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Rural Electrification Administration

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SUBJECT: Outside Plant Corrosion Considerations

TO: All Telephone Borrowers
REA Telephone Staff

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OFFICE OF PRIMARY INTEREST: Outside Plant Branch,
Telecommunications Standards Division

PREVIOUS INSTRUCTIONS: This bulletin replaces REA
Telecommunications Engineering & Construction Manual (TE&CM) 670,
Corrosion Considerations in Telecommunications in Outside Plant,
Issue 2, dated January 1982.

FILING INSTRUCTIONS: Discard REA Telecommunications Engineering
& Construction Manual (TE&CM) 670, Corrosion Considerations in
Telecommunications in Outside Plant, Issue 2, dated January 1982,
and replace it with this bulletin. File with 7 CFR 1751 and on
REANET.

PURPOSE: This bulletin provides REA borrowers, consulting
engineers, contractors and other interested parties with
information concerning the various aspects of corrosion which
should be considered in the preparation of a system design.

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09/02/93

Administrator

Date

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Outside Plant
Corrosion
Telecommunications

ABBREVIATIONS

ASTM	American Society For Testing And Materials
AWG	American Wire Gauge
B	Distance between electrodes
cm	Centimeter
cm/m	Centimeter per meter
dc	Direct current
EMF	Electromotive Force
m	Meter
NO _x	Nitrogen oxides
ohm·cm	Ohm·centimeter
OH ⁻	Hydroxyl ion
P	Average earth resistivity
pH	Potential of hydrogen
R	Resistance
REA	Rural Electrification Administration
SO _x	Sulfur oxides
TE&CM	Telecommunications Engineering and Construction Manual
Đ	Greek Letter, Pi, = 3.1416

DEFINITIONS

Active: A state in which a metal tends to corrode (opposite of passive). In a corrosion cell the active or corroding metal is the metal which is more negative in potential.

Amphoteric Metal: A metal susceptible to corrosion in both acidic or alkaline environments.

Anode: The electrode of an electrolytic cell at which oxidation or corrosion occurs (opposite of cathode). (Electrons flow away from the anode in the external circuit. It is usually the electrode where corrosion occurs and metal ions enter solution.)

Cathode: The electrode of an electrolytic cell at which reduction (and practically no corrosion) occurs (opposite of anode). (Electrons flow toward the cathode in the external circuit.)

Cathodic Polarization: Polarization of the cathode; a reduction from the initial potential resulting from current flow effects at or near the cathode surface. Potential becomes more active (negative) because of cathodic polarization.

Cathodic Protection: Reduction or elimination of corrosion by making the metal a cathode by means of an impressed direct current or attachment to a sacrificial anode.

Concentration Cell: A cell involving an electrolyte and two identical electrodes, with the potential resulting from differences in the chemistry of the environments adjacent to the two electrodes.

Differential Aeration Cell: A concentration cell caused by differences in oxygen concentration along the surface of a metal in an electrolyte.

Electrolyte: A substance that dissociates into ions in solution or when fused, thereby becoming electrically conducting.

Electromotive Force Series: A list of elements arranged according to their standard electrode potentials within an electrolyte, with noble metals such as gold being positive and active metals such as zinc being negative.

Galvanic Cell: A cell consisting of two dissimilar metals in contact with each other and with a common electrolyte (sometimes refers to two similar metals in contact with each other but with dissimilar electrolytes; differences can be small and more specifically defined as a concentration cell).

Galvanic Corrosion: Corrosion associated with the current resulting from the electrical coupling of dissimilar electrodes in an electrolyte.

Galvanic Series: A list of metals and alloys arranged according to their relative corrosion potentials in a given environment.

Holiday: A discontinuity (hole or gap) in a protective coating.

Local Cell: An electrochemical cell created on a metal surface because of a difference in potential between adjacent areas on that surface.

Monel: A corrosion-resistant alloy of nickel, copper, iron, and manganese.

Noble: The positive (increasingly oxidizing) direction of electrode potential.

Oxidation: Loss of electrons by a constituent of a chemical reaction. (Also refers to the corrosion of a metal that is exposed to an oxidizing gas at elevated temperatures.)

pH: A measure of the acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions, increasing with alkalinity and decreasing with increasing acidity.

Passive: The state of the metal surface characterized by low corrosion rates in a potential region that is strongly oxidizing for the metal.

Pitting: Corrosion of a metal surface, confined to a point or small area, that takes the form of cavities.

Polarization: The change from the open-circuit electrode potential as the result of the passage of current.

Reduction: The gain of electrons by a constituent of a chemical reaction.

Stray Current Corrosion: The corrosion caused by electric current from a source external to the intended electrical circuit, for example, extraneous current in the earth.

Stress Corrosion Cracking: A cracking process that requires the simultaneous action of a corrodent and sustained tensile stress. (This excludes corrosion-reduced sections which fail by fast fracture. It also excludes intercrystalline or transcrystalline corrosion which can disintegrate an alloy without either applied or residual stress.)

1. GENERAL

1.1 Corrosion of metals is one of the many problems that has to be considered by engineers when designing aerial, direct buried, or underground telecommunications systems. If not controlled, corrosion can result in costly replacement of facilities. The information and recommendations in this bulletin are advisory.

1.2 The Rural Electrification Administration (REA) Telecommunications Engineering and Construction Manual (TE&CM) 218, Plant Annual Cost Data for System Design Purposes (Planned conversion to REA Bulletin 1751B-230), provides cost data showing the depreciation rates and maintenance expenses to be applied to the various plant items in different areas throughout the United States. However, in some locations, corrosive conditions may exist which can greatly increase maintenance expense and cause the early replacement of some plant items. This can result in a severe economic burden on the operating telecommunications company.

1.3 Corrosive atmospheric conditions may exist over an entire service area of a telecommunications system, or may be confined to relatively small areas within the total service area. Rural environments which are usually free from industrial contaminants, represent most of the total land area of the United States. Exposed metals are expected to provide a relatively long service life when installed in rural areas. For example, galvanized steel has long been used in the telecommunications and electric power utilities and to learn of conductors and strand still in use after 40 years of service is not uncommon. The life expectancy of galvanized steel will vary with the amounts of contaminants present in the atmosphere. In severely corrosive environments, Class A galvanized coatings on steel conductors and strand may last for as little as 3 years.

1.4 The processes of corrosion are not always simple and their effects are not easily predicted. In many cases the effects of one type of corrosion will mask the effects of another type of corrosion so that neither is recognized. The following sections discuss the theory of corrosion and the application of this theory to practical situations in telecommunications systems.

1.5 A comprehensive set of definitions of terms relating to corrosion can be found in American Society For Testing And

Materials (ASTM) G 15, Standard Terminology Relating to Corrosion and Corrosion Testing.

2. CORROSION THEORY

2.1 Corrosion may follow any one of several general patterns. Basically stated, corrosion results from the instability of a construction material with the environment in which the material is placed. All materials, both organic and inorganic, can react with their environments and may eventually lose their usefulness for a given application. Some nonmetals tend to decompose, usually as the result of chemical interaction with some component of their environment.

2.2 Corrosion is the result of electrochemical, chemical, or biological reaction between a metal and its surroundings. Many of the destructive effects of corrosion are due to electrochemical reaction. The basic requirements for corrosion to occur in a given corrosion cell are as follows:

- a. An anode and cathode must be present to form a cell;
- b. An electrically conducting medium (electrolyte) contacting both the anode and cathode must be present;
- c. A metallic connection between the anode and cathode must be present; and
- d. A direct current (dc) potential between the anode and cathode causing current to flow must be present.

2.2.1 The anode is that metallic part of a corrosion cell from which metal ions separate from the metal and flow into the surrounding electrolyte. The metal is consumed (corroded) at the anode by this action. The cathode is that metallic part of a corrosion cell to which positively charged ions in the electrolyte flow and react with the negatively charged electrons in the metal. The cathode metal in an individual corrosion cell does not normally corrode, except when amphoteric metals are involved. Amphoteric metals are metals that corrode in either acidic or alkaline environments. If such metals are made excessively cathodic, the chemical reaction at the cathode can make the environment extremely alkaline and can cause corrosion to occur. Aluminum and lead are examples of amphoteric metals.

2.2.2 The anodes and cathodes can be adjacent (local cells) or far apart. The current can be self-generated or it can be impressed on the system from an outside source. The conducting medium can be water, wet soil or any solution which conducts electricity.

2.3 The anode corrodes. Metal at the anode chemically reacts with the electrolyte causing minute pieces of metal to dissolve and flow into the electrolyte. In the process the minute pieces

of metal lose negatively charged electrons to the anode metal and the minute pieces of metal enter into the electrolyte as positively charged ions. The loss of electrons by the metal ion at the anode is referred to as oxidation. The excess electrons left by the metal ions at the anode flow through the metal or through an external metallic path to the cathode. At the cathode-electrolyte interface electrons leave the metal and chemically react with positively charged ions in the electrolyte. The electron gain by the positively charged ions in the electrolyte at the cathode is referred to as reduction.

2.3.1 Since the generally accepted concept for the flow of electric current is opposite to the direction of electron flow, current flow in a corrosion cell is from anode to cathode in the electrolyte and from cathode to anode in the metal or metallic path.

2.3.2 The quantity of metal lost by the corrosion process is directly proportional to the amount of direct current which flows through the corrosion cell and early in the 19th century was quantitatively shown by Michael Faraday to be in accordance with the following equation:

$$W = k * I * t$$

Where:

W = Weight Loss in grams
k = Electrochemical Equivalent in grams/coulombs
I = Current in amperes
t = Time in seconds

It can be seen that for a given amount of current over a given period of time, the electrochemical equivalent (k) is the variable which determines the actual weight loss of the metal or material. Each metal or material has its own electrochemical equivalent which is a natural characteristic of that metal or material. For example, one ampere of current flowing for one year will corrode about 9 kilograms of steel.

2.4 When the positive metal ions leave the metal anode (corrosion sites), the remaining electrons flow to cathodic sites where they are discharged during the cathodic reactions. The principal cathodic reactions include hydrogen ion reduction to form hydrogen gas, oxygen reduction to form hydroxyl ions (OH^-), and reduction of water to hydroxide ions. Cathodic polarization occurs when the reaction products cover the cathodic sites. The rate of corrosion in soils is often controlled by the rate at which the reactants are supplied to, or the reaction products are removed from the cathodic sites (cathodic depolarization). Similarly, polarization may occur at the anode due to concentration of metal ions although this phenomena is of lesser importance in the soil. In the presence of moisture, the metal ions react with hydroxide ions to form hydroxides which in turn

react with oxygen to form oxides thus producing both cathodic and anodic depolarization.

3. TYPES OF CORROSION

3.1 Galvanic Corrosion

3.1.1 The corrosion resulting from current generated from differences in potential of metals in an electrolyte is referred to as galvanic corrosion.

3.1.2 Dissimilar metals, coupled electrically and placed in a conductive solution, satisfy the requirements for the basic corrosion cell. Two electrically coupled metals, in the presence of an electrolyte, constitute a special corrosion cell, called a galvanic cell, wherein one of the metals becomes cathodic and the other becomes anodic and corrodes. If the potential difference between the metals is small, corrosion usually will be slow. Conversely, if the potential difference between the metals is large, corrosion will usually be rapid.

3.1.3 During the galvanic corrosion process, an electric current flows as a result of the difference in the electrode potential of the two metals coupled electrically. The magnitude of the current determines the degree of corrosion of the more vulnerable material over and above the material's natural rate of deterioration alone in the same electrolyte. The quantity of galvanic corrosion is defined as the corrosion resulting from the electrochemical reaction. In the past galvanic has been erroneously defined as the total corrosion including normal decomposition.

3.1.4 An example of Galvanic Corrosion is shown in Figure 1. The galvanized steel 3-bolt clamp and the galvanized steel anchor rod act as anodes and the copper-steel guy strand acts as the cathode. The corrosion of the anchor rod and the 3-bolt clamp will be increased over the normal rate of corrosion by galvanic effect, unless the hardware is provided with some coating to prevent air and moisture from penetrating to the dissimilar metal connection.

3.1.5 From the galvanic corrosion behavior of metals and alloys, metals can be arranged in a series which will indicate their general tendency to form galvanic cells. Such a series can be used to predict the probable direction and the extent of galvanic effects. Table 1 is such a galvanic series and includes most metals used in outside plant environments. The table is qualitative and is intended only to indicate trends. The arrangement of the metals in the series is based on actual corrosion testing experience within sea water. Since more observations of galvanic behavior have been made in sea water than in any other single environment, the galvanic series listed in Table 1 should be used as a first approximation of the probable direction and extent of the galvanic effects in other

environments in the absence of data more directly applicable to such environments. The only way of predicting the direction and extent of the galvanic effects on a material in a specific environment is to perform potential measurements in the specific environment. The galvanic series listed in Table 1 should not be confused with the Electromotive Force (EMF) Series. In the EMF series the metals are arranged according to the potentials developed when immersed in a solution of their own ions of prescribed composition as to strength and chemical nature. The EMF series is of theoretical value and cannot be relied upon to predict the potential differences between metals in outside plant operating conditions.

TABLE 1
Galvanic Series of Metals in Sea Water

ANODIC END (Most Active)

Magnesium
Magnesium Alloys

Zinc

Aluminum

Cadmium

Steel or Iron
Cast Iron

18:8 Stainless Steel (active)
18:8:3 Stainless Steel (active)

Lead-Tin Solders
Lead
Tin

Nickel (active)
Inconel (active)
Hastelloy (active)

Brass
Copper
Bronze
Copper:Nickel Alloys
Monel

Silver Solder

Nickel (passive)
Inconel (passive)

18:8 Stainless Steel (passive)
18:8:3 Stainless Steel (passive)
Hastelloy C (passive)

Silver

Graphite
Gold
Platinum

CATHODIC END (Least Active)

3.1.6 Some of the metals in Table 1 are grouped together to indicate that the grouped members have little tendency to produce galvanic corrosion on each other and, therefore, are relatively safe to use in contact with one another. However, the coupling of metals widely separated in the series can result in galvanic corrosion of the metal higher in the list, i.e., the one most anodic. Usually the farther apart the two metals are in the series the greater the corrosive tendency. The relative position of a metal within a group sometimes changes with the environment, but rarely does a metal change from group to group. Note that stainless steel alloys 18:8 and 18:8:3 appear in two places in Table 1. They frequently change positions as indicated in the table depending upon the corrosiveness of the sea water. These two alloys demonstrate relatively good resistance to corrosion in their passive, more noble, condition.

3.1.7 The surface areas of the metals forming a galvanic cell are a major consideration in the rate of corrosion. A small piece of aluminum coupled with a large piece of copper will corrode much faster than a piece of aluminum equal in area to the copper. If circumstances dictate that dissimilar metals be in contact with one another, the area of the active (anodic) metal should be large with respect to the area of the passive (cathodic) metal.

3.2 Concentration Cell Corrosion

3.2.1 Another source of corrosion is ion concentration variance within an electrolyte surrounding a single piece of metal. Usually this form of corrosion originates in or around crevices. Early detection and prevention depend largely upon knowledge of the corrosion mechanism.

3.2.2 In general, the lower the metal ion concentration, the greater the tendency of the metal to dissolve, i.e., the lower the metal ion concentration, the higher is its solution potential. When a single metal surface is exposed to a corrosive environment which is not uniform in its metallic salt concentration from point to point, corrosion results in areas of lower concentration. Differences in oxygen concentration at a metal surface within a solution also develop different potentials over the points of contact with metallic surfaces. In both cases, the zone of greatest attack will be in the area of the

more dilute ion or oxygen concentration. This explains the rapid metal destruction associated with lap joints, crevices, or deposits that interfere with the flow of electrolyte over the entire surface of the metal.

3.2.3 As mentioned in Paragraph 3.2.2, differences in oxygen concentration on a metal surface will cause voltage differences to arise and thus accelerate the rate of corrosive attack. These oxygen concentration cells are typically associated with crevices or deposits that hinder diffusion of oxygen into the solution under the deposit. The lower concentration of oxygen creates an anode fostering corrosion which can eventually weaken the structure. With some alloys the effect of the oxygen concentration cell is exacerbated by electrolytic cells formed between the relatively small areas of activated alloy (anode) within crevices and large areas of passive alloy (cathode) around crevices. These cells are similar to, but generally more destructive than, normal oxygen concentration cells because corrosion activity is concentrated in small areas. This type of corrosion is most likely to be found in aluminum and stainless steel, although any metal which has been treated to form a protective coating may also be affected because of the possibility for holidays or aberrations in the coatings where corrosion may concentrate.

3.2.4 The concentration cell corrosion depicted in Figure 2 shows one cause for failure of corrosion-resistant steel (stainless steel) cable suspension strand in industrial and marine atmospheres. Dirt and soot from an industrial area or salt deposits in a marine atmosphere can settle upon the surface, enter into the interstices of the strand and retain moisture. A differential aeration cell is set up and the steel under the deposit becomes active (anodic) to the passive steel (cathodic) on the outer surface of the strand. Pitting of the stainless steel on the inside of the strand under the deposits will result, which may lead to stress corrosion cracking. Galvanized steel strand on the other hand will behave quite differently under similar conditions. The zinc coating on the galvanized steel strand will protect the steel until the zinc coating is completely consumed. The outside surfaces of the strand can show extensive corrosion while the inner surfaces of the strand are relatively unaffected.

3.2.5 Some metals form tight protective oxide films that normally resist corrosion. If the film is damaged, the film will repair itself if sufficient oxygen is present to oxidize the base metal. In the absence of sufficient oxygen to keep the oxide film in repair, the metal under the damaged film becomes active relative to the film protected surfaces and, as in the case of the oxygen cell, corrosion pitting will occur under the deposit. Similarly, concentration cell corrosion may occur on metal surfaces which are covered with nonmetallic materials. If manufacturing voids, cracks, scratches, or other accidental openings in a protective coating occur, moisture can enter under

the coating and cause a corrosion site. Severe pitting may result from local corrosion with the net damage more severe than if the entire metal area was exposed to the elements.

3.2.6 Dissimilar surface conditions on a metallic surface such as scratches or other abrasions and nonhomogeneous soil backfills can cause galvanic corrosion. For example, wrench abrasions on a metal surface will be anodic to the area around it and begin to corrode if there is an electrolyte. Also dissimilar soils in a backfill will induce galvanic corrosion. Where rocks and clay in a sand matrix are in contact with an exposed metal surface, pitting of the metal will occur from galvanic action.

3.3 Bacteriological Corrosion

3.3.1 Certain types of bacteria can establish conditions on the surface of underground metallic structures which will result in more rapid corrosion by existing cells. The most significant type of bacteria which can cause corrosion is the anaerobic type which means that the bacteria thrive in the absence of oxygen. The anaerobic bacterium which is the most common problem-causing corrosion bacterium is known as Desulfovibrio Desulfuricans. This form of bacteria reduces any sulfates present at the underground metal surface to produce hydrogen sulfide and consumes hydrogen in the process. At the metallic surface, hydrogen is consumed at the cathodic surfaces of the existing corrosion cells. This intensifies the action of the corrosion cell by depolarization. From the above it is apparent that the bacteria do not themselves attack the metal, but do result in the intensification of existing corrosion cells.

3.3.2 Anaerobic bacteria are likely to be found in heavy, dense, water logged soils where oxygen content is at a minimum. They can exist, however, under less favorable conditions or under a material coating which locally restricts the oxygen content.

3.3.3 Bacteria require organic material as a food supply. This food supply is normally available to some degree in the earth. However, if a major food supply is combined with a restricted oxygen content, the rate of corrosion can be intensified. An example of this action is a piece of wood lying against an underground metallic structure.

3.4 Stray Current Corrosion

3.4.1 Stray current corrosion is due to direct currents of external origin leaving a metal. Since corrosion is electrochemical in nature, metals ordinarily will corrode whenever current leaves the metal to pass into the electrolyte, regardless of the current source. Stray current corrosion can be caused by dynamic stray current and static stray current.

3.4.1.1 Dynamic stray currents are currents which change with time. Sources of dynamic stray current can cause changes in the

areas where current enters and leaves the structure and can cause reversal of current flow on a structure in some instances. This all results in changes in the location of the anodic and cathodic areas.

3.4.1.2 Static stray currents are currents which are from a steady state external dc voltage source which results in fixed anodic and cathodic areas on the affected structure with a relatively constant current flow on the structure.

3.4.1.3 Static stray currents tend to be more corrosive than dynamic stray currents per ampere of current leaving the underground structure and entering the environment. This is because the variable characteristics of dynamic stray currents, particularly where current reversals occur, cause them to take on some of the characteristics of alternating current which is relatively an insignificant source of corrosion. Therefore, the alternating current characteristic of dynamic stray current tends to reduce its corrosive impact to some degree. However, dynamic stray currents can cause serious corrosion problems where large stray currents are encountered.

3.4.2 Stray current corrosion can be either man-made or natural. Some of the man-made sources of stray direct current are as follows:

- a. Variable speed drives in transit systems;
- b. Load-carrying devices;
- c. Mining operations;
- d. Welding operations; and
- e. High voltage direct current electric power transmission systems.

The natural source of stray current is referred as telluric or earth current of magnetic origin. These are direct currents in the earth's crust which result from the variations in the earth's magnetic field which in turn result from variations in solar activity. The telluric currents are dynamic in nature because the anodic and cathodic areas on the structure are constantly changing as a result of reversals in the direction of current flow on the structure. The telluric currents usually affect long structures such as pipelines and tend to cause more corrosion problems in some parts of the world other than the United States.

3.4.3 Stray current corrosion was noted years ago in cities where direct current was used widely in industrial applications. In the rural areas lead sheathed telecommunications cables buried by telecommunications companies have been corroded by cathodic protection applied to cross-country pipelines to prevent corrosion of the pipelines.

3.4.4 In pipeline cathodic protection, a negative potential is impressed on the pipeline which causes electrical earth currents to flow to the pipeline, protecting it against corrosion. Since the conductivity of most metals exceeds the conductivity of average soils, buried metallic pipes or cables act as low resistance paths and tend to collect stray earth currents which may be present in the surrounding earth electrolyte. At the point where the stray currents enter these auxiliary conductors the earth becomes anodic and the pipe or cable becomes cathodic. But where the currents leave the auxiliary conductor (a pipe or cable) to enter the cathodically protected pipeline (See Figure 3), the metallic auxiliary conductor becomes anodic, and the resulting localized corrosion can be quite severe.

3.4.5 A comparison of stray current corrosion to galvanic corrosion reveals several differences. The damage caused where the direct current from an external source leaves a grounded metal is independent of oxygen concentration of the surrounding environment. The flow of stray currents usually develops sufficient voltage to force hydrogen discharge so corrosion is not limited to the oxygen reduction reaction. Likewise, stray current corrosion is not affected by deposits of corrosion products or protective coatings unless the coatings are perfect insulators. Defects in the coatings can actually result in more severe localized corrosion since the current is concentrated at these sites.

4. CORROSION BEHAVIOR OF METALS USED IN OUTSIDE PLANT CONSTRUCTION

4.1 Atmospheric Environments

4.1.1 Corrosive atmospheric environments have caused REA to become increasingly aware of the need for special attention in the choice of materials and construction practices. There are areas of the United States where plant maintenance and replacement costs are excessively high because of the corrosive nature of the atmospheres. The atmospheres are grouped into three general classifications which are industrial, marine, and rural.

4.1.2 Industrial atmospheres are among the most corrosive. The atmosphere around industrial plants may contain sulfur oxides and carbon dioxides in relatively high concentrations. Sulfur oxide and carbon dioxide both form acid films on exposed metals and, since most pollutants present in the atmosphere attract moisture, atmospheres high in these contaminants usually are very corrosive. Long range transport of industrial pollutants is responsible for acid deposition over large areas of the United States.

4.1.3 Marine atmospheres are corrosive because of the sea air and because of the industry usually located in those areas. The

depth of these coastal areas vary from approximately three kilometers to as much as thirty kilometers from the ocean. In some areas, such as along the Gulf Coast of Louisiana and Texas, typical marine corrosive atmospheres exist as far inland as 160 kilometers due to a combination of salt atmosphere and industrial fumes. Sea air contains chlorides and may contain traces of sulfur, carbon dioxide, and other components that, over a period of time, can become concentrated on metal surfaces. Furthermore, in areas immediately adjacent to the shore, the salt spray from the ocean thrown up by strong breezes contributes to the buildup of sea salt deposits on metals which keeps them wet a good portion of the time.

4.1.4 Years ago, exposed metals were expected to obtain their longest possible service life in rural atmospheres which represented approximately 80 percent of the United States. However, industrial pollutants which consist of sulfur oxides (SO_x) and nitrogen oxides (NO_x) are subject to chemical transformation in the atmosphere to form acids. These pollutants, which can be carried hundreds and sometimes thousands of kilometers cause acid deposition over wide areas of the United States. Consequently rural atmospheres can become corrosive.

4.1.5 Galvanized steel is widely used in the REA program for both hardware items and cable messenger strand. In industrial atmospheres the corrosion products formed on galvanized steel are zinc sulfate and zinc carbonate with zinc sulfate predominating. The zinc sulfate is soluble and is washed off by rain and blown off by wind. The zinc carbonate is removed chiefly by the erosion action of wind driven dirt and dust. This loss of corrosion products results in an accelerated deterioration of zinc in industrial atmospheres. The chlorides present in both industrial and marine atmospheres will attack the zinc coating on galvanized steel to form a zinc chloride. This zinc chloride compound will attract and retain moisture and then will react with other elements in the air to form zinc oxychloride and zinc carbonate. The resulting coating is porous and powdery and can be washed off quite easily. Because of the moisture-laden winds along the coast, corrosion products can build up faster than the rain can wash them off. Since the material remains wet most of the time, the corrosion will progress until the zinc is completely changed to compounds leaving base steel unprotected. The chemical composition of the base steel will determine the integrity of the oxide coating formed after the zinc has been sacrificed. Carbon steel will develop an oxide coating which will be porous and flaky. The oxide is not soluble but may be readily dislodged. Thus the carbon steel will continue to corrode. The oxide coating on the low alloy steel will be less porous and more adherent than the oxide on the carbon steel. The rate of diffusion of corrosive elements to the base metal will be low; consequently, the low alloy steel will be more corrosion resistant.

4.1.6 Copper and copper alloys, as well as copper-covered steel, are used to a great extent in the REA telecommunications program for conductors, shielding, and a variety of hardware items. Copper is the most sensitive to the sulfur oxides present in industrial atmospheres. New copper exposed to an industrial atmosphere will form a copper oxide coating which is not porous but is quite brittle. The sulfur dioxide and moisture in the air will combine with the copper oxide to convert part of it to basic copper sulfate. Copper corrosion products provide the familiar green patina appearance on copper. The recognized low rate of copper corrosion in the atmosphere is due to the protective patina. As long as the patina is not disturbed, the corrosion reaction will continue, but at a very slow rate. However, if the cuprous oxide underlayer is disturbed, fresh copper is exposed anew to the accelerated corrosion process.

4.1.7 The somewhat protective copper coating on a copper-covered steel conductor can be dislodged by vibration or abrasion under tension. Copper and copper-covered steel will probably corrode at a faster rate in a marine atmosphere than in an industrial environment because of the presence of chlorides and traces of sulfur. The surfaces of the metals are likely to remain wet a large share of the time because of salt spray. The copper will react with oxygen to produce a layer of basic copper oxide which is converted to basic copper sulfate and basic copper chloride in the salt air. The same copper oxide would be present as in the industrial environment but its combination with the chloride would cause the corrosion reaction to be stronger. The coating would probably be more porous which would hold more moisture and would allow more air to diffuse through to the base metal to continue the corrosion of the copper. Because there is a relatively thin layer of copper over the base steel in the copper-covered steel conductors, the tendency for the steel to be exposed to the atmosphere is very real. Once the steel is exposed to the atmosphere, a galvanic corrosion cell is formed with the steel anodic to the copper. Since the exposed area of the steel (anode) is small compared to the area of the copper (cathode) on the surface of the wire, the galvanic cell that results is active and the corrosion of the steel will be rapid.

4.1.8 Certain grades of stainless steel have been used for cable suspension and guy strands in industrial and marine areas to provide additional service life over that offered from Class C galvanized steel strand. Corrosion resistant steel forms a protective oxide coating to corrosive elements in the industrial and marine atmospheres by preventing moisture penetration to the base metal. However, when dirt and soot from industrial atmospheres and salt deposits from marine atmospheres settle upon the surface and into the interstices of the strand, an oxygen concentration cell is created. The corrosion resulting from the concentration cell and the subsequent stress corrosion cracking of the strand is quite serious. Cable suspension strand made of stainless steel can appear perfect but fail because of corrosion pitting inside the strand that is not apparent from visual

inspection. Some outside plant engineers favor the use of Class C galvanized steel strand over the corrosion resistant steel because of the oxygen concentration, stress corrosion phenomenon. Although the Class C galvanized steel strand has a shortened life span in a corrosive atmosphere, replacement can be planned whereas the failure of the corrosion resistant steel strand can not be predicted with certainty. The serious effects of premature or unexpected failure of a suspension strand carrying telecommunications cable should be a significant factor in selecting strand.

4.1.9 In addition to the three basic types of atmospheres found within the United States, there may exist commercial operations that could change the characteristics of the atmosphere in the environment which could result in accelerated corrosion of telecommunications outside plant products. Such operations exist in areas of high air pollution and include drilling or mining installations, chemical or fertilizer plants, burning slag dumps, sour gas field, etc. Also in hot humid areas, vegetation such as Spanish Moss can absorb moisture and in contact with a metallic structure can create a galvanic corrosion cell which could lead to serious corrosion. All of the above factors must be considered when evaluating the possibility of atmospheric corrosion of outside plant facilities.

4.2 Underground Environments

4.2.1 Underground equipment in the REA telecommunications program consists of anchors, anchor rods, ground rods, buried plant terminal housings, and buried cables and wires. A majority of currently installed telecommunications cable and wire plant is buried directly in the soil. The various shielding and armoring materials, when exposed to the environment of different soils, are subjected to all of the corrosion mechanisms. These corrosion mechanisms include the effects of dissimilar metals (galvanic couples), soil conditions, differential aeration, stray currents, and bacteria. From past experience the corrosion of anchor rods has proven to be the most important aspect of outside plant construction. The corrosion of galvanized steel anchor rods may be caused by dissimilar metal affects (galvanic couples), soil conditions (differential salt concentration or differential aeration) or by stray currents.

4.2.2 The general practice has been to use galvanized or copper-covered steel ground rods for grounding of metallic facilities or structures. Also a requirement on joint use construction, where the power system is of the multigrounded neutral type, is to bond the guy strand to the neutral either directly or through the cable messenger (suspension strand). The zinc and iron in a galvanized steel anchor rod, when buried in conducting earth, tend to develop a dc voltage that is more negative (anodic) than that of buried copper (cathodic). When the buried steel and copper are connected together by the power system neutral, as shown in Figure 4, currents will begin to flow through the

completed circuit from the steel through the conducting earth to the copper on the ground rod and the copper pole-butt grounds. Corrosion associated with such current flow is an example of galvanic corrosion.

4.2.2.1 Polarizing effects occur at the steel and copper surfaces in most soils and interfere with the flow of current so that it soon decreases to the point where no serious damage results. In the more aggressive soils, however, the current may continue to flow so that the steel is corroded at an excessive rate. Excessive underground corrosion is generally noticed on anchor rods first, and in many cases anchor rod corrosion is believed to be the entire problem, but other buried structures may be affected. Any buried structure connected to the power system neutral may be corroded as a result of galvanic action. Another example of corrosion due to galvanic action is the connection of telephone system copper covered ground rods to steel anchors and anchors rods.

4.2.2.2 Ungalvanized anchors are considered an important contributor to corrosion of steel anchor rods and may be the major contributor where the corrosion is not associated with currents in guys due to copper grounds. The mill scale on hot-rolled steel and oxide films on other steel is cathodic to galvanized and bright surfaces in much the same way as copper causes corrosion. Galvanizing of anchors requires prior removal of all oxide films, and the galvanizing offers additional corrosion protection to the anchor rod as well as to the anchor.

4.2.3 Differential aeration corrosion of an anchor rod can occur, regardless of the material used, even though it is electrically isolated from the power system's multigrounded neutral. A differential aeration corrosion cell (See Figure 5) may begin on the surface of the anchor rod where the lower portion of the rod, in contact with a soil low in oxygen, becomes anodic to the upper portion of the rod which is in contact with a soil having higher oxygen contents. Most corrosion failures of anchor rods occur within 15 centimeters of the anchor, and other structures also likely to have the greatest damage deep in the ground where moisture is present and oxygen excluded.

4.2.4 Stray currents from cathodic protection applied to cross-country pipelines have caused REA borrowers a number of corrosion problems. Stray currents from these cathodically protected pipeline systems can cause rapid corrosion of anchor rods, ground rods, metal sheathed cables, and other metallic structures placed underground. The first signs of stray current corrosion damage is likely to be failure of one or more anchor rods in low or wet locations. In the majority of cases this anchor rod failure can be noted from slack guys. This initial corrosion signal should initiate an investigation into the problem before further damage occurs.

5. CORROSION PREVENTION MEASURES

5.1 Atmospheric Environment

5.1.1 The atmospheric environment that exists in the area of proposed construction should be determined by the engineer during the early stages in the design of the telecommunications system. Corrosive atmospheric conditions may exist over an entire service area of a telecommunications system or may be confined to relatively small areas within the total service area. In heavily populated industrial areas that are spread over several square kilometers, the entire project area may be corrosive and require special consideration. On the other hand, in an area that is generally classified rural, a commercial operation could affect the service life of just a few kilometers of plant. One of the most valuable sources of information for the engineer is the historical performance of the various materials that are being replaced in a particular area. Obviously, if the material in the plant being replaced has been in service for 20 to 25 years there is no reason for serious concern.. When it is not possible to determine the service life of the existing plant because of a lack of records or personnel who remember when a certain section of line was built, the local electric utility may be able to furnish the necessary information. Many of the materials and the problems in the use of these materials are common to both the telecommunications and the electric utilities. Also a survey of the commercial and industrial activities in the service area should pinpoint those areas where special corrosion preventive measures should be taken.

5.1.2 Once the type of atmosphere in the proposed area of construction has been identified, a determination of materials best suited for use in that particular environment should be made. For best results consider areas immediately adjacent to the east coast and to the northwest coast of the United States to be marine, whereas the areas within 30 kilometers of the Gulf Coast of Louisiana and Texas and the coast of California south of San Francisco would be classified as marine-industrial. In the Gulf Coast areas of Louisiana and Texas, the belt from 30 kilometers to 160 kilometers from the coast would be classified as industrial because of the numerous oil wells, chemical processing, and oil and gas refinery operations.

5.1.3 Galvanized steel has been widely used for many years in the telecommunications industry for hardware items. Generally speaking, hardware items such as 3-bolt clamps, cable suspension clamps, machine bolts, thimble-eye bolts, etc., are available only in galvanized steel. However, in the past several years aluminum covered steel and aluminum alloy hardware items have been developed for use in outside plant construction. In severely corrosive industrial areas , where galvanized steel would have a shortened service life, the use of aluminum covered steel or aluminum alloy hardware is recommended where available. If the use of aluminum covered steel or aluminum alloy hardware is not used in these situations, galvanized steel hardware made

from low alloy steel should be used in preference to carbon steel.

5.1.4 One of the most important considerations in material selection for a given environment is to choose metals that will give good performance when fastened together. Metals that are widely separated in the galvanic series (Table 1) should not be placed in contact with one another. If the use of dissimilar metals cannot be avoided, then remember that the least damage occurs when the ratio of exposed area of noble (protected) to the exposed area of less noble (corroding) metal surfaces is kept as small as possible. Also, stranded wire used for bonding purposes should be tinned copper to minimize corrosion from joining dissimilar metals. When grounding wire is required to contact the soil, the bare copper should be insulated. Whenever possible a connection of dissimilar metals should be coated. When properly applied, the coating materials will prevent moisture and air from contacting the dissimilar metal connection and thus prevent galvanic corrosion at the jointing interface.

5.1.5 Galvanized steel has been used for many years in the telecommunications industry for cable messenger strand and for guy strand. The material is not adequate for applications in the more corrosive industrial and marine atmospheres. Experience to date indicates that aluminum-covered steel messenger strand and guy strand should be used in areas high in sulfur content, such as severely corrosive industrial atmospheres and near sulfur mining activities.

5.1.6 Polyethylene jacketed and insulated facilities are expected to experience good performance characteristics in all types of atmospheres. These products should be installed in areas that are highly corrosive.

5.2 Underground Environments

5.2.1 Corrosion of underground telecommunications systems is the most difficult to prevent because of the many factors that singly, or in combination, affect the course of the electro-chemical reaction. The major problem in corrosion prevention is to decide the corrective measures that will give satisfactory results at the least cost. Care must be taken to insure that the corrective measures taken to cure the corrosion does not reduce the intended performance of the telecommunications system. The important need is to adequately recognize the processes that are happening or can happen and the alternatives available, so that future corrosion problems can be minimized. There should be no need to reengineer for corrosion each time that a system is designed, constructed, or modified.

5.2.2 The guidelines set forth in the following paragraphs are intended to minimize underground corrosion of buried metal that is connected to or a part of the electrical grounding system and to reduce the difficulty and the cost of applying cathodic

protection where needed for further reducing the amount of underground corrosion.

5.2.2.1 Galvanic corrosion, caused by connecting dissimilar metals underground, has been the most prevalent and most serious type of corrosion experienced by the telecommunications and electric utility industries. In order to eliminate or to minimize galvanic corrosion of galvanized anchor rods, plumbing and well casings, and other metals connected to the grounding system, REA suggests that grounding of electrical protection apparatus on telecommunications systems follow the guidelines contained in this bulletin.

5.2.2.2 Where a driven ground rod is required for electrical protection (grounding) of the subscriber's premise in buried plant construction, a galvanized steel ground rod should be used.

5.2.2.3 On pole line construction, where a driven ground rod is required for electrical protection purposes and is to be interconnected with the guy and anchor assemblies, a galvanized steel ground rod should be used. In the event the ground rods are not interconnected with the guy and anchor assemblies, a copper-covered steel ground rod may be used.

5.2.2.4 Where joint use construction is contemplated with a multigrounded neutral power system inquiries should be made of the electric company as to its history of underground corrosion. A corrective program may have already been established. If so, the telecommunications system should follow a similar program. If there has been no experience of underground corrosion on the electric system, standard telecommunications construction practices can probably be followed with satisfactory results.

5.2.2.5 The use of galvanized anchors, in addition to the galvanized anchor rods, will further reduce the rate of corrosion. A substantial amount of protection against corrosion can be achieved at very little increase in cost. This is especially important in areas of low earth resistivity.

5.2.2.6 Stray current corrosion, resulting from cathodic protection, can be reduced in underground telecommunications plant by either electrically insulating the telecommunications facilities from the stray currents or installing a mitigation bond between the telecommunications facilities and the foreign structure being cathodically protected. Usually the anchor rods and anchors can more easily and more economically be protected by insulating them from the dc source; however a mitigation bond can easily be provided between the dc source and the multigrounded neutral. If stray current corrosion is being experienced on buried metallic sheathed cables, the best method for reducing its effects probably will be to install a mitigation bond.

5.2.2.7 When new construction is being contemplated in the vicinity of a buried pipe system, municipal water system, or a

gas utility system, a determination should be made as to the corrosion protection measures being employed between the telecommunications facilities and the foreign structure being cathodically protected. Every effort should be made to outline a program with these companies that will assure the telecommunications facilities of the maximum practical corrosion protection from the effects of these cathodically protected foreign structures. Figure 6 shows an example of a coordinated effort to arrest the corrosive effects on the buried cable of the stray currents generated by the cathodic protection applied to the pipeline. A mitigation bond was placed between the buried metal shielded cable and the cathodically protected pipeline to provide a low resistance path back to the rectifier station for the stray currents.

6. ENVIRONMENTAL CONDITIONS AFFECTING THE SELECTION OF CABLE OR WIRE SHIELDS

6.1 Many factors, such as construction personnel, equipment, rock, etc., can damage the cable or wire sheath during construction. Manufacturing defects, lightning, and rodents can also contribute to sheath damage. A greater incidence of sheath damage is experienced in gopher areas and exposure of the metallic shield is more prevalent. Filled cable and wire designs and good construction practices have substantially reduced sheath damage, but are not likely to eliminate it completely. The proper selection of shielded cable or wire for use in problem areas will provide maximum corrosion protection for buried cable or wire.

6.2 The evaluation of the corrosivity of a soil is complex. Some of the soil properties that affect corrosion are soil resistivity, stray currents, pH, drainage or aeration, moisture content, and soluble salts present. Studies sponsored by REA have shown that NO SINGLE PROPERTY OF A SOIL is an accurate indicator of its corrosivity to a particular metal.

6.3 Shields incorporating copper, copper alloys, and copper/alloy steel and copper/stainless steel combinations comprise a significant portion of the cable or wire system. Copper exhibits slow, uniform corrosion in most soil conditions. However, in highly acidic or in sulfur-containing soils, corrosion of copper may accelerate. Because copper is cathodic to most metals in the outside plant (i.e., carbon steel or cast iron), it will receive cathodic protection from these metals within reasonable proximity, thus extending its life. However, in newer installations the water and gas systems are often nonmetallic or electrically insulated, which eliminates the cast iron or steel as a sacrificial anode. When galvanically coupled with other copper structures such as power system neutrals, these shields are not susceptible to accelerated corrosion. In many environments copper exhibits satisfactory corrosion resistance; however in an aggressive environment copper may corrode.

6.3.1 When certain chemical constituents are present in the soil such as sulfides, bicarbonates, and ammonium compounds, corrosion of copper can occur. In soils contaminated by fertilizers, cinders, and decaying organic matter, the rate of corrosion will be greater than that observed in less aggressive environments.

6.3.2 Marine and industrial environments, which may transport pollutants great distances, frequently contain sulfur compounds such as hydrogen sulfide which may permeate the jacket and cause corrosion of copper. The soils containing sulfate ions and anaerobic, sulfide generating bacteria have in some isolated instances also caused treeing of the cable or wire jacket.

6.3.3 Copper clad stainless steel or copper clad alloy steel laminates have demonstrated satisfactory corrosion resistance in tests and in service in a wide range of environments. The outer layer performs comparably to solid copper and to copper alloys in soils where copper has satisfactory corrosion resistance. In more aggressive soils i.e., low pH, high sulfide levels, where copper corrosion is accelerated, test and field results have shown that the stainless steel or alloy steel remains passive and acts as a corrosion barrier protecting the inner copper layer from corrosion. Thus the shield integrity may be prolonged.

6.3.4 The primary mechanisms which can contribute to the corrosive attack of copper are as follows:

- a. Direct attack in acidic, sulfide, and ammonia containing soils;
- b. Electrolytic corrosion from external sources of direct current; and
- c. Corrosion under the influence of alternating current.

6.4 The use of plastic coated aluminum since the early 1960's indicates its use as one approach in controlling corrosion for shields in buried cables used in the outside plant. Plastic coated aluminum has demonstrated satisfactory corrosion resistance in field tests, laboratory tests, and service in a wide range of environments for over 25 years.

Note: For uniformity, the words coated and coating are used in this bulletin to describe metallic components covered with plastic materials whether by solvent release coating, film laminating or extrusion coating. The intent of the reference is to address the performance of the coated materials, not to describe the process of preparation.

6.4.1 The plastic coating restricts the area of aluminum subjected to corrosion. The polymer coating forms a chemical bond with the metal which effectively counteracts the mechanical forces generated during the corrosion process that attempt to

detach the coating. Also, the chemical bond prevents the migration of moisture and chemicals along the interface of the copolymer coating and aluminum thus retarding corrosion.

6.4.2 The forces which damage the outer jacket also will likely damage the plastic coating. In this case, localized corrosion of the aluminum may occur wherever the coatings are damaged due to the same factors which corrode bare aluminum. However, coatings which are chemically bonded to a metal substrate will generally restrict the corrosion to the vicinity of the damaged region. In outside plant areas where the jacket is more susceptible to mechanical damage, the coated aluminum should be bonded to the jacket since bonded-sheath improves the puncture resistance and toughness of the cable and thus reduces the possibility of cable damage.

6.4.3 Since galvanized steel is recommended for use as ground rods, galvanic corrosion of the plastic coated aluminum shield is greatly reduced. However, where the plastic coated aluminum shield is coupled to a copper shield, careful consideration needs to be given to the area of cathode (copper), anode (coated aluminum), and distance of the electrolyte between the metals.

6.4.4 If the plastic coating on the aluminum is damaged, corrosion may be initiated. Factors which are likely to corrode the bare aluminum are as follows:

- a. Direct attack in soils;
- b. Galvanic corrosion;
- c. Dynamic and static stray currents from external sources; and
- d. Differential aeration.

Aluminum is an amphoteric metal and it corrodes more rapidly in highly acidic and highly alkaline media, i.e., at pH levels below 5.0 and greater than 8.5. The rate of corrosion also depends on the specific ions present. Chlorides and sulfates are considered aggressive towards aluminum. Also when aluminum is coupled to copper and other passive metals, corrosion of aluminum can be severe due to galvanic effects. Although these mechanisms are pertinent to exposed bare aluminum at defects in plastic coated aluminum, the rate at which corrosion occurs for plastic coated aluminum is mitigated by the presence of the plastic coating, as described in the previous paragraphs.

6.4.5 Marine and industrial environments, which may transport pollutants great distances, frequently contain sulfur compounds such as hydrogen sulfide which may permeate through the jacket and cause corrosion.

6.4.6 The primary mechanisms which can contribute to the corrosive attack of bare aluminum are:

- a. Direct attack in highly acidic and highly alkaline soils;
- b. Chlorides and sulfates;
- c. Electrolytic corrosion from external sources of direct current;
- d. Corrosion under the influence of alternating current;
- e. Galvanic effects when coupled to copper;
- f. Galvanic effects when coupled to other passive metals; and
- g. Differential aeration.

6.5 The corrosion of bare steel due to the various factors thus far described for aluminum and copper in the text is well recognized. Bare steel is more susceptible to corrosion in acidic rather than neutral or alkaline media. The plastic coatings on both aluminum and steel reduce the corrosion from the environment. The use of coated steel provides the first line of defense from corrosive elements if the jacket is damaged and also protection to the coated aluminum for it to perform vital shielding functions. If the plastic coating on the steel is damaged, corrosion may be initiated with subsequent dissolution of the steel. Further corrosion of the exposed steel may proceed according to the primary mechanisms referenced in Paragraph 6.4.6.

6.6 Certain locations in the country may have severe corrosion conditions which are more harmful to one type of cable or wire shield or cable armor than another. In such areas, the engineer should determine the cable or wire material which is best suited for these particular soil conditions. To determine a potentially corrosive environment, the engineer should measure the earth resistivity, identify the pH level of the soil, and gather historical data from company files and from other utilities in the exchange area. Soil resistivity is an indicator of corrosivity as shown in Table 2; as well as, is historical data. However, the latter should be viewed in light of changing soil conditions caused by acid rain, long-range transport of industrial pollutants in the atmosphere, deicing practices, fertilizers, etc. If there has been no prior construction in the vicinity of a new site, the soil resistivity and pH at the new site should be determined and compared to measurements taken at similar sites with some long-term in place construction. For example, if soil measurements along a new cable or wire route indicate a neutral pH with low soil resistivity and a similar site with long lived coated aluminum cable plant is nearby with a

good performance history, coated aluminum shielded cable could probably be used at the new site with no problems.

TABLE 2
Soil Corrosivity Versus Resistivity

Resistivity (Ohm·cm)	Soil Corrosivity (description)
Below 500	Very Corrosive
500 to 1000	Corrosive
1000 to 2000	Moderately Corrosive
2000 to 10,000	Mildly Corrosive
Above 10,000	Progressively Less Corrosive

6.7 Soil properties can be obtained from the local Soil Conservation office or samples can be sent to an independent laboratory for property measurements. Soil resistivity is the easiest measurement and should be made on site following the recommended techniques listed in Section 7. Figures 7 through 11 show the general soil resistivity throughout the United States but are not meant as a substitute for local measurements.

7. SOIL MEASUREMENTS

7.1 Soil Resistivity

7.1.1 Soil resistivity can be measured in a number of ways. The most accurate method is to obtain some soil at the cable or wire burial depth and measure the resistivity in the laboratory under controlled conditions which include saturating the soil with distilled water. A field measurement can be made at the soil burial depth using the four terminal method shown in Figure 12. Four small test electrodes (stubs of number 8 American Wire Gauge (AWG) wire will suffice) are placed to the same depth and equal distances apart in a straight line. Four separate lead wires connect the electrodes to the four terminals on the soil resistivity tester as shown in Figure 12. Hence, the name of the test: The Four Terminal Method.

7.1.2 The theory behind the Four Terminal Method showed that if electrode depth A is kept small compared to the distance between electrodes B, the following equation applies:

$$P = 2DBR$$

Where:

- P = Average soil resistivity to depth B in ohm·cm
- D = 3.1416
- B = Distance between electrodes
- R = Instrument reading in ohms

7.1.3 Since copper cable or wire is usually buried at a depth of 0.6 to 1 meter (m), the average soil resistivity should be measured to at least 1.2 m. For buried fiber optic cable, the average soil resistivity should be measured to at 1.5 m because this cable is usually buried at a depth of 1 to 1.2 m. Where a cable is to be buried at a depth greater than 1.2 m, the average soil resistivity should be measured at the 1.2 m depth plus 25 percent. The electrode depth should not exceed 10 percent of the electrode spacing dimension. A 7.6 centimeter (cm) electrode depth should be adequate. Black vinyl tape may be placed 7.6 cm from the ends of the electrodes as a depth gauge. Assuming an instrument reading of 30 ohms is obtained at 1.2 m electrode spacing, the soil resistivity would be calculated as follows:

$$\begin{aligned}
 P &= 2DBR \\
 &= 2 * (3.1416) * (1.2 \text{ m} \times 100 \text{ cm/m}) * (30) \\
 &= 754 * (30 \text{ ohms}) \\
 &= 22,620 \text{ ohm}\cdot\text{cm}
 \end{aligned}$$

Therefore, if the 1.2 m electrode spacing is maintained the soil resistivity is 754 times the instrument reading in ohms. If an electrode spacing of 0.86 m is maintained a multiplier of 500 will result yielding resistivity at 0.86 m which is a realistic cable or wire placement depth. Typical soil resistivity values to be expected are given in Table 3.

TABLE 3
Typical Soil Resistivity Values

<u>Soil Types</u>	<u>Soil Resistivity (Ohm·cm)</u>
Sand Saturated with Sea Water	100 - 200
Marsh	200 - 400
Clay	200 - 15,000
Sand and Gravel	5,000 - 100,000
Clay Mixed with Sand Gravel	1,000 - 135,000
Shale	1,000 - 50,000
Rock	50,000 - 1,000,000
Limestone	500 - 400,000

Note: A description of the Four Terminal Method is described in ASTM G 57, latest issue, Standard Method for Field Measurement of Soil Resistivity Using the Wenner Four Electrode Method.

7.2 Soil pH

7.2.1 Soil pH can be measured with a number of commercially available battery-powered meters. These high-impedance meters measure the potential difference between a sensing electrode whose potential changes with the hydrogen ion concentration and a reference electrode (usually calomel). Commercially available combination electrodes consisting of a saturated calomel reference electrode and an electrode combined as one single electrode are available. The easiest and most practical method to measure soil pH is the use of a commercial meter in conjunction with a combination electrode.

7.2.2 The pH meter and electrodes are standardized by immersion in standard solutions of known pH and adjustment of the standardized dial in accordance with the manufacturers' recommendations or ASTM G 51, latest issue.

7.2.3 The contact area of the glass electrode or combination electrode should be pressed against undisturbed soil at the location of interest. With the electrodes in place, set the meter to read pH, allow sufficient time for equilibrium to be established, then take the meter reading. Again allow the meter to equilibrate, then reread the meter. The values obtained should agree within 0.2 units to be acceptable.

7.2.4 It is best to bore and make the pH measurement at the depth of interest. A subsurface probe for accomplishing this is described in ASTM G 51, latest issue, Standard Test Method for pH of Soil for Use in Corrosion Testing. Soil samples can be brought to the surface with a boring tool or post-hole digger and the measurement made in the field on the soil thus obtained. The least desirable method is to make the measurement on soil returned to the laboratory, however, if this is done the measurement should be made within 24 hours from the time the sample was obtained. Under no circumstances should a surface pH measurement be construed as the pH of the soil at the cable depth.

FIGURE 1 EXAMPLE OF GALVANIC CORROSION

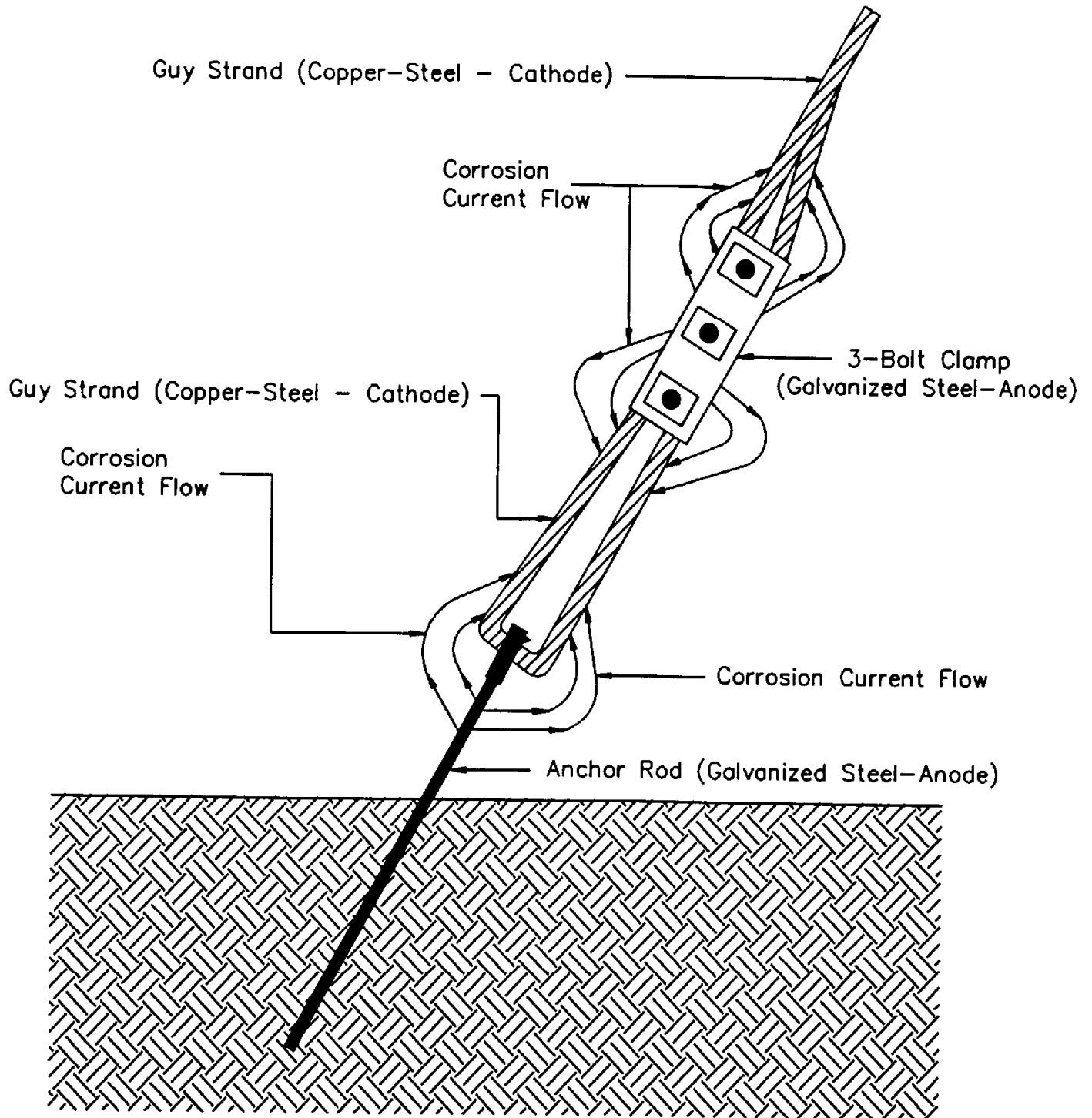


FIGURE 2 EXAMPLE OF CONCENTRATION CELL CORROSION

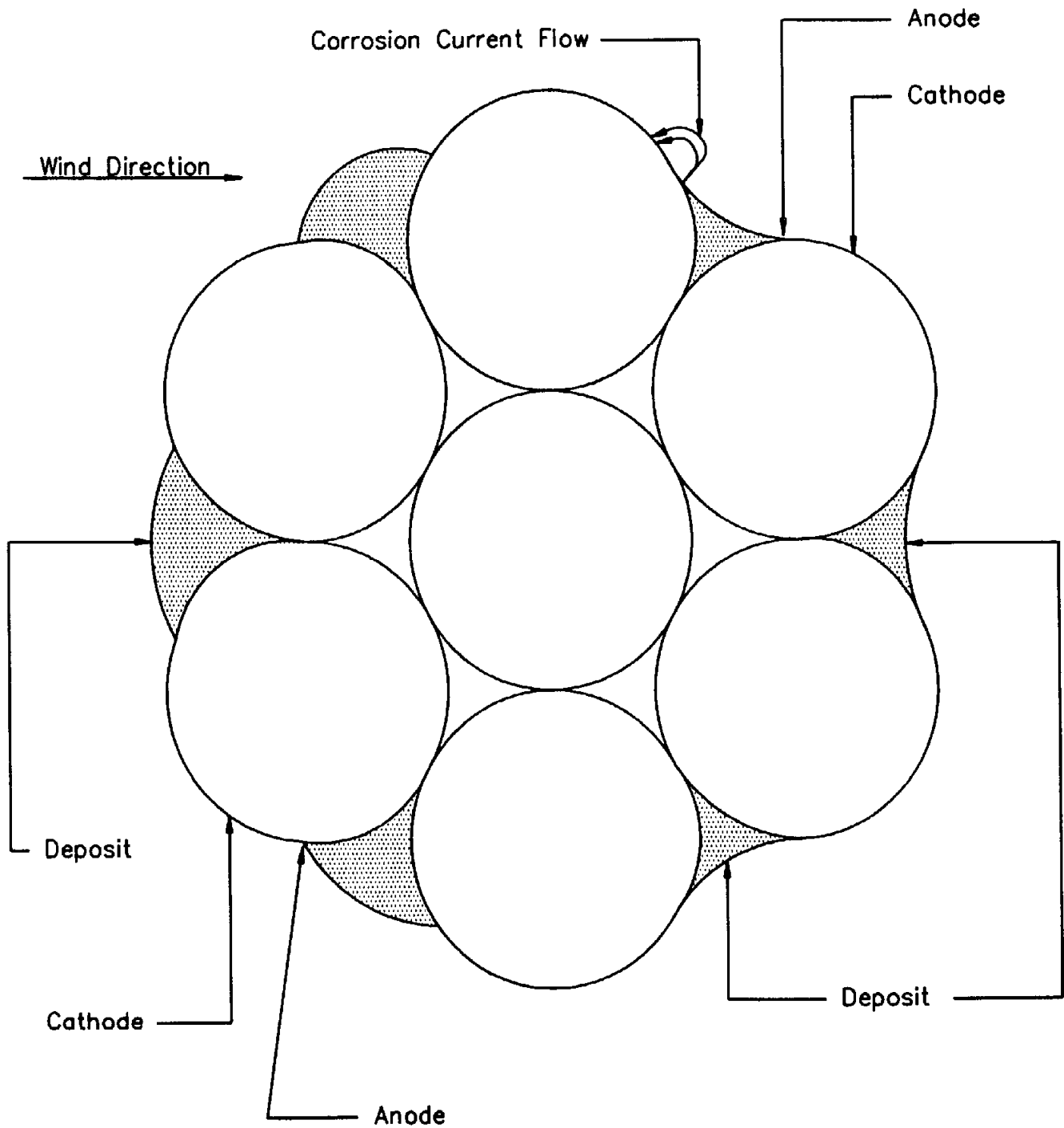


FIGURE 3 EXAMPLE OF STRAY CURRENT CORROSION

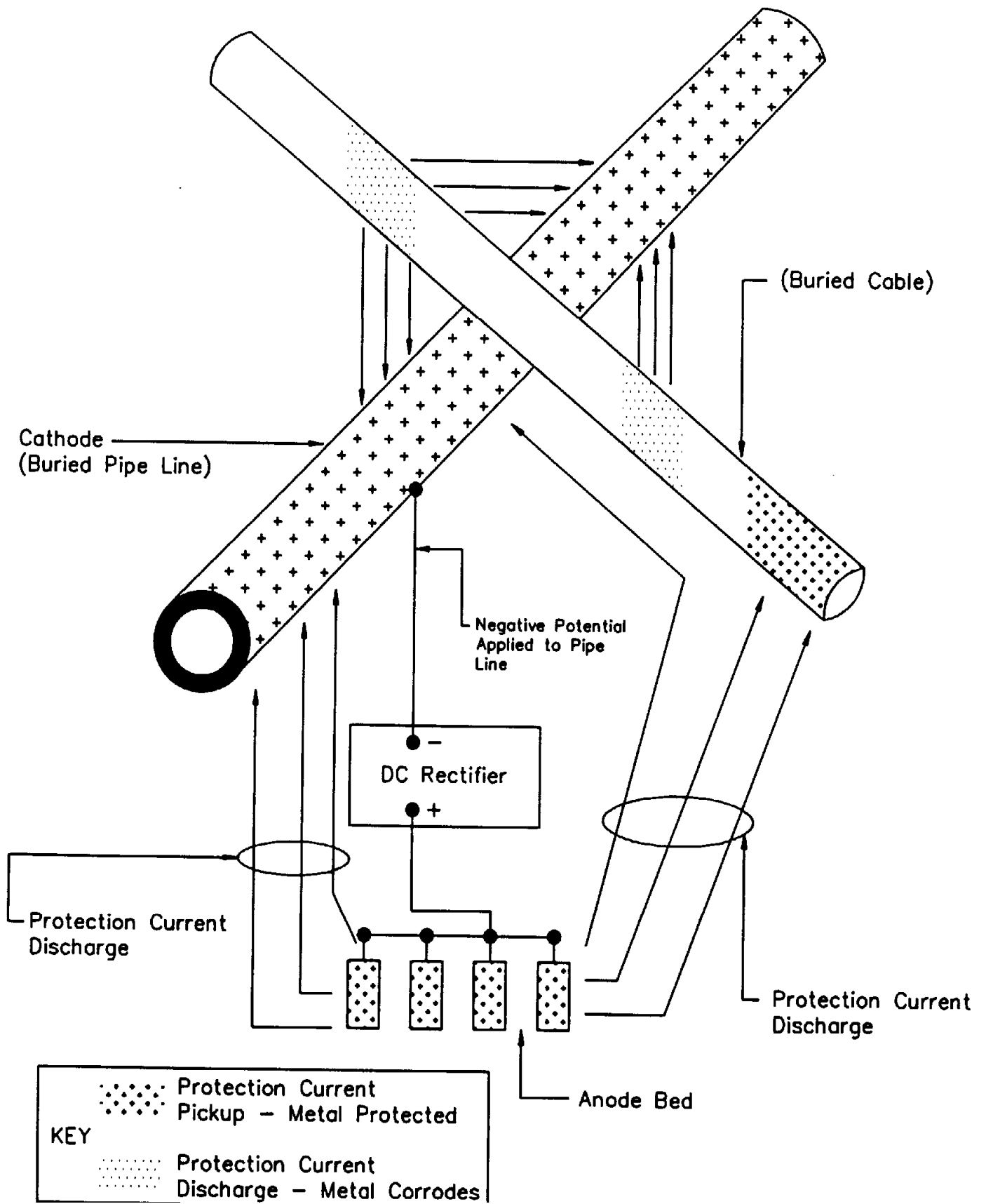


FIGURE 4 ANCHOR ROD CORROSION – GALVANIC COUPLE

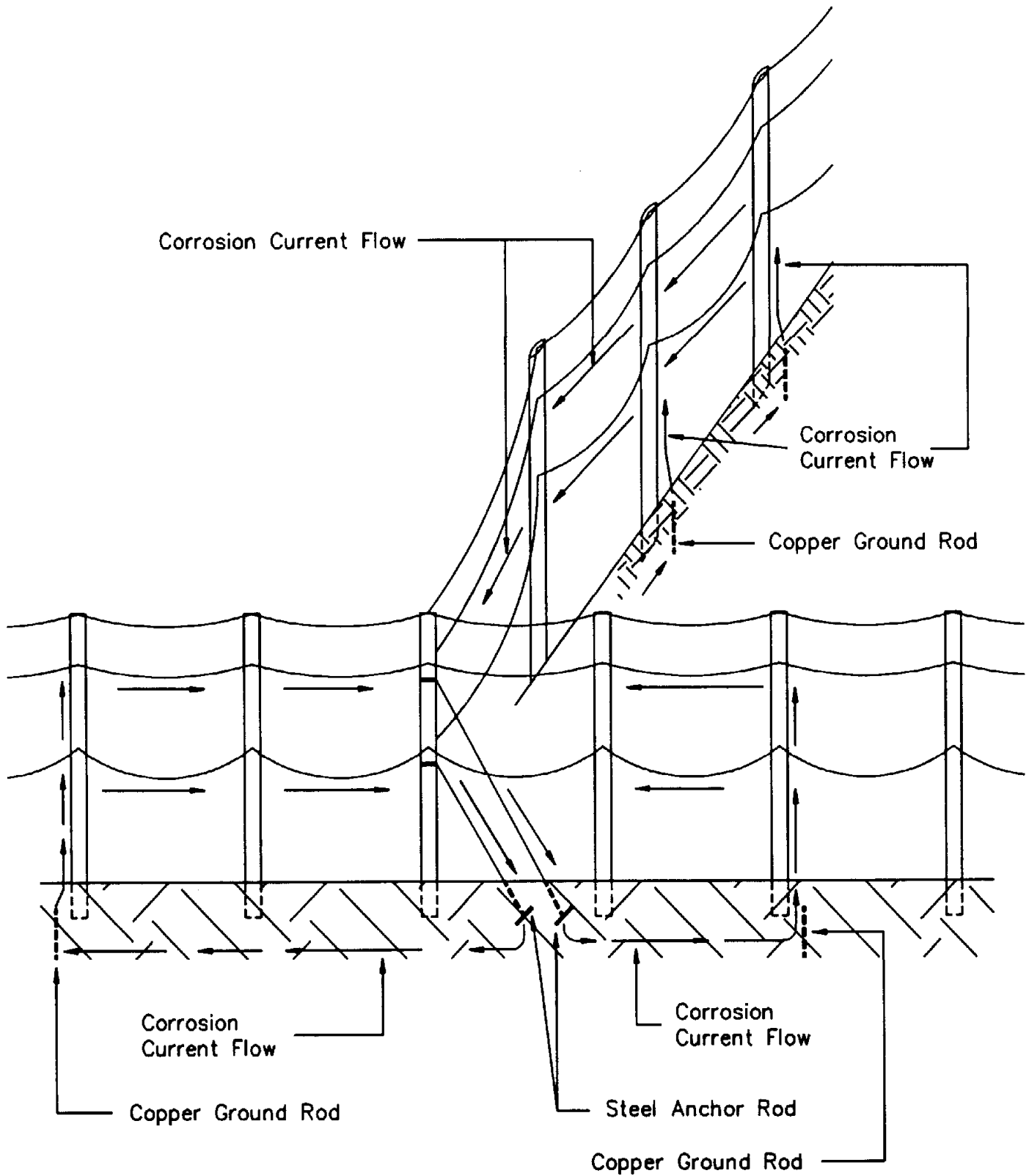


FIGURE 5 ANCHOR ROD CORROSION – DIFFERENTIAL AERATION CELL

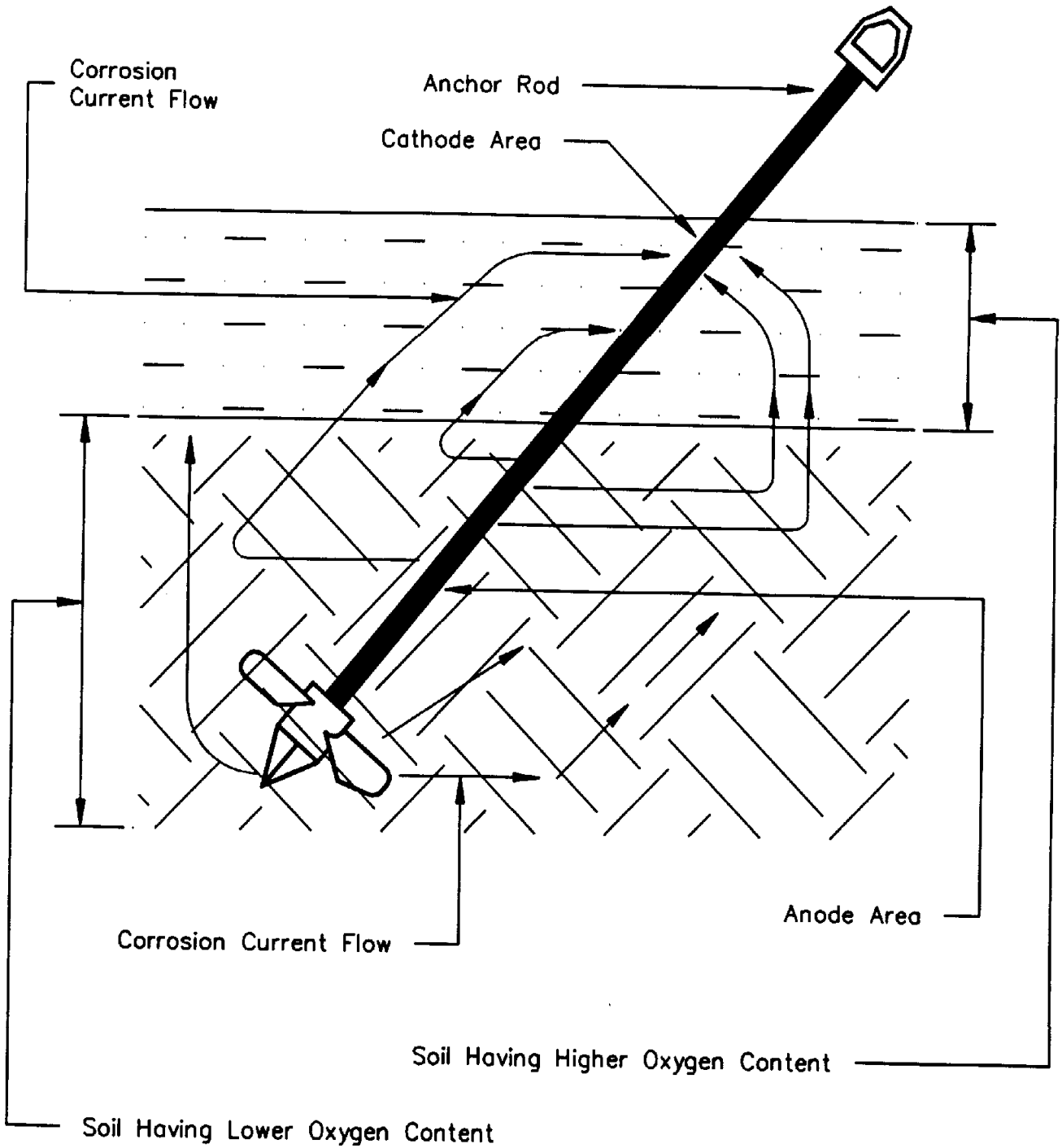


FIGURE 6 COORDINATED STRAY CURRENT PROTECTION

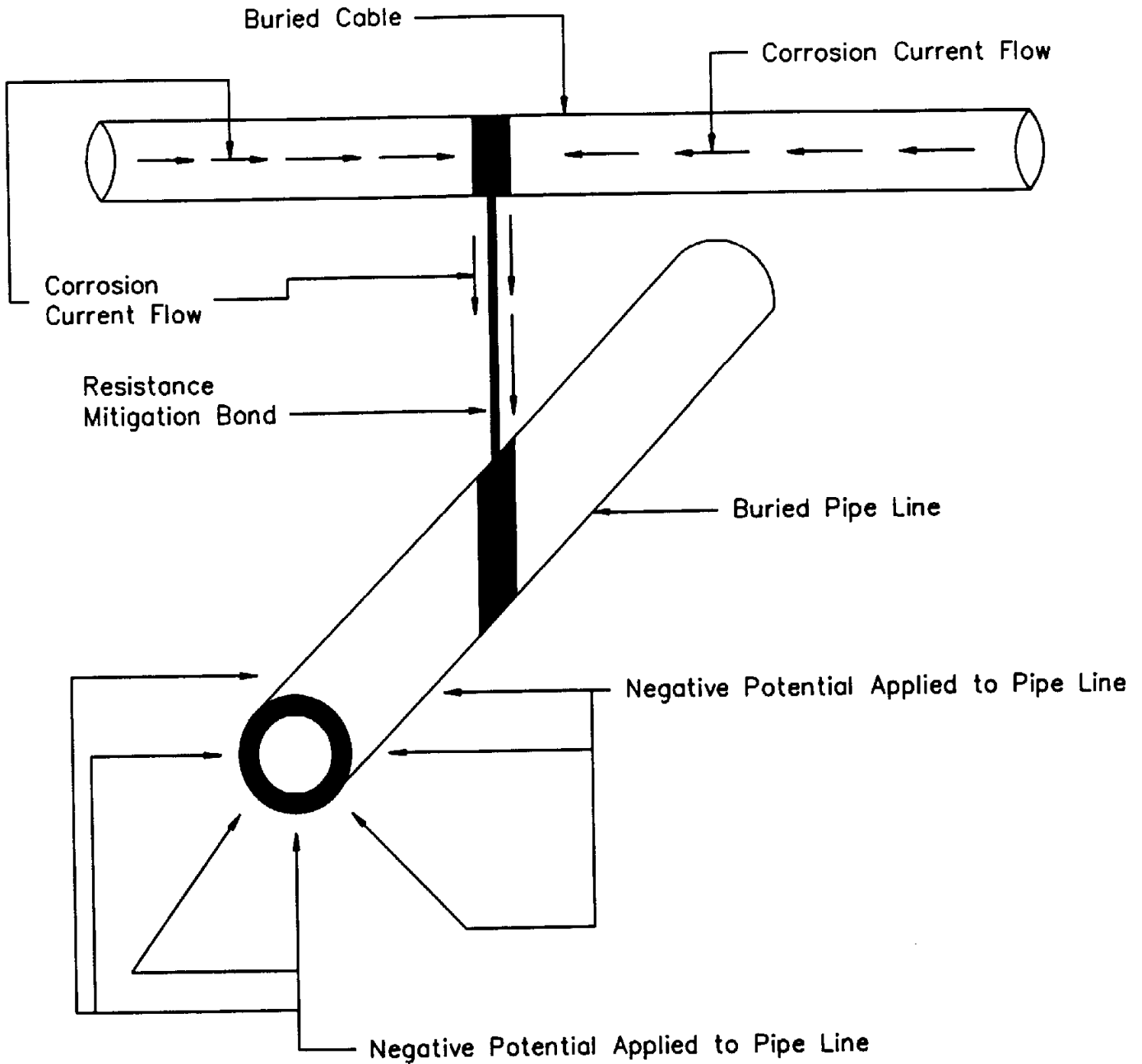
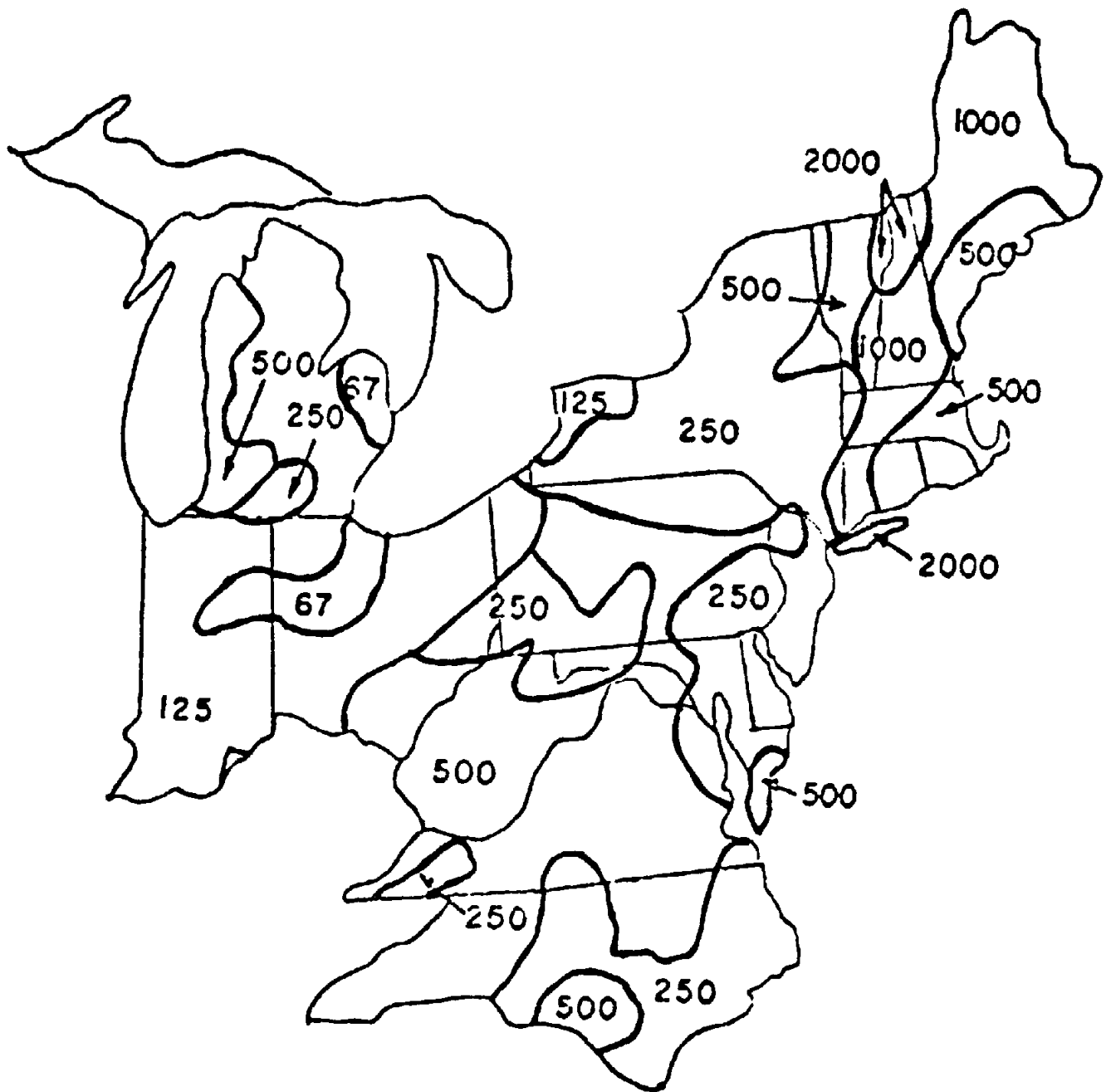
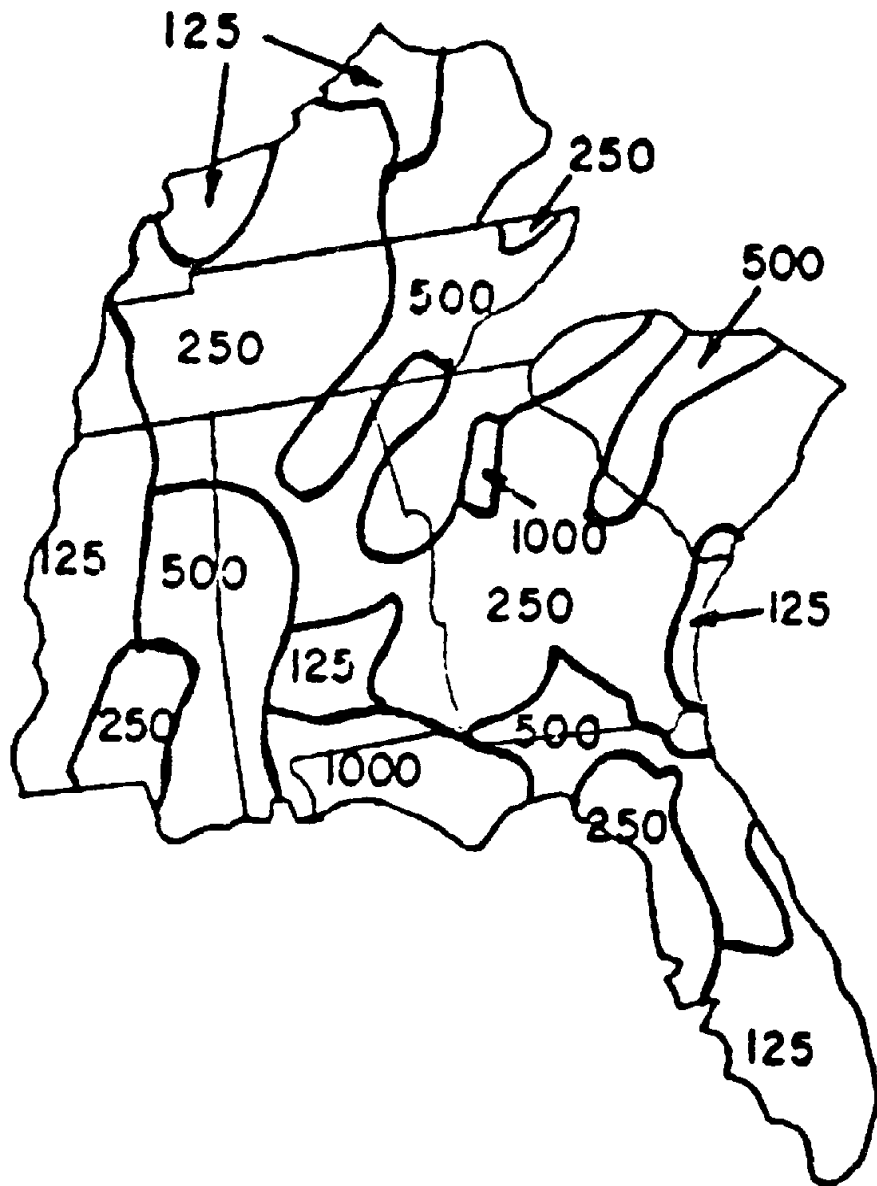


FIGURE 7 ESTIMATED AVERAGE EARTH RESISTIVITY
NORTHEAST REGION



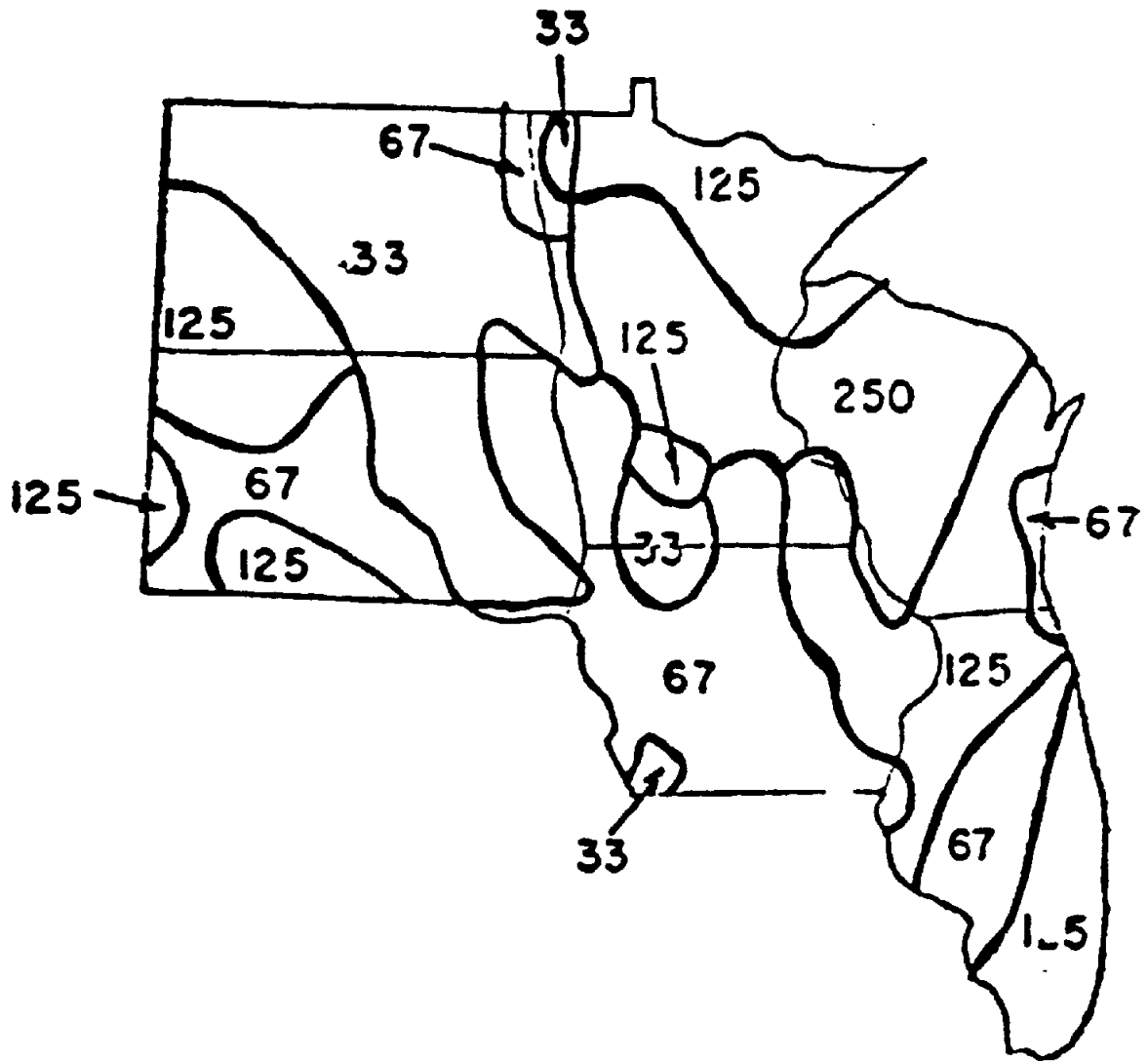
Note: Resistivity is in Meter-Ohms

FIGURE 8 ESTIMATED AVERAGE EARTH RESISTIVITY
SOUTHEAST REGION



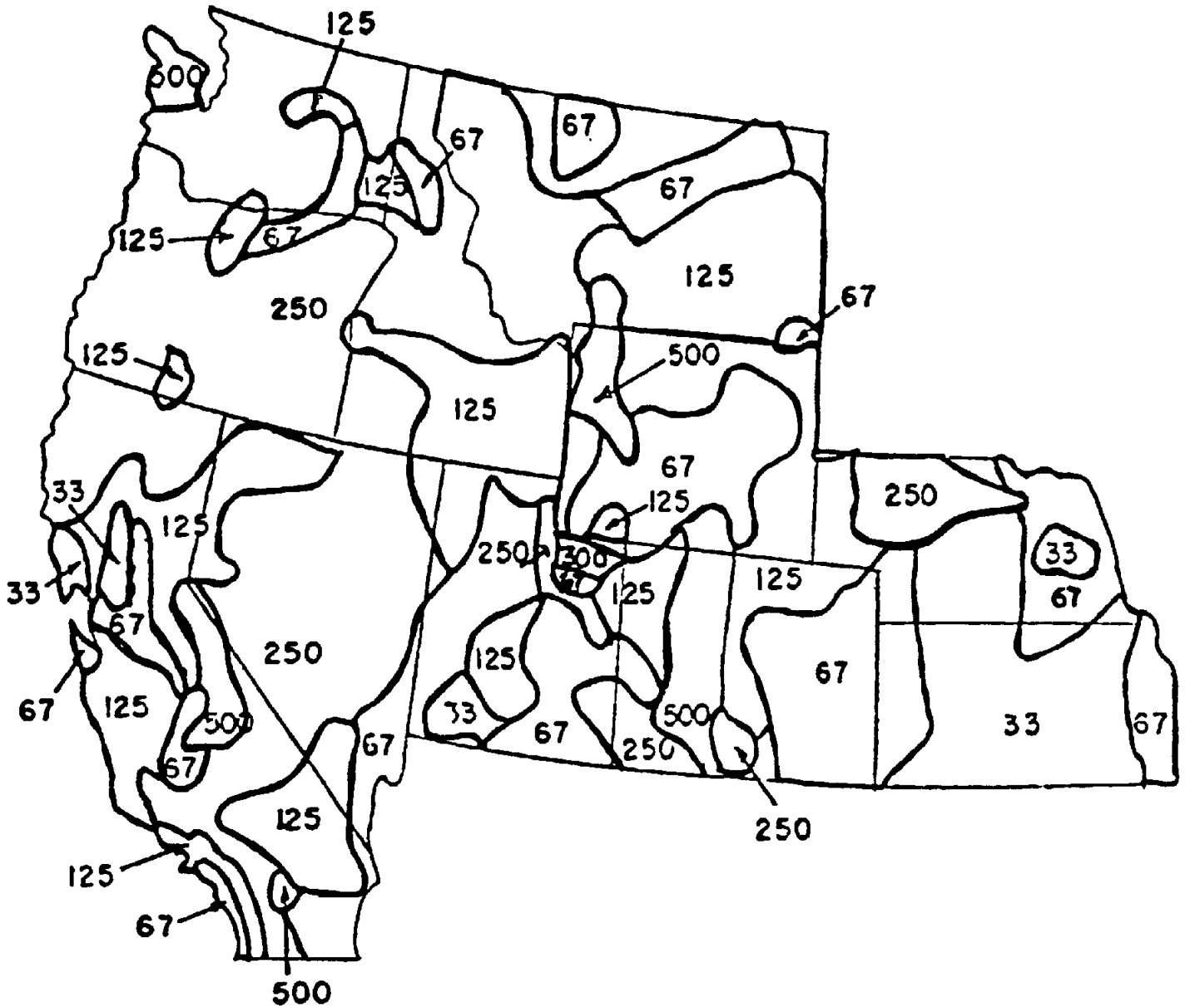
Note: Resistivity is in Meter-Ohms

FIGURE 9 ESTIMATED AVERAGE EARTH RESISTIVITY
NORTH CENTRAL REGION



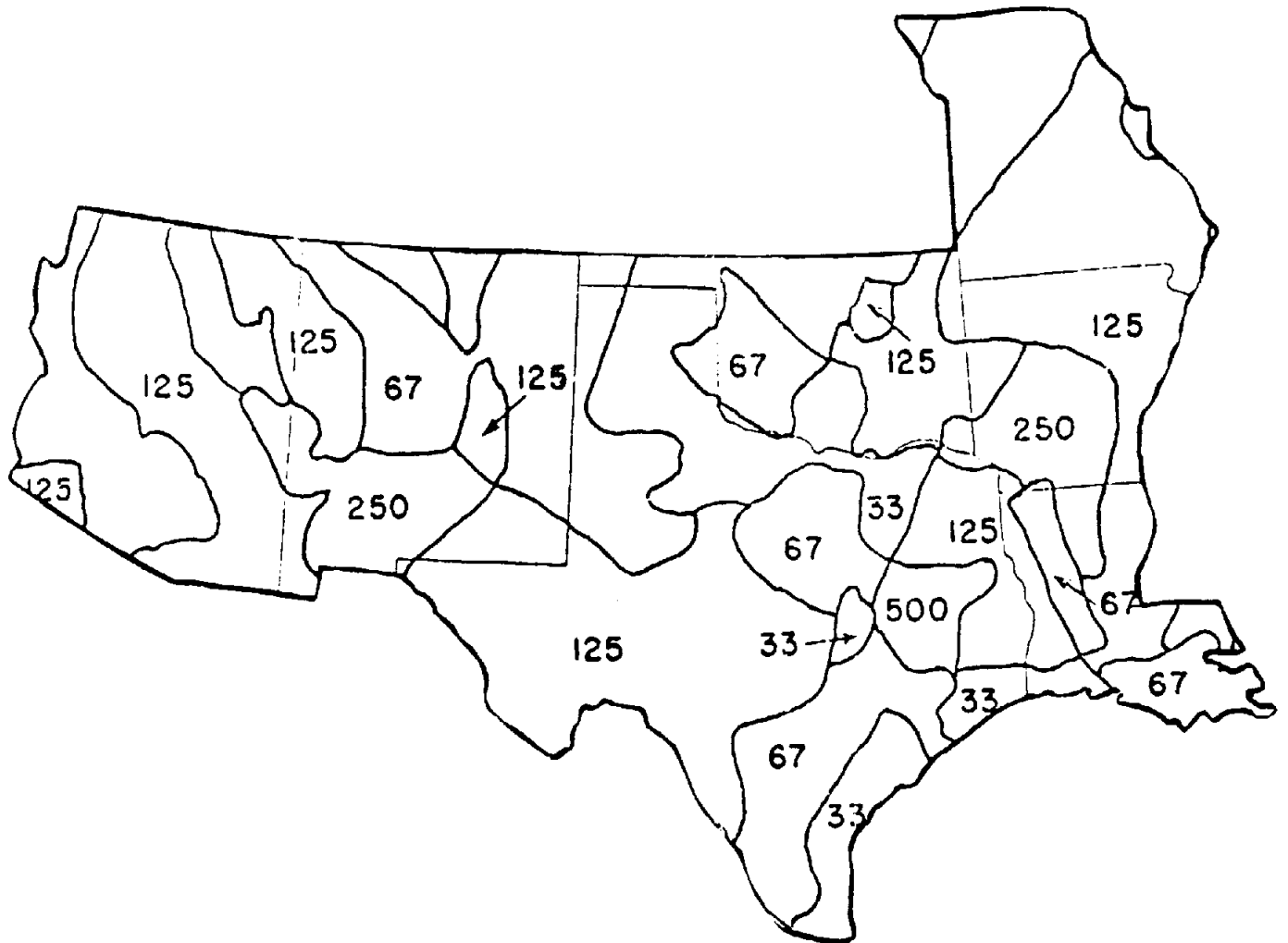
Note: Resistivity is in Meter-Ohms

FIGURE 10 ESTIMATED AVERAGE EARTH RESISTIVITY
WESTERN REGION



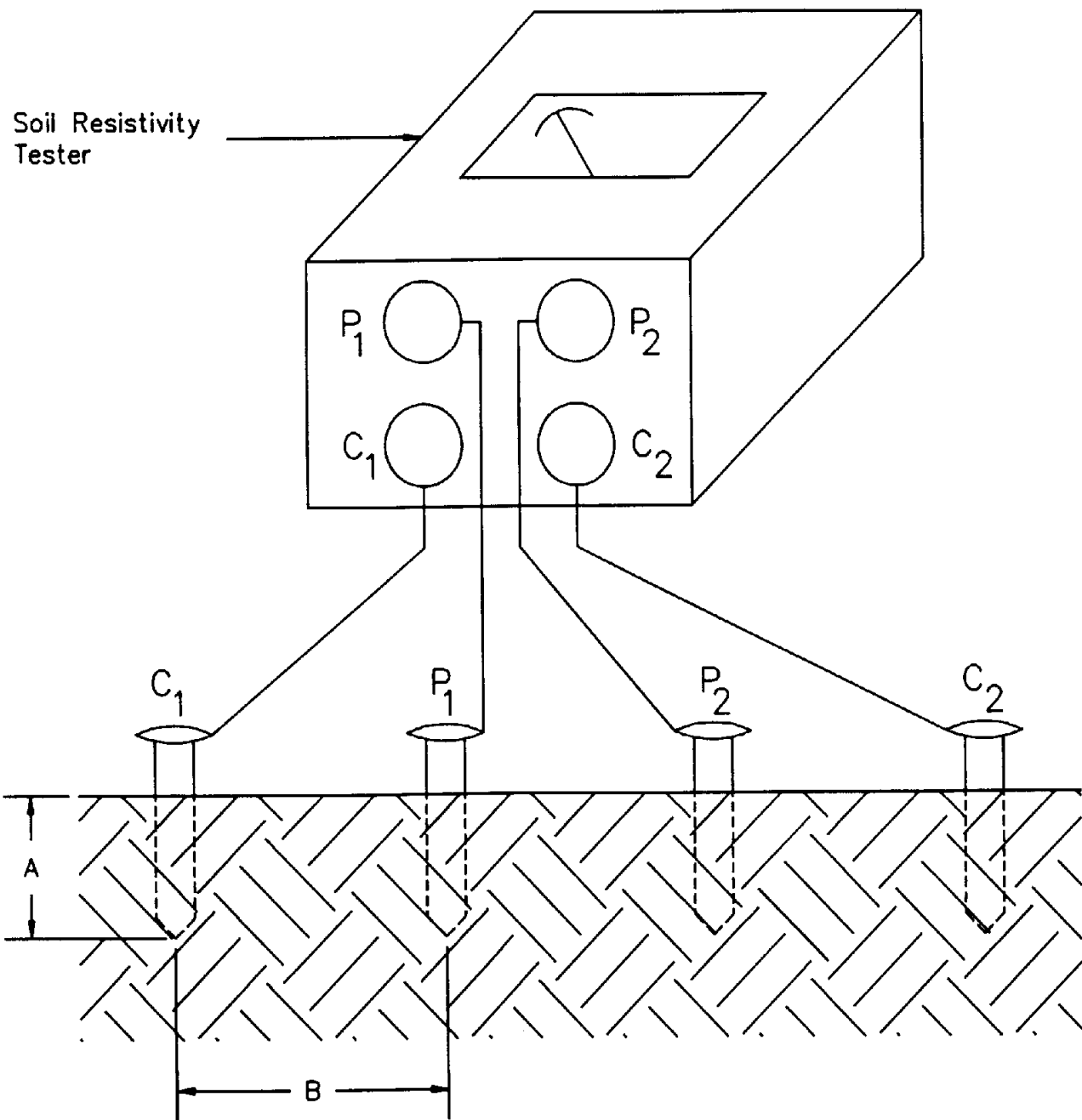
Note: Resistivity is in Meter-Ohms

FIGURE 11 ESTIMATED AVERAGE EARTH RESISTIVITY
SOUTHWEST REGION



Note: Resistivity is in Meter-Ohms

FIGURE 12 SOIL RESISTIVITY MEASUREMENT PROCEDURE



Notes:

1. Electrodes are placed in a straight line at equal intervals.
2. "A" must be less than "B"/10.