Various Methods of Electrolytic Mitigation

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VARIOUS METHODS OF

ELECTROLYTIC MITIGATION

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VARIOUS METHODS OF
ELECTROLYTIC MITIGATION

A THESIS SUBMITTED TO THE ELECTRICAL
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THE DEGREE OF ELECTRICAL ENGINEER

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VARIOUS METHODS OF ELECTROLYTIC MITIGATION.

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INTRODUCTION.

I. Brief Description of Electrolysis.

A. History.

Late in the 18th century Volta discovered that an electric current could be produced by the chemical action of dissimilar metals in an electrolyte. Galvani and Sulzer had noted the phenomena even earlier as evidenced by their familiar frog leg experiment. In the year 1800 Nicholson and Carlisle, with the use of the Voltaic pile, produced and recognized the chemical effect of an electric current. From this beginning noted investigators in whose ranks may be mentioned Davy, Faraday, Clausius, Hittorf, Kohlrausch, and Arrhenius, have advanced the science of electro-chemistry.

In ~~1838~~ *1888 it was found that the ground might be used as an electrical conductor and the City of Richmond, Virginia, first made use of this discovery in a grounded return trolley system. It was not long (1891) until the destruction of lead telephone cable sheathing and thin-walled service pipes by electro-chemical processes, indicated the possibility of danger from stray currents in the earth. In the 20 years since that time, the trolley has come into common use. In practically every instance

*B.C.S.

the rail return has been installed and the metallic structures below the surface valued at over a billion dollars, are exposed to the destructive effects of the stray currents from these returns.

B. Economic Importance.

That the question is important, is evidenced by the replies to several hundred letters recently sent out to building inspectors, railway, water, and gas companies throughout the United States. Out of 200 cities reporting, 100 discussed cases of damage, and their own method of protection, if any. Of the other 100 many had had no investigation and often the railway or pipe systems are too young for effects of corrosion to be forcibly brought to their attention. The damage is estimated in hundreds of thousands of dollars in single cities, and the 100 cities reporting destruction of mains 80 have spent $1,000. to $100,000. on methods of mitigation. The increase of fire hazard, uncertainty of service, and leakage from mains, are as serious questions as the actual depreciation of the system. With the reports of building and bridge deterioration, through the corrosion of the girders and footings and disintegration of concrete, the value of certain structural materials is questioned by builders, and doubt causes construction to be delayed or abandoned. The indefinite extent of the damage, its close relation to natural corrosion, and general ignorance of electrochemical phenomena fosters litigation, and suits for damages drag through the courts with great cost and little benefit to either party when terminated. A better understanding of the conditions attendant upon electrolytic corrosion and methods of mitigating the trouble is imperative.

C. Definition.

Electrolysis may be defined as the chemical decomposition produced by an electrical current. In some fields electrolysis has come to mean the destruction of commercial structures by stray currents. This latter is the only phase considered in this paper. The metal forming the anode of an electrolytic unit through which electrical currents flow, is chemically separated from the mass and oxidized. This results in the pitting of the anode, until the metal can no longer fulfill the purpose for which it was designed. This metal may be a lead telephone cable sheath, a water or gas main, the reinforcing of a building, or the footings of a steel bridge. Other detrimental effects of stray currents have been observed. The bursting of concrete surrounding the anode is of great importance, but more notably the disintegration or chemical change of concrete surrounding the cathode, which phenomenon has been observed by Mr. O. S. Peters of the Bureau of Standards and described in the paper, "Electrolysis in Concrete", in the Montana State College files. The chief source of vagabond currents is found to be the rail return of trolley systems but electrolytic damage has resulted from "grounds" on power and lighting circuits.

II. Purpose of Paper.

Various methods of eliminating or mitigating this evil have been proposed. It is the purpose of this paper to review these methods, to suggest additions and prove with data collected from various cities their practicability. The construction, plan of operation, desirable and objectionable features, and general feasibility will be discussed in connection with each system.

DISCUSSION.

I. Methods of Mitigation.

The methods of mitigating electrolysis may be divided into three main divisions; 1st: Those methods which have as their object the elimination or reduction of the potential gradients producing stray currents in the earth. 2nd: The reduction of current in the endangered system. 3rd: The reduction of the electrolytic damage with no attempt to reduce the potential or current. These may be subdivided into many systems devised by engineers, there being more than a score of methods which have been utilized in minimizing electrolytic corrosion or which promise relief in cases of damage.

A. Elimination or Reduction of Ground Potential Gradients.

The removal of the cause or source of the current most naturally suggests itself to the mind. Recent decisions by the courts establish the principle that the electric railways are responsible for the current from their systems (see the cases of Dayton, Ohio, Minneapolis, Minn., and Peoria[x], Ill.). The attitude of the Germans and English is to place the burden on the railways. The German regulations[+] approach the subject fundamentally from the standpoint of potential reduction and provide for heavy, costly construction of the return circuit.

1. Insulated Return.

(a) Double Trolley.

The extreme in this direction is the insulated return, making no use of the rails as current conductors. The cities of Havana, Cuba, and Cincinnati, Ohio, have solved the electrolytic problem by use of the overhead double trolley; two trolley wires sustained by the same suspension, 24" to 30" apart. The first cost of such a system is estimated at 50% more than the usual single trolley system. The difficulties of operation are greatly increased by the presence of two trolley poles, the short space between wires carrying full railway potential, suspension insulation and intersection of lines at cross-

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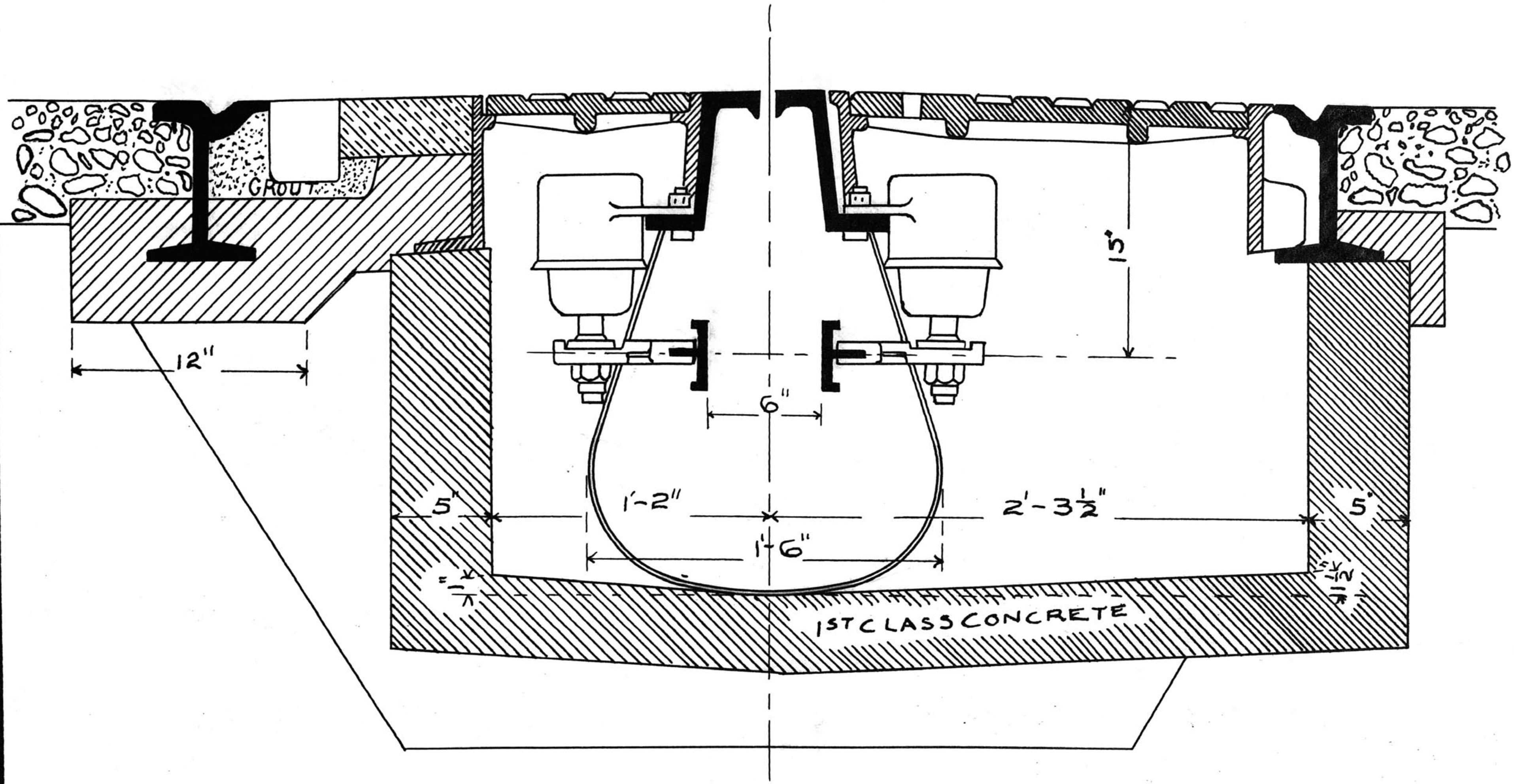
x The most interesting case, Circuit Court N D Illinois E D #24,143. September 30, 1910.

+ See Electrotechnische Zeitschrift; May 25, 1911.

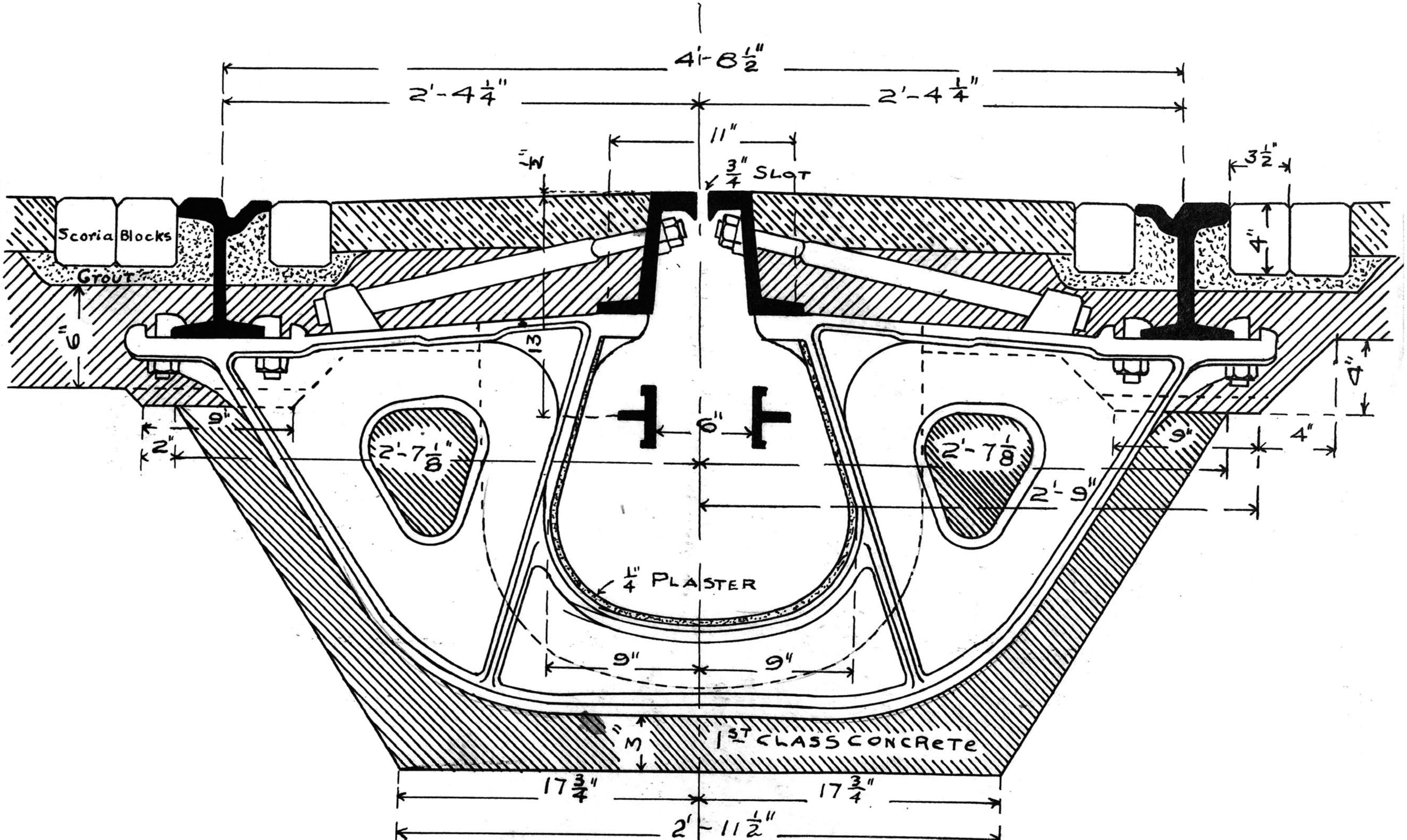
ings. The words of the General Superintendent of the Department of Public Service of Cincinnati "We have the double trolley system and no injury of water pipes from electrolysis or soil", prove the effectiveness of the system from an electrolytic standpoint. Observed ground potentials on the underground double trolley system of Washington prove conclusively that either insulated system will prevent electrolysis.

The track construction of the underground system is shown by Figure 1. The rails, duct walls, conductor bars, and slot edge are supported by cast iron yokes spaced every 10 feet and resting on a concrete bed. The conductor bars are mild steel 20 pounds per yard spaced seven inches apart. The current is carried to the motors through sliding contact shoes attached to a built-up steel plate or "plough". This "plough" extends through the slot from a movable support on the front truck of the car. The problems of insulation and intersections have been solved and the continuity of service under all conditions of weather and traffic are not surpassed by any overhead trolley system. Troubles do arise because of the narrow gap between, and location of conductor bar and method of attaching plough. But the chief reason that this system will not become common is



SECTION AT INSULATOR TRAPS

Fig. 1A



Cross Section At Yoke

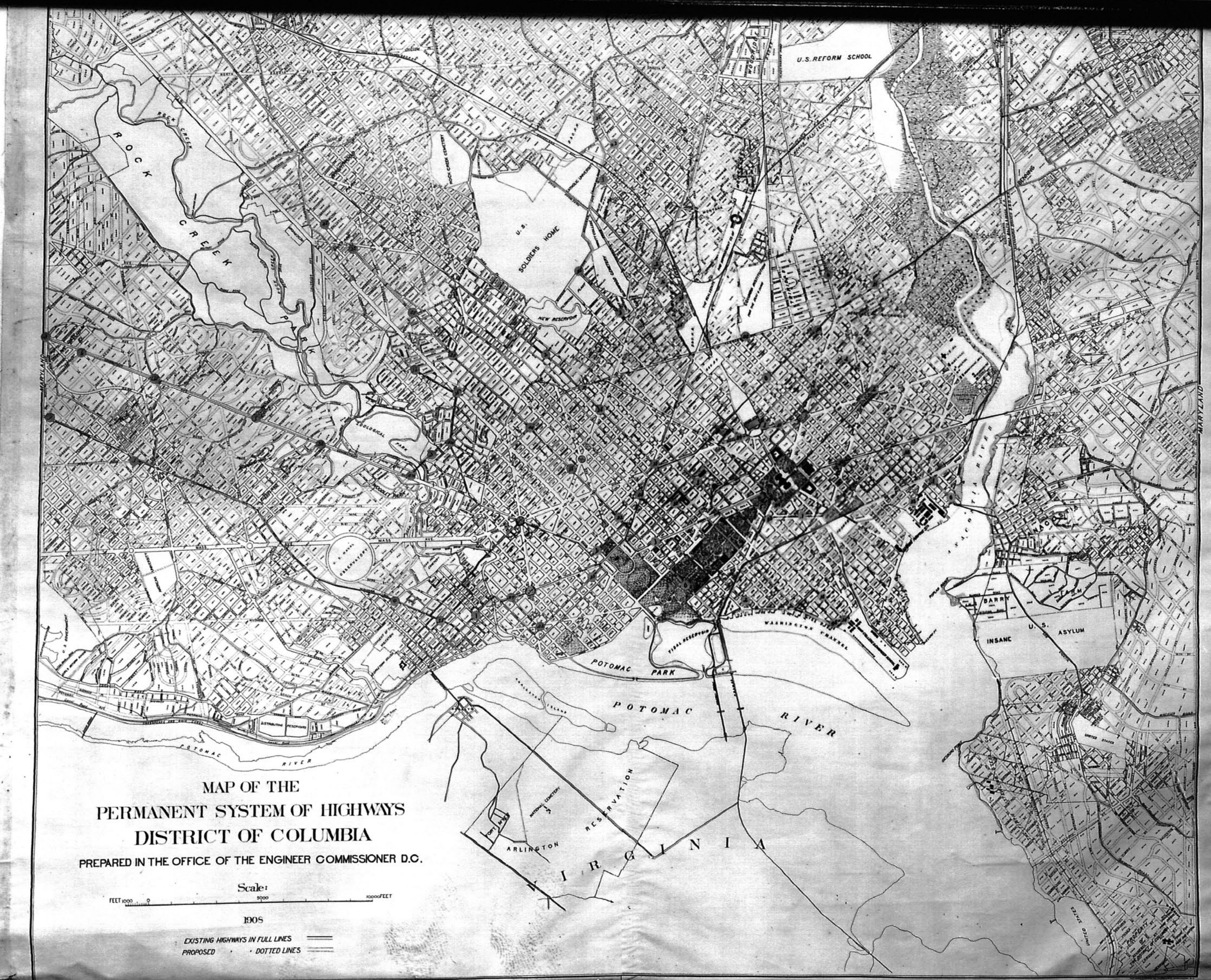
Fig. 1B

the excessive initial cost of line, an overhead burden which most municipal railways could not support. The beauty of Washington streets is greatly enhanced by the absence of poles and suspension work. The freedom from electrolysis is shown by the very low potentials between pipes and ground in the area served by this system and no existing positive area. The values given in Table 1 were taken in connection with a survey of the District of Columbia. The map (#1) of the District shows that some suburban sections have higher potentials than the downtown district, these being served by rail return systems. The circular locations are negative+ and the square positive potential. The maximum potentials found in the down-town district do not exceed two or three tenths volts and there are no extended positive or negative areas. The low potentials, evidence of no serious corrosion in the excavations made for this work and the freedom from damage experienced by the water and gas distributors, make a perfect case for the double trolley.

(b) Insulated Structure.

In the case of elevated roads it has been the prac-

+ "Positive" and "negative" from the standpoint of the pipe systems' polarity to the rails or earth, this being the accepted convention in electrolytic discussion.



MAP OF THE
PERMANENT SYSTEM OF HIGHWAYS
DISTRICT OF COLUMBIA
PREPARED IN THE OFFICE OF THE ENGINEER COMMISSIONER D.C.
Scale:
FEET 1000 0 5000 10000 FEET
1908
EXISTING HIGHWAYS IN FULL LINES
PROPOSED " DOTTED LINES
MARYLAND
U.S. REFORM SCHOOL
ROCK CREEK PARK
U.S. SOLDIERS HOME
ROCK CREEK CEMETERY
NEW RESERVOIR
ZOOLOGICAL PARK
POTOMAC PARK
TIDAL RESERVOIR
WASHINGTON CHANNEL
POTOMAC RIVER
BARRY FARM
U.S. INSANE ASYLUM
ARLINGTON
RESERVATION
NATIONAL CEMETERY
FORT MYER
VIRGINIA
UNITED STATES

TABLE 1.

POTENTIAL OF PIPE TO EARTH

Weston Instrument No. 25144

Washington, D.C.

Date	Location	Volts	Hour	Remarks
May 16, 1911	18th St. & Columbia Road	.075	3:00	
"	16th St. & Columbia Road	.15	3:10	
"	17th St. & Park Road	-.12	3:20	
"	14th St. & Park Road	.25	3:30	
"	14th St. & Quincy	-.05	3:50	
May 17, 1911	14th & U Sts.	.05	8:55	
"	14th & P Sts.	.15	9:15	
"	14th & I Sts.	.02	9:25	
"	New York Ave. & 11th St.	-.05	9:35	
"	Massachusetts Ave. & Union Station	.1	10:05	
"	New York Ave. & 7th St.	-.15	9:45	
"	D & 7th Sts., N. E.	.12	10:25	
"	D & 13th Sts. N. E.	.2	10:45	Substation
"	13th St & East Capital	.2	11:00	
"	17th & H Sts.	.2	11:45	
May 20, 1911	18th & G Sts.	-.05	8:10	
"	13½ & F Sts.	.1	8:25	
"	9th & F Sts.	-.05	8:35	
"	5th & F Sts.	-.1	8:40	
"	Massachusetts Ave. & F St.	.04	8:50	
"	Massachusetts Ave. & 2nd St. N.E.	.01	9:00	

TABLE 1 (cont)

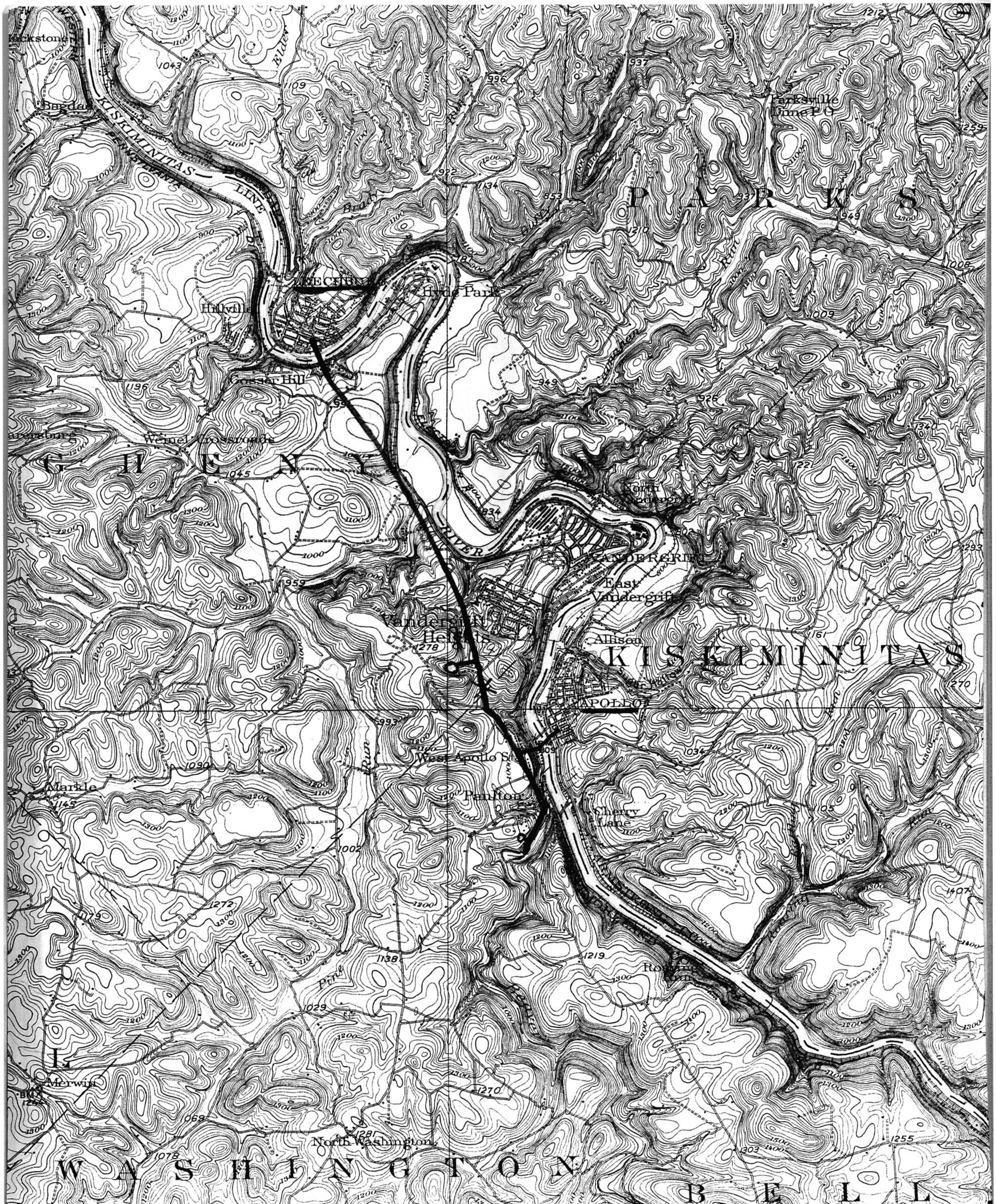
POTENTIAL OF PIPE TO EARTH

Date	Location	Volts	Hour	Remarks
May 20, 1911	5th & H Sts. N. E.	0	9:10	
"	13th & H Sts. N. E.	.04	9:20	
"	19th & Bennings Road N. E.	.01	9:30	1200 V. Double trolley
"	4 squares E. on Bennings Rd.	-.0	9:45	
"	M St. & Florida Ave.	.03	10:00	
"	12th & Randolph Sts.	.05	11:35	1200 V. system
"	Georgia Ave. & Howard St.	-.2	12:10	
"	7th & R Sts. N. W.	-.05	12:20	
"	7th & K Sts. N. W.	-.05	12;30	
"	14th & A Sts. S. W.	0	1:55	
"	11th & F Sts. S. W.	.2	2:10	
"	Water & O Sts. S. W.	.45	2:20	High - steady - probably galvanic
"	4½ & P Sts. S. W.	-.15	2:25	
"	4½ & M Sts. S. E.	-.15	2:30	
"	7th & M Sts. S. E.	-.02	2:40	
"	11th & M Sts. S. E.	.1	2:50	
"	11th & O Sts. S. E.	- 0	3:00	
"	11th & G Sts. S. E.	.02	3:05	
"	4th & Pennsylvania Ave. S. E.	.04	3:15	
"	Delaware Ave. & Canal S.E.	-.1	3;25	
"	3rd & Canal Sts. S. E.	-.03	3:30	
"	S. W. of Capitol	.04	3:35	
"	25th & G Sts. N.W.	.02	3:55	
"	25th & Penn. Ave. N. W.	-.07	4:10	

tice to insulate the third rail but leave the running, negative return rails in contact with the structure. The destruction of footings of the frame work as well as outside property has been prevented by the insulation of these structures or the rails. This is feasible at a small expense, it being possible to make all leakage paths of very high resistance by the use of wooden ties and more careful location of steel supporting stringers and spikes which might come in contact with them.

2. Motor Cars.

The car driven with an internal combustion engine and a generator-motor connection with the driving wheels is entering the field with the interurban trolley and local steam-road service and will be a great factor in such traffic in a few years. The long distances and usual poor track construction produce high potential gradients in the earth. The situation at Apollo and Leechburg, Pa., (See Map 2) is especially suited to an installation of motor cars. Gas and water mains connect the two municipalities which are four miles apart. A single-track trolley line with many curves and grades, seven miles long, furnished hourly service. The power

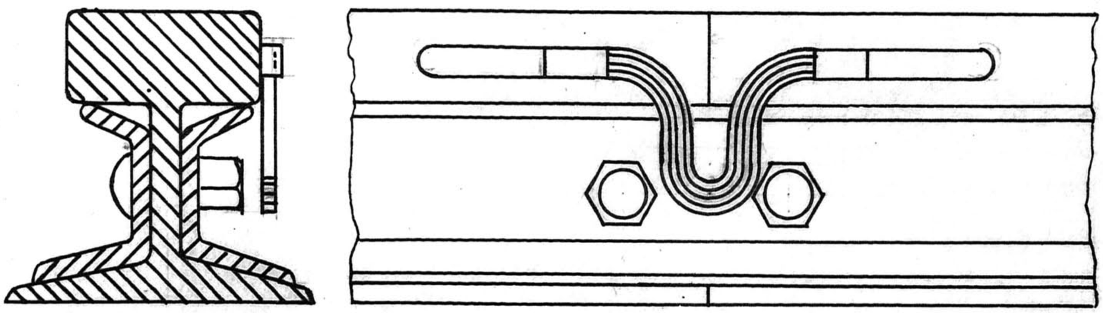

KISKIMINITAS
LINE
Hillville
Gosser Hill
Weinel Crossroads
Hyde Park
P A R K S
North Vandergrift
VANDERGRIFT
East Vandergrift
Vandergrift Heights
Allison
K I S K I M I N I T A S
APOLLO
West Apollo Sta.
Markle
Cherry Lane
North Washington
Merwin
W A S H I N G T O N
B E L L
RIVER

house is located in Leechburg and much trouble is experienced in the destruction of service pipes there. Telephone cable sheathes in Apollo have been destroyed in a short time by discharging current collected from the rails into the gas and water mains. Potential readings between pipes and rails were obtained reaching a value of 17 volts in the negative area (Apollo) and +8 volts in Leechburg. Current readings on the water line were reduced decidedly by one 18-foot wood-stave section across which a maximum potential difference of 5.0 volts existed. The current at one point was about 6 amperes, notwithstanding the fact that the above mentioned 18-foot wood stave section broke the line into two insulated sections.

Two motor cars would replace the power house, overhead feeders, rolling stock and track bonding, reduce the cost of operation and maintenance, improve the service, and eliminate electrolysis. Such a remedy is feasible in only a few instances but is most desirable here.

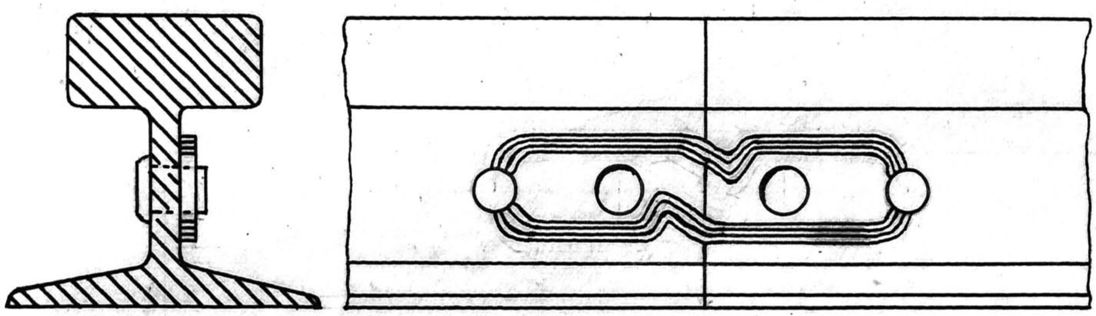
3. Track Return.

Much may be done in the reduction of ground potentials by reducing the resistance of the rail return. On parallel track lines one or two blocks apart, the current distribution will be unequal unless intersecting or connecting tracks serve as equalizing points. Joint-bonding has much to do with the high potential differences. Many types of bonds are in use, a number of which may well be described. (See Fig. 2). A plastic bond made by drilling the fish-plate and base of rail and filling with a soft amalgam has received some attention, but no thorough test. The support under the joint must be firm and the fish-plate secured in place. This is important with all types of bonds. The welding of the rail abutting ends by the thermite process has been used effectively. The bond having $\frac{3}{4}$" terminals forced into reamed taper holes in the web of the rail and upset on the opposite side may be placed under the fish-plate or outside. The short type is made up of strap copper which often breaks due to the vibration of a short length clamped between rails and fish-plate. The longer bonds have a strand cable length and the same copper terminals. The electrical conductivity of this bond is high but decreases with age. The braized bond is a short leaf bond attached to the head of the rail by a variety of braizing and soldering processes. Bonds applied with a high temperature and using heavy pressure and brass as



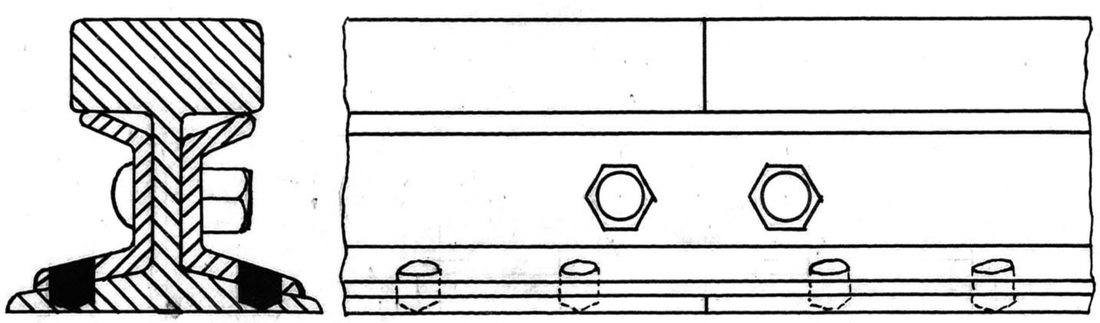
Brazed Bond

Fig. 2_c



Short Pressed Bond

Fig. 2_b



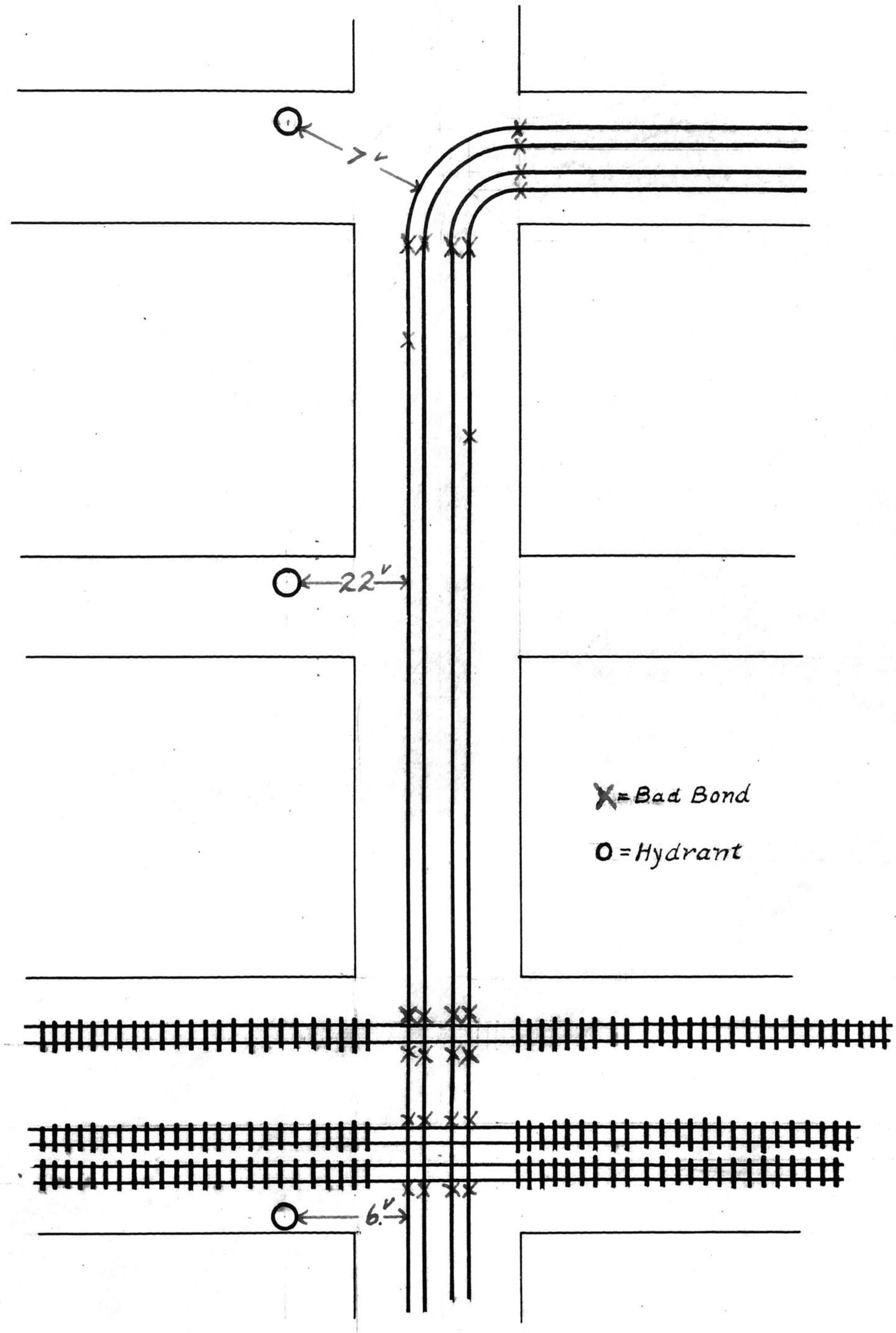
Plastic Bond

Fig. 2_a

in bra\zing compound are mechanically strong and very good electrically. Intersections with other rails, especially on steam roads, and switches are especially subject to vibration and bonding around them is very necessary. The German ordinances provide that such bonds and jumpers shall have a cross-section of 80 square millimeters or about 160,000 circular mils of copper. A heavy wire zigzagging from one rail to the other produces a more uniform distribution of current and bridges accidental bad bonds.

The necessity of such track improvement is shown by some observations from Erie, Pa. In making a survey of Erie potentials between pipes and rails were recorded. On Peach Street (see Figure 3) the double-track trolley

See Succeeding Page.



Effect of Bad Track Bonding
Fig 3

line crosses 4 steam tracks and two blocks north the trolley turns a corner and is broken by switches. The potential between these rails and the water main in this section reached a maximum of 22 volts while the maximum potential reached on either side was 6 to 7 volts. At the terminal of another line, a maximum potential of 100 volts was observed between water main and track. A number of bad joints 200 to 300 feet away produced this condition, favorable to high current leakage. Many high resistance joints in Erie were due to a faulty bed under the joints which allowed free vibration and destruction of the bonds. The influence of road-bed may be exerted in a number of ways.

4. High Resistance Road-bed.

The leakage from the track is dependent upon another factor, the resistance between the rails and the ground. The influence of a high-resistance road-bed is shown by data collected on the Chevy Chase car line (see Map 3). This is one of the few ground return lines of Washington, D. C. A constant load of 300 amperes was carried on this line during a night test with a connection between the trolley and rails at the extreme end. To obtain Table 2, the potential drop on a 10' section

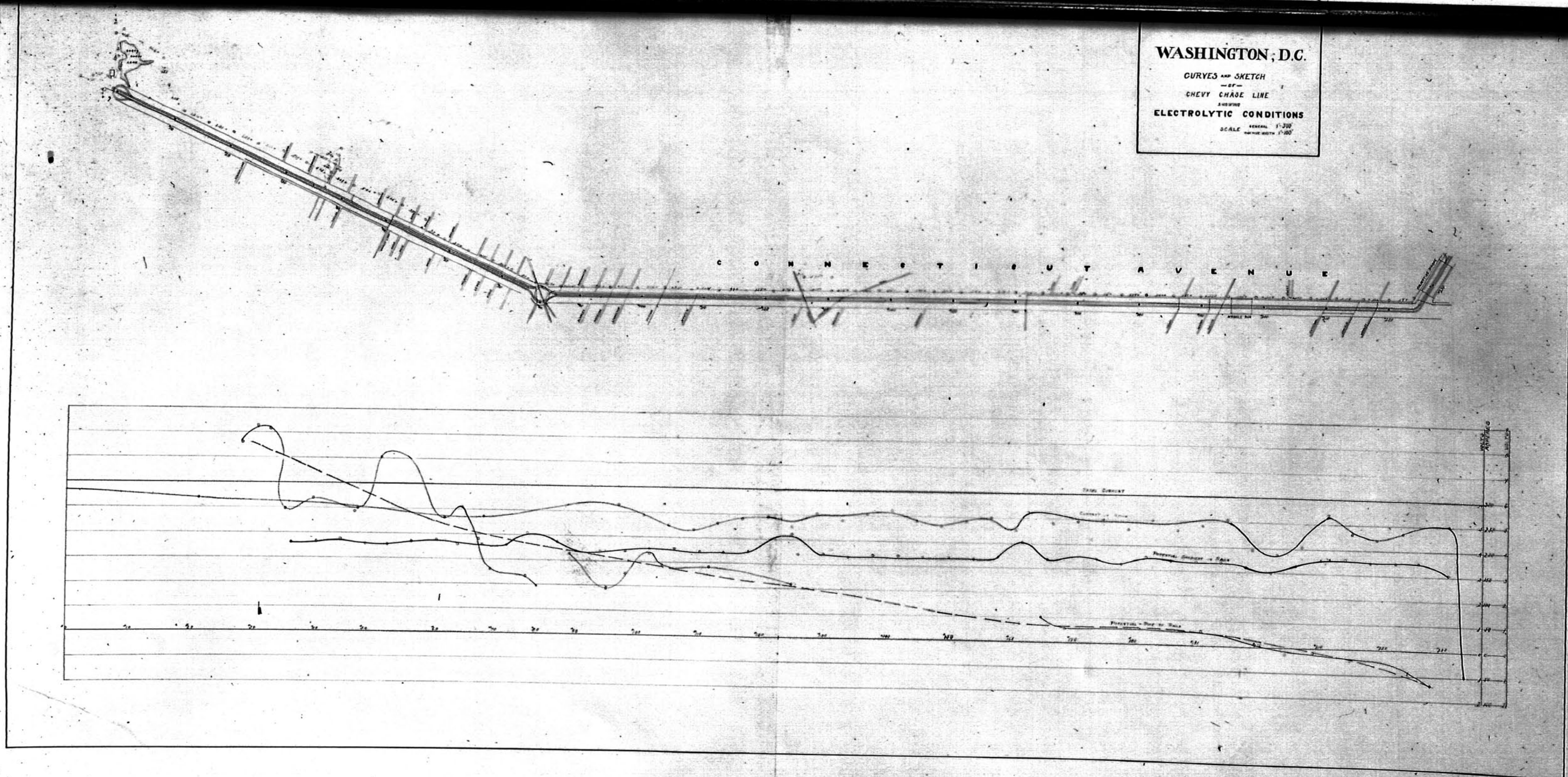

WASHINGTON; D.C.
CURVES AND SKETCH OF CHEVY CHASE LINE SHOWING ELECTROLYTIC CONDITIONS
SCALE GENERAL 1"-300'
CONNECTICUT AVENUE
TOTAL CURRENT
CURRENT IN RAILS
POTENTIAL GRADIENT IN RAILS
POTENTIAL - PIPE TO RAILS

TABLE 2.

CURRENT IN RAILS.

Constant Load - Night Test

April 30, 1911.

Chevy Chase Line,

Washington, D. C.

Hour	Pole No.	Potential on Rails No. 1	No. 2	No. 3	No. 4	Millivolts Total	Corrected x 1.11	Amperes
A.M. 2:40	234 E. of bond	0	.8	2.3	2.4	5.5	6.1	50.5
2:50	231 W. of bond	4.0	9.2	7.4	6.5	27.1	30.1	249.
3:00	223	6.6	6.8	6.2	5.8	25.4	28.2	233.
3:04	219	6.0	6.4	5.5	6.3	24.2	26.8	222.
3:08	215	8.0	5.0	7.0	5.0	25.	27.8	230.
3:14	211	8.0	8.0	7.0	6.0	29.	32.2	266.
3:16	207	6.0	5.0	5.0	6.0	22.	24.4	202.
3:20	203	6.0	5.0	4.0	5.0	20.	22.2	184.
3:24	199	6.0	6.0	4.	5.0	21.	23.3	193.
3:28	195	7.0	7.0	7.5	6.0	27.5	30.5	252.
3:32	191	7.0	6.0	6.0	7.0	26.0	28.9	239.
3:35	187	6.5	5.5	7.0	6.0	25.0	27.8	230.
3:39	183	6.0	8.0	6.5	6.0	26.5	29.4	243.
3:43	179	6.0	6.0	6.0	7.0	25.0	27.8	230.
3:45	175	7.0	6.5	7.0	6.5	27.0	30.0	248.
3:48	171	7.0	6.5	6.0	7.0	26.5	29.4	243.
3:51	167	7.0	5.0	7.5	6.5	26.0	28.9	239.

TABLE 2 (Cont)

CURRENT IN RAILS

Hour	Pole No.	Potential in Rails No. 1	No. 2	No. 3	No. 4	Millivolts Total	Corrected	Amperes
3:55	163	8.5	5.5	7.0	7.5	28.5	31.6	261.
4:04	161	6.0	6.5	7.0	5.0	24.5	27.2	225.
4:13	157	6.5	6.0	7.0	7.5	27.0	30.0	248.
4:15	153	7.5	6.0	6.0	6.5	26.0	28.9	239.
4:18	149	6.5	6.0	6.5	6.0	25.0	27.8	230.
4:20	145	6.5	7.0	6.5	6.0	26.0	28.9	239.
4:22	141	7.5	7.0	7.5	6.5	28.5	31.6	261.
4:25	137	7.0	6.0	7.5	7.0	27.5	30.5	252.
4:27	133	6.0	6.5	6.5	7.0	26.0	28.9	239.
4:31	129	6.5	7.0	7.0	7.0	27.5	30.5	252.
4:34	125	5.5	7.0	6.0	6.0	24.5	27.2	225.
4:38	121	7.0	6.5	6.0	7.0	26.5	29.4	243.
4:41	117	7.0	6.0	7.0	6.0	26.0	28.9	239.
4:43	113	6.0	7.0	7.0	5.0	25.0	27.8	230.
4:46	109	6.0	5.5	5.0	7.0	23.5	26.1	216.
4:48	105	5.8	5.5	6.5	6.5	24.3	27.0	223.
4:50	101	6.0	6.0	7.0	7.5	26.5	29.4	243.
4:53	97	7.5	6.5	7.5	7.0	28.5	31.6	262.
5:02	68	7.0	5.5	6.0	7.0	25.5	28.3	234.
5:12	48	7.0	6.0	7.5	6.5	27.0	30.0	248.
5:27	21	8.0	7.0	7.5	7.0	29.	32.2	266.
							Average	240.

of each rail was measured, and with the constants of these rails the current flowing in the rails calculated. The first reading of Table 2 shows 50.5 amperes flowing in the rails on the opposite side of the connection from the power house. This current is discharged by the rails of the city system and must find its way to the power house back through the ground. The first set of observations on the other side of the connection totals 249 amperes. The horizontal green line of Map #3 is the 300-ampere power house load, and the green curve just below the current in the rails. The drop in the total length of track was 21 volts as measured with the use of the Bell Telephone lines. At certain points the current drops to less than 200 amperes, but the average is 240 amperes, 96 per cent of the current first traveling toward the power house. This large value is due to high résistance road-bed of rock ballast, high resistance soil, and the fact that the rails are elevated above the surface on ties for a part of the distance (Bradley Lane to Lake). The low current values are explained in some instances by a low wet section as at Klingle Run Bridge or by high resistance joints as at Pierce Mill Road, Chappel Road, and Chevy Chase Circle. The Curve

"Potential Gradient in Rails" has ordinates proportional to the product of the current and resistance of rails and joints, the values being taken from Table 3. The low current in the rails over Klingle Run has made both curves turn downward at this point. (Note readings in Tables 2 and 3 at Poles #195 to #196). The "Potential Gradient in Rails" increases at the three other points mentioned, although the current decreases. High resistance joints were located in these spans. The water mains paralleling this line are broken into three sections. The POtential "Pipe to Rail" is shown by Table 4, and on the Chevy Chase Line map by the irregular curve with a maximum of 15 volts pipes positive to rails. This is a higher value than is found in many cities where serious damage has occurred. Table 5 contains data showing current flow in these mains. The average current is 2.2 amperes. The maximum is only 3.6 amperes on the 12 inch cast main on Calvert Street bridge. This is not a serious value when discharged by a large area of pipe surface as is probable here with no high potentials across joints and a low gradient between pipe and other conductors. The use of a well-drained foundation of concrete or crushed rock will not only reduce the current in the earth by lowering the joint re-

TABLE 3

POTENTIAL GRADIENT IN RAILS

500' Spans

Constant Load - Night Test

Weston Instrument No.25144

April 30, 1911.

Chevy Chase Line,

Washington, D. C.

Hour A. M.	Potential Spaces	Potential Volts	Station	Pole No.
			0	233
3:04	15.5	.31	1	229
3:07	17.5	.35	2	223½
3:15	17.5	.35	3	220½
3:20	17.5	.35	4	216½
3:24	18.	.36	5	212½
3:27	17.7	.35	6	208
3:30	16.5	.33	7	204
3:33	15.0	.30	8	200
3:36	16.0	.32	9	196
3:38	16.7	.33	10	192
3:41	16.8	.34	11	188
3:43	16.9	.34	12	184
3:46	17.5	.35	13	180
	16.0	.32	14	176
	17.0	.34	15	172
3:55	17.4	.358	16	168
	16.8	.336	17	164
	20.2	.404	18	160

TABLE 3 (Cont)

POTENTIAL GRADIENT IN RAILS.

Hour A.M.	Potential Spaces	Volts	Station	Pole No.
4:10	17.0	.34	19	156½
	16.5	.33	20	152½
	16.7	.33	21	148½
4:19	16.7	.33	22	144½
	17.0	.34	23	140½
	17.0	.34	24	136½
3:28	16.5	.33	25	132½
	17.1	.34	26	128½
	17.0	.34	27	124
	16.9	.34	28	120
	17.5	.35	29	116
4:42	17.2	.34	30	112
	17.2	.34	31	108
	17.8	.36	32	104
	17.8	.36	33	100
	17.1	.34	34	96
4:54	17.0	.34	35	92
	17.0	.34	36	88
5:00	18.8	.36	37	84
	20.5	.41	38	74

TABLE 3 (Cont)

POTENTIAL GRADIENT IN RAILS.

Hour A.M.	Potential Spaces	Volts	Station	Pole No.
			38	74
5:00	18.0	.36	39	70
5:12	18.0	.36	40	66
	18.0	.36	41	62
	18.8	.38	42	58
	18.5	.37	43	54
	17.9	.36	44	50
	17.9	.36	45	46
5:25	18.8	.38	46	42
	18.1	.36	47	38
	18.2	.36	48	34

TABLE 4.

POTENTIAL

PIPE TO RAILS.

Chevy Chase Line,

Washington, D. C.

Date	Hour	Type of Connection	Pole No.	Potential - Volts Ave.	Max.	Min.	Location
April 19, 1911	11:24	Hydrant	28	7.60	12.3	3.4	Woodbine St.
"	11:10	"	30½	8.27	14.6	2.1	Virgilia St.
"	10:51	"	32½	8.14	14.8	1.4	Underwood St.
"	10:35	"	35	4.94	10.3	1.3	Percy St.
"	10:19	"	39½	5.34	9.8	2.1	South of Chevy Chase College
"	10:02	"	47½	4.87	8.8	1.3	Meadow Lane
April 17, 1911	12:07	"	51	7.00	12.5	4.0	Bradley Lane
"	11:04	"	59	6.21	9.6	3.3	Oxford St.
"	10:41	"	61½	4.63	8.0	2.4	Newlands St.
"	10:18	Manhole	64½	5.07	8.5	3.0	Melrose St.
April 18, 1911	11:55	Hydrant	67	3.82	7.9	.9	Lenox St.
"	11:32	"	69½	2.59	4.6	1.0	Kirke St.
"	10:26	Excavation	75	2.30	4.7	0	N. of Circle
"	3:18	Hydrant	80	1.93	4.15	.25	Grafton St.
April 21, 1911	10:00	"	89½	3.26	7.0	1.1	Northampton St.
"	10:29	"	95	1.87	4.5	.5	Morrison St.
"	11:04	"	98	2.48	5.5	-.2	Livingston

TABLE 4 (cont)

POTENTIAL

PIPE TO RAILS

Date	Hour	Type of Connection	Pole No.	Potential - Volts Ave.	Max.	Min.	Location
April 21, 1911	11:40	Hydrant	102	3.32	5.1	1.5	
"	2:50	"	104½	2.85	5.0	-1.0	Keokuk St.
"	3:15	"	111½	2.81	5.1	.4	
April 24, 1911	10:25	Trough	125	2.17	4.2	- .2	Chappel Road
"	12:07	Hydrant	165½	.976	2.0	- .1	Upton Street
"	1:25	"	169	.506	1.8	-1.0	Tilden Street
"	2:02	"	191	.555	1.7	- .6	
"	2:28	"	204½	-.268	.12	-1.7	Zoo Park Entrance
"	2:56	"	209	-.172	.1	- .6	Cathedral Ave.
"	3:15	"	215	-.461	.12	-1.2	Garfield St.
"	3:31	"	218	-.344	-.04	- .84	Woodley Road
"	3:55	"	228½	-1.36	-.15	-2.8	Woodley Place - Wend
April 26, 1911	9:50	"		-3.25	-6.1		Wisconsin Ave. & Pierce Mill Road

TABLE 5

CURRENT IN WATER PIPES

Weston Instrument No. 7438.

Chevy Chase Line,
Washington, D. C.

	Date 1911	Hour	Pole No.	Pipe Diameter	Polarity	Span Meters	Location	M.V. Potential Max.	M.V. Potential Ave.	Calcul. I Ave.	Corrosion
1	April 17	2:25	74	12"	S	2.77	N. of Chevy Chas Col.	.3	.2	1.3	
2	"	2:45	64½	12"	S	3.52	Melrose St.	.15	.1	2.1	
3	"	2:45	64½	12"	S	1.486	Melrose St.	.45	.3	3.6	
4	"	3:30	51	12"	S	3.39	Bradley Lane	.7	.4	2.1	
5	"	4:30	51	12" & 16"	S	2 Joints	Bradley Lane	.9	.5	?	Very slight
6	"	4:30	51	12"	S	.9	Bradley Lane	.1	.1	2.0	(Heavy oxide (No pitting.
7	April 18	10:00	98	6"	S	2.43	Livingston	0	0	0	Almost none
8	April 24	11:00	126½	12"	S	1.47	Chappel Road	.3	.3	3.6	None
9	April 25	10:00	162	12"	S	1.75	Pierce Mill Road		.05	.9	Heavy oxide No pitting
10	"	12:05	195	12"	S	3.36½	Klingle Run	.6	.8	1.6	None exposed
11	"	2:15	228¼	12"	N	1.96	W. end Calvert	.6	.4	3.6	None exposed
12	"	2:30	234	12"	N	2.47	E. end Calvert	.7	.4	2.9	None exposed

sistance, but by increasing the contact resistance of the rails to the ground. This is a very important consideration and should be observed in all road construction. The suburban trolley with the rails and ties above the surface will release a very small per cent of current to the earth. The roadway should be well-crowned and the track at the highest point. The common practice of using salt at switches is to be deplored since it increases ground conductivity and contact conductivity.

5. Distribution of Feeding Points.

With the 500-600-volt trolley systems commonly used, heavy loads return to the power houses over long stretches of rail conductor in more or less imperfect state of bonding resulting in some large differences of potential in the system. Some idea of the present value of these potentials in American cities may be gained from the data in Table 6. These potentials were obtained by the use of telephone lines as voltmeter leads, contact being made on the rails at the power house and at points from one to several miles away as given in the column "Distance". The maximum potential observed was in Erie, 53 volts being recorded between the power house and a point $2\frac{1}{2}$ miles away. The average potential per mile in

TABLE 6

TOTAL POTENTIAL DIFFERENCES.

Weston Instrument No. 5258.

Date 1911	City	Distance	Potential - Volts Max.	Ave.	Min.
June 17	Altoona, Pa.	1 mile		12.4	
"	" "	2 miles		21.4	
"	" "	$2\frac{1}{2}$ miles		15.4	
Aug. 7	Pittsburgh, Pa.	1 mile	19.	17.0	13.
"	" "	1 "	16.	14.0	12.
"	" "	1 "	27.	22.4	19.
"	" "	1 "	21.	18.3	16.
"	" "	2 miles	24.	20.3	16.
"	" "	2 "	21.	17.4	13.
"	" "	2 "	23.	17.0	11.
"	" "	2 "	27.	24.8	22.
"	" "	3 "	25.	21.2	18.
"	" "	3 "	20.	16.1	14.
"	" "	3 "	19.	11.4	9.
"	" "	3 "	22.	19.5	16.
"	" "	4 "	34.	28.9	22.
"	" "	4 "	32.	28.1	24.
Aug. 22	Erie, Pa.	$\frac{1}{2}$ mile	8.	6.4	5.
"		$\frac{1}{2}$ "	9.	6.6	4.

TABLE 6 (Cont)

TOTAL POTENTIAL DIFFERENCES.

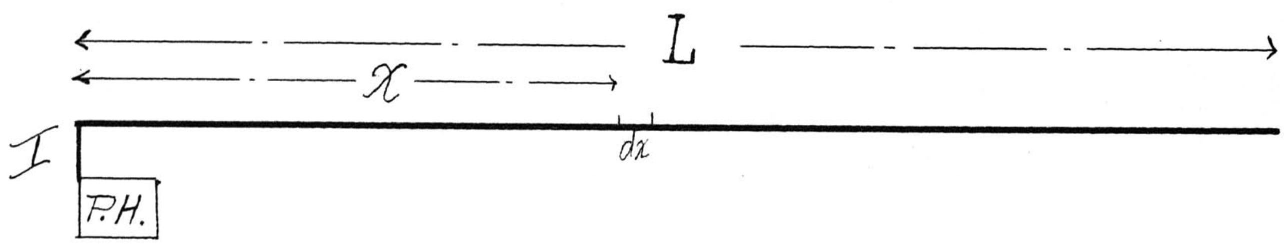
Date 1911	City	Distance	Potential - Volts Max.	Ave.	Min.
Aug. 23	Erie, Pa.	½ mile	10.	6.0	4.
"	" "	½ mile	13.	8.1	6.
"	" "	½ mile	7.	5.0	1.
Aug. 22	" "	½ "	9.	6.2	4.
"	" "	1 "	15.	11.1	6.
"	" "	1 "	19.	11.8	7.
"	" "	1 "	18.	11.8	2.
"	" "	1 "	13.	8.4	6.
"	" "	1 "	16.	10.9	6.
"	" "	1 "	16.	11.2	8.
"	" "	1 "	11.	5.9	3.
"	" "	1½ miles	28.	13.3	8.
"	" "	1½ "	16.	11.8	7.
"	" "	1½ "	-14.	-10.7	-8.
Aug. 23	" "	1½ "	24.	15.5	9.
"	" "	1½ "	25.	15.7	8.
"	" "	1½ "	12.	8.3	5.
"	" "	1½ "	32.	20.4	8.
"	" "	1½ "	23.	16.9	13.
"	" "	1½ "	22.	13.3	8.
"	" "	2 "	43.	23.9	11.

TABLE 6.(Cont)

TOTAL POTENTIAL DIFFERENCES

Date 1911	City	Distance	Potential - Volts Max.	Ave.	Min.
Aug. 23	Erie, Pa.	2 miles	38.	17.	9.
"	" "	2 "	22.	14.9	8.
Aug. 22	" "	2 "	28.	17.4	10.
Aug. 23	" "	2 "	23.	15.7	8.
"	" "	2 "	26.	16.8	7.
"	" "	2½ "	30.	15.6	10.
Sept. 29	Ashtabula, O.	½ mile	8.	5.2	0.7
"	" "	2 miles	13.	8.4	3.
"	" "	3 "	24.	11.	4.
Oct. 18	Sharon, Pa.	½ mile	5.8	3.4	.5
"	" "	½ "	7.5	4.6	1.7
"	" "	1 "	14.4	7.9	3.
"	" "	1 "	13.0	9.2	1.8
"	" "	1½ miles	22.0	13.4	6.
Apr. 20	Washington, D.C.	5 "		21.	

Erie was 9.5 volts. In Pittsburgh the maximum observed was 34 volts at a distance of four miles and the average potential per mile, 10.5 volts. In Ashtabula an average of 6.2 volts per mile existed. If the average potential column is compared with the value permitted by German regulations ($2\frac{1}{2}$ volts between extreme points) and the maximum column with the common English provision of 7.5 volts, we realize the probable danger of American millions invested in and dependent on the integrity of water and gas mains and cable-sheathes. The German regulations were formulated by some of their best engineers including such men as Michalke, Otto and Besig after years of careful study of the problem. American and German financial and construction methods and conditions differ widely, but a study of the means employed to attain the small differences of potential specified is most instructive. Perfection of rail return by the use of joint and cross bonds, insulated conductors, and high resistance roadbed has a decided effect but is not sufficient. In addition a division of length and load by means of feeding points to the rails must be effected. This may be done by separate power houses, substations, radial feeders or the three-wire system. These will be discussed in the order mentioned. A mathematical discussion of the effect of additional feeding points will make the possibilities quite evident.



Let us consider the ideal condition of a straight length of track (L) miles long with the power house connected to the rails at one end. (R) is the resistance of the track per unit length, (I) the total P.H. load which is uniformly distributed along the rails. The current flowing in the rails at any point (x) distance from the P. H. is

$$i = \frac{I}{L}(L - x)$$

$$i = I\left(1 - \frac{x}{L}\right)$$

The drop in any length (dx) is

$$dv = i\ R\ dx$$

Integrating the drop in the length (x) is obtained

$$v = \quad i\ R\ dx = RI\left(x - \frac{x^2}{2L}\right) \qquad (I)$$

which is the equation of the curve representing the potential along the length (L). See Figure 4 Curve I_4. The terminal voltage-potential above power house at end of line or when $x = L$

$$V = R\,I\left(x - \frac{x^2}{2L}\right)$$

$$= R\,I\left(L - \frac{L}{2}\right)$$

$$= \frac{R\,I\,L}{2}$$

If the feeding point were transferred to the center of the length (L) by means of an insulated feeder the same equation would apply but with a halved load and length and the value (R_1I) the potential drop in the feeder added to each value. See Curve II_4. If the power house were at the point $\frac{L}{2}$ or the "booster" method applied to the radial feeder at the same point, the potential represented by Curve III_4 would result. Two power houses or feeders with boosters at $\frac{L}{4}$ and $\frac{3L}{4}$ would produce the potential Curve IV_4.

If the power house is connected at the end and a radial feeder of resistance R_1 is connected at $\frac{L}{2}$ we have the connection commonly used, and the equations of the potential curve can be developed in the following manner.

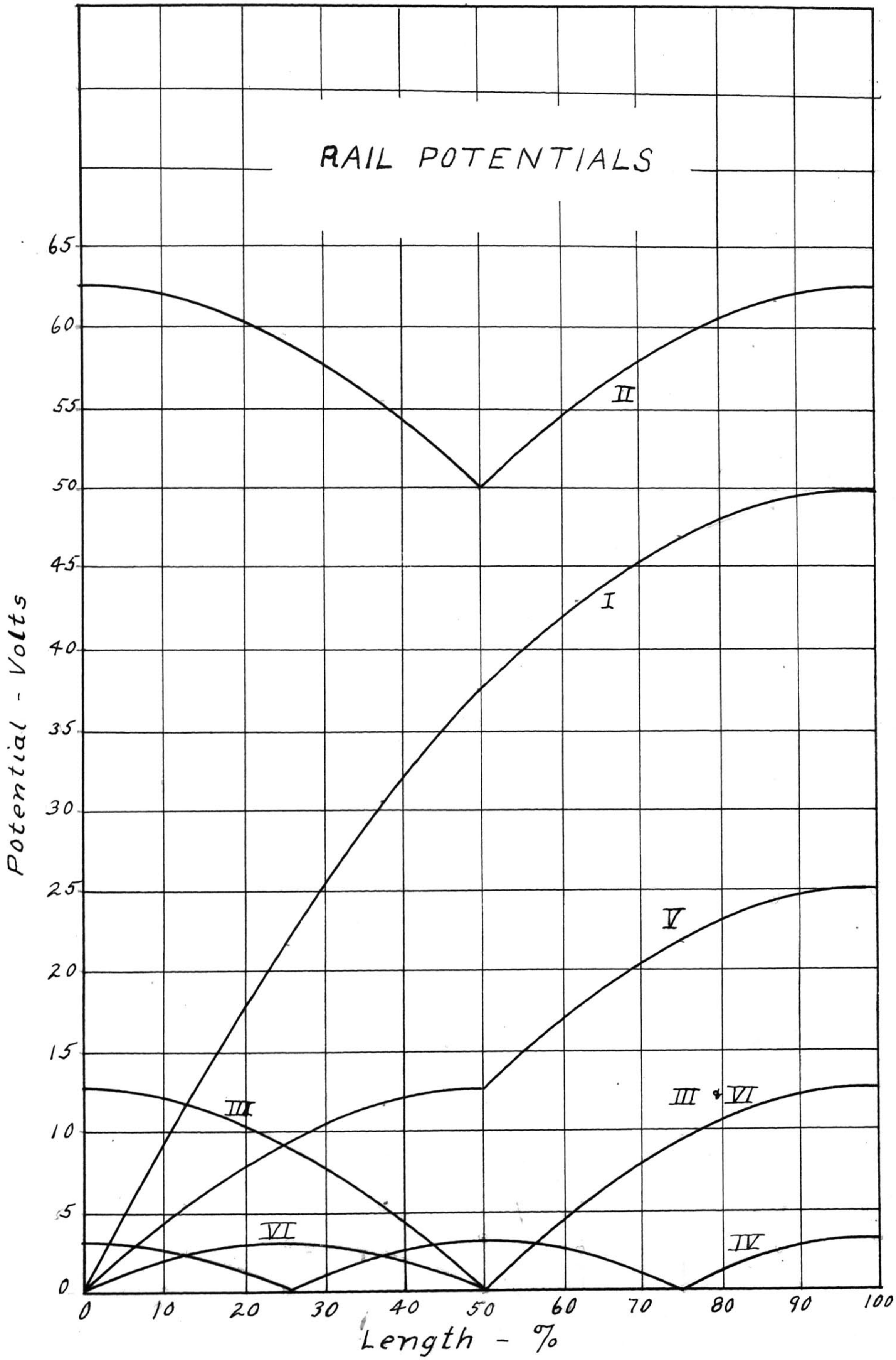

RAIL POTENTIALS
Potential - Volts
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
Length - %
II
I
V
III
III & VI
VI
IV

Fig. 4.

TABLE 7.

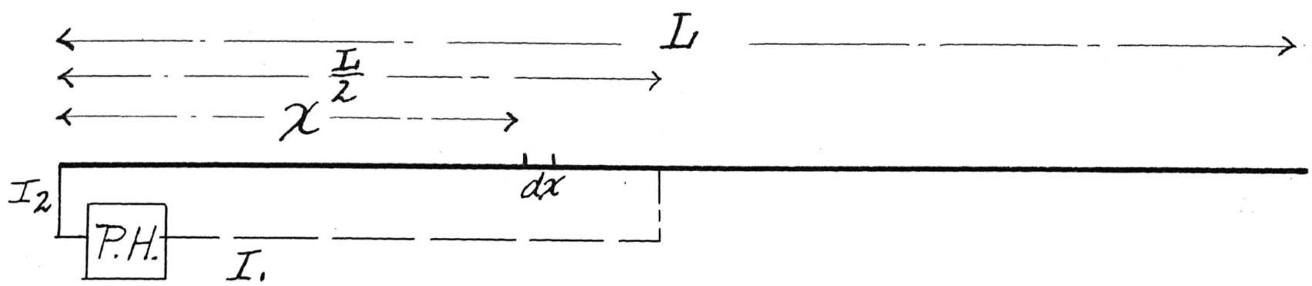
DATA FOR POTENTIAL CURVES OF FIG. 4.

Miles	Volts	Volts	Volts	Volts	Volts	Volts
0	0	12.5	3.125	37.5	0	0
			2.93			1.36
$\frac{1}{2}$	11.73	11.73	2.34	36.73	5.47	2.34
			1.36			2.93
1	21.9	9.375	0	34.38	9.375	3.125
			1.36			2.93
$1\frac{1}{2}$	30.5	5.47	2.34	30.47	11.72	2.34
			2.93			1.36
2	37.5	0	3.125	25.	12.5	0
			2.93			
$2\frac{1}{2}$	43.0	5.47	2.34	30.47	17.96	5.47
			1.36			
3	46.9	9.375	0	34.38	21.75	9.375
			1.36			
$3\frac{1}{2}$	49.25	11.73	2.34	36.73	24.22	11.73
			2.93			
4	50.0	12.5	3.125	37.5	25.	125.
Losses K.W.	125.	31.25	15.6+	156.25	62.5	93.05

L = 4 miles
I = 5000 Amperes
R = .005 Ω/mile
R_1 = .005 Ω/

NOTE – Booster used for VI.

I. Power House at one end.
II. Power House at middle.
III. 2 Power Houses at $\frac{1}{2}$ and $\frac{3}{4}$ Line
IV. Feeder at middle of line.
V. Power House at end and Feeder at middle of line.
VI. Power House at end and Feeder Booster at $\frac{1}{2}$ line.



I = Total current

I_1= Feeder current

I_2= Rail current

The current at any point between the P. H. and $\frac{L}{2}$ x distant from the P. H. is

$$i = I_2 - I\frac{x}{L}$$

The potential drop in the length dx

$$dv = R\ i\ dx$$

Substituting and integrating the potential at any point between P.H. and $\frac{L}{2}$

$$V = \int_{x=o}^{x=\frac{L}{2}} R\left(I_2 - I\frac{x}{L}\right) dx = R\ I_2\left(x - \frac{Ix^2}{2L}\right)\Bigg|_o^{\frac{L}{2}} \qquad (I)$$

If $x = \frac{L}{2}$ The potential at that point

$$V = R\left(\frac{I_2L}{2} - \frac{I\ L}{8}\right) \qquad (II)$$

The potential drop in the feeder

$$V_F = R_1 I_1 \text{ but } I_1 = I - I_2$$

Subst. $$= R_1 \left(I - I_2\right)$$

Applying Kirchoffs law of the potentials in a closed circle

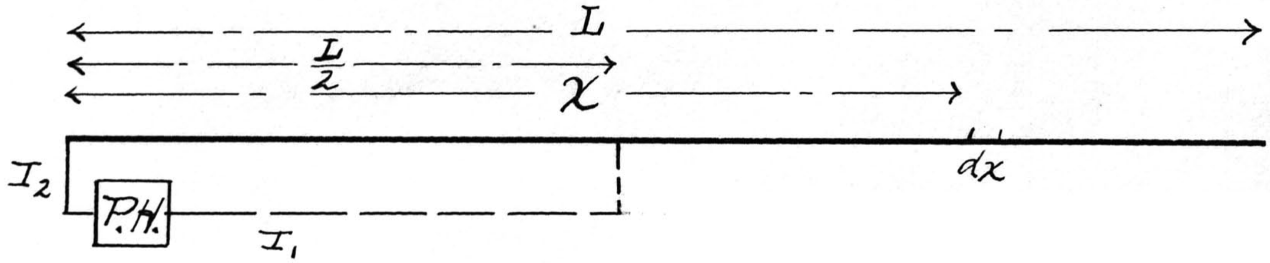
$$V = V_F$$

$$R\left(\frac{I_2\,L}{2} - \frac{I\,L}{8}\right) = R_1\,(I - I_2)$$

Solving for I_2 (the only unknown is the equation)

$$I_2\left(\frac{RL}{2} + R_1\right) = I\,(R_1 + \frac{RL}{8})$$

$$I_2 = \frac{I}{4}\left(\frac{R\,L + 8\,R_1}{R\,L + 2\,R_1}\right)$$



The current at any point between $\frac{L}{2}$ and L x distant from P. H.

$$i_3 = I\left(\frac{L - x}{L}\right)$$

The potential drop in the length (dx)

$$dv_3 = R\ i\ dx$$

The potential above the potential at $\frac{L}{2}$ is then

$$V_3 = \int_{x=\frac{L}{2}}^{x=x} R\ i_3\ dx = RI\left(\frac{2Lx-x^2}{2L}\right)$$

$$= RI\left(-\frac{3L}{8} + x - \frac{x^2}{2L}\right) \qquad \text{III}$$

Combining this equation with the expression for the potential of $\frac{L}{2}$ (II)

$$V = R\left(\frac{I_2 L}{2} - \frac{IL}{8}\right) + RI\left(\frac{3L}{8} + x - \frac{x^2}{2L}\right)$$

$$= RI\left(\frac{L}{8}\left[\frac{RL + 8\ R_1}{RL + 2\ R_1}\right] - \frac{L}{8} - \frac{3L}{8} + x - \frac{x^2}{2L}\right)$$

$$= \frac{RI}{L}\left(\frac{L^2}{8}\left[\frac{RL + 8\ R_1}{RL + 2R_1}\right] - \frac{L^2}{2} + Lx - \frac{x^2}{2}\right) \qquad \text{IV}$$

The equations I and IV give the two sections of Curves V_4 and VI_4.

In V_4 the resistance of the feeder equals the resistance of a unit length of rail return ($R_1 = R$). $R_1 = 0$ in VI_4 an equivalent condition possible to obtain only with a booster in the feeder circuit (the common German system).

Discussion of curves. — The rate of advance of electrolytic corrosion into the pipe walls is proportional to the density of current discharge. The current density depends on the total potential difference on the rails or more directly the potential between pipe and rail at both ends. Since the potential fall in the pipe system is always only a small per cent of the total rail potential, the potential between pipe and rail will be practically constant whether the system is L or $\frac{L}{2}$ miles long, if the total rail drop is the same for both distances. It was probably on account of this consideration that the German regulations specify a certain voltage limit in the municipality and not per unit length. Therefore it is true that the current density and total current discharge under the conditions of Curve I_4, are about four times as great as Curve II_4 or III_4, although the potential per mile is only two times as great. The maximum difference of potential on the rails may be said to be the determining factor in electrolytic damage. Since in Curves II_4 and III_4 the value is the same the electrolytic damage will be the same but the financial aspect is decidedly different in the two cases, due to the power loss in II.

(a) Power Stations.

The change in conditions shown in Curves III and IV may be brought about by additional power houses or substations. There is a reduction of the maximum voltage difference on the same length of line from 50 volts to 3.125 volts or 1/16 of the value with a change from one feeding point to two and the correct location of these points. In many of the larger American cities the large, economically-situated and efficient central power plant with high tension transmission to substations of simple construction is taking the place of the slow-speed equipment in stations feeding to the rails and trolleys at extreme ends. The advent of the large-unit steam turbine, high-tension transmission, and improved alternating current motors for driving railway generators are among the influences bringing the substations, which are situated at the critical points, into common use. Thus Spokane may use the hydro-electric power of that section to the best advantage and Pittsburgh may have a large plant on an island miles from the business district with a convenient supply of fuel and water. The use of the sturdy squirrel-cage induction motor in some stations reducesthe cost of operation, the line power-factor being controlled by the synchronous machines of other stations. The efficiency of the whole system is high, the loss due to conversion of power and investment in converting machinery being overbalanced by the gain in generating and transmission efficiency.

Another consideration favoring the substation from an electrolytic standpoint, other than the reduction of potentials is the possibility of placing the station and resulting positive area in high, dry ground, (a location usually directly opposed to a steam plant requiring a convenient water supply) and in sections where few water and gas mains are laid. Three substations of the Pittsburgh system are thus wisely located; the Forbes Avenue station fulfilling the first condition and Ardmore and Verona the second. The old custom of using large ground plates or heavy returns uninsulated from the ground is to be deplored and discouraged in every instance. It is the most direct way of increasing the damage with no proportionate gain in return conductivity.

(b) Radial Feeders.

In the smaller cities one steam plant with direct-connected 500-600 direct current generators is giving the service in the most economical way; alternating current and substations not being feasible. Potentials may be reduced with radial feeders to the rails. Disconnecting the power house from the nearby rails and running a feeder to the middle of the line as illustrated in Curve IV_4, reduces the potential to $\frac{1}{4}$ of the previous value and the RI^2 return loss is increased about 20%. A large cross section of copper has been used in this design, 21 million circular mils, and at the common power and copper costs, about five times this area would be the most economical from the standpoint of annual operation expense. But with the feeder given the copper is working far below its current capacity, and an increase in cross section would be opposed to present practice of working all materials to the limit of their capacity. If the power house and feeder are connected to the rails the distribution of potential is as shown in Curve V, the maximum potential difference being reduced to one-half the value with power house alone, but double the feeder alone. The return losses are also one-half of condition I_4 and two-fifths the feeder alone (IV). Putting a booster in series with the feeder, the potential at the middle point may be made equal to the power house potential. The distribution of load is changed, the return losses increased one-third and the potential decreased to one-fourth of the original value. Thus the use of the booster (or sucker) may be made very effective in the reduction of potential differences and in reducing the cross-section of feeders. These low voltage machines of large current capacity add the complications to the plant incident to any rotating machinery. The kilowatts produced by the booster and lost in the radial feeders cost more than if supplied by the main generators. The custom of using boosters has not been widely followed in this country but will receive more attention than any other protective method applicable through the railway equipment.

(c) 3-wire System.

A modification of the radial feeders is obtained with the 3-wire system as designed for one or two of the large cities of this country but not in operation as far as the author is informed. The plan, in brief, is to operate two generators in series, connecting the middle point to the rail system and connecting the two extremes to the trolley which is divided into two sections. These sections are best arranged to supply power to lines running parallel to each other and adjacent, either the double tracks of the same street or parallel streets two or four squares apart. The two sections must carry approximately equal loads and frequent interconnections of rails are necessary for the best results. Then each such connection (which would usually be the intersecting tracks necessary to traffic) would serve as feeding points and the maximum potential difference might easily drop to 1% of the usual return values. Such potentials as exist would be reversing in direction as well as fluctuating widely in location and value, giving the advantage of action of alternating current in reducing electro-chemical action.

Only standard equipment would be necessary in such a system in power house line and rolling stock and the cost of installation would not greatly exceed the usual two-wire road. The objections to the system are numerous although not vital. 1st: The necessity of always operating two machines when one might carry the load. 2nd: The higher operating voltage and the increased life hazard. 3rd: The increased life hazard due to certain switching apparatus and machinery usually grounded being 500 volts above, e.g. series field, equalizing bus and switches. 4th: Complications at intersections of the two trolleys and the difficulties of insulation. 5th: The two potentials and the motormen's danger of reversal. These might all be overcome more easily than many problems that have been solved if the importance of electrolysis was realized at the time of construction and this system adopted and developed. It is most attractive from an electrolytic standpoint, and the fact that it is practically untried is its greatest weakness.

6. Increase of Operating Voltage.

If the current on the rails could be reduced and their resistance remain the same, the potential differences impressed on the earth would be reduced by the same ratio. Increasing the operating voltage would produce this result and the 1200 volt and 2500 volt systems introduced by one of the largest electrical companies, would reduce the potentials 50 and 75 per cent. But these high voltages were designed primarily for interurban traffic and would be dangerous for city streets. The question is serious when the high potential exists at a few isolated points as in the proposed 3-wire system but would be greatly magnified with these potentials existing at all points between trolley and ground. Special machines or two machines to produce the potential are necessary. In the design of returns the potential drop as a per cent of the operating voltage is the limiting factor in cross-section calculations. That is a 10 per cent drop on a 600-volt system would mean 60 volts but on a 1200-volt line would be 120 volts.

B. Reduction of Current on Pipe Systems.

The Special Master in the electrolysis case of the Peoria Water Works Co. vs. the Peoria Railway Co. stated as one "ultimate fact" that "The complainant can do nothing to prevent the injury". A consideration of various methods of protection applicable to the subsurface systems may lead to a somewhat different conclusion. The prevention of <u>all</u> injury by such methods is hardly possible but if the rate of such injury is reduced until the natural length of life or usefulness of the system is accomplished, our economic conditions cannot demand more. Moreover, if the annual cost of the protective system exceeds the annual losses due to the deterioration of metallic structures and attendant uncertainties, a financial and an engineering mistake has been made whether the railway or the damaged corporation pays for it. Society must pay for it eventually.

1. Location of Pipes.

Without reducing the potential gradients due to the railway system the problem of reducing the current flow on the pipes and the resulting discharge therefrom may be approached from several standpoints. Placing the pipes in areas having no potential gradient is manifestly impossible since they must serve the same sections and the potentials in the earth exist hundreds of feet from the railway lines. But the gradient is very much higher within the first 10 to 20 feet, 50 to 75 per cent of the total existing within that range. The excessive damage to pipes a few feet away indicates this and potentials observed in the various cities prove it. The mains lying directly below the tracks or service pipes crossing below them are the parts of the systems usually most affected. This was markedly true in Altoona, Pa. where a large main under the track burst and in Ashtabula, Ohio, where services at these points last only about a year. In downtown districts with the large water demand and frequent services extending across the street, a main on either side of the street has been substituted, each supplying only the one side. If a main lying on one side of the street has become too small, a second may be laid on the opposite side and supply the services which formerly crossed under the tracks. When a main or service crosses under the track it may be laid deep. The alleys and streets without tracks may be used and property supplied from the rear or side. The re-location of the pipes of an old system is not feasible but in new installations this is an important consideration.

2. Cement and Conduit.

To insulate the pipe from the earth at all points or at the critical points has been proposed and experimented with for some years. Cement has been proposed but the electrical conductivity of cement is proportional to the moisture it retains or absorbs. Experiments at the Bureau of Standards with various cement water-proofing compounds indicate that it is practically impossible to make cement a non-conductor when exposed to moisture. One company makes a wrought pipe covered with a layer of cement and a steel cover. With the usual cauked lead joint this pipe was found to be susceptible to electrolytic action. The resistance of very dense cement is higher than that of concrete having voids under the same moisture conditions+ The cost of covering a pipe system

+See Bureau of Standards Electrolysis in Reinforced Concrete by Rosa, McCollum and Peters.

with cement or laying cement pipe is an additional objection. The chemical effect of cement and its use as a joint material will be discussed later. Conduit like cement if dry serves effectively as a protection but they may fill with ground seekage and damage occur. Lead cable sheathes suffer from electrolysis although always placed in ducts when under ground. This is especially serious because of the thin walls of the sheathes, the necessity of a continuous, water-proof protection, and the large electrochemical equivalent of lead.

3. Paints and Treated Textiles.

The insulation of water and gas conductors by paints and paper and cloth applied in layers with paints between has been practised to a certain extent. There are many paints on the market recommended by their makers as protectors from electrolysis. These are applied by dipping or brushing or in the case of textiles the alternate layers of textile and paint are applied. The painting may be done at quite a low cost but the use of textiles increases the cost decidedly. The existence of coatings in good condition on pipes which have been in the ground 15 to 20 years as was observed frequently in the field shows their value as protection against natural corrosion but the presence of an electrical potential imposes a more trying condition.

The Bureau of Standards is testing many of these paints and textiles under a low electrical potential, 4 volts. In only a few cases has a paint been found which would stand up under this test for more than a few weeks many breaking down in less than a day. The textiles are giving better results but it is a matter of uncertainty how long the coating will remain perfect. When a slight opening or pin hole develops, the chemical action will be concentrated there and the results are more serious than if the action were distributed. Since the damage occurs at the anode, it is a question whether paint is desirable in the positive area as it will only tend, if the paint breaks down, to cause pitting of greater depth. Painted pipe in the negative area will increase the resistance to ground even though it be punctured in many places and paint is of great value in preventing natural corrosion. The use of paint cannot therefore be depended upon to prevent electrolysis even in the case of expensive textile covering.

4. Insulating or High Resistance Joints.

The prevention of current flowing into the pipes or out of them by means of paints and treated textiles has proven a doubtful and costly expedient. The prevention or reduction of this current flow by breaking the pipe up into insulated sections electrically has been used quite extensively. The sections may be so short that the resistance of each against the ground is high when compared with the total length. The resistance _in_ the pipe may be great enough to reduce the current practically to zero. Since every joint is paralleled by a short earth path, many comparatively low resistance joints are more effective than a few very high resistance joints. In practice a joint of very high resistance is exceedingly difficult to obtain. This is due to the presence of moisture and salts in the soil or some inherent quality of the joint material. The location of insulating joints in dry or high-resistance soils has received little attention. This would increase the resistance of the shunt path which is usually by far a better conductor than the joint material and therefore increases the resistance of the circuit by a proportional amount. Many types of resistance joints have been proposed and used and the most common are discussed and compared here.

<u>Lead.</u> The almost universal joint material for cast iron mains is lead melted and poured into place and caulked until tight. Lead has proven a satisfactory joint material being convenient to use and making a joint which may be repaired by recaulking. Contrary to the common belief a joint of appreciable resistance is produced with the use of lead. This is not surprising when it is considered that both bell and spigot are commonly heavily coated with paint, sometimes the spigot is not rammed home into the bell, and the lead is not at a high enough temperature to destroy the paint. Table 8 gives the resistance of a number of lead joints found in the systems of Wilkinsburg, Pittsburgh, and Erie. The values are not consistent enough to plot curves comparing resistance and size or age. An average of the resistance in ohms is unfair because of the various sizes but reducing the resistance to an expression in feet of the same sized pipe as that in which the joint is found gives a basis of comparison. The average resistance of the 76 joints measured is 69', or since the lengths of pipe are 12' long, the resistance of the continuous pipe has been increased by 575 per cent. This would reduce the current in the pipe to a certain extent but the resistance is small in comparison with the so-called insulating joints.

TABLE 8.

LEAD JOINTS.

Location	Size	Age	Resistance	
	Inches	Years	Ohms	' Pipe
Wilkinsburg, Pa.	6	15	.00044	9.2
"	6	new	.000002	.2
"	30	25	.0002	43.
"	30	25	.0017	370.
Pittsburgh, Pa.	8	15	.00067	18.
"	8	15	.0017	45.
"	8	15	.00072	20.
"	8	15	.0016	44.
"	8	15	.00065	17.
"	8	15	.0003	5.
"	12	15	.00018	11.
"	12	15	.000072	4.
"	12	10	.0076	440.
"	12	10	.00054	32.
"	6	10	.00021	4.4
"	6	10	.00021	4.4
"	6	10	.0022	4.6
"	6	10	.00035	7.4
"	6	10	.0012	26.
"	6	25	.0054	13.
"	6	25	.00042	8.7

TABLE 8 (Cont)

LEAD JOINTS

Location	Size	Age	Resistance	
	Inches	Years	Ohms	/Pipe
Pittsburgh, Pa.	20	25	.000026	3.2
"	6	20	.00078	16.
"	6	20	.03	620.
"	6	20	.003	58.
"	6	20	.00094	20.
"	20	25	.000029	3.6
"	20	25	.000015	1.8
"	6	?	.000053	1.1
"	6	20	.015	320.
"	20	25	.000018	2.3
"	4	20	.08	11.
"	6	10	.008	170.
"	6	10	.0055	110.
"	8	20	.00078	22.
"	8	20	.000048	1.3
"	8	20	.00054	15.
"	20	25	.005	620.
"	8	15	.0014	37.
"	8	15	.0013	34.
"	20	3	.000072	9.0

TABLE 8 (Cont)

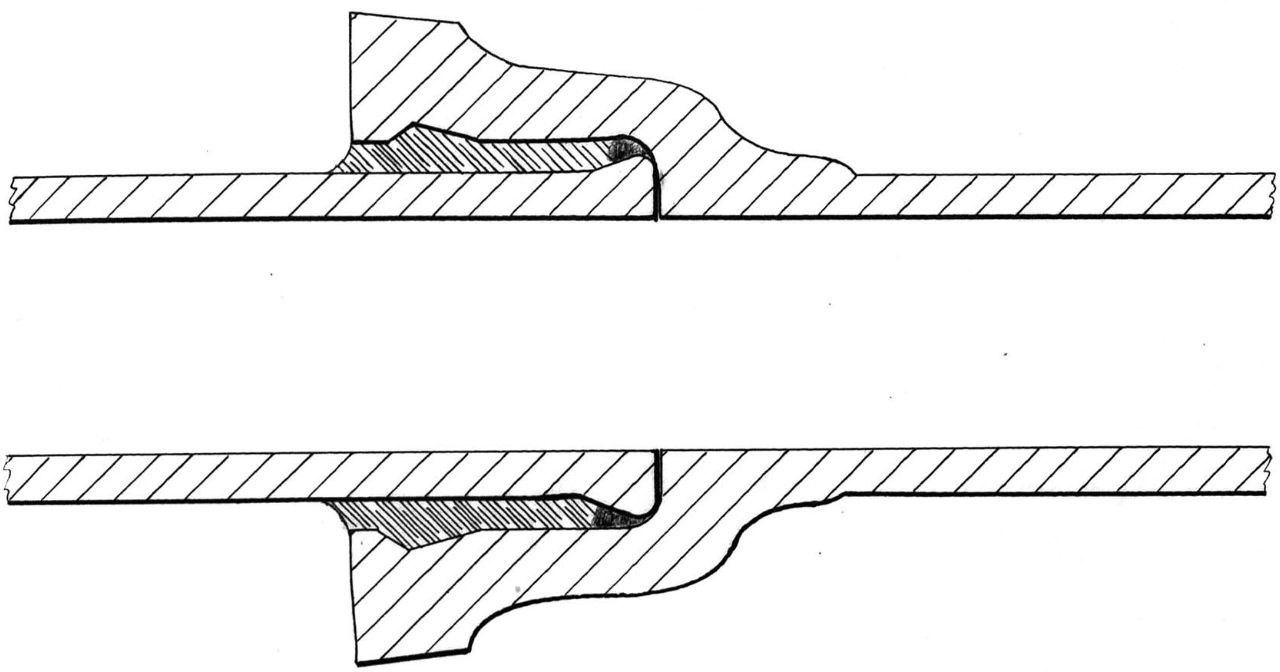
LEAD JOINTS

Location	Size	Age	Resistance	
	Inches	Years	Ohms	'Pipe
Pittsburgh, Pa.	8	15	.00012	3.2
"	8	15	.00075	20.
"	36	25	.000047	14.
"	36	25	.000044	13.
"	8	15	.00013	3.5
"	8	15	.00022	6.0
"	20	3	.000029	3.6
"	20	3	.000026	3.3
Erie, Pa.	12	15	.00024	14.
"	12	15	.00024	14.
"	6	40	.0034	70.8
"	6	40	.00055	11.3
"	30	20	.000034	7.
"	30	20	.000021	4.5
"	6	15	.0029	157.
"	6	15	.0001	5.3
"	6	15	.0084	460.
"	4	24	.0017	24.
"	4	24	.0039	54.
"	6	21	.0004	8.4

TABLE 8 (Cont)

LEAD JOINTS

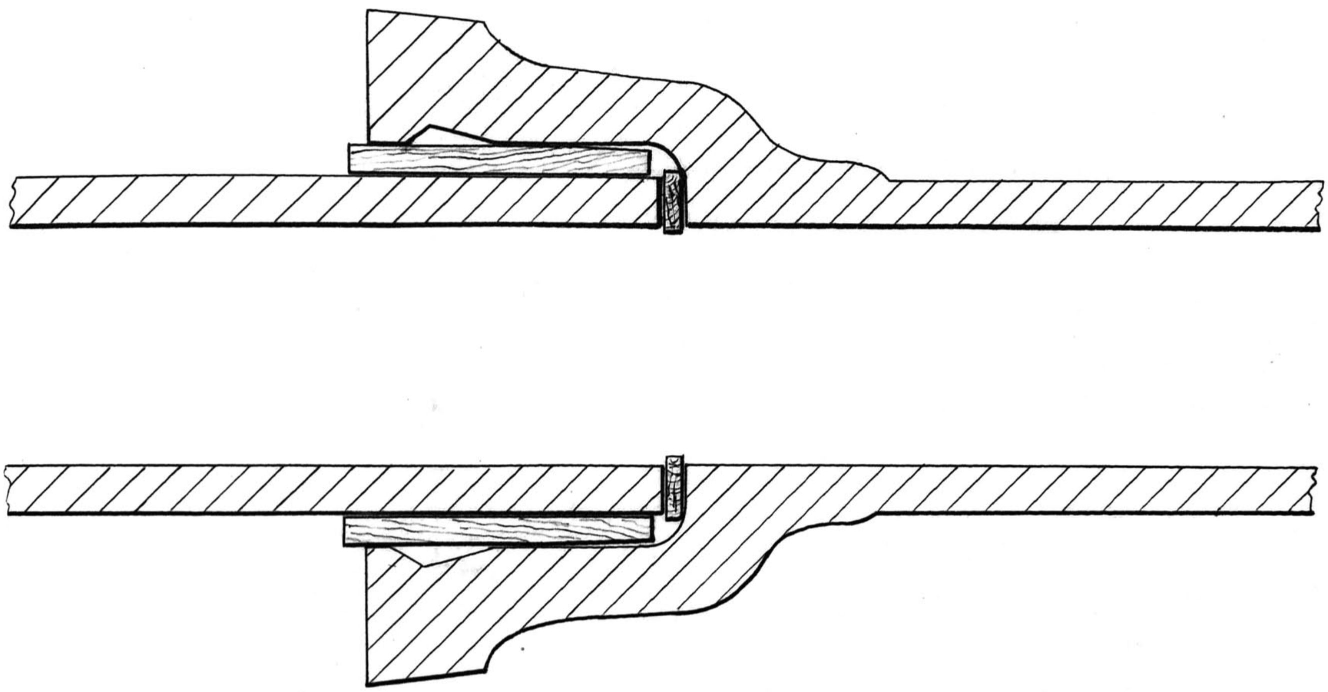
Location	Size	Age	Resistance	
	Inches	Years	Ohms	/Pipe
Erie, Pa.	6	21	.00053	11.1
"	20	24	.0003	37.
"	20	24	.00008	9.5
"	20	14	.00004	6.8
"	20	14	.000013	2.3
"	6	40	.008	165.
"	6	40	.0067	140.
"	6	16	.001	21.
"	6	16	.0013	26.
"	6	8	.0003	6.
"	6	8	.002	38.
"	4		.0017	25.
"	6		.000015	3.1
"	6	20	.0003	5.5
Average				69.



LEAD JOINT - NOT INSULATING

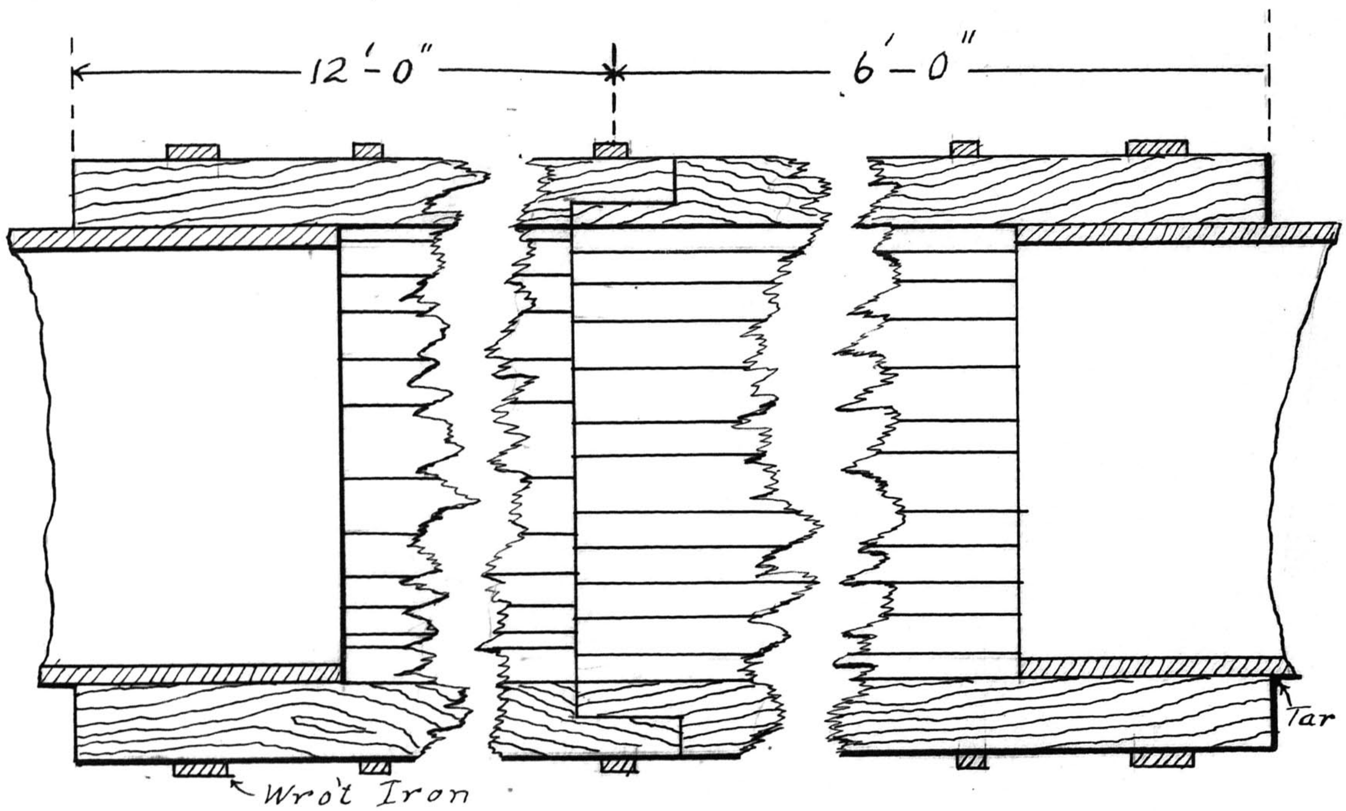
Fig. 5.

<u>Wood.</u> Joints or section of wood have proven quite satisfactory for water service with moderate pressures. The joint used in Boston by the Metropolitan Water Co. is made up of a ring separating the bell and spigot ends and slightly tapering wedges driven in the space usually occupied by lead. (See Fig. 6). The resistance of these joints is high, usually one ohm or more. On the higher pressures (over 100#) such a joint may not be depended on unless a retaining ring is clamped in place to prevent the wedges from being forced out. The durability of wood might be questioned but the instances of the long life of wooden sections when protected from weather and oxygen are common. The use of wood stave sections as insulating joints has been shown to be an effective but expensive method. The Pennsylvania Water Company is using an 18-foot section in the main connecting two boroughs (see Fig. 7 for a detail of this construction). The resistance of this joint is about 7 ohms, although it lies in very wet soil. As stated above a number of short, lower-resistance joints would prove as effective and could be installed at a lower cost. Wooden joints are not feasible for gas because of their porosity and this is true of other joint materials, among them leadite.



WOODEN JOINT - INSULATING.

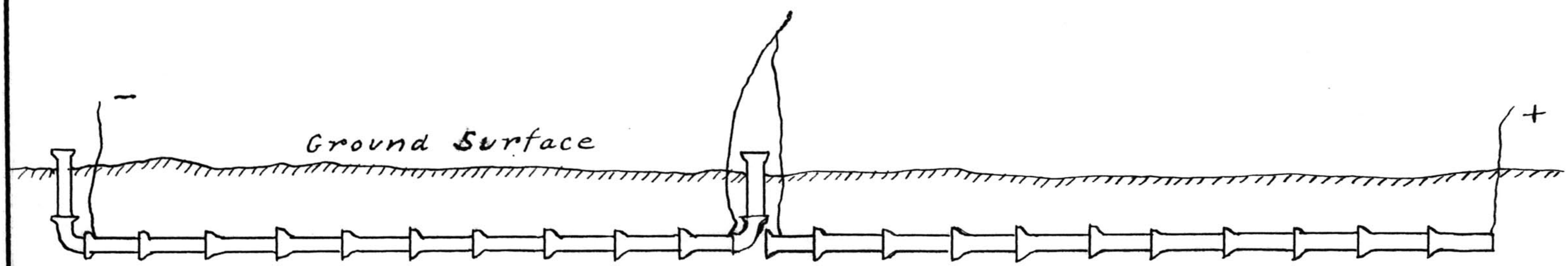
Fig. 6



Wood Stave Insulating Section

Fig. 7.

Leadite. A patent compound called leadite has been used quite extensively and satisfactorily in water mains for the last 4 or 5 years. The joint has the same form as the lead joint Fig. 5. A compound of sand and sulphur which has the following advantages when used for pouring joints in cast water mains: It melts at a lower temperature than lead, it is light in weight (requiring a higher "gate" but a sufficient quantity for the largest joint can be handled in a melting kettle without the use of a derrick), it is more economical both in first cost and also in labor of installation as it neither requires nor permits caulking, leaks appearing when the joint is new soon seal themselves, the joints will withstand shocks or vibration far better than lead, and the joint when new has a very high resistance. These features recommend it as an almost ideal compound for the purpose, but it has certain weaknesses which render its usefulness questionable. It will not make a gas tight joint and is not recommended for such use. The resistance which is high when new rapidly falls to a surprisingly low value. The resistance of a line laid at the Bureau of Standards having 17 leadite joints, 9 lengths filled with water and 10 lengths containing no water was 2,174 ohms on July 7th, 1911, the day the line was completed and covered. It dropped steadily and on March 30,



Leadite Line
at
Bureau of Standards

Fig. 9.

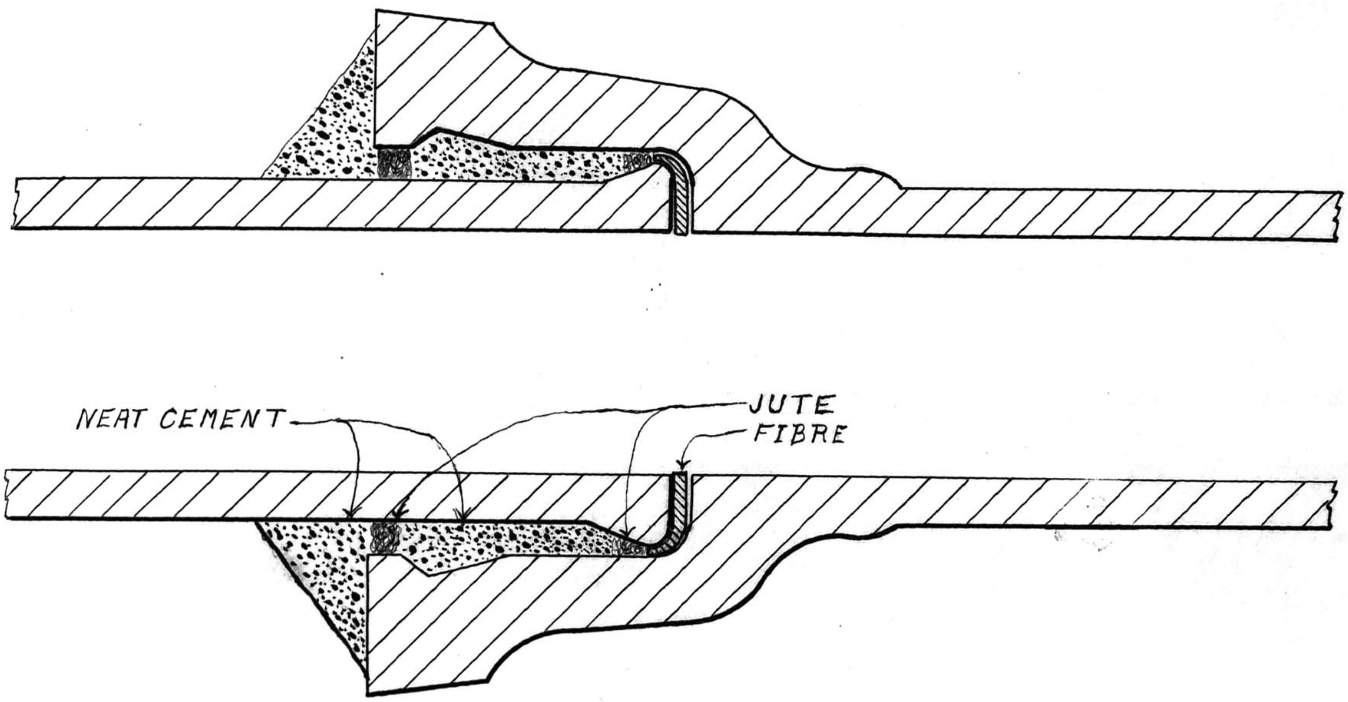
1912, had a resistance of .5 ohms. Leadite joints laid with no effort to separate bell and spigot (as was carefully done in the Bureau of Standards) show low resistances in some cases comparable with lead. In a series of readings obtained in Wilkinsburg (See Table 9) the resistance averages less than .1 of an ohm or expressed in an equivalent size of pipe 4301'. This value is great enough to prevent any damaging current from flowing if every joint is leadite and no very unusual earth potentials exist. The cause of the falling off of resistance has been the subject of much conjecture and some experimental work. A black material is found deposited in the angle between bell and spigot, and in cases where considerable current has been flowing through the line the positive side of the joint below this black deposit has been found badly corroded and pitted. The presence of sulphur and the possibility of the formation of sulphuric acid may explain the low resistance of the older joints and the serious corrosion. The corrosion may also explain the sealing of leaks. These usually occur because of a poor bond between iron and joint material and the presence of moisture would hasten the formation of an oxide which would close the small openings. To use a compound which increases the corrosion is dangerous and some other compound must be substituted.

TABLE 9.

LEADITE JOINTS

Location	Size Inches	Age Years	Resistance Ohms	Resistance Pipe
Wilkinsburg, Pa.	8	4	.00133	36.
"	8	4	.033	900.
"	12	3	.123	7100.
"	12	3	.0003	75.
"	12	3	.004	241.
"	12	3	.014	810.
"	12	3	.03	1770.
"	12	3	.03	1770.
"	12	2	.002	120.
"	12	2	.018	1100.
"	12	2	.051	3000.
"	30	3	.015	3300.
"	30	3	.0012	275.
"	12	3	.0052	315.
"	12	3	.0052	315.
"	12	3	.0113	660.
"	12	3	.226	13200.
"	12	4	.357	20600.
"	12	4	.268	15450.
"	12	4	.357	20600.
"	12	4	.028	1650.
"	12	4	.057	3300.
			Average	4381.

Cement. Cement has been used as a pipe joint material for 10 or 15 years but has failed so frequently that it has not come into general use. The joints often leak, the line has no flexibility, bells being found broken when shifts occur due to contraction, expansion, or sliding of the pipe bed, and there is no particular economy in installation. However, if properly installed, the first objections may be overcome and the joint has the advantage of a permanent high resistance. The Cambridge Gas Company has had better success than any other company and ascribe their good results to careful construction of the joints. In constructing the joint, jute and neat cement are used (see Fig. 8) a ring of jute followed by the neat cement which fills the annular space. Then another ring of jute which is caulked vigorously until the cement is forced into every crevice and is dense and firm. A cement collar is finally added mainly as a protection for the jute. The covering and foundation of the line are very important since the joints must not be disturbed while setting and as little as possible by later movements. It would seem desirable to make up the cement joints in the company yard with two half-lengths and allow the setting to occur there. These lengths could be made up readily on the surface



CEMENT JOINT- INSULATING

Fig. 8.

and assembled in the ditch with lead joints. This would give the line the desirable flexibility and a cement joint with its high resistance every third or fourth length would be sufficient for any potential gradient.

The resistance of cement joints installed with no idea of producing an insulating joint is extremely variable due to the high resistance of the cement and low resistance of a metallic contact. Table 10 gives a few such joints in a gas main in Ashtabula, Ohio. The lowest resistance being 0.002 ohm and the highest 16 ohms. These do not compare with a series of joints made at the Bureau of Standards. The average resistance of these when new was 276 ohms. Six months later the resistance had risen to 800 ohms. The value of cement as a joint material is increased because the resistance becomes greater when a current passes through it due to polarization and the formation of a high resistance film on the cathode surface. The decreased efficiency of corrosion of iron has an influence which will be discussed in another section. The effect of polarization is made quite evident by some resistance measurements at the Bureau of Standards. Using a direct current method a joint had a resistance of 357 ohms, and by

TABLE 10.

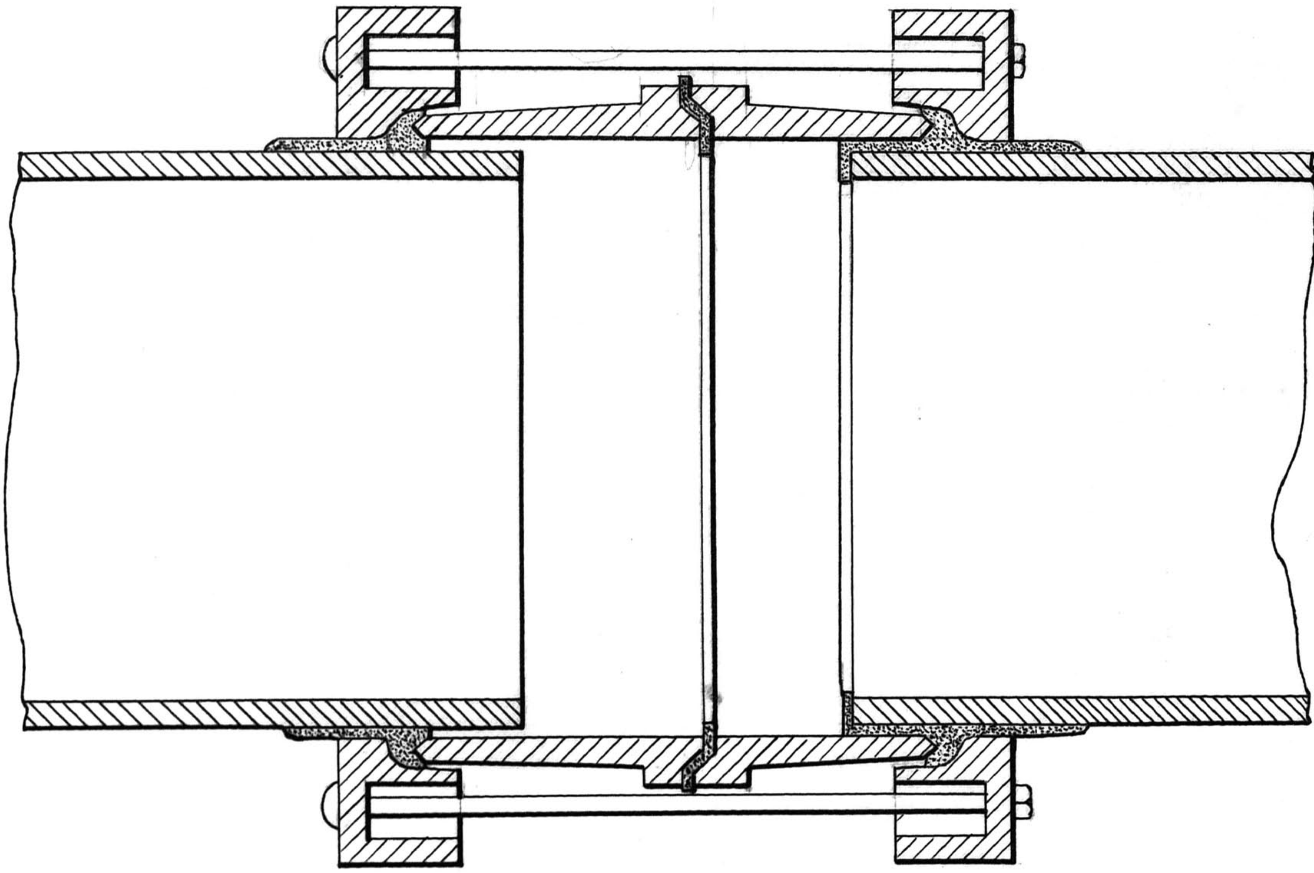
CEMENT JOINTS - RESISTANCE

	Size	Age	Resistance	
Location	Inches	Years	Ohms	Pipe
Ashtabula, O.	6	10	.002	44.
"	6	10	.004	88.
"	6	10	.21	4400.
"	6	10	.0021	46.
"	6	10	.14	2900.
"	6	10	16.	350000.
"	6	10	0.21	4400.

a Kahlraush bridge method, alternating current, the resistance appeared to be 210 ohms. It might be well to state that all joint resistances given in the tables are the result of direct current calculations and with the potential to which they are usually subjected.

Rubber gasket couplings. The above description has covered cast iron bell and spigot joints, but probably 50% of all pipe systems is of wrought iron or steel commonly joined by threaded couplings. Their protection is even more important than cast iron because the walls are lighter and the surface is not protected by a "silacious slag" as is the case with cast iron. Couplings made up of metal sections and rubber gaskets have been in use for over 20 years (a newspaper mentions a line laid at Malta, Ohio, in 1891). From a mechanical standpoint they are very satisfactory since they may be assembled on the surface, they serve as reliable expansion joints and they will hold any pressure without leaking. The rubber forming the gaskets has withstood the action of time, moisture and soil remarkably well, probably because so little of it is exposed, being covered with the metal parts. Artificial gas or some of the entrained volatile matter is known to have a detrimental effect on rubber. Sufficient evidence on this point has not been obtainable to determine the behavior of gaskets under such conditions, but couplings are now in use on artificial gas mains in a number of places and definite information will be available in a few years. It is stated by controlling companies that the line may be laid with rubber gasket couplings as cheaply as with the ordinary screw coupling. A coupling has been designed for insertion in a line already laid (See Fig. 10). The resistance of this coupling is not decidedly high due to the short leakage paths and perhaps to the sulphur present in all rubber. However they show a higher resistance than that of any other type of joint (See Table 11). The current was so small in three of the 10 observations that only the lower limit may be set. The resistance may be decidedly higher.

<u>Lead Sheath Insulating Joints.</u> It is often desirable to break the lead sheath of telephone and power cables into insulated sections although its electrical continuity is, under most circumstances, a most desirable property and is made use of in protecting the cables from electrolysis by means of negative feeders. Abbott's Telephony discusses the desirability of insulating joints in sheaths and the importance of having such joints absolutely



— DRESSER COUPLING —

Fig. 10

TABLE 11.

DRESSER COUPLINGS - RESISTANCE

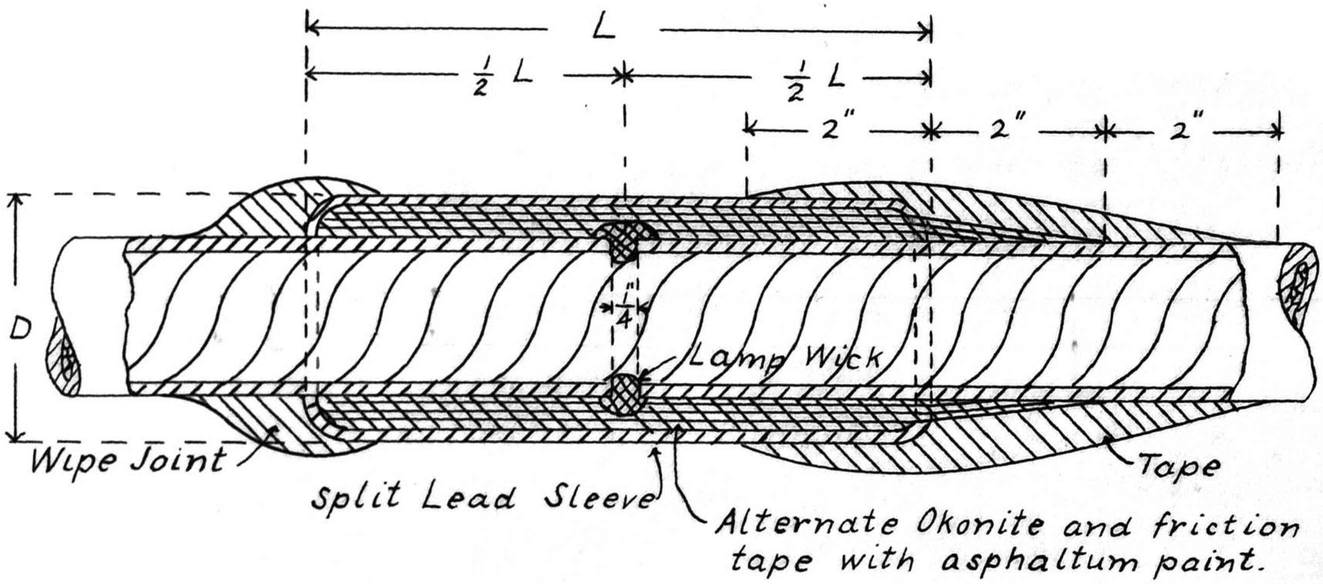
No. 6 D.C.R.

Location	Size	Age	Resistance	
	Inches	Years	Ohms	Pipe
Erie, Pa.	4	4	> 2.64	>183,000
"	6	4	.36	36,000
"	4	4	4.96	292,000
"	6	4	4.65	480,000
"	4	4	.43	25,000
"	6	4	> 5.35	> 560,000
"	8	4	> 9.	>1,400,000
Ashtabula, O.	4	2	10.65	1,600,000
"	4	2	9.5	560,000
"	6	2	.29	59,500

INSULATION JOINT

used by the

C. D. & P. Tel. Co. Pittsburg Pa.



VALUES OF "L" AND "D" FOR DIFFERENT CABLES					
Size of Cable	L	D	Size of Cable	L	D
25 Pr. 16 Ga.	10"	2½"	150 Pr. 19 Ga.	8"	2½"
50 Pr. 22 Ga.	8"	2"	150 Pr. 16 Ga.	10"	3½"
50 Pr. 19 Ga.	8"	2½"	200 Pr. 22 Ga.	8"	2½"
50 Pr. 16 Ga.	8"	2½"	200 Pr. 19 Ga.	10"	3"
50 Pr. 13/16 Ga.	8"	3"	300 Pr. 22 Ga.	10"	3"
75 Pr. 13/16 Ga.	10"	3"	300 Pr. 19 Ga.	10"	3½"
100 Pr. 22 Ga.	8"	2"	400 Pr. 22 Ga.	10"	3½"
100 Pr. 19 Ga.	10"	3"	600 Pr. 22 Ga	10"	3½"
125 Pr. 13/16 Ga.	10"	3½"			

ESTIMATE OF COST

2 Rolls Okonite tape	$ .30	1 lb. Parafine	$ .10
2 " Friction "	.20	1 yd. lamp wicking	.10
2 lb. Wiping Solder	.36	½ pt. Asphaltum	.10
¼ lb. Fine "	.05	1 lead sleeve 12" x 3½"	.40

Tot 1.61

Labor 1.00

$ 2.61

Fig. 11.

waterproof. The Bell Telephone Co. of America has a design improving on Abbotts', the details and cost of which are shown in Fig. 11. This has proven effective in insulation and moisture-proof qualities. Some sheaths cannot be protected in any other manner especially where large currents are collected from the metal work of bridges and in areas where return feeders cannot be used.

Summary of Insulating Joints. In brief, cement, leadite, or wooden joints are economical and effective in laying cast iron water lines, cement joints are satisfactory for cast gas mains, the rubber gasket coupling is suitable for laying wrought iron or steel mains whether water or gas, and this coupling is most suitable for insertion in mains already in service whether cast iron, wrought iron, or steel.

C. Reduction of Electrolytic Corrosion without Reducing Potential Gradient or Current.

Under this head are grouped a number of methods of mitigating the effects of electrolysis, some ingenious, but mainly and more commonly natural methods in quite general use to-day.

1. Reversals of Current.

When an electric current producing a chemical action is reversed, the chemical action may also be reversed. It can be seen that if a small quantity of metal were oxidized during one-half cycle and reduced in the other half, the corrosion might be confined to a very thin coat on the surface. If the action is not perfectly reversable or if the oxidized material becomes disconnected from the foundation metal, the corrosion or efficiency of corrosion will be more nearly unity.

(a) Commercial Frequencies.

The successful operation of alternating current motors on some trolley lines has proven the feasibility and desirability of this system under some circumstances. The chief advantage is the decreased transmission cost over long lines when compared with low tension direct-current transmission. Increase of motor and car costs, greater life hazard due to the high tension and operation difficulties point to the conclusion that it is economically improbable that the alternating systems will be adopted within the cities. 25 cycles is the frequency employed on several interurban lines which have been operating quite successfully for a number of years. The efficiency of corrosion with 60 to 25 cycles varies from

1 to 3 per cent which is low enough to insure any metal structures almost their full length of life. This has very little chance of becoming a common system even though the chief weakness (the alternating current motor) is perfected. The effect of the alternating current interurban lines at least is not seriously detrimental to the subsurface structures.

(b) Hourly or Daily Reversals.

It has been proposed to reverse the polarity at longer intervals by means of switches in the power houses, every hour or every twenty-four hours. The difficulties this would involve are the same as those discussed under other heads. They may be summarized, 1st: Increased life hazard due to high potential of generating and switching apparatus above the ground. 2nd: The constant errors by operators of cars certain to follow such reversals. Reversals which cause equal currents to flow in opposite directions in succeeding intervals will cause portions continuously positive or negative with an unidirectional current to suffer oxidation during half the time and then a reducing action. That is as much oxidation will occur but it will be divided over both areas. Another effect is produced because upon reversal the oxidizing action must change the elements produce reduction and which are still in the circuit before the metal is attacked. A series of experiments conducted in the Bureau of Standards' laboratories show that this reversibility of chemical reaction with 24 hour reversals of current, reduces the efficiency of corrosion to about 60 per cent. Since the corrosion is distributed by the reversal the damage at any point in the usual positive area is 50 per cent of 60 per cent or 30 per cent.

(c) Herrick's Patent.

Since one of the essential features of Herrick's plan as set forth by the patent is the reversal of the current, it is therefore included under that head but the plan as far as any protective feature is concerned should be included under "Negative Return Feeders" in a later section. The plan as outlined is to connect a booster to the neutral point of the pipe system to be protected for a certain period, drawing current from the pipe system. Then during a longer period the neutral point is connected to the negative bus-bar through the booster but with an auxiliary field disconnected. Fig. 10 which is a reproduction from the patent drawings, leaves the plan rather uncertain and the description does not clarify the situation. But certain deductions follow quite evidently from a study of the system.

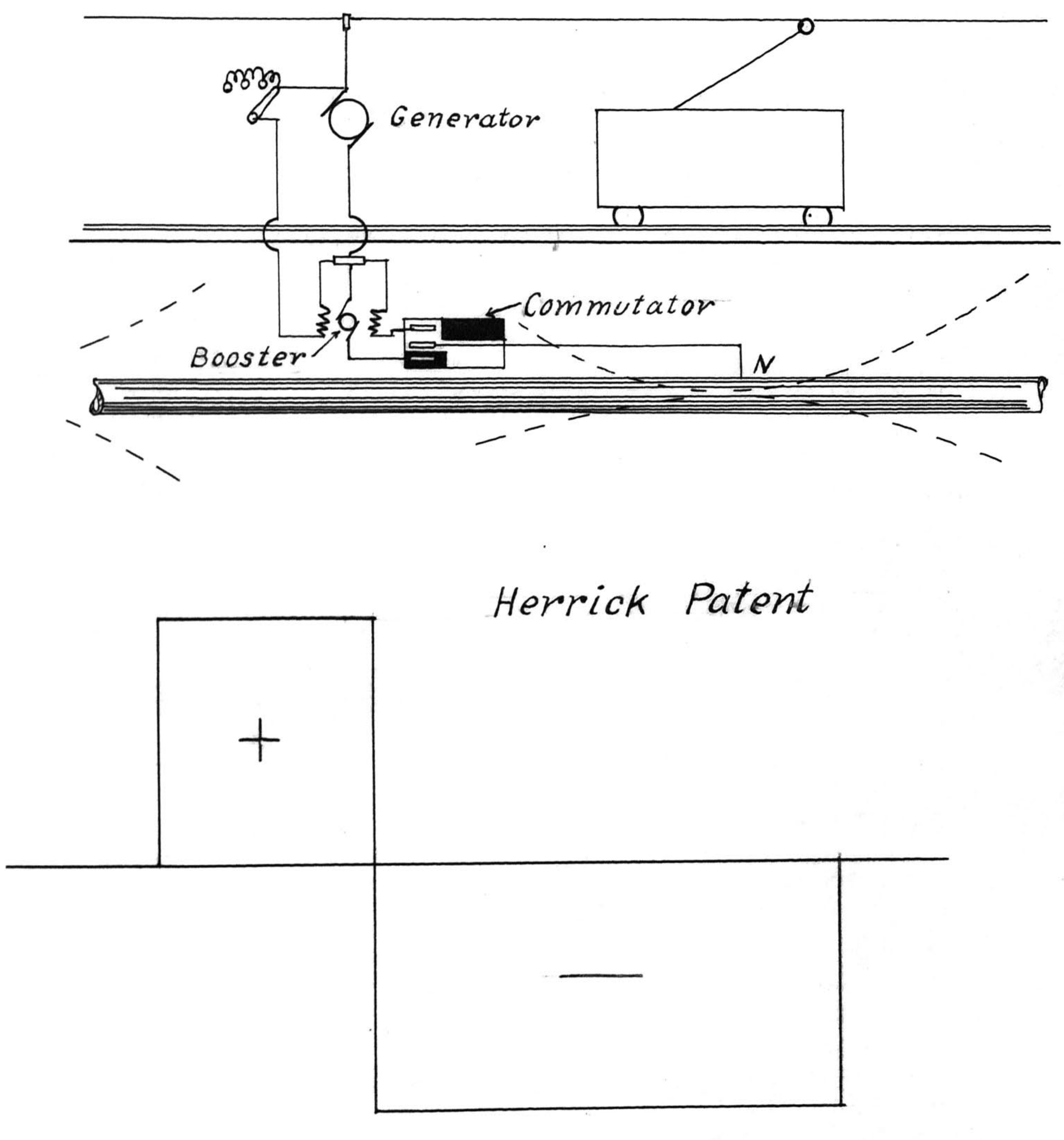


Fig. 12.

Claim of Patent. To make the usual positive portion of pipe system negative during part of a cycle thereby protecting the surface by a "hydrated film".

Equipment. D. C. generator with 2 fields; one 550-volt from Railway bus and the other excited by the current flowing from the pipe at the neutral point to the negative bus. Also commutator which alternately connects the variable field and the direct current generator to the neutral point of the pipe system; the generator being connected for a longer period.

Advantages. The system will make the pipes negative to the rails thereby preventing electrolysis in the usual positive area.

Reversal of current in the joints of the positive area but this is small (see patent).

The current is drawn from a central point in the pipe system thereby subdividing it among several mains.

Weaknesses. The system has all the objections of the common negative return feeders to pipes; increase of current, danger to unprotected pipe lines, danger from fire in gas main and joint electrolysis. Furthermore, its cost is greater than the common negative returns because of

1st: A greater length of copper (to the neutral point) and greater cross section.

2nd: Alternating current device.

3rd: Operation costs.

It adds complication to the power house equipment.

Its connection at the neutral point means that it will have less effect on the most positive points (near the power house) while the auxiliary generator field is out and that the generator voltage must be proportionately greater to make these points negative.

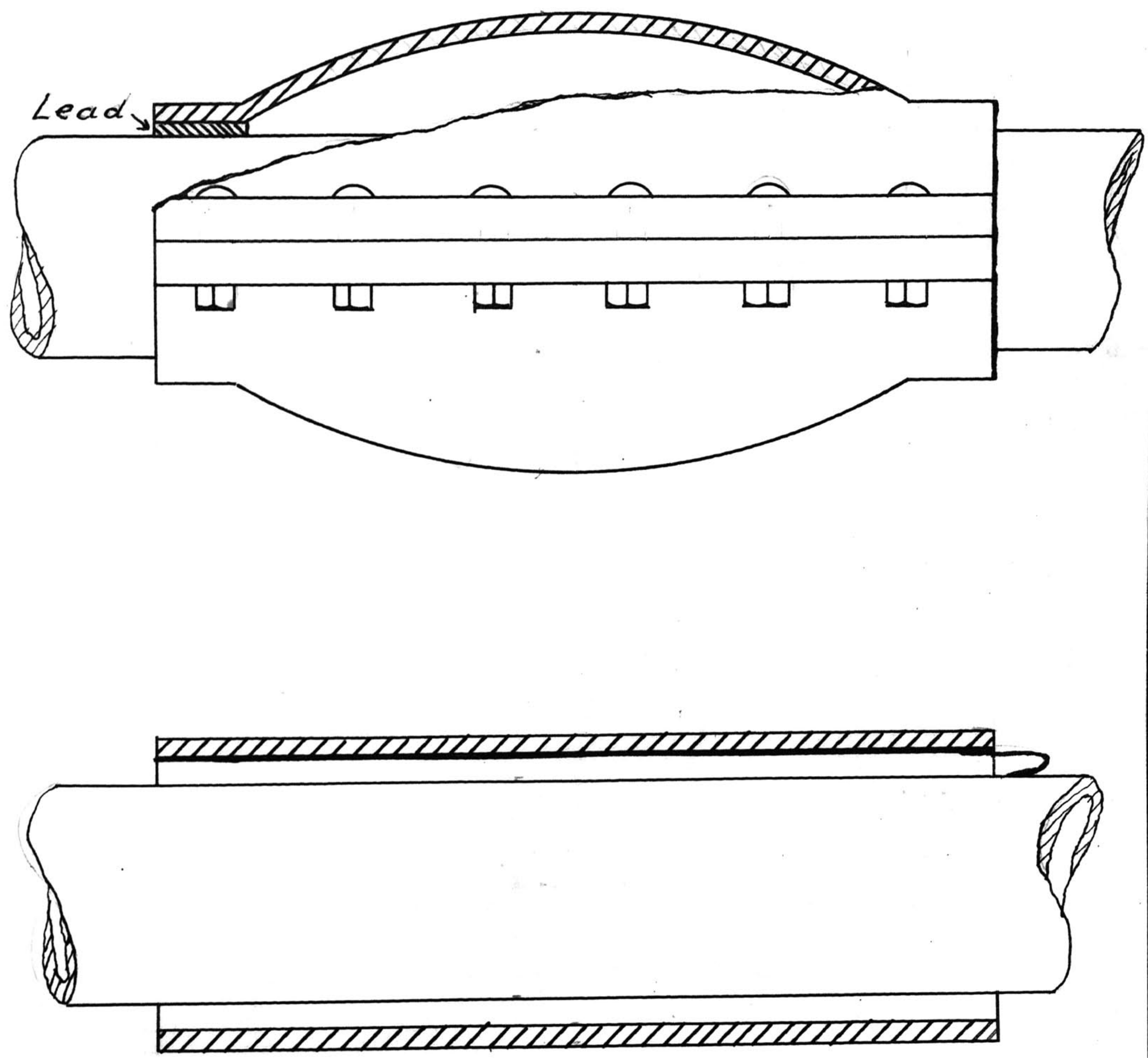
An increased current from the negative area due to the above increase in voltage.

2. Removal of Current.

Since electrolytic damage occurs at points where the current flows from the metal into a moist medium - or a "conductor of the second class", if this current could be conducted away by a metal path this damage might be avoided. The current will be concentrated on the low resistance paths, making it necessary that the metallic paths have a lower resistance or a potential be impressed in the direction to assist the flow. The removal of current has been accomplished in several ways.

(a) Electrolysis Sleeves.

At point where the discharge tends to be concentrated due to the proximity of two conductors or because of low resistance due to moisture or chemical conditions, the corrosion will be very rapid. By surrounding the positive conductor with a metal covering or sleeve and connecting them electrically, the discharge will take place from the sleeve, corroding it instead of the conductor which is carrying the operating pressure of water or gas. The extent of the applicability of electrolysis sleeves is limited since the discharge is very commonly distributed over large sections of the pipe systems and it is impracticable to sheath great lengths. The expense of installing a single sleeve is large and the area protected comparatively small. The sleeve used by the United Natural Gas Co. (see upper sketch Fig. 11) is a casting in two parts clamped with a lead packing at each end which assists in making the sleeve water tight (provision against the entrance of soil water) and forms the electrical connection. This may be placed on a pipe already in service. The use of a large section of pipe (see lower sketch Fig. 11) to surround the conductor, bonding them together has been quite commonly practised. There are some situations where they may be used successfully but for the general protection of a system some other method is necessary.



Electrolytic Sleeves

Fig. 13.

(b) Negative Return Feeders.

Since the negative bus of the power stations is almost universally connected to the rails of a rail return system, these rails near the power station are at the lowest potential. The pipes in this vicinity have received current from distant points and are positive and subject to destruction in the area near the station. By connect- the pipes to the negative bus their potential is reduced even equal to or below that of the rails. This ratio of potential of pipe and rail depends on the drop in the feeders, rails and pipes and the location of the feeding points.

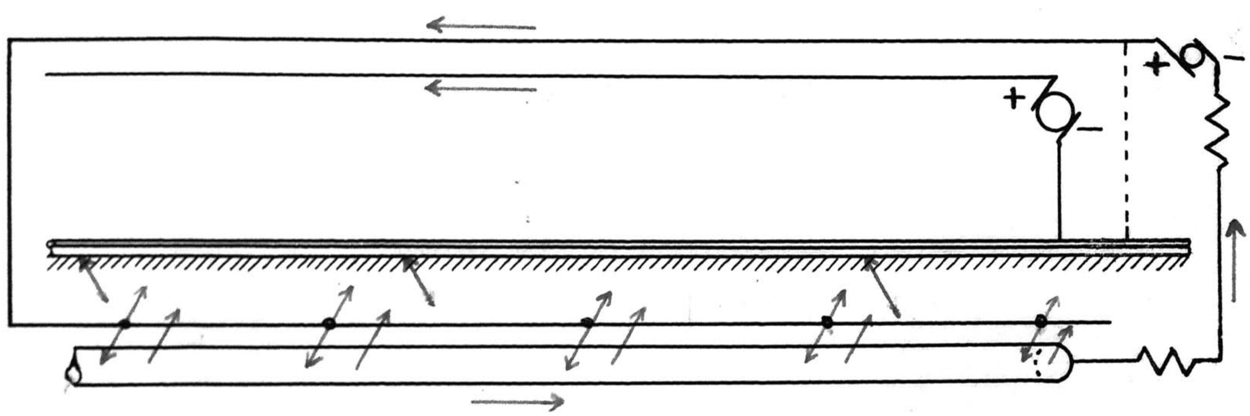
This is almost undoubtedly the system whereby electrolytic discharge may be prevented in the commonly-called positive area with the smallest investment. Only a small cross section of short cables are necessary and these may be worked to the limit of their current carrying capacity. The pipes may be made neutral or negative at all points and the danger of general corrosion abolished. Moreover a large part of the railway load may be returned to the power station over these feeders and connected pipe mains, a return system of large cross-section and great length which the railway has obtained with a very small expenditure. In Erie about 14 per cent of the total load was being carried by the pipe system with a very poor equipment of negative returns. In Altoona 12 per cent was flowing over the pipes. In several power stations of Pittsburgh 30 per cent to 40 per cent was being returned over the underground mains, amounting to 6000 amperes for a single station.

The tremendous increase of current on the water and gas mains is a reason for some concern on the part of the companies operating them. If an adjacent main chances not to be connected in this plan of protection its danger will be increased as the high potential gradient will be very much nearer than that from the surface rails. The breaking of a gas main carrying several hundred amperes or a very much smaller current has produced fires and explosions and is a constant menace. Cement, leadite, or high resistance lead joints will cause these increased currents to shunt around them going through the earth path paralleling the joints. Corrosion of the positive side of the joints or of lead has been noted in various instances. In Table 8 showing a series of lead-joint resistances, the observed potentials across these joints indicate that two out of fifty are in danger of joint leakage occurring. Such a percentage of joint failures would make a pipe system worthless and this danger is not confined to the positive area. The railway companies design and install such a system for the protection of the mains. The switching apparatus is placed in an inconspicuous place and receives no further attention since it is not an essential part of the operating equipment. The railway lines change, new power stations are started and the negative return system becomes a positive detriment to the water and gas mains. The operation of equipment by one company for the benefit of another cannot be successful. Several notable examples may be found in American cities to-day, since the negative returns to pipes have been installed in a more or less desultory fashion in many municipalities.

(c) Geppert Patent.

The principle of the Geppert patent as set forth in the "Patentschrift Nr. 211612 Klasse 20K, Groppe 18" is that of a negative return feeder with certain modifications. The positive section of the pipe system is connected to the negative pole of an auxiliary generator (see Fig. 12). The positive pole of this generator is connected to a series of ground plates (Anoden) buried close to the pipes. This has been tested at Karlsruhe with indications that the current was not increased decidedly in the mains (this depending on the relative resistance from anodes to pipe and anodes to rails) and that the pipes were negative to ground.

But this system adds expense decidedly over the com-



Geppert Patent

Fig. 14.

mon negative return system not only in generating and cable equipment, but in excavation along all pipe-lines in the positive area and the interment of the masses of iron used as ground plates and the connection cables. The current discharged from these plates would be much greater than that discharged by the pipes under the former conditions and the necessity of replacing plates and cables would be a difficult and expensive item of maintenance. The addition of rotating machinery whether operated by the railways or by the companies controlling the mains is a complication avoided wherever possible.

(d) Zinc and Lead.

In the potential series of metals lead is positive to iron by about .2 volts and zinc is negative by about .5 volt. This property which causes zinc to discharge the current into an electrolyte when zinc and iron are connected together and are anode, and causes iron to discharge in the case of an iron-lead anode, is the basis for the protection of boilers by zinc plates suspended in the water, the galvanizing applied to iron and steel, and the lead lining for wrought steel tubing. The surface area protected is limited to that near the protecting metal and protection is not complete even in the immediate vicinity if the impressed potential passes a certain value – the potential difference of the metals. The use of these combinations is quite common and the results are favorable. General application to pipe systems is impracticable because of expense and high potentials.

3. Reduction of Efficiency of Corrosion.

(a) Chemicals.

The theoretical amount of corrosion due to the passage of a certain quantity of electricity may be reduced by the presence of chemicals in the electrolyte. Most notable among the materials in common use, cement stands as having properties which cause the efficiency of corrosion of iron to fall to 2 per cent or 3 per cent. Although not an insulator, this lowered efficiency of corrosion, the polarization effects and the formation of a high resistance film with the passage of current make it very desirable for the protection of iron. This is not true of lead since the efficiency of corrosion of lead often rises above 100 per cent when surrounded bycement. There are hydroxides, chromates and many other compounds which allow only a very low efficiency of corrosion or produce passivity of the metal. The efficiency of corrosion in dry soils is found to be very much lower than in wet soils and this is a fact which may be of more general use than the cement and other chemicals' effectiveness in the protection of water and gas mains.

III. Effect of Systems on Bridges and Buildings.

The frequent reports of bridge and building destruction by stray currents which, although often exaggerated, have a very good foundation show that such structures must be protected. Referring to the main divisions of the methods of mitigation "The Elimination or Reduction of Ground Potential Gradients" will protect the steel of such structures except in the case of local stray currents. "The Reduction of Current in the Pipe Systems" will also be effective because the stray currents are found to be received from commonly the pipe systems. In the City of Pittsburgh with its complete system of negative return feeders, currents were found flowing into and out of buildings over the pipes. The pipes were found to be in very close electrical connection with the building frames. The use of waterproofing compounds on the foundation walls, the placing of high resistance blocks of stone under the steel footings, and the separation of the building and bridge pipes from the outside systems by insulating joints is most desirable. To avoid damage due to local circuits, grounds must be avoided.

Conclusion.

A number of other methods or modification of methods could be named and others will be constantly developed, but the fundamental methods and those which have proven most effective have been discussed. No one method is sufficient or practicable in most situations, but a combination of methods which the author believes to be most feasible economically, and effective electrolytically, is added.

The Combination of Methods best:

(a) On New Systems.

A very different course must be followed with systems to be installed and those already in use. In installing a new railway system, the roadbed should be well-drained and solid, either of concrete or rock ballast. This will decrease leakage to ground and assist in the maintenance of track bonding which should be done thoroughly with "cables around special work", as well as at all joints. Good bonds may be made by braizing, welding, soldering, or applying a pressed bond if the work is carefully done. As frequent power stations as the load will justify with small unit plants, and these located in the elevated, dry sections of the city and near the traffic centers where numerous tracks intersect, will tend to reduce the potential gradients to a minimum. Radial feeders may still be necessary in some instances.

In locating new pipes they should be placed as far as possible from the rails and deep when going under them. When the future demand will justify it, a pipe on either side of the street is desirable. But laying the line with cement and lead at alternate joints if a cast iron line, and rubber gasket couplings at every joint if wrought iron or steel, will have much more influence than the other provisions. Laying the line in natural soil avoiding cinders or slag is important on account of natural corrosion.

(b) Old Systems.

The decrease of potential gradients by improving track return, increasing power stations, but most especially by radial feeders to rails, is economical and effective. The insertion of insulation joints at all track and pipe intersections and at frequent intervals throughout the pipe systems will prevent all electrolytic damage.

In closing I wish to acknowledge the suggestions and assistance in obtaining data of the following members of the Bureau of Standards scientific staff.

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