U. S. DEPARTMENT OF COMMERCE
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ABSTRACTS AND SUMMARIES OF THE BUREAU OF STANDARDS PUBLICATIONS ON STRAY-CURRENT ELECTROLYSIS

By E. R. SHEPARD

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U. S. DEPARTMENT OF COMMERCE
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By E. R. Shepard

ABSTRACT

This circular consists of the essential conclusions drawn from the work of the Bureau of Standards on stray-current electrolysis during a period of 15 years as presented in a series of 17 technologic papers. Most of these individual papers are now available only in reference libraries.

CONTENTS

I. INTRODUCTION

During the period of development and expansion of the electric-railway industry of the country the Bureau of Standards made extensive field and laboratory investigations relative to stray-current electrolysis and its mitigation and published its findings in 17 technologic papers. These reports have had wide circulation, and many of them are now out of print.

While the number of requests annually for information on this subject is smaller than formerly, owing to diminishing street-railway traffic, the elimination of many interurban lines, and to a better understanding of the problem by utility engineers, there remains, nevertheless, a considerable interest in the subject, as indicated by the bureau's correspondence.

To meet this demand without reprinting many of the papers which are out of print this circular is issued as an index and summary of the subject. Where access to the original publications is desired, they can usually be found in the larger city libraries and in the files of many utility operating companies.

The 1921 Report of the American Committee on Electrolysis on which the Bureau of Standards collaborated, and which contains such material as the nine organizations comprising the committee membership could unanimously agree upon, is available from the American Institute of Electrical Engineers, 33 West Thirty-ninth Street, New York, N. Y., at $1 per copy.

II. ABSTRACT OF TECHNOLOGIC PAPERS

1. *Surface insulation of pipes as a means of preventing electrolysis, Burton McCollum and O. S. Peters, Technologic Paper No. 15, January 5, 1914* (*out of print*).—Tests were made on a large number of paints, dips, and fabricated wrappings to determine their protective value as pipe coatings when subjected to the action of stray-current electrolysis. Painted specimens were submerged in water and in dilute acid. Some were subjected to a positive and some to a negative potential difference of 4 volts, while others were not subjected to any electrical stress. Periodic measurements of the electrical resistance of each specimen were made, and the time of failure, as indicated by the passage of 1.5 milliamperes, was noted. Bituminous and other coating compounds were tested without reinforcing and also in combination with various wrapping materials by submerging them in water and subjecting the coatings to positive and negative potential differences of from 4 to 15 volts. Failure was indicated by the passage of from 2 to 3 milliamperes. A number of wrapped specimens were buried in the soil and tested in the same manner as were those submerged in water. The authors arrived at the following conclusions:

Summing up the results of the foregoing experiments it is evident that they indicate that such pipe paints, dips, and wrappings as have been brought to our attention are, with practically no exception, of no value whatever for protecting pipes from electrolysis when applied in the positive areas near the power houses. If, however, they are applied in negative areas, they may be of considerable temporary value in reducing the current picked up by the pipe, and in that way indirectly they may reduce damage in positive areas.

We wish to emphasize the fact that the results of these tests are not to be considered as throwing light on the value of these coatings for protecting various metals from natural soil corrosion, as the tests were designed solely for the purpose of testing the value of these coatings as a means for protecting against electrolysis from stray currents, where the corroding influences are of much greater magnitude than those producing local galvanic action, which is largely responsible for slow corrosion of iron in soil. Whatever use may be made of such coatings in the negative areas for reducing the amount of current flow in the pipes, it should always be looked upon as a secondary means of mitigation only and not depended upon as a chief means of protecting pipes.

2. *Electrolysis in concrete, E. B. Rosa, Burton McCollum, and O. S. Peters, Technologic Paper No. 18, March 19, 1913 (available from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 35 cents).*—Extensive experiments are described and from the results of these the authors draw the following conclusions:

(1) The observations of previous investigators that the passage of current from an iron anode into normal wet concrete caused the destruction of the test specimen by cracking were only partly confirmed. This effect was found not to occur in most of the specimens tested when the potential gradient was less than about 15 volts through a distance of 3 inches, or about 60 volts per foot. These figures must be considered as but roughly approximate, as they depend much on conditions.

(2) Of the numerous theories that have been advanced for the cracking of reinforced concrete due to electric current, that one which attributes it to oxidation of the iron anode following electrolytic corrosion has been fully established. The oxides formed occupy 2.2 times as great a volume as the original iron, and the pressure resulting from this increase of volume causes the block to crack open.

(3) Metals which do not form insoluble end products of corrosion and all noncorrodable anodes never cause cracking of the concrete as a result of the passage of an electric current.

(4) The mechanical pressure developed at the iron anode surface by corrosion of the iron has been measured in a number of cases and has been found to reach values as high as 4,700 pounds per square inch, a value more than sufficient to account for the phenomena of cracking that have been observed.

(5) Suggestions of some engineers[1] that copper-clad steel or aluminum be used as reinforcing material have been shown to be impracticable, since the copper coating is readily destroyed and the aluminum is attacked by the alkali in the concrete.

(6) Corrosion of iron anodes even in wet concrete is very slight at temperatures below about 45° C. (113° F.).

(7) For any fixed temperature the amount of corrosion for a given number of ampere hours is independent of the current strength.

(8) The lack of corrosion of the iron at temperatures below 45° C. is due to the inhibiting effect of the $Ca(OH)_2$ and possibly other alkalies in the concrete.

(9) The rapid destruction of anode specimens of moist concrete at high voltages (60 to 100 volts or more) is made possible mainly by the heating effect of the current, which raises the temperature above the limit mentioned above. If the specimen be artificially cooled no appreciable corrosion occurs, and no cracking results.

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[1] Magnusson and Smith, The Electrolysis of Steel in Concrete, Proc. A. I. E. E., vol. 30, p. 939.

(10) The potential gradient necessary to produce a temperature rise to 45° C. with consequent corrosion, in the specimens used, was about 60 volts per foot. For air-dried concrete it is much higher. This shows that under actual conditions corrosion from stray currents may be expected only under special or extreme conditions as noted below. These figures are but roughly approximate since they will vary greatly with the conditions, such as the size, form, and composition of the specimen, but they serve to show the order of magnitude of the voltage required to produce trouble.

(11) Since the passivity of iron in concrete is due chiefly to the $Ca(OH)_2$ present it appears probable that old structures in which the $Ca(OH)_2$ has been largely converted into carbonate will be more susceptible to the effects of electric currents than comparatively new concrete with which the foregoing experiments have been made. The increase in the efficiency of corrosion would, however, be at least partly offset by the increase in the resistance of the concrete which would accompany the change.

(12) The addition of a small amount of salt (a fraction of 1 per cent) to concrete (as is frequently done to prevent freezing while setting) has a twofold effect, viz, it greatly increases the initial conductivity of the wet concrete, thus allowing more current to flow, and it also destroys the passive condition of the iron at ordinary temperatures, thus multiplying by many hundreds of times the rate of corrosion and consequent tendency of the concrete to crack. Salt should, therefore, never be used in structures that may be subjected to electrolytic action. Further, reinforced concrete structures built in contact with sea water, or in salt marshes, are more susceptible to electrolysis troubles than concrete not subjected to such influences.

(13) Specimens of normal wet concrete carrying currents increase their resistance a hundredfold or more in the course of a few weeks, which fact still further lessens danger of trouble.

(14) The rise of electrical resistance is probably due to a number of causes among which are the precipitation of $CaCO_3$ within the pores of the concrete thus plugging them up. A slight amount of salt tends to prevent this precipitation and interferes with the rise of resistance, thus still further emphasizing the detrimental effect of salt.

(15) Contrary to the observations of previous investigators there was a distinct softening of the concrete near the cathode. This begins at the cathode surface and slowly spreads outward, in some cases as far as one-fourth inch or more. After exposure to the air this softened layer becomes very hard again, but remains brittle and friable.

(16) The softening effect at the cathode noted above, caused under the conditions of the experiments, practically complete destruction of the bond between reinforcing material and the concrete, reducing it to a few per cent of its normal value.

(17) Unlike the anode effect which becomes serious in normal concrete only on comparatively high voltages, the cathode effect develops at all voltages used in the experiments, the rate being roughly proportional to the voltage in a given specimen.

(18) In general the cathode effect occurs under conditions which may not infrequently occur in practice and is therefore probably a more serious matter practically than the anode effect about which

so much has been written. This trouble is unlikely to be serious, however, except where the concrete is wet and the potential differences rather large.

(19) The softening of the concrete at the cathode is due chiefly to the gradual concentration of Na and K near the cathode by the passage of electric current. In time the alkali becomes so strong as to attack the cement.

(20) Softening at the cathode is increased by increasing the Na and K content of the cement, and reduced by diminishing this content, at least within the range below 10 per cent of the total salts.

(21) The softening of the concrete has never been observed, except very close to the cathode, the main body of the concrete remaining perfectly sound. Numerous tests show conclusively that the crushing strength of the main body of the concrete is not reduced even when the potential gradient is maintained at 175 volts per foot for over a year.

(22) Because of the cathode effect noted above, the proposal to protect reinforced buildings by maintaining the reinforcing material cathode as by a battery or booster would be much more dangerous than no protection at all.

(23) Aside from slight heating, which is usually negligible, the only effect which an electric current has on unreinforced concrete is to cause a migration of the water soluble elements. Consequently, in the absence of electrodes, the ultimate effect of current flow on the physical properties of the concrete is not materially different from that of slow seepage, which also removes the water soluble elements. Nonreinforced concrete buildings are therefore immune from trouble due to stray earth currents. They might, however, be injured by the grounding of power wires within the structure, since these or the inclosing conduits would then act as electrodes.

(24) Conditions arise in practice which give rise to damage due to stray currents, but the danger from this source has been greatly overestimated. While precautions are necessary under certain conditions, there is no cause for serious alarm.

(25) If reinforced concrete could be thoroughly waterproofed, it would greatly increase its resistance and diminish accordingly the danger from either the anode or cathode effects. It should be emphasized, however, that waterproofing to prevent electrolysis is a much more difficult matter than waterproofing to maintain a moderate degree of dryness, because of the much higher degree of waterproofing required in the former case. It has been found that practically all of the waterproofing agents now on the market that are intended to be mixed with the concrete, are of little value as preventives of electrolysis. Waterproofing membranes, etc., applied to the surface can be made more effective and when properly applied may have considerable effect in preventing the entry of earth currents into the concrete.

(26) Painting or otherwise coating iron with an alkali resisting metal preservative before embedding it in concrete may serve to minimize the dangers of electrolysis, but no such coating has been found that does not prevent the proper formation of the bond between the concrete and iron when the concrete sets.

(27) In order to insure safety of reinforced concrete from electrolysis the investigation shows that potential gradients must be kept much lower in structures exposed to the action of salt waters, pickling baths, and all solutions which tend to destroy the passive state of iron.

(28) All direct-current electric power circuits within the concrete building should be kept free from grounds. If the power supply comes from a central station the local circuits should be periodically disconnected and tested for grounds and incipient defects in the insulation. In the case of isolated plants, ground detectors should be installed and the system kept free from grounds at all times.

(29) All pipe lines entering concrete buildings should, if possible, be provided with insulating joints outside the building. If a pipe line passes through a building and continues beyond, one or more insulating joints should be placed on each side of the building. If the potential drop around the isolated section is large, say, 8 or 10 volts or more, the isolated portion should be shunted by means of a copper cable.

(30) Lead-covered cables entering such buildings should be isolated from the concrete. Wooden or other nonmetallic supports which prevent actual contact between the cable and the concrete will give sufficient isolation for this purpose. Such isolation of the lead-covered cable is desirable for the protection of the cable as well as the building.

(31) The interconnection of all metal work within a building is an advantage where practicable, provided that all pipe lines entering the building are equipped with insulating joints and lead cables are taken care of as indicated in the preceding paragraph, but the grounding of such interconnected metal work or any part of it to ground plates or to pipe lines outside of the insulating joints is to be strictly avoided.

(32) In making a diagnosis of the cause of damage in any particular case, the fact that a fairly large voltage reading may be obtained somewhere about the structure should not be taken as sufficient evidence that the trouble is due to electrolysis. The distance between the points, and particularly the character of the intervening medium are of much greater importance than the mere magnitude of the voltage reading. As a precautionary measure, however, all potential readings about a reinforced-concrete structure should be kept as low as practicable.

3. *Electrolytic corrosion of iron in soils, Burton McCollum and K. H. Logan, Technologic Paper No. 25, June 12, 1913 (out of print)*.—This paper contains the results of some of the earliest laboratory work of the Bureau of Standards on electrolytic corrosion, particularly on the effects of moisture, temperature, current density, and other factors on the efficiency of electrolytic corrosion in soils. Following are the authors' general conclusions drawn from the experimental data:

(1) The current density has a marked effect on efficiency of corrosion of iron in soils, the efficiency of corrosion being, in general, greater the lower the current density. In saturated soils the corrosion may vary between 20 per cent and about 140 per cent for the range of current densities between 5 and 0.05 milliampere per square centimeter.

(2) Moisture content in the soil also has a marked effect on the efficiency of corrosion, the corrosion efficiency being, in general, greater with increasing moisture content up to saturation of the soil. Beyond this point increased moisture content has comparatively little effect.

(3) Temperature changes within the limits commonly met with in practice have no important effect on corrosion efficiency.

(4) The depth of burial of pipes has no direct effect on corrosion efficiency, provided other conditions remain constant. In practice, however, the moisture content, current carried by the pipes, and various other factors which affect corrosion efficiency will vary with depth, so that indirectly differences due to depth may be noted.

(5) The amount of oxygen present has no appreciable effect on the efficiency of corrosion in the case of iron immersed in liquid electrolyte.

(6) Corrosion efficiency of iron embedded in earth is always greater in open vessels than in sealed vessels.

(7) The amount of oxygen present has a marked effect on the end products of corrosion. If the corrosion is rapid and the supply of oxygen small, there will be a preponderance of magnetic oxide, while if the rate of corrosion is low and the supply of oxygen abundant the ferric oxide will predominate. Owing to the fact that the supply of oxygen around pipes buried in earth is always more or less limited, the character of the oxides gives some indication as to the rate of corrosion, and thus indirectly the cause of the corrosion, if local conditions are properly considered.

(8) There is no material difference in the efficiency of corrosion shown by the various kinds of iron commonly used in the manufacture of underground pipes.

(9) The fact that a given chemical tends strongly to inhibit either self-corrosion or electrolytic corrosion in liquids is no indication that it will materially retard electrolysis of iron embedded in soils.

(10) Pitting of iron embedded in soils is affected not only by a nonhomogeneous condition of the iron or soil, but also by the chemicals contained in the soil.

(11) The efficiency of corrosion was found not to be a function of the voltage except in so far as the current density may be affected. Voltages as low as 0.1 and 0.6 volt showed practically the same efficiency of corrosion as 5 to 10 volts or higher.

(12) Corrosion tests on a large number of different kinds of soil from widely different sources with average moisture content and moderate current density indicate that corrosion efficiencies between 50 and 110 per cent may usually be expected under most practical conditions.

(13) The resistance of soils varies throughout a very wide range with variations in moisture content, the resistance of the comparatively dry soil being of the order of several hundred times the resistance of the same soil at about saturation. Above saturation increase in moisture content has but little effect on the resistance of the soil.

(14) Because of the great variations in resistance of earth with moisture content, voltage surveys should not be made at times when the earth is extremely dry.

(15) The resistance of the soil varies greatly with temperature within the ordinary range encountered in practice. In the case of the soil tested the resistance at 18° below zero centigrade was over two hundred times as great as at 18° above zero centigrade. Even at about freezing temperature the resistance will be several times that at summer temperatures. This not only has an important bearing on the magnitude of the electrolysis trouble that may occur at different seasons, but it also indicates that where practicable voltage surveys should not be made when extremely low temperatures prevail.

(16) The experimental results given in this paper have an important bearing on the subject of electrolysis mitigation through the limitation of voltage drop in the negative return. For some years the chief means of preventing trouble from electrolysis in certain foreign countries has been the limitation of the permissible voltage drop between any two points on the return circuit. In some places the limit has been placed on the maximum voltage during peak load, whereas in other cases the average voltage for 24 hours has been the determining factor. It will be evident that if the total amount of damage which results is proportional to the average current, then the limitation of the average voltage would be more logical than the limitation of the peak-load voltage, since in the former case the cost of meeting the voltage limitation in any given case would be proportionate to the danger involved irrespective of the station load factor; whereas if the voltage at peak load is the determining factor the cost of complying with the requirements depends not only on the danger involved but on the load factor of the system, and the poorer the load factor the greater its cost will be. It appears from the data presented in this paper that the rate of damage does not increase as fast as the voltage increases, because of the tendency toward lower corrosion efficiencies at higher current densities. This indicates that, with a given average all-day current the actual amount of electrolysis that would occur would be less with a bad load factor than with a good load factor, and hence points to the undesirability of penalizing a high peak of short duration. It would appear more logical, therefore, in so far as the damage itself is concerned, to make the average all-day voltage the basis of the limitation rather than the voltage at time of peak load.

4. *Earth resistance and its relation to electrolysis of underground structures, Burton McCollum and K. H. Logan, Technologic Paper No. 26, December 20, 1915* (*out of print*).—The resistivity of the soil in which metallic structures are buried is shown to be of much importance with respect to electrolysis of these structures. Three methods of measuring the specific resistance of the soil, two of which do not require the removal of the soil from its original position, are described. Results of soil-resistivity measurements by each method are compared, and it is shown that any of the described methods is satisfactory for practical purposes, although each has advantages over the others under certain conditions.

The results of a large number of measurements of resistivity of soil samples from widely separated points in the United States have been tabulated. These data show great variations in soil resistivity and indicate the desirability of a study of local soil conditions in connection with any complete electrolysis survey. The majority of soils tested show resistivities of between 1,000 and 5,000 ohm-centimeters.

A number of factors have been found to influence the resistivity of the soil. Increasing the pressure on a sample of soil under test tends to increase the conductance of the sample slightly, especially if the original pressure is low. Increase in moisture increases the conductance of the soil if it is not saturated with water. The amount and kind of soluble material in the soil affects its resistivity. The resistivity of soil is found to increase as its temperature falls, especially when the freezing point of water is reached. The flow of current through the soil has been found to produce an apparent temporary increase in soil resistivity in the neighborhood of the electrodes.

The relation of soil resistivity to electrolysis is considered from the standpoint of leakage from street railway lines using the track as a return current. The importance of good rail bonding and of well-drained roadbed is pointed out.

The relations of the various factors affecting leakage resistance (namely, character of the soil, pressure, moisture, freezing, polarization, and surface films) to the electrolysis problem are described, and it is shown that a knowledge of the resistivity of the soil is of importance in estimating the danger indicated by potential-difference and potential-gradient measurements. It is also shown that the moisture and temperature of the soil materially affect the amount of current escaping from the grounded track used as a return circuit, and that these factors must be given due consideration in the interpretation of data obtained during an electrolysis survey.

5. *Special studies in electrolysis mitigation. I. A preliminary study of conditions in Springfield, Ohio, with recommendations for mitigation and control, E. B. Rosa and Burton McCollum, Technologic Paper No. 27, June 19, 1913* (*out of print*).—This paper was mainly of local and temporary interest and contains nothing of general importance not found in Technologic Paper No. 52.

6. *Methods of making electrolysis surveys, Burton McCollum and G. H. Ahlborn, Technologic Paper No. 28, August, 1916* (*out of print*).—Superseded by Technologic Paper No. 355. (See 17 below.)

7. *Special studies in electrolysis mitigation. II. An experimental test on a system of insulated negative feeders in St. Louis, E. B. Rosa, Burton McCollum, and K. H. Logan, Technologic Paper No. 32, December 27, 1913* (*out of print*).—The paper describes experimental tests in a typical street-railway substation district in St. Louis. A system of negative feeders was in use which could easily be converted into an insulated negative feeder system[2] by the introduction of resistors at selected points.

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[2] The term "insulated negative feeder system" as here used, refers to a system of return conductors so proportioned as to size, length, and total circuit resistance as to permit of controlling the amount of current returned from the track network at selected points and thereby limiting and controlling the potential gradients and over-all voltage drops on the track network within the substation district. This system usually involves a resistor between the negative bus and the track at its nearest point of approach to the supply station. The currents from other points of connection to the track are controlled by the size and length of the respective feeders and by the use of auxiliary resistors. The terms "insulated" and "uninsulated" are therefore not used here in the ordinary sense, but rather to indicate whether the negative feeders are connected directly in parallel with the tracks or as indicated above.

Measurements were made of potential gradients and over-all voltage drops on tracks, potential differences between water pipes and tracks, and electric current flow on water and gas mains under both systems of negative feeders. Following is a brief summary of the results of such measurements. The recorded values are the averages of the number of measurements indicated.

Comparison of electrolysis conditions under uninsulated and insulated negative feeder systems	Uninsulated feeders		Insulated feeders	
	Number of tests	Average	Number of tests	Average
Potential gradients on rails	21	0.93 v	26	0.46 v
Over-all voltage drops on rails	22	10.4 v	22	1.8 v
Current flow on gas and water pipes (pipes not drained)	21	13.0 a	21	3.1 a
Current flow on gas and water pipes (pipes drained)	21	40.0 a	21	4.0 a
Potential differences between pipes and rails (pipes not drained):				
A, potentials originally over 1 volt	14	2.44 v	14	.33 v
B, potentials originally less than 1 volt	14	.49 v	14	.28 v
C, potentials originally negative	8	−.31 v	8	.56 v

v=volt; a=emperes.

The authors summarize their conclusions as follows:

(1) An examination of the preceding data on current flow in the pipes, potential differences between pipes and rails, and over-all potential differences shows that under the insulated negative feeder system these values range from one-half to one-seventh of the corresponding values which prevail under the uninsulated feeder system. These ratios represent approximately the difference in electrolysis damage that would result in the two cases.

(2) For substantially the same installation cost very much better electrolysis conditions can be secured with insulated negative feeders than with uninsulated feeders.

(3) When the potential differences in the track return are reduced to the low values that can readily be obtained by means of insulated negative feeders, the tying in of the pipes to the tracks has a much smaller tendency to cause heavy current flow in the pipes than if such reduction of potential differences is not realized.

(4) Where good voltage conditions in the negative return are maintained, the insulated feeder system can, in most cases, be installed so as to yield far greater economies both in installation and operation costs than is possible with uninsulated feeders.

(5) In the case of old stations in which there is already a large amount of negative copper installed in such a way that it is impracticable to insulate it, the insulated feeder system would still be economical in case it is desired to lower potential differences in the negative return below those at present existing. Wherever such reduction of potential differences is contemplated the insulated feeder system will show the same marked economy over the uninsulated system as is shown in the case of new stations.

(6) Negative feeders which are so laid that they can not be insulated will not be used any less efficiently if supplemented by insulated feeders than if uninsulated feeders are added, provided equally

good voltage conditions in the track are maintained in both cases. The opinion that such uninsulated copper is largely wasted if supplemented by insulated feeders is therefore based on a misconception. Uninsulated negative feeders are always wasteful wherever good voltage conditions in the negative return are required, and any addition to such uninsulated feeders is an extension of this waste; this can be avoided by using insulated negative feeders for all extension work.

8. *Electrolysis and its mitigation, E. B. Rosa and Burton McCollum, Technologic Paper No. 52, 2d ed., November 25, 1918 (out of print)*.—This paper contains a comprehensive discussion of various methods of electrolysis mitigation of which the following is a brief summary:

(1) The electrolysis problem was for a long time neglected in America, and partly as a result of this, is now more serious than in those European countries which early met it by Government regulations. During the last few years, however, much greater attention is being given to this subject by railway companies generally.

(2) Electrolysis may give rise to a number of different classes of injury, such as fires, explosions, and damage to concrete structures. However, the damage from these effects is in the aggregate relatively small. By far the greater portion of the damage due to electrolysis is that arising from corrosion of underground pipes and cables. In particular, electrolytic damage to concrete structures is to be feared only where voltage conditions are exceptionally severe, or in the case of comparatively low voltages when salt has been added to the concrete either during or after construction.

(3) In general, those remedial measures that are applicable to pipe systems should be regarded as secondary means of mitigation of electrolysis trouble, the principal reliance being proper construction and maintenance of the railway return circuit. In special cases, however, mitigative measures may be applied only to the underground structures.

(4) The protection of pipes from electrolysis by the use of chemicals, such as, for examples, lime or other soluble hydroxides which tend to render iron passive when it is made anode, has been found to be of only temporary value. Because of diffusion into the surrounding earth and the infiltration of other earth salts which may have a counteracting influence, the protection afforded by this means is too short lived to justify its application except, perhaps, in very special cases where conditions are peculiarly suited to its use.

(5) The principle of maintaining an underground piping or cable system negative to the earth at all times by the use of boosters, batteries, or a metal which is electropositive to the one to be protected is termed cathodic protection. A great many attempts have been made to utilize this idea and a number of patented methods of electrolysis prevention are based upon it. The extent of protection afforded an underground system by this means depends upon the size and location of the auxiliary anodes as well as upon the amount of electrical energy used. Experiments indicate that it is not a practical means of protecting bare piping systems because of the expense involved. Under special conditions it is economically applicable to

cable sheaths, but when so used there is danger of cathodic corrosion resulting from the concentration of alkali on the lead sheaths. The use of zinc electrodes for maintaining pipes or cable sheaths cathodic to the earth is ordinarily without merit because of their very local influence and the rapid deterioration of the zinc.

(6) Conducting coatings, as a means of preventing electrolysis, have proved impractical. All noncorrodible metals available for this purpose are too expensive for commercial application and nonmetallic coatings, such as black oxide or particles of coke in combination with a binder, have invariably been harmful in their effects because of their tendency to produce a greatly increased amount of local or galvanic action.

(7) Electric screens have been used in some cases to reduce electrolysis on pipes passing under street railway track or where they are in close proximity to other underground structures to which they tend to discharge current. The most common and effective type of screen is a large pipe inclosing the pipe to be protected. The protected pipe, being electrically connected to the screen, is shielded at the expense of the latter and if the outer pipe is of heavy material, it will afford indefinite protection.

(8) Insulating joints in piping systems have found rather extensive use as a means of interrupting the current flow in pipes and thereby reducing electrolysis. They are more appropriate for new installations than for existing systems as the cost of installing them in old lines is usually prohibitive. The value of insulating joints as a means of mitigating electrolysis depends upon a large number of factors, including kind of joint, distribution of joints, nature and extent of piping system, and the frequency of metallic connections with other underground systems. Cement joints have a high electrical resistance when compared with lead joints and when properly used will afford satisfactory protection against stray currents. Leadite joints have a high initial resistance which rapidly diminishes with time. They can not be depended upon to remain permanently insulating and their permanent value as a preventative of electrolysis is at least questionable. The distribution of insulating joints in a pipe line should depend upon the potential gradient in the earth parallel to the line. A sufficient number of joints should be installed to limit the potential drop across the individual joints in cast-iron mains to from 0.1 to 0.4 volt, while in wrought iron or steel pipes a voltage not exceeding about one-third of these values should be allowed. The lower limit applies to pipes in low-resistance soils and to joints having a short leakage path, and the upper limit to pipes in relatively high-resistance soils and to joints having a long leakage path. Insulating joints are particularly effective in excluding current from isolated pipe lines which cross under street-railway tracks or from one system which contacts with another at relatively few points. They are not well adapted to ordinary city distribution systems.

(9) As a means of preventing electrolysis, electrical drainage has had a wider application than any other mitigative measure. In most cases, however, this system, as well as insulating joints, should be restricted to use as an auxiliary means of protection, after reasonable precautions have been taken to reduce potential drops in the

tracks to as low values as are economically practicable. It is best adapted to lead cable sheaths and isolated pipe systems without insulating joints. The drainage of one system of pipes will, of course, lower its potential with respect to neighboring metallic structures, thereby tending to injure the latter. This calls for drainage of the injured system and a competitive system of drainage is thereby established. This competitive condition might, to a large extent, be prevented by a system of unified drainage, whereby all underground structures in the community are drained as a unit and not independently by the several operating companies. In general, our study of pipe drainage has convinced us that while it can, under certain conditions, be used to advantage as a secondary means of lessening the trouble, its installation in connection with most city networks as a principal means of electrolysis mitigation is an unwise procedure. In any case where drainage is used, the drainage should be through the medium of insulated feeders, so adjusted as to take the minimum possible current from the underground structures at all points.

(10) Of the methods applicable to railways the most important of those which have been thoroughly tried out are the adequate maintenance of track bonding, the use of a proper number and location of power houses or substations, and, where the carrying capacity of the rails is not sufficient to return current to stations without excessive drop, the use of insulated negative feeders for the return of such current; these latter being much more economical than uninsulated feeders where large reductions of potential drop are required. A comparison of electrolysis conditions under insulated and unisulated feeder systems, respectively, in a typical substation district in St. Louis, is given in the abstract of Technologic Paper No. 32. The term "insulated negative feeder system" is also defined.

(11) The 3-wire system of distribution has proved effective in relieving electrolysis and should prove satisfactory from the electrolysis standpoint where operating conditions are favorable to its use. It affords a simple and inexpensive means of obtaining relatively low average over-all potential drops on the tracks, but involves certain difficulties and limitations in operation. Several schemes of trolley sectionalization are possible, the one best adapted to urban service being the 3-zone system in which the trolley wire is maintained negative throughout a middle zone and positive on the inner and outer zones of a substation district. The relatively small saving in energy losses in the track in a 3-wire system are more than counterbalanced by the increased station losses due to the necessity of always maintaining two sets of generators. Where the entire capacity of a station is required to start heavy interurban trains or to carry the peak load, the conversion to 3-wire operation will necessitate the installation of additional generating capacity or else 3-wire operation will have to be confined to off-peak periods. This latter expedient, while resorted to in some present installations, is decidedly objectionable as it tends to defeat the very purpose of the system and introduces serious complications into the problem of electrical drainage of the underground structures. The cost of converting a system for 3-wire operation is small if compared with the cost of an insulated negative feeder system or additional substations that would

give the same degree of protection from electrolysis. From the operating standpoint the most serious objection to the 3-wire system is a reduction in station capacity; and from the electrolysis standpoint, wide fluctuations in voltage conditions on the underground structures brought about by the movement of cars from a zone of one polarity to that of the opposite polarity. Thus far, too little experience has been had with this system to justify more than tentative conclusions. (Since the publication of this paper, 3-wire systems of street-railway operation have been installed in Winnipeg and in Atlanta, Ga.)

(12) Such remedial measures as have been adopted in this country have usually been applied to the pipes, and, in general, they have proven much less effective than measures used in certain foreign countries where regulations limiting voltage drops in the negative return have long been in effect and have been accompanied by substantial freedom from electrolysis troubles. Experience both here and abroad indicates that such limitation of voltage drop is necessary to a satisfactory solution of the problem.

(13) In defining the voltage limitations either the all-day average value or the average value for a period not less than one-half hour may be used; the former, however, is preferable, since it affords the best criterion of the actual danger involved and is also more satisfactory from the standpoint of the railway companies. A shorter period than half an hour is too short to give a satisfactory basis for voltage regulations that are to be applied to the railway systems.

(14) In fixing voltage limitations some plan analogous to the zone system should be adopted, the voltage limits prescribed for the various zones being determined largely by the degree of development of the underground utilities in the various zones.

(15) The voltage drops either in the tracks or in the pipes, and earth may be used as the basis for fixing limitation, but, in general, the latter is to be preferred.

(16) Under most conditions over-all voltages in railway tracks should be limited to about 2 to 4 volts, and the potential gradients should, in general, be restricted to about 0.3 to 0.4 volt per thousand feet, these figures being all-day average values, or to corresponding values based on averages for a period of not less than half an hour. The higher over-all voltage limit will generally apply to the longer feeding distance and outlying districts, while the higher potential gradient limit can be permitted where feeding distances are relatively short. Potential drops on pipe systems should be, roughly, half of these figures.

(17) In order that ready determination of voltage drops can be made at any time, potential wires should be installed running from some central point to selected points on the railway or pipe networks. These points should include the points of approximately highest and lowest potential, and preferably also some intermediate points.

(18) Exemption from any regulations regarding track voltages should be made in special cases as set forth in this paper, where local conditions make it improbable that any serious damage would result.

(19) Any regulations governing electrolysis mitigation should be made to apply not alone to the railway system, but should also define

the responsibilities of the owners of underground utilities, since the latter can often contribute materially to the diminution of the trouble at a practically negligible cost.

9. *Special studies in electrolysis mitigation. III. A report on conditions in Springfield, Ohio, with insulated feeder system installed, Burton McCollum and George A. Ahlborn, Technologic Paper No. 54, February 5, 1916 (out of print).*—This paper was mainly of local and temporary interest and contains nothing of general interest not found in Technologic Paper No. 52 and other papers here reviewed.

10. *Special studies in electrolysis mitigation. IV. A preliminary report on electrolysis conditions in Elyria, Ohio, with recommendations for mitigation, Burton McCollum and K. H. Logan, Technologic Paper No. 55, January 22, 1916, (out of print).*—The paper describes electrolysis conditions in Elyria as they existed in 1914 and contains recommendations for mitigation. Three methods of improving conditions are proposed—(*a*) the reduction of feeding distances by the installation of additional substations, (*b*) the interconnection of tracks of different electric-railway systems at points within the city of Elyria, and (*c*) the installation of insulated negative feeders. Detailed calculations and a complete cost study of all of the proposed changes are given. The figures indicate that not only would electrolysis conditions be improved greatly by adopting the proposed changes, but that economies and improvements in operation would also result. While the paper was largely of local interest, it is of value to anyone wishing to carry out similar calculations.

11. *Modern practice in the construction and maintenance of rail joints and bonds in electric railways, E. R. Shepard, Technologic Paper No. 62, 2d ed., February 8, 1920 (out of print).*—The paper describes the various types of rail bonds and joints in use and analyses the replies to a questionnaire sent to 130 electric-railway companies throughout the country, asking for information regarding their experience and practice in the bonding and welding of rail joints. Replies from 42 companies were received, representing 8,600 miles of single track, or 20 per cent of the mileage in the United States. Among the general conclusions arrived at by the author are the following:

(1) Practically all types of standard modern bonds, when selected to meet local conditions and installed according to the best modern practices, will give satisfactory results with an almost negligible percentage of failures on joints which are properly maintained. The problem of rail-bond maintenance is largely that of joint maintenance. No bond can be expected to last continuously on a loose and poorly supported rail joint. No one type of bond can be said to be better than all other types. Each has its advantages and disadvantages and the selection of a bond for any particular service should be governed by the type of construction on which it is to be used, the grade of labor available for installation, and upon numerous other local conditions.

(2) While welded joints are being used more than ever before, there is also a growing tendency to adopt improved mechanical joints and various forms of special joints, several of which are a combination

of welded and bolted or welded and riveted joints. These special joints seem to be meeting the demands of service with fewer failures and better results generally than any of the standard types.

(3) It has been demonstrated that the saving of power alone will not justify the best modern practice in bonding. Such practice, however, is justified and strongly recommended from the standpoint of good voltage conditions in the return circuit, which not only make for good electrolysis conditions but also for more satisfactory operation.

(4) Attention is again called to the fact that the problem of track bonding is still in a state of evolution. New inventions and improvements in methods and practices have been so frequent during recent years that many types of bonds and joints can still be said to be in the experimental stage. Carefully kept records and a free interchange of experiences on the part of the operating companies will do much toward the establishment of definite and standard practice in this particular field.

An appendix describes developments and improvements in rail-joint bonding and welding practices not contained in the first edition of the paper published in 1916.

12. *Leakage of currents from electric railways, Burton McCollum and K. H. Logan, Technologic Paper No. 63, March 14, 1916 (out of print).*—The paper is a technical and mathematical analysis of the laws which determine the amount of leakage of current from electric railway tracks. The following conclusions of the authors are based on the general equations which they derive:

(1) The voltage and current conditions in the return circuit are characterized by three constants, namely, the resistance of the track per unit length, the leakage resistance between track and ground per unit length, and the feeding distance.

(2) The effect of track resistance on leakage currents is exactly the inverse of leakage resistance; hence an increase in leakage resistance in any given ratio reduces leakage currents in the same degree as increasing the conductance of the tracks in the same ratio. This emphasizes the importance from an electrolysis standpoint of so constructing the roadbed as to give the highest practicable leakage resistance.

(3) The leakage current from any given line increases much faster than the length of the line. This shows the importance of reducing feeding distances as much as practicable.

(4) Where the bus is not grounded there will be distinct positive and negative areas and the relative extent of the positive and negative areas is not a constant but varies with the length of the line, the track resistance, and the leakage resistance.

(5) For short track lengths the percentage of the total current which leaks from the tracks increases practically as the square of the feeding distance.

(6) For long feeding distances the rate of change of leakage current with distance is much less than for short feeding distances.

(7) The maximum leakage current increases less rapidly than the track resistance, except where the track resistance is very low.

(8) If the leakage resistance is small, such as that corresponding to an average concrete roadbed or track embedded in damp soil, the

leakage current decreases very rapidly with increase in leakage resistance. For high values of leakage resistance, however, the effect of increasing the leakage resistance on the total leakage current is much less.

(9) If the bus be grounded, as by connecting it to the buried pipe systems, the total leakage current is greatly increased.

(10) With grounded bus the rate of increase in leakage current becomes relatively small as the power house is approached and becomes zero at the negative bus.

(11) Where conditions are relatively good increase in leakage resistance has a greater effect in reducing leakage currents if the bus is grounded than when it is ungrounded.

(12) When the conditions are such as to give rise to only moderate leakage currents, the maximum leakage may be more than doubled by grounding the negative bus. Where leakage conditions are bad the ratio of increase in leakage current due to grounding is less but the increase is still quite marked. This emphasizes the importance of insulating the negative bus.

(13) If the bus be grounded, the maximum leakage increases more rapidly than the feeding distance. For ordinary values of track resistance and leakage resistance this is particularly true for feeding distances up to about 15,000 or 16,000 feet.

(14) For very long feeding distances, such as are frequently encountered on interurban lines, practically all of the current may return by way of the earth.

(15) Potential gradients in the tracks may be materially reduced due to leakage currents, and this reduction is more marked if the bus is grounded. Low potential gradients are not in themselves, therefore, a definite indication of good electrolysis conditions, but on the contrary may be due to excessive leakage of current from the tracks. Other factors must be considered, therefore, in interpreting gradient measurements.

(16) For any given line the relative value of the gradients for grounded and ungrounded bus is the same for all points on the line. For very long lines the ratio varies practically inversely as the length of the line.

(17) The reduction of over-all potentials due to leakage currents is relatively much greater in long lines than in short lines and greater with grounded bus than with ungrounded bus. For very long lines and the moderate leakage and track resistance assumed the over-all potentials are reduced in case of the ungrounded bus to about 20 per cent, and in case of the grounded bus to about 5 per cent of the values they would have if there were no leakage. It is evident, therefore, that low over-all potentials, like low potential gradients, are not a positive indication of good electrolysis conditions. It is necessary to know the cause of the low values before their significance can be determined. Certain measures, such as insulating tracks, that can be taken to reduce leakage currents may greatly increase both gradients and over-all potentials, although they would greatly improve electrolysis conditions.

(18) If there be no leakage the over-all potential drop is proportional to the first power of the track resistance and to the square of the feeding distance.

(19) If there is leakage and the bus is ungrounded, then as either the track resistance or feeding distance increases indefinitely the over-all potential tends to become proportional to square root of the track resistance and the first power of the feeding distance.

(20) As the track resistance or feeding distance increases indefinitely the over-all potential, in the case of the grounded bus, tends to become independent of both the track resistance and feeding distance.

(21) If the bus is ungrounded, the intensity of the leakage current at the outer end of the line is less than at the power house end (current returning to the tracks may be regarded as negative leakage current); and the difference is greater the lower the leakage resistance and the greater the length. Hence, operating with trolley negative would, in general, tend to reduce the rapidity with which trouble would become acute. The corrosion would, however, be distributed over a larger territory and its total amount would be substantially unchanged.

(22) As the track resistance is increased indefinitely the potential difference at the outer end of the line approaches a finite maximum value. A similar result follows from an indefinite increase in the feeding distance.

(23) Although high leakage resistance lowers the leakage current, it also increases the potential difference between tracks and earth. High potential differences are not in themselves, therefore, a definite indication of leakage current.

(24) As the track resistance or feeding distance increases indefinitely, the potential difference between tracks and ground at power house becomes indefinitely large, and the area of the positive zone becomes indefinitely small. Thus, with high track resistance or long feeding distances there will be very severe trouble in a relatively small area.

(25) High track resistances and low leakage resistance both tend to reduce the size of the positive area, although tending to increase the total amount of leakage current, and hence they greatly increase the severity of the electrolysis trouble near the power house. A relatively small positive area, therefore, is an indication of bad electrolysis conditions generally. The length of the positive zone varies from a maximum of 42 per cent of the feeding distance under ideal electrolysis conditions to an indefinitely small value where electrolysis conditions are particularly bad.

(26) With the bus ungrounded the potential difference at the power house is nearly proportional to the length of the line except for short lines.

(27) With the bus grounded the potential difference at the power house is zero and the change in potential difference is most rapid in the region of the power house.

(28) Increase in either the roadbed or the track resistance increases the potential difference at the end of the line.

(29) Leakage resistance is much more influential with respect to potential differences than track resistance.

13. *Influence of frequency of alternating or infrequently reversed current on electrolytic corrosion, Burton McCollum and G. H. Ahlborn, Technologic Paper No. 72, August 15, 1916, (out of print).*—

This paper describes experimental work done to determine the coefficient of corrosion or iron and lead in soil with varying frequencies of alternating or reversed current with 60 cycles per second as the highest frequency and a two-week period as the lowest, some direct-current tests being made as a check on the methods. The results show:

(1) The corrosion of both iron and lead electrodes decreases with increasing frequency of reversal of the current.

(2) The corrosion is practically negligible for both metals when the period of the cycle is not greater than about five minutes.

(3) With iron electrodes a limiting frequency is reached between 15 and 60 cycles per second, beyond which no appreciable corrosion occurs. No such limit was reached in the lead tests, although it may exist at a higher frequency than 60 cycles.

(4) With periodically reversed currents, the addition of sodium carbonate to the soil reduces the loss in the case of iron and increases it in the case of lead.

(5) The coefficient of corrosion of lead, under the soil conditions described in the report, when subjected to the action of direct current, was found to be only about 25 per cent of the theoretical value.

(6) The corrosion of lead reaches practically the maximum value with a frequency of reversal lying between one day and one week.

(7) The corrosion of iron does not reach a maximum value until the period of the cycle is considerably in excess of two weeks.

(8) The most important conclusion to be drawn from these investigations is that in the so-called neutral zone of street-railway networks, where the pipes continually reverse in polarity, the damage is much less than would be expected from a consideration of the arithmetical average of the current discharged from the pipes into the earth. Where pipes are alternately positive and negative with periods not exceeding 10 or 15 minutes, the algebraic sum of the current discharged is more nearly a correct index to the total damage that will result than any other figure that can readily be obtained.

(9) The reduction in corrosion due to periodically reversed currents appears to be due to the fact that the corrosive process is in a large degree reversible; so that the metal corroded during the half cycle when current is being discharged is in large measure redeposited during the succeeding half cycle when the current flows toward the metal. This redeposited metal may not be of much value mechanically, but it serves as an anode surface during the next succeeding half cycle, and thus protects the uncorroded metal beneath.

(10) The extent to which the corrosive process is reversible depends upon the freedom with which the electrolyte circulates, and particularly on the freedom of access of such substances as oxygen or carbon dioxide, which may result in secondary reactions giving rise to insoluble precipitates of the corroded metal. It is largely for this reason that the corrosion becomes greater with a longer period of the cycle, since the longer the period the greater will be the effect of these secondary reactions.

Subsequent to the publication of Technologic Paper No. 72, the results of additional experiments were published by E. R. Shepard, of the Bureau of Standards, in the Journal of the American Electrochemical Society, volume 39, 1921, under the title “ Electrolytic Corrosion of Lead by Continuous and Periodic Currents." Following are the conclusions based on these experiments:

(1) The results of these experiments agree generally with those obtained by McCollum and Ahlborn, with the exception, however, that in earth, under favorable conditions, with continuous current, a coefficient of corrosion of 100 per cent was obtained. The low value reported by McCollum and Ahlborn was undoubtedly the result of using a lower moisture content than that employed in this series, and not tamping the earth around the electrodes.

(2) With continuous current, the coefficient of corrosion in both tap water and earth decreases with an increase in current density, reaching a minimum of about 50 per cent for current densities of 5 milliamperes per square centimeter. The theoretical maximum value of 100 per cent was found for low current densities of the order of 0.5 milliampere per square centimeter and less.

(3) The coefficient of corrosion drops off rapidly as the moisture content of earth is decreased below the saturation point. For 40 per cent moisture content and greater, if the earth is well tamped about the specimens, the full theoretical amount of corrosion occurs.

(4) The coefficient of corrosion of lead in tap water decreases with time, but little or no decrease in the coefficient is observed with specimens in saturated earth.

(5) With periodically reversed currents in which the anodic and cathodic conditions are equal—that is, when the algebraic average value of the ampere-hours is zero—the coefficient of corrosion based on the anodic current decreases rapidly with time, reaching a value of about 14 per cent after 465 hours in saturated earth and about 50 per cent in tap water.

(6) The coefficient of corrosion increases with the percentage of the total ampere-hours contributing to an anodic condition.

14. *Data on electric railway track leakage, G. H. Ahlborn, Technologic Paper No. 75, August 22, 1916, available from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 10 cents)*.—This paper describes a method of measuring the electrical resistance to leakage of current from electric railway tracks and gives experimental values of leakage resistance for three lines on which tests were made.

A suburban line in Washington, having rock ballast with ties and rails embedded, and a surface finish of Tarvia was found to have an average leakage resistance of 1.76 ohms for 1,000 feet of double track.

A single-track interurban line, in well-drained gravelly soil and in which the rails were in only occasional contact with the soil, was found to have an average leakage resistance of 14.57 ohms for 1,000 feet.

A single-track interurban line built on low and poorly drained clay and gravel, lying close to a salt marsh, for the greater part of its length, and having rails in contact with the earth at many points, had an average leakage resistance of 1.81 ohms for 1,000 feet.

15. *Leakage resistance of street railway roadbeds and its relation to electrolysis of underground structures, E. R. Shepard, Technologic Paper No. 127, October 6, 1919 (out of print)*.—The paper describes several methods of measuring the leakage resistance of electric rail-

way roadbeds and gives the results of such measurements under various weather conditions, on a number of short experimental roadbeds built on the grounds of the Bureau of Standards and on several city and interurban lines. Following are the conclusions based on these experiments:

(1) Roadbeds constructed with solid-concrete ballast and vitrified brick or other nonporous pavements have a low leakage resistance to earth, which is affected only moderately by seasonal and weather changes. There is little difference between wood and steel ties in their effects on the resistance of roadbeds of this kind. Insulating layers of bituminous materials are not of practical value in reducing leakage currents from such roadbeds. The resistance of 1,000 feet of single roadbed of this type is from 0.2 to 0.5 ohm under ordinary conditions, but may be double or treble these values when the ballast is frozen to a depth of 1 foot or more. For double roadbed of this type the resistance is approximately 70 per cent of that for single roadbed, or the leakage from double track would be about 40 to 50 per cent greater than from single track.

(2) Roadbeds constructed with a foundation of clean, crushed stone under a concrete paving base have a much higher resistance than roadbeds with a solid-concrete ballast. In the case of the experimental roadbeds the ratio was found to be about 3 to 1.

(3) Roadbeds with a full crushed-stone ballast and a Tarvia finish have a very high leakage resistance, which is of the order of 2 to 5 ohms for 1,000 feet of single track. The leakage from a double roadbed of this type and other high-resistance types is from 80 to 100 per cent greater than from single roadbeds.

(4) The resistance of earth roadbeds in which the ties are embedded, and therefore kept in a moist condition, is much lower than that of open-construction roadbeds, being from 1 to 1.5 ohms for 1,000 feet of single track under normal conditions and considerably more when the ground is frozen.

(5) The resistance of roadbeds of open construction is subject to wide variations, depending on the condition of the ties and ballast. In very dry weather with good ballast the resistance will be 10 to 15 ohms, and even more for 1,000 feet of single track, but when wet will drop to from 3 to 5 ohms. Cinders, gravel, and particularly crushed stone, when used as ballast in open-track construction, produce very high resistance roadbeds. Earth has a tendency to keep the ties moist and therefore increases the leakage.

(6) Open-construction track is often considered as being insulated from the earth, but this is not strictly true, even though the leakage may not be in harmful amounts when compared with other types of construction. Assuming a potential difference between a track and the earth of 5 volts and a leakage resistance of 10 ohms per 1,000 feet of single roadbed, the total leakage per mile of track would be 2.64 amperes. This small leakage current would not ordinarily be harmful to underground structures in the vicinity of the track.

(7) Zinc chloride and other chemical salts used as preservatives render ties highly conducting and greatly increase leakage currents from tracks. Unless combined with some other material, such as creosote, these salts gradually leach out, particularly in damp climates, and eventually their influence on the resistance of roadbeds

disappears. Creosote has very little effect upon the resistance of wood ties, but a treating material consisting of 75 per cent gas oil and 25 per cent creosote appears to increase their resistance materially. No direct comparison, however, was made between these two treatments. Open-track construction on which ties treated in this manner were employed had a leakage resistance about twice as great as similar roadbeds with untreated ties and about four times as great as roadbeds with chemically treated ties.

SUGGESTIONS REGARDING ROADBED CONSTRUCTION

Electric railway companies can do much toward reducing leakage currents from their tracks by observing the following suggestions regarding roadbed construction:

(1) Solid-concrete ballast should be abandoned, and clean crushed stone should be used as a foundation under ties. This type of construction is approved by the American Electric Railway Association, as it gives greater resiliency to the track and is cheaper than the full concrete ballast.

(2) Where crushed stone or gravel is used it should be kept clean by proper coverings or pavements. If earth, sand, or street dirt is permitted to filter into ballast of this character, its function as an insulating material is greatly impaired.

(3) Salt, which is often used to prevent frogs and switches from freezing, will greatly reduce the resistance of roadbeds and should be avoided if possible.

(4) In open construction, rails should be kept out of contact with the earth. The roadbed should be well drained to prevent fine material from washing into the ballast and to keep the ties as dry as possible. Vegetation should be kept down, as this tends to make the roadbed moist and to fill the ballast with foreign material.

(5) Zinc chloride and similar chemical preservatives should be avoided where the escape of stray currents is objectionable or where block signals are used. A treating mixture of creosote and gas oil improves the insulating properties of wood ties.

16. *Practical application of the earth-current meter, Burton McCollum and K. H. Logan, Technologic Paper No. 351, August 18, 1927 (available from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 20 cents).*—This paper describes the theory, calibration, and application of an instrument developed by the Bureau of Standards and used chiefly for quantitative measurement of stray currents at or near pipe surfaces. Although it is not well adapted for general electrolysis surveys because of the time and expense involved in its use, the fact that quantitative and definite data can be obtained with it at specific locations renders it invaluable in the interpretation of other and more general electrolysis measurements.

The paper is not readily abstracted or summarized as it consists largely of detailed descriptions of the theory of the instrument and of methods of using it under different conditions.

17. *Electrolysis testing, Burton McCollum and K. H. Logan, Technologic Paper No. 355, September 28, 1927 (available from the Superintendent of Documents, Government Printing Office, Wash-*

ington, D. C., at 30 cents).—This paper supersedes Technologic Paper No. 28, entitled "Methods of Making Electrolysis Surveys." The need for a revision of this latter paper was brought about by the development of the earth-current meter which measures the intensity of discharge of current from a pipe line at any specific location, a factor more closely related to the rate of corrosion than any other which can readily be determined.

Experience with the new method indicates that the older methods do not directly determine the hazard of buried structures, and that under certain conditions some of the tests lead to erroneous conclusions. In the present paper the various electrolysis tests are discussed in the light of the most recent data concerning them. The older methods of determining general electrolysis conditions are first discussed and then a detailed description of the new apparatus and methods for studying local conditions is given. This is followed by a description of tests for the determination of track conditions and a discussion of the interpretation of electrolysis data.

Washington, December 1, 1932.