THE BELL SYSTEM
TECHNICAL JOURNAL

DEVOTED TO THE SCIENTIFIC AND ENGINEERING
ASPECTS OF ELECTRICAL COMMUNICATION

Volume 51 January 1972 Number 1

Soil Burial Tests:

Soil Burial of Materials and Structures

By R. A. CONNOLLY

(Manuscript received July 28, 1971)

The Bell System emphasis on burying the transmission media plant directly in the soil resulted in the initiation of a study in 1956 designed to determine the behavior of commercial and experimental materials in the soil. For this study, two test sites representative of soils of large sections of the country were employed: one in Bainbridge, Georgia, and the other in Roswell, New Mexico, typical acid and alkaline soils, respectively. The soil characteristics, test plot design, sample preparation, installation and removal schedules, and overall areas of responsibilities are discussed in this paper. A detailed discussion of the effect of up to eight years of soil burial exposure on molded plastics, casting resins, rubbers and metal-to-rubber bonds, electrical and structural laminates, adhesives, tapes, and coated conductors are covered in companion papers. The history of the problems with buried structures and the engineering implications are stressed.

I. INTRODUCTION

In the late 1950s, the Bell System started to bury exchange area plant directly in the soil and now some 80 percent of annual additions to service individual homes are buried. By 1975, almost all newly installed distribution plant will be in this environment. Figure 1, from H. Southworth,[1] shows the trends in the underground, aerial, and buried telephone cable plant over the last sixteen years. The advantages of buried plant over conventional aerial plant are that it is potentially lower in first cost, less subject to service interruptions by natural causes, not affected by trees, faster to install, and more aesthetic.[2] In contrast to this, it is less flexible and additions are costly while workmen in other operations may cause damage to buried lines. In addition, armored cable and wire must be used in rock and gopher-infested areas.

In the mid-1950s, the accelerating trend to bury the telephone distribution circuits to homes was thwarted somewhat by problems in the areas of wire and cable design, materials, and construction techniques. The long-range economy of buried plant depends in large measure on the ability of materials to withstand factors in soil environments

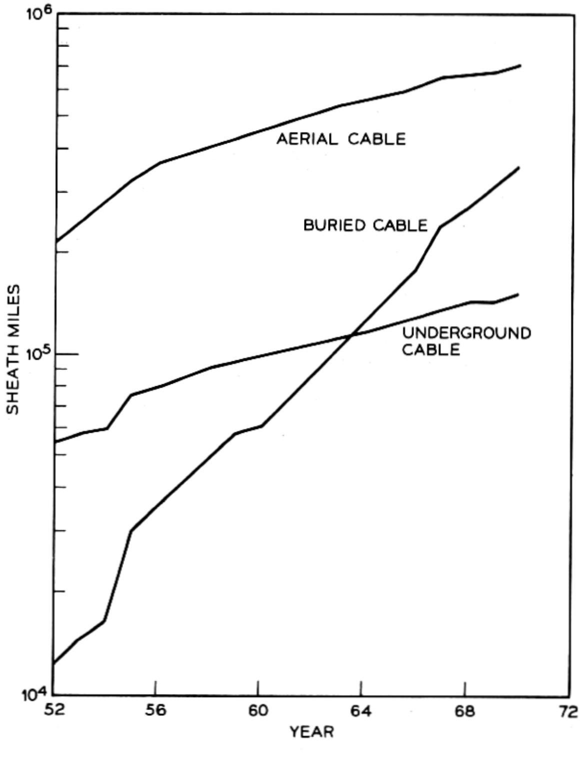

Fig. 1—Cable sheath miles in Bell System (excluding Long Lines).

which may affect their performance. Therefore, it was considered important that the wires, cables, structures, and the materials which might be used in their fabrication be evaluated in subterranean environments to determine their resistance to physical, chemical, and biological degradation under conditions expected to accelerate such attack. Consequently, in 1956 a committee was set up to design an appropriate program and to implement the necessary action to meet this need for accumulating environmental data on material performance. Their program included the study of materials in use at that time and those which might find application in the form of cable, wire, terminals, splices, and ducts. The soil environment presents many factors that may affect the buried telephone plant, and some explanation of these is necessary for an understanding of the problems to be faced.

II. CHARACTERISTICS OF SOIL ENVIRONMENTS

The soil, which provides a more severe environment than underground duct exposure, is complex and difficult to describe. There are some 200 different soil types within the continental United States, including fertile agricultural soils, prairies, forest land, sand dunes, bogs, and swamps, all of which differ chemically, physically, and biologically. Our buried telephone plant must be capable of functioning in all these situations.

2.1 *Chemical*

The bulk of most soils is made up of inorganic matter which ranges from 60 percent to 99 percent of the total weight, averaging 95 percent. About 47 percent is oxygen, as shown in Table I. The abundance of oxygen and its oxides clearly suggests that the environment can cause chemical modifications of materials. The trace elements, such as Cl and S, are especially active.

The organic matter in the soil is as complex as any existing in nature. Constituents include plant and animal tissues, living and dead microbial cells, microbial synthesized compounds, and endless arrays of derivatives of these materials produced as the result of microbial activity. Soils contain most, if not all, of the naturally occurring organic compounds, such as sugars, starches, carbohydrates, hemicellulose, pectins, celluloses, lignins, fats, and proteins. However, the concentration of organic matter in most soils is less than 5 percent[3] as an overall average.

The natural composition of the soil, although varied, is generally made up of only the above materials. In addition, however, there

TABLE I—AVERAGE CHEMICAL COMPOSITION OF THE EARTH'S CRUST*

Element	% Element	% Oxide
O	46.5	
Si	27.6	59.7
Al	8.1	15.22
Fe	5.1	6.81
Ca	3.6	5.10
Mg	2.1	3.45
Na	2.8	3.71
K	2.6	3.11
Ti	0.6	1.03
P	0.12	0.30
Mn	0.09	0.11
S	0.06	1.30
Cl	0.05	
C	0.04	

* Based on 95 percent igneous rocks, 4 percent shales, 0.75 percent sandstone and 0.25 percent limestone (F. E. Bear[3]).

can be many other chemicals that, through man's activities, find their way into the soil. These include: gasoline, diesel fuel, lubricating oil, grease, trichloroethylene, and organic chemical wastes in general. Many of these materials can adversely affect the performance of the plastic components of the cable, as for example, swelling of polymers exposed to petroleum derivatives. Also, cinders may contribute acid conditions and provide a highly corrosive environment for many metallic materials.

2.2 *Biological*

The soil abounds with plant and animal life, and no soil is completely free from living organisms. The organisms that can be found in at least some locations that are of concern include bacteria, fungi, insects, and rodents. Because of the complexity of the interactions of the above organisms, laboratory tests to duplicate the natural environment are not yet possible.

2.2.1 *Microorganisms*

The most numerous and the smallest organisms are the one-celled bacteria which range from 0.5 μm to 10 μm in length. A cubic inch may contain as many as a trillion individual cells. They range in shape from spheres to straight, curved, or helical rods. They occur in the air, in the soil, in natural bodies of water, and even in the deepest parts of the oceans. Among the bacteria, many types are able to decompose organic material into carbon dioxide, water, and ammonia. These are heterotrophic organisms in contrast to species which are capable of using carbon from inorganic sources. C. E. ZoBell and J. D. Beckwith[4] found that rubber is attacked by a large number of bacterial species, as indicated by oxygen consumption, carbon dioxide production, loss in weight, and swelling of the rubber. This study also showed that rubber is decomposed faster by mixed cultures than by pure cultures.

P. L. Steinberg[5] found that with biochemical oxygen demand tests (BOD) using enrichment cultures of bacteria at 5 and 20°C, externally plasticized poly (vinyl chloride) and elastomeric materials, except neoprene containing zinc oxide and magnesium oxide, showed significant oxygen consumption. Polyethylene and internally plasticized poly (vinyl chloride) copolymers and pure poly (vinyl chloride) resins were not attacked at either temperature. W. G. Walter, et al.,[6] found that a large list of plastics, including polyethylene, poly (vinyl chloride), nylon, Teflon, and Saran would not inhibit growth of *Micrococcus pyogenes* and *Streptoccus sp.* in the presence of milk. Experiments[7] with polyethylene of different molecular weights have shown that the bacterial activity was most significant at the lowest molecular weight, 4800, which is well below that used in wire and cable structures.

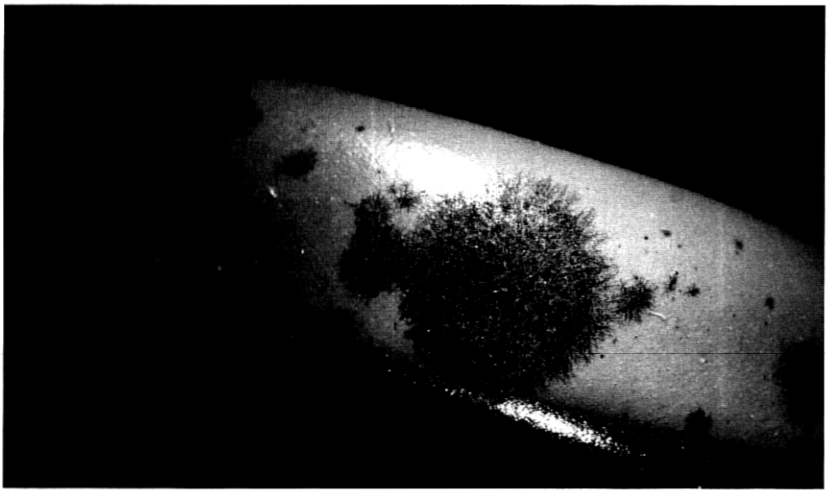

Fig. 2—Fungal growth, *Aureobasidium pullulans*, and *Cladosporium cladosporiodes*, on vinyl chloride coating.

In recent years, more interest has been shown in fungi with respect to materials degradation than any other group of organisms. It is estimated that there are between 10^4 and 10^6 viable fungal organisms per gram of soil, and, although smaller in number, they probably equal the bacteria in sheer weight of microbial protoplasm. Fungi lack chlorophyll and, therefore, are unable to utilize energy directly from the sun. The fungi of greatest interest in degradation are the molds or mildews which can manufacture organic constituents. As heterotrophic organisms, the fungi are exceptionally well equipped to undertake the rapid decomposition of virtually all the major plant constituents, including cellulose.

It is a generally accepted fact that fungi are not capable of attacking the base resins of synthetic polymers such as polyethylene, poly (vinyl chloride), etc. When attack does occur, it is because of additives such as plasticizers, lubricants, oils, and waxes which are added to alter the properties of the base resin.[8] An example of this is the fungal attack on vinyl chloride plastic wire coating, as illustrated in Fig. 2, which is due to susceptible plasticizers and stabilizers. Figure 3 clearly shows the effect of fungi on elongation and tensile strength of a plasticized poly (vinyl chloride).[9] Likewise, J. T. Blake, et al.,[10] demonstrated

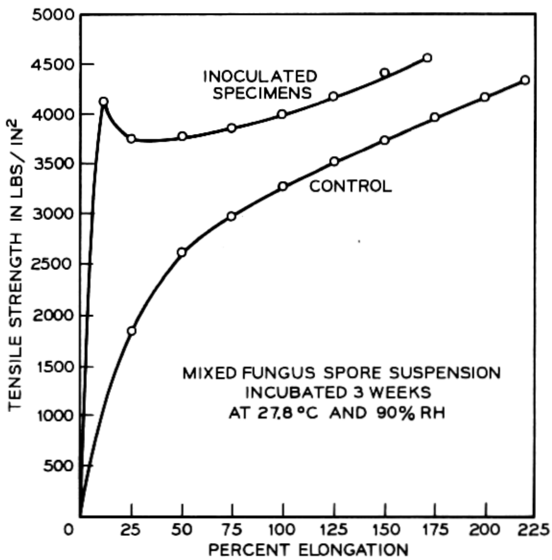

Fig. 3—Effect of fungi on tensile strength and elongation of vinyl chloride plastic containing a nutrient plasticizer.

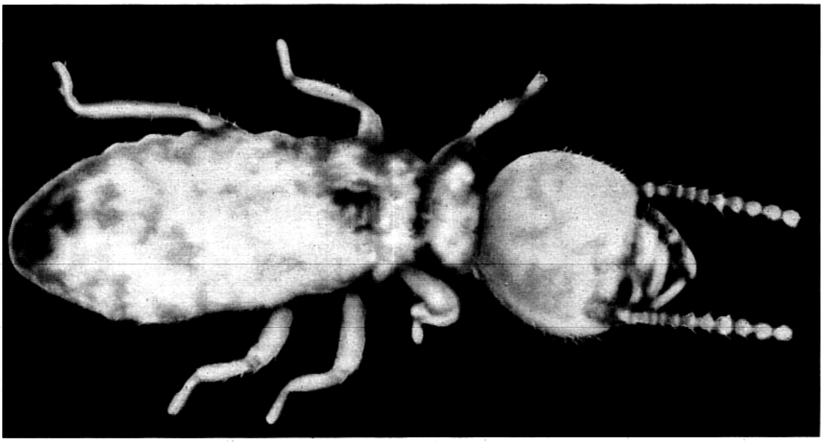

Fig. 4—Native termite worker.

that natural rubber and GRS insulation (which are mixtures of many materials) are inherently vulnerable to fungi to the point where they will fail electrically in moist environments.

2.2.2 *Macroorganisms*

The macroorganisms in the soil capable of damaging engineering materials include a large number of species. For example, entomologists estimate there are as many as 500,000 different species of insects. Because of food habits and behavior patterns exhibited cover a wide range, it is not surprising that many articles made from organic materials are totally destroyed by insect attack. Various species of termites (Fig. 4), ants, and beetles which damage telephone structures in the same way comprise the predominant groups of insects that damage materials in the soil. Recently, the Formosan termite has been introduced into this country in the Houston, Texas, area and has subsequently spread to Louisiana and South Carolina.[11–13] This species has caused considerable damage to buried telephone and power cables in Japan, Hawaii, and Australia, and indications are that it will be a more destructive pest than our native species.

Insect damage to the transmission media plant is not nearly as spectacular as that of the rodents, but is just as sure since there are almost an infinite number of individuals. One of the best examples of damage by termites and/or ants is presented in Fig. 5 which shows an underground wire that has been chewed. The armor of this particular wire eventually corroded, and the structure ultimately failed electrically.

Fig. 5—Underground wire damaged by insects after two years of service in Decatur, Alabama.

G. Flatau[14] stated in 1966 that as much as 5 percent of the sheath faults to plastic jacketed cables in Australia are caused by insects. More recently,[15] the Australians have demonstrated that they can extrude a nylon jacket on cables up to 1.5 inches in diameter to provide adequate insect protection for direct burial cables. F. J. Gay and A. H. Wetherly[16] found that changing the nature and amount of plasticizer can materially improve the termite resistance of plasticized poly (vinyl chloride), and a similar improvement can be effected in polyethylene by changing from a low- to high-density resin.

Rodents represent the largest class of animals that consistently attack buried underground structures, including cable. They possess characteristic chisel-like incisor teeth, especially adapted for gnawing, which they use in their search for food or shelter. By far, the most serious rodent enemy of buried wire and cable is the pocket gopher (*Geomes bursarius*), shown in Fig. 6, which ranges from 4.5 to 9 inches in length. These animals have external cheek pouches which are fur-

Fig. 6—The pocket gopher (*Geomes bursarius*).

lined so they do not have to ingest the material they chew. It is reported by R. Blain[17] that the two upper incisors of adult pocket gophers grow 9 inches per year, while the two lower incisors average 14 inches per year for a total of 46 inches tooth growth per year per animal. The food of pocket gophers consists entirely of plant material which they consume at the rate of as much as four pounds per day. It is not clear why they sometimes gnaw on things other than plant material such as cable. Some say it is because cables are rootlike in appearance, while others think that they serve as barriers to the animals. A typical example of gopher damage is shown in Fig. 7 where the tooth marks are clearly evident on the polyethylene jacket and lead sheath of a Lepeth cable. Gross damage such as this may cause immediate service interruption in paired cable, or eventually allow water to enter the cable with resulting transmission problems and ultimately service interruptions.

There have been many examples of gopher damage to Bell System plant. R. A. Connolly and R. E. Landstrom[18] have reported that the damage in a given location does not necessarily decrease with time and may even increase significantly. This idea is in contrast to the earlier view that the incidence of damage becomes less as the soil becomes more compact. This study showed that the pocket gopher does not damage cables much larger than 2 inches in diameter.

The Alberta Government Telephone Company reported[19] that 29 percent of the sheath faults in 1966–67 were caused by pocket gophers, *Thomomys talpoides*. They reported that there has not been a single instance of attack on an aluminum shield which is contrary

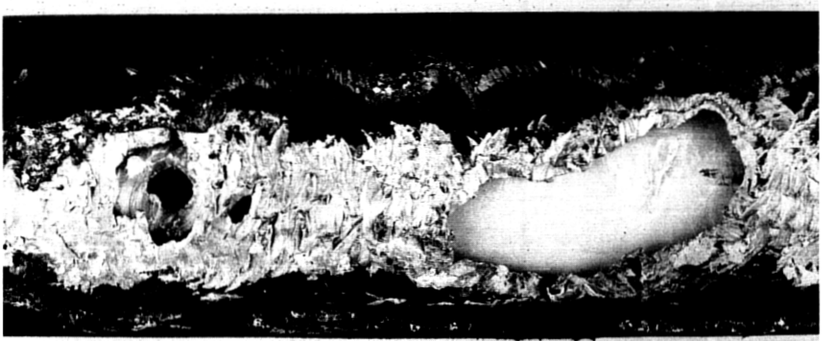

Fig. 7—Lepeth cable damaged by gophers after six years of exposure in Omaha, Nebraska, showing tooth marks and significant loss of material.

to laboratory test data and the expected field performance. They also stated that a far more serious rodent problem than gopher attack on cables is posed by mice in pedestal terminals where they chew on the conductor insulation. In 1953, W. E. Howard[20] found that materials that have resisted gopher attack include 0.005-inch steel armor, aluminum basket weave, and 1/4 inch and 1/8 inch hardware cloth mesh wrapped around the outer jackets of experimental samples. In addition, there was rapid penetration of all nonmetallic cable armor using the following materials: cotton braid, asphaltic saturant asbestos, polyethylene, polychloroprene, vinyl, glass braid, and glass yarn.

Over the years the Bell System has not experienced large losses due to insects and rodents because of good cable and wire design. However, the trend of the combined incidences of rodent and insect damage to the Bell System from 1957 to 1968 are shown in Fig. 8 where it is clear that the rate is increasing more rapidly than for corrosion and lightning. The prediction is that if the Formosan termite becomes more widely spread the rate of increase will be even more pronounced.

2.3 *Physical*

The physical soil environment varies from location to location throughout the continental United States and varies within small

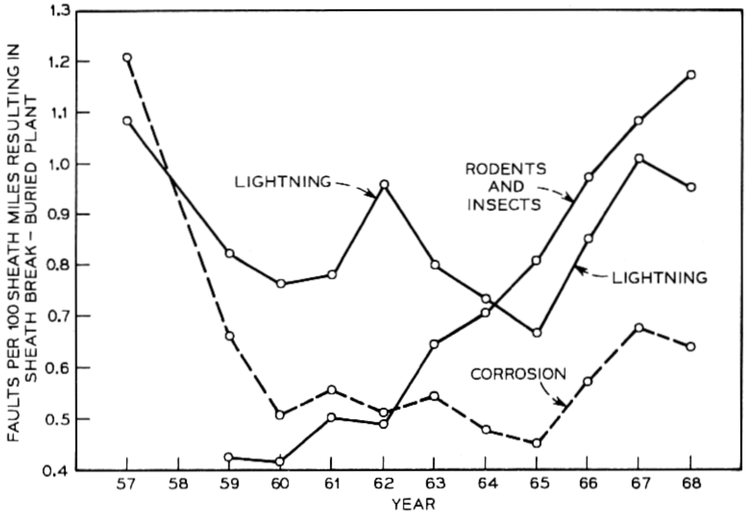

Fig. 8—Rate of sheath break faults with time from insects and rodents, lightning, and corrosion (excluding Long Lines).

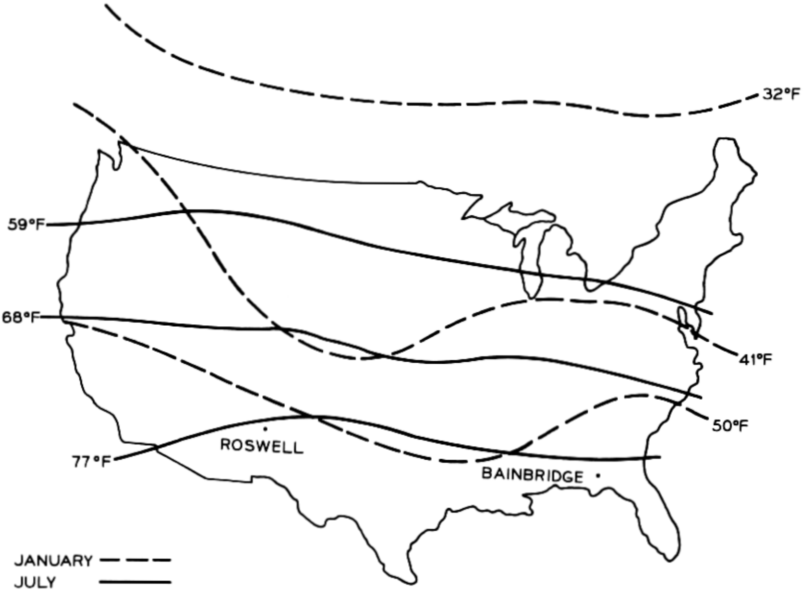

Fig. 9—Ground temperature at 120 cm (from J. H. Chang[21]).

areas and includes factors such as temperature, moisture, soil texture, and lightning.

2.3.1 *Temperature*

Soil temperature, of course, varies with depth, season, and time of day. With respect to materials performance, temperature is not usually critical except where metal and plastics are used in the same structure, and differential thermal expansion becomes a factor. Figure 9 roughly shows the temperature for July and January for the continental United States[21] at a depth of 120 cm. It is clear that at this depth the annual fluctuations are in the neighborhood of 17 to 18°F and that freezing and thawing is not generally a problem except where the cable and wire leaves the ground. The National Electric Light Association[22] measured minimum and maximum earth temperatures at depths from 2 to 8 feet in eleven U. S. cities. The data at the 4-foot level show an annual fluctuation of 15°F in Bloomfield, New Jersey, and 27°F at Clarksburg, West Virginia, which bracket the above figures.

2.3.2 *Moisture*

The annual rainfall of the continental United States varies from nearly zero in the Western deserts to 60 inches of rain in the Southeast and Pacific Northwest. Generally the Eastern states receive 40–50 inches per year. Though a wide range of precipitation is evident, Bell System equipment must be designed to function in the worst situation, which is effectively soil saturated with water.

2.3.3 *Soil Texture*

The presence of rocks and/or hardpan, where with effort cables and wires can be buried, presents very real problems of damage to the cable in the backfilling operations. When the problem becomes severe enough, especially with critical cables, mechanical protection is added in the form of steel tapes. However, such protection is not always used when it should be and rock damage may result. Small rocks and concretions, if tamped, or if a vehicle is used to compact the soil, may cause sheath damage, which can expose the metallic elements of the cable. Of course, where large rocks are used in backfilling, damage invariably results even if tamping is not done.

2.3.4 *Lightning*

When lightning strikes a plastic jacketed cable, it punctures the jacket by fusion, resulting in a hole 2 mils or larger in diameter. The current then travels along the shield and jumps to earth and punctures the jacket again, possibly at 5- to 10-foot intervals for as long as a mile in either direction from the initial strike.[23] The frequency of damage by lightning varies markedly throughout the country. E. D. Sunde[24] has shown that the number of days with lightning storms per year ranges from a high of 90 in Florida to a low of 5 on the West Coast. There is no location in the United States where lightning is not a potential problem. The nature of the soil affects the behavior of strokes once they hit the ground and how they act once they find their way on a buried telephone structure since the soil resistivity can vary from hundreds of ohm centimeters to hundreds of thousands of ohm centimeters. Figure 8 shows that the detected service interrupting (as reported by the Operating Bell Telephone Companies) faults due to lightning have varied from 0.7 to 1.1 per hundred sheath miles over the last ten years.

III. PREFERRED CHARACTERISTICS FOR BURIED PLANT MATERIALS

Any transmission media system must be able to withstand the adverse forces of nature, as discussed above, for the forty-year design life of the system. This means that the unprotected materials exposed to the environment must be chemically stable, provide a water barrier, and be resistant to biological attack.

One type of buried cable consists (from the core outward) of a layer of polyethylene, an aluminum shield, and a steel armor coated on the outside with asphalt flooding, followed by a polyethylene jacket.

On any cable, the outermost element will generally be organic rather than metallic because of the problems with corrosion of any of the metals used in cable construction. Consequently, one of the major functions of these materials is corrosion protection. They also offer some mechanical strength to the core and provide a smooth, relatively slippery surface necessary in installing cables with plows or trenchers. Specific properties required of the outer plastic element include resistance to environmental stress-cracking, low water permeability, tensile strength, abrasion resistance, cut-through resistance, flexibility, toughness, and good low-temperature brittleness characteristics.

The present tin-plated steel and aluminum used in sheath construction are not basically highly corrosion resistant materials. The steel offers high tensile strength and permits soldering to obtain an hermetic seal, while the aluminum offers high conductivity. The plastic jacket and the asphaltic flooding used on the steel are designed to isolate and protect these metals from the soil enviromnent.

IV. DESIGN OF SOIL BURIAL PROGRAM

Although the above considerations have a bearing on material performance, this test program was designed primarily to evaluate the effect of microbial, chemical, and physical factors. The sample selection, sample shapes, and exposure methods were not aimed at determining the effect of lightning, rocks, temperature, etc., on material performance.

It is impossible in any soil test to duplicate each of the countless combinations of biological and chemical associations which exist in the natural environment throughout the country. Consequently, it was immediately clear that one test site would not serve the purpose, and the Soil Burial Committee decided that two test plots should be established, one typical of acid and one typical of alkaline soils that were, in turn, representative of large sections of the country.

4.1 *Test Site Selection*

The first step in selecting the sites was to examine the isothermal and regional soil maps of the United States to define areas of interest.[25]

Then, detailed soil maps of the states and counties in the selected regions were examined to find the most appropriate soil types. With this information, local telephone company personnel assisted in locating specific sites. Laboratories representatives then extracted soil samples at various locations and depths in more than twenty-five candidate tracts. They analyzed these samples chemically and physically, and ultimately selected an 11-acre site in Georgia and a 15-acre site in New Mexico designated, respectively, the Bainbridge and Roswell Environmental Test Plots.

The soil analysis was a vital consideration in the selection of the test plots. Table II gives the chemical characteristics of the two sites finally chosen. The pH of the Bainbridge soil shows it to be a strongly acid environment in contrast to the Roswell plot which is only mildly alkaline. The resistivity of the two soils was not measured originally, but was found to be 2000 and 40,000 ohm centimeters, respectively, in 1969. N. D. Tomashov[26] classifies soils in the 1000 to 2000 ohm cm range as medium to high, and soils above 10,000 ohm cm as low in electrolytic aggressiveness. Although the plots were not selected on the basis of their corrosiveness, it is useful information for certain classes of materials such as the metal-to-rubber bonds.

The Bainbridge soil, Tifton Fine Sandy Loam, contains a large quantity of iron concretions which may comprise as much as 20 to 25 percent of the soil. The topsoil is a dark gray loam containing some organic matter in contrast to the subsoil which is a deep yellow, mealy, heavy, sandy clay which contains some imperfectly formed soft brown

TABLE II—SOIL BURIAL TEST PLOT CHARACTERISTICS

Characteristics	Topsoil		Subsoil	
	Bainbridge	Roswell	Bainbridge	Roswell
pH	5.3	8.1	5.1	7.9
Resistivity, ohm-cm	2000*	48,000*	2000*	48,000*
Organic matter	2.0%	1.2%	0.94%	0.35%
Magnesium	23 ppm	369 ppm	17 ppm	266 ppm
Phosphorus	5 ppm	4 ppm	4 ppm	7 ppm
Potasium	24 ppm	111 ppm	7 ppm	58 ppm
Calcium	244 ppm	4236 ppm	120 ppm	4455 ppm
Total nitrogen	0.03%	0.09%	0.015%	0.05%
Chloride	<10 ppm	50 ppm	<10 ppm	50 ppm
Sulfate	<10 ppm	100 ppm	<20 ppm	100 ppm

* Combined topsoil and subsoil.

concretions. The Reagan Clay Loam at Roswell is dark brown, calcareous with little organic matter. The subsoil is gray due to an accumulation of carbonate of lime and is firm or slightly cemented.

4.2 *Test Plot Layout*

The two test plots have essentially the same layout and are divided into quadrants by roadways, as shown in Fig. 10, to provide easy access to the sample locations. Two of the quadrants are used for exposure of the material samples, the third quadrant is for the insulated wires, and the fourth quadrant is for cables and cable hardware (these samples will not be covered in these papers). The quadrants were laid out such that the individual rows of samples are 10 feet apart to allow trucks to be driven close to the samples during installation and removal periods. This spacing also allows room for the necessary periodic maintenance operations.

For protection of the samples, a 25-foot fire lane bounds the test plot proper just outside a 7-foot-high Cyclone fence. It is of interest that to date there has been no vandalism or fire damage to the test plots, either inside or outside the fence. A 20-foot-square cinder block test house, located near the center of the plot, was designed to store the equipment and samples before installation, and to house services such as telephone, water, and power.

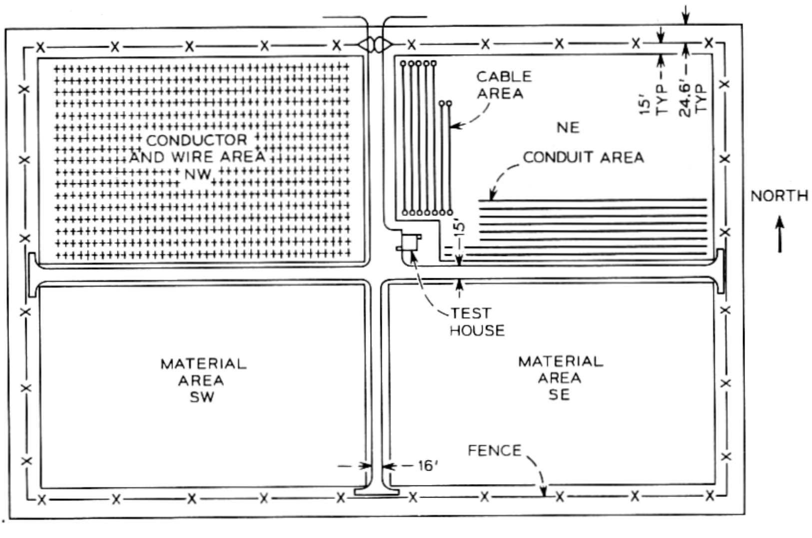

Fig. 10—Roswell environmental test plot.

4.3 *Samples*

All the materials groups participating in this program prepared samples according to their standard methods of testing. However, for the most part, the rubber and thermoplastic samples are in the form of 1/8 inch thick dumbbell-shaped specimens, injection molded or stamped from sheet stock. The thermosetting materials such as casting resins, structural laminates, and electrical laminates were exposed as 1/8 inch thick rectangular sheets. A wide range of polyolefins, poly (vinyl chloride), and rubber insulated or jacketed wires have been under test. All the plastic coated wires were extruded on both copper and aluminum conductors while the rubber was applied to copper-steel lead and brass plated conductors as well as on aluminum. The wires were generally 22 AWG wires with 30 mils of insulation.

Table III gives the general breakdown of the types and numbers of material and wire samples tested in this program. To date some 25,000 individual samples have been tested representing 287 different materials and combinations.

The number of replicates installed ranged from material to material, but basically, enough specimens were put in originally so that at each inspection a minimum of two (but an average of about five) samples could be removed for testing after each exposure period.

4.4 *Exposure Methods*

For exposure purposes, the material samples are attached to 3-foot-long polyethylene tubes with polyethylene rivets. The tubes are sub-

TABLE III—MATERIALS UNDER SOIL BURIAL TESTING

Materials Under Test	Number of Types	Number of Samples
Molded plastics	75	5,720
Casting resins	3	216
Electrical grade reinforced plastics	23	7,922
Structural reinforced plastics	20	2,600
Bonded structural laminates and stainless	4	431
steel samples	25	2,040
Rubber	17	1,080
Rubber-to-metal bonds	15	300
Rubber covered conductors	25	880
Plastic covered conductors	78	3,120
Tapes	6	936
	287	24,814

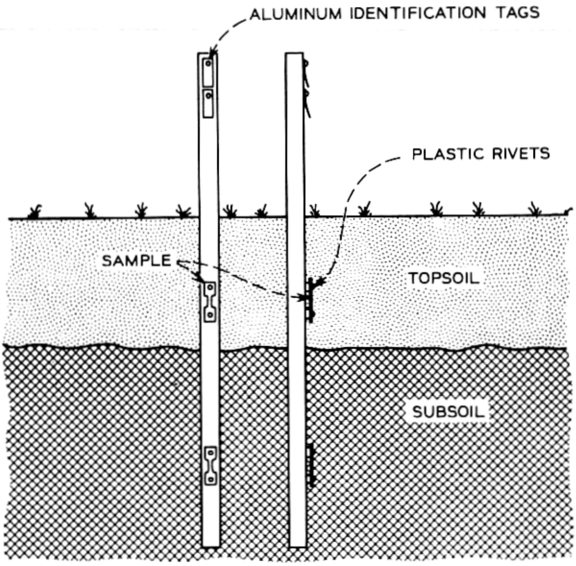

Fig. 11—Front and side view of rubber and molded plastics tensile samples mounted on polyethylene pipe.

sequently buried vertically in the ground in such a manner that the center of the top sample is in the topsoil, 6 inches below the surface, and the bottom sample is in the subsoil, 18 inches below the surface. The material used for the supporting structures was low-density polyethylene plus 2.5 percent fine channel black and 0.1 percent thiocresol antioxidant. Figures 11 and 12 illustrate how these samples were mounted. When in place, 12 inches of the tube protrude above

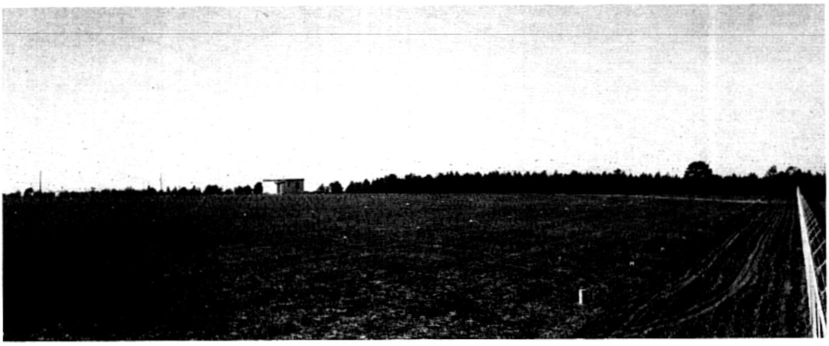

Fig. 12—Material section of Bainbridge environmental test plot.

the ground; aluminum identification tags are attached to this portion of the tube, as shown in Fig. 11.

The insulated wire samples were exposed in the form of helixes, 12 inches in diameter, and were connected to a terminal in such a way that half of the replicates of a given material were initially under constant 48-volt potential and half were not. About 4 feet of each end of the coil was in the topsoil, and the remainder of the sample was in the subsoil down to a depth of 2 feet. The design of the exposure of these samples is shown in Fig. 13.

The exposure schedule initially selected was the geometric progression 1, 2, 4, 8, 16, and 32 years. The eight-year inspections have been made, and no further samples are scheduled to be removed until 1974 at Bainbridge and 1976 at Roswell with the exception of samples installed after the initial installations and, therefore, on a different removal schedule.

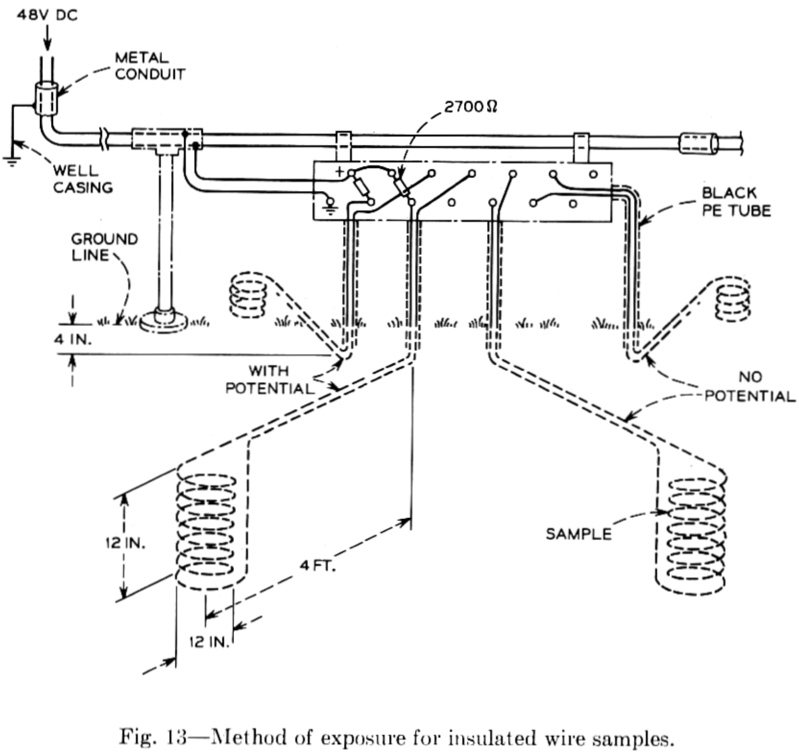

Fig. 13—Method of exposure for insulated wire samples.

TABLE IV—LIST OF TESTS CONDUCTED ON EXPOSED SAMPLES

Material	Visual	Adhesion	Tensile Strength	Tensile Modulus	Tensile Yield	Tensile Shear	Ultimate Elongation	Modulus of Rupture	Modulus of Elasticity	Flexural Strength	Flexural Modulus	Rockwell Hardness	Barcol Hardness	Insulation Resistance	Dielectric Strength	Capacitance
Molded plastics	X		X	X	X		X			X	X	X		X		
Casting resins	X		X				X	X	X			X	X	X		
Electrical laminates	X								X	X				X		
Glass fiber reinforced plastics	X								X	X						
Adhesives	X					X										
Rubber	X		X			X										
Rubber-to-metal bonds	X															
Rubber coated conductors	X													X	X	X
Plastic coated conductors	X													X	X	X
Tapes	X	X	X				X									

4.5 *Sample Evaluation*

The samples are carefully removed from the ground by shovel or by hand, and a casual visual examination is made on each one at that time. Next, the samples are packed and sent back to Murray Hill where a more detailed visual examination is made after cleaning the samples of adhering soil and debris. Physical and biological degradation is specifically noted, i.e., loss of material, cracks, decay, insect damage, discoloration, etc. The samples are then returned to the group responsible for them who then make the appropriate mechanical and electrical tests to detect any changes that may have occurred due to exposure. The tests conducted on the various classes of materials are given in Table IV.

V. RESULTS

Only two papers have been published on this project to date. One by Connolly[25] described the overall program and some of the preliminary observations on the first set of samples removed from Bainbridge in 1959. The second one by J. B. DeCoste[27] reported in detail on the performance of vinyl chloride plastics used as electrical insulations or cable jackets after four years of exposure. He found that performance was affected more by composition, particularly the choice and concentration of plasticizers, than by burial location or depth, electrical potential, or metallic conductors used. Nonmigratory and/or inherently resistant plasticizers such as tricresyl phosphate, polyesters, nitrile rubber, and dipentaerythrital esters give the best performance, while phthalate plasticizers were more susceptible to attack.

The test results after up to eight years of exposure will be discussed in the following papers by those responsible for each class of materials.

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