LINE AND TRACK
(PART 2)

RAIL JOINTS

1. No part of electric-railway track construction calls for greater care than the track joints; in fact the life of a track is in most cases limited by the life of the joints. If there is the slightest unevenness or looseness, the pounding action soon flattens the rails at the ends and matters rapidly go from bad to worse. Again, poor joints usually imply poor electrical connection between abutting rails so that in

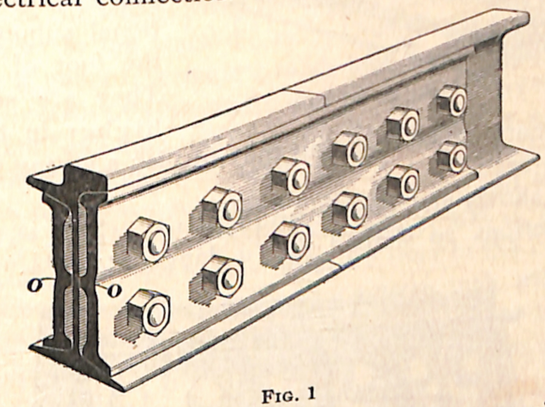


FIG. 1

electric railways, where the track is used as one side of the circuit, good joints are of even greater importance than on steam roads. Electrical contact may be made between the rails by means of copper bond wires or other bonding appliances, but if the joint is not good mechanically the continual movement and jarring will, sooner or later, impair the bond contacts. A great many kinds of rail joint have been

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devised, but it will be possible to describe here only a few of the more important ones.

2. Fish-Plates or Splice Bars.—Fig. 1 shows a standard 12-bolt joint made with two **fish-plates, splice bars, joint plates,** or **channel plates,** as they are variously called. The plates are provided with projecting ribs *O, O,* to prevent buckling when the bolts are drawn up, while flanges at the top and bottom bear against the under side of the head and tram and the upper side of the foot, thus adding to the stiffness of the joint.

3. Base-Supporting Joints.—In order to provide additional strength and stiffness, a number of rail joints have been devised which, in addition to the support furnished by well-fitting joint plates, provide additional support under the foot of the rail. They are somewhat higher in first cost than ordinary splice bars, but they furnish a strong joint and are much used.

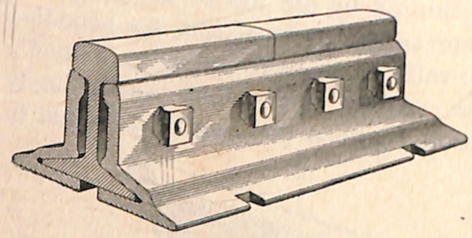


FIG. 2

Fig. 2 shows the **continuous joint,** which is made of rolled sections so shaped that a flange projects under the rail from each side, thus adding to the stiffness and holding the abutting rail ends firmly in line. Fig. 3 shows the **Atlas joint** made of ribbed steel castings; in addition to the usual rail bolts, it has two bolts on the under side. Fig. 4 shows

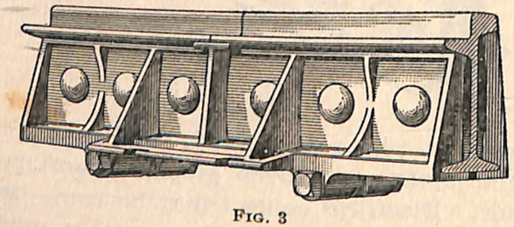


FIG. 3

the **Weber joint;** it is made of two channel plates very similar to those ordinarily used, while in addition a rolled angle is bolted on one side and projects under the foot of the rail. The space between the angle iron and splice bar is filled with a piece of well-seasoned Southern pine that provides a certain amount of elasticity and thus takes up the looseness due to wear on the bearing surfaces of the channel plates caused by small relative movement between the plates and rail.

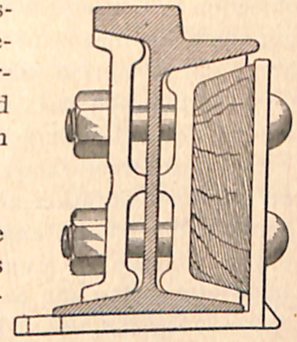


FIG. 4

4. Rail Expansion.—Rails are subjected to considerable variations in temperature, which cause corresponding changes in their length. On ordinary steam roads or on electric roads run where there is no paving, expansion is allowed for byplay in the track bolts. Thus, in cold weather there will be a gap of perhaps $\frac{1}{4}$ to $\frac{5}{16}$ inch between the rail ends while in warm weather there will be scarcely any space at all. Mild steel expands .0000065 of its length for each degree Fahrenheit increase in temperature. Assuming that the extreme difference in temperature that the rail is subjected to is 100° F., a track would be $.0000065 \times 100 = .00065$ of its length longer in the hottest weather than in the coldest.

A stress of 1,000 pounds per square inch will stretch a mild steel bar .00003 of its length. Hence, if a rail is stretched .00065 of its length, the stress in the rail will be $\frac{.00065}{.00003} \times 1{,}000 = 21{,}666$ pounds. If the rails are continuous and firmly anchored so that there is no play at the joints, the track as a whole must expand and contract. The rails will expand with increase in temperature, thus causing compressive stresses; and on contracting with decrease in temperature, the rails will be stretched but the stresses so caused will not exceed 22,000 pounds per square inch under the conditions assumed. A safe value for the elastic

limit of steel is 40,000 pounds per square inch; i. e., steel subjected to any stress below this amount will not take a permanent set but will return to its original length when the stress is removed. If, therefore, a track is located so that it cannot buckle sidewise and get out of line, there is no objection to butting the ends of the rails together and fastening them by means of some form of joint that allows no longitudinal motion whatever. In paved streets this condition is met and it is now a very common practice to use methods of rail joining that give a continuous rail.

In paved streets, the rails are not subjected to such rapid or extreme variations of temperature as on open tracks, because the paving equalizes the temperature to a certain extent. There are a number of types of solid joint, the most important being the *cast welded*, the *electrically welded*, the *thermit*, and the *zinc*. The use of these is confined to paved streets, in cities, where the rails cannot get out of alinement and where the traffic is heavy enough to warrant the expense of such joints. For open trackwork they are not allowable, because provision must here be made for expansion and, even neglecting this, the expense of solid joints would be too great in most cases.

5. Cast welded joints are made by molding cast iron around the abutting ends of the rails, which are first thoroughly cleaned for a distance of 6 or 8 inches, on each side of the joint, by means of a sand blast. A cast-iron mold is then clamped around the rail ends and iron poured in, thus forming a joint, as shown in Fig. 5, where l is the cast iron molded around the rail ends. In order to make these joints, considerable apparatus is required—a portable cupola is needed for melting the iron, and there must also be a sand blast for

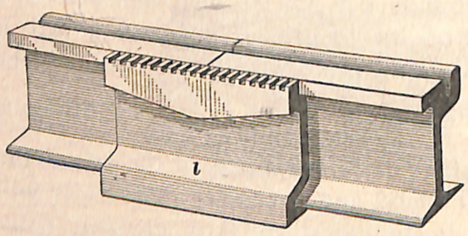


FIG. 5

cleaning the rails. To make the joints at all reasonable in price, a large number must be done at a time. The weight of iron varies from 70 to 225 pounds, depending on the shape of the joint and the section of the rail.

Fig. 6 shows one form of Falk joint; the sides of the cast-iron part are straight, thus making the joint much easier to pave around than when the sides are curved. The weight of iron in the joint shown in Fig. 6, which represents one of the heavier types, is about 170 pounds. In cast welding, the iron is poured at high temperature and it appears to fuse into the surface of the steel rail, thus forming a joint that is strong mechanically and of high conductivity. The conductivity of the joint, as compared with an equal length of rail, depends to

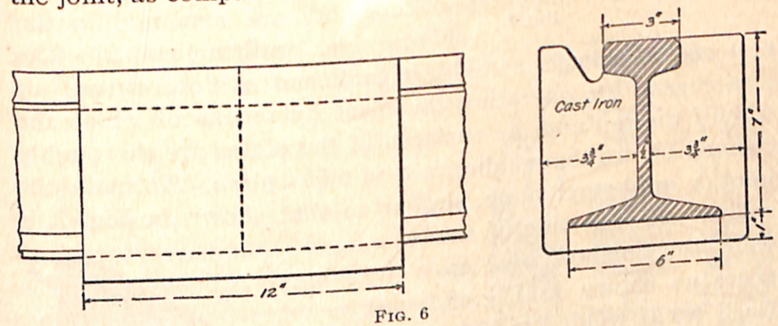


FIG. 6

some extent on the amount of iron used. In some cases the joint resistance may be about 10 per cent. higher than that of a corresponding length of rail, while in others numerous tests have shown that the resistance is as low or even lower than that of the rail. It is claimed by some that cast welding anneals the ends of the rail, thus softening them and causing them to pound or flatten out more than the rest of the rail; but on a number of roads where the cast welded joint has been used for several years no bad effects from this source have been noted.

6. Electrically Welded Joint.—The method of making electrically welded joints as carried out by the Lorain Steel Company consists in welding bars to each side of the web of the rail by passing a very large current through the bars and

rail. Quite an elaborate outfit is required for this process and, like cast welding, it is only applicable where a large number of joints are to be made. The outfit consists of four cars: first, a sand-blast car; second, the car carrying the welder; third, a car attached to the welding car and carrying the transforming apparatus for supplying the welder with current; fourth, a car provided with machinery for grinding off the rail treads after the joints have been welded; the cars are arranged in the order named. The first car contains a sand-blast tank and a motor-driven air compressor for operating the blast by means of which the web of the rail and the surfaces of the plates are thoroughly cleaned before the welding action takes place. To make the joint, a mild-steel plate, similar to that shown in Fig. 7, is welded on each side of the web; the finished joint appears as shown in Fig. 8. Each bar is welded in three places corresponding to the raised parts a, b, c, Fig. 7. The bosses a, b at the ends of the bar are formed under a drop hammer, which forces the metal in on one side and out on the other, the depression in one side being afterwards filled with a piece of metal. The boss at c, which comes opposite the joint between the rails, is made by placing a small strip of steel over the bar. The object of the bosses is to localize the welding current and thus confine the welding to a certain area; each boss has an area of about $3\frac{1}{2}$ square inches so

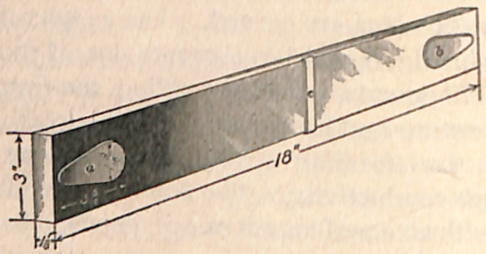


FIG. 7

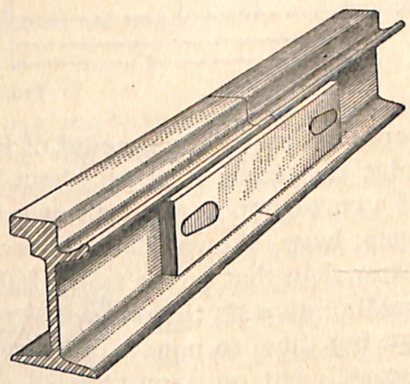


FIG. 8

that the welded area on each bar is about $10\frac{1}{2}$ square inches, or 21 square inches for the two bars. After the rails have been cleaned, lined up carefully, and the bars wedged in position, the joint is ready for welding by means of the electric welder suspended from the front of the second car.

7. The operation of welding will be understood from Fig. 9, which shows the main parts of the welder and their relation to the joint. The two splice bars a, a are located so that the center boss comes opposite the end of rail b. The terminals c, d of the welding transformer e are pressed against the splice bars by means of levers f, g that are pushed apart at their upper ends by pistons working in a hydraulic cylinder h. Just sufficient pressure is applied to hold the bars in place and provide good contact. The secondary of the transformer consists of a single loop of very heavy conductor, so that a very large current at low pressure is delivered. The whole welding apparatus is suspended from a yoke k carried by an arm l extending from the front of the car and arranged so that the welder can be moved in any direction to permit an easy and rapid adjustment to the joint. The primary of the transformer is supplied with alternating current obtained from a rotary converter located in the third car and driven by direct current from the trolley. Suitable regulating devices are provided so that the voltage applied to the welder can be maintained fairly constant, even though the trolley voltage varies considerably.

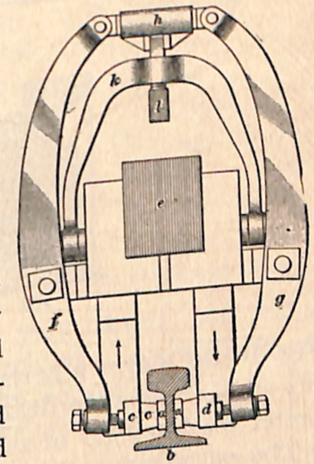


FIG. 9

The weld in the center of the bars is made first. In about $2\frac{1}{2}$ minutes after the current is turned on, the joint is brought up to a welding heat; the current is then cut off and the pressure on the joint increased by the hydraulic cylinder h,

the total pressure applied being about 37 tons. After a few moments, the pressure is released and the welder adjusted to one of the end welds where the process is repeated, only with both end welds, the heavy pressure is maintained until the metal has cooled below a glowing heat; it has been found that this makes the weld tougher. Since the middle weld is made first, the bars become expanded because of the heat, and since the end welds are made before the middle weld has cooled off, the ends of the bars are fastened to the rail while the metal is expanded. Hence, as the bars cool, the ends of the rail are pulled together, thus making a very close joint.

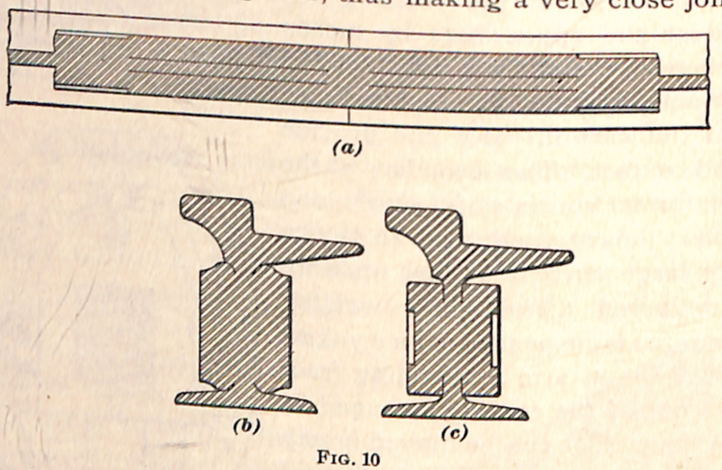


FIG. 10

Fig. 10 (*a*) shows a horizontal section of a completed joint; (*b*) and (*c*) show vertical sections, (*b*) being a section of the center weld and (*c*) of an end weld.

The current supplied to the primary of the transformer is stepped down to a pressure of about 7 volts. The secondary current used for a weld is about 25,000 amperes. The secondary voltage, however, drops somewhat when this large current is flowing so that the power actually taken from the line is not as great as $25{,}000 \times 7 = 175$ kilowatts. As a general rule, about 125 kilowatts for $2\frac{1}{2}$ minutes is sufficient for welding an ordinary joint. On the average, about 80 joints can be made in 24 hours; as a continuous process, working day and night, it takes from 13 to 15 minutes per joint.

8. Numerous tests show that an electrically welded joint of this construction has a resistance less than that of a corresponding length of rail. Table I shows the results of some tests made by the General Electric Company. The rails were a standard 6-inch girder type, about 6.7 square inches in area, and splice bars similar to those just described were used.

TABLE I

RESISTANCE OF ELECTRICALLY WELDED RAIL JOINTS

Joint Number	Resistance Over Joint Ohms	Resistance Over Equal Length of Rail Ohms	Per Cent. Conductivity of Joint Compared With Solid Rail
1	.00001675	.0000279	166.29
2	.00001625	.00002636	162.2
3	.0000182	.00002785	156
4	.0000168	.00002292	136.26
5	.00001559	.0000233	144
6	.00001602	.0000278	177
7	.00001457	.0000238	159
8	.0000196	.0000266	125

The electrically welded joint is very strong, and rails seldom pull apart at the point of welding. Also, the head of the rail is not made hot enough to soften it, and the splice bars do not interfere with the paving.

9. Thermit Joint.—A method of making solid rail joints that has recently come into use is the **thermit process,** invented by Dr. Hans Goldschmidt. It has shown remarkably good results and gives a joint equal to the rail in conductivity. Careful measurements have shown that the wear at the joints after a year's service does not exceed, appreciably, the wear on the rail.

Thermit is a mixture of finely divided iron oxide and aluminum. The metal aluminum has a great affinity for oxygen, and if this mixture is given a local initial heating

by so-called "ignition powder," a very rapid chemical reaction takes place throughout the whole mixture, and a large amount of heat is liberated. The iron oxide gives up its oxygen to the aluminum and aluminum oxide is formed; at the same time the iron oxide is reduced to pure iron. The heat produced by the reaction is so intense that the mass of molten iron has a temperature of about 3,000° C., and if poured around a rail joint a perfect weld will result.

The appliances required for making a joint by this process are very simple and easily moved from place to place; the cost per joint is practically the same whether a few or many are made, and in this respect the process possesses an advantage over cast welding and electric welding, which are practically out of the question if only a few joints are to be made.

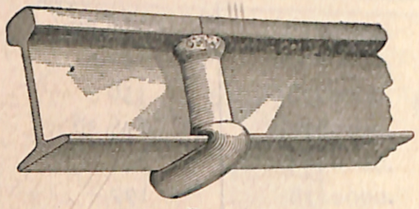
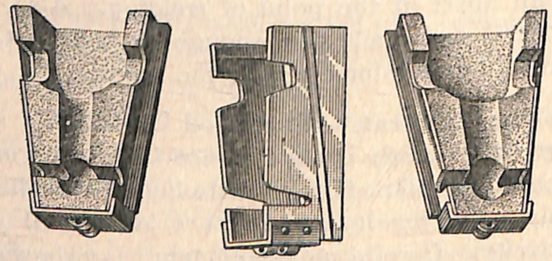


FIG. 11

10. Fig. 11 shows a rail joint made with thermit, and Fig. 12 shows the molds that are clamped on either side of the rail to receive the melted metal. These vary in form according to the shape of the rail section, and are made by placing a sheet-iron case (*b*) over a model, or pattern, of the joint



(*a*) (*b*) (*c*)

FIG. 12

and tamping it full of a mixture of china clay and loam; (*a*) and (*c*) show the molds for the two sides of a rail. The edges of the mold are smeared with clay, so as to form a

tight joint, and the halves are then clamped into position, the ends of the rails being first carefully lined up. The thermit compound is placed in a cone-shaped crucible mounted on a tripod directly over the mold; from 15 to 20 pounds is used for each joint, depending on the size of the rail. The crucible is made of an iron case lined with magnesia, and the bottom is formed of a hard magnesia stone provided with a renewable outlet that will stand from nine to ten runs. The hole in the outlet is stopped by a plug. Dirt on the rail ends is cleaned off by means of a scratch brush, and it is not necessary to use a sand blast. A small amount of ignition powder is placed on top of the thermit and lighted by means of a match; in a few seconds the chemical reaction is over and the lower part of the crucible contains a mass of liquid steel at very high temperature, while the slag (aluminum oxide or corundum) floats on top. The crucible is then tapped by knocking the plug in the bottom upwards and the steel runs into the mold in a $\frac{1}{2}$-inch stream. The weight of steel obtained from the reaction is one-half the weight of the thermit mixture. The mold is made so that the metal strikes the under part of the rail first and works its way up to the top, thus carrying up any dirt or slag that may be present. The steel is so extremely hot that it alloys instantly with the ends of the rail and substances, such as manganese or silicon, are generally incorporated in the thermit mixture, so that the steel has approximately the same composition as the rail. After a few seconds, the metal becomes solid and the molds may be removed.

11. Zinc Joint.—This joint, Fig. 13, is used on a large scale in Philadelphia, and is the invention of Messrs. C. B. Voynow and H. B. Nichols. The channel plates *a*, *a* are similar in their general shape to those used for the continuous rail joint, Fig. 2, except that there is a space left around the foot of the rail and between the upper flanges of the channel plates and the under side of the tram and head of the rail. The rail ends and plates are cleaned with a sand blast, after which the latter are bolted in position by two temporary

bolts and the holes reamed to a uniform size of $1\frac{1}{32}$ inches by means of a portable pneumatic reamer. The plates are then fastened by twelve 1-inch steel rivets driven by a pneumatic riveter. The riveting process expands the rivets so that the holes are filled tightly. Clamps are then put in position to hold asbestos cloth pads that cover the bottom and ends of the plate; the spaces between the head and tram and plates are calked temporarily with asbestos cloth. The whole joint is then heated by means of portable fuel-oil burners until the temperature is raised to 300° or 400° F., after which molten zinc is poured through a 1-inch hole located in the center of the foot of the plate; space *b* is

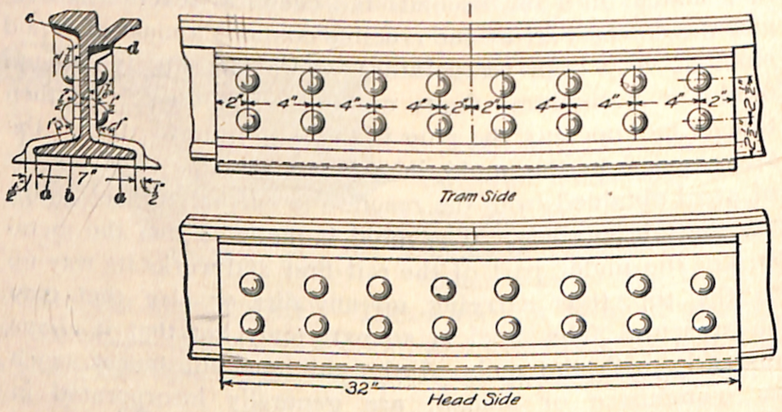


FIG. 13

thus filled with zinc. Dams made of castings padded with asbestos cloth are then arranged around the top of the rail, and spaces *c*, *d* also filled with zinc. This makes a very rigid joint, which allows none of the slight rubbing action that occurs in all bolted fish-plate joints and which sooner or later loosens them. Since the iron surfaces are first thoroughly heated, the zinc attaches itself to the clean iron surfaces, which become galvanized, thus forming a very good electrical contact. Tests have shown that the resistance, after 2 years of continuous use under heavy traffic, is less than that of an equal length of rail. From $22\frac{1}{2}$ to 26 pounds of zinc is required for a joint similar to that shown in Fig. 13.

Outside of the cost of the zinc and the labor of preparing the joint and pouring the metal, the cost of this joint is little more than that of an ordinary one with bolted channel plates.

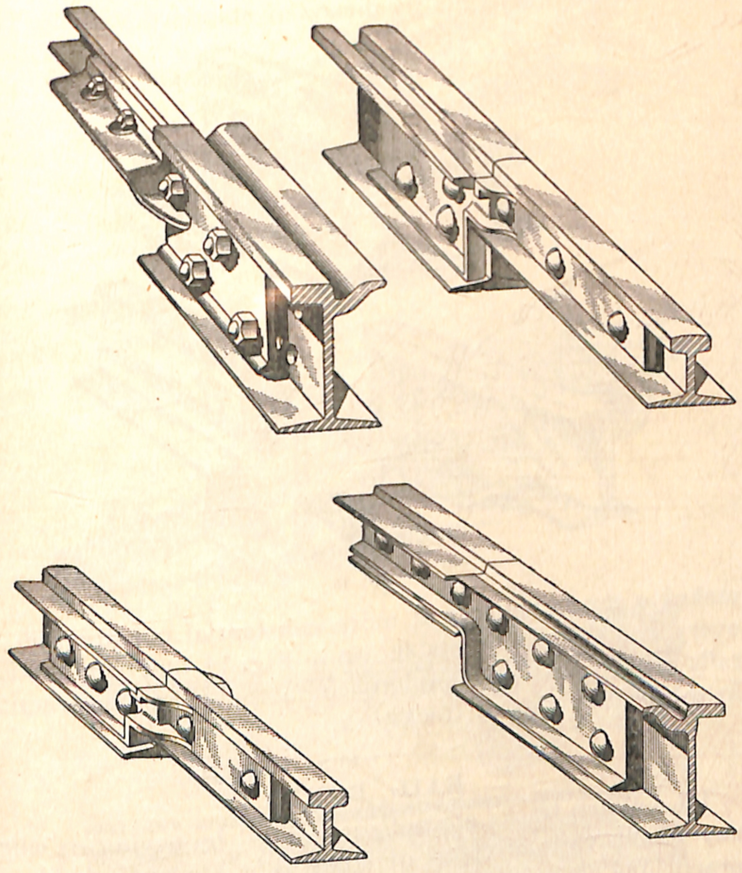


FIG. 14

12. Combination Joints.—Where a rail of one section is to be joined to another of different section, a **combination joint** is used; these can be made by using either special splice bars or by means of a section of special rail in the form of a steel casting. Fig. 14 shows four combination

joints where T rails are joined to girder rails; the special splice bars may be forged or made of cast steel.

Fig. 15 shows three forms of combination rail of cast steel. These can be obtained in any desired length and are joined to the other rails by means of standard joints. This

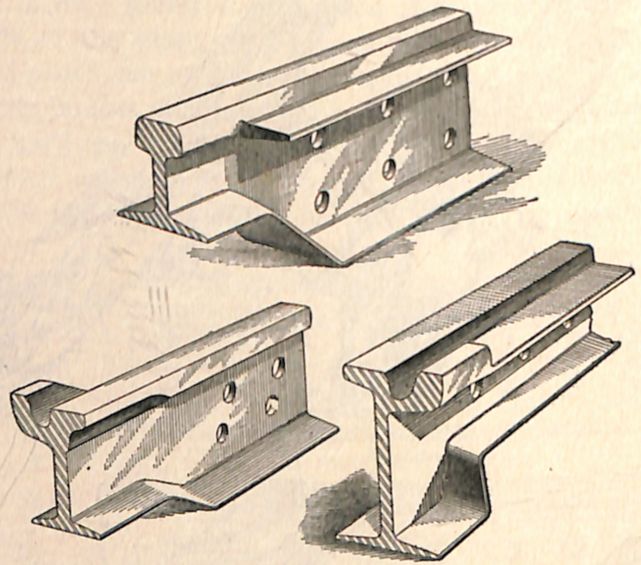


FIG. 15

makes a much better and more substantial construction in every way than the joints shown in Fig. 14, and combination rails are now used in preference to the older construction in the best grades of trackwork.

RAIL BONDS

13. When tracks are not surrounded by paving or when any of the various types of solid joint are not considered practicable on account of cost, the ordinary fish-plates must be supplemented by connections, or **rail bonds**, that will carry the current from rail to rail. The fish-plates cannot be depended on to carry the current, because they soon become loose or rusty and offer a high resistance. A great many styles of rail bond are in use so that it will be possible to describe here only a few typical examples. No matter what

type is used, it must always be remembered that if a joint is mechanically poor, the continual movement and pounding

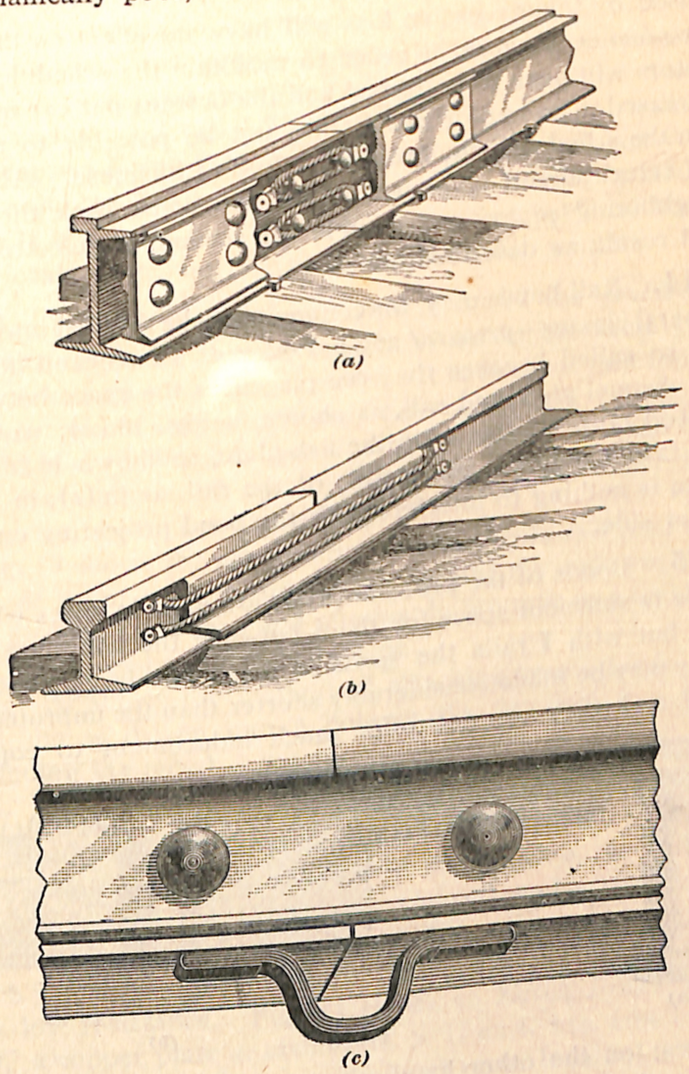


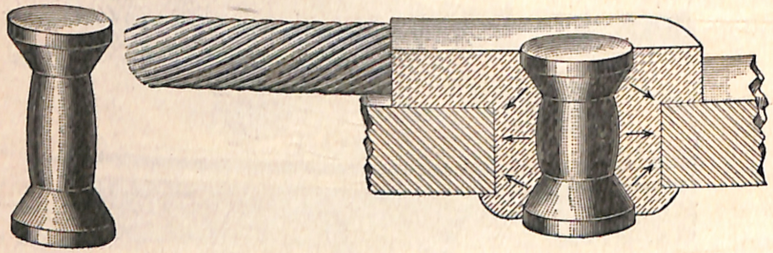
FIG. 16

will sooner or later decrease the efficiency of the bond. It is highly important therefore that the joints be kept in good condition.

If a track is poorly bonded, there will be a continual loss of power due to the resistance at the joints. Low voltage caused by this excessive loss will have its effect on the car equipments, because in order to maintain the schedules the motors will have to be forced and the current per car will be increased. In some cases it may not be possible to maintain the schedules, thus causing a loss of business. Also, if the return circuit is poor, current will come back through neighboring pipes, and trouble on account of electrolysis will result, as described later.

14. Rail bonds may, for convenience, be divided into two general classes—*protected* and *unprotected*. **Protected bonds** are so called because they are placed in the space between the channel plate and rail, as shown in Fig. 16 (*a*); **unprotected bonds** either span the fish-plate, as shown in (*b*), or are fastened to the under side of the rail, as in (*c*), in case there is nothing to interfere with the bond projecting on the under side.

15. Bonds of the protected type are used in cases where there is sufficient space for them between the fish-plate and rail, but with T rails the space is often not large enough. They may be made considerably shorter than the unprotected type and they do not offer much inducement to copper



(*a*) (*b*)

FIG. 17

thieves; on the other hand, short bonds less than 6 inches in length are liable to give trouble from breakage. The bonds shown in Fig. 16 (*a*) and (*b*) are of the General Electric type, made by casting copper terminals on a stranded copper conductor. The copper is cast around

an iron plug of the form shown in Fig. 17 (*a*), and after the terminal has been fitted in the web of the rail the plug is compressed to the form shown in (*b*), thus forcing the metal out against the wall of the hole, as indicated by the arrows, and providing a very firm contact between the terminal and rail. The bond, Fig. 16 (*c*), is made of thin copper strips soldered together at the ends so as to form solid terminals, which are attached to the rail by soldering. It has been found in some cases that soldered bonds deteriorate when they are in contact with damp earth.

16. Fig. 18 shows a protected bond of the *double-loop type* shaped so as to give flexibility and at the same time allow openings for the track bolts. It is made of thin copper strips on which copper terminals have been cast. After the terminals *a*, *b* have been passed through the holes in the rail, they are compressed by a special screw compressor that forces the metal out sidewise.

Fig. 19 shows the construction of an *all-wire rail bond* that is made up of copper cable cut to length; the ends are then cold pressed as shown, and afterwards brought to a welding heat and forged to their final shape.

Fig. 20 shows the method of attaching *crown bonds*. A steel pin is driven into a hole in the terminal lug, thus expanding the metal.

17. Solid Copper Protected Bonds.—Very satisfactory results in rail bonding have been obtained by using solid plates pressed firmly against the rail web, the contact surfaces being first thoroughly cleaned and coated with copper-mercury amalgam of about the consistency of putty, which adheres to the surfaces and makes a connection of very low resistance. Fig. 21 shows an *Edison-Brown solid bond;* a copper plate *a*, about 3 in. × $1\frac{1}{2}$ in. × $\frac{1}{8}$ in. (the exact dimensions vary with the style of rail to be bonded) is held tightly against the rail when the fish-plates are bolted up. Plate *a* has two depressions and two corresponding bosses on the opposite side, that form the contact surfaces; the plate is covered by a thin steel sheet *b* against which a

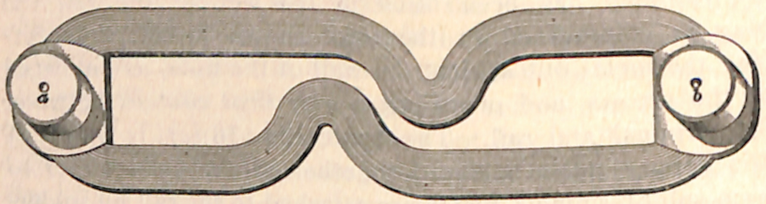


FIG. 18

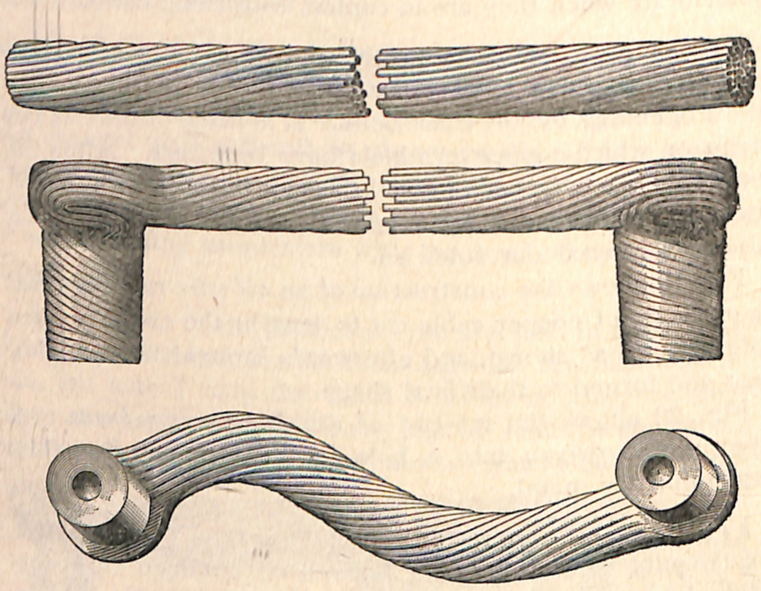


FIG. 19

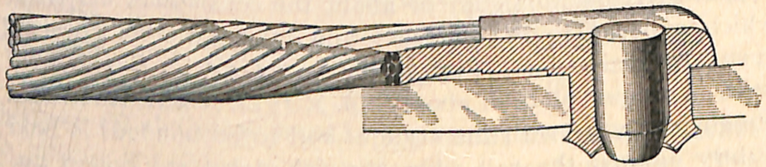


FIG. 20

spring washer *c* bears. The rail is first brightened by means of an emery wheel and the contact surfaces then amalgamated and covered with a thin layer of the alloy. The plate is surrounded by a cork *d*, treated with linseed oil, which, when compressed by the fish-plate, forms a seal around the bond that remains tight even when the fish-plate is loosened considerably. Joints made with amalgam have, after several years of operation, been taken apart and the contact surfaces found to be as bright as when first installed.

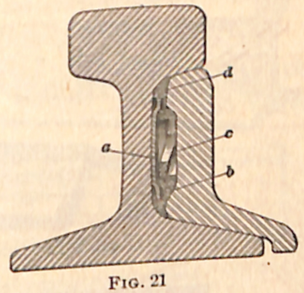


FIG. 21

The *Ajax* solid copper-plate bond, Fig. 22, consists of a piece of copper *a* protected by a steel sheet *b* against which bear cup-pointed setscrews *c*, *c* tapped into plate *d*. The contact surfaces on the rail are first ground off and both rail and bond treated with Edison-Brown amalgam.

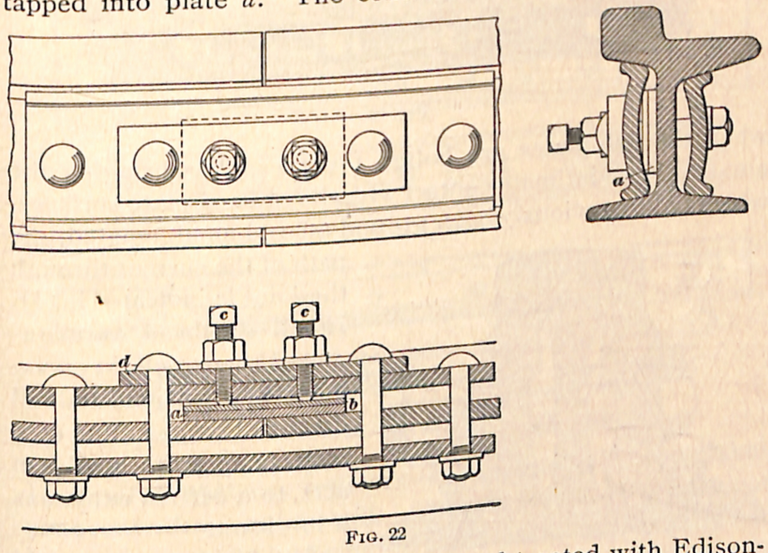


FIG. 22

18. Plastic Bond.—Where the fish-plates or channel plates are of large cross-section they can be made to serve as

a bond by providing good contact between the plates and rail. Fig. 23 shows an amalgam bond for this class of work; the plastic amalgam *a* is held in a cork case, which is compressed

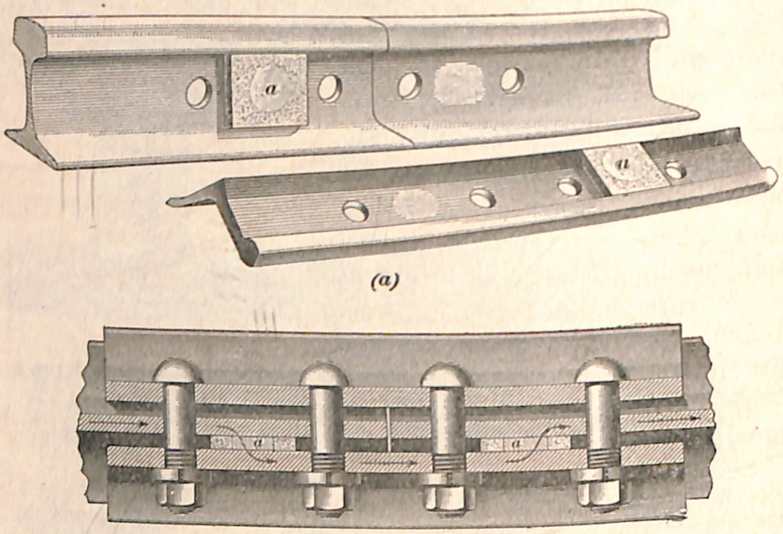


FIG. 23

when the fish-plates are bolted together, thus bringing the amalgam into intimate contact with the rail and plate surfaces, which have previously been ground off and amalgamated; the path of the current through the joint is indicated in (*b*). In all of these amalgamated bonds a slight movement between bond and rail does not impair the contact; in fact the amalgam acts, to a certain extent, as a lubricant.

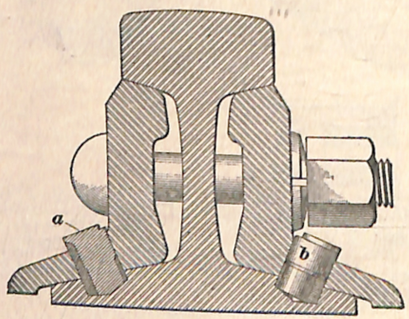


FIG. 24

Fig. 24 shows a method of bonding T rails with plastic plug bonds. The fish-plates provide the connection between the abutting rails, and electrical contact is made by means of copper plugs *a*, *b*, T-shaped in section, that are well

amalgamated and also dip into amalgam placed in the hole. The plugs are afterwards locked in place by burring over with a hammer and blunt chisel. The lower part of the plug is considerably smaller than the hole, so that a certain amount of relative movement between the angle plate and rail can take place with variations in temperature.

19. Wire Bond With Amalgamated Contacts. Fig. 25 shows three styles of bond, devised by Mr. W. E.

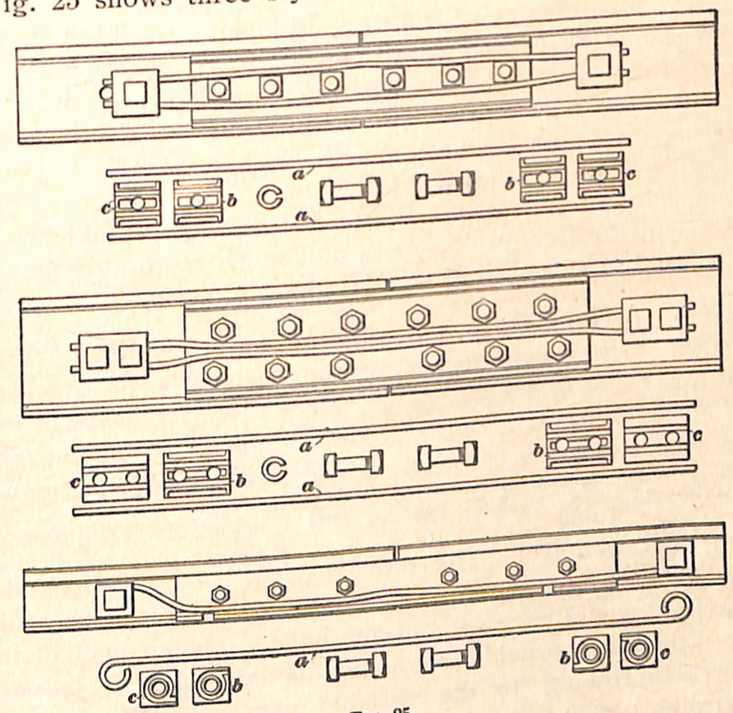


FIG. 25

Harrington, that use ordinary 0000 copper wire for making connection from rail to rail. The wires *a*, *a* are held in contact with the rails by being clamped between two plates *b*, *c* provided with grooves to receive the wires. The contact surface on the web is ground off and covered with plastic amalgam, and an amalgamated cast copper plate is placed against the web of the rail; after the grooves in the casting

and the ends of the wire have been well covered with alloy, a cast-iron plate is placed on top and the whole drawn up tightly by a 1-inch bolt provided with a spring lock washer. Bonds of this type are easily applied; the contacts do not deteriorate, and tests have shown that the resistance across the joint is no greater than that of a corresponding length of rail, provided the bonds are properly proportioned with regard to the rail section.

20. Resistance of Bonds.—In making track joints, the aim should be to keep the electrical resistance at least as low as the resistance of a corresponding length of rail. It is not difficult to do this with a new joint, but the constant jarring and slight movements to which the bonds are subjected will often cause a great increase in resistance. Poor connections from rail to rail are just as detrimental as poor joints in the overhead feeders and much more attention is now paid to efficient rail bonding than formerly.

21. A No. 0000 B. & S. wire has a cross-section of .1662 square inch which, assuming the resistance of steel as 10 times that of copper, is equivalent to 1.662 square inches of steel. A bond 1 foot long connecting two 60-pound rails (6 square inches cross-section) will have a resistance equal to that of $\frac{6}{1.662} = 3.61$ feet of rail, neglecting resistance at the bond contacts. The total resistance of a joint is the resistance of the bond in parallel with the resistance that the joint would have without any bond. The channel plates or fish-plates provide some conductivity, but it is very uncertain owing to the variable nature of the contacts between plates and rail. If the work is done carefully, the resistance as measured across the fish-plates and bond, say 3 feet of rail, can be kept as low as the resistance of 3 feet of solid rail. It is necessary, of course, to proportion the bonding according to the weight of the rail; for example, a 90-pound rail should be bonded heavier than a 60-pound, either by using a heavier bond connection or, preferably, by providing two or more bonds at each joint.

TABLE II

LENGTHS OF RAIL EQUAL IN RESISTANCE TO BOND 1 FOOT LONG

Weight of Rail Pounds per Yard	Cross-Section Square Inches	Equivalent Cross-Section of Copper Square Inches	Feet of Rail Equal in Resistance to Bond 1 Foot Long Assuming Resistance of Steel = 10 × Resistance of Copper							
			Single No. 0000 B. & S.	Two No. 0000 B. & S. in Parallel	Single No. 000 B. & S.	Two No. 000 B. & S. in Parallel	Single No. 00 B. & S.	Two No. 00 B. & S. in Parallel	Single No. 0 B. & S.	Two No. 0 B. & S. in Parallel
40	4	.4	2.41	1.21	3.04	1.52	3.82	1.91	4.82	2.41
45	4.5	.45	2.71	1.36	3.41	1.71	4.31	2.16	5.42	2.71
50	5	.5	3.01	1.51	3.79	1.89	4.78	2.39	6.03	3.02
55	5.5	.55	3.31	1.66	4.17	2.09	5.26	2.63	6.63	3.32
60	6	.6	3.61	1.81	4.55	2.28	5.74	2.87	7.24	3.62
65	6.5	.65	3.91	1.96	4.93	2.47	6.22	3.11	7.84	3.92
70	7	.7	4.21	2.11	5.31	2.66	6.70	3.35	8.44	4.22
75	7.5	.75	4.51	2.26	5.69	2.85	7.18	3.59	9.04	4.52
80	8	.8	4.81	2.41	6.07	3.04	7.65	3.83	9.65	4.83
85	8.5	.85	5.11	2.56	6.45	3.23	8.13	4.07	10.25	5.13
90	9	.9	5.41	2.71	6.82	3.41	8.61	4.31	10.85	5.43
95	9.5	.95	5.71	2.86	7.21	3.61	9.09	4.55	11.46	5.73
100	10	1.00	6.01	3.01	7.59	3.79	9.57	4.79	12.06	6.03
105	10.5	1.05	6.31	3.16	7.96	3.98	10.05	5.03	12.66	6.33
110	11	1.10	6.61	3.31	8.34	4.17	10.52	5.26	13.27	6.64
115	11.5	1.15	6.91	3.46	8.73	4.37	11.01	5.51	13.87	6.94

22. Table II shows the lengths of rail that are equal in resistance to bonds of various sizes 1 foot long. Thus, if a 70-pound rail is bonded with two No. 0000 bonds, each 1 foot long, the resistance of the bonds is equal to that of 2.11 feet of rail, assuming that the resistance between bonds and rail is negligible and that steel has a resistance 10 times that of copper.

23. The cost of bonds for a given piece of track is such a small item, compared with the total cost, that it pays to be liberal when installing them. Table III shows the resistance of a number of types of bond as measured by Mr. W. E. Harrington. These tests show that it is advisable to use amalgam on bond contacts even with those types of bond that were originally designed for use without amalgam.

24. Cross-Bonding.—It is necessary to cross-bond the rails at certain intervals so that a break in one or more joints may not seriously impair the conductivity of the return circuit. For example, consider a single-track road where the two rails are bonded throughout but not connected to each other. If a break occurs at a given joint, the portion beyond the joint is of no use in aiding as a return for the current and an additional load is thrown on the other rail. If, however, the rails are cross-connected at intervals, the current can flow around the break and only a small section of the rail is cut out. On double-track roads all four rails should be connected together. Cross-bonding, with No. 0000 copper, should be provided at least every 500 feet; tinned wire is very commonly used for this purpose. For similar reasons, the current should be carried around all switches, frogs, and special work by means of heavy bond wires (250,000- or 500,000-circular-mil cable). Joints in special work are liable to work loose because of the pounding, and it pays to take extra precautions in the bonding at all such points on the road.

25. Return Feeders.—It is usually necessary to connect the track to the negative bus-bar in the power house by

TABLE III

RESISTANCE OF RAIL BONDS

No.	Kind of Rail	Kind of Bond	Distance Center to Center of Bond Contacts Inches	Length of Bond Inches	Size of Contact	Size of Bond B. & S.	Number of Wires	Resistance Ohms
1	7-inch girder, Pennsylvania Steel Co. Sec. No. 238	Iron channel pin	45	48	$\frac{9}{16}$-in. pin	0	1	.00071
2		Crown	30	36	$\frac{7}{8}$-in. head	0000	1	.000247
3		Crown (amalgamated)	30	36	$\frac{7}{8}$-in. head	0000	1	.000185
4		Columbia	30	36	$\frac{7}{8}$-in. head	0000	1	.000131
5		Columbia (amalgamated)	30	36	$\frac{7}{8}$-in. head	0000	1	.000126
6		Stranded crown	5	7	$\frac{7}{8}$-in. head	0000	1	.0001
7		Plastic socket	$3\frac{1}{2}$					.000093
8		Ajax bond		$8\frac{1}{2}$	$8\frac{1}{4}$-sq. in.	$\frac{1}{4}$-sq. in. section		.000041
9		Solid rail (no joint)	24					.000024
10		Joint only (no bond)	24					.00071
11	60-lb. T	Ajax (double)	30					.00004
12	60-lb. T	Solid rail (no joint)	30					.000035
13	9-in. girder	Ajax	24	$5\frac{3}{4}$	$5\frac{3}{4}$-sq. in.	$\frac{3}{8}$-sq. in. section		.000031
14		Solid rail	24					.00002

means of a number of return feeders; these are very often attached to the rails by bond connections similar to regular rail bonds.

Fig. 26 shows a return feeder attached by means of a cast-iron terminal and plastic bond; terminal *a* holds the cork case against the web, forming a receptacle into which are

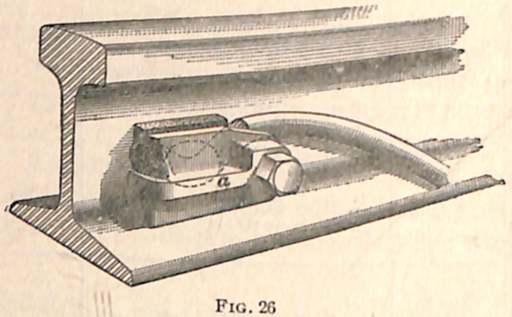


FIG. 26

placed the end of the wire and some of the plastic alloy. The cable end and the spot on the rail are also amalgamated and the casting is bolted to the rail by a $\frac{3}{4}$-inch bolt that is afterwards riveted over to prevent loosening. Similar terminals are used for loops around special work. Fig. 27 shows an electrically welded or brazed feeder cable connection; a copper block *a* about 4 inches square and $1\frac{1}{2}$ inches thick is provided with a groove on one face to take the cable when the block is placed against the rail, as shown. A steel plate *b* is placed over the block, and the cable and blocks brazed to the rail by means of the electric welder. Hard spelter is used, and by this means a 500,000-circular-mil cable can be attached to the rail so that the carrying capacity at the contact is fully as good as that of the cable.

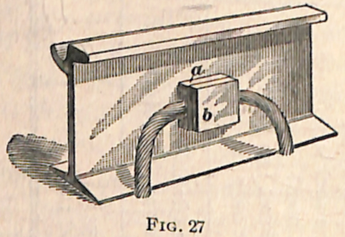


FIG. 27

At one time, it was customary to run a ground conductor parallel to the rails and tap it to them at frequent intervals in order to improve the conductivity of the return circuit. If

the rails are properly bonded so as to take full advantage of their conductivity there is no need of such an auxiliary wire and its use has been practically abandoned; the money may be used to better advantage in improving the rail bonding.

BOND TESTING

26. No matter how well a track may be bonded, tests should be made frequently to see that the bonds are in good condition. This is especially necessary around railroad crossings, special work, or wherever low joints are noticed. It is not necessary to measure the actual resistance of each joint; comparative readings are all that is required. For a given class of bonding, the resistance of a joint in good condition as compared with a certain length of rail is known, and it is only necessary to measure the resistance of the joint in terms of rail length; any joints showing an abnormally high resistance can then be investigated. Usually 3 feet of rail is taken as the standard and the resistance, measured between two points 18 inches on either side of the joint, is compared with that of 3 feet of rail. For example, the bonding may be such that a joint in good condition has a resistance perhaps slightly over that of 3 feet of rail, and if a test showed that the resistance were over twice that of the standard rail length, the bonding would be considered poor.

27. Drop-of-Potential Test.—The simplest method of testing for poor bonds is by measuring the drop across the joint by means of a millivoltmeter and comparing this with the drop across 3 feet of rail. Fig. 28 shows a method of doing this very rapidly and accurately by means of a test car especially fitted up for the purpose. A wooden beam *a* is suspended underneath the rear car platform so that it will be a few inches above the rail. A spring is arranged to press down on the beam and means are also provided for raising it when not in use. To the under side of the beam are attached two stiff copper brushes *b*, *b'*; these are made of several leaves of sheet copper and are set on a slant, as shown, so that they will slide easily along the rail and make

a good running contact. They should have at least 1 square inch contact surface with the rail; high-contact resistance will have a marked effect on the accuracy of the millivoltmeter readings. A resistance c is carried on the car so that a large steady current can be made to flow through the track; resistance wire wound on a frame and submerged in a barrel of water is capable of carrying a large current and furnishes a resistance that is fairly constant.

In making bond tests, it is best to pass sufficient current through the joints to give good readable deflections on the millivoltmeter and the current used to propel the test car, or that taken by other cars on the line, is not usually large

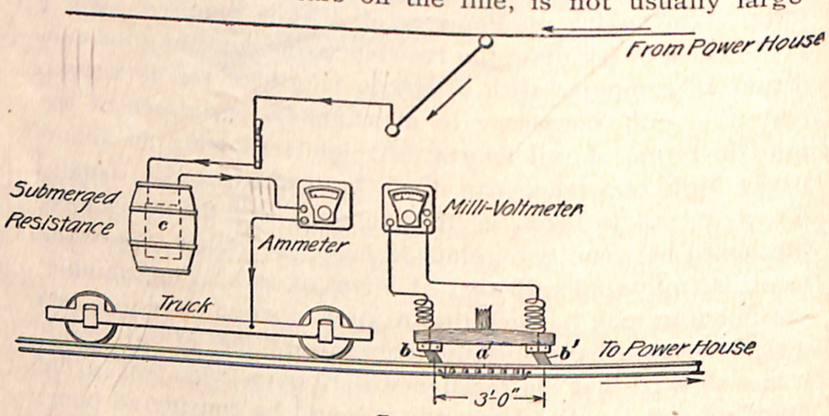


FIG. 28

enough or steady enough for the purpose. The current flows from the trolley, through the resistance and ammeter to the truck and rails, and thence back through the track to the power house. The brushes b, b' are placed 3 feet apart, and as the car moves slowly over the track the brushes span the joints in succession. A millivoltmeter is connected to the brushes, and when the brushes are as shown in Fig. 28 it indicates the drop across the joint. When the brushes are not on a joint, the voltmeter reading is the drop across 3 feet of solid rail. Since the current in the rail is the same as that in the joint, the voltmeter readings are proportional to the resistances of 3 feet of rail and 3 feet including the joint. The car can also be fitted with another set of brushes

over the other rail, this set being connected to a second voltmeter; tests of the bonds on both sides of the track can thus be made at the same time. The rheostat is adjusted so that a normal joint will give a good readable deflection and the car is then run slowly over the line, any joints that give abnormally high readings can thus be quickly located, marked by ejecting whitewash on the track, and afterwards examined.

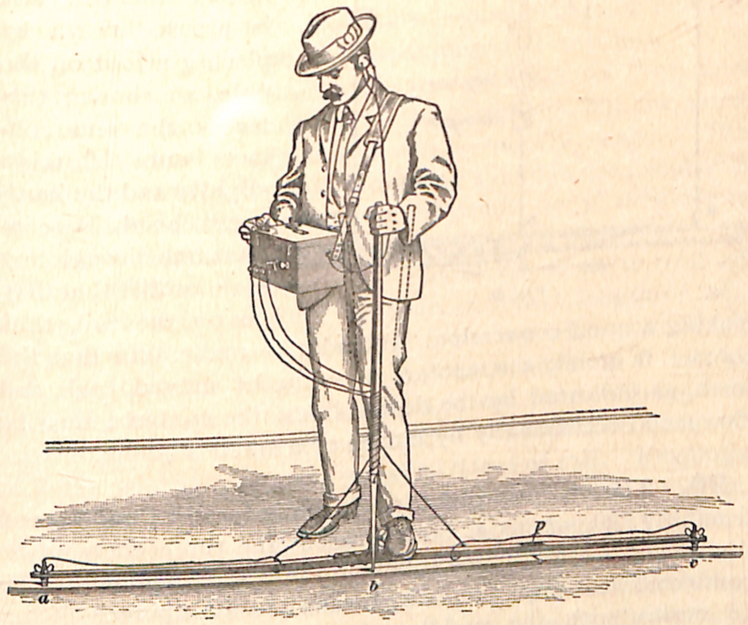


FIG. 29

The test should preferably be carried out at some time when traffic is light so as not to interfere with the regular operation of the cars.

28. Conant Bond Tester.—The method of testing devised by Mr. R. W. Conant, while it is not as rapid as the one just described, is very useful where a moderate number of joints are to be gone over. Fig. 29 shows the method of using the instrument. A T-shaped pole is provided with three hardened-steel knife-edge contacts a, b, c, and

when the pole is placed on the rail as shown, contacts b, c span the rail joint and a, b span 3 feet of solid rail, plate p being placed over the joint. The pole is made of tough wood that has considerable spring to it and when the two end contacts rest on the rail, the center contact is 1 or 2 inches above the rail and is pressed down by placing a foot on the pole, as shown; this forces the end contacts out sidewise slightly and the hardened chisel-like contacts cut through any scale or dirt that may be on the rail, thus making a good connection. In order to make sure that the contact is good, the center pole can be moved back and forth, as indicated by the dotted lines; the contacts must be sharpened occasionally by means of a small oilstone.

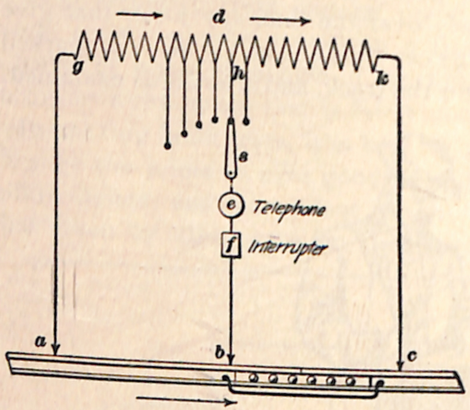


FIG. 30

29. The operation of the instrument will be understood from Fig. 30, where a, b, c represent the three contacts on the rail; d is a resistance to which the central contact can be connected at various points by means of a multipoint switch s. In series with the middle wire is included a telephone receiver e and an interrupter f consisting of a clockwork mechanism that drives a toothed contact wheel on which presses a small contact spring. The instrument works on the principle of a Wheatstone bridge and is operated by current obtained from the rail.

Assume that the rail current is represented by the heavy arrow; it will be the same in the section of rail $a\,b$ and in the joint $b\,c$ and will fluctuate according to the number of cars in operation beyond the joint. Resistance d being shunted across the rail and joint, part of the current will

flow as shown by the small arrows. If the rail section $a\,b$ is equal in resistance to the joint $b\,c$ and if switch s is so placed that resistance $g\,h$ is equal to $h\,k$, there will be no current in the middle wire and no sound in the telephone because points h and b will be at the same potential. If the joint has a greater resistance than the rail section, a balance can be obtained by moving the switch to the left, thus virtually shifting point h along the resistance until the drops through the two resistance sections become equal to the drops through the corresponding rail sections. It is hardly possible to obtain such an exact balance that there will be no sound whatever in the telephone, but the point where the sound is a minimum can be quickly located. The interrupter is used to make a clicking sound in the telephone; fluctuations in the railway current would not in themselves be regular enough to give an easily detected sound.

The contacts of switch s are numbered so as to read off the resistance of the joint in terms of 3-foot length of rail. Thus, if a balance is obtained with the switch on point 1 it indicates that the joint has a resistance equal to 3 feet of rail. If a balance is obtained on 1.5, the joint resistance is equal to 1.5×3 or 4.5 feet of rail; if a balance is obtained on 2, the joint resistance is equal to 6 feet of rail. Readings from 1 to 2 are considered as indicating good bonding; readings on points 3 or 4 indicate poor bonding; all readings above 4 indicate bad bonding. For any given class of bonding, the point at which the switch should give a balance for a good joint is known, and bad joints can be easily located. Good bonding will never have a resistance greater than twice the same length of rail, and in the better class of work it will not exceed 1 to 1.5 times an equal length of rail; in fact, if proper care is taken there is no reason why the joint resistance should not be less than that of a 3-foot rail length, particularly if solid rail joints are used.

30. Table IV shows the results of some tests on different bonds made by the method shown in Fig. 28.* They were

* W. E. Harrington, Journal of the Franklin Institute, Vol. CLVII.

TABLE IV

RESULTS OF RAIL-BOND TESTS

No.	Trade Name of Bond	Trade Name of Rail Section	Line Voltage	Amperes Used	Drop Across 3-Foot Section of Rail (Millivolts)	Drop Across 3-Foot Section Including Bond (Millivolts)	Ratio Resistance of Bond to Rail	Date Placed	Style of Joint
1	C. & S. No. 1 (See Fig. 25)	9-inch girder Pennsylvania Steel Co. Sec. 200	550	200	28	12	.43	1899	Regulation fish-plate
2	C. & S. No. 2 (See Fig. 25)	9-inch girder Pennsylvania Steel Co. Sec. 200	545	220	27	15	.55	1900	Regulation fish-plate
3	C. & S. No. 3 (See Fig. 25)	4½-inch T Pennsylvania Steel Co. Sec. 237	540	150	30	12	.40	1901	Regulation fish-plate
4	Bryan	7-inch girder Pennsylvania Steel Co. Sec. 238	550	200	25	14	.55	1900	Regulation fish-plate
5	Flexible plug	4½-inch Wharton	425	140	40	80	2.00	1900	Regulation fish-plate
6	Crown plug	6-inch Wharton	430	150	24	75	3.12	1896	Regulation fish-plate
7	Trenton plug	6-inch Wharton	430	155	25	78	3.12	1898	Regulation fish-plate
8	Cast weld	9-inch girder Pennsylvania Steel Co. Sec. 200	555	200	28	12	.43	1898	Cast weld Wharton
9	Plastic Edison-Brown	9-inch girder Pennsylvania Steel Co. Sec. 200	550	200	27	18	.66	1896	Regulation fish-plate
10	Flexible U bond	7-inch girder	460	180	28	35	1.25	1899	Regulation fish-plate
11	Ajax	9-inch girder Pennsylvania Steel Co. Sec. 200	560	160	29	26	.90	1900	Regulation fish-plate

made in September, 1903, so that the bonds had been in use for periods ranging from 2 to 7 years.

31. Testing Resistance of Track-Return Circuit. After a road has been in operation some time, it is often found that the drop on certain sections is larger than it should be and the question naturally arises as to whether the track return is at fault or whether more copper is required in the overhead feeders. To find this out, it is necessary to know the comparative resistances of the two; if the track resistance is high compared with that of the overhead line, additional return feeders should be run and vice versa.

Fig. 31 shows one method of measuring the resistance of a railway circuit; FF is the feeder running out to the section under consideration and RR the rail return. A time

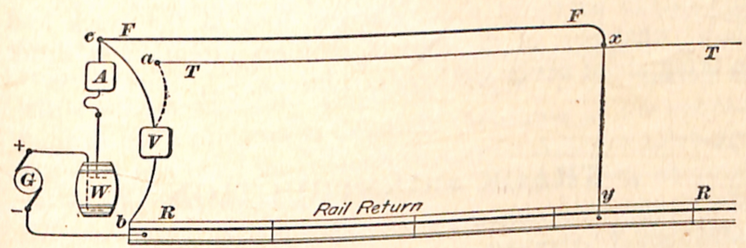


FIG. 31

is selected at night, when traffic can be kept off the section for a short time, and a water rheostat W is connected in series with the feeder F and the regular feeder ammeter A. The feeding-in point x is connected to the track as shown at xy, and a steady current sent through the circuit $G+-W-A-c-F-F-x-y-R-G-$. The drop through the entire feeder and rail circuit is measured by a voltmeter V connected to c and b. From the readings of A and V, the total resistance of the feeder and rail circuit is at once determined. The resistance of the feeder FF can be calculated from its known length and cross-section, and its resistance subtracted from the total resistance of the circuit will give the resistance of the track return.

The above method of finding the resistance of the track return assumes that there are no bad joints or unusually poor conductivity in any part of the feeder FF, but such is not always the case. If the trolley wire runs back to the power house or if there is another feeder near by that can be used as a pressure wire, the drops in the feeder and track can be measured separately and an accurate idea gained as to just how the drop is distributed. For example, if the upper voltmeter terminal is connected to the end a of the trolley wire instead of to c, the reading obtained will be the drop through the track alone, because the voltmeter takes such a small current that there will be practically no drop through Tx. If one terminal of the voltmeter is connected to c and the other to a, the reading obtained will be the drop in the feeder FF. This method is the one to be preferred, because it at once gives an accurate comparison between the loss in the overhead work and the loss in the track and shows what part of the system requires attention in order to bring about better working conditions.

TRACK CONSTRUCTION

GENERAL FEATURES

32. The kind of track construction to be used for a given road will depend largely on where the road is located, and the allowable cost. If the soil has a very poor bottom, the subwork of the roadbed must be much more substantial than where the soil is firm or where there is a rock bottom. Again, in some places provision must be made for draining the roadbed.

33. Ties.—The woods most commonly used for ties are white oak, red oak, cedar, chestnut, yellow pine, hemlock, and spruce; oak is used more than any of the others. Ties for a standard gauge (4 feet $8\frac{1}{2}$ inches) road are usually 6 in. × 8 in. × 8 ft. and are spaced from 2 to $2\frac{1}{2}$ feet between

centers. In some classes of trackwork in paved streets, where the tracks are largely supported by concrete, the spacing of the ties may be much wider than that required for an open track; in fact, in certain classes of construction, ties are dispensed with altogether, the rails being held to gauge by means of tie-rods spaced about 10 feet apart.

The life of a tie depends much on climatic conditions and the material in which it is bedded. Under ordinary conditions, sound oak, cedar, or chestnut ties should last from 8 to 10 years, while pine, hemlock, and spruce will last from 4 to 6 years. Ties, when completely covered, deteriorate much more rapidly than when partly exposed; when they are raised on stone ballast, the drainage is much more perfect than when buried in earth, and the life is much longer.

34. Arrangement of Joints.—In placing the rails, opinion is divided as to how the joints should be disposed; some engineers prefer putting the joints opposite each other, while others advocate staggering them, i. e., making the joint in one rail come in line with the center of the opposite rail. It has been the general custom in America to stagger the joints, but the use of opposite joints is now becoming more common, as many engineers are strongly of the opinion that they are much to be preferred to staggered joints. When staggered joints are in bad condition, the car acquires a disagreeable side-rolling motion very much like that due to a sprung axle. The car is thrown from one side of the track to the other and the part of the rail opposite a joint becomes worn unevenly, thus making the side motion still worse, with the result that the track is thrown out of alinement. With opposite joints, the worst that can happen is an up-and-down motion, which will jolt the car, but will not cause the severe side thrusts that are always found with defective staggered joints.

35. Methods of Installing Electric Roadbeds.—On interurban electric roads, steam construction can be followed closely. It frequently happens, however, that electric roads

are run in streets that, if not already paved, will be at some future time, and hence the conditions are somewhat changed. The methods of building electric roads differ so radically that it can be truly said that the only elements of construction in common to all electric roads are the earth and the rails. Some roads have wooden cross-ties, some metal, and others have no cross-ties at all. One road must build an expensive substructure for its roadbed and another, on account of natural conditions, may have to lay scarcely any roadbed. There can be no better way of bringing out these several points in construction than to take examples of roads on which they occur.

TYPICAL ROADBEDS

INTERURBAN ROADS

36. The permanent character of the track as a whole depends greatly on the character of the roadbed; if, after the substructure is laid, the roadbed gives or swerves in places, everything that rests on it gives and swerves also, so that in course of time the surface of the track becomes undulating and serpentine in outline. Electric interurban roads, as far as possible, now follow steam-road practice in their roadbed and trackwork, and for out-of-town work they could not do better.

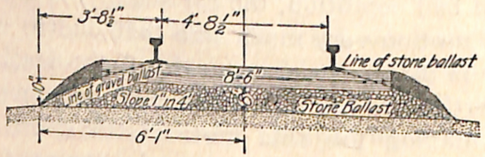


FIG. 32

Fig. 32 shows a standard steam-road construction; other examples of track construction for cross-country roads have already been shown in connection with line work. The same care and exactness that are observed in steam-road construction should be observed in electric railroading, where the train speeds are often almost as high and other conditions just as severe.

CITY ROADS

37. Fig. 33 shows a cross-section of a substantial roadbed in the State of New York. The figure shows a single track only, although the road is double track. A trench 23 inches deep is opened up 18 feet wide and is well rolled and

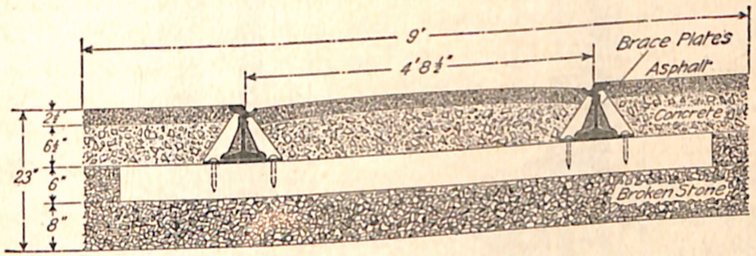


FIG. 33

filled to a depth of 8 inches with 2-inch broken stone, soft spots in the rolled surface being dug out and also filled with stone or other solid material. The stone is rolled until it is firm at a depth of 8 inches. On this ballast are laid the ties, 6 in. × 7 in. × 7 ft. 6 in., a little less than 2 feet between centers, except at the joints, which are supported by three ties about 15 inches between centers; 60-foot rails are then laid on the ties, ends butted and joints staggered; before jointing, the ends of the rails and the joint plates are well cleaned to take the bonds. The rails are then coupled, the plates bolted tight, brace plates installed every 3 or 4 feet, ties lined up and spiked to the rail. The track is then lined and surfaced and the space between the ties filled with broken stone, well tamped to the top of the tie. The rail is then finally

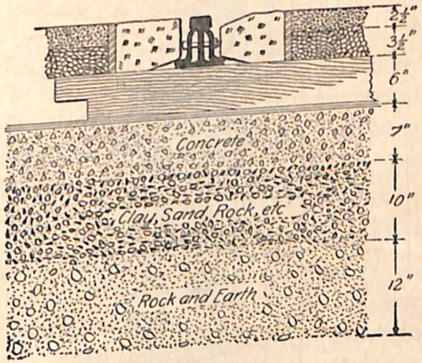


FIG. 34

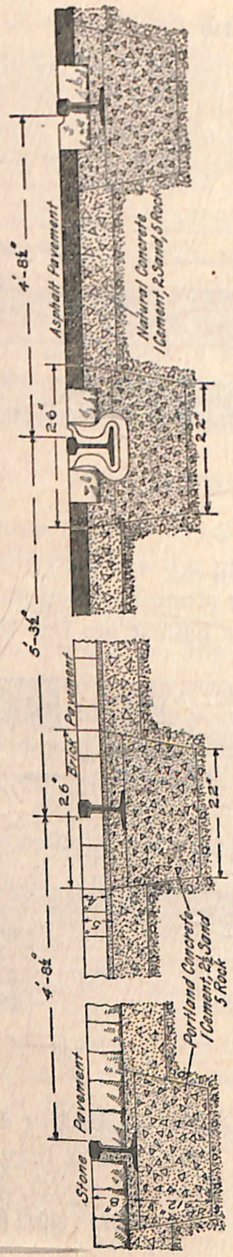


FIG. 35

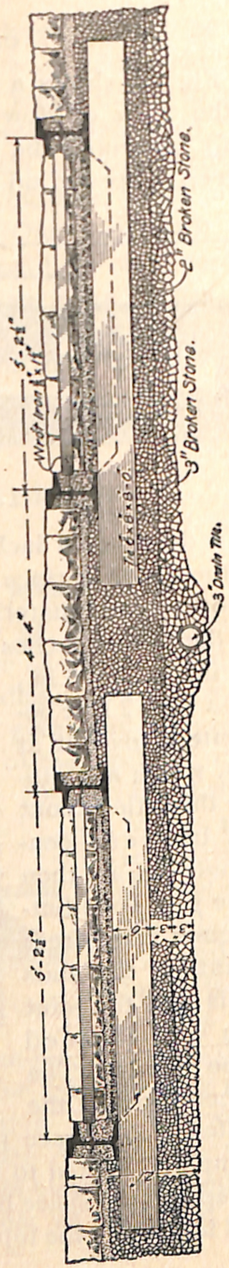


FIG. 36

lined, the joints secured, and the broken stone or concrete brought up to the paving.

38. Fig. 34 is an example of a roadbed construction on a weak subsoil. A trench 36 inches deep and the width of the tracks is dug and, as shown by the figure, it is filled to a depth of 29 inches with successive layers of 12 inches of hard earth and rock well beaten down; 10 inches of earth, pebbles, clay, sand, and rocks, well tamped; 7 inches of new concrete; and $6'' \times 8'' \times 8'$ hard pine ties, previously boiled in asphalt, are laid on the concrete to take 80-pound **T** rails.

39. Fig. 35 shows the construction used by the Twin City Rapid Transit Company, operating in St. Paul and Minneapolis, for tracks with stone, brick, or asphalt pavement. The rails rest on longitudinal concrete beams tied together by a bed of concrete. Cast welded joints 16 inches long and weighing 190 pounds are used. The cast joint is especially shaped so as to interfere as little as possible with the paving. The rails are 8-inch shanghai **T** type, weigh 79 pounds per yard, and are in 60-foot lengths.

40. Fig. 36 shows a construction used for double-track work with stone pavement in Pittsburg. The rail is 90-pound girder in 60-foot lengths. The foundation is of broken stone, and drainage is provided by 3-inch drain tiles placed between the tracks, as shown. The gauge of the track is, in this case, 6 inches wider than standard, being 5 feet $2\frac{1}{2}$ inches.

41. Fig. 37 shows a very heavy track construction with concrete, used in Philadelphia. The track is supported on cast-iron chairs provided with screws for adjusting and holding the track to gauge. The chairs are spaced 5 feet apart and are bedded in concrete, as shown; a solid sheet of concrete $4\frac{1}{2}$ inches thick, together with tie-rods at regular intervals, prevent any spreading of the concrete stringers on which the rails are carried.

42. Fig. 38 shows a section of track construction in Detroit that combines the concrete-beam feature and the steel

cross-tie (3-inch angle bars) used more as a tie-rod for keeping the rails to gauge than as a solid resting place for the rails. The concrete-beam work ordinarily goes to a depth of only 6 inches, but in soft spots it may be as deep as 2 feet.

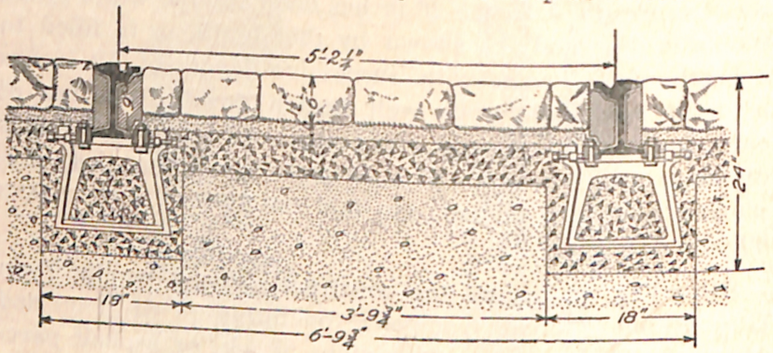


FIG. 37

43. Fig. 39 shows a construction adopted in New Orleans where the subsoil is very soft and yielding. Several of the

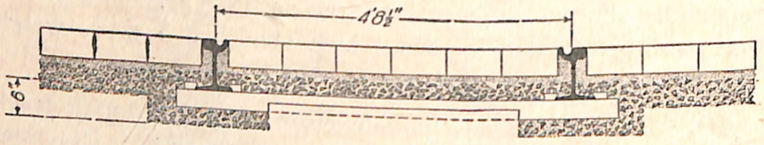


FIG. 38

long lines in the city are built on neutral ground between two driveways, so that they are not subjected to the wear

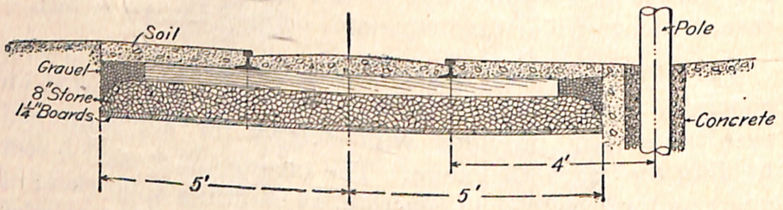


FIG. 39

and tear of wagon traffic. This location of the track admits of the use of a T rail as shown in Fig. 39. The first step is to dig two trenches, one for each track, about 2 feet deep and 10 feet wide. On the bottoms of the leveled trenches

are laid lengthwise 1¼-inch yellow-pine boards; these act as the foundation for a layer of 1½-inch broken stone, on which the 6″ × 8″ × 8′ creosoted yellow-pine ties rest, 2 feet between centers. The space between the ties is filled partly with broken stone and partly with gravel that goes to the top of the ties. On top of the gravel is put a layer of soil in which grass is sown, so that a few months after the work is done the whole neutral ground is grass-grown—a feature that almost does away entirely with the clouds of dust ordinarily raised by a car in course of rapid transit. The plank construction on the bottom of the roadbed prevents the tendency of the track to sink into the soil and cause undulations in the surface line of the rail.

44. Use of Plank to Secure Even Pavement.—In some classes of track construction, where there is very little space between the upper surface of the ties and the under side of the pavement in which to place a solid foundation for the pavement, an uneven road surface is almost sure to result because of settlement between the ties. The roadbed should be designed so that the pavement will have an even and secure foundation, but in cases where this is not possible it has been found advantageous to lay the pavement on rough hemlock planks that have been placed on the ties; a thin bedding of sand is placed beneath the pavement. The planking affords an even support but, like the ties, it has to be renewed in course of time.

THIRD-RAIL ROADS

45. Form of Third Rail.—In practically all the third-rail roads so far installed, the conductor rail has been of the ordinary T section. Other sections have been proposed, one of which, suggested by Mr. W. B. Potter, is shown in Fig. 40. It is not necessary to have the same degree of stiffness in a conductor rail that is required in a track rail, and the plain rectangular section shown in Fig. 40 was designed with the idea of making the rail as easy to roll as possible; also, to provide a simple means of clamping the rails at joints without

drilling holes through them. A rail of this section weighs about 98 pounds per yard. So far, however, special shapes have not been introduced to any extent, as the standard T sections are more easily obtained.

46. Location of Third Rail.—The third rail may be located on either side of the track, as may be most convenient; on double-track roads, the two third rails are usually placed between the tracks. At different points on a road, it may be found advisable to change the location of the rail from one side to the other, but as both sides of the cars are equipped with collecting shoes, this makes no difference so far as the collection of current is concerned. The relation of the third rail to the track rails varies on different roads and is determined largely by the clearance that must be allowed for locomotives or rolling stock that may be run over the road. Where steam locomotives are run over a third-rail road, the conductor rail must be located so as not to interfere with the locomotive

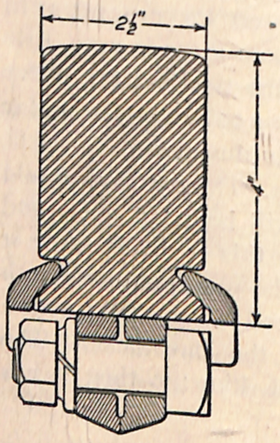


FIG. 40

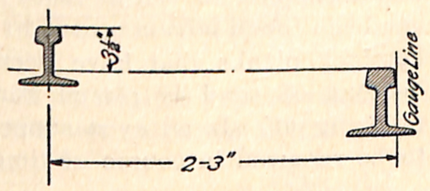


FIG. 41

cylinders, which usually project farther than any other part. Fig. 41 shows the location recommended by a committee of the Master Car Builders' Association. The center of the third rail is 2 feet 3 inches from the gauge line of the nearer track rail and the tread of the third rail is $3\frac{1}{2}$ inches above that of the track rail. The size of the third rail for a given road is determined, to a certain extent, by the amount of current required for the cars. Weights less than 60 pounds per yard are seldom used, unless the traffic is light, and very often the rail is of the same weight as the track rails;

60-foot rails are desirable because of the decreased number of joints.

47. Protection of Third Rail.—On many roads, the third rail is not protected in any way, but there is a growing demand for protection of some kind that will make it difficult for accidental contact to be established between the third rail and ground or track rails. Also, protection is desirable to prevent the accumulation of ice or snow on the rail. Fig. 42 shows a simple method of protection as used on a number of elevated roads. Planks are run parallel to the rail and project about 2 inches above the head; anything accidentally dropped across the rail is prevented from making contact by the projecting planks. This

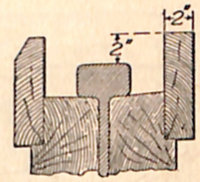


FIG. 42

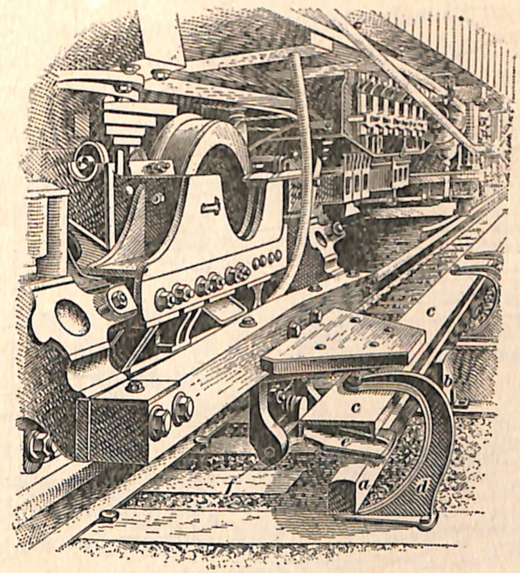


FIG. 43

method does not protect the rail from snow or sleet, nor does it afford as great a measure of safety as the plan shown in Figs. 43 and 44, which represents a protected third rail used by the General Electric Company.

Fig. 43 shows the general arrangement of the third rail and collecting shoe with reference to the motor truck, and Fig. 44 shows the details. The conductor rail *a* is supported on reconstructed granite insulators *b* and is covered by a

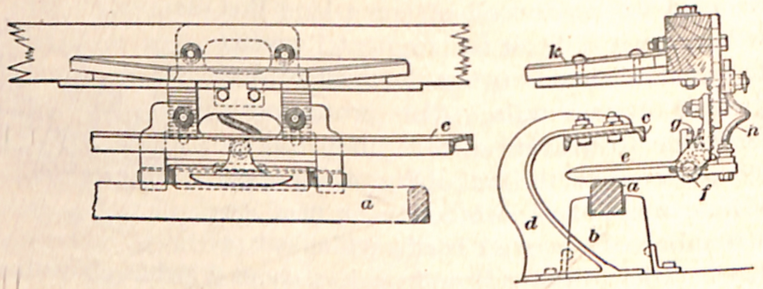


Fig. 44

channel iron *c* fastened to brackets *d* that rest on ties projecting about 18 inches beyond the regular ties. The shoe *e* is in the form of a flat plate hinged at *f* and held in contact with the rail by the spring *g*; flexible cable *h* connects the

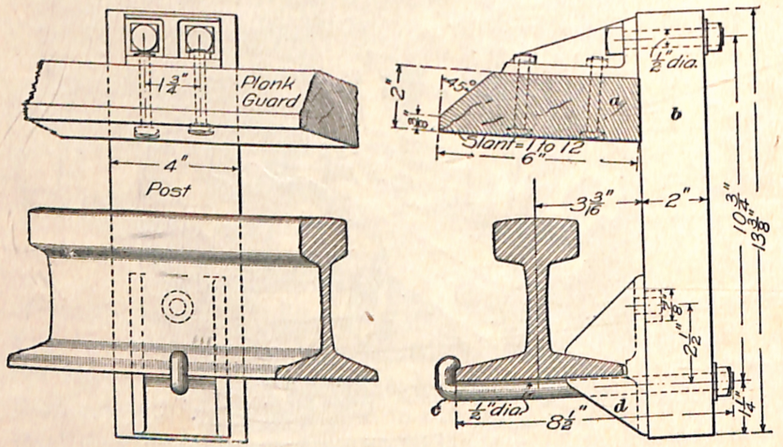


Fig. 45

shoe to the main trunk wire running to the controlling apparatus. A projecting wooden guard *k* prevents accidental contact with the parts of the shoe. With this construction, it is almost impossible for any one to step on the third rail

or for pieces of metal to drop across it and the track rails, thereby causing a short circuit.

48. A modification of the method just described is shown in Fig. 45, which represents the method of rail protection used on the Wilkes-Barre and Hazleton road; a very similar method is used on the New York subway, and in both cases the style of shoe shown in Fig. 44 is employed. The guard consists of a 2-inch pine plank *a* fastened to $2'' \times 4''$ oak posts *b*, as shown. The posts are supported from the foot of the rail by clamping them by means of a special bolt *c* and a bearing casting *d*, formed to fit the foot of the rail. The construction as a whole is much cheaper than that shown in Fig. 43 and affords equally good protection. Fig. 46 shows the arrangement of the third-rail guard used on the New York subway.

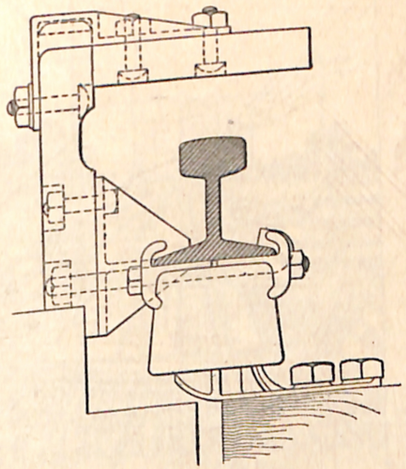


Fig. 46

49. Arrangement of Third Rail at Highway Crossings.—Where a third-rail road crosses a public highway, it is necessary to break the contact rail and make connection by means of a cable carried across either overhead or underground. The connection is nearly always made by means of underground cable, which is much shorter than an overhead one could possibly be. Fig. 47 shows a typical crossing. The contact rail *a* is provided with cast-steel, inclined, approach blocks *b*, *b* that allow the shoes to glide on to the rails without shock. At *c*, a cable is attached to the rail and is carried underground to *d*, where it connects to the rail again, thus preserving the continuity of the conducting system; the cable should have a cross-section equivalent, in carrying capacity, to that of the rail;

1,000,000-circular-mil, lead-covered, paper-insulated cable is often used for this purpose.

Various methods are used for running the cable; one very common plan is to incase it in tile and fill the tile, at the ends, with insulating compound that will prevent water from entering. The cable must be thoroughly insulated from the ground, otherwise there will be leakage and consequent electrolytic action that will eat away the cable in course of time. Fig. 48 shows a method used on a third-rail road in

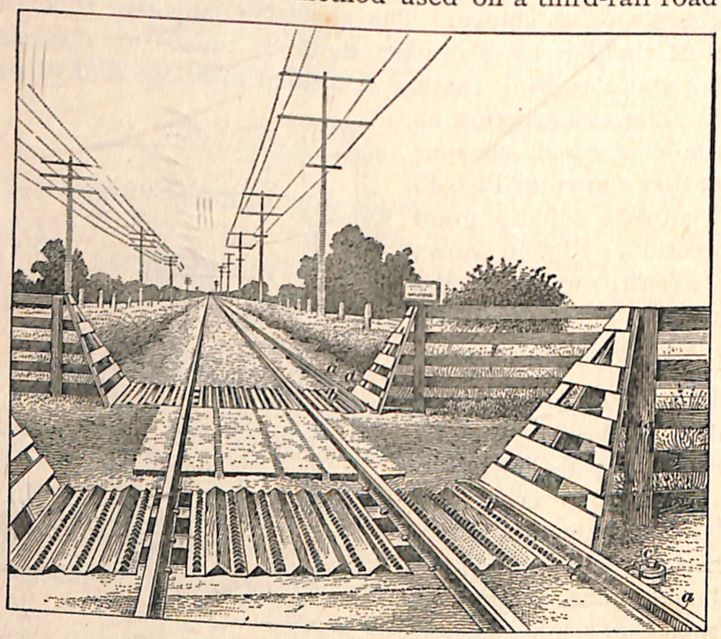


FIG. 47

Michigan, where the cable is carried through a heavy porcelain insulator set in a cast-iron pipe. The strands of the cable are soldered into a terminal casting and after the lower part of the insulator has been plugged with oakum the space is filled with insulating compound that prevents moisture from entering the paper insulation of the cable, which, in this case, has a lead sheath covered with jute treated with asphalt. A brass cap is bolted to the cable terminal and from it two 300,000-circular-mil flexible bonds connect to the

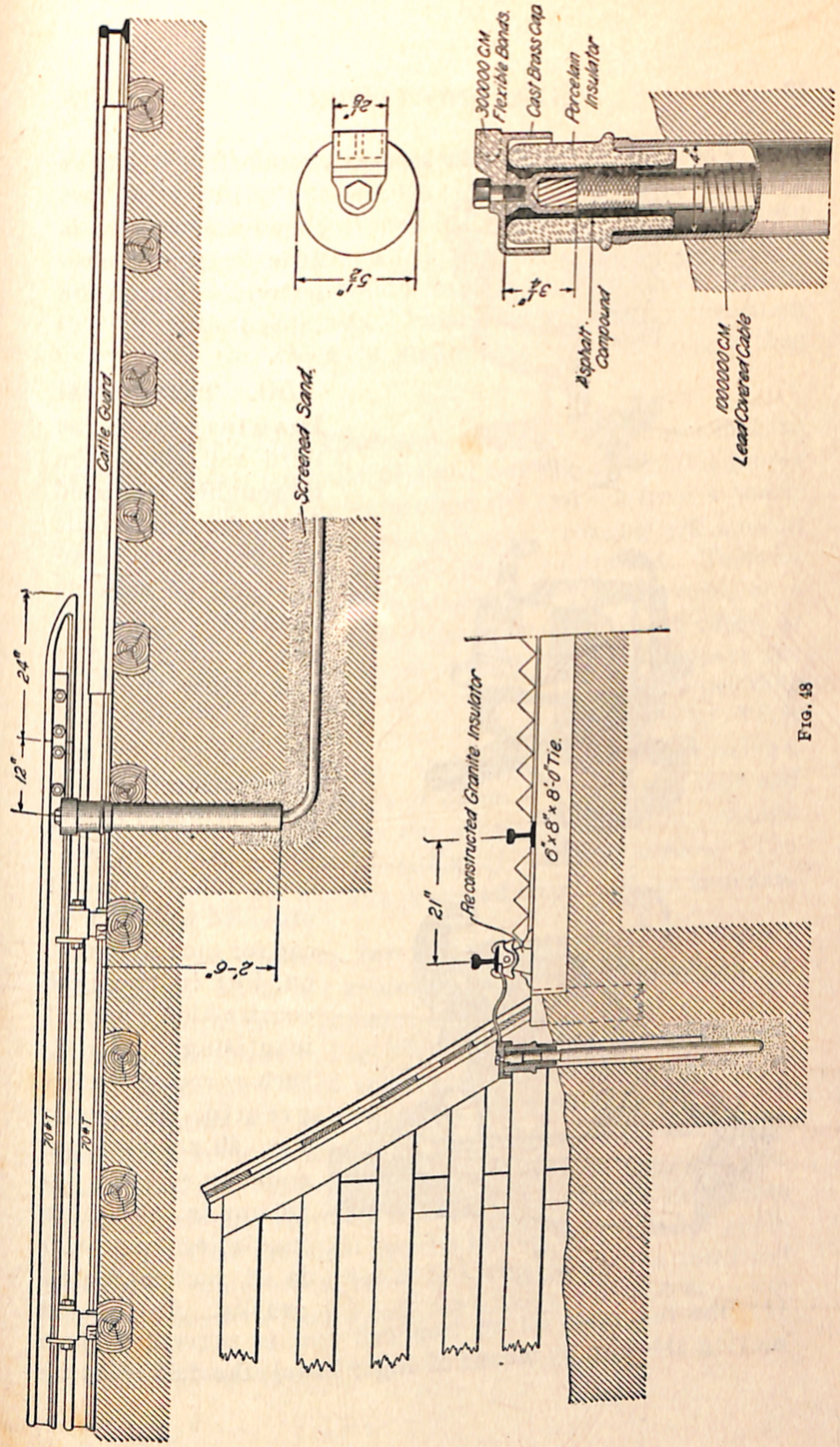


FIG. 48

rail. The cable is bedded in screened sand after it leaves the pipe; with this construction there is little danger of electrolytic action on the cable sheath.

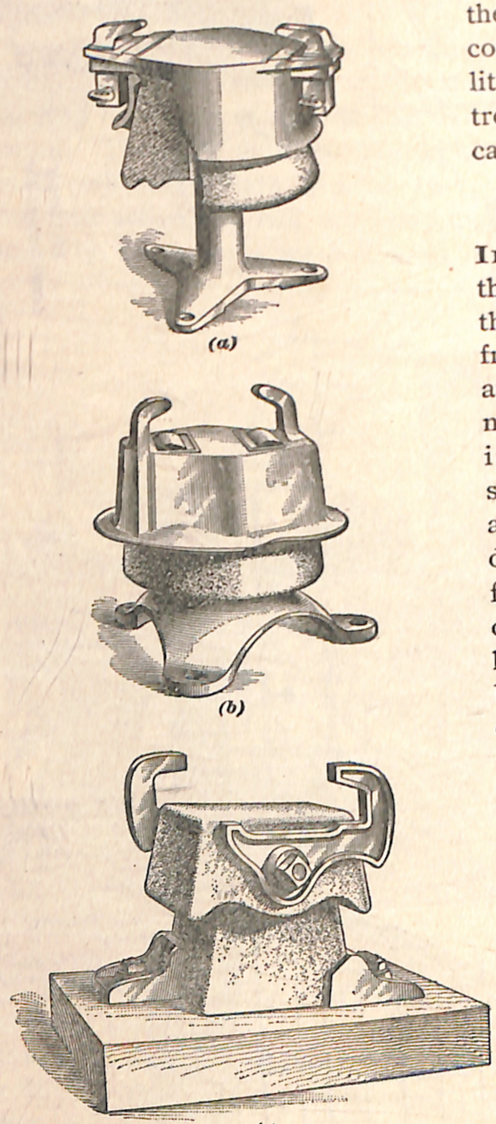


FIG. 49

50. Third-Rail Insulators.—The third rail should be thoroughly insulated from the track rails and ground by being mounted on suitable insulators that are strong mechanically and allow the conductor rail freedom for expansion and contraction. They have, in many cases, been made of specially treated wood provided with an iron cap for the rail to rest on, but in the best construction special insulating material, such as reconstructed granite, is used. Fig. 49 shows three common types of insulator in which the insulating material is of reconstructed granite. In (*a*) and (*b*), the rail rests on an iron cap and is prevented from moving sidewise by means of lugs; in (*c*), the rail rests on the granite block and is restrained sidewise by special castings held by a bolt passing through the molded granite. All fastenings should allow a certain amount of up-and-down play; the weight of the rail is amply sufficient to hold it in place, and if it is too tightly fastened undue strains will be thrown on the insulators. Insulators are usually placed on every fifth tie, which is made about 2 feet longer than the others.

51. Third-Rail Leakage.—Tests have shown that the current leakage per mile of third rail is very small if proper precautions are taken; very often the leakage from a poorly insulated underground cable at a road crossing will amount to more than that from several miles of third rail. Tests by Mr. R. P. Leavitt,* on the Albany and Hudson road, on a section of third rail entirely disconnected from all cables at crossings, showed a leakage varying from .057 ampere per mile, after a rain lasting 20 hours, to .023 ampere per mile in hard freezing weather with light snow on track. Tests made on the whole road, including cables at crossings, showed an average leakage of about .5 ampere per mile and investigation showed that the greater part of the leakage was due to defective insulation of crossing cables. The insulators were of specially prepared wood with an iron cap.

52. Sleet Cutters for Third Rail.—Where the head of the third rail is not protected from rain or snow, as, for example, with the ordinary unprotected rail or with the arrangement shown in Fig. 42, considerable trouble is caused by the accumulation of snow and ice. A rain followed by freezing forms a thin film of ice on the rail, which is very difficult to remove and is a non-conductor of electricity. When third-rail roads were first operated on a large scale, numerous tie-ups resulted from this cause, but experience has shown that the sleet can be removed by suitable appliances. In some cases, brine is sprinkled on the third rail from a tank carried on a car, but a better method is to use

*Street Railway Journal, Vol. XXI, No. 16.

some form of sleet cutter. Fig. 50 shows the sleet-cutting device used on the Manhattan Elevated Railway, New York. It is fastened to an extension of the beam that supports the collecting shoe so that the cutter, or scraper, is directly in advance of the shoe. The cutter consists of a number of steel plates *a* cast into a block *b*, the plates being set at an

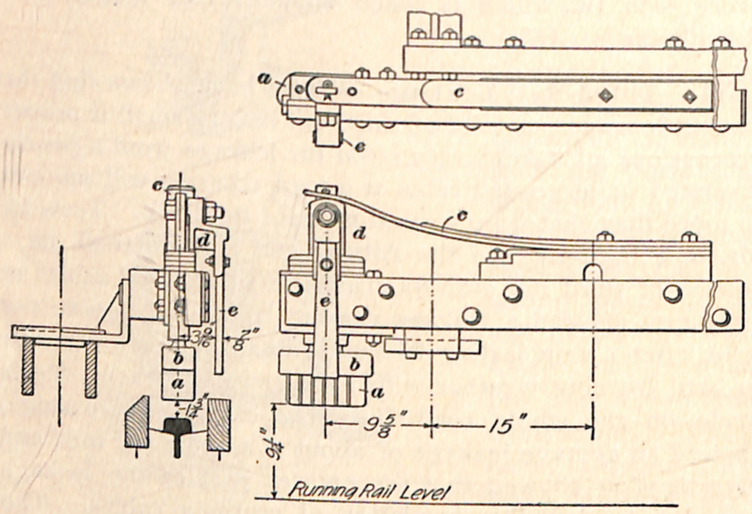


FIG. 50

angle so that they will slide over any slight projections at the rail joints. The cutter is pressed against the rail by a flat spring *c*, and a cam *d* operated by lever *e* is arranged to hold the shoe up when it is not in use. By moving lever *e* to one side, the shoe can be lowered by the motorman or it can be operated by a tripping device controlled from a central point.

53. Fig. 51 shows a style of contact shoe and sleet brush used on the Brooklyn elevated road. The shoe *a* is of the ordinary link type and is suspended from a steel casting *b*, which also forms one of the terminals for the shoe fuse *c*. The other terminal *d* of the fuse is insulated from casting *b*, and to it is attached the cable *e* leading to the controlling devices. The sleet cutter consists of a stiff brush *f* made of

steel ribbon $\frac{1}{8}$ inch wide, No. 23 B. & S. thick, set in a hard maple block. The brush is insulated from its guide bar and is pressed against the rail by spring *g* with a pressure of about 75 pounds. When not in use, the brushes are raised from the rail and held up by throwing handle *h*.

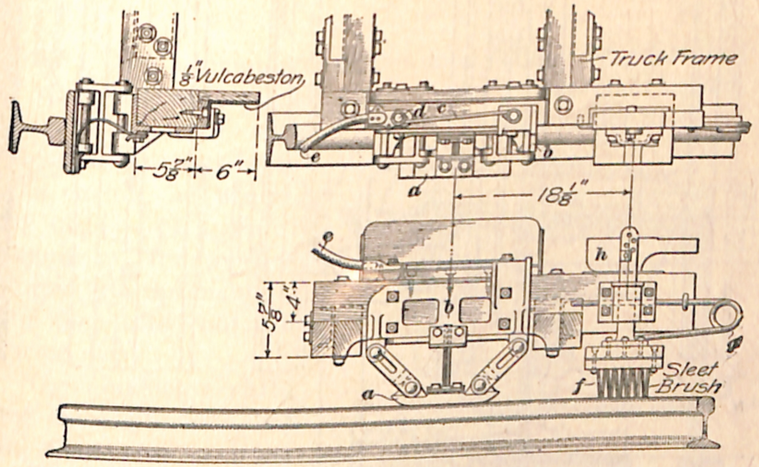


FIG. 51

On third-rail roads four shoes are placed on each car, one on each side of each truck, so that the car will always be supplied with current no matter on which side of the track the third rail may be placed.

CONDUIT ROADS

54. Fig. 52 shows a conduit construction, used in New York, that may be taken as typical of this class of roads. The rails are supported on heavy cast-iron yokes *a* spaced 5 feet apart; every third yoke is provided with handholes, as shown, and carries the insulators *b* to which the conductor rails *c*, *c* are fastened. The conductor rails are thus supported at intervals of 15 feet. Fig. 53 is a larger section of one of the handhole yokes, showing the method of supporting the conductor rail. The conduit between yokes is made of concrete filled in around a sheet-iron form that is afterwards

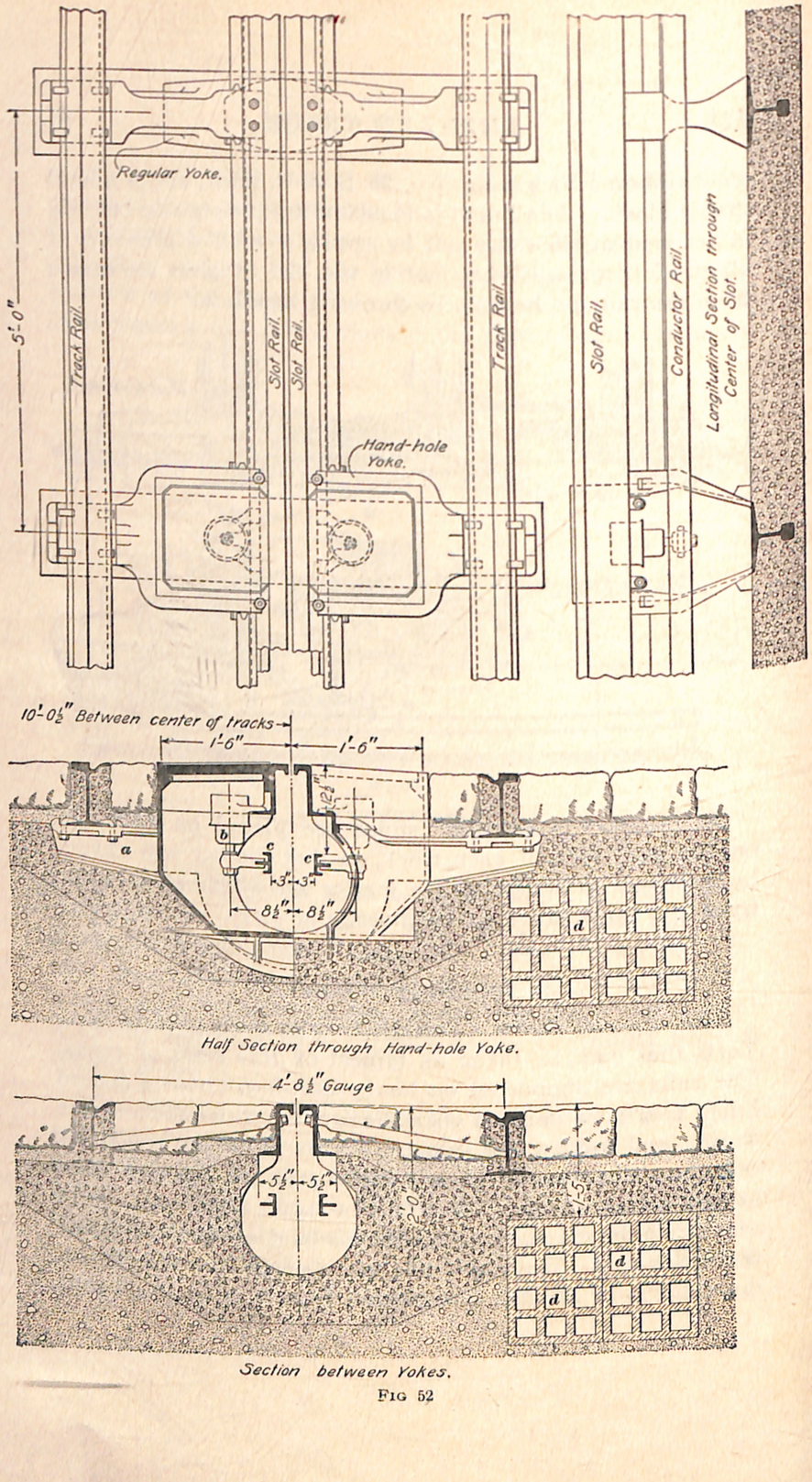


FIG 52

removed. Each manhole is connected to the sewer by a 6-inch pipe and the outgoing and return feeders supplying different sections of the conductor rails are run in terra-cotta ducts *d*, *d*, Fig. 52. To facilitate the installation of new feeders or the repair of old ones, manholes are provided every 400 feet.

55. Mud accumulates in the main conduit very fast, and if not promptly removed gives trouble. The main conduit must be cleaned about once a month in the summer time, and perhaps oftener than this during the winter. By means of special scrapers, the mud is drawn into the manhole and then lifted out and carted away.

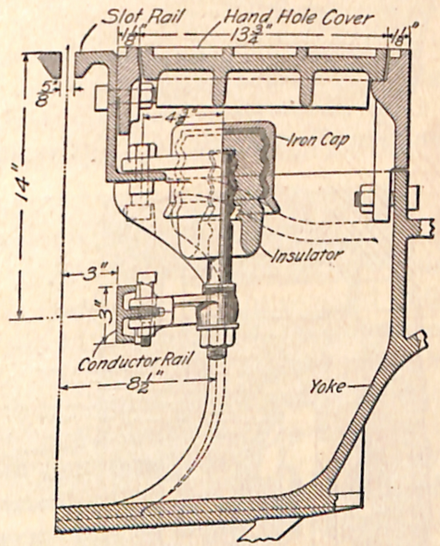


FIG. 53

The conductor rails are not continuous, but are divided into sections about a mile long, and each section is fed by its own feeder from the power house. There is no electrical connection between these feeders, so that the road is cut up into insulated sections, and trouble on one section is not so liable to interfere with the traffic on the others. Each feeder has its own switch and circuit-breaker, and in case a ground occurs on one section the circuit-breaker on that section flies out and the attendant in charge at the power house can tell exactly on what stretch of track the trouble is. Splitting the road into sections supplied by individual feeders also has the advantage that in case of a block on the road, the simultaneous efforts of all the motormen to start their cars will not cause heavy overloads in the power house,

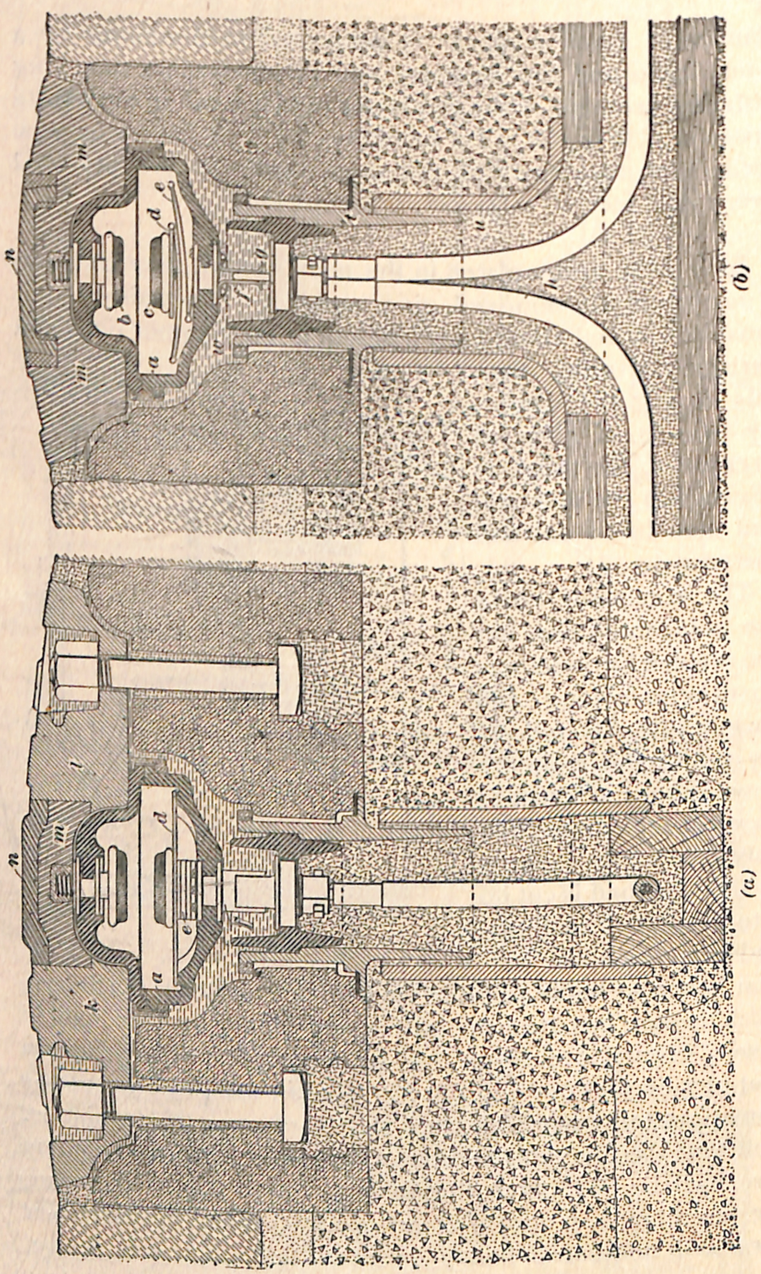


FIG. 54

because the switchboard attendant has every section of the road under his control and can compel the cars to start up, one section at a time.

It is necessary that the yokes be well designed to resist the pressure of the earth (which is packed down by the heavy traffic) and the very heavy pressure in cold climates, due to the freezing of the soil, with its accompanying expansion. Wrought iron, steel, and cast iron have been used for this purpose, the latter, perhaps, being the most common. When yokes of light weight are put in, trouble is often occasioned by breakage. The conduit may be lined with steel plates or it may be constructed on the sides of concrete alone; in some cases the metal yokes have been replaced by concrete, but the best practice is to use heavy castings ranging in weight from 200 to 400 pounds or more, according to the depth of the conduit and the character of the wagon traffic expected.

SURFACE-CONTACT ROADS

56. As very few of these roads have been put into actual operation, the description here given will be confined to the system of the Lorain Steel Company, as successfully operated at Wolverhampton, England. The general principles of this system have already been described, and as the track rails and roadbed are installed in the same way as for an overhead system, it will only be necessary to explain the construction of the contact switches and the method of collecting current from them. Fig. 54 shows longitudinal and transverse sections of the contact switches placed between the rails, and Fig. 55 shows the relation of one of the magnets on the car, to the parts of the switch. The switch contacts, Fig. 54, are contained in a water-tight vulcabeston case a and take the form of carbon disks, b being fixed and c movable. The lower contact c is attached to an iron plate or armature d that is $4\frac{3}{4}$ inches long, 2 inches wide, and $\frac{1}{16}$ inch thick, and connected to the terminal clips f through a folded copper strip e that serves as a flexible connection and also guides the armature when it is drawn

upwards by the magnets on the car. The feeder cable connects to the fixed clip g, so that when case a is in place, contact c connects to feed-wire h. The cover consists of four parts, k, l, m, and n; parts k and l are of cast iron and m and n of hard manganese steel, which is practically non-magnetic. Piece n takes the wear of the collecting shoe and is renewable, being held in place by lead run in around it. The switch contact case is fastened to plate m, so that by removing the cover the whole case can be disconnected

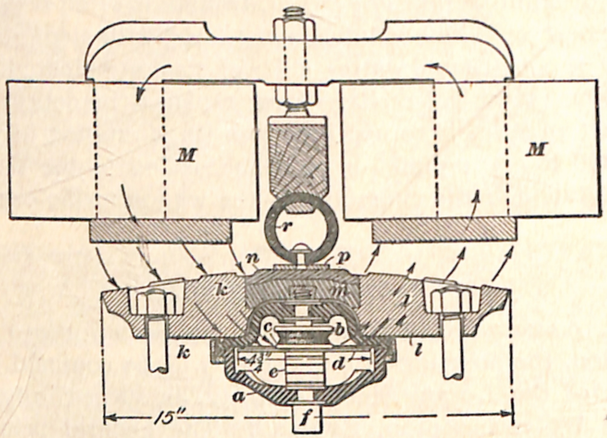


FIG. 55

from the feed-wire. The cover is bolted to a strong block $s\,s$ of reconstructed granite and the feed-wire passes up through a cast-iron sleeve t that fits into a Y casting u; t and u are filled with insulating compound. Space w is filled with a heavy insulating oil that prevents moisture from accumulating around the live terminal g and thus avoids surface leakage. The contact studs are placed 10 feet apart.

57. The operation of the system will be understood from Fig. 55, where $M\,M$ represents one of the magnets; the parts of the switch are lettered to correspond with Fig. 54. Six magnets are suspended under the car, extending over a space of 16 feet and, since the studs are only 10 feet apart,

the forward switch is operated before the back one is dropped and arcing at the switch contacts is avoided. The pieces of manganese steel m, n between the side blocks k, l are practically non-magnetic; hence, when a magnet is over a switch, as in Fig. 55, the lines of force take the path indicated by the arrows and pass through the light armature d, which is drawn up, thus bringing the carbon contacts together. As soon as the magnets move from the stud, armature d drops; and since the contacts are of carbon there is very little danger of their sticking. The collecting shoe consists of a flat copper strip p about 12 feet long bent up at each end and fastened to a piece of heavy rubber hose r, which provides pressure between the shoe and the studs and at the same time permits considerable flexibility. The shoe is long enough to bridge across two contact studs, thus providing a continuous collection of current. The magnets are compound wound. When the car is at rest, the shunt winding keeps the contact switches closed, so that the car can be started; the series winding provides excitation in case the voltage becomes too low for the shunt winding to operate the switches; it also holds the switches more firmly in contact as the current taken by the car increases. An eight-cell storage battery is provided on each car so that the series winding can be excited when the car is started for the first time or in case the power is shut off the line temporarily.