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**The Institution of Post Office Electrical Engineers.**

## **Corrosion and Communications**

**C. E. RICHARDS, F.I.C.**

A Paper read before the London Centre of the Institution on the  
9th May, 1939.

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## INTRODUCTION.

The study of metallic corrosion is now a vast business and only the briefest survey of one aspect of it can be made in this paper. Following a general and theoretical introduction a short review will be given of those points which are of direct interest to the communications engineer.

The cost of metallic corrosion has been variously estimated from time to time; in 1920 Sir Robert Hadfield stated that the corrosion of iron and steel alone cost the world £700,000,000 a year. Since then the cost has been compared with the world's expenditure on armaments—but that was a few years ago. Coming down from these enormous figures, whose significance it is hard to grasp, the corrosion of underground cables cost the Post Office Engineering Department £140,000, between 1932 and 1936, for engineering charges alone.

The complaint is often made that modern metals are not so resistant as those made many years ago. It may truthfully be pointed out that lead pipes laid in Bath by the Romans are still in good condition, whilst some lead cables laid in Bath by the Post Office only last a few months or years. The statement is, however, only partly true. We have no record of the number of lead pipes laid by the Romans which have completely disappeared, and we sometimes forget the thousands of miles of lead cables which give no trouble. The super-refining of metals which is now usual—British or Empire refined lead generally contains less than 0.01% total impurity—has in some cases resulted in a product which is less resistant to corrosion, but in general the reverse is the case. One factor which is not always remembered is that with modern uniform metals, and our present knowledge of their strength and behaviour, we tend to work with smaller sections than our fore-runners. In certain cases, even though we know that the modern product is not in many ways as good as the old one, we just cannot go back. Puddled iron, for instance, is recognised as being for many purposes superior to mild steel, but money will not buy it in adequate quantities. Iron puddling is becoming a lost art, and we must make the best use of the material available.

## HISTORICAL SURVEY.

Until comparatively recently, workers on corrosion had no guiding principles, and the behaviour of corroding metals was little understood. Investigators have been so active, however, that over 10 years ago Vernon was able to compile a bibliography with nearly 4,000 entries. Faraday is known to have worked on the subject and to have thought that there must be an essential link between chemical action and voltaic electricity. Davy went so far as to suggest an electrochemical method of preserving copper ships-bottoms from sea water attack—by clamping on strips of zinc,

a method many may have used for protecting lead sheathed cables.

The main steps in the ordered study of corrosion were:—

### The "Acid" Theory of Corrosion.

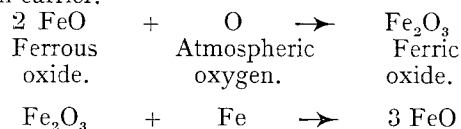
In 1871 Calvert suggested that the corrosion of iron in the presence of oxygen depended on the presence of a small amount of acid, generally thought to be carbon dioxide.

### The "Electrochemical" Theory.

Metals have a tendency to dissolve in water (solution pressure), but will only continue to do so when in contact with a metal of lower solution pressure. (A corollary of this is that an absolutely pure metal will not corrode; so far there is no proof of this.)

### The "Colloidal" Theory.

In 1921 Friend suggested that colloidal iron hydroxide (the term "colloidal" is descriptive of matter in a jelly-like and not crystalline form), which is formed when iron rusts, acted as an intermediary in promoting the attack. Iron possesses more than one oxide and it was thought that by passing alternately from the ferric (higher oxide) to the ferrous (lower oxide) condition, iron oxide would act as an oxygen carrier.



In this form the theory could only account for the corrosion of the limited number of metals which give more than one oxide. It was found, however, that colloidal oxides were often formed at spots where metals were corroding, and they were thought to have a primary influence on the course of the attack. It is now believed that although colloids do influence the attack on a metal their effect is secondary to the electrochemical effects.

### The "Newer Electrochemical" Theory.

This theory explains in the most satisfactory way yet the known basic facts of corrosion and is widely accepted to-day as giving the most truthful picture. The theory claims that the principal factor governing the corrosion of metals in the presence of moisture and in cases in which the evolution of gaseous hydrogen does not take place, is the availability of oxygen to the surface of the corroding metal. Oxygen acts as a depolariser and removes nascent hydrogen from the surface of the corroding metal. The hydrogen is removed fastest from those areas the oxygen can reach most readily and as it is removed the local electrode potential is changed. This gives rise to circulating currents and causes a redistribution of the ions in the

solution. Briefly the result is that the aerated parts of the metal become cathodic and are protected whilst the oxygen-starved parts become anodic and tend to go into solution.

This theory is compatible with the facts which led to the formulation of the older electrochemical and the colloidal theories and in its wider interpretation must include both these principles as secondary factors which may even in many cases assume primary importance.

## **OCCURRENCE AND PREVENTION OF CORROSION.**

Corrosion, in the Communications field, can be conveniently considered under three main headings:

- A. Corrosion of apparatus indoors.
- B. Atmospheric corrosion of outdoor plant.
- C. Underground and underwater corrosion.

It is not possible to regard these as watertight compartments though this will be done as far as practicable.

Almost all the discussion of corrosion will be of that type of attack which requires the presence of both oxygen and moisture. It would be wrong, however, not to mention two important exceptions; these are:

D. Direct chemical attack; at high temperatures many metals will combine directly with atmospheric oxygen and form scale, etc. Moisture may play no part in such actions, and direct corrosion can take place in such atmospheres as chlorine or sulphur dioxide.

E. Hydrogen-evolution attack, such as occurs when zinc is dissolved in hydrochloric acid to make "killed spirits." Moisture must be present in the general case, but there is no need for oxygen. The possibility of this action taking place depends fundamentally on two factors, the electrode potential of the metal and the pH value (which may be regarded as the effective—as distinct from the percentage—acidity of the corroding liquid). If both the electrode potential of the metal and the pH value of the solution are low enough, gaseous hydrogen will tend to be evolved. (N.B.—A low pH value is characteristic of a strongly acid solution and a high value, over 7, is given by alkaline solutions.)

### **A. INDOOR CORROSION.**

Telephone and telegraph plant is largely housed in heated, and often in air-conditioned, buildings. Serious corrosion of apparatus is not therefore to be expected. It must, however, be clearly understood that it is not necessary for visible moisture to appear on a surface before corrosion can occur. Corrosion products tend to attract water out of the air and it has been shown that for each metal there is a critical atmospheric humidity below which tarnishing and rusting scarcely occur and above which the rate of attack suddenly increases. This critical humidity is round about 65%. If the humidity is greater than this the corrosion products can absorb from the air that moisture which is needed for the attack to continue. The number of days in the year when the relative humidity is below 65% is comparatively small.

Another general principle which must be borne in mind is that dust is very liable to start corrosive attack. Dust particles often contain electrolytes and are liable to set up minute primary cells about an exposed surface. It has been found that merely by screening a piece of polished steel in a muslin cage, rusting is almost prevented; further, a piece of steel having been exposed in a cage for some time develops a resistance to attack which is not possessed by a freshly-polished specimen.

The only metal which needs serious attention indoors is iron; non-ferrous metals only tarnish slowly in pure atmospheres. Special cases may, however, arise in which air containing sulphur acids, usually derived from fuel burning, or salt from the sea reaches the apparatus.

Before dealing with the various methods of protection a few examples of corrosion attack of apparatus will be described, but the list is in no way complete.

### **Corrosion of copper windings.**

Relay and other coil windings are sometimes found to be attacked in most inaccessible places. It is often clear that atmospheric conditions can have had no effect, but the cause has often been the use of an unsuitable interleaving paper or the presence of dressing in a fabric. A number of cases have been found of relay windings which have corroded through in the layer next to the interleaving. In some of these it seems certain that the sulphur in the bitumenised paper has become locally oxidised to sulphuric acid and that either straightforward corrosion or electrolysis has occurred at a pinhole in the enamel on the wire. In these cases the corrosion product always contains copper sulphate. Where white or coloured material has been used in contact with enamelled wire similar faults due to the presence of soluble chlorides in the paper have been found, and it may be pointed out that magnesium chloride is a common softening agent in certain materials.

In fairness to the telephone contractors it should be added that these faults do not often occur. They are more frequent in the cheaper types of radio goods.

Electrolytic damage has been found in damp places when switchboard wires, insulated with ordinary, unwashed cotton have been used, and the general use of washed cotton or other higher grade wrapping has been recommended.

### **Corrosion of relay springs.**

An interesting case of the electrolytic corrosion of nickel silver relay springs occurred on some "flat" type relays. In this pattern two of the springs rest on the cut edge of some S.R.B.P. board (popularly known as Bakelite sheet) and it was found that, owing to a poor supply of sheet being used, current was flowing across the sheet from one spring to another. A special feature of this was that the cathode was attacked, not the anode, apparently due to the residual ammonia in the sheet.

### **Corrosion of iron parts.**

Practically all ferrous parts are protected in some way, but in many cases protection has been inadequate and rust shows in spots or small patches. When iron

parts have been protected by zinc or cadmium small spots of rust are not, as a rule, very important as they do not spread very quickly; they do show, however, that the finish was not good enough. Rust spots showing through nickel plating or paint are more serious, as the rust may spread between the coating and the iron and cause the coating to peel off.

## PROTECTION OF INDOOR APPARATUS FROM CORROSION.

The finishes available are:—

1. Paint or lacquer.
2. Chemical finishes.
3. Electro-deposited or sprayed metal, etc.

It must be realized that it is generally impracticable to give such full protection to ironwork that it will resist the worst conditions which it may encounter. Some measure of compromise is necessary and it is important to strike a proper balance between manufacturing and operating difficulties.

### (1) Paint and lacquer.

Paint is not suitable for many types of apparatus, being rather coarse and needing comparatively thick coats. It is used mainly on the more massive types of ironwork such as angle iron frames, etc. Lacquers are, generally speaking, similar to paints but are capable of application in thinner films. Some lacquers are air drying and others require stoving at low or high temperatures. Lacquers are now made from very many basic substances, *e.g.*, natural and synthetic resins, nitrocellulose, cellulose acetate, etc. There is an enormous selection, and a good lacquer coating is a thoroughly protective finish. Lacquers seldom adhere well to polished ironwork and they do not often give coatings free from pinholes; for these reasons they give their best results when used in conjunction with other types of finish, either chemical or metallic. Lacquered brass is a well known finish and though its appearance may not appeal to everyone it is a very resistant material.

### (2) Chemical finishes.

Iron and steel can be given a resistant finish by forming an impermeable and inert film on the surface. In the usual treatment the iron enters into the reaction and provides part of the compound. Coslettizing, Parkerizing and Bonderizing are examples of such finishes. Coslett produced his film of iron phosphate by boiling the parts in dilute phosphoric acid. Parkerizing and Bonderizing are modern developments of this process. The phosphate films so produced are themselves slightly protective, but perhaps their greatest asset is that they form an admirable base on which to apply paint or lacquer. A feature about organic finishes applied on phosphated iron is that even if the coating is scratched right down to the metal, rust does not spread nearly so easily below the paint or lacquer as it does if there is no intermediate coat. Typical items on which phosphated coatings are used are coin-collecting boxes and motor car bodies. The finish is also very useful for small bolts, screws, etc., which, after phosphating, are oiled with linseed oil and baked.

### (3) Electro-deposited finishes (better known as electro-plate).

These are divisible into two types: those which are anodic and those which are cathodic to the basis metal. An anodic coating is one which is attacked by corrosive influences preferentially to the basis metal. The reverse holds in the case of a cathodic coating. Anodic coatings (such as zinc or cadmium on iron) give both mechanical and electrochemical protection to the basis metal. Cathodic coatings (nickel on iron) only afford mechanical protection.

The various metallic finishes used and some of their properties are:—

#### *Zinc.*

This may be deposited from an acid or cyanide bath; the former is more usual and gives a brighter finish. Zinc from an acid bath tends to build up on corners and edges and does not deposit well in holes and crevices. An acid zinc bath is therefore said to have poor "throwing power." Cyanide zinc is darker and throws better. Recently a "bright" zinc bath has been developed based on the cyanide bath, to which certain additions are made. The final product is dipped momentarily in dilute nitric or chromic acid and has then a very attractive appearance. Zinc is a soft metal and when a plated article is taken from the bath it has a very sensitive surface. It is liable to fingermark and to be scratched and bruised. For these reasons it is usual to lacquer zinc finished articles before they have to be handled. Colourless and grey lacquer are used, the latter being generally preferred.

#### *Cadmium.*

This plating was introduced about 1926 and for several years was the fashionable finish. Extravagant claims were made for it and it has not yet entirely lived down the bad reputation which it achieved. It is deposited from a cyanide bath and throws well. As usually deposited it is dull and needs lacquering. Westbrooke, however, developed a bath containing turkey-red oil and a little nickel which gives brilliant deposits. Cadmium plating should be regarded with suspicion for electrical apparatus as it has a pronounced tendency to react with some forms of insulating material, *e.g.*, empire cloth and S.R.B.P., forming a bulky white powdery product. This has given trouble in certain of the P.O. Engineering Department's apparatus, though the exact cause does not appear to be known.

#### *Nickel.*

This is generally deposited from a slightly acid sulphate bath. Scrupulous cleanliness is necessary or very poor deposits will be obtained. In modern practice the vats are warm, and continuously stirred and filtered. It is usual when depositing nickel on iron to use an undercoating of copper or cadmium, but first-class results can be obtained without this. As deposited, nickel is dull, and for many electrical purposes is left so. For decorative work it is buffed and may be finished with chromium. Thin nickel coatings always contain pinholes, and under normal conditions non-porous coatings cannot be obtained unless they are at least 1.5 mils thick. Recently baths

have been described from which it is possible to deposit bright nickel direct, but so far the technique has not been widely adopted in this country.

#### Chromium.

This is only a tarnish-resisting finish, and on iron articles must be applied over a substantial and non-porous layer of nickel or copper. The metal is deposited from a chromic acid bath which must be operated under strictly controlled conditions as it gives off a very dangerous spray. Chromium deposits are generally only 0.01—0.05 mil thick.

#### Sprayed and other metallic finishes.

Metal spraying is well known and generally suitable for the larger types of article. Zinc is the metal most generally used. The finish is, however, not often applicable to apparatus parts as it almost essentially is applied in greater thickness than can be tolerated on them. It is also necessary to sand or shot-blast before metal spraying, and this, whilst no drawback on structural ironwork, is not always desirable with piece parts.

Sherardizing is performed by packing the parts (iron or steel) to be treated in zinc dust and heating them at about 350°C for some hours. The iron

surface is converted into zinc-iron alloy, and, if the treatment has only been short, there is practically no change in the dimensions of the parts. It should be added that the protection afforded depends largely on the amount of zinc-iron alloy formed, and that when high grade protection is required the treatment must be long and the dimensions will alter.

#### Aluminium.

Aluminium generally requires no protection as it forms its own protective oxide skin on exposure to the air. It is possible, however, to give it a thicker and more resistant film. This is produced by making the aluminium an anode in a suitable electrolyte. The principal baths used are chromic, sulphuric and oxalic acids. The hard impermeable film so formed may be coloured by organic dyestuffs and may be made more resistant by subsequent oiling or lacquering. Aluminium protected in this way is extremely resistant to corrosive attack, and withstands handling very well.

#### Appropriate finishes for indoor apparatus.

It is important that metallic parts shall be appropriately as well as adequately protected and the following general guide may help:—

TABLE 1.

Basis metal.	Type of use.	Principal finish.	Thickness (mils).	Additional treatment if any.	Remarks.
Iron and Steel	General	Zinc	≧ 0.35	Lacquer	
Iron	Parts in magnetic circuits, in which a non-magnetic finish is intolerable.	Nickel	≧ 0.4	Lacquer, if used, must not be applied to bearing surfaces.	A "flash" coating of copper 0.2 mil may be used if desired.
Iron and Steel	Decorative	Nickel and Chromium	≧ 0.7 0.02	—	Copper undercoating on the iron may be included.
Iron and Steel	When close tolerances are required.	Cadmium	0.2	—	Not to be in contact with organic insulating material.
Iron and Steel	Small screws, bolts, etc.	Zinc Sherardizing Parkerizing	— — —	Lacquer Lacquer	Barrel or basket-finished parts.
Iron and Steel	Parts which can be finished black or in colours.	Parkerizing	—	Lacquer, preferably of the baking variety.	
Brass, etc.	General	Lacquer, preferably stoving type	—		
Brass, etc.	Where white finish is desirable.	Nickel	≧ 0.07	Lacquer, when possible.	
Brass, etc.	Decorative	Nickel and Chromium	≧ 0.5 0.02		
Zinc base die castings	Decorative	Nickel	≧ 0.5	Chromium if desired.	
Aluminium	General	Anodizing	—	Dyed and lacquered if desired.	Most aluminium work needs no protection.

## B. ATMOSPHERIC CORROSION OF OUTDOOR PLANT.

In the Post Office Engineering Department there are two general types of metals used in outdoor work; these are iron and copper alloys. A certain amount of lead alloy is used as aerial cable, but as this does not suffer from corrosion trouble it will not be considered here. In other countries aluminium alloys have been used for line wire and are of some interest.

### Iron and Steel.

Iron and steel are used for most overhead structural work, such as pole steps, arm bolts, stay wires, insulator spindles, etc. The life of these articles is affected by three things:

1. The atmosphere to which they are exposed.
2. The type of protection.
3. The basic metal.

#### 1. The effect of the atmosphere.

Atmospheric conditions have an astounding effect on the life of iron and steel. These metals can be exposed for long periods to dry and pure outdoor atmospheres without rusting appreciably, but any increase in humidity and/or pollution at once puts up the rate of rusting. So far as this country is concerned the humidity is practically always high enough—even when it is not raining—for rusting to occur rapidly, though in the Alps and in places like the Sahara the rate is very slow.

Atmospheric pollution is mostly due to the burning of coal or its derivatives—gas, coke, etc. Coal invariably contains sulphur which in the course of burning is converted into sulphurous and sulphuric acids. Both these are very corrosive, the former being probably the more active. In regions where the most coal is burned the sulphur acids in the atmosphere are greatest and metals decay fastest. Such atmospheres are found in large manufacturing towns, though domestic grates have a big responsibility. Burning raw coal, in addition to causing gaseous pollution of the air, gives rise to soot, which, settling on metals, assists corrosion by forming a series of primary cells.

The effect of different atmospheres on the rate of corrosion of iron and steel can be seen from the following tables:—

TABLE 2.

CORROSION IN ONE YEAR EXPRESSED IN MILLIONTHS OF AN INCH.

(J.C. Hudson, Rep. Corr. Comm. Iron & Steel Inst. 1935, 3, 49)

	Ingot Iron.	Zinc.
Khartoum . . . . .	28	22
Abisko . . . . .	158	36
Aro . . . . .	339	57
Basra . . . . .	400	28
Singapore . . . . .	517	46
Apapa . . . . .	654	38
Llanwrtyd Wells . . . . .	1888	118
Calshot . . . . .	2104	121
South Africa . . . . .	2603	176
Dove Holes Tunnel (up-side)	2841	3609
" " (down-side)	3066	3449
Motherwell . . . . .	3137	180
Woolwich . . . . .	3472	146
Sheffield . . . . .	3883	576

TABLE 3.

RELATIVE CORROSION RATES OF MILD STEEL AND ZINC, EXPRESSED IN OZS./SQ. FT./YEAR.

(Richards, J., Iron & Steel Inst. 1938, p. 144.)

	Mild Steel.	Zinc.
St. Helens . . . . .	5.05	0.34
Widnes . . . . .	5.05	0.56
Warrington . . . . .	5.72	0.24
Sheffield . . . . .	3.6	0.26
Maryland (Stratford) . . . . .	2.7	0.17
Birmingham . . . . .	2.7	0.11
Hanley . . . . .	4.9	0.21
Taplow . . . . .	2.1	0.11
Aberdeen . . . . .	1.6	0.08
Shepherds Bush . . . . .	2.46	0.28
Dollis Hill . . . . .	1.7	0.11
Marlborough . . . . .	1.4	0.06
Plumpton (near Penrith) . . . . .	1.4	0.04
Spalding . . . . .	1.5	0.06
Aberystwyth . . . . .	1.37	0.04

Corrosion of galvanized iron takes place in two stages, the zinc first wastes away without, however, allowing any appreciable amount of iron to go. When most of the zinc has gone the exposed iron begins rusting. Fig. 1 is typical of the way in which the

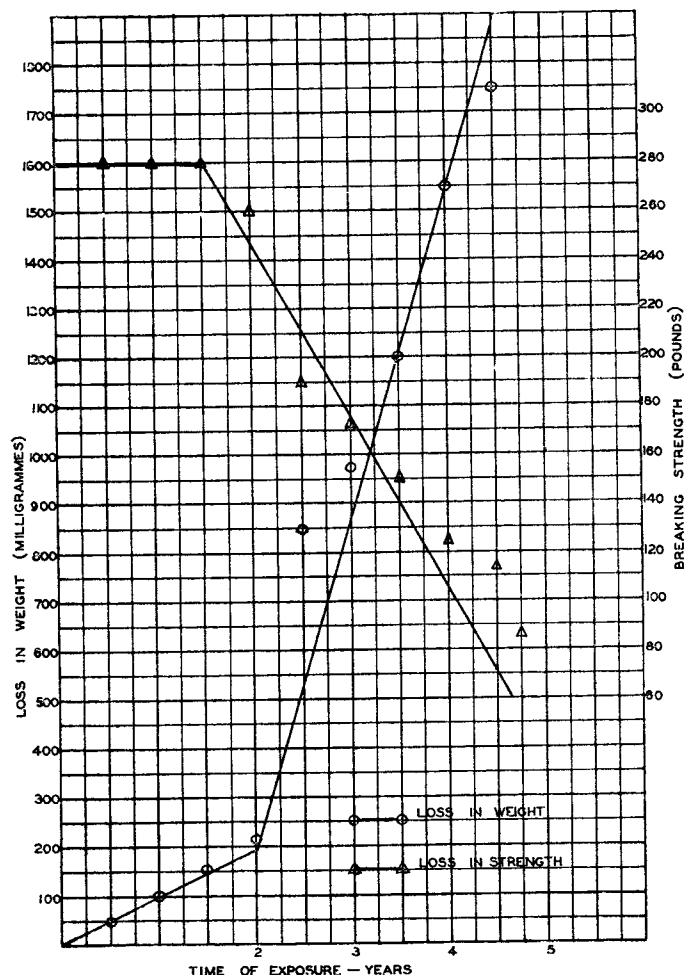


FIG. 1.—RATE OF LOSS IN WEIGHT AND LOSS IN STRENGTH OF WIRE, SUPPLY NO. 11. 14 S.W.G. AT ST. HELENS.

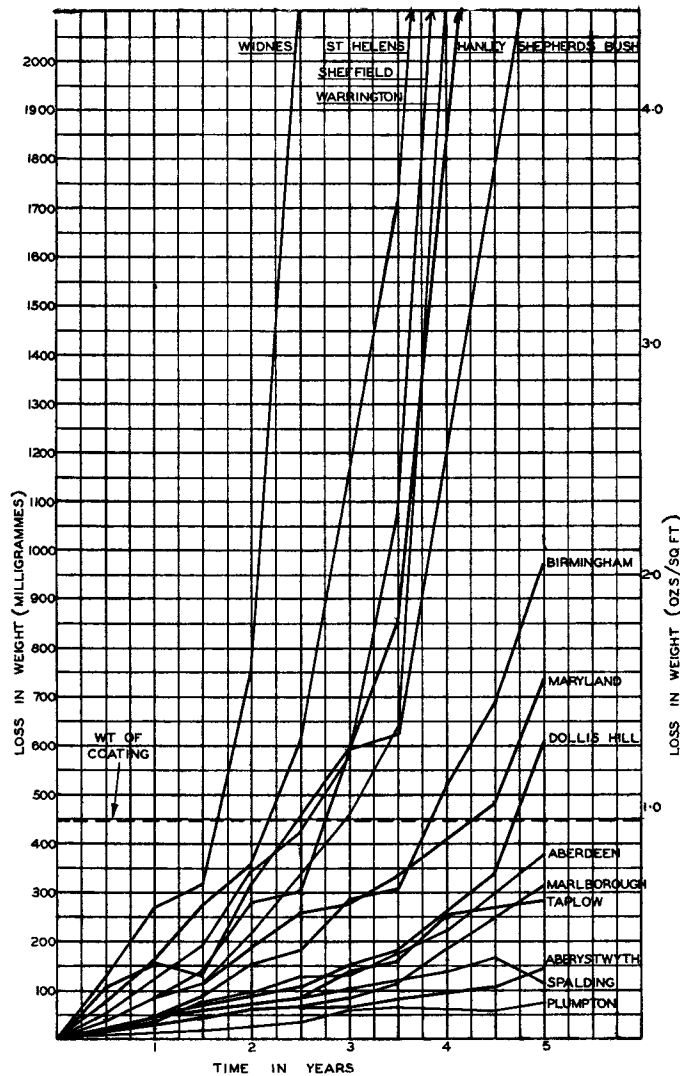


FIG. 2.—RATE OF LOSS IN WEIGHT OF WIRE, SUPPLY NO. 11. IN DIFFERENT PLACES.

weight and strength of galvanized wire change during exposure, and Fig. 2 shows how profoundly the place of exposure influences the rate of decay. In this country the rates of loss of zinc and iron are about 0.27 and 4.25 oz./sq. ft./year in industrial areas, 0.14 and 1.96 in urban areas and 0.05 and 1.42 in rural areas. It will be seen that the life of galvanizing is greatly influenced by the thickness of the zinc on it, and Figs. 3 and 4 show the effect of thickness of zinc and atmospheric conditions on the life and cost of maintenance of a pole stay, assuming a 30 years pole life.

### 2. The type of protection.

The way in which the zinc is applied to ironwork is of minor importance compared with the applied thickness, electro-deposited and hot-dipped coatings failing at the same rate. Thickness does, in fact, seem to be more important than continuity of coat, although a combination of the two is naturally desirable.

Cadmium plating has frequently been advocated as an alternative to zinc and it is often stated that a thick-

ness of 0.3 mil cadmium will give as much protection as 1 mil zinc. Whilst this may possibly be true under certain conditions, it is definitely not so in the case of outdoor atmospheric exposure, particularly in industrial and urban areas. In these places cadmium corrodes about 1/3 to 1/2 as fast again as zinc.

### 3. The basis metal.

Generally speaking mild steel is the basis substance of modern iron and steel structures and its composition is as a rule of minor importance. There is, however, one exception; the presence of small amounts of copper in the steel has a great influence on the corrosion rate when the metal is exposed to atmospheric attack. This is particularly noticeable when the atmosphere is of the industrial type. In Departmental tests of galvanized wire it was found that basis metal containing 0.15% copper corroded appreciably slower than one with only 0.05%, which itself rusted at about 2/3 the rate of a steel with only 0.008% copper. Tests by many authorities have established that a small amount of copper in steel is a real help in com-

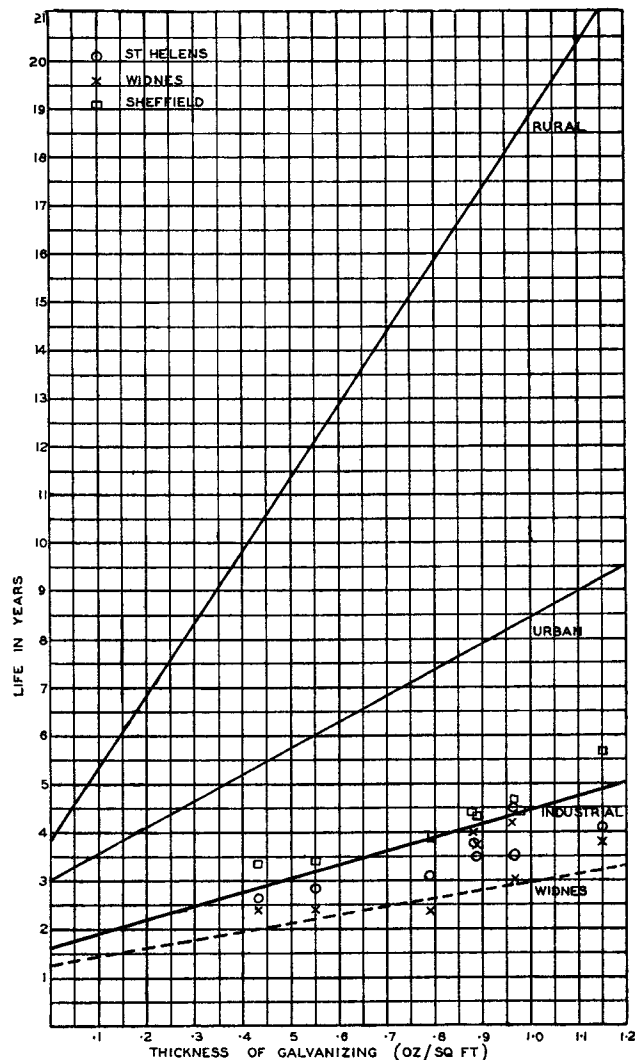


FIG. 3.—RELATION BETWEEN LIFE OF WIRE AND THICKNESS OF GALVANIZING. NO. 8 S.W.G. WIRE.



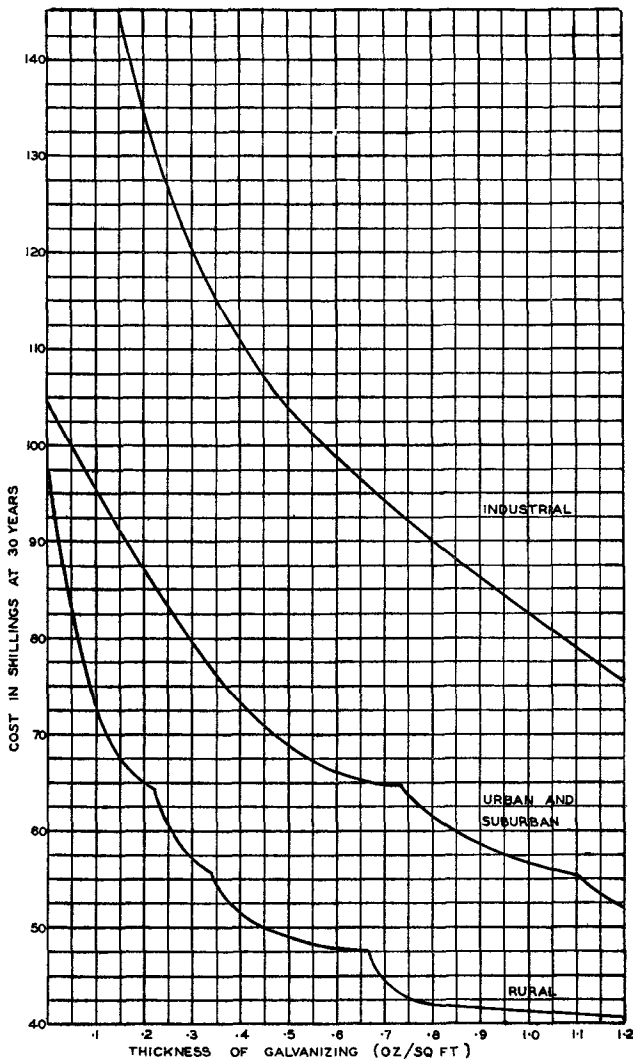


FIG. 4.—RELATION BETWEEN THICKNESS OF GALVANIZING AND COST OF ERECTING AND MAINTAINING A POLE STAY FOR 30 YEARS.

bating atmospheric corrosion, but it is most important to remember that this statement means just what it says, and no more. Copper-bearing steel is not as good as plain steel in sea water.

There is considerable evidence that genuine wrought iron made by the puddling process resisted corrosion longer than modern steels. This appears to be mainly due to the interleaving of slag and iron in the puddling process. Puddled iron is very scarce nowadays and one firm in the U.S.A. has developed a modernized process in which molten mild steel is run into a bath of slag and churned in it to produce the puddling effect. It is claimed that this material (Aston-Byers iron) has most of the desirable properties of wrought iron.

**Copper Alloys.**

Copper and cadmium copper are the only important metals nowadays, the latter metal having superseded bronze in this country. For the general purpose of corrosion study the two metals can, to a great extent,

be regarded as one. Since aerial open lines must almost essentially be erected with bare wire there is little which can be done to reduce corrosion.

Copper alloys are very susceptible to sulphur polluted atmospheres.

TABLE 4.

Locality.	Erected.	Recovered.	Percentage Loss by Corrosion*
Liverpool, Toxteth Docks	1924	1932	40
Petersfield	1923	1932	8
Farnworth (Lancs.)	1923	1932	27
Gt. Bedwyn (Berks.)	1923	1932	6

\* Based on measurements of weight, resistance and strength.

In the ordinary way pure sea coast atmospheres do not seriously corrode the wires, though it is sometimes reported that they become embrittled. Near the coast corrosion and embrittlement near twisted sleeve joints have been apparent, but the use of jelly-filled sleeves or of black varnish has reduced this trouble considerably.

Hudson has calculated the average thickness (in millionths of an inch) of the corroded layer produced in one year in various atmospheres. The figures he finds for H.C. copper and cadmium copper wires are:

TABLE 5.

Locality.	Full Exposure.		Stevenson Screen.	
	H.C. Copper.	Cadmium Copper.	H.C. Copper.	Cadmium Copper.
Cardington	16	15	139	150
Bourneville	37	34	242	264
Wakefield	40	42	371	402
Birmingham	116	120	302	350
Southport	39	39	383	407
Average	50	50	288	314

The same author also conducted a five-year test at South Kensington in which he found that the annual corrosion rate of H.C. copper and cadmium copper were 196 and 203 millionths of an inch when measured by the resistance method and 156 and 166 millionths measured by decrease in breaking load.

From the figures quoted it can be seen that there is little difference between H.C. copper and cadmium copper, and that the sulphur-bearing industrial atmospheres are the most destructive.

**Aluminium Alloys.**

Although steel-cored stranded aluminium wire is used for power transmission, pure aluminium is not suitable for overhead telephone lines owing to its low strength. When aluminium is alloyed to increase its strength it usually becomes very easily corrodible, the duralumin alloys, for example, generally requiring special preservative treatment. One series of aluminium alloys, however, is fairly resistant to corrosion: the aluminium-magnesium-silicon alloys,

known as Aldrey or Silmalec. Aldrey has been used with some success on the Continent and Silmalec has been tried experimentally in this country. Its mechanical properties, compared with cadmium-copper line wire are:—

TABLE 6.

	Cadmium-Copper	Silmalec.
Specific gravity	8.95	2.68
Electrical resistivity	2.1 microhms/cm <sup>3</sup>	3.5 microhms/cm <sup>3</sup>
Thermal expansion per °C.	$1.65 \times 10^{-5}$	$2.23 \times 10^{-5}$
Tensile strength	43 tons sq. in.	22 tons sq. in.
Endurance strength (10 <sup>7</sup> cycles)	9 tons sq. in.	4.5 tons sq. in.

Silmalec in a suburban atmosphere corrodes rather faster than the copper alloy line wires; measured by increase of electrical resistance the rates found at Dollis Hill were 2.07% per annum for Silmalec and 1.85% per annum for cadmium copper and bronze. (It must be remembered that the cadmium copper and the aluminium alloy wires had the same original conductivity, i.e., 40 lb. cadmium copper having a diameter of 0.050", was being compared with aluminium alloy of a diameter of 0.0625", which is the same as that of 70 lb. cadmium copper.)

### C. UNDERGROUND CORROSION.

To a very large extent underground corrosion means, to the communications engineer, the corrosion of lead-covered cables.\* There is no need to describe current methods of underground construction; they are occasionally criticised, but since similar methods are used in most countries having comparable conditions, it is improbable that they can be readily improved and at the same time remain an economic proposition. With regard to the materials used, British and American practice is to use earthenware ducts whilst French and German engineers use a large amount of concrete. Asbestos-cement ducts are being tried in this country. Two interesting types of construction are under trial on the Continent. In France they have evolved a type of monolithic concrete duct which may be multi-way. A concrete bed is prepared and a number of water-inflated rubber hoses are laid on it, appropriately spaced. These are surrounded and covered with concrete. After the concrete has set the hoses are deflated and pulled out. In Italy a concrete trough is first built and stainless steel frames carrying porcelain rollers are fitted at intervals. These support the cables clear of any water, which is drained away from the bottom of the trough. The top of the trough is closed by precast concrete slabs.

Cable sheath corrosion is broadly classed as "chemical" or "electrolytic." The terms are perhaps unfortunate since the latter category is used for many cases which, whilst being chemical in origin, show the same symptoms which would be produced by stray current electrolysis.

\* This question is considered more fully by W. G. Radley and C. E. Richards, J.I.E.E. 85, 1939, 685-712.

Chemical corrosion is destruction of a metal by the action of a corrosive material such as soil water, sewage, or moist lime. Chemical corrosion is associated with circulating currents, but they usually have only a very restricted path.

Electrolytic corrosion is that due to flow of current by an ionic path to or from a cable sheath. This includes:—

1. Natural current electrolysis which is caused by circulating currents set up in the cable system itself, probably due to differences in the earth through which the cable passes.
2. Stray current electrolysis in which the current flowing to or from the sheath is derived from some external system. Leakages from D.C. tramways, electric railways and faulty D.C. lighting circuits are frequent causes.

In connexion with electrolysis, it has sometimes been held that the amount of damage done bears no relation to the current which has passed. Experiments have shown, however, that provided due allowance is made for the chemical corrosion which would take place in the absence of current, Faraday's Laws of Electrolysis are obeyed, and that even in cases in which the current reverses for a large proportion of the time, the corrosion occurring is equivalent to the net current flow—See Tables 7 and 8.

TABLE 7.  
APPLICABILITY OF FARADAY LAWS.

Coulombs Passed.	Theoretical Loss. m.g.	Actual Loss. m.g.	Electrolytic Loss. m.g.
0	0	47	0
14.5	56	105	58
15.9	61	123	76
24.5	94	139	92

TABLE 8.  
CORROSION OF LEAD BY INTERMITTENT AND REVERSING CURRENTS.

Ratio of Cycle.		Duration of cycle sec.	Corrosion equivalent of coulombs passed (mg. of lead).		Electrolytic corrosion actually measured (mg. of lead).
Time positive	Time negative		Gross.	Nett.	
Positive	—	—	875	875	888
10	—	12	1033	977	985
3*	1*	1	793	353	367
3*	2	12	485	234	242
3	2*	1	316	53	73
2*	3	12	390	-89	-40†

\* The current in this direction was greater than that in the reverse direction.

† This does not mean that the plate gained in weight, but that the loss was less than that of a no-current blank in the same water.

It is a matter of some importance to be able to determine the cause of corrosion of a cable. After a considerable amount of experimental work it has been decided that there is no golden rule. The information

which can be gleaned from a chemical and microscopical examination of the damaged sheath must be carefully considered together with all the other information which can be obtained, particularly from the results of electrical tests and the data given in the reports from the locality. As a guide to the diagnosis of the cause of failure of a cable sheath the following table has been drawn up. It summarises present knowledge, but must not be regarded as final and definite.

TABLE 9.  
DIAGNOSIS OF THE CAUSE OF SHEATH FAILURE.  
(a) Character of attack.

Indicating electrolysis.	Indicating chemical corrosion.
Steep-sided pits, sometimes undercut, and long corroded furrows in the metal. Pits may be distributed at random or may run in straight lines along the cable. Visible fissures between the crystal grains in the metal to the extent that it is sometimes possible to detach individual grains.	A more uniform attack in which the crystal boundaries are not subjected to preferential damage.  Corrosion which tends to take place uniformly over the surface of the metal, and, if it causes pits, does not form undercut ones, but rather the shallow, saucer-like kind.

(b) Composition and Character of Corrosion Product.

Indicating electrolysis.	Indicating chemical corrosion.
Transparent watery crystals of corrosion product or white needles. Analysis shows a composition rich in chlorides and sulphates.  In many cases lead peroxide is found, using Trillets reagent.	Opaque powdery corrosion product or red, crystalline litharge. The corrosion product is substantially lead carbonate, basic lead carbonate or lead oxide. The presence of lead peroxide is unusual, but nitrites may be detected.

(c) Composition of Earth Water.

Indicating electrolysis.	Indicating chemical corrosion.
Clean, neutral earth water containing only normal amounts of chloride, carbonates and sulphates, and substantially free from organic matter, ammonia and other forms of nitrogen.	Acid or alkaline waters outside the usual range of 6.5—8.5 pH. High chloride concentration, presence of ammonia, nitrates or nitrites, presence of organic matter, particularly in colloidal form. Waters containing sewage or farmyard drainings are very harmful.

### “ Burn-outs.”

Occasionally a sample is submitted for diagnosis of the cause of corrosion and, although it looks like corrosion yet no corrosion product can be found, its place being taken by a mass of spongy lead. These faults are “ burn-outs ” and are due to breakdown of electric supply mains.

### Corrosion product inside the sheath.

It is often pointed out that lead peroxide exists in the inside of a corroded cable sheath. This has no significance whatever, being due to electrolysis between the positive lead sheath and the negative conductors *after* water has entered the cable. The source of e.m.f. is, of course, the exchange battery.

## METHODS OF PROTECTION AGAINST UNDERGROUND CORROSION.

### (1) Choice of sheathing metal.

The hope has been expressed that some alloy of lead could be found which would corrode less readily than lead. After very many tests it has been concluded that no alloy at present known is to be preferred to lead for general service. Alloys are known which are more resistant than the pure metal to some particular forms of attack, but these are found to fail under other practical conditions. There is, however, not much difference between the more widely used lead alloys and pure lead.

Choice of sheathing material is not entirely determined by its resistance to corrosion; it is essential that any alloy used should be capable of being extruded readily and that a cable covered with it should handle almost as easily as one sheathed with pure lead. These restrictions severely limit the materials which can be considered and pure lead remains a choice on which it is difficult to improve.

### (2) Non-metallic sheathings.

Several non-metallic substances are known which seem at first to be suitable for replacing lead as cable sheathing; cellulose acetate, vinyl, styrol and acrylic acid resins are in this class. Certain grades of rubber are also mechanically suitable. Although there is little experience of paper-cored cables sheathed in these plastics the information available shows that most of them are not impervious enough to water. A cable recently tested was sheathed in vinyl plastic and it was found impossible to desiccate it above 400 megohms per mile when the cable was immersed in water. Desiccation was continued for several weeks.

### (3) Protective coverings.

The well known “ tape and compound ” protected cables are first passed through a hot bitumen bath and then lapped with two layers of vacuum-impregnated hessian tape. Although this material does not keep the water out effectively and does not insulate the sheath electrically, it is quite effective in preventing corrosion. It has one serious drawback; it may possibly strip from the cable when drawing-in, and, if the cable must be drawn out later, it is even more liable to do so. For cases in which “ drawing-over ” is anticipated it is unsuitable. “ Rubber-wax ” protection consists of extruding over the lead sheath a plastic rubber-wax mixture which is tough and does not rot. Cables protected in this way slide easily and can be drawn over one another. The protection and insulation afforded by this construction is very much

higher than with tape and compound, megohms instead of ohms per mile. The use of this protection is restricted by its cost.

**(4) Protection by the use of chemical inhibitors.**

Certain chemicals when added to naturally corrosive waters will materially reduce their activity. Silicates, chromates, phosphates, molybdates and tungstates were all found to be effective in reducing the corrosion of lead by earth waters. These substances act by producing as a primary corrosion product a tightly adherent film of an insoluble lead compound which prevents further action on the metal. It also appreciably increases the difficulty of current passing from the metal to the surrounding water.

TABLE 10.

INCREASED CABLE LIFE RESULTING FROM THE USE OF SILICATED PETROLEUM JELLY.

Cases in which the (treated) replacement lengths lasted longer than the original (untreated) lengths	203
Cases in which the treated lengths failed in less time than the original lengths	33
Total failures of silicated cables, April, 1931—May, 1937	64*
Average life of original lengths	2.6 years
Average life of replacement lengths	3.8 years

\* Includes 12 cases which cannot be dealt with elsewhere in this analysis owing to lack of data.

Since 1931, following favourable laboratory results, a field trial of the use of an emulsion of sodium silicate in petroleum jelly for lubricating cables has been conducted. An analysis of the life of 248 replacement lengths which had been treated in this way was made in 1937; the results are given in Table 10. It might also be added that apart from the use of an inhibitor the generous application of cable lubricant has been found in the United States to reduce corrosion of bare lead-sheathed cables in conduit.

**(5) Protection from stray currents.**

Protected cables as already described are largely free from stray current corrosion, but protection of this type cannot be afforded to installed cables. Breaking up the electrical continuity of the cable sheath by means of insulating gaps is at present being tried on a large scale in this country. A ring is cut from the lead sheath and the space thus made is filled level with rubber or other insulating material and one or more layers of Okonite tape are applied over this and the sheath before the rubber muff is fitted and the whole clamped up solid. Fig. 5 shows how the fitting of insulating gaps has kept the potential between one cable system and earth at a very low value.

The use of insulating gaps alone is not favoured in many countries abroad, where schemes of electrical drainage are extensively used. Drainage, consisting essentially of connecting the system to be protected to a low potential part of the traction system, can be very effective but is always liable to expose the services of other undertakings—gas, water, electricity, etc., to even greater danger than before. Co-operative electrolysis surveys are very desirable before attempting drainage and it may be necessary to drain lead cables and ferrous pipes separately. The design of

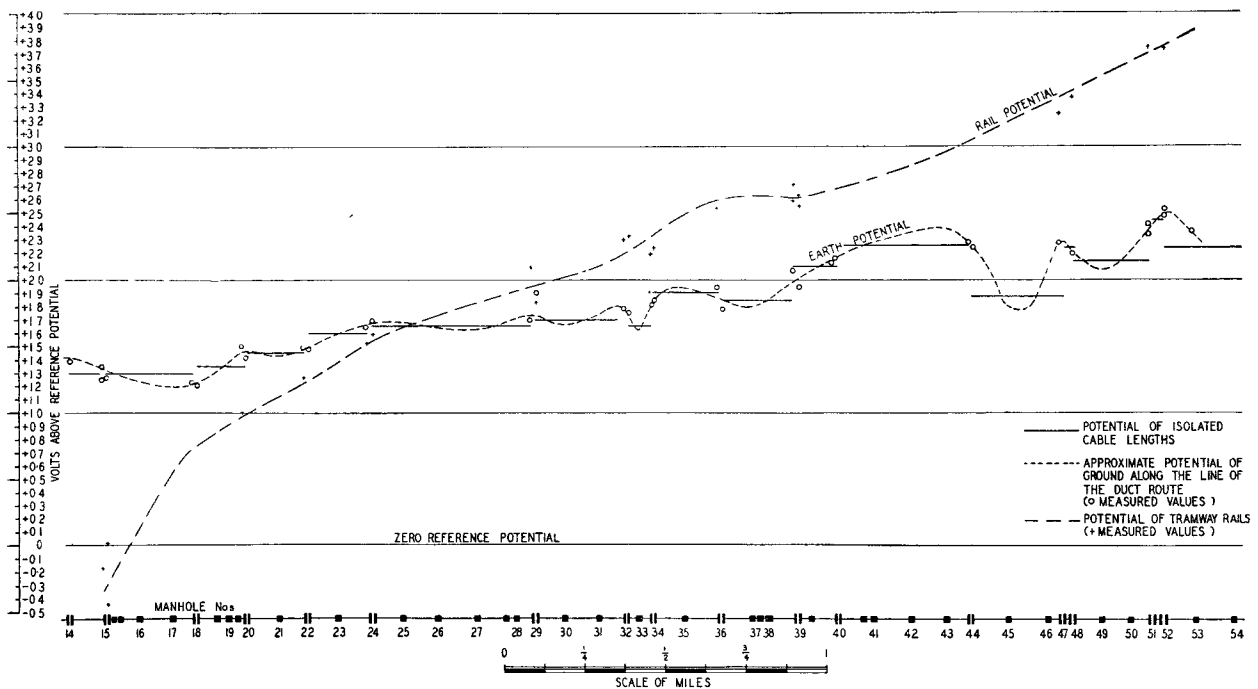


FIG. 5.—POTENTIAL OF CABLE SHEATHS AFTER INSERTION OF INSULATING GAPS.

the drainage bonds should also be given careful thought.

Cathodic protection can sometimes be useful, since, if a cable system is given a slight negative potential not only is stray current electrolysis prevented, but chemical corrosion may also be reduced. Cathodic protection of lead-sheathed cable and lead pipes must be very carefully done since alkali may be produced in certain areas and cause serious damage. With bare lead cable the current consumption cannot be neglected.

All the above methods deal with the protection of the cable system by operating on it. It must not be overlooked, however, that the cause of stray current corrosion is almost always a badly designed or maintained traction system and that much can be done by operating on this. Faulty (high resistance) rail joints and inadequate or badly arranged negative feeders are the greatest sources of trouble. Reduction of the voltage drop between different parts of the track by reducing track resistance and balancing the feeder system to equalise rail potentials at the points of connexion of the feeders will go a long way to prevent electrolysis. The modern trend towards trolley buses using insulated return conductors is also a welcome one.

### CONCLUSION.

A very brief picture has been given of the corrosion problem in the Communications field; the effect of corrosion has been described and preventive measures have been in some instances mentioned. It has been found possible with certain types of attack to estimate the life of plant fairly accurately and so to arrive at an idea of the cost of corrosion and the economic value of protection.

It must be remembered that corrosion can generally be prevented; sometimes this costs but little and is only a matter of forethought in design. Often, however, the cure is expensive and it becomes a question of commercial economics to say just how much protection shall be provided; sometimes it may be cheaper

to allow the plant to waste and then replace it, rather than protect it adequately.

Lastly, there is the psychological factor; in the Author's opinion it is better to err on the side of over-protection, since this gives the operator a chance to be proud of his plant. Apparatus which rusts, even though the rusting may have no technical significance, is apt to be regarded as shoddy and treated as such.

### AUTHOR'S NOTE.

The literature on metallic corrosion is very extensive and it is difficult to give references to any short list of original papers which will adequately cover the subject, which is, however, comprehensively covered in the following five books:—

Speller—“Corrosion, Causes and Prevention” (McGraw-Hill, 1935).

*A general treatise dealing with the theoretical and practical aspects and giving extensive details of methods of protection.*

Evans—“Metallic Corrosion, Passivity and Protection” (Arnold, 1937).

*A comprehensive book with emphasis on the work of the author and his collaborator at Cambridge since 1923.*

Burns and Schuh—“Protective Coatings for Metals” (Reinhold Publishing Corp., 1939).

*Of particular interest to Telephone Engineers since Mr. Burns is Assistant Chemical Director of the Bell Telephone Laboratories.*

Scott Ewing—“Soil Corrosion and Pipe-Line Protection” (Amer. Gas Assoc., 1938).

*The corrosion and protection of pipe lines in the U.S.A.*

Hudson—“The Corrosion of Iron and Steel” (Chapman & Hall, 1940).

*This is a comprehensive survey of the problem, with particular reference to the work done by the Corrosion Commission of the Iron and Steel Institute and the British Iron and Steel Federation.*