 7), four metal pins are driven into the earth in a straight line, equally spaced (spacing = "a" feet). The average soil resistivity will be determined to a depth equal to the space (a) between the pins. To make the measurement, a battery current (I), controlled with a rheostat and measured with an ammeter, is passed through the outside pair of pins, and the resulting differences of potential (E) between the inner pins are observed. The average soil resistivity (p) to a depth of "a" is given in ohm-centimeters by the formula (see NAVDOCKS MO-306, *Corrosion Prevention and Control*):

$$p = \frac{191aE,}{I}$$

where,

p = resistivity,
a = spacing between pins (feet),
E = voltage between the pins,
I = current passed between the two outer pins.

Tests are usually made to a depth of several feet below the depth of the structure to be protected. Measurements recorded must be averaged.

1.5.4 Structure-to-Soil Potential Measurement. Structure-to-soil potential (voltage) measurements are used to locate the possible existence of corrosive areas on such metal structures as a pipe or tank. The same type of measurement is used to determine the adequacy of protection where cathodic protection is installed. When making these measurements, it is necessary to connect a voltmeter between a reference electrode and the structure (pipe or tank). The commonly used reference electrode is a copper-copper sulfate half-cell. It is used to provide a low constant resistance contact with the soil (fig 8). A suitable high-resistance voltmeter should be used for this type of measurement. A meter of 20,000 ohms per volt will be satisfactory. A meter with a higher resistance, a potentiometer, or a vacuum tube voltmeter may be used. Figure 9 shows a typical test setup

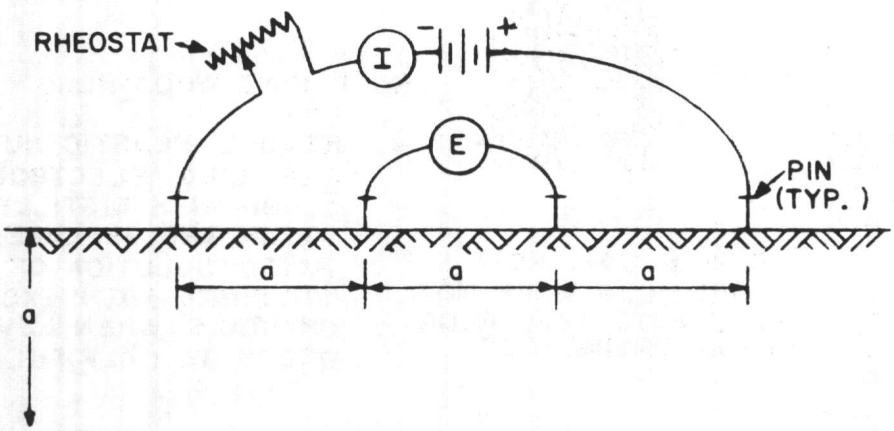


FIGURE 7

Four-Pin Resistivity Measurement

for a structure-to-soil potential measurement. The structure-to-soil potential is a criterion of protection. A potential (voltage) of —0.85 (referred to a copper-copper sulfate electrode) will, in virtually every case, be indicative of full protection. A —0.85-volt pipe-to-soil (structure-to-soil potential) has been adopted as a criterion of protection for bare steel and iron structures in soil or water. A reading of —1.0-volt is a criterion for complete protection of a well-coated pipe. The higher value for the well-coated pipe is recommended because of the high IR (voltage) drop through the coating. Extreme care must be taken to assure good con-

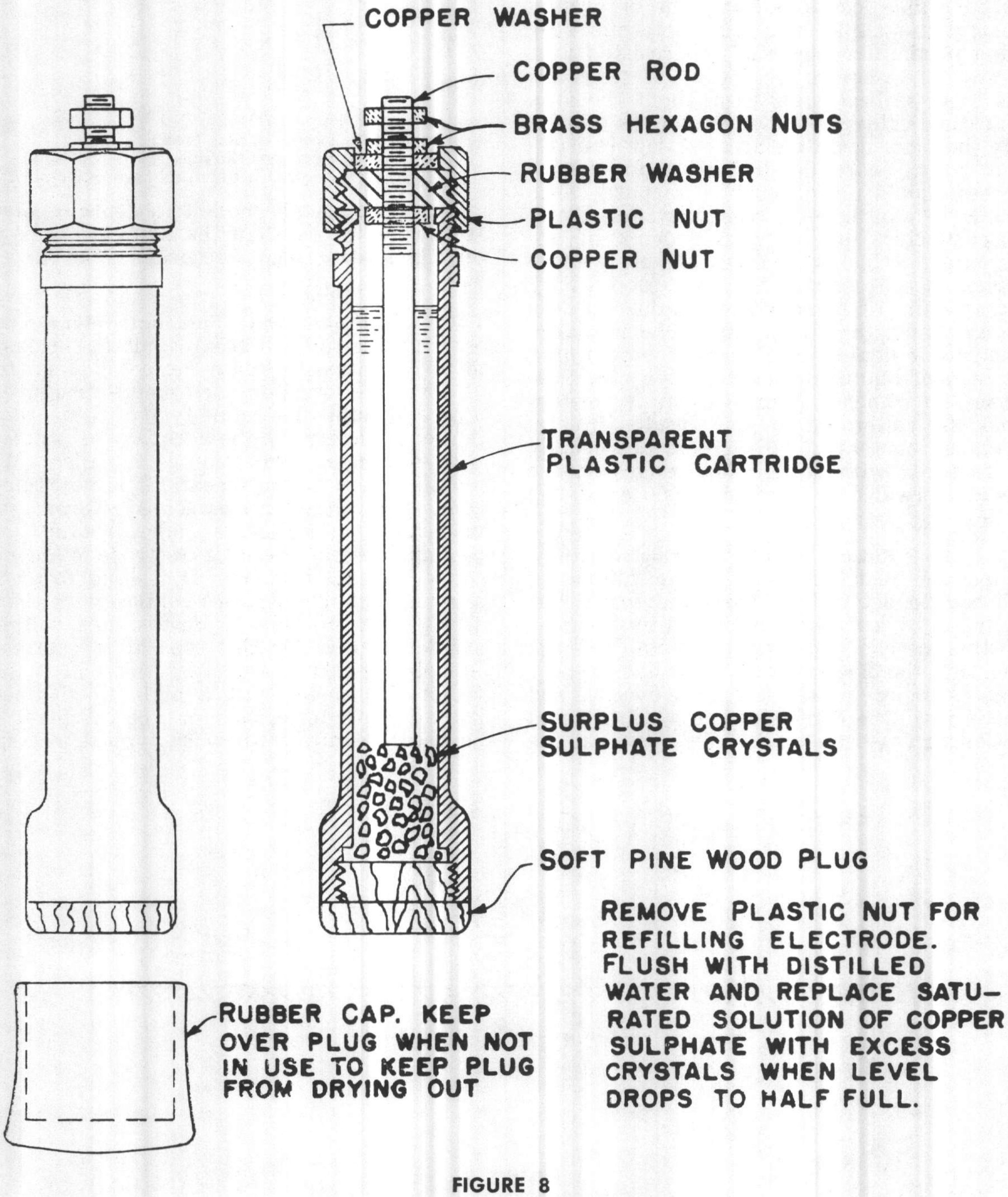


FIGURE 8

Copper Sulfate Half Cell

tact with the structure if it is contacted by a probe bar which is pushed through the earth. An insulated probe bar should be used to eliminate any effect the voltage-to-earth of the bar might have on the reading. It may be necessary to repeat the measurements several times to obtain consistent results.

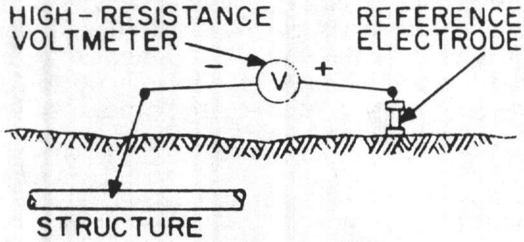


FIGURE 9

Structure to Soil Potential Measurement

1.5.5 Cathodic Protection Current Requirements. Current requirements to protect a metal structure may be estimated as indicated in the examples given in appendix C. Current requirement data, covering many field installations on new and old pipe, are indicated in the following figures:

Bare pipe	1	ma./sq. ft. (anode system)
Bare pipe	3	ma./sq. ft. (impressed current system)
Old coated pipe	0.2	ma./sq. ft. (anode or impressed
New coated pipe	0.1	ma./sq. ft. current system).

1.6 CATHODIC PROTECTION CURRENT TESTS.

(1) Obtain representative resistivity data for soil at or near the pipe depths along the pipeline (see par. 1.5.3.1).

(2) Calculate the average soil resistivity at or near the pipe depth. The shepard cane method indicates a v e r a g e soil resistivity, whereas the 4-pin method does not (NAVDOCKS MO–306, *Corrosion Prevention and Control.*)

(3) Cathodic protection current requirements.

(a) Obtain the cathodic protection current requirements from the curves in figure B–1, using the previously obtained soil resistivity data.

(b) As an alternate method, obtain the cathodic protection current requirements (see fig. B–4) from field tests. When this alternate method is employed, it is not necessary to measure the soil resistivity except for the purpose of selecting locations for anodes or ground beds.

(4) Determine the protection current source (par. 1.7 and 1.7.3).

(a) Anode system. Determine the number of anodes needed, the most advantageous size, and the grouping and location for magnesium or zinc anode beds from paragraph 3.1 and appendixes C and F.

(b) Impressed current system. Determine the size of the rectifier required to drive the ground bed current through the soil to the pipe (par. 2.4.1 and appendix C). Determine the number of graphite rods, and the grouping and location for the graphite rod ground bed (pars. 2.2.2 and 2.2.5).

(5) After a system is installed, a period of 2 weeks should be allowed for the conditions to stabilize. Pipe-to-soil potential measurements should be conducted to determine the adequacy of protection (par. 1.5.4).

1.7 CATHODIC PROTECTION CURRENT SOURCE.

After determining the protection current requirement for a pipe section of system which is to be placed under cathodic protection, the next step is to decide which source of cathodic protection current should be used.

1.7.1 Galvanic Anodes. Galvanic anodes are generally the most convenient and economical current source for requirements up to approximately 5 amperes. Practical limitations are mainly confined to soil resistivity values and current requirements per unit length of pipe. As a general rule, galvanic anodes are preferred in congested locations where interference with adjacent structures may occur. The total current can be readily controlled by the number of anodes installed and the spacing between them. The two types of anodes in general use are magnesium and zinc, which are in various shapes and sizes.

1.7.1.1 Magnesium Anodes. Magnesium anodes are packaged with the necessary backfill material, and are available in such ranges as the following:

Weight	*Resistivity range (use)*
9 lbs	Above 3,000 ohm-cm.
17 lbs	1,800–3,000 ohm-cm.
32 lbs	800–1,800 ohm-cm.
50 lbs	Below 800 ohm-cm.

The 17-pound and the 32-pound weights are weights most commonly used.

1.7.1.2 Zinc Anodes. Zince anodes are extensively used in fairly low resistant soil when the current requirement is small. Zinc is available in 14-pound and 23-pound sizes, and must be installed in a gypsum backfill material. The current output of either type of anode may be controlled by the spacing of the anodes in the multiple installation, or by a resistor in series with the anode when a single anode is used. It is practical to limit the spacing between the anodes to a value that will limit the current so as to obtain a 10- to 15-year life expectancy.

This will be discussed further in paragraph 2.1.1.

1.7.2 Rectifiers. When the current requirements at one point exceed 5 amperes, a rectifier is generally the most economical source of cathodic-protection current. However, for requirements under 5 amperes, the power cost may be excessive because of minimum billing. A disadvantage in using rectifiers, regardless of the current requirement, is the relatively high-operating voltage in the vicinity of the ground bed and the tie-in to the structure being protected. This high voltage, plus a relatively high-current density at and near the ground bed rods, is a factor to be considered when there are foreign underground metal structures nearby. Therefore, to avoid interference with such structures, it is necessary to locate rectifier installations in relatively isolated areas, but near a source of commercial power.

1.7.3 Physical Factors. There are several factors to be taken into consideration when selecting a current source. These may be broken down into:

(1) soil resistivity,

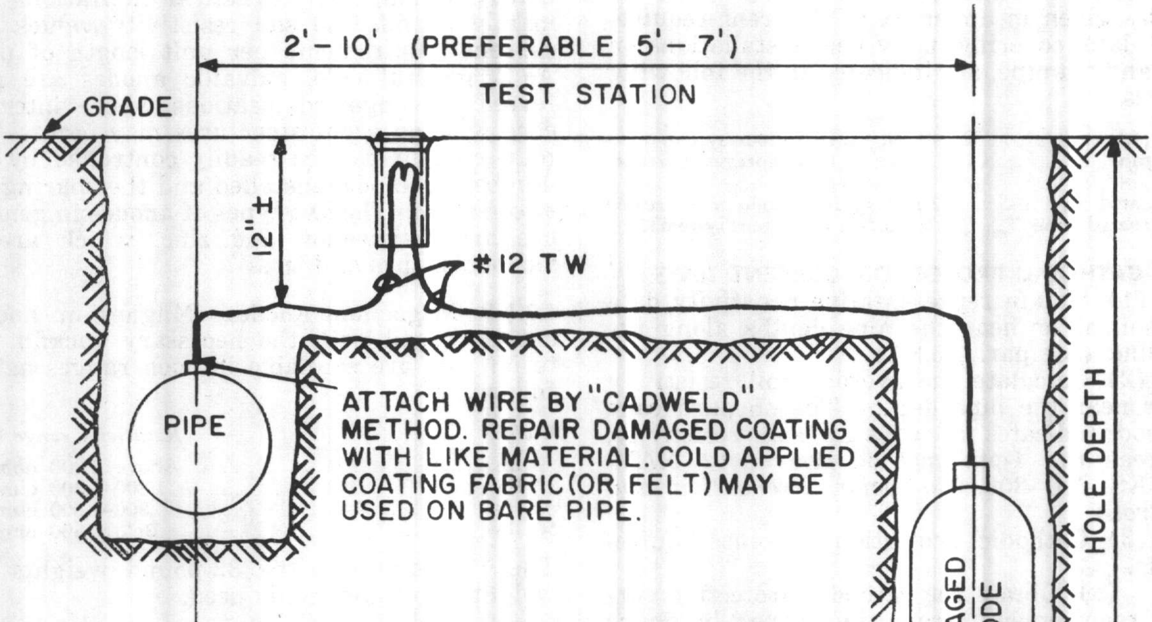
(2) area into which anodes or ground bed may be installed, and

(3) source of commercial power.

Of these three factors, the first to be considered would be soil resistivity. Either magnesium or zinc may be satisfactorily used in soil below 1,500 ohm-cm. (see fig. 10). Magnesium may be used to protect bare pipe in soils up to 5,000 ohm-cm., and to protect coated pipe in soils up to 10,000 ohm-cm.

	Pipe	*Soil resistivity*
Magnesium	Bare	Up to 5,000 ohm-cm.
Magnesium	Coated	Up to 10,000 ohm-cm.
Zinc	Bare	Up to 1,500 ohm-cm.
Zinc	Coated	Up to 2,500 ohm-cm.

When deciding between magnesium and zinc, the prime consideration is the current requirement per unit length to be protected. For a long life, low-current-installation zinc is usu-



ANODE WEIGHT	PACKAGE SIZE		HOLE SIZE	
	DIAM.	LENGTH	DIAM.	DEPTH
17#	6 1/2"	24"	7 1/2"	6'-0"
34#	8"	28"	9 1/2"	6'-6"

FIGURE 10

Typical Magnesium Anode Installation

ally preferred because of its self-regulating action (magnesium and zinc anode life curves, in NAVDOCKS DM-4). Normally, rectifiers should not be considered for installation requiring less than 5 amperes, except in the case of bare pipe in soils with resistivities greater than 5,000 ohm-cm. In soil having a resistivity greater than about 1,500 ohm-cm., zinc is not considered practical except in installations of small current, such as well-coated new pipe. Zinc is not recommended for installations in soil having a resistivity greater than 2,500 ohm-cm. Magnesium anodes, 17-pound or 32-pound types, may be successfully used to protect bare pipe in soils up to 4,000 or 5,000 ohm-cm.

When soil resistivity is greater than 5,000 ohm-cm., it is considered unsatisfactory for galvanic anode installations, except to protect coated pipe requiring a small amount of current. If it is necessary to install galvanic anodes in soils of this value, anodes should be spaced as wide apart as practical, and in small groups. Although both soil resistivity and current requirements may indicate a rectifier installation, it may be impractical because of foreign metal structures in the area. In congested areas, galvanic anodes are believed to be the only satisfactory source of power. In this case, either magnesium or zinc anodes should be used even though they are not the most economical source of power. Normally, cathodic-protection installations will not be

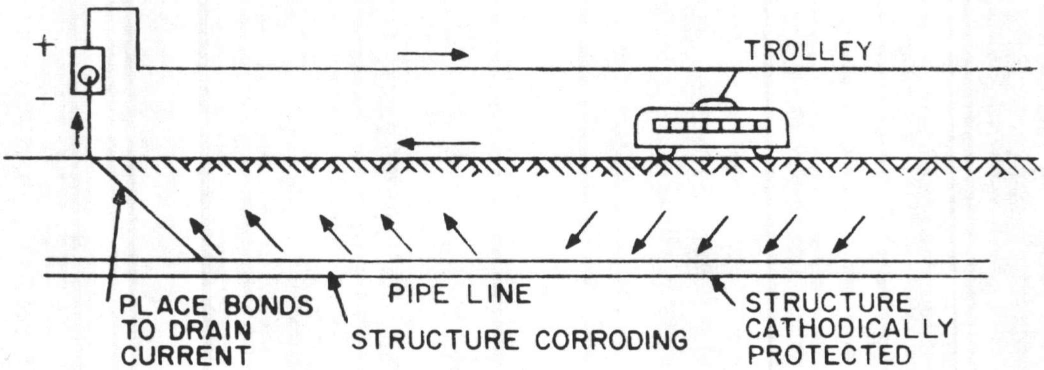


FIGURE 11

Stray Current Corrosion—From Trolley

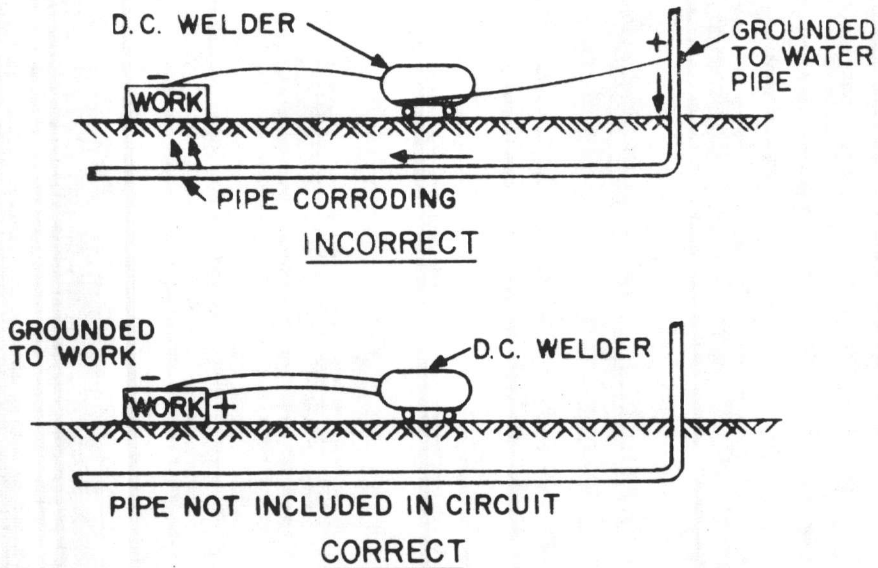


FIGURE 12

Stray Current Corrosion—From Welder

placed where the soil resistivity is extremely high throughout the area. Sometimes, it may be necessary to install the galvanic anode in a horizontal manner to take advantage of a thin stratum of low resistance soils.

1.8 STRAY CURRENT CORROSION (ELECTROLYSIS). The general method for eliminating or minimizing stray, direct current from an electric railway and from electric welders is as follows.

(1) Reduce the resistance of the track circuit by eliminating high-resistance rail joints and by installing additional negative feeders parallel to the track (this work must be done by the traction company).

(2) Carefully insulate all buried pipe at points where they cross the railway tracks to minimize the picking up of current.

(3) Install bond wires between pipelines at locations where current is passed from one line to the other so that the current is transferred through the wire instead of the soils.

(4) Install drain wire between the pipe and the track in the vicinity of the substation where there is a tendency for the current to be discharged from the pipe and picked up by the track or underground negative feeder (fig. 11).

(5) When using welding units, make sure to ground unit to structure being welded. Do not ground to water pipe or foreign structure (fig. 12).

CHAPTER 2. ANODE, GROUND BED, AND RECTIFIER INSTALLATIONS

2.1 INSTALLATION OF GALVANIC ANODES. The desired output determines both the material used and the arrangement of individual anodes.

2.1.1 Location of Anode Bed. The soil resistivity and the available space factors can be determined by a complete investigation of the pipe or structure to be protected and the soils in the vicinity of the anodes. It is important to choose a location where the soil has a low resistivity and where it remains moist. (Low, poorly drained areas are generally good locations.) This area should be determined by making soil tests using suitable types of instruments (see par. 1.5.3.1). Generally, the installation should be made, whenever possible, in accordance with the standard installation sketch shown in figure 10 and in appendix F. Modifications in the grouping or spacing of anodes may be necessary, but the general procedure will be the same. The following precautions should be observed.

(1) Care must be taken not to break or damage the connecting line wires to anodes.

(2) Backfill should make firm contact with the side of the holes and anodes, and there should be no voids present. (Used with zinc anodes.)

(3) Anodes should be spaced as near the center of the hole as practicable.

(4) All electrical connections must be soldered, and must be taped with rubber and friction tape.

(5) The anode connecting wire should be welded to the pipe. A Cadweld thermite welding kit may be used. Each weld must be coated to ensure insulation from soil.

2.1.2 Spacing of Anodes (Galvanic). The ground-bed resistance decreases as the space between the anodes increases. For bare pipe, anodes should be located 10 feet from the pipe with a maximum spacing between anodes of not more than 70 feet. For coated pipe, anodes should be located 10 feet from the pipe and may be spaced several hundred feet apart (appendix F).

2.2 INSTALLATION OF GROUND BEDS. Ground beds for impressed current systems usually consist of two or more graphite rods. The proper number of rods should be selected and properly spaced to form a bed whose resistance is such that the total annual cost will be a minimum (fig. 13). A high-resistance bed requires an excessive amount of power, and a low-resistance bed may require too great an original investment. The recommended standard rod to be used with a rectifier is a 3″ × 60″ graphite rod. Other sizes of rods are available and may be used when the desired current per rod will not give the desired life from the 3″ × 60″ size. Table 1 lists the maximum current output for graphite rods for use in soil or fresh water.

TABLE 1

Maximum Current Output per Graphite Anode

Anode size	*In soil with backfill*	*Suspended in fresh water*
3″ × 60″	4.0 amperes	1.0 amperes
4″ × 80″	7.0 amperes	1.8 amperes

2.2.1 Ground Bed Location. The ground bed should be located in the area of lowest resistance (same as for galvanic anodes) which is nearest the point where corrosion has been determined to be severe (see par. 2.1.1). The availability of power is important. Ground beds can be located as near as 50 feet from a coated pipe. The maximum distance should seldom exceed 1,500 feet. Normally, the vertically positioned graphite rods are installated in 12″ × 108″ holes with coke breeze backfill. The backfill should extend at least 1 foot above and below the rods. Although graphite rods are preferred, carbon rods or scrap steel may be substituted. The installation of scrap steel is the same as for that of graphite rods. A 1-inch-wide strip of primer pipeline enamel must be applied to the entire length of each section of scrap steel to prevent them from separating in operation.

2.2.2 Spacing and Number of Rods. Ground-bed resistance decreases as the space between the rods increases. However, little is gained by spacings of more than 20 feet, except in high-resistive soils. In such soils, spacing up to 35

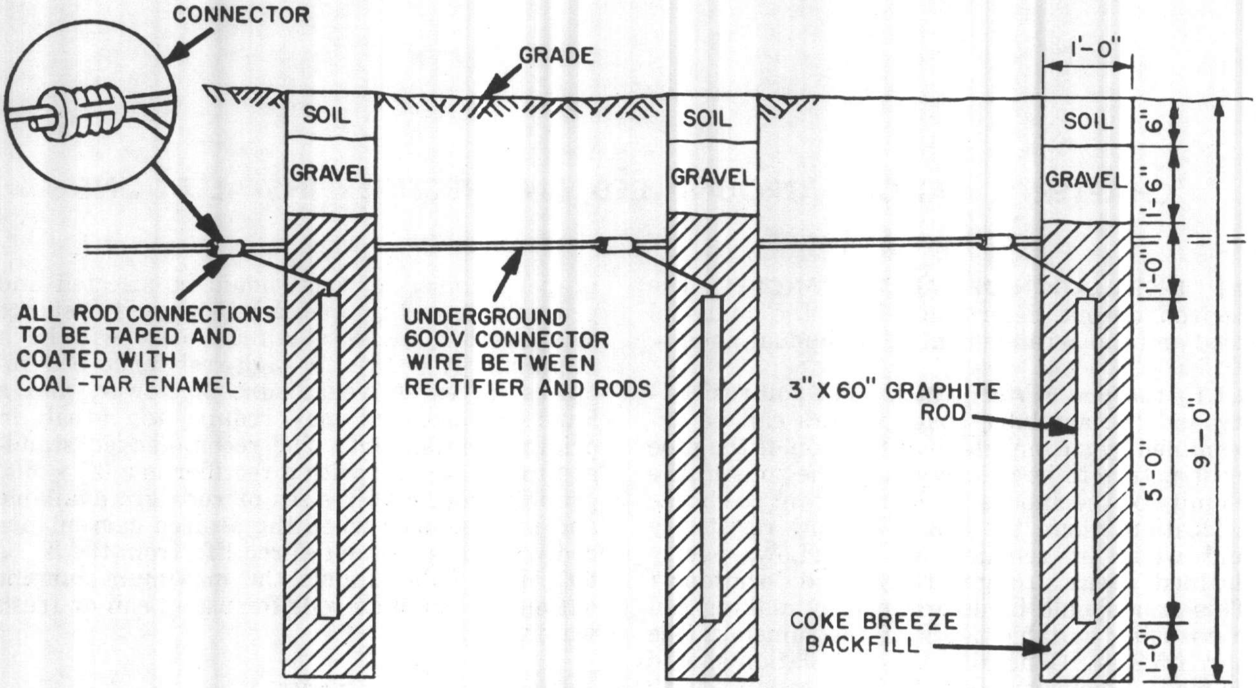


FIGURE 13

Vertical Rod Installation Detail of Typical Impressed Current Ground Bed

feet may be economical. The installation seldom should have more than 15 rods per ground bed.

2.2.3 Backfill Material. To obtain the maximum efficiency and life from graphite or carbon rods, special backfill coke breeze should be tamped around the rods at the time of installation.

2.2.4 Wiring. Graphite rods are equipped with a 5-foot, No. 8, stranded-copper lead, which is insulated with rubber under a neoprene sheath. Care must be taken when running bus leads and when making connections to the ground-bed rods. Bus leads should be insulated with highly impervious insulating material. The recommended insulating material is natural rubber under a neoprene jacket. Considerable care should be taken to ensure that all joints are well insulated since any conductor exposed to the soil would be rapidly destroyed by the rectifier current. All joints in the cable system should be made with as low a resistance as can be obtained. Bolted joints, if used, should be filed flat, and made up very tightly. Soldering and brazing are the preferred methods (fig. 13). The connecting wire bus from the rods may be welded to the pipe with a Cadweld thermite welding kit. Each weld should be coated to ensure that an insulated connection has been made. Cable size should be large enough to minimize voltage drop and to handle additional current in future years. Increased current demand may result from line coating deterioration or additional metal area protection.

2.2.5 Determining The Size Of The Ground Bed. To determine the ground-bed size required to protect a certain buried-metal structure, the following steps should be observed.

(1) Measure the average soil resistivity at normal graphite rod depth (par. 1.7 and 2.2).

(2) Determine the total current required to provide protection (appendix B).

(3) Determine the number of graphite rods needed in the ground-bed to carry the total protection current.

$$\text{Number of rods} = \frac{\text{Total protection current (appendix B)}}{\text{4 amperes (table I)}}$$

Example:

Total protection current = 16 amperes.
Maximum current per graphite rod = 4 amperes (table I).

$$\text{Total rods} = \frac{16 \text{ amperes}}{4 \text{ amperes}} = 4 \text{ rods.}$$

Note: to provide reserve current capacity always add one additional rod to the number of rods needed.

2.3 RESISTANCE OF GROUND BED. Compute the resistance to soil for the ground-bed determined in Item (3) of paragraph 2.2.5.

(1) The resistance to soil of a single graphite rod is found by:

$$R = \frac{pK}{1,000};$$

where,

R = resistance in ohms for a single graphite rod,
p = soil resistivity in ohm-cm,
K = a constant 3.0 for a 3″ × 60″ graphite rod.

(2) The resistance to soil for several graphite rods in parallel is found by:

$$R_t = \frac{R}{0.6N};$$

R_t = ground bed resistance to soil,
R = resistance in ohms for a single graphite rod,
N = number of graphite rods in the ground bed,
0.6 = reducing factor for mutual interference between rods.

Example:
Average soil resistivity = 1200 ohm-cm.,
Total protection current = 16 amperes,
Number of graphite rods required = 5 rods.

$$R = \frac{pK}{1,000} = \frac{1,200 \times 3}{1,000} = 3.6 \text{ ohms (for one rod)},$$

$$R_t = \frac{R}{0.6N} = \frac{3.6}{0.6 \times 5} = 1.2 \text{ ohms (5-rod ground-bed)}.$$

2.4 RECTIFIERS. Normally, the rectifier installations must be tailormade to fit the prevailing condition. The leads should be run as nearly as practicable to conform with the recommended standard procedure. It is desirable that the leads run in such a manner as to be neat in appearance and properly protected from tampering or accidental damage. The supply voltage to a rectifier is high enough to be dangerous. Contact with the supply voltage may result in severe electrical shock or, under adverse conditions, it may be fatal. For this reason, all connections should be well taped and protected from the operator as well as from the public. Under no condition should a rectifier be serviced with power on. Personnel servicing or adjusting the rectifier should be familiar with the rectifier installation wiring as well as with the conditions necessary for complete protection of the pipe.

2.4.1 Determining the Size of the Rectifier. When using an impressed current system, the current requirements for the protection of bare pipe should be calculated at 3 milliamperes per square foot of metal to be protected, rather than at 1 milliampere, when using magnesium anodes. This is because more current is being absorbed by the pipe area near the physical location of the rectifier. The size of the rectifiers needed to protect the pipe is dependent upon three factors.

(1) ground bed resistance R_t (par. 2.3),
(2) permanence, and
(3) cost.

If the ground-bed resistance is 1.2 ohms and a protection current of 16 amperes is needed, then the rectifier voltage (E) required would be:

$$E = (I \times R_t) = 16 \times 1.2 = 19.2 \text{ volts}$$

where

E = rectifier voltage,
I = total protection current needed (appendix B),
R_t = total ground bed resistance (par. 2.3).

To provide sufficient capacity for additional current demands because of dry seasons and pipe-system growth, the rectifier should be capable of supplying 20 volts at 20 amperes. The total output power will be 307 watts. If the ground-bed resistance were reduced to 0.4 ohm by use of a lower resistivity site, the same protection current could be provided by an 8-volt rectifier, and the power consumption could be cut in half (par. 2.3).

It is a safe practice to install a rectifier of greater capacity than that indicated by the original calculations. If more current is temporarily needed, as is the case during prolonged dry weather, the voltage of the rectifier may be increased. This plan is adapted to a cathodic-protection system in which the rods are not carrying their full rated current output under normal conditions.

2.4.2 Criteria for Protection. The criterion for the complete protection of a well-coated pipe is a pipe-to-soil voltage of 1 volt. A minimum voltage of 0.85 volt is used for poorly coated or bare pipe. The higher value for the well-coated pipe is advisable because of the high voltage (IR) drop through the coating.

2.5 SUMMARY OF THE USES OF CATHODIC PROTECTION

2.5.1 Galvanic Anode Systems. Galvanic anode systems are used most often in the following types of installations:

(1) local or hot-spot protection on pipelines;
(2) small isolated tanks (exterior and interior);
(3) moderate size tank farms;
(4) general protection on well-coated lines;
(5) building utility service protection;
(6) all types of installations when power is not available;

(7) hazardous location installations where commercial power is not permissible; and

(8) restricted area protection, such as on condenser water boxes.

2.5.2 Impressed Current Systems. This type of system is usually used for the following types of installations:

(1) bare and poorly coated pipe lines of all sizes;

(2) large tank installations (exterior);

(3) water storage tanks (interior);

(4) protection of several services in an area; and

(5) process tanks, particularly those containing acids.

2.5.3 Coated Piping. Good coating materials, correctly applied, materially reduce the corrosion of buried or submerged metal structures. However, by the very nature of corrosion process, pitting can proceed rapidly at any flaws which may exist in the coating (par. 1.4). Therefore, coating should be supplemented with cathodic protection. While the complete protection of a bare pipe may require from 1 to 3 milliamperes of current per square foot of surface area, a new, well-coated pipe will require only 0.1 milliamperes per square foot.

CHAPTER 3. GOOD INSTALLATION PRACTICES

3.1 GALVANIC ANODE OR GROUND BED LOCATION. Low, poorly drained areas are generally good locations for an anode or ground bed installation, since a moist environment is highly desirable for efficient anode operation. The ground bed should be located in an area of lowest soil resistance and nearest those points where corrosion has been determined to be most severe. Of prime consideration in choosing sites for either galvanic anodes or rectifier ground beds is the location of foreign underground metal structures relative to the position of the proposed installation. In the event that insufficient clearances are maintained, the foreign metal structure may pick up current in the region of the ground-bed influence and discharge it into the ground at some other point, thus causing or accelerating corrosion of the foreign structures. Therefore, rectifier ground beds should under no conditions be located closer than 50 feet from the structure to be protected, or 500 feet from such foreign structures as water lines, underground telephone cables, etc. Galvanic anode installations are not so critical, but they should generally be at least 20 feet from a foreign structure with either type of installation, and particularly if the spacing limitations cannot be maintained. Structure-to-soil voltage tests (par. 1.5.4) should be made on the foreign metal structures after the protection system is installed to determine if there is danger of damage to such structures.

If damage is possible, the Field Engineering Office, Maintenance Division, should be advised and assistance requested by means of an Engineering Service Request. When a galvanic anode or rectifier ground bed must be installed it is most important that a site be obtained on which future improvements, buildings, paving, etc., will not block the maintenance of the cathodic protection system. To obtain immediate current output from a ground bed, the backfill may be puddled; that is, water may be added to the dry backfill mixture in the hole and mixed with a stick. This can be done by pouring in 1 or 2 gallons each of backfill and water and mixing them, and then by adding more backfill and water.

3.2 INSULATING. After deciding on the piping section to be protected, first electrically isolate this section from the remainder of the piping system. This may be done by insulating the valve flanges or by installing Dresser-type couplings at the desired points (appendix D). If desirable and practical, insulating should be done so as to provide sectionalizing points to break major protected sections into smaller sections for test purposes. This also reduces the surface area to be protected, and eliminates surface area that might not require protection. Buried metal tanks should be insulated from any metal pipelines or other metal structures before application of cathodic protection and vice versa. It is necessary to insulate at all gasline regulators within a section that is to be protected. Normally, this can be done by installing suitable fittings at all regulators (appendix D).

3.3 BONDING. All underground Dresser couplings that are to be included within the protected pipe section should be bonded at the same time that the insulating work is done. All open Dresser couplings must be located if the pipe section is to be protected as a unit. In special cases, some Dresser valves may not be bonded if it is practical to protect the piping in small units by installing distributed galvanic anodes. Usually, Dresser couplings in the buried pipe system can be located after cathodic-protection installations have been made, and after the protective current has been applied. After partial protection has been obtained, open Dresser valves will be indicated by differences in pipe-to-soil voltages (appendix D).

3.4 INSTALLATION OF TEST LEADS. Sufficient tests leads, terminating in handholes, should be provided throughout the protected pipe system or structure to provide the necessary contacts with the buried piping for checking the operation of a cathodic-protection system. These test leads may be used for determining the adequacy of protection and for troubleshooting. Test leads may be installed when new pipe is installed, or when repairs are made to leaky pipe.

CHAPTER 4. MAINTAINING CATHODIC PROTECTION SYSTEMS

4.1 GALVANIC ANODE SYSTEMS. Periodic pipe-to-soil voltage tests (par. 1.5.4) are required to maintain galvanic anode systems having magnesium or zinc anode beds. The purpose of these tests is to determine whether adequate protection is obtained.

4.1.1 Test Data Interpretation. The minimum pipe-to-soil voltage, with reference to a copper-copper sulphate half-cell, should be —0.85 volts. The maximum pipe-to-soil voltage should be —1.5 volts. Should the pipe-to-soil voltage drop below —0.85 volts, the anode current should be increased. If the voltage increases above —1.5 volts, the anode current should be decreased. The proper anode current output requirement is not a fixed value, but is dependent on the proper pipe-to-soil voltages being maintained to give adequate protection. A decrease in the pipe-to-soil voltage of 100 millivolts indicates that the anode beds are failing to deliver the required output current. The anode beds in the vicinity of the low pipe-to-soil voltage on the metal structure should be checked to determine which bed is at fault. Each anode bed should be checked for required current output.

4.1.2 Current Output Adjustment. The required current output of each anode bed is determined at the test points at the time the anode bed is installed, and is recorded on a facility history record card. The current output of magnesium anode beds can be controlled by means of a 10-ohm adjustable resistor inserted in the anode-bed lead which connects to the metal structure. This resistor is usually placed in the handhole which contains the test lead (fig. D–4). The current output of the anode bed is decreased by adjusting the resistor so that more resistance is inserted in the circuit. A decrease in the resistance of the adjustable resistor will increase the current output of the bed. The current output of the anode bed can be measured by inserting a milliameter in series with the anode bed lead. Certain anode leads are usually brought to ground surface to permit this type to be tested (fig. D–4). An 0.1- or 0.01-ohm shunt, installed in the anode lead, can also be used for current measurement by measuring the millivolt drop across the shunt.

4.1.3 Causes of Low Current Output. Dry soil at the anode-bed site is a common reason for low output current. This is more common during dry seasons of the year. Wetting down the soil reduces the soil resistivity and permits increased anode current output. The current output of anode beds will decrease with time as the beds become stabilized. Corroded connections or control resistors in the test leads can affect output current. Magnesium and zinc anodes are sacrificial anodes which will be expended after a number of years. Generally, the anodes will be expended at the end of 10 years. Current output at that time will reduce virtually to zero. As the anodes are expended, a point will be reached where the current output can no longer be adjusted by the resistor to provide adequate protection. This will be indicated by pipe-to-soil voltage readings of less than —0.80 volt. When this occurs, additional anodes should be installed, or the existing ones replaced.

4.1.4 When to Measure Pipe-to-Soil Voltages. Tests should be made once every 2 months for the first 6 months after the cathodic protection system is installed. Thereafter, pipe-to-soil voltage tests should be scheduled four times a year. If the operation of the protected structure is interrupted or changed by any of the following occurrences, pipe-to-soil voltage tests should be made immediately in addition to the normally scheduled tests.

(1) Additions to the protected structure are made by new construction.

(2) Portions of the protected structure are removed by eliminating some of the underground services.

(3) The ground beds and cables are inspected to determine their condition, at which time the soil around the anodes is disturbed.

4.2 IMPRESSED CURRENT SYSTEMS. Impressed current systems have an external direct-current voltage source (rectifier) and graphite rods to provide protection. The maintenance required consists of periodically checking the current output of the protected system and pipe-to-soil voltage measurements made on the protected structure to determine that adequate protection is obtained. The amount of current flowing through the cathodic protection system is controlled by regulating the voltage at the rectifier unit. The grouping and arrangement of the graphite rods provide the required distribution of the current to all metal areas to be protected. The output current required to give protection is established at the time the cathodic-protection system is installed, and is recorded both on a card in the rectifier box and on a facility history record card.

4.2.1 Test Data Interpretation. The minimum pipe-to-soil voltage, with reference to a copper-copper sulfate half-cell, should be —0.85 volts. The maximum pipe-to-soil voltage should be —1.5 volts. Should the pipe-to-soil voltage drop below —0.85 volts, the ground-bed current should be increased (par. 4.2.2). If the voltage increases above —1.5 volts, the ground-bed output current should be decreased. The proper ground-bed current output requirement is not a fixed value, but is dependent on the proper pipe-to-soil voltages being maintained to give adequate protection. A decrease in the pipe-to-soil voltage will measure less than —0.85 volts. This is another indication of inadequate protection. Low current output may be caused by:

(1) High soil resistivity at ground-bed site during dry seasons (soil area at the ground-bed site should be wetted down during dry seasons and before adjusting the rectifier voltage taps);

(2) defects in wiring, which cause a short circuit or an open circuit;

(3) blown fuses, a.c. or d.c.;

(4) a.c. switch open;

(5) low a.c. input voltage;

(6) graphite rod lead broken;

(7) additional metal area has been added; or

(8) graphite rods which should be replaced.

4.2.2 When to Measure Pipe-to-Soil Voltages. Tests should be made once every 2 months for the first 6 months after the cathodic-protection system is installed. Thereafter, pipe-to-soil voltage tests should be scheduled four times a year. If operation of the protected structure is interrupted or changed by any of the following occurrences, pipe-to-soil tests should be made immediately in addition to the normally scheduled tests.

(1) New construction results in additions to the protected structure.

(2) Portions of the protected structure are removed by eliminating some of the underground services.

(3) The ground beds and cables are inspected to determine their condition, at which time soil around the anodes is disturbed.

4.3 ADJUSTMENT AND REPAIRS. Upon receiving evidence that a cathodic protection system is not operating at a proper current output, the inspector should immediately prepare a work request for the shop assistance needed to:

(1) Water the soil area at galvanic anodes and graphite rod locations during dry seasons of the year;

(2) perform routine test (soil resistivity, pipe-to-soil voltage, and current output);

(3) make minor adjustments and repairs to the rectifier (always remember to turn off the power to the rectifier before servicing).

4.4 MAINTENANCE INSPECTION AND RECORDS. The most effective corrosion control program is considered useless without records. Accordingly, a large amount of data must be recorded. Office records with duplicate field copies should be set up to include a summary of all work accomplished so that station forces or FEO* personnel can evaluate the effectiveness of the work and forecast any possible failures of protection. These records require regular field inspections of the protection system. These inspections should be scheduled as follows:

(1) Semiannual and annual inspections, performed by station personnel, of systems installed at activities. A complete system check once every 6 months should be performed by a FEO representative. This complete system check includes such work as recording on Bureau forms [NavDocks Form 2501(9–57), appendix 6] pipe-to-soil voltages at all test leads; measuring current flow at all shunts and IR drop test leads; checking all mechanical connections for tightness and contact at shunt junctions, bonds, rectifiers and insulating flanges; checking the current output of galvanic anode bed and ground bed; and making the necessary current adjustments in the cathodic-protection system.

(2) Monthly and weekly checks performed by station forces consist of:

(a) visual inspections of the apparent operating conditions of rectifiers, bonds, shunt junctions, and insulating flanges;

(b) observing and recording rectifier meter readings (current voltage);

(c) observing the defects and reporting such defects to the cognizant Field Engineering Office.

4.4.1 Permanent Records. Permanent records should be maintained, and should be kept so that the following information will be easily accessible:

(1) The current output of each galvanic anode bed,

(2) the rectifier voltage and current readings (impressed current system),

(3) the dates of wetting of galvanic anode beds,

* Field Engineering Office.

(4) the dates of wetting of impressed current system ground beds (graphite rods), and

(5) the repairs and replacements of equipment, galvanic anodes and graphite rods.

4.4.2 Comparison with Past Records. When new readings are recorded on the facility history record cards, the person entering them should immediately compare new readings with past readings. This will serve to determine:

(1) Whether there is deterioration of the cathodic protection system that might permit pipeline corrosion, and

(2) whether there is any seasonal variation in the galvanic anode or graphite rod resistance that could cause an overload of the anodes or graphite rods.

4.5 MAINTENANCE OF TEST EQUIPMENT. Instruments containing dry cell batteries should be checked monthly for rundown batteries which should be replaced to prevent possible damage to equipment by corrosion products from wornout batteries.

4.6 COPPER SULFATE ELECTRODES. Copper sulfate electrodes (fig. 8) should be kept full of a saturated solution of copper sulfate, with a few surplus crystals of copper sulfate to maintain the solution in a saturated condition. Pure copper sulfate and distilled water should be used in preparing the solution. Every 6 months, or if the solution becomes cloudy, it should be discarded, and the electrode should be rinsed out thoroughly with distilled water and refilled with fresh copper sulfate solution. When the electrode is not in use, keep a wooden plug, covered with a rubber cap, at the end of the electrode. This prevents the wood from drying out, thus keeping the resistance low.

4.7 TEST LEADS. Spring clips on test leads and jumper wires should be checked frequently to ensure that they are tightly connected, and that there are no breaks inside the insulation near the clip connection. This may be checked by pulling firmly on the clip to determine if it will separate from the wire.

4.8 DPWO TECHNICAL SERVICES AVAILABLE TO NAVAL ACTIVITIES

(1) Perform complex corrosion engineering surveys.

(2) Make periodic measurements to determine the adequacy of protection provided by existing cathodic protection systems.

(3) Prepare plans and specifications for complex cathodic-protection systems.

(4) Train station personnel in such areas as:

(a) The causes of corrosion and control methods;

(b) the test methods for determining whether metal structures are being attacked by corrosion;

(c) the use of cathodic-protection test instruments;

(d) the interpretation of soil resistivity measurements and structure-to-soil voltage readings;

(e) the checking of station cathodic-protection instruments.

GLOSSARY

ANODE: A sacrificial electrode for providing current to protect corroding metals.

ANODE BED: A group of magnesium anodes connected to a common header cable for cathodic protection.

BACKFILL: A ground-bed material used with bare anodes. It lowers annode-to-soil resistance and permits current to flow more freely.

CARBON: The anode material used with a rectifier to protect corroding metals.

CATHODE: Position of metal to which current flows (protected metal).

CATHODIC PROTECTION: The reduction or prevention of the corrosion of a metal surface through a method of applying an external direct-current voltage.

COATING: A protective coating placed on a pipe or metal structure to insulate it from the soil. (Coal tar enamels, asphalts, paints and tapes.)

COPPER SULFATE ELECTRODE (Half-cell): A standard or reference electrode used for measuring pipe-to-soil (or to water) potentials.

CURRENT DENSITY: The amount of applied, direct current required to give protection. (Bare pipe, 1 to 3 ma.; coated pipe, 0.1 ma.)

DRAINAGE POINT: The position on the pipe or metal structure under protection where the galvanic anode or the negative terminal of the rectifier is attached.

DURION: The anode material used with a rectifier for providing current to protect corroding metals.

ELECTROLYTE: A chemical substance (liquid), such as water, soil, or other chemical solutions, that will conduct electric currents.

ELECTROLYSIS: Corrosion caused by stray, direct current from electric railway systems or d.c. generators.

GALVANIC CORROSION: Corrosion of buried metals caused by differential soil environments, dissimilar metals, differential aeration.

GALVO LINE (Magnesium Ribbon): A flexible extruded magnesium anode with a small cross section area.

GALVO PACK: A magnesium anode with self-contained backfill.

GRAPHITE ROD: Used with a rectifier to provide current for the protection of corroding metals.

GROUND-BED: A ground-bed is usually associated with impressed current systems. The bed requires graphite or carbon rods.

"HOT SPOT" PROTECTION: Cathodic protection applied locally to overcome a particularly bad corrosion condition which is worse than that encountered elsewhere in the installation.

IMPRESSED CURRENT SYSTEM: A rectifier and ground-bed (carbon or graphite) used in soils above 5,000 ohms-cm. or when currents exceeding 5 a. are required.

MAGNESIUM (Anodes): Used to protect bare metal in soils of less than 5,000 ohm-cm., or to protect coated piping up to 10,000 ohm-cm.

PIPE-TO-SOIL POTENTIAL (Structure): (1) Indicates the corrosive condition of a metal surface. (2) Indicates the amount of protection applied. (—0.85 volts, as measured to a copper-sulfate electrode, will prevent corrosion.)

RECTIFIER: A direct current source used to force current from a ground-bed (carbon or graphite) through the soil to the metal to be protected.

RECTIFIER SYSTEM—IMPRESSED CURRENT SYSTEM: A combination rectifier and ground bed used for cathodic protection.

SHEPARD CANE: Instrument used to measure soil resistivity.

SOIL (OR WATER) RESISTIVITY: The degree to which soil (or water) resists the flow of electric current. The unit of measurement used is ohm-centimeter.

TEST LEADS: Leads attached to a metal structure and brought to the surface; they are usually placed in handholes. These leads are used for: testing to determine the adequacy of protection; and pipe-to-soil tests.

VIBRAGROUND: Instrument used to measure soil resistivities and current density.

ZINC (Anode): Used with special backfill to protect metal in soils of less than 2,500 ohm-cm.

APPENDIX A

Electromotive Series

It is known that all metals can be arranged in a regular order of electrical voltage. This arrangement is called the electromotive series, and was established by a laboratory experiment conducted under very rigid standardized conditions. Table A–1 gives a brief form of this series, and lists the common metals which are of interest in metal structure corrosion work.

Magnesium, zinc, and aluminum have high potentials with respect to the soil. Their potentials are higher than any of the ferrous metals; that is, steel or cast iron. This relationship between magnesium, zinc and aluminum on the one hand, and iron on the other, has considerable significance in metal structure corrosion work. When any metal listed in table A–1 is connected to any metal lower on the table, and is buried with it underground, the metal higher on the scale will be corroded, and will protect the one lower on the scale.

TABLE A–1

Extract from the Electromotive Series

Metals	*Comparative voltages*
Magnesium	1.720
Zinc	1.055
Aluminum	0.825
Bright steel	0.598
Bright cast iron	0.592
Cast iron	0.574
Steel	0.558
Lead	0.551
Rusty steel	0.335
Copper	0.245
Silver	0.091
Carbon	0.089

APPENDIX B

Protection Current Curves

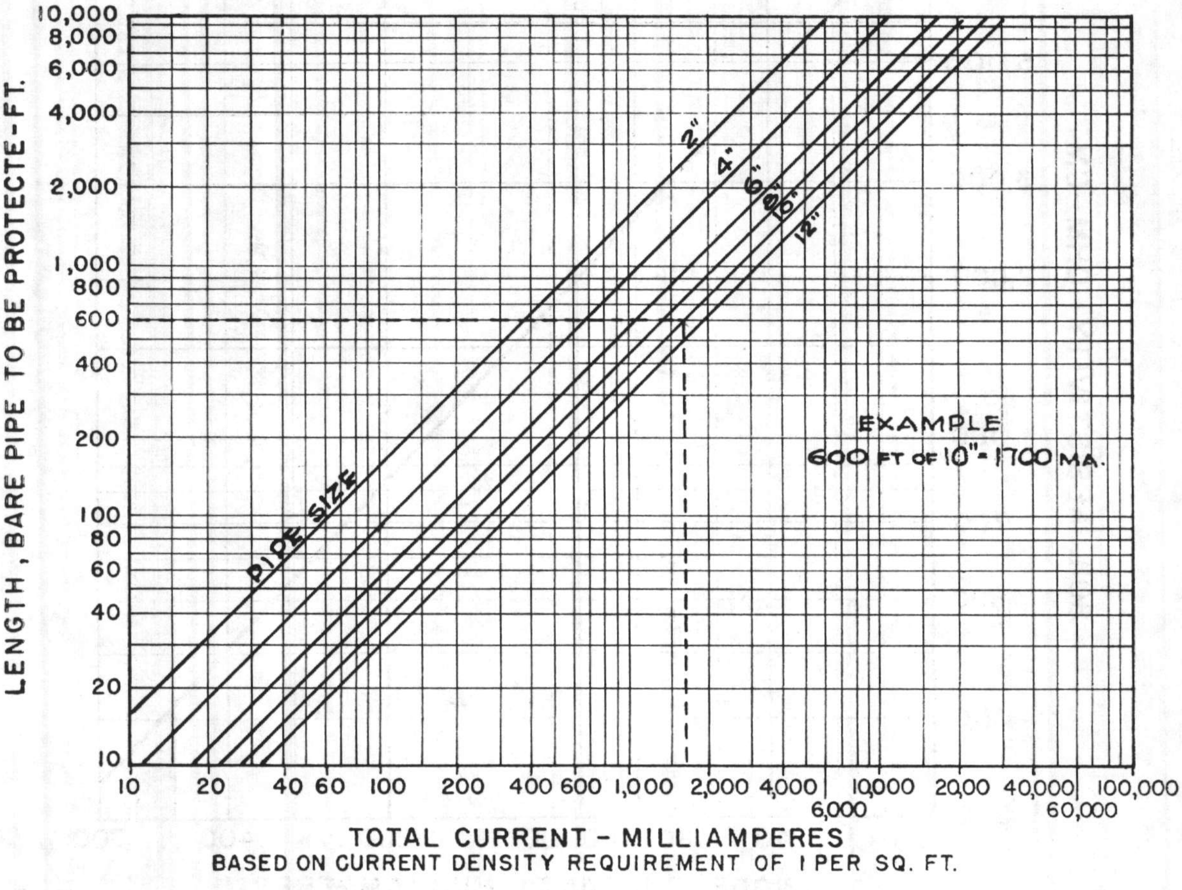


FIGURE B–1

Protection Current Requirement Curve for Several Pipe Sizes

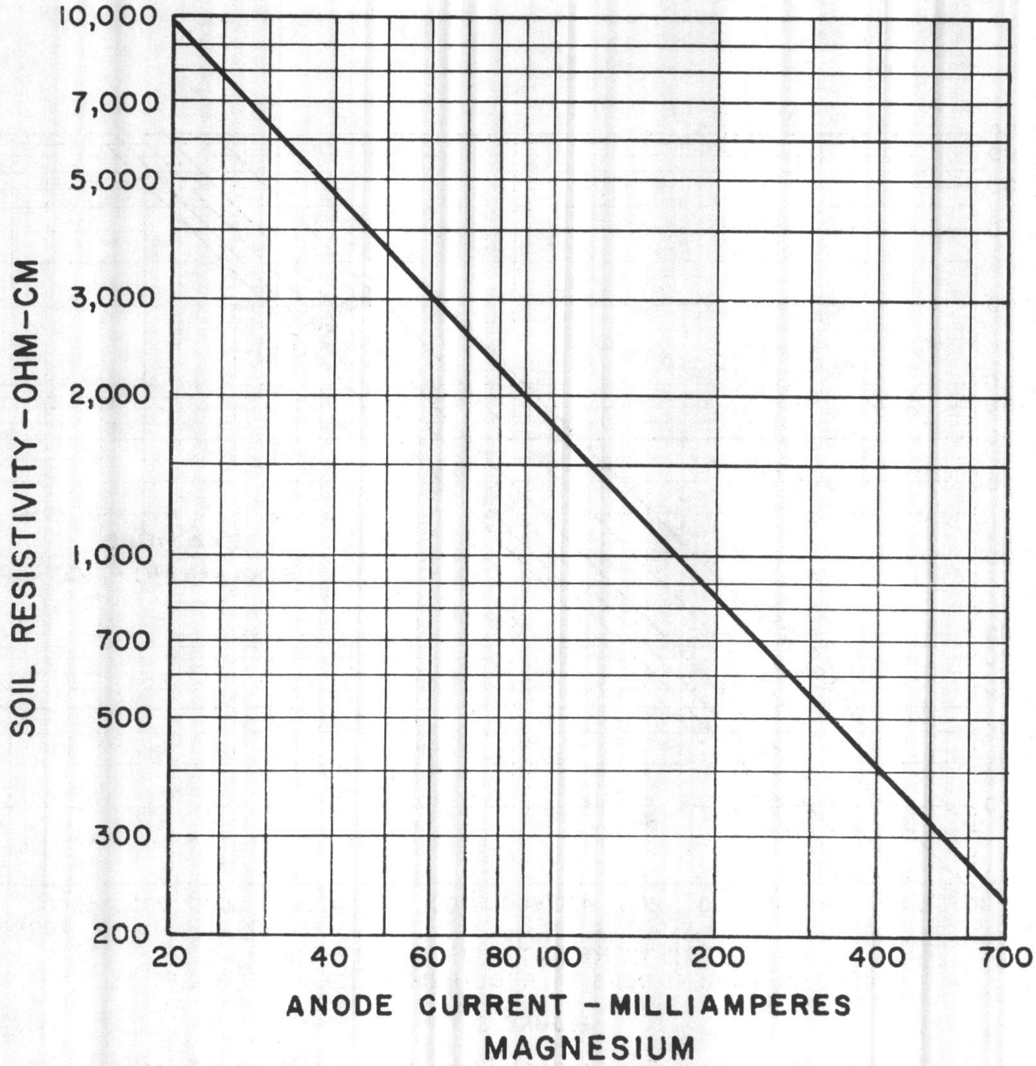


FIGURE B–2

Soil Resistivity vs. Magnesium Anode Current Output

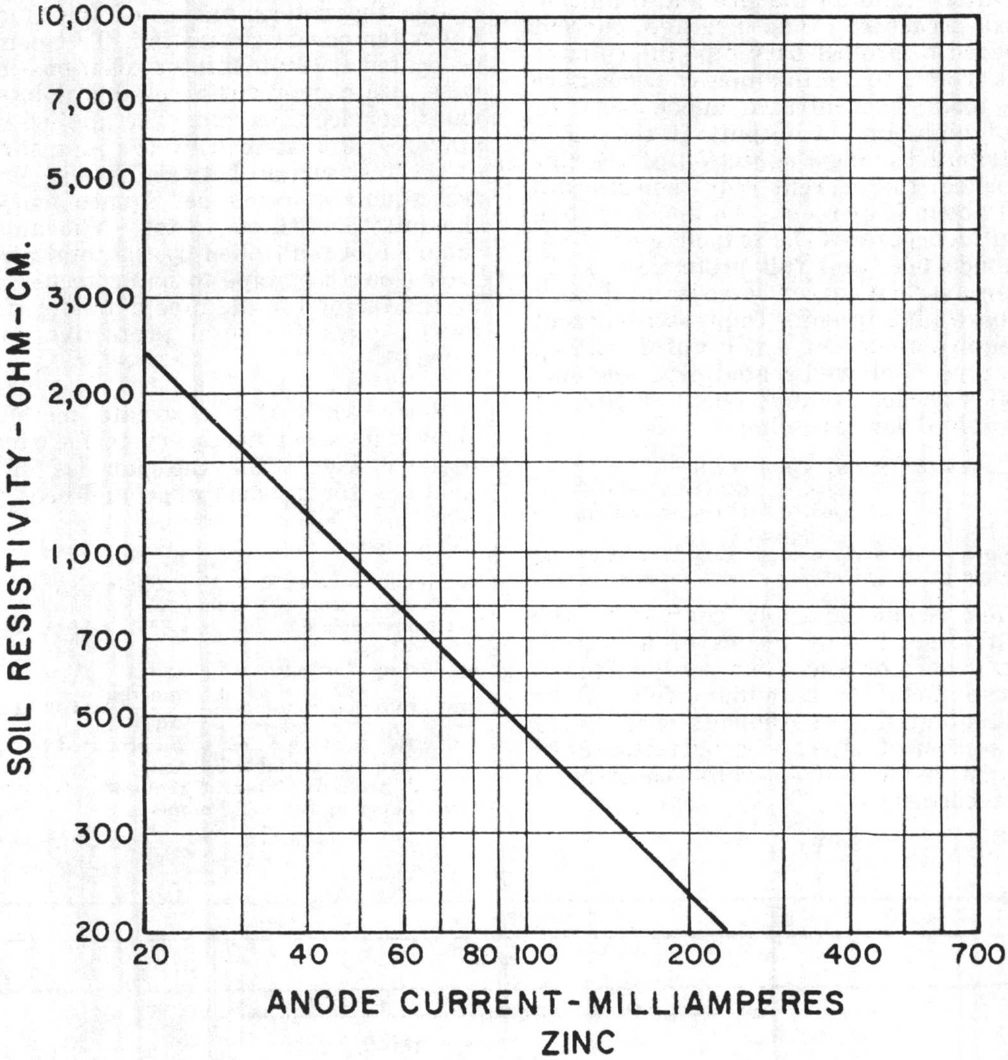


FIGURE B-3

Soil Resistivity vs. Zinc Anode Current Output

CATHODIC PROTECTION CURRENT TESTS (ALTERNATE METHOD)

Current Requirements. Cathodic-protection current tests are performed to determine how much current will be required to adequately protect a metal structure. Current requirements for cathodic protection depend greatly on soil conditions and on the size and condition of a metal structure. The average current density needed to protect bare pipe in ordinary soils varies from 1 to 3 milliamperes per square foot when using concentrated anode beds, or rectifiers of high-current output. If the anode bed is distributed along the section of the line to be protected, the current requirements will be reduced about 70 percent. An anode system installation incorporates the principle of a distributed anode bed, and full protection is obtained at an average current density of 1 ma./sq. ft. of bare pipe in soil. Impressed current systems require a current density of 3 ma./sq. ft. of bare pipe. For well-coated pipe, the current densities needed are only about 10 percent of those required for bare pipe.

Current Estimating Values Criterion

Bare pipe	1	ma./sq. ft. (anode system)
Bare pipe	3	ma./sq. ft. (impressed current system)
Old-coated pipe	0.2	ma./sq. ft. (anode or impressed
New-coated pipe	0.1	ma./sq. ft. current system).

Alternate Test Method. Apply current to the corrosive pipe section by means of a battery or welding generator and a temporary ground bed of scrap metal or aluminum foil. Make pipe-to-soil potential measurements (par. 1.5.4) along the section of pipe to be protected until readings just below −0.85 volts (protection level) are recorded.

I_a = Applied test current,
X = Distance in feet to 0.84 volt,
Y = Distance in feet to 0.84 volt,
Z = Total distance in feet to be protected,
A = Applied current connecting point.

The distance between test points X and Y (see fig. B–4) and the known size of the pipe enable the determination of the surface area under temporary protection. Test points should be located at 100-foot intervals if possible; otherwise, use convenient accessible points, such as vales, service taps, etc. The applied current in amperes (I_a) divided by the pipe surface area of the test section between X and Y in square feet equals amperes per square foot, which is the unit protection factor. The amperes per square foot multiplied by the total pipe surface area (length of pipe to be protected multiplied by the factor for the pipe diameter, from table B–1) equals the total protective current required.

Note: when this alternate method is employed, it is not necessary to measure soil resistivity except for the purpose of selecting locations for anodes or ground-beds.

Example:

Test point distances X + Y = 200 feet.
Pipe size diameter = 6 inches
Total pipe surface = 200′ × 1.734′ (table B–1) = 347 sq. ft.
Applied test current = 0.4 amperes.

$$\text{Unit protection factor} = \frac{0.4 \text{ amperes}}{347 \text{ sq. ft.}} = 0.0012 \text{ a. per sq. ft.}$$

Effective total pipe area to be protected — 1,200 × 1.73 = 2,100 sq. ft. (see table B–1).

Total protection current required = 2,100 sq. ft. × 0.0012 a. per sq. ft. = 2.52 amperes.

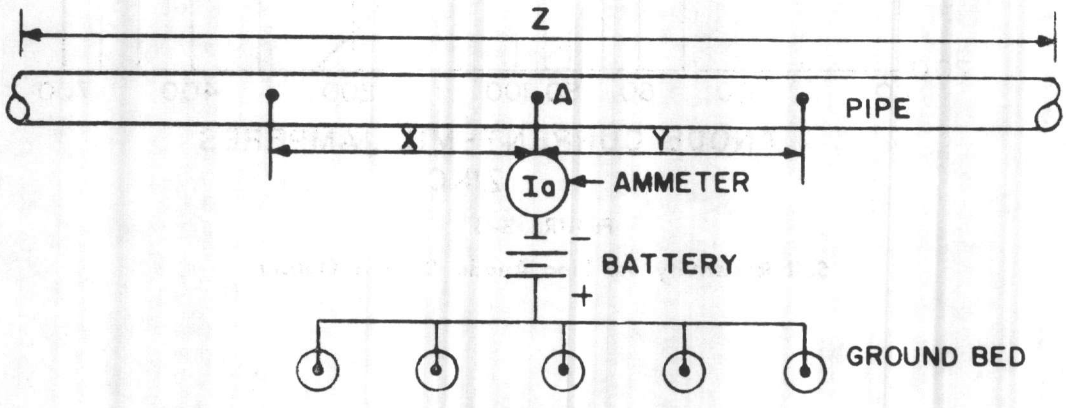


FIGURE B–4

Alternate Method for Determining Protection Current Requirement

TABLE B–1

Metal Pipe Surface Area

Nominal size (inches)	*Surface sq. ft. per ft. length*
¾	0.275
1	0.344
1¼	0.434
1½	0.497
2	0.622
2½	0.753
3	0.916
3½	1.047
4	1.178
4½	1.309
5	1.456
6	1.734
8	2.258
10	2.82
12	3.34
14	3.67
16	4.19
18	4.71
20	5.24
22	5.76
24	6.28
30	7.85

Cast Iron Pipe

Nominal diameter (inches)	*Surface sq. ft. per foot*
3	0.995
4	1.257
6	1.806
8	2.369
10	2.906
12	3.456
16	4.660

Square feet of bare pipe × 1 ma./per sq. ft. (magnesium system).

Square feet of bare pipe × 3 ma./per sq. ft. (impressed current system).

Square feet of coated pipe × 0.1 ma./per sq. ft. (magnesium or impressed current system).

APPENDIX C

Cathodic Protection Examples

PROTECTION FOR SECTION OF STEEL PIPE

Example:

Pipe size	10 inches
Pipe length	600 feet
Soil	2,000 ohm-cm.
Coating	None.
Protection current (bare pipe).	1 ma./sq. ft. (magnesium anode system) 3 ma./sq. ft. (impressed current system) (Par. 1.5.5 through 2.3)

Galvanic Anode System. The number of magnesium galvanic anodes necessary for the protection of a section of metal pipe requiring a certain current density may be determined by using the curves in Figures 6, B–1, and B–2.

(1) The current requirement curve (fig. B–1) indicates that 1,600 ma. of current is required to protect 600 feet of bare pipe at 1 ma. per sq. ft.

(2) The soil resistivity magnesium anode output curve (fig. B–1) indicates that a magnesium anode will deliver 90 ma. in soil of 2,000 ohm-cm.

(3) The number of anodes required to provide the required current is:

$$\text{Number of anodes required} = \frac{\text{protection current required}}{\text{output (current) per anode}}$$

$$\text{Number of anodes required} = \frac{1600 \text{ ma.}}{90 \text{ ma.}} = 17.8 \text{ or } 18 \text{ anodes}$$

(4) Select the magnesium anodes of proper weight for 2,000 ohm-cm. soil resistivity using the tables in paragraphs 1.7.1.1 and 1.7.3. (2,000 ohm-cm. soil requires 17-lb. anodes (magnesium))

(5) Estimated cost of installing eighteen 17-lb. magnesium anodes:

18 anodes at \$40 each (labor and material)	\$720
150 ft. of collector cable at \$0.35 per ft.	53
	773

IMPRESSED CURRENT SYSTEM. The size of the rectifier and ground-bed can be determined by the following steps:

(1) The current requirement curve (fig. B–1) indicates that 1,600 ma. of current is required to protect 600 feet of bare pipe at the rate of 1 ma. per sq. ft. Paragraph 2.4.1 recommends that 3 ma. per sq. ft. of bare pipe be used with impressed current systems. Therefore, for an impressed current system, the current requirement is 1,600 ma. × 3, or 4,800 milliamperes.

(2) Determine the resistance of a single 3″ × 60″ graphite rod to ground by using the formula: (par. 2.3)

$$R = \frac{3.0p}{1{,}000} = \frac{3 \times 2{,}000}{1{,}000} = 6 \text{ ohms.}$$

(3) The number of graphite rods (N) required to handle the needed current density at the maximum allowable current per graphite rod is determined by:

$$N = \frac{4.8 \text{ amperes}}{4 \text{ amperes per rod}} = 1.2 \text{ or } 2 \text{ rods needed (table I)}$$

An additional rod is added as instructed in paragraph 2.2.5.

(4) Determine the resistance of the 2-rod ground-bed by:

$$R_t = \frac{R}{0.6N} \text{ (par. 2.3)},$$

$$R_t = \frac{6}{0.6 \times 2} = 5 \text{ ohms}$$

(5) Determine the rectifier voltage (E) needed to drive the required current density of 4.8 amperes for the ground-bed. The total voltage supplied should be at least 3 volts more than the computed value to allow for the voltage drop in the conductors and the season variations in the soil resistivity.

$$\text{Voltage (E)} = (I \times R) + 3 \text{ volts (par. 2.4.1)}$$

$$\text{Voltage (E)} = (4.8 \times 5) + 3 = 27 \text{ volts.}$$

(6) The rectifier selected should have a 27-volt, 5-ampere capacity.

(7) The estimated cost of installing the impressed current system is:

2 graphite rods at \$60 (labor, rods, backfill) each	\$120
1 rectifier (27 volts, 5 amperes) installed	375
200 feet of wire	100
Conduit and miscellaneous material	100
	695

Annual power cost computed at 60 percent rectifier efficiency is:

$$\frac{4.8 \text{ a.} \times 27 \text{ volts} \times 8760 \text{ hrs. per yr.} \times \$0.02 \text{ per kw.-hr.}}{60 \text{ percent efficiency} \times 1{,}000} = \$37.85$$

Cost comparison:

Magnesium anode system		$773
Impressed current system, installation cost	$695	
Power cost for 8 years	302	
Equivalent cost, impressed current system	997	

Note: Use anode system because of low resistivity soil, and less than 5 amperes of current (par. 1.7.1).

PROTECTION FOR SECTION OF STEEL PIPE

Example:

Pipe size	10 inches
Pipe length	600 feet
Soil	2,000 ohm-cm.
Coating	Enamel
Protection current (coated pipe).	0.1 ma./sq. ft. (magnesium anode system) 0.1 ma./sq. ft. (impressed current system) (par. 1.5.5)

Galvanic Anode System. The number of magnesium galvanic anodes necessary to protect a section of metal pipe requiring a certain current density may be determined by using the curves in appendix B.

(1) Current requirement curve (fig. B–1) indicates that 1,600 milliamperes (ma.) of current is required to protect 600 feet of bare pipe at 1 ma. per sq. ft. For coated pipe, 0.1 ma. per sq. ft. is required. Therefore, protection current required in this case is 1,600 ma. × 0.1, or 160 milliamperes.

(2) The soil resistivity anode output curve (Figure B–2) indicates that a magnesium anode will deliver 90 ma. in soil of 2,000 ohm-cm.

(3) The number of anodes needed to provide the required current is:

$$\text{Number of anodes required} = \frac{\text{protection current required}}{\text{output (current) per anode}}$$

$$\text{Number of anodes required} = \frac{160\text{ ma.}}{90\text{ ma.}} = 1.78 \text{ or } 2 \text{ anodes}$$

(4) Select magnesium anodes of proper weight for 2,000 ohm-cm. soil resistivity, using the table in Paragraph 1.7.1.1. 2,000 ohm-cm. soil requires the use of 17-lb. anodes.

(5) Estimated cost of installing two 17-lb. magnesium anodes is:

2 anodes at $40 (labor and material) each (wire included with anode at no cost) $80

Impressed Current System. The size of the rectifier and ground bed can be determined by the following steps.

(1) Current requirement curve (fig. B–1) indicates that 1,600 ma. of current is required to protect 600 feet of bare pipe at 1 ma. per sq. ft. Coated pipe protection current requirements are calculated at 0.1 ma. per sq. ft. of pipe. The protection current required is 1,600 ma. × 0.1 or 160 ma. (0.16 a.).

Note: The total protection current required is 0.16 a. and the soil resistivity is 2,000 ohm-cm. Since the protection current required is well under the 5–a. minimum limit recommended for an impressed current system, and since the soil resistivity is low, a magnesium anode system is recommended.

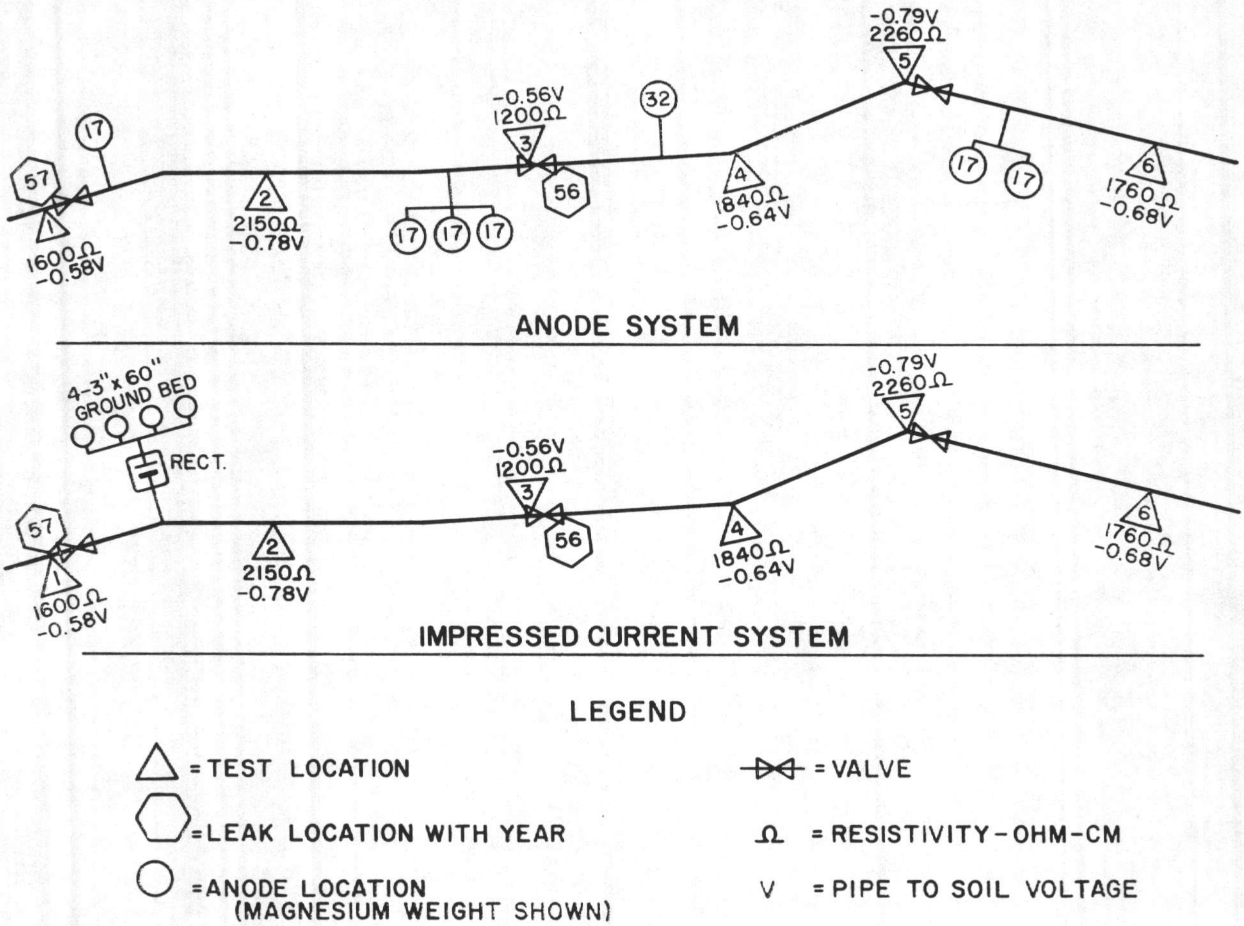
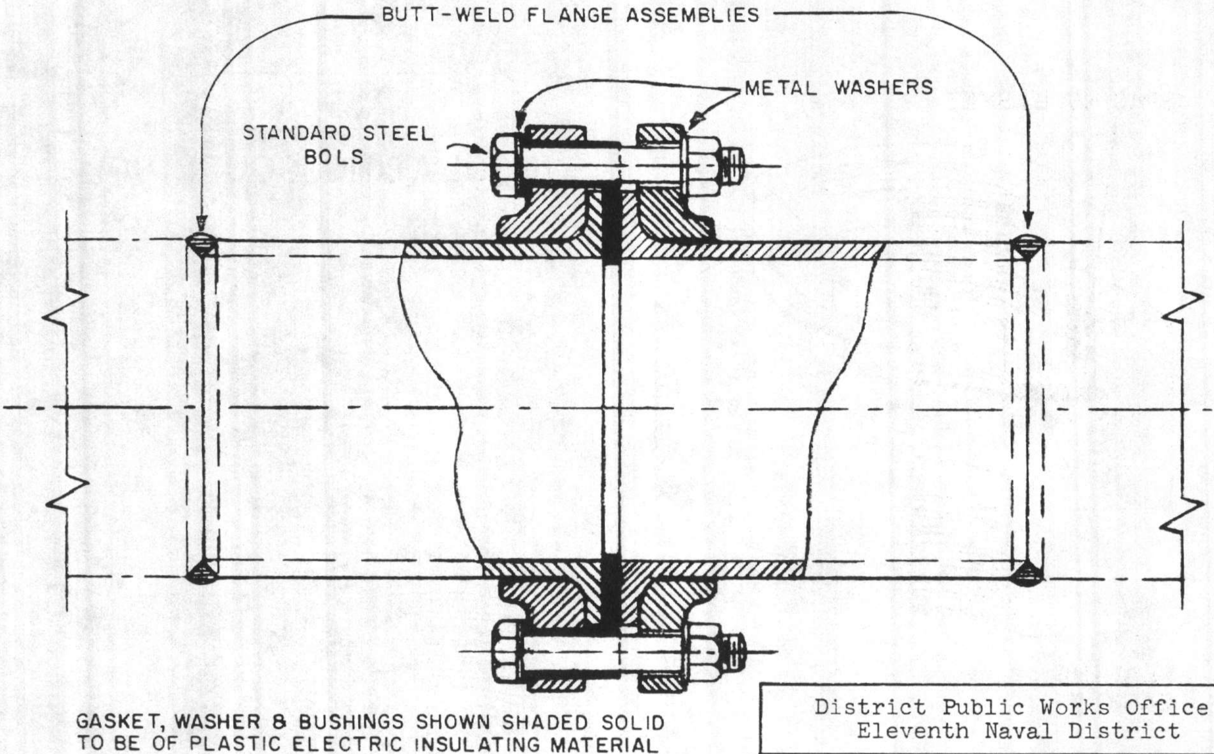


FIGURE C–1

Typical System Map Records

APPENDIX D

Insulating and Bonding



District Public Works Office
Eleventh Naval District

Section thru Typical Insulating Joint

Not Drawn to Scale

FIGURE D–1

Flange Insulator

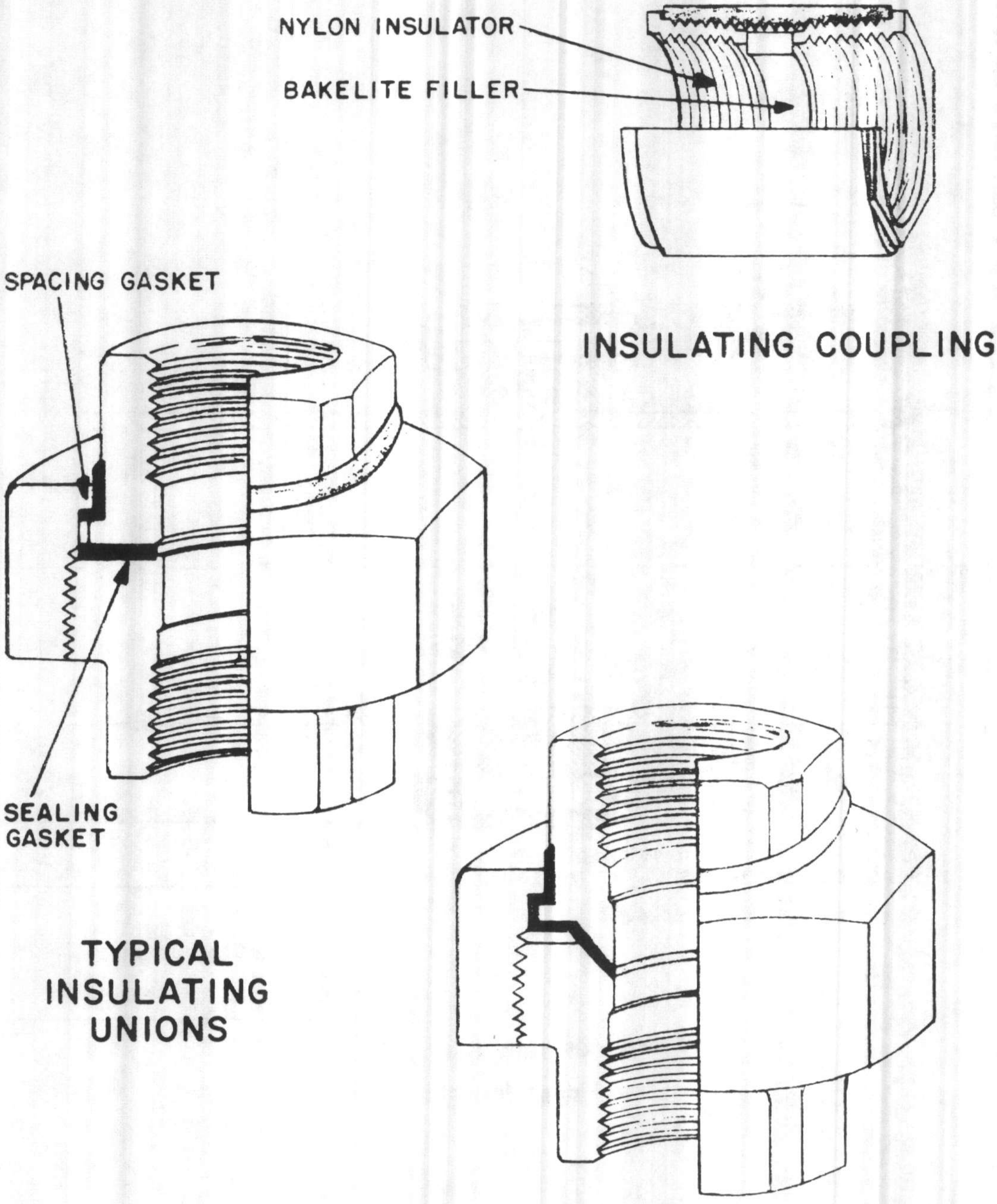
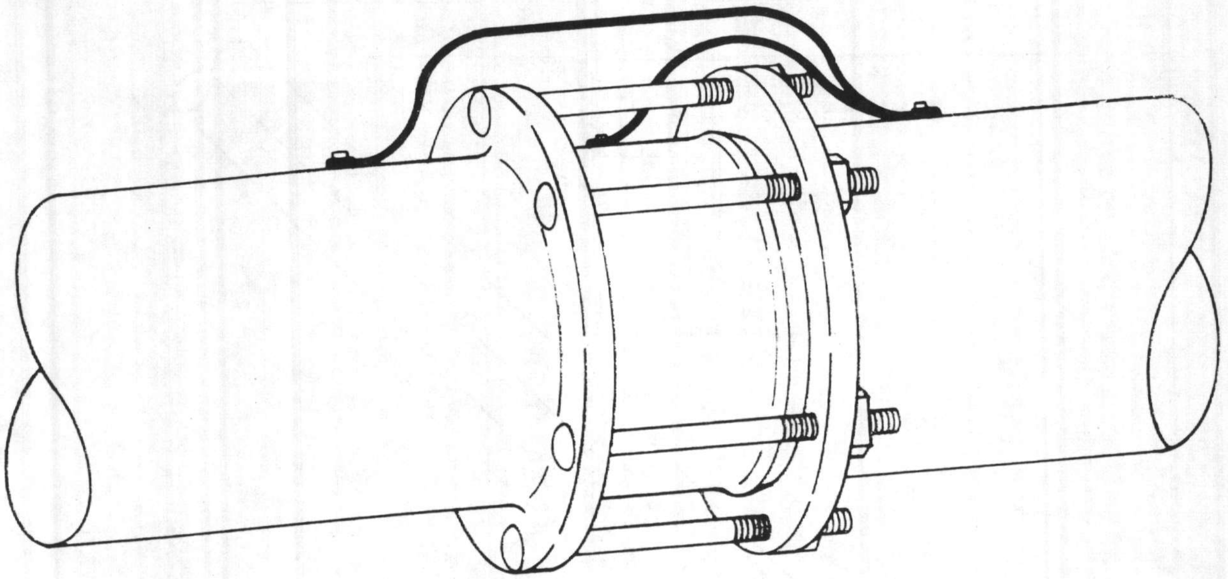


FIGURE D–2

Insulator Union



DISTRICT PUBLIC WORKS OFFICE
MAINTENANCE PLANNING DIVISION
ELEVENTH NAVAL DISTRICT

PIPE SECTIONS CONNECTED
BY THERMO WELDED BOND,
== 4/0, 7 STRAND COPPER CABLE

Not drawn to scale

FIGURE D–3

Thermoweld Bond

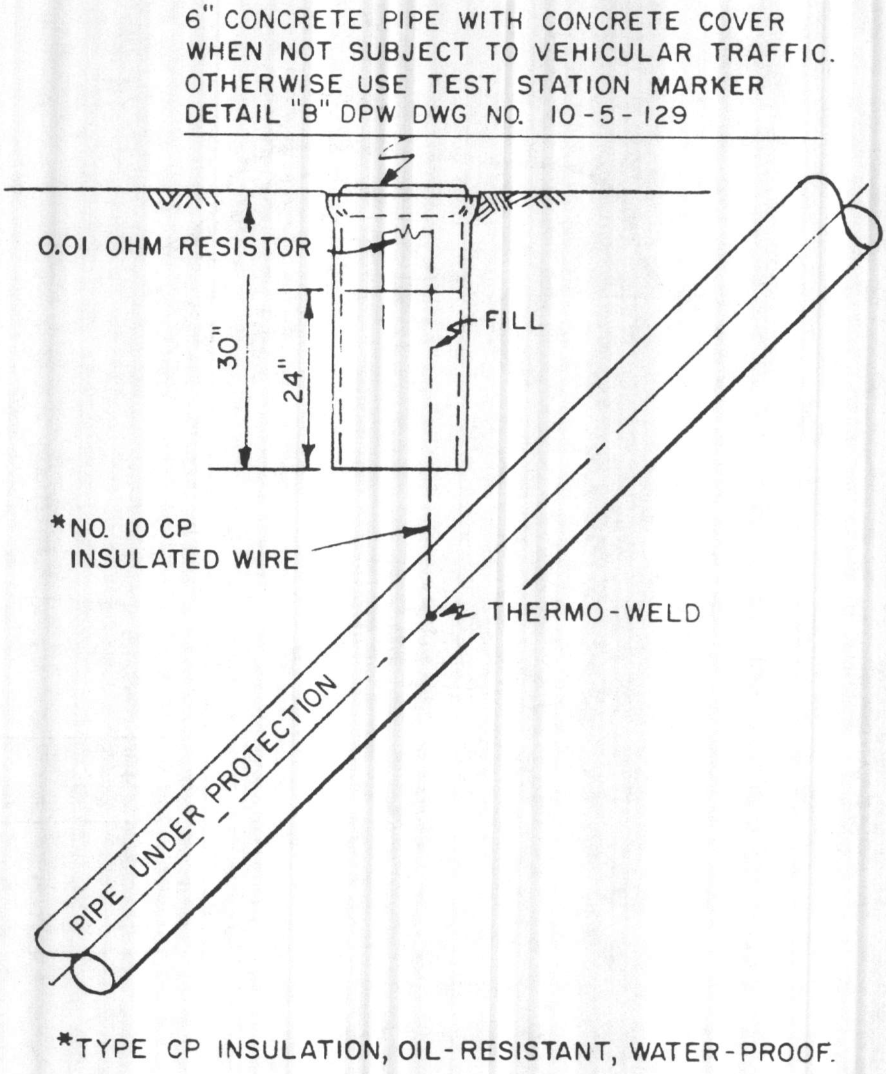


FIGURE D–4

Typical Installation Test Leads

APPENDIX E

Cathodic Protection Test Instruments and Equipment

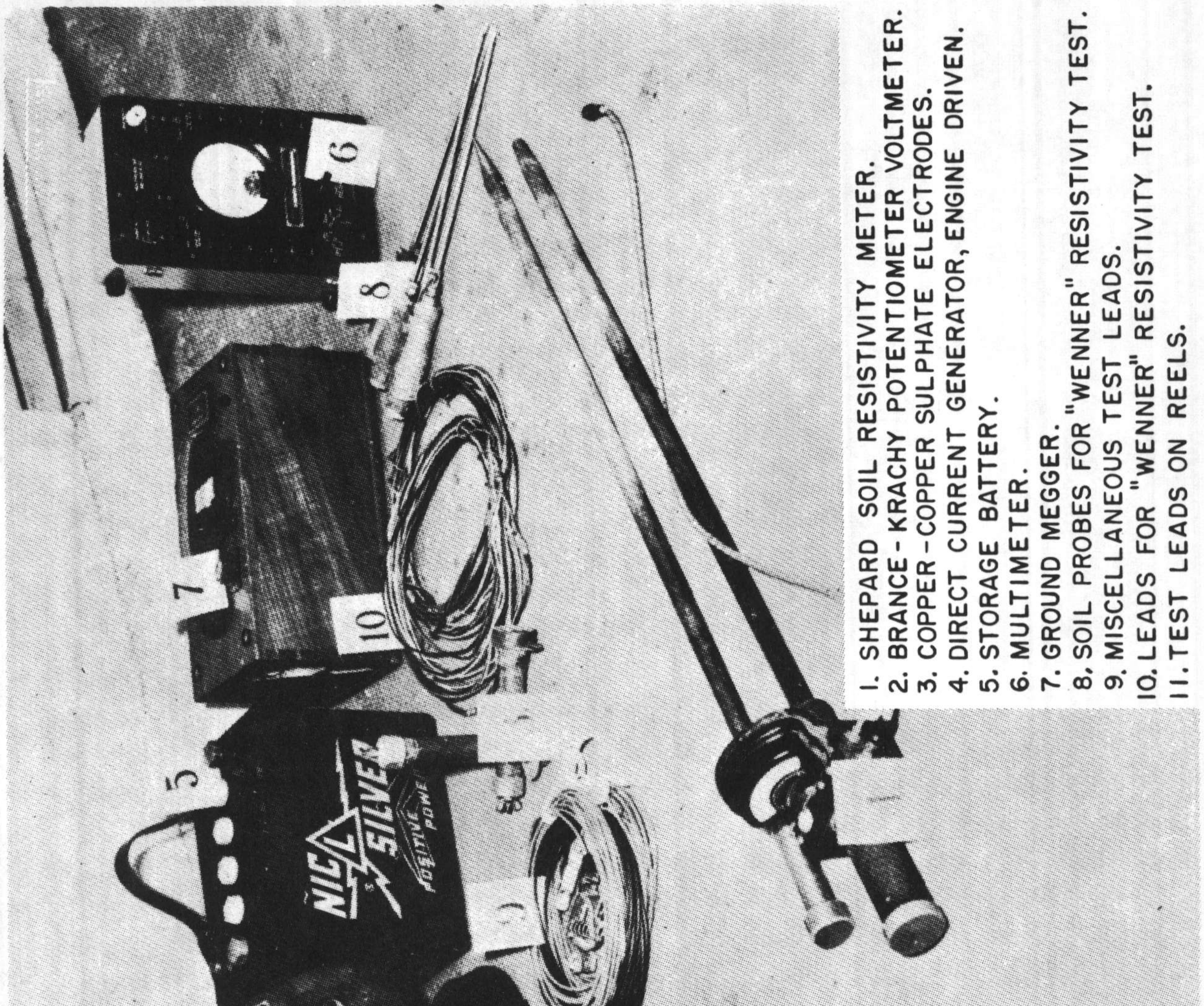


FIGURE E–1

Equipment Required for Cathodic Protection Tests

APPENDIX F

Anode and Ground Bed Installations

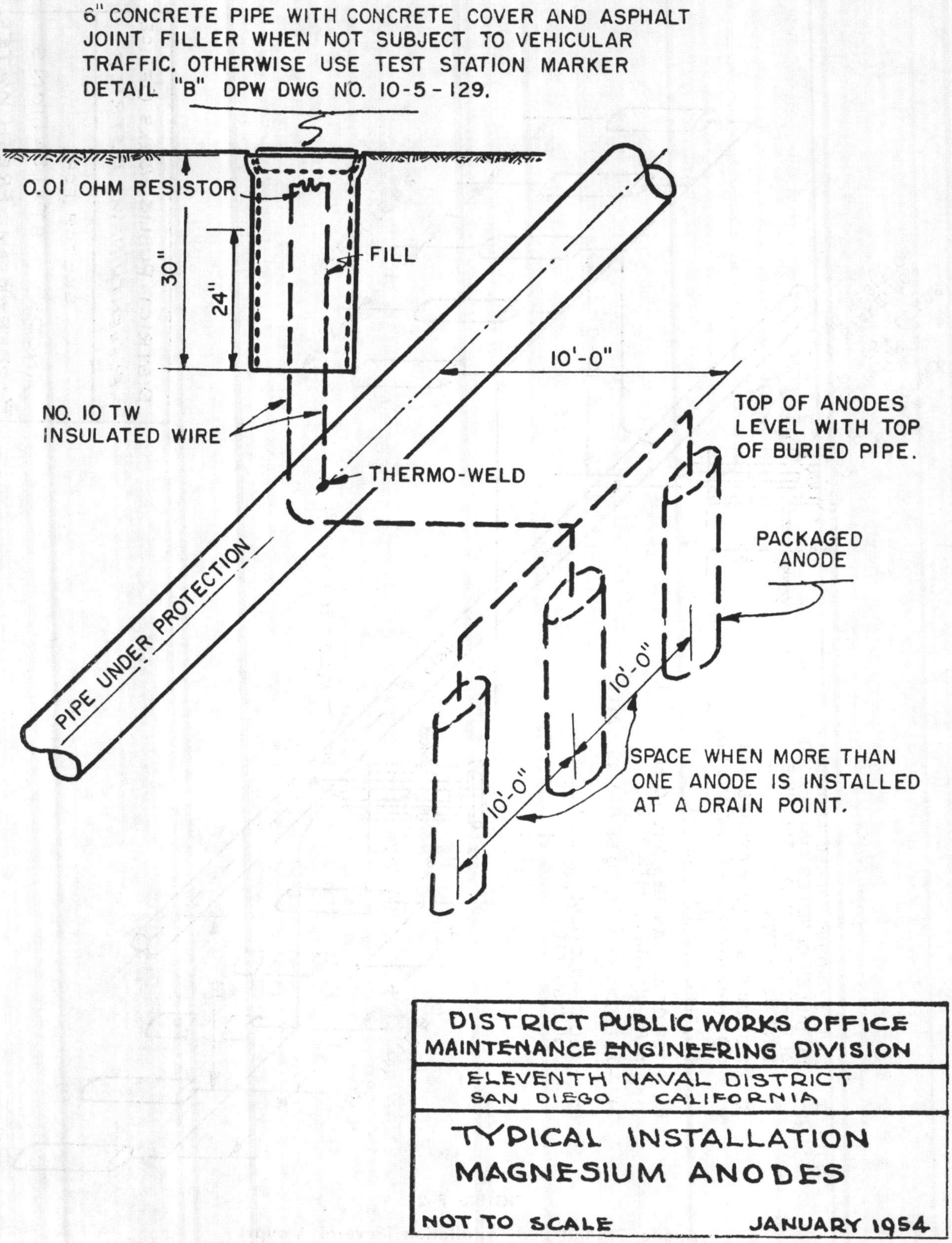


FIGURE F-1

Anode Ground Bed Installation (Single anode or single anode group.)

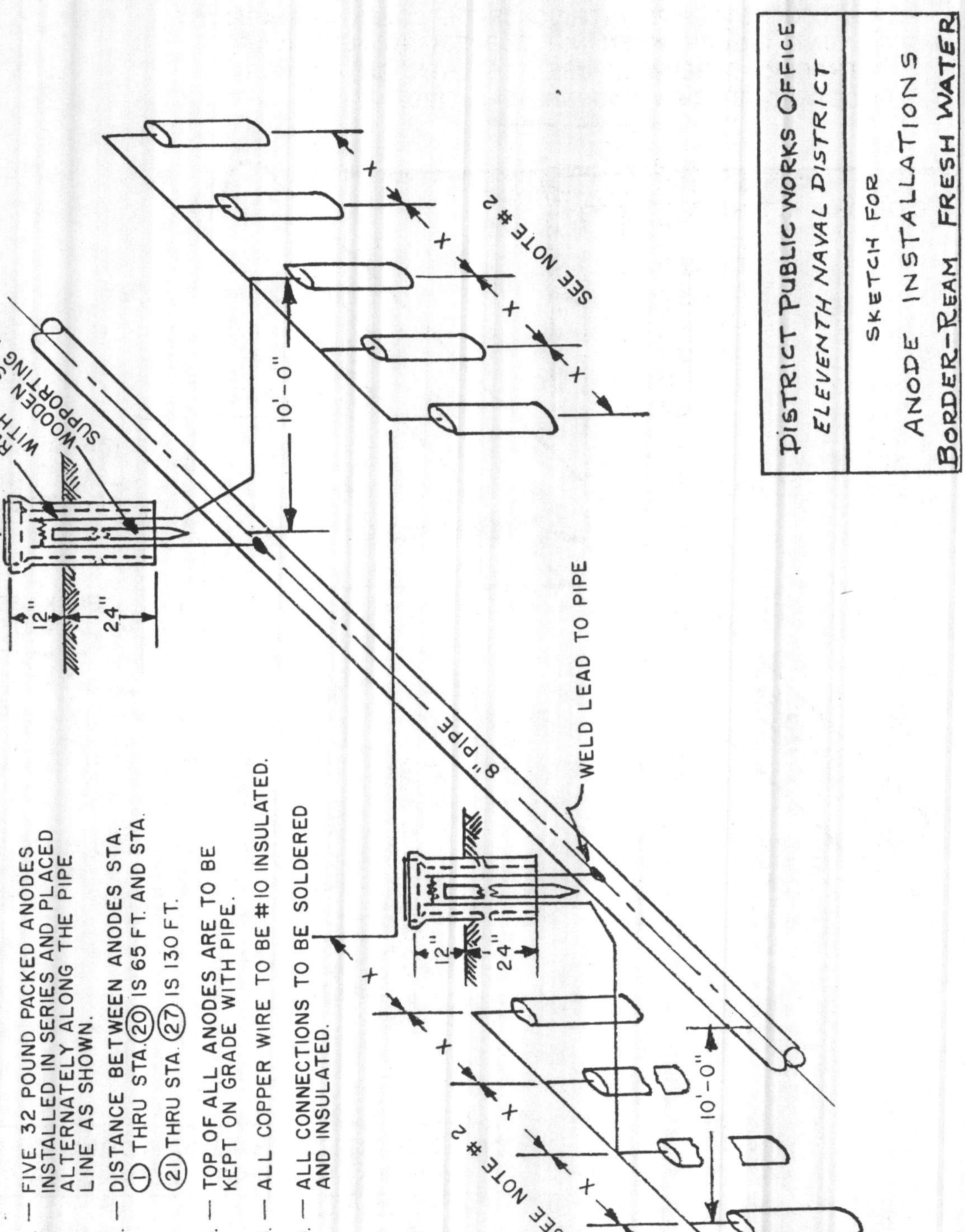
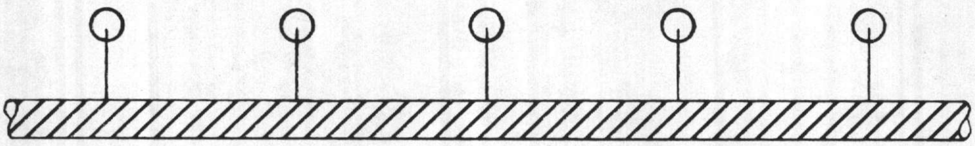


FIGURE F–2

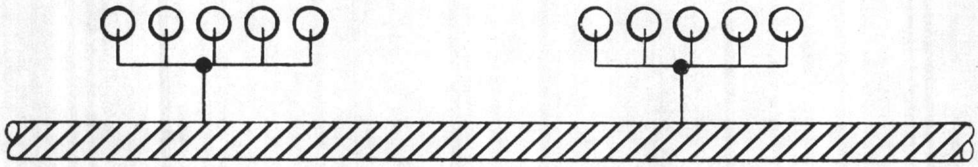
Anode Ground Bed Installation (Several groups)

A



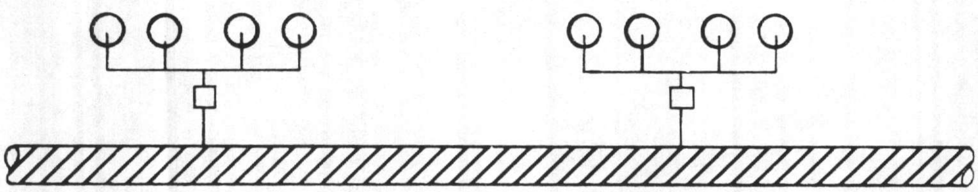
GALVANIC ANODES DISTRIBUTED ALONG PIPE LINE

B



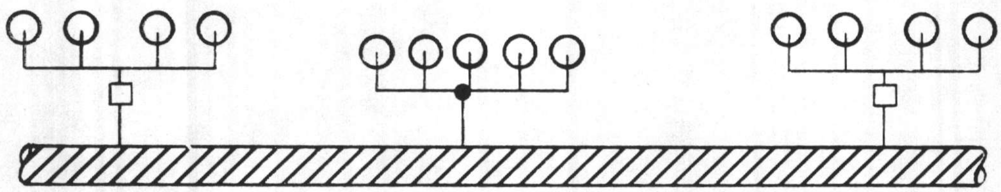
GROUPED ANODES

C



RECTIFIER AND GROUND-BED INSTALLATION

D



COMBINATION OF B AND C

COMBINATIONS OF CATHODIC PROTECTION INSTALLATIONS

FIGURE F–3

Combinations of Cathodic Protection Installations

APPENDIX G

Inspection and Maintenance Record Forms

USE INSPECTION GUIDE

CODE
NI NOT INSPECTED
✓ SATISFACTORY
X ADJUSTMENT REQUIRED
(X) ADJUSTMENT ACCOMPLISHED
– NOT APPLICABLE
XX REPAIRS REQUIRED
(XX) REPAIRS ACCOMPLISHED

WORK CENTER

CHARGE PM INSPECTION TO
JO

FACTORS AFFECTING INSPECTION
KEYS TOOLS

DATE INSPECTED	FREQ.	CHECK POINTS SCHEDULED FOR INSPECTION	CHECK POINTS																INSPECTOR'S INITIALS	INSPECTION HOURS		DEFICIENCY REPORT MADE	
			1 17 33	2 18 34	3 19 35	4 20 36	5 21 37	6 22 38	7 23 39	8 24 40	9 25 41	10 26 42	11 27 43	12 28 44	13 29 45	14 30 46	15 31 47	16 32 48		STD.	USED	YES	NO

(BUFF)

PROPERTY NO. | DESCRIPTION | CATEGORY CODE | LOCATION

INSPECTION CHECKOFF CARD
NAVDOCKS 2501 (9-57)

D-60887

PREVENTIVE MAINTENANCE INSPECTION—Insp. Guide E-14

(Check Points 2–15; Frequency S.A.)

Location ________________________________ (Station & Site)

Description ____________________ (Mfg. & Rating) Rectifier No. ______

Date	Volts	Amps	Remarks	Date	Volts	Amps	Remarks

RECORD OF RECTIFIER READINGS (S.A.)

Preventive Maintenance Form

USE INSPECTION GUIDE	CODE NI NOT INSPECTED ✓ SATISFACTORY	X ADJUSTMENT REQUIRED Ⓧ ADJUSTMENT ACCOMPLISHED	– NOT APPLICABLE XX REPAIRS REQUIRED ⓍⓍ REPAIRS ACCOMPLISHED	WORK CENTER	CHARGE PM INSPECTION TO JO

FACTORS AFFECTING INSPECTION

KEYS TOOLS

DATE INSPECTED	FREQ.	CHECK POINTS SCHEDULED FOR INSPECTION	CHECK POINTS																INSPECTOR'S INITIALS	INSPECTION HOURS		DEFICIENCY REPORT MADE	
			1 17 33	2 18 34	3 19 35	4 20 36	5 21 37	6 22 38	7 23 39	8 24 40	9 25 41	10 26 42	11 27 43	12 28 44	13 29 45	14 30 46	15 31 47	16 32 48		STD.	USED	YES	NO

(GREEN)

PROPERTY NO.	DESCRIPTION	CATEGORY CODE	LOCATION

INSPECTION CHECKOFF CARD
NAVDOCKS 2501 (9-57)

CONTROL INSPECTION

Inspection Guide E-14

(Check points 1–14; Frequency: Annual)

Check for adequacy of Preventive Maintenance Inspection.

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