CORROSION CONSIDERATIONS IN TELECOMMUNICATIONS IN OUTSIDE PLANT

CONTENTS

1. GENERAL

1.1 This section is intended to provide REA borrowers, consulting engineers and other interested parties with technical information for the design and construction of REA borrowers' telephone systems. The section discusses various aspects of corrosion which should be considered in the preparation of a system design.

1.2 Revision of this section was necessary so that a broad selection of material would be available for Outside Plant Application.

1.2.1 In the past, use of the coated aluminum shield was restricted to areas where the earth resistivity was in excess of twenty-five hundred ohm-cm. Earth resistivity is only one of several factors which affects the corrosion of metals. This revision covers the earth resistivity restriction and allows a broader interpretation of corrosion conditions.

1.3 REA TE&CM 218, "Plant Annual Cost Data for System Design Purposes", 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 telephone company.

1.4 Corrosive atmospheric conditions may exist over an entire service area of a telephone 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 placed 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 to which the steel is exposed. In severely corrosive environments, the Class A galvanized coatings on steel conductors and strand may be protective for as little as 3 years.

1.5 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. In the following paragraphs, the section discusses the theory of corrosion and the application of this theory to practical situations in telecommunication systems.

1.6 Definitions of terms relating to corrosion used in this document can be found in ASTM G 15-79, "Standard Definitions of Terms Relating to Corrosion and Corrosion Testing".

2. THEORY AND MECHANISM OF CORROSION

2.1 General Theory

2.1.1 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. Metallic corrosion is accelerated when both moisture and air (oxygen) are present. 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.

2.1.2 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 electrochemical corrosion are that anodes and cathodes be present to form a cell and direct current must flow. For current to flow there must be an electrically conducting medium. 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 (electrolyte).

2.1.3 The anode corrodes. Metal at the anode dissolves into the electrolyte as positively charged ions. Electrons flow through the return circuit to the cathode. The loss of electrons at the anode is oxidation: The acceptance of electrons at the cathode is reduction. Since the generally accepted concept for current flow is opposite to the direction of electron flow, the current flows from the metal surface of the anode, through the electrolytic solution to the cathode via the return circuit from the cathode to the anode, then through the metal anode to its surface completing the circuit. The quantity of direct current which passes through the cell is proportional to the amount of metal that corrodes. For example, one ampere flowing for one year will corrode about 9 kilograms of steel.

2.1.4 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 hydroxide ions (OH^-) and reduction of water to form 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 cathode sites (cathodic depolarization). Similarly, polarization may occur at the anode due to the 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.

2.2 Galvanic Corrosion results from current generated from the differences in potential of metals in an electrolyte.

2.2.1 Dissimilar metals, coupled electrically in a conductive solution, satisfy the requirements for galvanic corrosion. The two coupled metals, in the presence of an electrolyte, constitute a galvanic cell wherein one becomes cathodic and the other becomes anodic which corrodes. If the potential difference between the metals is small, corrosion will be slow.

2.2.2 During the 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 acceleration of the corrosion of the more vulnerable material over and above its natural rate of deterioration. 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 the normal decomposition.

2.2.3 An example of a "Galvanic Couple" is shown in Figure 1; the galvanized steel 3-bolt clamp and the anchor rod act as anodes and the copper-steel guy strand acts as the cathode.

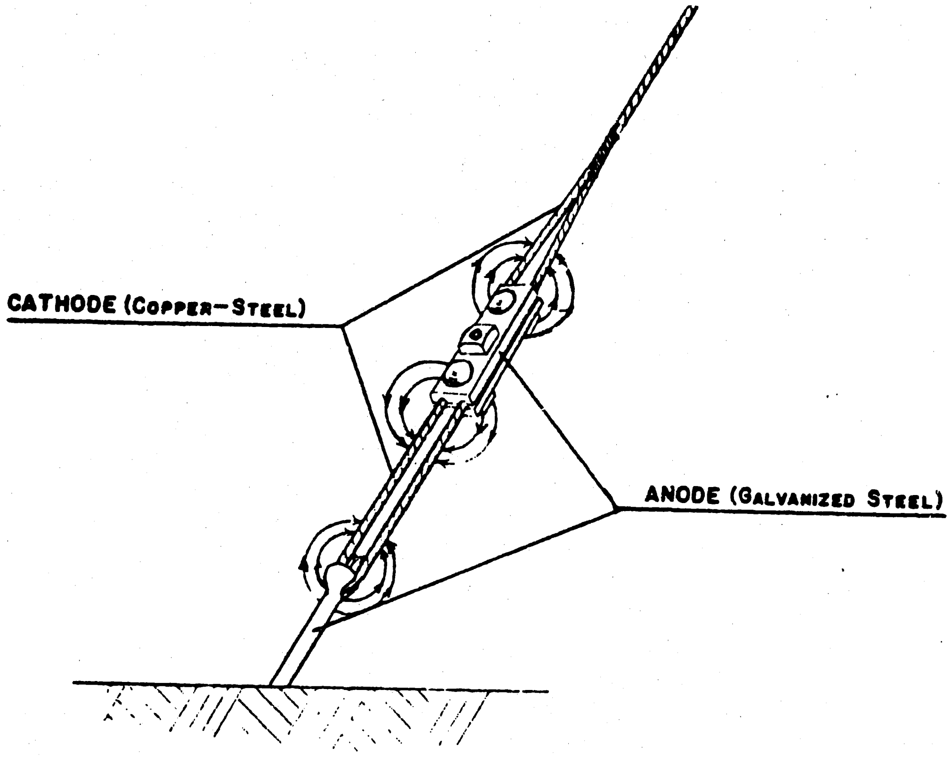


FIGURE 1. GALVANIC CORROSION

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.

2.2.4 A knowledge of the galvanic corrosion behavior of metals and alloys allows the metals to 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 of galvanic effects. Table I is a galvanic series including most metals used in outside plant environments. The table is qualitative and is intended only to indicate trends. The arrangement of the series is based on the actual corrosion testing experience within laboratories or under plant operating conditions and 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.

2.2.5 Some of the metals in Table I 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 environment, but rarely does a metal change from group to group. Note that stainless alloys 18:8 and 18:8:3 appear in two places in Table I. They frequently change positions as indicated in the Table depending upon the corrosive medium. These two alloys demonstrate relatively good resistance to corrosion in their passive, more noble, condition.

2.2.6 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.

2.3 Another source of galvanic corrosion is ion concentration variance within a liquid on a single metal. Usually this form of corrosion originates in or around crevices. Early detection and prevention depend largely upon knowledge of the corrosion mechanism.

2.3.1 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.

2.3.2 Differences in oxygen concentration on a metal surface will 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 initiating corrosion which weakens the structure. With some alloys the effect of the oxygen concentration cell is increased by the electrolytic cell formed between the relatively small area of activated alloy (anode) within the crevice and a large area of passive alloy (cathode) around the crevice. These cells are similar to, but generally more powerful than, normal oxygen concentration cells. 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. The concentration cell corrosion 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.

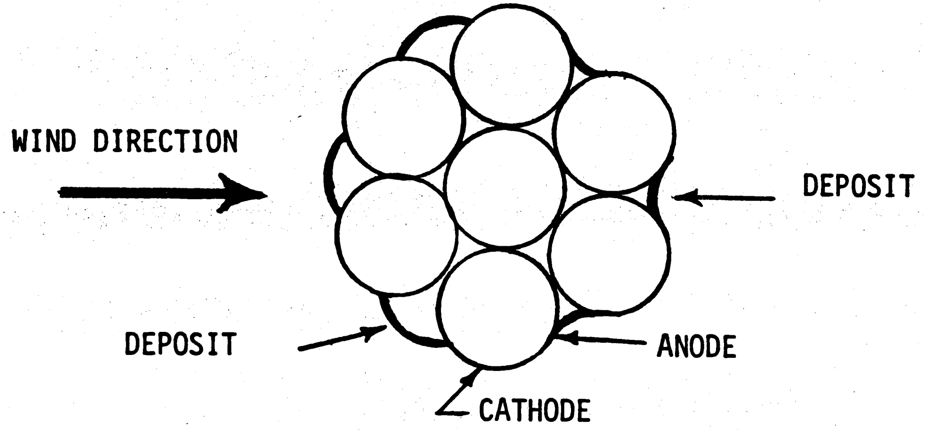


FIGURE 2. CONCENTRATION CELL CORROSION

Galvanized steel strand on the other hand will behave quite differently under similar conditions. The zinc on the galvanized steel strand will protect the steel until the zinc is completely consumed. The outside surfaces of the strand can show extensive corrosion while the inner surfaces of the strand are relatively unaffected.

2.3.3 Some metals form tight protective oxide films that normally resist corrosion. The film will repair itself in case it is damaged 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 nonmetallics. If manufacturing voids, cracks, scratches or other accidential 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 were exposed to the elements.

2.3.4 Dissimilar surface conditions on a metallic surface such as scratches or other abrasions and nonhomogeneous soil backfills will 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 will occur from galvanic action.

2.4 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 source of the current. Stray current corrosion was noted years ago in cities where direct current was used widely in industry for variable speed drives in transit systems and load-carrying devices. In the rural areas lead sheathed telephone cables buried by telephone companies have been corroded by cathodic protection applied to cross-country pipe-lines to prevent their corrosion.

2.4.1 In cathodic protection, a negative potential is impressed on the pipe line which causes electrical earth currents to flow to the pipe line, protecting it against stray current corrosion. Since the conductivity of most metals exceeds the conductivity of average soils, any 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 cathodic. But where the currents leave the auxiliary conductor, a pipe or cable, to enter the cathodically protected pipe line (See Figure 3), the metallic auxiliary conductor becomes anodic, and the resulting localized corrosion can be quite severe.

2.4.2. 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.

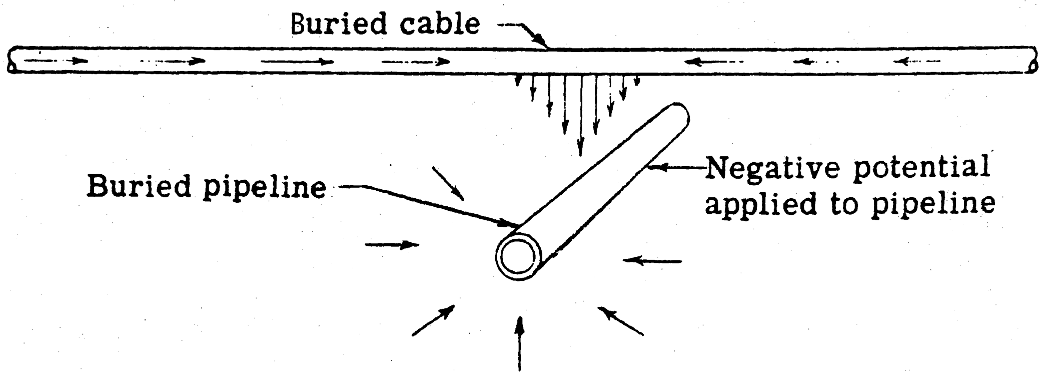


FIGURE 3. STRAY CURRENT CORROSION

3. CORROSION BEHAVIOR OF MATERIALS USED IN OUTSIDE PLANT CONSTRUCTION

3.1 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 of industrial, marine and rural.

3.1.1 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.

3.1.2 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 150 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. Futhermore, 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, this keeps them wet a good portion of the time.

3.1.3 Years ago, exposed metals were expected to obtain their longest possible 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 for hundreds, and sometimes thousands of kilometers cause acid deposition over wide areas of the United States. Consequently rural atmospheres can become corrosive.

3.1.4 Galvanized steel is widely used in the REA program for both hardware items and cable messenger. In industrial atmospheres the corrosion products formed on galvanized steel are zinc sulfate and zinc carbonate with the 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 the 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 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.

3.1.5 Copper and its alloys, as well as copper-covered steel, are used to a great extent in the REA telecommunication program for conductors and a variety of fittings. Copper is 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 coating 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.

3.1.6 The somewhat protective coating can be dislodged by vibration or abrasion wherever copper-covered steel is used as a conductor under tension. Copper and copper-covered steel will probably corrode at a faster rate in a marine atmosphere than in an industrial area 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 the 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 area 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 copper-steel conductors, the tendency for the steel to be exposed is very real. Once the steel is exposed to the atmosphere, a galvanic 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.

3.1.7 Certain grades of stainless steel have been used for cable suspension strand and guy strands in industrial and marine areas to provide additional service life over that offered from Grade C galvanized steel strand (See Figure 2).

Corrosion resistant steel forms a protective oxide coating to corrosive elements in the industrial and marine atmospheres by preventing moisture penetration to the base steel. 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 suspension strand over 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 telecommunication cable should be a significant factor in selecting strand.

3.1.8 In addition to the three basic types of atmospheres found within the United States, there may exist commercial operations that would change the characteristics of the atmosphere in the environment and might indicate accelerated corrosion. Such operations exist in areas of high air pollution and include drilling or mining installations, chemical plants, fertilizer plants, burning slag dumps, sour gas fields, 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 cell which could cause serious corrosion. All of these factors must be considered when evaluating the possibility of atmospheric corrosion of outside plant facilities.

3.2 Underground equipment in the REA Telecommunication Program consists of anchors, anchor rods, grounding rods, buried plant terminal housings and buried cables and wire. A majority of the presently installed telephone cable plant is buried directly in the soil. The various shielding materials, when exposed to the environment of different soils, are subject to all of the corrosion mechanisms. These corrosion mechanisms include the effects of dissimilar metals (galvanic couples), soil conditions, differential aeration and stray currents. From past experience the corrosion of anchor rods has proven to be a 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.

3.2.1 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 multi-grounded 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 d-c voltage that is more negative (anodic) than that of buried copper (cathodic). When the buried steel and copper are connected together by the 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.

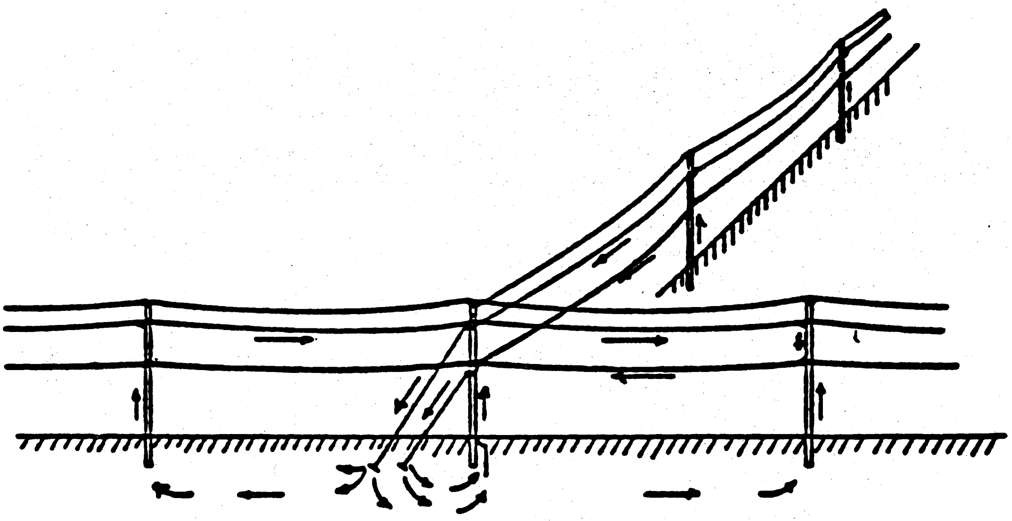


FIGURE 4. ANCHOR ROD CORROSION - GALVANIC COUPLE

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 system neutral may be corroded as a result of galvanic action.

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 steel surfaces and induces galvanic corrosion of the 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.

3.2.2 Differential aeration corrosion of an anchor rod can occur, regardless of the material used, even though it is electrically isolated from the multigrounded neutral. A differential aeration 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 soil having higher oxygen contents. Most corrosion failures of anchor rods occur within 15 centimeters of the anchor, and other structures also are likely to have the greatest damage deep in the ground where moisture is present and oxygen excluded.

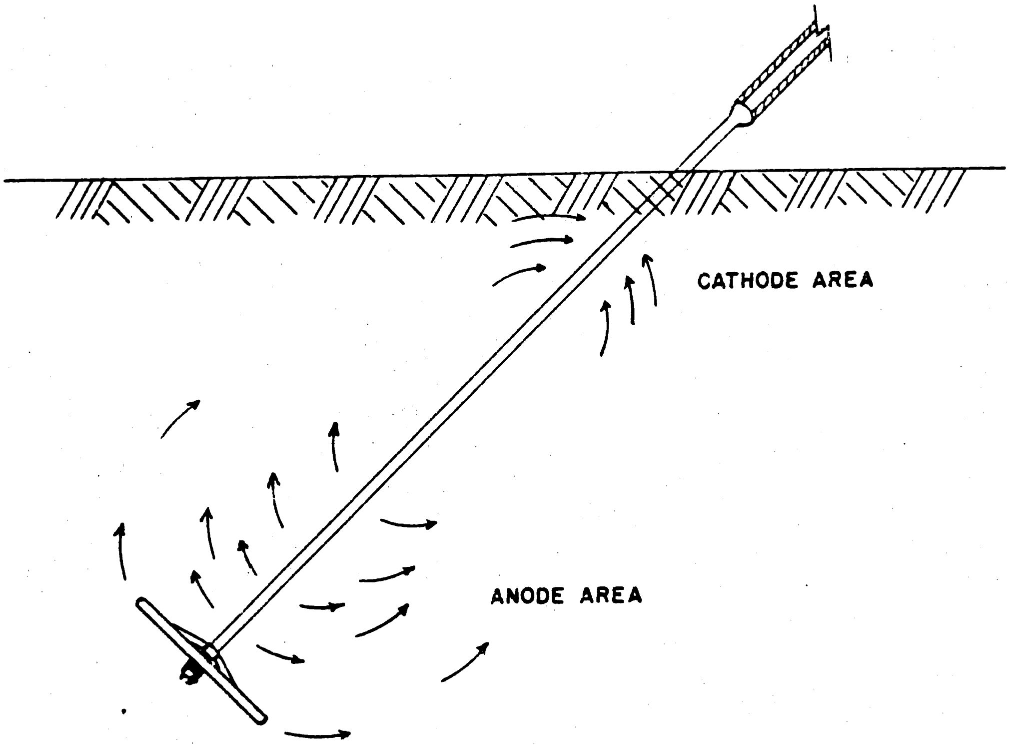


FIGURE 5. ANCHOR ROD CORROSION - DIFFERENTIAL AERATION CELL

3.2.3 Stray currents have caused REA borrowers a number of corrosion problems from cathodic protection applied to cross-country pipe lines. The telephone companies were unaware that pipe lines were in the vicinity of the buried cables until the companies began to investigate the cause of corrosion and found the phenomenon shown in Figure 3. Stray currents from these cathodically protected pipe line 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 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 before further damage occurs.

4. CORROSION PREVENTION MEASURES

4.1 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 telephone system. Corrosive atmospheric conditions may exist over an entire service area of a telephone system or may be confined to relatively small areas within the total service area. In a heavily populated industrial area that spreads over several square miles, 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 or 25 years there is no reason for serious concern. When it is not possible to determine the life of the existing plant because of 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 telephone 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.

4.1.1 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 150 kilometers from the coast would be classified as industrial because of the numerous oil wells, chemical processing, and oil and gas refinery operations.

4.1.2 Galvanized steel has been widely used for many years in the telephone industry for hardware items. Generally speaking, hardware items such as 3-bolt clamps, cable suspension clamps, machine bolts, thimbleye bolts, etc., are available only in galvanized steel. However, in the past few years investigations have been made as to the possible use of aluminum covered steel or aluminum alloy hardware items. In severely corrosive industrial areas, where galvanized steel would have a shortened life, the use of aluminum-covered steel or aluminum alloy hardware is recommended where available. Until the aluminum materials become generally available, galvanized steel hardware made from low alloy steel should be used in preference to carbon steel.

4.1.3 One of the most important considerations in materials 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 I) 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, all solid or stranded wire used for bonding or grounding purposes should be tinned copper to minimize corrosion from joining dissimilar metals. When the bonding or grounding wire is required to contact the soil, the tinned copper should be insulated. Whenever possible a connection of dissimilar metals should be coated. When properly applied, coating materials will prevent moisture and air from contacting the dissimilar metal connection and thus prevent galvanic corrosion at the joining interface.

4.1.4 Galvanized steel has been used for many years in the telephone industry for line conductors, 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 line wire, 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. Also, aluminum-covered messenger is especially needed for bare aluminum coaxial cable applications.

4.1.5 Polyethylene insulated facilities are expected to experience good performance characteristics in all types of atmospheres. Serious consideration should be given to using insulated wire and cable products in areas that are highly corrosive, since substantial corrosion protection is achieved at little additional expense. The use of the Figure 8 cables should give very satisfactory results where proper attention is given to the restoration of the insulation when it is damaged or removed for installation purposes.

4.2 Corrosion of underground telecommunication systems is the most difficult to prevent because of the many factors that singly, or in combination, affect the course of the electrochemical reaction. The major problem in corrosion prevention is to decide the corrective measures that will give satisfactory results at least cost. Care must be taken to insure that the connective measures taken to cure the corrosion does not reduce the intended performance of the communication system. The important need is to adequately recognize the things 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.

NOTE: The recommendations 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.

4.2.1 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 recommends that grounding of electrical protection apparatus on telecommunication systems follow the guidelines contained in this section.

4.2.2 The general practice should be to install galvanized steel ground rods wherever the station protector assembly unit requires a driven ground. The interconnection or common grounding of the protector, electric service ground, and metallic water pipe constitutes the most important principle of safeguarding the customer and his equipment against shock and fire hazards. This principle must not be sacrificed under any circumstances.

4.2.3 Where a driven ground rod is required for electrical protection (grounding) in buried plant construction, a galvanized steel ground rod should be used.

4.2.4 On the 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-steel ground rod may be used.

4.2.5 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 telephone system should follow a similar program. If there has been no experience of underground corrosion on the electric system, standard construction practices can probably be followed with satisfactory results.

4.2.6 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.

4.2.7 Stray current corrosion, resulting from cathodic protection, can be reduced in underground telephone plant by either electrically insulating the telephone facilities from the stray currents or installing a mitigation bond between the telecommunication facilities and the foreign structure being cathodically protected. Usually the anchor rods and anchors can most easily and most economically be protected by insulating them from the d-c source, that is, unless a mitigation bond can easily be provided between the d-c source and the multiground neutral. If stray current corrosion is being experienced on buried metallic sheathed cables, the best method probably will be to install a mitigation bond as shown in Figure 6.

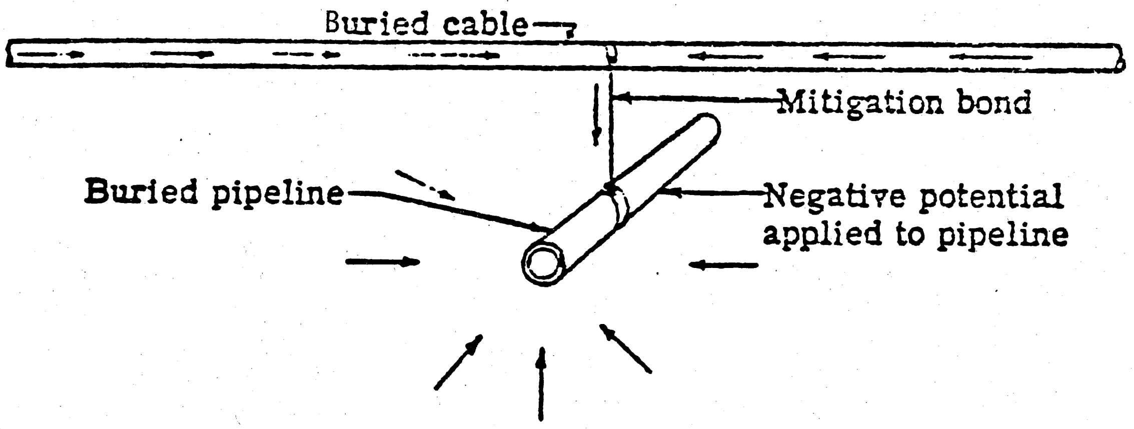


FIGURE 6. COORDINATED STRAY CURRENT PROTECTION

When new construction is being contemplated in the vicinity of a buried pipe system, municipal water system or gas utility system, a determination should be made as to the corrosion protection measures being employed between telecommunication facilities and the foreign structure being cathodically protected. Usually the anchor rods and anchors can most easily and most economically be protected by insulating them from the d-c source, that is, unless a mitigation bond can easily be provided between the d-c source and the multiground neutral. If stray current corrosion is being experienced on buried metallic sheathed cables, the best method probably will be to install a mitigation bond as shown in Figure 6, which is 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 pipe line to provide a low resistance path back to the rectifier station for the stray currents.

5. ENVIRONMENTAL CONDITIONS AFFECTING THE SELECTION OF CABLE SHIELDS

5.1 Many factors, such as construction personnel, equipment, rock, etc., can damage the cable 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. Improved filled cable designs and good construction practices have substantially reduced sheath damage, but are not likely to eliminate it completely. The proper selection of shielded cable for use in problem areas will provide maximum corrosion protection for the buried cable plant.

5.2 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. Recent studies sponsored by REA have shown that NO SINGLE PROPERTY OF A SOIL is an accurate indicator of its corrosivity to a particular metal.

5.3 Shields incorporating copper, copper alloys, and copper/stainless steel combinations comprise a significant portion of the cable 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 those 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. In many environments copper exhibits satisfactory corrosion resistance; however in an aggressive environment copper may corrode.

5.3.1 When certain chemical constituants 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.

5.3.2 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 of copper. The soils containing sulfate ions and anaerobic, sulfide generating bacteria have in some isolated instances also caused sulfide treeing of the cable jacket.

5.3.3 Copper clad stainless 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, tests and field results have shown that the stainless steel remains passive and acts as a corrosion barrier protecting the inner copper layer from corrosion. Thus shield integrity may be prolonged.

5.3.4 Primary mechanisms which can contribute to the corrosive attack of copper are:

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

5.4 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. In order to understand how plastic coatings behave, factors which are likely to corrode bare aluminum should be considered. These are: direct attack in soils, galvanic, stray currents from external sources of d-c and a-c currents, and differential aeration. Aluminum is an amphoteric metal and it corrodes more rapidly in highly acidic and highly alkaline media, i.e., at pH 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.

Note: For uniformity, the words coated and coating are used in this Section 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.

5.4.1 The plastic coating restricts the area of aluminum subjected to corrosion. The polymer 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.

5.4.2 The forces which damage the outer jacket will likely damage the plastic coating also. In this case, localized corrosion of aluminum will occur wherever 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.

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

5.4.4 If the plastic coating on the aluminum is damaged corrosion is initiated by dissolution of aluminum, followed by differential aeration and continued corrosion of the aluminum.

5.4.5 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 of aluminum.

5.4.6 Mechanism which can contribute to the corrosive attack of aluminum are:

* Direct attack in highly acidic and highly alkaline soils;
* Chlorides and sulfates;
* Electrolytic corrosion from external sources of direct current;
* Corrosion under the influence of a-c current;
* Galvanic effects when coupled to copper;
* Differential aeration.

5.5 The corrosion of steel due to the various factors thus far described for aluminum and copper in the text is well recognized. 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 provides protection to the coated aluminum for it to perform vital shielding functions.

5.5.1 If the plastic coating on steel is damaged, corrosion is initiated by dissolution of the steel. Further corrosion of the coated steel/coated aluminum proceeds according to the following primary mechanisms:

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

5.6 Certain locations in the country may have severe corrosion conditions which are more harmful to one type of cable shield or armor than another. In such areas, the engineer should determine the cable 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 soil pH, and gather historical data from his own files and from other utilities in the exchange area. Soil resistivity is an indicator of corrosivity, 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 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 could probably be used at the new site with no problems.

5.6.1 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 Paragraph 6. Figures 7A through 7E show the general soil resistivity throughout the United States but are not meant to substitute for local measurements.

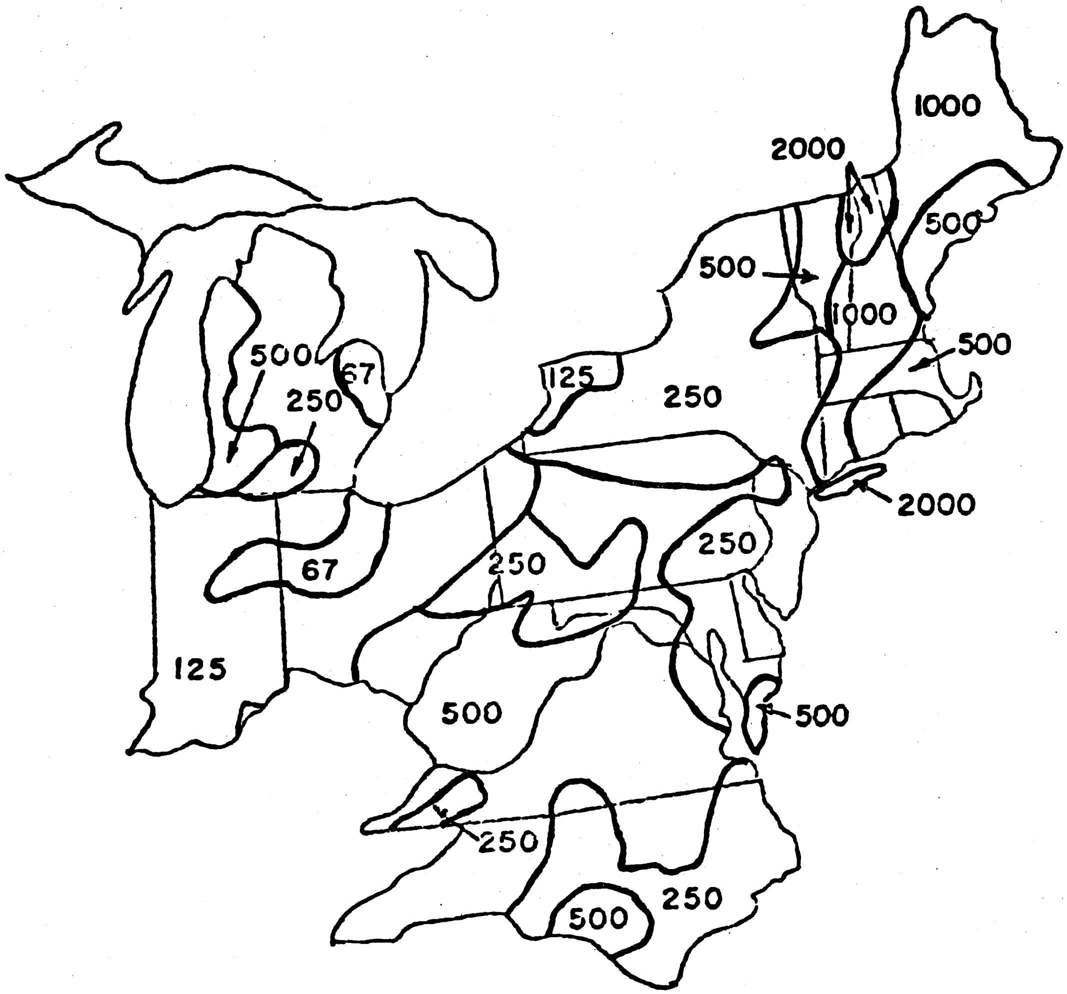


FIGURE 7A
ESTIMATED AVERAGE EARTH RESISTIVITY IN NORTHEAST AREA, METER-OHMS

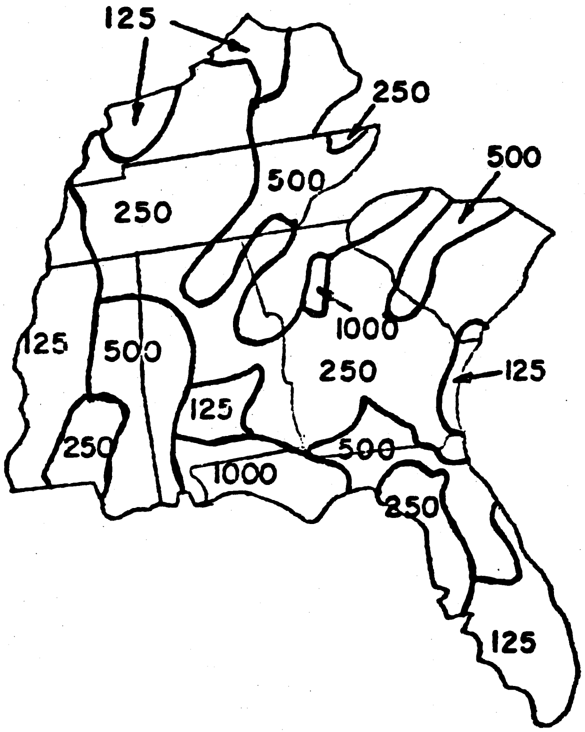


FIGURE 7B
ESTIMATED AVERAGE EARTH RESISTIVITY IN SOUTHEAST AREA, METER-OHMS

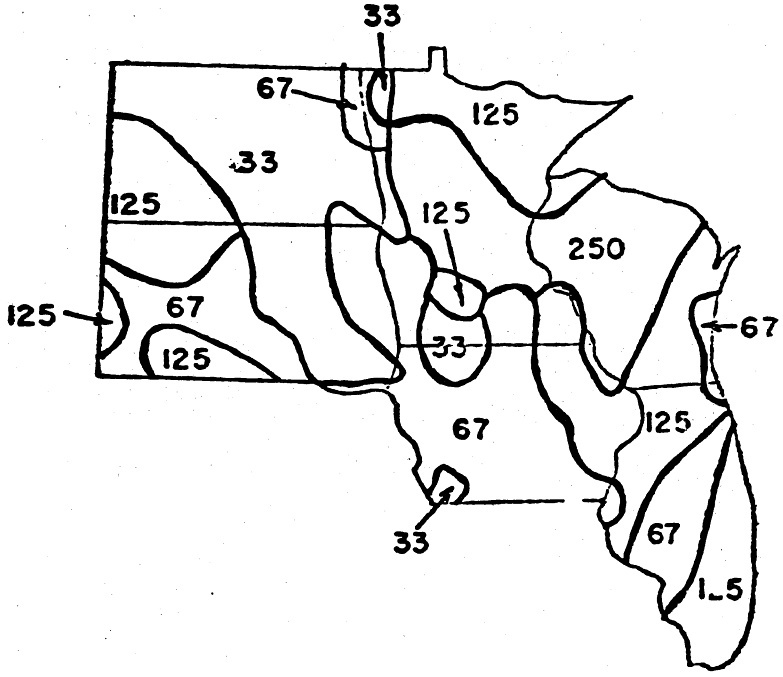


FIGURE 7C
ESTIMATED AVERAGE EARTH RESISTIVITY IN NORTH CENTRAL AREA, METER-OHMS

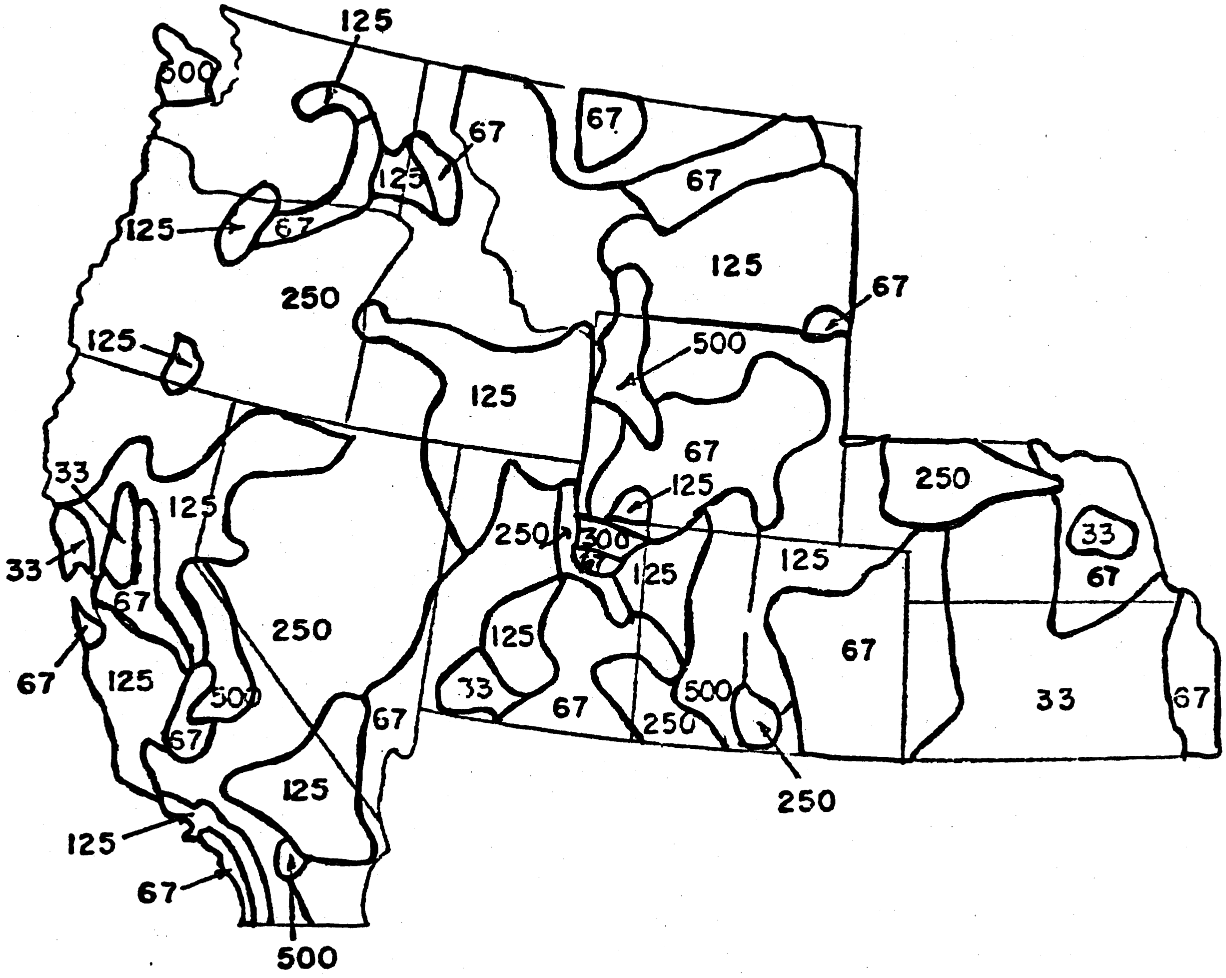


FIGURE 7D
ESTIMATED AVERAGE EARTH RESISTIVITY IN WESTERN AREA, METER-OHMS

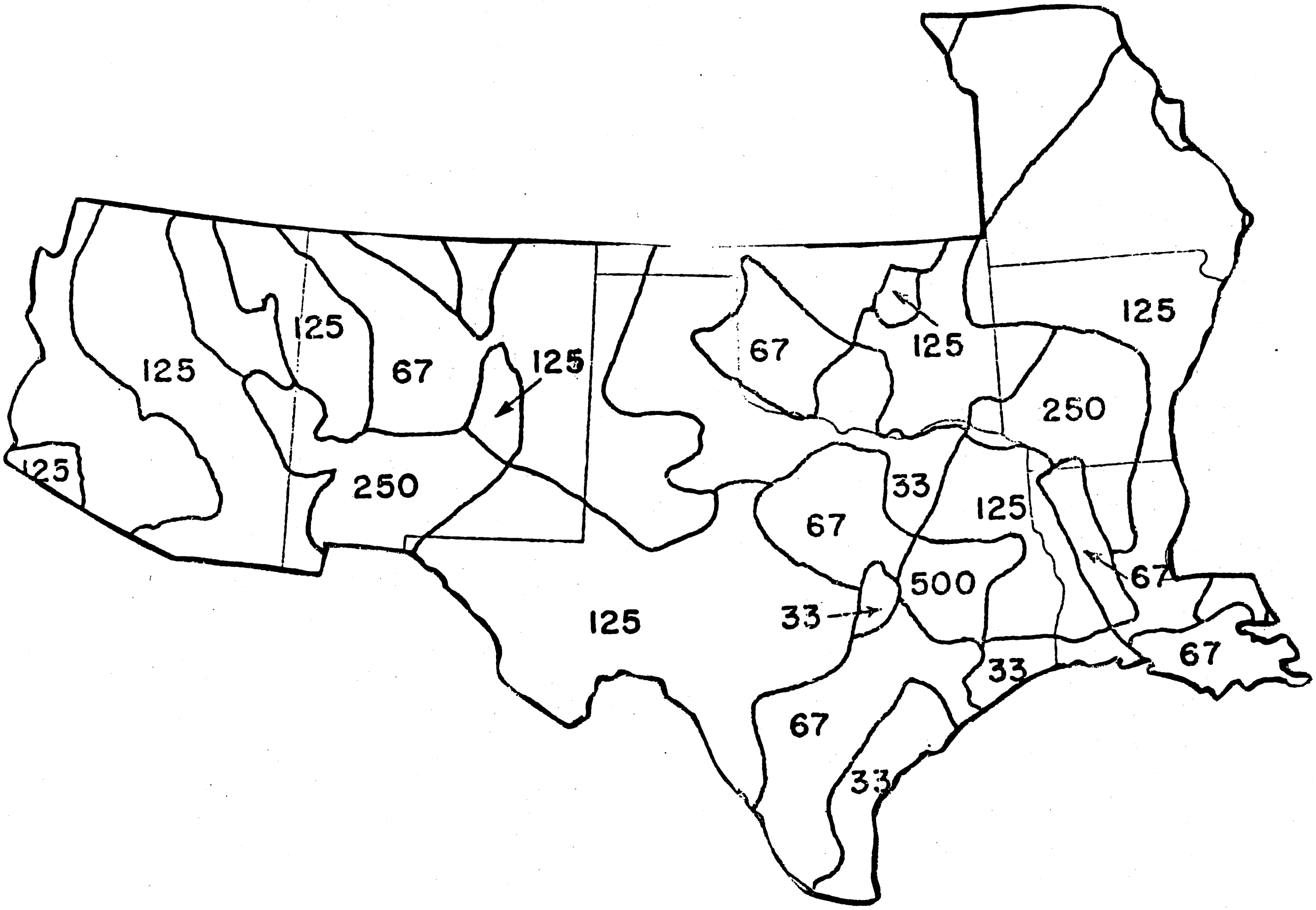


FIGURE 7E
ESTIMATED AVERAGE EARTH RESISTIVITY IN SOUTHWEST AREA, METER-OHMS

6. MEASUREMENTS

6.1 Earth resistivity can be measured in a number of ways. The most accurate method is to obtain some soil at the cable 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 "Shepard Canes". However, the easiest and most practical way is to use the four terminal method shown in Figure 8. Four small test electrodes (stubs of No. 8 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 earth resistivity tester, as shown. Hence, the name of this test: the four terminal method.

6.1.1 Dr. Frank Wenner of the U.S. National Bureau of Standards developed the theory behind the test in 1915. He showed that if the electrode depth "A" is kept small compared to the distance beween electrodes "B", the following equation applies:

$$\rho = 2\pi BR$$

Where "ρ" is the average earth resistivity to depth "B" in ohm-centimeters, π is the constant 3.1416, "B" is the distance between the electrodes in centimeters, and "R" is the instrument reading in ohms.

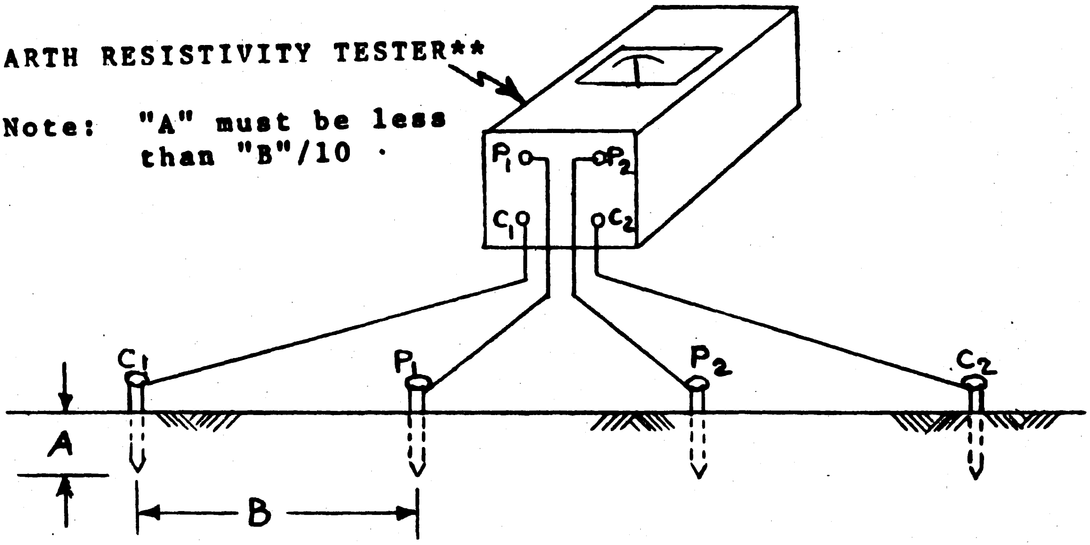
6.1.2 Since the cable is usually buried at a depth of 0.6 to 1 meter (2 to 3 feet), the average earth resistivity should be measured to at least 1.2 meters (4 feet) depth. The electrode depth should not exceed 10 percent of the electrode spacing dimension. A 5 centimeters (3 inches) electrode depth should be adequate. Black vinyl tape may be placed 5 centimeters (3 inches) from the ends of the electrodes as a depth gauge. Assuming an instrument reading of 30 ohms is obtained at 1.2 meters (4 feet) electrode spacing, the earth resistivity would be calculated as follows:

$$\begin{aligned}\rho &= 2\pi BR\\ &= 2\ (3.1416\ (1.2\text{ m} \times 100\text{ cm/m}))\text{ or,}\\ &= 2\ (3.1416\ (4\text{ ft} \times 12\text{ in./ft} \times 2.54\text{ cm/in.}))\quad (30)\\ &= 766\text{ centimeters } (30)\text{ ohms}\\ &= 22{,}980\text{ ohm-centimeters}\end{aligned}$$

Therefore, if the 1.2 meters (4 feet) electrode spacing is maintained, the earth resistivity is 766 times the instrument reading in ohms. If an electrode spacing of 0.86 meters (31 inches) is maintained a multiplier of 500 will result yielding resistivity at .86 meter (31 inches) which is a realistic cable placement depth.

Note: A description of this method is described in ASTM G 57-78, "Standard Method for Field Measurement of Soil Resistivity Using the Wenner Four Electrode Method".

6.1.3 Typical earth resistivity values to be expected are given in Table II.



EARTH RESISTIVITY TESTER**

Note: "A" must be less than "B"/10 .

Electrodes are placed in a straight line at equal intervals.

**ASSOCIATED RESEARCH, INC. MODEL 293,

MODEL 263A, BIDDLE CO. 563, or an equivalent

FIGURE 8. EARTH RESISTIVITY MEASUREMENT PROCEDURE

6.2 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.

6.2.1 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 manufactures' recommendations or ASTM G 51-77.

6.2.2 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.

6.2.3 It is best to bore a hole and make the pH measurement at the depth of interest. A subsurface probe for accomplishing this is described in the ASTM noted below. 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.

Note: A complete description of this method is described in ASTM G 51-77, "Standard Test Method for pH of Soil for use in Corrosion Testing".

Note: Under no circumstances should a surface pH measurement be construed as the pH of the soil at the cable depth.

Table I
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 (active)
18:8:3 Stainless (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 (passive)
18:8:3 Stainless (passive)
Hastelloy C (passive)

Silver

Graphite
Gold
Platinum

CATHODIC END (Least Active)

Table II

RANGE OF RESISTIVITY VALUES FOR SEVERAL TYPES OF SOILS

Soil Type	Resistivity, ohm-centimeters
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

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