LINE AND TRACK

(PART 1)

THE LINE

1. The term **line**, when used in connection with an electric railway, covers quite a large field of work. It may apply to the wires used for supplying current to the cars, or to a high-tension transmission line for transmitting the power from a distant power station. It also includes the various devices used for transmitting the current for cars operated by surface-contact or by conduit systems.

OVERHEAD LINE WORK

2. General Features.—When **overhead construction** is spoken of, it is generally understood to refer to the common overhead-trolley system that is used wherever it is permitted, because it is so much cheaper than any of the other systems. Overhead construction includes the setting of the poles, the stringing of the feed-wires and the trolley wire, with its span wires, guard wires, anchor wires, insulating hangers, coupling devices, switches, etc. The feed-wires, or feeders, i. e., the wires communicating directly between the generators at the station and the several points of distribution, are carried overhead or are laid underground if necessary. When the feeders are carried overhead, it is the rule to support them on cross-arms from the same poles that support the span wires and trolley. Sometimes, however, if the feeder followed the line of the track, it would be unnecessarily long; in such a case, its route would lie across country or across town, as the case might be.

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3. In Fig. 1, *P* is the site of the power house, and *k–a–C B–b–e* is the trolley wire, which of course has to follow the track. The wire is divided into two sections, *a* and *b*, separated by the line circuit-breaker, or section insulator, *C B*; the term circuit-breaker used in connection with line work denotes a fitting for putting a break, or insulating joint, in the trolley line. Each section of the wire is fed by its own feeder. Feeder b_1 feeds into section *a* at *a* and follows the line of the track up to that point; b_2 feeds the second section at *b*, but instead of following the track and taking the long path around, as shown by the dotted line, it cuts across, as shown by the full line, thus effecting a great saving in length. It is, as a rule, cheaper in such cases to take the short cut, even if a pole line has to be erected just for the feeder, because great length in a feeder not only means a great outlay in copper, but the additional resistance helps to defeat the purpose of the feeder—that of keeping the voltage up to a practicable value on the line.

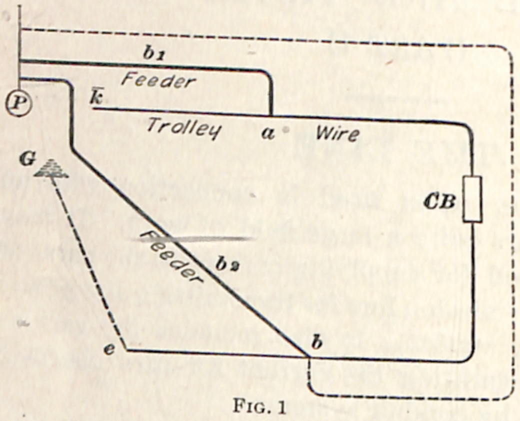


FIG. 1

4. Most overhead-trolley systems use a **rail return**, and it is just as important to provide a good path in the return circuit as in the outgoing lines; in fact, in some cases it is of more importance, because when the rail circuit is poor, current is liable to return on neighboring pipes and thus cause damage by electrolysis, as will be explained later.

Fig. 1 shows that although feeder b_2 allows the current a short path from the power house to the point of distribution *b*, it does not provide a short path back to the power house. The return current must follow the rail, and it would be very easy under such conditions for a greater drop to take place

in the track return than in the overhead feeder. A ground wire run from some point on the rail in the neighborhood of *b*, or even from the end *e* to the ground bus-bar at the power station, would greatly improve the service.

FEEDERS

5. The distributing system of an electric railway may be generally divided into two parts—the **feeders** and the **working conductor.** The latter usually takes the form of a trolley wire in overhead work, but it may be a third rail or the conductor rail in a conduit system. The feeders are usually in the form of heavy cables run from the station to supply different sections of the working conductor. In small towns and cities or on cross-country roads, feeders are run on poles, because this is the cheapest construction. In large cities, however, they are run underground. City ordinances often prohibit running them overhead on account of their unsightliness and also on account of their being a nuisance and source of danger in case of fires. Underground construction is expensive, but it has its advantages. Electric-railway companies objected very strongly when they were first required to put their feeders underground, but many of them are now strongly in favor of it. Underground wires are not disabled by snow and sleet storms, and on the whole their service is more reliable than that of overhead wires.

Where feeders are run underground, they are usually in the form of lead-covered cables; these are pulled into ducts, and manholes are provided at intervals to allow access to the cables for making repairs and locating faults, as previously explained in connection with the general subject of line construction.

6. General Methods of Feeding.—The simplest method of line construction is to use a single wire, serving both the purpose of trolley wire and feeder; but with a heavy load, the drop of potential at the end of the line, except in special cases, is too great when the trolley wire alone is used. It is, therefore, necessary to run a heavy cable alongside the trolley wire and tap it into the wire at intervals along the route. Such a plan is shown in Fig. 2, where *m n* is the trolley wire, *a b* the feeder, and *f*, *f*

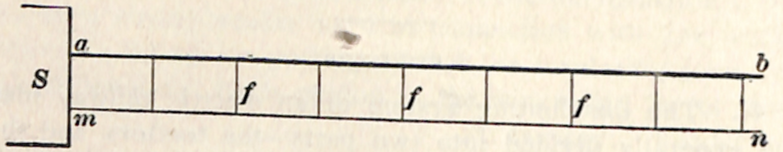


FIG. 2

the taps; the power station is supposed to be at one end of the line at *S*. It would be much more economical if the power station were in the center, as in Fig. 3, so that it might feed in both directions and thereby halve the distance from the power house to either end of the line.

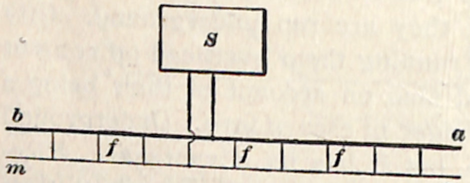


FIG. 3

If the trolley wire is divided into a number of sections *c*, *d*, *e*, *f*, *g*, each connected at its center to the feeder *a b*, as shown in Fig. 4, the drop in potential at any point would be due only to the feeder and that portion of the trolley line between the point in question and the tap. In case of a fire at any place along the route or in case of a ground on a bridge or in a tunnel, the power could be shut off in that district without disturbing the other parts of the

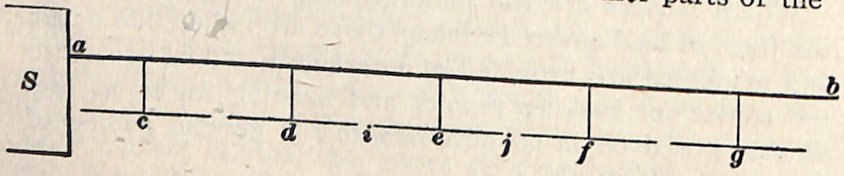


FIG. 4

line. To do this, each tap should be provided with a switch, Fig. 5, mounted on the pole at the point of connection to the feeder. The lower terminal is connected to the trolley, and when the switch is opened the blade can be thrown all

the way down and the door closed. All the exposed parts are then dead and the switch cannot be closed until the door is unlocked. The several sections of the trolley wire are well insulated from one another by line circuit-breakers, or section insulators, which will be described later.

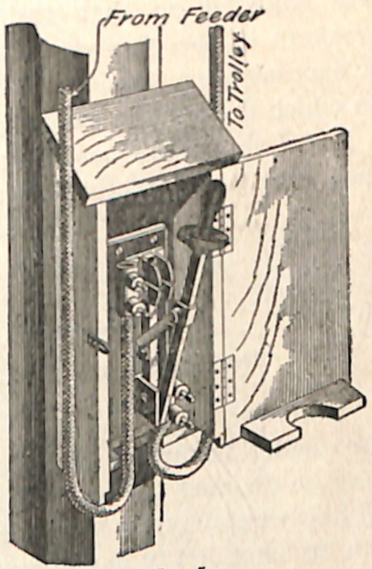


FIG. 5

7. Fig. 6 is a plan of feeder wiring that approaches the condition where the trolley wire is divided into several sections, each of which is provided with its own feeder. But in the case shown in Fig. 6, each feeder supplies several sections of trolley wire by means of extension feeders or mains *a f*, *f b* on the end of the main feeder and an independent tap running to each section of trolley. It is advisable to connect the ends *b i* of the mains by means of a fuse or circuit-breaker, thus tying the different parts of the system together. Then, in case one part is heavily loaded, the feeders and mains supplying the other part can help to supply current. For example, if section *i j* carries a heavy load, current can be supplied by way of feeder *e f* and main *f b*, but if a short circuit or excessive overload occurs on *i j*, the

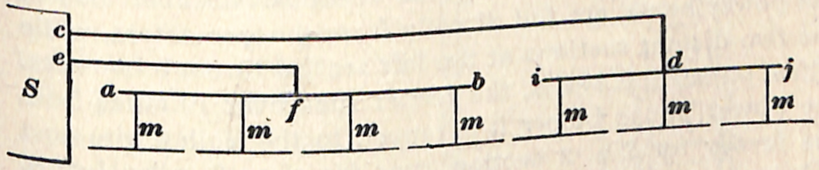


FIG. 6

fuse or circuit-breaker at *b i* will let go before the main circuit-breaker on feeder *e f* in the station, with the final result that current will be cut off from section *i j* but not from the rest of the road. Where several feeders are run out from a station, it is advisable to tie them together in this manner, because it will help greatly to equalize the voltage, and if circuit-breakers are installed at the junction points and properly adjusted so that they will trip before the circuit-breakers in the station, the power, in case of short circuits or excessive overloads, will be cut off from only that section on which the trouble exists.

Fig. 7 shows the best plan for a feeder service. In this case, each trolley section has a feeder of its own. Of course,

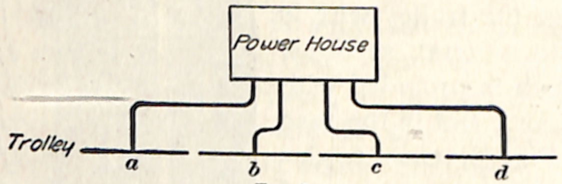


Fig. 7

the feeder is tapped into its section in as many places as may be deemed advisable. Each feeder and its section of trolley wire may be looked on as a single unit, and the idea can be extended to any system, however large. Such a plan not only simplifies calculations, but limits the field for troubles as well. Any trolley section can be cut out by means of its feeder switch.

8. Booster Feeders.—Fig. 8 shows the layout of feeders for an interurban road in Ohio, and illustrates the use of booster feeders for supplying distant sections. The road is 18½ miles long and the power house is situated 6 miles from one end. The two 6-mile sections on either side of the power house are fed directly from the generators, while the two distant sections at the left are fed through boosters. Thus, on section No. *3*, the feeder runs over 10 miles from the power house before it is tapped to the trolley wire, and the feeder for No. *2* section runs for over 6 miles before being tapped. Each section can, therefore, be supplied with different voltages at the power station, thus compensating for the larger drop and maintaining an approximately uniform voltage on all parts of the road. In Fig. 8, the two No. 00 trolley wires are tied together and attached to the feeder,

there being about four trolley-feeder taps to the mile. Current is carried from the rails to the station by four return feeders of 795,000 circular mils each. The trolley feeders are not of the same cross-section throughout, but are reduced in size after they begin to tap into the trolley wire. For example, the feeder for No. *3* section is 715,500 circular mils for 10¼ miles from the station and 397,500 circular mils for the remainder of the distance. The road for which this feeding system is designed operates on an average six interurban cars 49 feet 5 inches long over all, equipped with four 75-horsepower motors geared for a maximum speed of 40 miles per hour. The feeders are of aluminum and their cross-section for equal conductivity, if made of copper, would be about 60 per cent. of the cross-sectional areas indicated in Fig. 8.

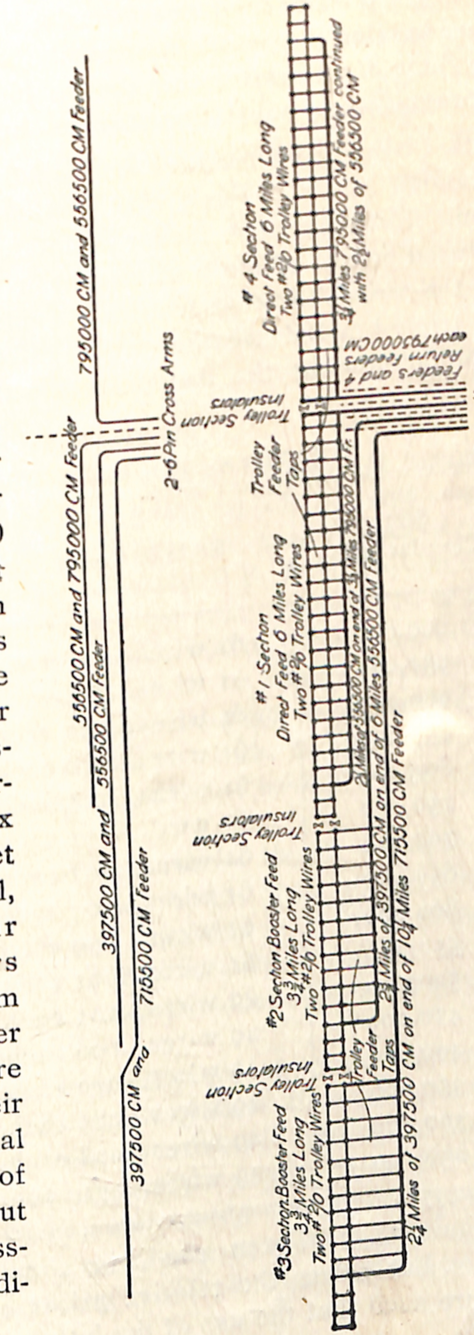


Fig. 8

In selecting the points

to which booster feeders are run, it is frequently advisable to bear in mind the possibility of installing line storage batteries at some future date, and choose locations where sites for storage-battery substations can be obtained without difficulty.

9. Overhead feeders are usually in the form of heavy stranded cables covered with weather-proof braided insulation. If a very large feeder is not required, solid wire may be used or two or more wires may be run in parallel to make up the requisite cross-section. Table I gives the make-up of triple-braided weather-proof railway feeder cables as manufactured by the American Electrical Works.

TABLE I

WEATHER-PROOF FEEDER CABLES

Size Circular Mils	Style of Conductor	Approximate Weight per Mile Pounds
1,000,000	61 wires, .128 each	19,000
950,000	61 wires, .125 each	18,250
900,000	61 wires, .122 each	17,280
850,000	61 wires, .118 each	16,320
800,000	61 wires, .115 each	15,360
750,000	61 wires, .111 each	14,400
700,000	61 wires, .107 each	13,450
650,000	61 wires, .103 each	12,480
600,000	61 wires, .099 each	11,600
550,000	61 wires, .091 each	10,560
500,000	49 wires, .101 each	9,800
450,000	49 wires, .096 each	8,600
400,000	49 wires, .090 each	7,500
350,000	49 wires, .085 each	6,500
300,000	49 wires, .078 each	5,500
250,000	49 wires, .071 each	4,860

Aluminum has been used, in some cases, for railway feeders, but unless the relative prices of copper and aluminum are such that the use of the latter effects a considerable

saving in cost, copper is preferred and is used in the great majority of cases. Since the conductivity of aluminum is about 60 per cent. that of copper, the cross-section of a copper feeder for a given service will be $\frac{6}{10}$ times that of an aluminum feeder for the same service, or the aluminum feeder will have a cross-section of $1\frac{2}{3}$ times that of a copper feeder. For example, if a 300,000-circular-mil copper cable is required for a given service, an aluminum cable for the same service must have a cross-section of $300,000 \times 1\frac{2}{3} = 500,000$ circular mils.

TROLLEY WIRE

10. Material.—Trolley wire is of hard-drawn copper for all ordinary work. In some cases, especially tough composition wire is used on curves where the wear is excessive. Trolley wire is seldom less than No. 0 B. & S., though on some old lines wire as small as Nos. 1, 2, or even 3 B. & S. was used. Some roads now use No. 000 or 0000, but No. 00 is by far the most popular size, and if the feeding system is laid out properly there is little advantage in using larger trolley wire. It only makes a greater weight to be supported by the span wires and hangers, thus increasing the cost of the line supports.

Hard-drawn copper is used because its tensile strength is greater and its wearing qualities better than soft copper. Its resistance is slightly higher, but this is of little consequence because the trolley is not usually depended on to carry the current for any great distance. Table II gives data on hard-drawn copper.

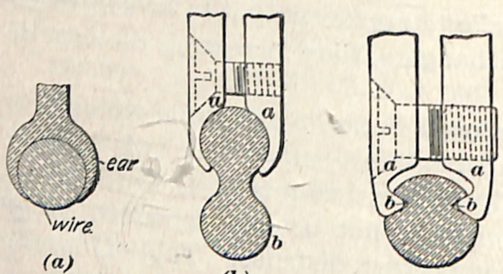
For trolley wire on curves or other places where there are strain and wear on the wire much greater than on straight stretches of track, **phono-electric** wire is frequently used. This is a special composition or alloy wire made by the Bridgeport Brass Company, and stated to have a tensile strength from 40 to 45 per cent. greater than that of hard-drawn copper; its conductivity is 50 per cent. that of pure copper.

TABLE II

HARD-DRAWN COPPER TROLLEY WIRE

Number B. & S.	Diameter Mils	Area Circular Mils	Weight per 1,000 Feet Pounds	Weight per Mile Pounds	Resistance Ohms per 1,000 Feet	Resistance Ohms per Mile	Breaking Weight Pounds
0000	460	211,600	640.5	3,381.4	.05004	.2642	8,310
000	410	167,805	508.0	2,682.2	.06309	.3331	6,580
00	365	133,079	402.8	2,126.8	.07956	.4201	5,226
0	325	105,535	319.5	1,686.9	.1003	.5297	4,558
1	289	83,694	253.3	1,337.2	.1265	.6679	3,746
2	258	66,373	200.9	1,060.6	.1595	.8423	3,127
3	229	52,634	159.3	841.09	.2011	1.0620	2,480

11. Shape of Trolley Wire.—Trolley wire is nearly always round in cross-section, as this shape answers for most work in towns and cities where the speed is not high. Fig. 9 (*a*) shows the ordinary round wire held by a soldered ear. The ear is tapered down to an edge, so that it will allow the under-running trolley wheel to pass as smoothly as possible. Even if the fins on the ear are thin, there is always more or less of a jump when the wheel passes under the hanger, which causes trouble if the car runs at high speed; the sparking caused by the jump eats away the hanger and leads to breakage in course of time. The jump is even more pronounced if ears that clamp the wire, instead of being soldered, are used.



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

FIG. 9

For cross-country or interurban roads, where high speed is attained, it is very desirable to have the trolley wire so suspended that it will offer a smooth running surface for the

trolley. Fig. 9 (*b*) shows a wire designed to accomplish this. It is the shape of a figure 8 in cross-section and the upper part is gripped by the clamp ears *a*, *a*, the lower part *b* being free from obstruction. The objection to this style of wire is that if it becomes twisted between supports, so that it lies crosswise, the wheel does not run well.

Fig. 9 (*c*) shows a style of wire introduced by the General Electric Company. This wire, also, is supported by clamp ears *a*, *a*, and the surface presented to the trolley wheel is

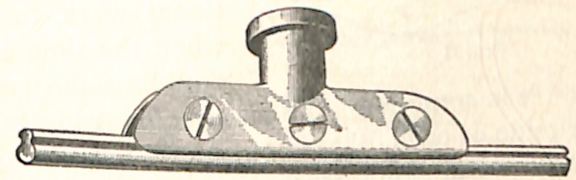


FIG. 10

smooth. The wire is practically circular in cross-section, with the exception of the two grooves *b*, *b* in the side, so that if the wire twists between supports it does not interfere perceptibly with the smooth running of the wheel when high speeds are attained. Fig. 10 shows the method of supporting this wire.

When soldered ears are used, the obstruction offered is so slight that a round wire answers in the great majority of cases. When clamped ears, however, are desired, and when high speeds are developed, these specially shaped trolley wires will be found advantageous.

METHODS OF ARRANGING TROLLEY WIRE

12. There are three styles of support for trolley wires: they may be suspended from brackets on poles at the side of the road; a double track may be provided with center poles carrying the wires on a projecting arm on either side; or the poles may be placed at the sides of the street and the trolley wire supported by span wires stretched across.

13. Span-Wire Construction.—This is the most common method of suspension, and it is preferred for the following reasons: In the first place, it does not obstruct the center of the roadway like the center-pole construction; in the second place, there are locations where only one side of the road can be used, as on country roads, where passages for two teams must be left outside of the track. Again, where a single track is laid with the prospect of making it a double track if the traffic warrants doing so, the side-pole span-wire construction leaves very little additional work to be done when the time comes for doubling the track. In

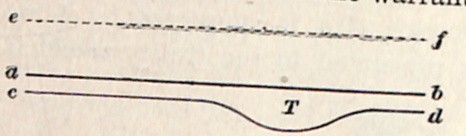


Fig. 11

such a case, it is sometimes the practice to string two trolley wires alongside of each other about 8 or 10 inches apart. As long as the road is single track, the cars use one wire when going one way and the other wire when returning; this saves overhead special work at turnouts and saves copper in the feed-wires. When the time comes for doubling the track,

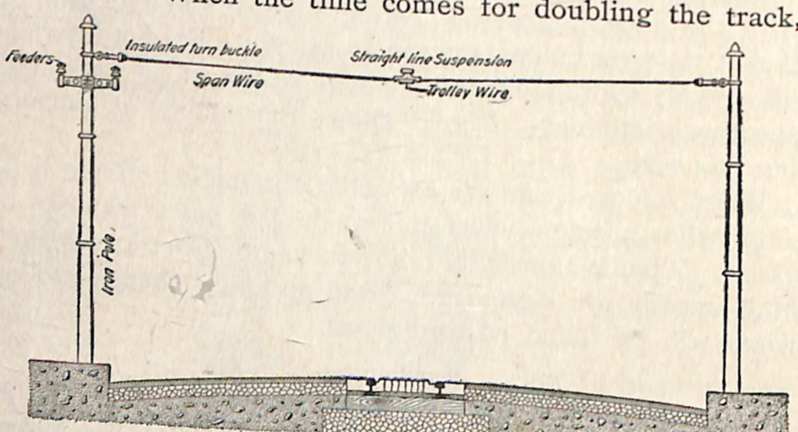


Fig. 12

it is only necessary to slide one wire into place and see to its insulation from the ground. In such straightaway construction, it may be that no feeders are used, in which case the road cannot be divided into sections, but the two wires must be continuous from the power house to the end of the line.

In Fig. 11, *a b* is one trolley wire and *c d* is the other; *T* is a turnout—a switch where cars can pass each other; the

dotted line *e f* shows the position of the wire *a b* after it has been moved over to the second track. This parallel construction does away with the necessity of any overhead

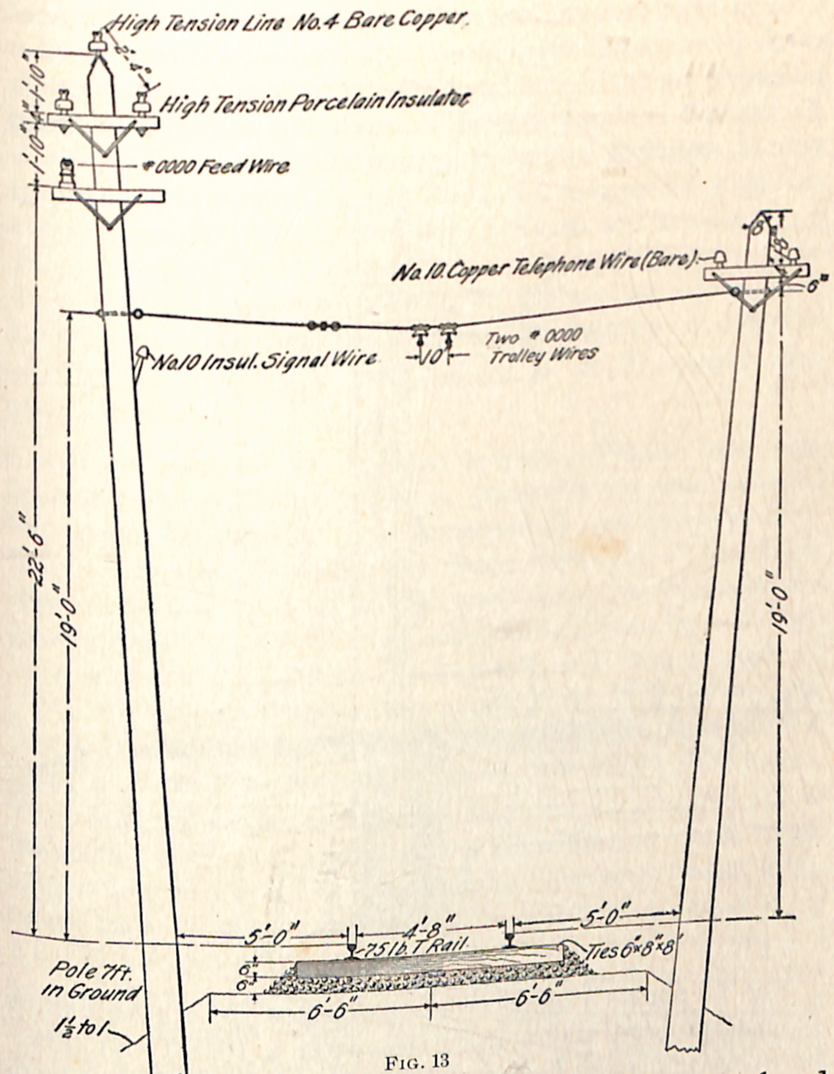


Fig. 13

special work at the turnouts, and if all turnouts are placed on the same side of the track, it leaves one wire straight.

14. Fig. 12 shows a general arrangement for span-wire suspension in cities. In this case iron poles are shown, so that an insulating turnbuckle is used between the pole and the span wire. The trolley hanger is also insulated, so that there is high insulation between the trolley wire and the ground even though iron poles are used. The feeders are carried on cross-arms bolted to the poles. Where wooden poles are used, the insulated turnbuckles are often omitted. An eyebolt is simply passed through the pole and the span wire is stretched by screwing up a nut.

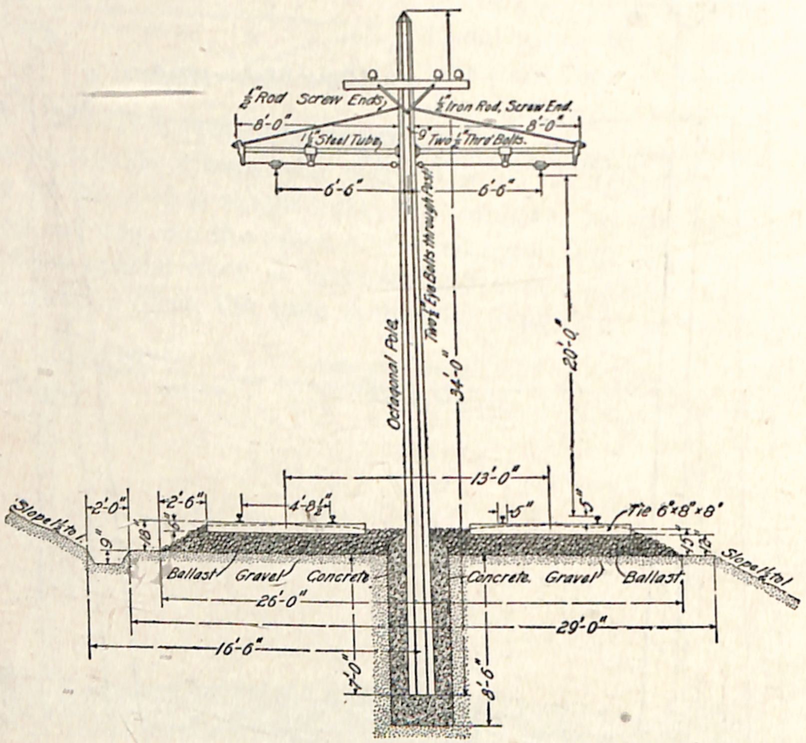


Fig. 14

Fig. 13 shows a span-wire construction for a single-track interurban road where the poles carry a 16,000 volt three-phase transmission line in addition to the direct-current feed-wire. The suspension carries two No. 0000 trolley wires suspended 10 inches apart. The poles are 8 inches in diameter at the top and are set 7 feet in the ground. The span wire is of $\frac{3}{8}$-inch twisted steel.

15. Center-pole construction can be used to good advantage on wide streets where poles in the center of the street will not obstruct the traffic. It is also much used for interurban roads operated with an overhead trolley.

Fig. 14 shows a substantial center-pole construction on an interurban road in New York State. The poles are of yellow pine, octagonal in cross-section, and are set in concrete, as shown, in order to give them a firm base. A single No. 000 trolley wire is used over each track and is suspended 20 feet above the rails. The trolley-wire hangers are attached to a small stranded steel cable, thus making the suspension flexible and taking up the blow of the trolley wheel as it passes the supports. The cross-arm carries a 500,000-circular-mil feeder and two No. 10 B. & S. copper telephone wires.

16. Side-Bracket Construction.—When this construction is used, the track is generally on one side of the street; it is used most extensively for cross-country lines where a single track runs along one side of the highway. For this class of work, cheap gas-pipe brackets are generally used; and since the construction calls for only one pole, whereas a span wire requires two, it is less expensive.

Fig. 15 shows a side-bracket construction of good design. The bracket is braced from above and below, a $\frac{1}{2}$-inch tie-rod being used for the upper brace and $1\frac{1}{4}$-inch pipe for the lower. The feeders are carried on the cross-arm and tapped on to the trolley wire, as shown by the connection *a*, *a*. Line lightning arresters are mounted at suitable intervals, five or more to the mile, as shown at *b*, and are connected to ground by No. 00 weather-proof wire *c*. The best way to obtain a ground for these arresters is to attach the ground wire to the rails, as indicated. Two trolley wires of figure 8 cross-section equivalent to No. 00 B. & S. are used; telephone wires are carried on side brackets *d*, *d*.

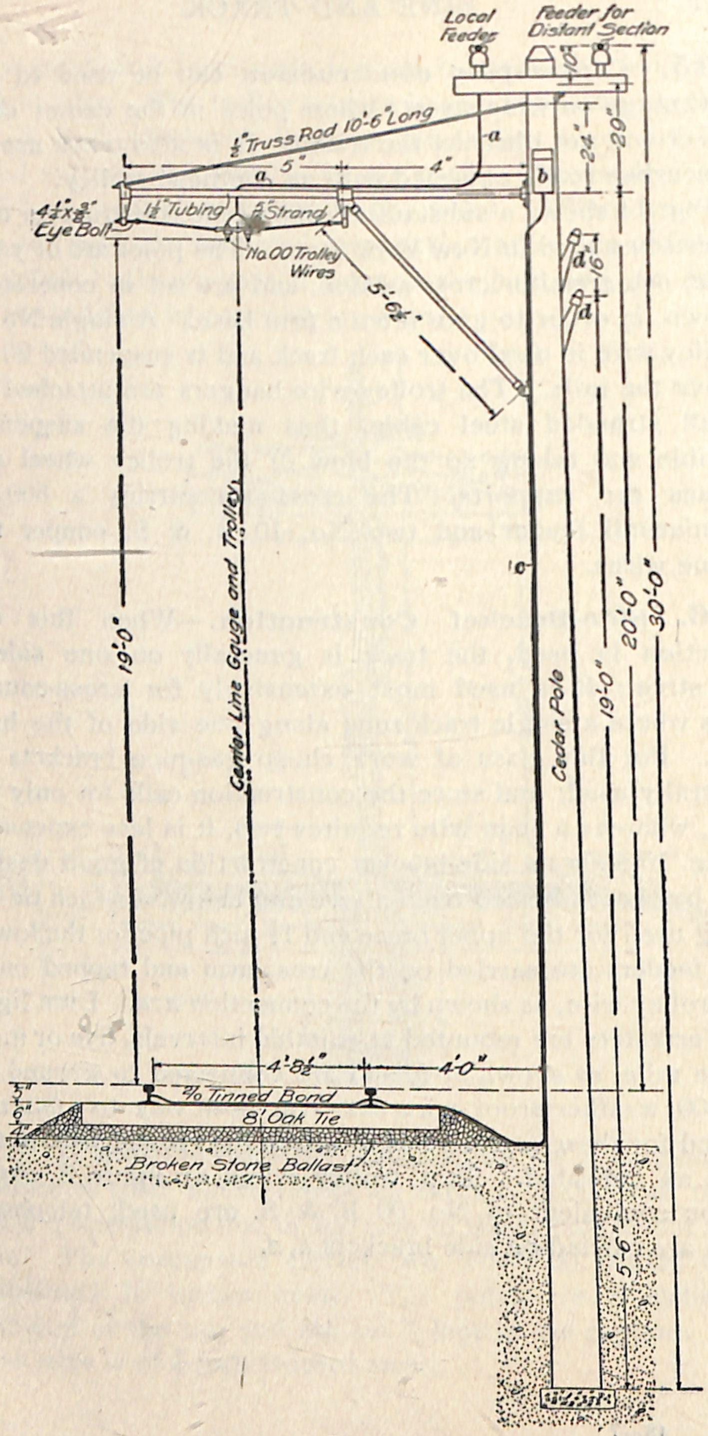


FIG. 15

POLES

17. Poles are either of steel or wood. For cross-country or suburban roads wooden poles are generally used, since appearances are not of so much consequence as with city roads; and even in cities, wooden poles are erected when there is no strong objection to them on the ground of unsightliness. For city work tubular wrought-iron or steel poles of the telescope type are very common; these are usually made up of three sizes of pipe welded together. Seamless steel-tube poles are also coming into much favor. Iron or steel poles are invariably set in concrete, for which the following is a suitable composition:

Portland cement	1 part
Clean sharp sand	2 parts
Clean broken stone	3 parts

18. Wooden poles are usually of chestnut, hard pine, cedar, or redwood. The use of redwood poles is confined mostly to a few of the western states. Poles with tops less than 8 inches in diameter should not be used in railway work; they may be suitable for some classes of telephone and telegraph line construction, but they are too light for the heavier work of electric railways. Chestnut poles should, preferably, be second growth and left in their round natural condition. Poles sawed to octagonal shape are usually of hard pine. In general, while sawed poles present a better appearance than round poles in their natural condition, the removal of the outer part of the wood shortens their life. If poles are kept well painted, their life will be prolonged, to say nothing of the improvement in their appearance. The part in the ground should, with the exception of the base, be coated with tar or some other preservative compound. Experience has shown that it is better to leave the bottom uncovered by the tar, because the center of the pole then remains constantly damp and does not rot as quickly. In many cases, poles are treated with creosote in order to prolong their life. Table III gives data relating to untreated poles of best quality American yellow pine or cedar.

TABLE III

APPROXIMATE SIZES, WEIGHTS, ETC. OF WOODEN POLES

Length Feet	Diameter		Volume Cubic Feet	Shape of Section	Weight Pounds	Allowable Side Strain for 7-Inch Deflection
	Top Inches	Bottom Inches				
28	8	10	12.5	Circular	600 to 700	725
28	8	10	13.2	Octagonal	650 to 800	725
30	8	10	13.4	Circular	670 to 820	700
30	8	10	14.2	Octagonal	700 to 840	700
30	9	12	19.1	Octagonal	900 to 1,140	850

19. Setting Wooden Poles.—Wooden poles are not, as a rule, set with concrete, although there is no good reason why they should not be. When the side-pole span-wire construction is used, they should have their earth bearing increased by the proper disposal of several large stones. A couple of stones should be jammed into the hole alongside of the pole on the side away from the track and a couple more near the mouth of the hole on the side next the track. This will do a great deal toward preventing the span of wire from pulling the tops of the poles together. A piece of timber may be substituted for the stones on the track side, in which case it should be about 3 feet long and 8 square inches in cross-section. After the pole has been placed in position, it should be solidly tamped around to make a firm bed. The tamping should be done while the pole is free; if done while there is tension on the span wire, the effect will be just the opposite to that desired. On straight stretches of track, using side-bracket construction, the poles should be given a rake backwards from the track, the top of the pole not being more than 2 or 3 inches out of plumb. Where side poles are used, with span wires, the rake should be considerably greater because of the tendency of the span wire to pull the tops together (see Fig. 13). In soft ground, the rake should be from 8 to 12 inches, depending on the character of the ground and the kind of pole foundation; the more yielding

the soil the greater should be the rake. In setting poles having a rake, it is advisable to use a spirit level or plumb-bob; by doing this they will all be on a uniform slant, whereas if the eye alone is depended on, the pole line may be very uneven. The poles are usually spaced from 100 to 125 feet apart. In cities 100 feet, or about 53 to the mile, is a common average; while in other places, where a lighter construction is sufficient, they may be placed 125 feet apart, or about 42 to the mile.

20. Tubular Steel Poles.—Fig. 16 shows a tubular steel pole adapted to the various types of construction, (*a*) being for the side bracket, (*b*) for the center pole, (*c*) for the span wire. The method of attaching the span wire to the pole in (*c*) is shown in the small detail sketch. A

TABLE IV

APPROXIMATE WEIGHTS OF IRON POLES

Style of Pipe	Diameter of Sections			Length Feet	Weight Pounds
	Bottom Inches	Middle Inches	Top Inches		
Standard	5	4	3	27	350
Extra heavy . . .	5	4	3	27	500
Standard	6	5	4	28	475
Extra heavy . . .	6	5	4	28	700
Standard	7	6	5	30	600
Extra heavy . . .	7	6	5	30	1,000
Standard	8	7	6	30	825
Extra heavy . . .	8	7	6	30	1,300

clamp is fastened around the pole and to it is attached a turnbuckle that allows the tension on the span wire to be adjusted. Usually this turnbuckle is insulated in order to provide insulation between the trolley wire and ground in addition to that afforded by the trolley-wire hanger. Feed-wires are carried on an iron cross-arm bolted to the pole,

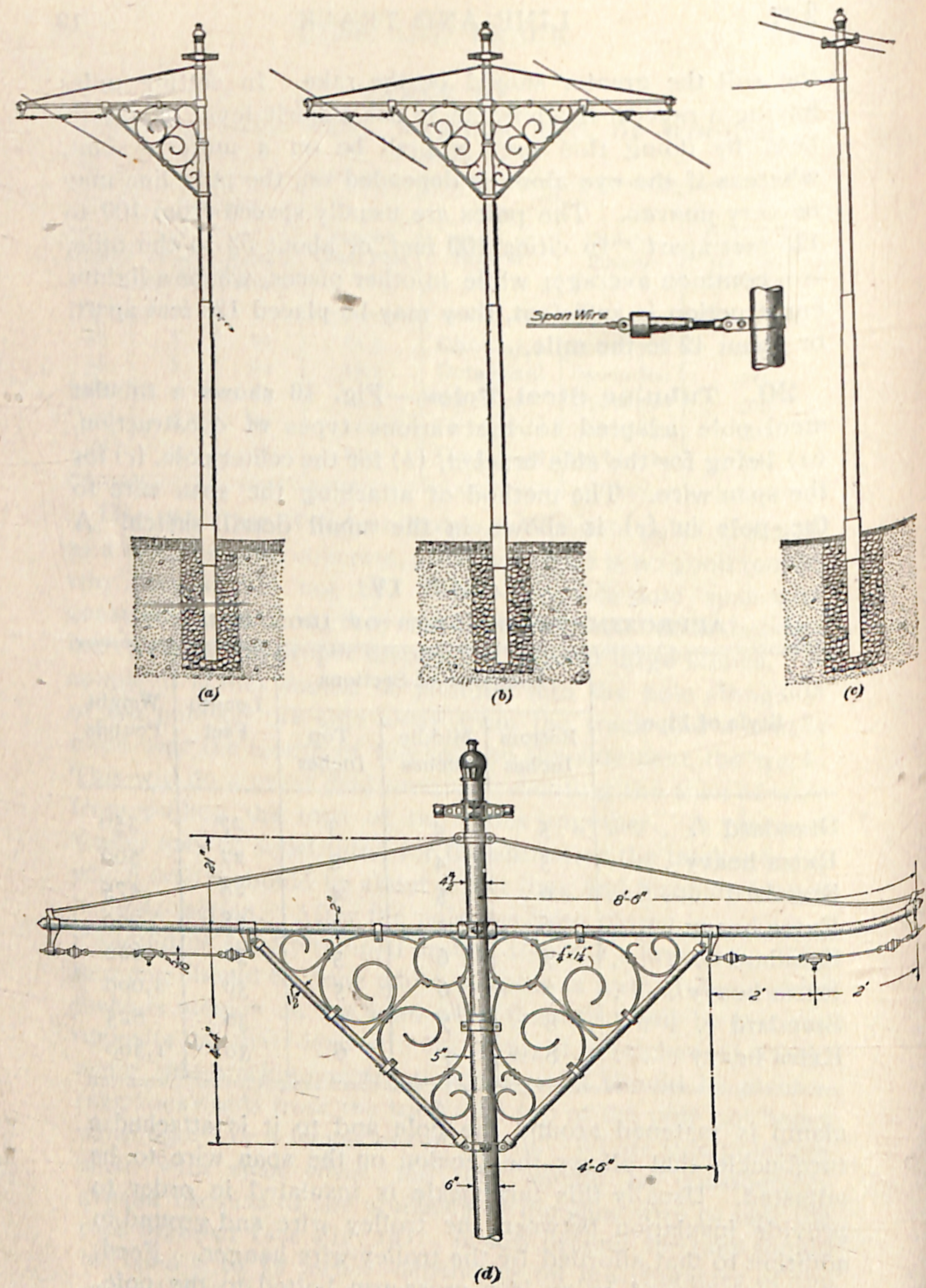


Fig. 16

as in (*c*). An enlarged view of the center-pole top is shown in (*d*). The trolley-wire hanger is not fastened rigidly to the horizontal cross-arm but is flexibly supported from a short span wire stretched between brackets; the span wire is usually made of stranded steel cable about $\frac{5}{16}$ inch in diameter. Table IV gives the approximate weight of iron poles.

Steel poles are sometimes made in other than the telescope tubular form. Poles made of pressed steel parts riveted together have been used; also latticework poles built up of structural steel. In the majority of cases, however, the telescope type of pole is the one generally adopted.

LINE FITTINGS AND LINE ERECTION

TROLLEY WIRE AND FEEDERS

21. The general arrangement of wiring for a double track is shown in Fig. 17. The poles *p* are placed not more than 125 feet apart measured along the road, and between opposite poles are stretched the span wires *s*. At intervals of about 500 feet and at the approach to all curves, anchor wires *a* are put up, being secured by special hangers, as at *h*. These take up the strain on the trolley wire in the

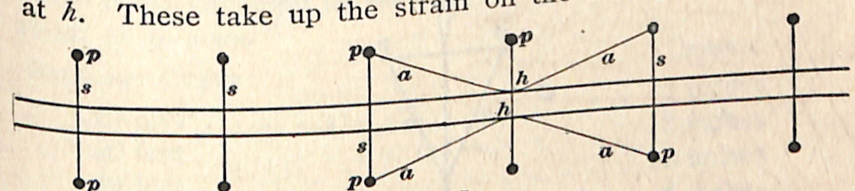


Fig. 17

direction of its length, for it must be borne in mind that the trolley wire is put up under considerable tension, so that should it break it would draw apart in both directions if there were no anchor wires to hold it in position. The two general methods of stringing the trolley wire depend on whether it is put up dead or alive; i. e., whether the current is off or on. In the first case, the wire is run off the reel under the span wires and is then raised and tied temporarily to them; the tension is put on afterwards and the wire fastened to the insulators.

If the wire is put up alive, the reel is put on a flat car that is moved by a trolley car. As fast as the wire is paid off, it is fastened to the insulators, once for all, by a line crew that follows close behind. It may be necessary to go over the

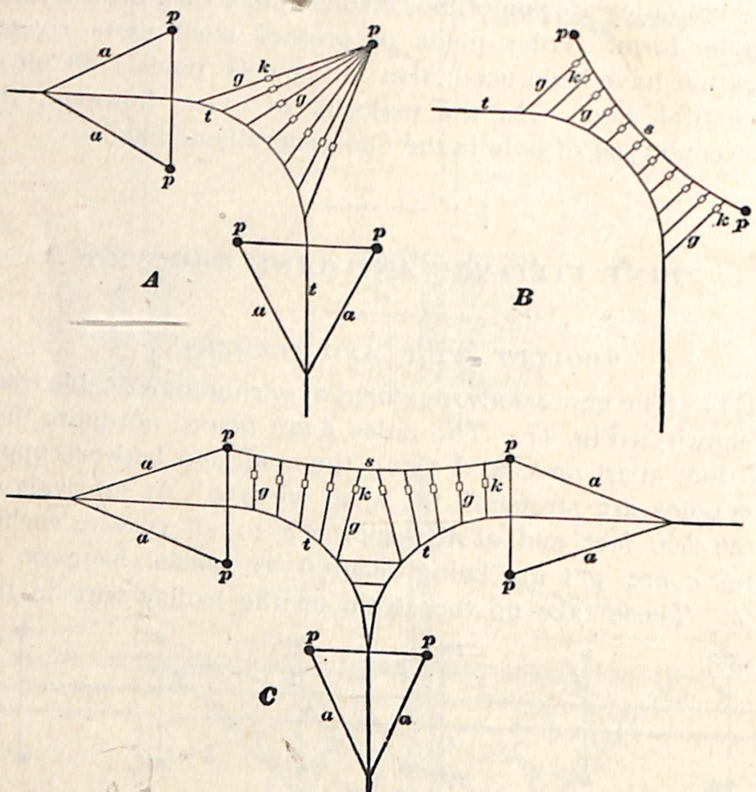


Fig. 18

road afterwards and make a final adjustment, especially at curves and crossings.

22. Erection at Curves.—The method of securing the trolley wire at curves is shown in Fig. 18, where *A* represents the arrangement of guy wires *g* attached to the trolley wire *t* when a single pole is used. Strain insulators are

usually inserted, as shown at *k*, and the trolley wire, at the beginning of the tangent or straight portion, is held by anchor wires *a*. A flexible method of suspension is shown in diagram *B*, where a heavy span wire *s* holds up the guy wires; this form of construction tends to equalize the strains on the span wires, and is generally adopted in place of *A*, which is the older method. A double curve is shown at *C*, the different wires and poles being designated by the same letters as in the preceding layouts.

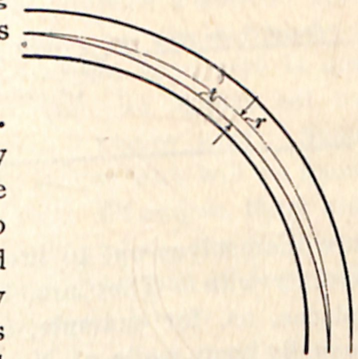


Fig. 19

23. Offset in Trolley Wire. In going around a curve, the trolley wire does not follow the center line between the rails as it would do if the trolley wheel were applied to the wire at a point immediately over the center of the car, but it is shifted over toward the inside rail by a distance that depends on the radius of the curve. This departure from the center line of the track is shown in Fig. 19, where the curve *r* is the center line of the rails and *t* the path of the trolley wire. The amount of offset measured at the middle of a 90° curve at the point indicated by the arrows in the figure should be about as follows:

Radius of Curve	Offset
40 feet	16 inches
50 feet	13 inches
60 feet	12 inches
80 feet	8 inches
100 feet	6 inches
120 feet	5 inches
150 feet	4 inches
200 feet	3 inches

The object of the offset is to allow the trolley wheel to lie more closely to the wire; it would not do this so well if the wire followed the center line of the track, as the wheel would lie diagonally across the wire and cause a large amount of wear on curves.

24. Guard Wires.—In some places, guard wires are located above the trolley wires, as shown in Fig. 20. They are placed about 18 inches above and to one side of the trolley wire, their object being to prevent telephone or other wires from falling across the trolley wire. Guard wires are now very little used, as they are of doubtful advantage and

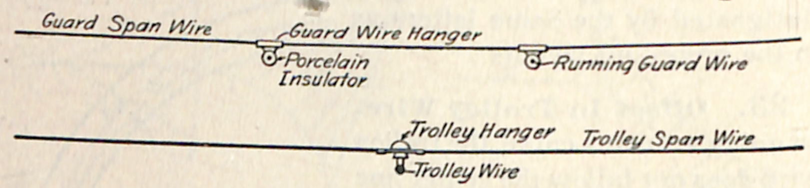


FIG. 20

are themselves apt to break and come in contact with the trolley wire. They are, however, useful in some special places, as, for example, at railway crossings. They have usually been made of No. 6 or 8 B. W. G. bare galvanized-iron wire, but it is now considered better to use weatherproof insulated iron wire, as the insulation adds much to the effectiveness of the guard.

25. Tension on Trolley Wire.—In putting up trolley wire, judgment must be used regarding the tension put on it. Thus, wire strung in hot weather must be allowed more sag than that put up in cold weather, otherwise the contraction will put severe strains not only on the trolley wire itself, but on the whole overhead construction. A range of 80° F. between summer and winter temperatures is not at all unusual, and this corresponds to a variation of nearly 4 feet per mile in the length of the trolley wire. For a 125-foot span of No. 0 wire, put up with a tension of 2,000 pounds, the sag at the center of the span will be, according to Mr. E. A. Merrill, 3.8 inches; for a tension of 1,500 pounds, 5 inches; for 750 pounds, 9.5 inches; for 500 pounds, 15 inches. Dawson recommends as a safe allowance for localities where the temperature does not fall below −20° F., a sag equal to three-fourths of 1 per cent. of

the span when the wire is strung at the ordinary temperature of 60° to 65° F. Thus, for a 125-foot span, a sag of about 11¼ inches would be allowed, and in the warmest weather the sag would not exceed 15 inches.

26. Span Wire.—Span wire is usually made of galvanized iron or steel, and in the best construction, stranded wire is always used. A common size is $\frac{5}{16}$ inch in diameter, made of seven strands, No. 12 B. W. G. Where a heavier construction is desired, $\frac{3}{8}$-inch stranded wire, made of seven strands, No. 11 B. W. G., is used. Solid span wire is not desirable, but in case it is used, the size should not be smaller than No. 1 B. & S. for No. 0 trolley wire. Span wires should be placed so that the trolley wire will be from 19 to 20 feet above the top of the rail. Of course, there are places where this rule cannot be adhered to, for at steam railroad crossings the wire must be higher than 19 feet, and under elevated structures it must be much lower.

27. Insulators.—The hanger supporting the trolley wire is always constructed so as to provide thorough insulation, except in cases where it is used to connect the trolley wire to a feeder. With wooden poles, the hanger provides sufficient insulation between the trolley wire and ground, so that it is not necessary to insulate the span wire from the

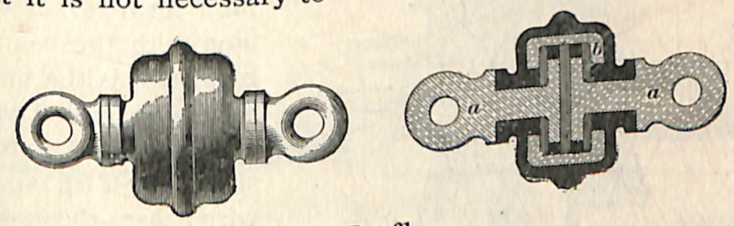


FIG. 21

poles. With iron poles, insulators are generally used in the span wire as an additional precaution. Fig. 21 shows an ordinary strain insulator much used whenever a span wire or pull-off is to be insulated from the pole. The span wires are attached to *a*, *a*, and the pull is taken up against piece *b*, which is separated from *a*, *a* by insulating material. The whole insulator, with the exception of the two eyes, is covered with molded insulation. Fig. 22 shows two styles of insulated turnbuckle for span-wire construction with iron poles.

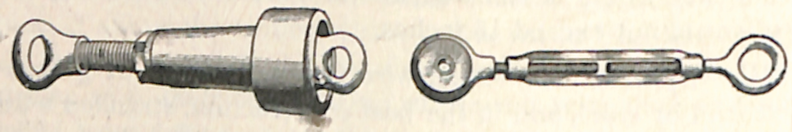


Fig. 22

28. Trolley-Wire Suspensions.—The hangers for suspending the trolley wire are made in a great variety of designs, but in general they consist of three parts, namely,

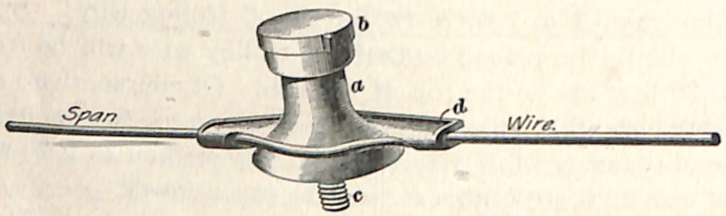


Fig. 23

a casting or body that is held by the span wire or bracket, an ear that grips or is soldered to the trolley wire, and an insulating material that separates the ear from the casting. Fig. 23 shows a common form of suspension with the ear removed; *a* is the main casting provided with the grooved extensions *d*. The span wire passes through *d* and around *a*, thus holding the hanger in place; by using a special tool, hangers are easily sprung into place on the span wire. Bolt *c* is bedded in molded insulating material and the casting is covered by a metal cap *b*. The ear to which the trolley wire is fastened screws on *c*. Fig. 24

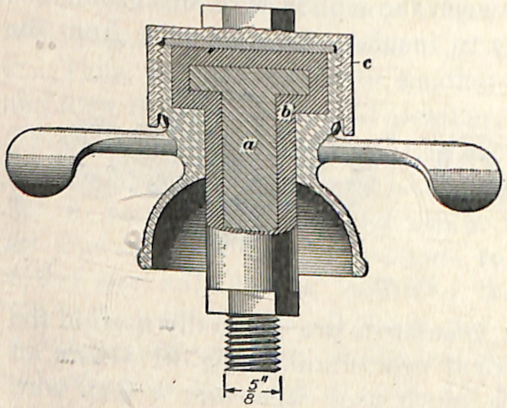


Fig. 24

is a sectional view of a hanger very similar to that in Fig. 23. The bolt *a*, with its molded insulation *b*, is held firmly in place by the screw cap *c*, but can be easily removed by unscrewing the cap.

The metal castings for overhead fittings are made either of malleable iron or brass. The ears, when soldered, are

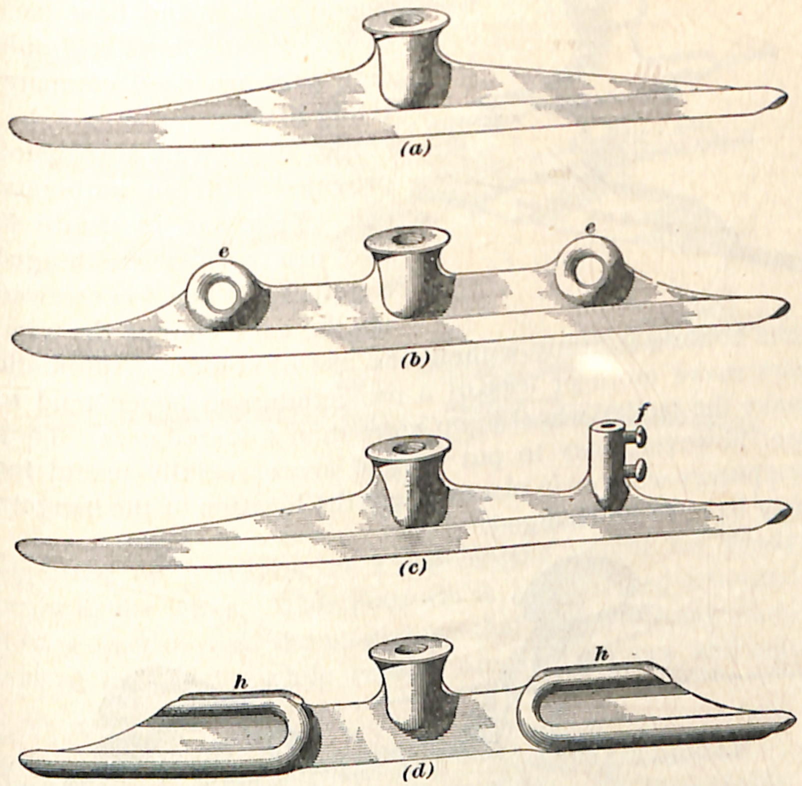


Fig. 25

made of brass; those designed to clamp on the wire are usually made of malleable iron.

Fig. 25 shows four styles of ears intended for soldering to the trolley wire. They are provided with a groove on the under side, in which the wire lies. The ear shown at (*a*) is known as a **plain ear**; it is used for ordinary straight-ahead work. (*b*) shows a **strain ear**, so called because it is provided with lugs *e*, *e*, to which the wires *a*, *a*, Fig. 17, are attached. (*c*) is a **feeder ear**; it is provided with a lug *f*, to which the tap from the feeder attaches. (*d*) is a **splicing ear**, used where the trolley wire comes to an end at a hanger. This ear serves the double purpose of holding the wire and acting as a splice. The ends of the trolley wire are passed up through two openings *h*, *h* and bent back over. Feeder ears and splicing ears are used comparatively little.

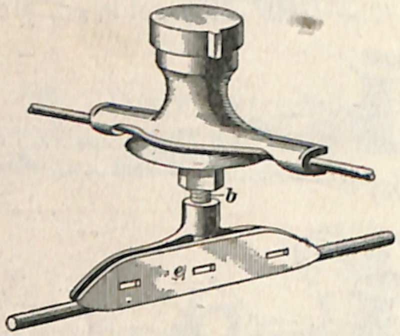


Fig. 26

Fig. 26 shows a suspension provided with an automatic ear. This ear is made in two parts that are hinged together. When *b* is screwed up, the ear *e* clamps the wire, thus holding it firmly without the use of solder. Automatic ears make more or less of a projection, and hence tend to make the trolley wheel jump more than soldered ears. They are, however, easy to put up and are especially useful for temporary work or in places where the location of the hangers may have to be changed.

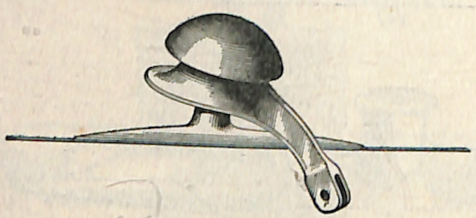


Fig. 27

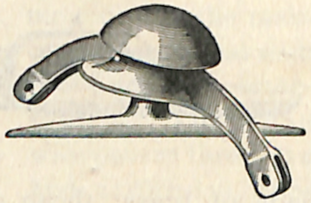


Fig. 28

29. In rounding a curve, the trolley wire is at first stretched in temporary wire slings and anchored, after which the hangers or pull-over clamps are attached. For ordinary curves, suspensions such as shown in Figs. 27 and 28 may be used. Fig. 27 shows a single-curve suspension used with single-track work; Fig. 28 is a double-curve suspension used

where there are two trolley wires and where a span wire or pull-off wire must be attached to each side of the hanger.

For suspending trolley wires and making repairs on the same, a "tower wagon" is used; this consists of a platform

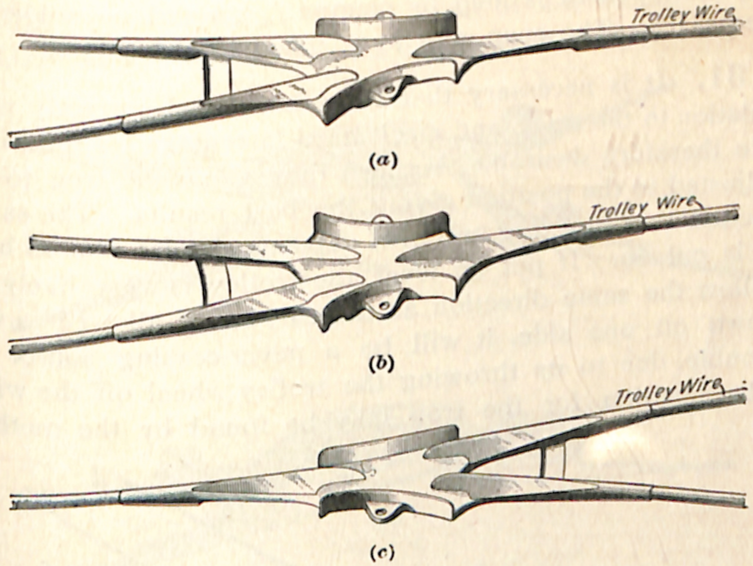


Fig. 29

supported on a wagon at a convenient height for ready access to the wires. This platform is generally so arranged as to project beyond the wagon, so that the latter may stand clear of the tracks while repairs are in progress and not

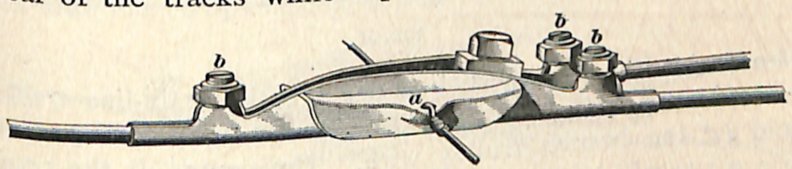


Fig. 30

interfere with regular traffic. When not in use, the platform may be lowered to the wagon by means of a winch.

30. Frogs.—At the point where one line branches from another, overhead switches, or **frogs**, are used to guide the trolley wheel from one wire to the other. Fig. 29 (*a*) shows the under side of a simple two-way **V** frog of a type that is largely used; (*b*) is a right-hand frog and (*c*) a left-hand frog. In these frogs the trolley wire is soldered into the ears. Fig. 30 shows a **V** frog in its natural position. In this case, the trolley wire is held by clamps *b*, *b*, *b* and no solder is necessary. The span wire is attached to the ears *a*.

31. It is necessary that frogs be placed correctly with relation to the track, and mechanical fastenings for the wires are therefore desirable, because they allow the frog to be adjusted to the position giving the best results. The satisfaction that any frog will give depends a great deal on how it is put up. If put up level, the trolley is very likely to follow the same direction as the car, but if allowed to sag down on one side, it will be a never-ceasing source of trouble, due to its throwing the trolley wheel off the wire. The position for the frog may be found by the method

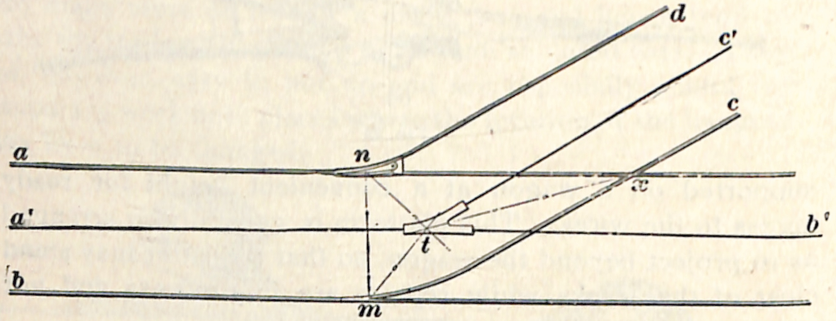


Fig. 31

shown in Fig. 31, where *a* and *b* are the main-line tracks, *c* and *d* the branch-line tracks, *a' b'* the main trolley wire, and *t c'* the branch trolley wire. The center of the triangle *n x m* will be at a point *t* where the lines bisecting each angle meet; and this determines the position of the frog. It will be a little removed from the center lines of the tracks. In practice it is often found necessary to shift a frog after it has been put up in order to make the trolley wheels run over it without jumping off. Lateral adjustment can be obtained by means of the turnbuckles attached to the span

wires. When a frog is first connected, the trolley wire should be left long and the end coiled up on top of the frog so that the latter can be shifted forwards or backwards in case such adjustment is afterwards found necessary.

32. Cross-Overs.—At the point of intersection of two trolley lines, a device called a **cross-over** is used. Fig. 32

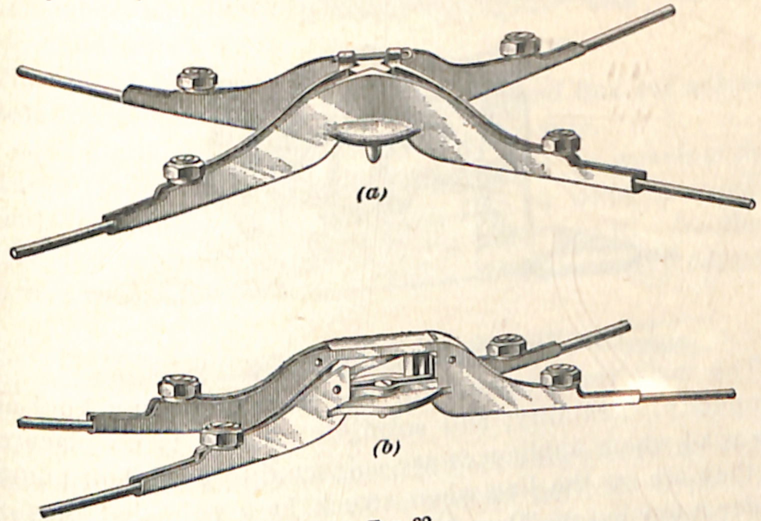


Fig. 32

shows two common forms of cross-overs; (*a*) is used where the two lines cross at right angles, (*b*) where they cross at an acute angle. Where the intersecting trolley wires belong to different companies, it is necessary to insulate the wires

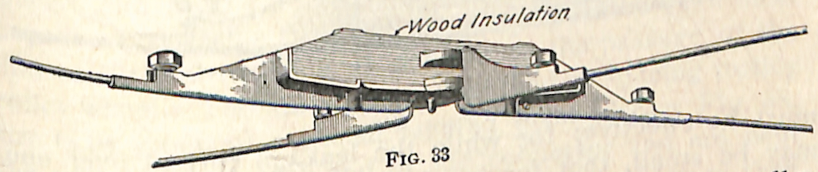


Fig. 33

from each other. In such a case, a special insulating trolley crossing, Fig. 33, must be used.

33. Section Insulators.—Section insulators are placed at the junction of two divisions that are fed by separate feeders from the power house, and are commonly known as

line circuit-breakers or simply **line breakers.** The direct line of the trolley wire is unbroken, allowing the trolley wheel to run smoothly across the insulating material (usually hardwood) that separates the two castings to which the sections of trolley wire are attached. Figs. 34 and 35 show two satisfactory types of section insulators, the insulating material in both cases being hardwood.

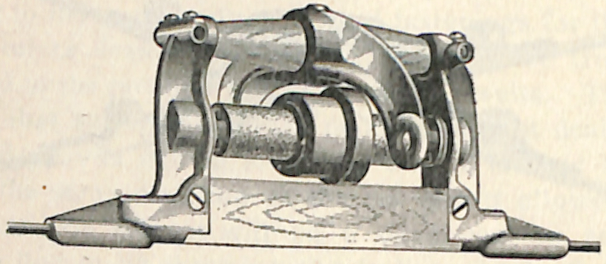


Fig. 34

The main requirements for line devices of any kind are simplicity, durability, and strength. There is no place on the road where appliances are subjected to as violent knocks as they are on the line when struck by a pole that flies off under a tension of 20 or 25 pounds with the car going 20 or 30 miles an hour. Where the device has an insulator, this

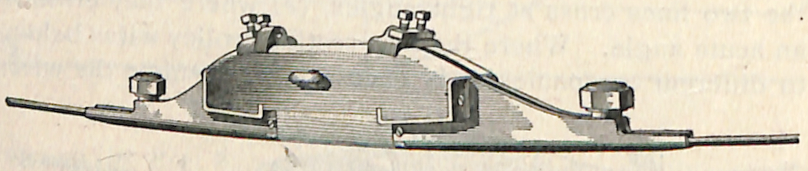


Fig. 35

must be effective; for while the leakage current over one may be small, that for hundreds of them in parallel máy amount to considerable. Every line should be subjected to a constant and careful inspection, and as soon as a fault begins to assert itself, it should be remedied at once.

34. Feeder Splicing.—The feeders, if they are not in the form of large cables, are usually joined by using the

ordinary Western Union joint, Fig. 36, or by a long twisted joint, as in Fig. 37. In the latter case the insulation is removed for about 2 feet from the ends, and the wires twisted together while under tension and then soldered. This makes a good joint and it is much neater and less bulky than the Western Union when used with large solid wires, such as No. 000 or No. 0000.

Fig. 36

A solution of resin in alcohol makes a good flux for soldering such joints, as it does not corrode the wire.

Large feeder cables may be joined either by weaving the strands together and soldering or else by using a copper sleeve and thoroughly soldering the ends into it. Another effective method of joining cables is to slip a heávy copper

Fig. 37

sleeve over the joint and then subject this sleeve to very heavy pressure by means of a special portable hydraulic press. All overhead wires after being spliced should be thoroughly taped, so as to provide an insulation at least equal to the covering on the wire.

35. Splicing Trolley Wires.—When a trolley wire is spliced, the joint has to be mechanically strong, because there is considerable strain on the wire; also, the joint must offer as little obstruction as possible to the passage of the trolley wheel. The most common method of splicing trolley wire is by means of a tinned tapered brass sleeve, Fig. 38. The wires go in at each end of the connector and are bent up through the openings *a, a*. The remaining space is then poured full of melted solder and the ends of the wire trimmed off. This connector will give excellent service if care is taken to see that it is made of heavy enough material and is a good fit for the wire. (*b*) shows dimensions for a satisfactory connector for No. 00 wire.

The splicing ear shown in Fig. 25 (*d*) represents another device for splicing trolley wire. The general idea is the same as that used in the tubular trolley connector, except that it must be used at a point of support, as indicated by the lug for attaching to the hanger. The ends of the wire to be

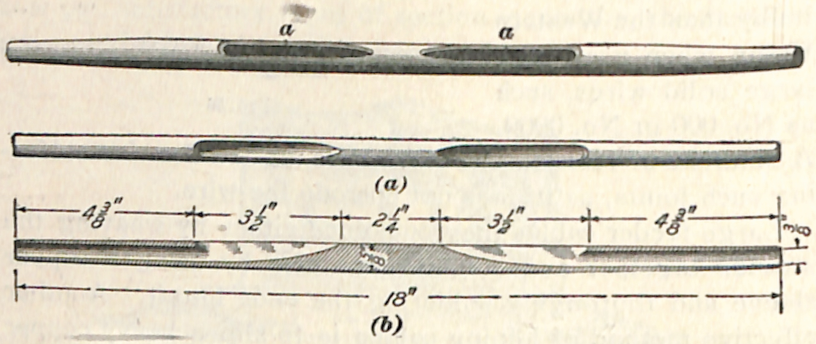


Fig. 38

spliced go into the ear at the ends, pass up through the holes *h*, *h*, and are turned back and trimmed off. The fins on the lower edge of the ear are clinched and the whole is then sweated with solder and cleaned off. Splicing ears do not always call for the use of solder; in some of them the wire is held by means of screw clamps, but they all have the disadvantage that a splice cannot be made except where there is a hanger, whereas with a sleeve connector, a splice can be made anywhere on the line.

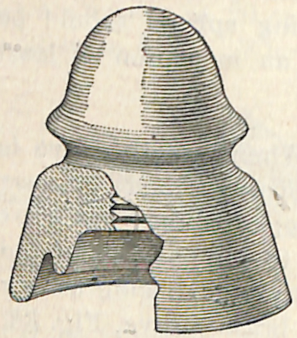


Fig. 39

36. Feeder Insulators.—Heavy glass insulators may be used for supporting feeders of ordinary size. In the case of large feeders, however, the strain is very great and glass insulators are liable to crack. This is especially so at curves, where the strain on the insulator may be very heavy.

Where the heavy feeder cable subjects the pole insulator to a side strain, as at corners and curves, insulators of

composition material, such as molded mica, are used, because this material is tougher than glass and does not crack under the strain. Fig. 39 shows one of these insulators having a groove large enough to take a cable up to 500,000 circular mils cross-section. Fig. 40 shows another style where the top is made of bronze and the lower part of molded insulation. The feeder rests in the groove and is held in place by the screw cap *a*. Fig. 41 shows still another style, in which the cable also rests in a groove on top, but is held in position by means of a tie-wire.

Fig. 40

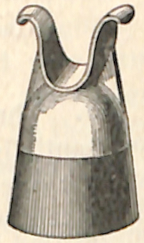


Fig. 41

37. Connecting Feeders to Trolley Wire.—Fig. 42 shows the most common method of tapping the feeder to the trolley wire. A piece of solid weather-proof feed-wire (No. 00 to 0000) is tapped on to the feeder and is fastened to the strain insulator *a* by passing the end of the wire through the eye of the insulator and giving it a few turns around itself. The other end of the feed-wire is attached to one end of strain insulator *b*, which is placed at some distance to the left of the trolley hanger so that it will not be struck in case the trolley wheel flies off the wire. For the balance

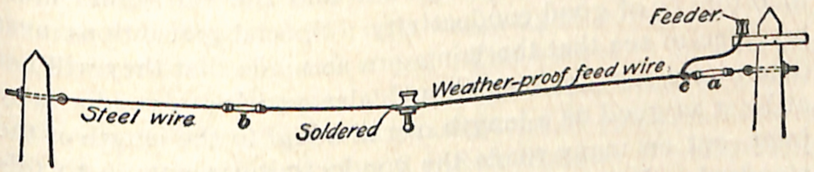


Fig. 42

of the span from *b*, ordinary steel span wire is used, though in some cases the copper wire is run clear across and strain insulator *b* placed near the pole in the same position as *a*. The weather-proof insulation is removed from the feed-wire at the point where the trolley-wire hanger is attached, the hanger having a solid brass bell, without the usual insulation, soldered to the span wire.

38. Line Lightning Arresters.—The overhead distributing system of an electric railway should be liberally supplied with lightning arresters. There should be at least five to the mile and a good ground connection should be provided by connecting to the rail. The arresters used for this work are practically the same as those for indoor location in power stations, except that they are enclosed in weather-proof cases.

THE TRACK

39. The **track** on which electric cars are to run must be substantially constructed. Each car carries its own motors and the track is subjected to much greater wear and tear than if the cars were propelled by some outside source of power, as, for example, on a cable road. The rails are subjected to the grinding action of the wheels whenever slippage occurs and the weight of the motors on the trucks is so great that unevenness in the track causes severe pounding. When electric railroads were first installed, the track construction was altogether too light and the whole tendency has been toward heavier construction, until at present the trackwork on the best electric railways is fully as substantial as that on trunk-line steam roads. On most electric railways, the track is used for one side of the circuit and the rail joints must therefore be of good conductivity. Special precautions must be taken to see that the joints are so made that they will not deteriorate rapidly; they should also provide a conductivity at least as good as a length of rail equal to the length of the joint, but on many roads the conductivity is not up to this standard. Rails for electric roads, as now built, seldom weigh less than 60 pounds per yard, and in most cases weigh more. Many interurban roads use rails weighing 80 or 90 pounds per yard, and for city tracks, where high rails must often be used on account of paving, the weight will run over 100 pounds per yard.

The kind of roadbed and rail to be used depends on where the road is located. If the soil has a very poor bottom, the

subwork must be more substantial than where the soil is firm or where there is rock. The construction also depends a great deal on the traffic, and in many cases on city ordinances that call for a certain class of rail.

RAILS

40. Composition of Track Rails.—Rails are always of mild steel; i. e., steel containing a low percentage of carbon, together with manganese, silicon, and very small percentages of sulphur and phosphorus. The percentages of carbon and manganese have a marked effect on the hardness of the rail; if small, the rail will be soft and its wearing qualities poor; if high, the rail will be brittle and its electrical conductivity will be low. Table V shows the limiting percentages of carbon, phosphorus, silicon, and manganese as specified for track rails for a number of prominent street-railway systems in the United States. These will give an idea as to what is considered a desirable composition for rails; it will be noted that the percentages of the different substances do not differ greatly.

41. Cross-Section and Weight of Rails.—Rails are always designated by the number of pounds per yard that they weigh. Thus, a rail weighing 60 pounds per yard is known as a 60-pound rail; one weighing 80 pounds per yard, as an 80-pound rail; and so on. The weight in pounds per yard divided by 10 gives the cross-sectional area, in square inches, approximately. For example, an 80-pound rail would have a cross-section of $\frac{80}{10} = 8$ square inches. We may write

$$A = \frac{W_y}{10} \qquad (1)$$

where A = area of rail section, in square inches;
W_y = weight of rail, in pounds, per yard.

Rule I.—*To find the area of cross-section of a rail, divide the weight, in pounds, per yard by 10.*

TABLE V

RAIL COMPOSITION

Road	Carbon Per Cent.	Phosphorus Per Cent.	Silicon Per Cent.	Manganese Per Cent.	Sulphur Per Cent.	Remarks
Boston	.50 to .60	Not over .08	.10 to .15	.80 to 1.00	Not over .08	Rails with carbon below .50 per cent. or above .62 per cent. will be rejected
Buffalo	.43 to .53	Not over .10	Not to exceed .20	.80 to 1.10		
Denver	.46 to .56	.10 or less	.10 or over			
Philadelphia .	.45 to .55	Not over .10	.20	.80 to 1.00		
	.37 to .45	Not over .10	.07 to .15	.70 to 1.10	Not over .05	Illinois Steel Co. standard specification for rails under 70 lb.
	.45 to .55	Not over .10	.10 to .20	.80 to 1.00	Not over .05	Same for rails over 70 lb. per yard

To find the weight of rails required per mile of single track, the following simple formula may be used:

$$W_t = 1.76\ W_y \qquad (2)$$

where W_t = weight of rails, in tons, for 1 mile of single track;

W_y = weight of rail, in pounds, per yard.

Rule II.—*The number of tons weight of rail required for 1 mile of single track is equal to 1.76 times the weight of the rail, in pounds, per yard.*

42. Resistance of Track Rails.—Since, in most electric railways, the track is used as one side of the circuit, it is important to know the electrical resistance of steel. The resistance of mild steel varies greatly with its composition, the harder the steel, the higher is the resistance. Track rails are selected for their wearing qualities; hence, a certain degree of hardness is essential; but where a rail is used simply as a working conductor, as in third-rail systems, it can often be made of softer steel, because the only wear to which it is subjected is that of the collecting shoes.

Extended tests made by Mr. J. A. Capp on specimens of rails obtained from different sources show specific electrical resistances varying from 6.4 to 13.2 times that of copper. A fine grade of Swedish wrought iron showed a resistance of about 6 times that of copper. It has been customary to assume, in making calculations regarding track resistance, that steel ordinarily used in track rails has a specific resistance of 7 times that of copper. However, tests show that in most cases the specific resistance is much higher than this, and to be on the safe side, 10 would be more nearly in accordance with the facts and will be so taken here.

43. Steel for Conductor Rails.—In most cases where roads have been operated by a third rail or from special conductor rails, as in slot systems, the rails have been rolled from material the same as used for the track. Rails rolled of special steel to secure higher conductivity would cost too much in the majority of cases. Mr. Capp's tests show that by properly limiting the impurities in the steel there is no difficulty in securing a composition that can be made without greatly increasing the cost and that will have a resistance not over 8 times that of copper. The element having the greatest effect on the resistance is manganese, and if the percentage of this is kept down, the other impurities can be present in a considerable amount without causing a very high resistance. Chemically pure iron has a resistance approximately 4.5 times that of copper, and comparatively small percentages of impurities increase the resistance in a marked degree. Pure iron, even if it could be obtained at reasonable cost, would not be suitable for conductor rails because it would not be hard enough to stand the wear of the collecting shoes. At the same time, if a conductor rail is made with percentages of carbon and manganese lower than ordinarily used, the conductivity can be improved. Mr. Capp recommends the following composition as giving a resistance not exceeding 8 times that of copper: Carbon not to exceed .15 per cent.; manganese not to exceed .30 per cent.; phosphorus not to exceed .06 per cent.; and silicon not to exceed .05 per cent. On some large systems, for example, on the New York subway, where the length of conductor rail is sufficient to warrant the preparation of special steel, it has been used; but for ordinary roads, standard rails have in many cases been installed.

44. Formulas for Track Resistance.—A copper bar of 1 square inch cross-section has an area of 1,273,236 circular mils. The resistance of 1 mil-foot of commercial copper may be taken as 10.8 ohms; hence, the resistance of a bar of copper 1 square inch cross-section and 1 foot long would be $\frac{10.8}{1,273,236}$, and a bar 1 yard long would have a resistance of $\frac{10.8 \times 3}{1,273,236}$ ohms. If W_y is the weight of a rail, in pounds per yard, its cross-sectional area, in square inches, is $\frac{W_y}{10}$;

and if we assume that the resistance of ordinary rail steel is 10 times that of copper, a rail having a cross-section of $\frac{W_y}{10}$ square inches will be equivalent to a copper bar of $\frac{W_y}{100}$ square inches cross-section. Hence, if the resistance of 1 yard of copper bar of 1 square inch cross-section is $\frac{10.8 \times 3}{1,273,236}$ ohms, a yard of rail of weight W_y will have a resistance of $\frac{10.8 \times 3}{1,273,236 \times \frac{W_y}{100}} = \frac{.00254}{W_y}$ ohm; or

$$R_y = \frac{.00254}{W_y} \qquad (3)$$

where R_y = resistance, in ohms, per yard of rail;
W_y = weight of rail, in pounds, per yard.

Rule I.—*The resistance, in ohms, of 1 yard of steel rail is equal to .00254 divided by the weight, in pounds, per yard.*

Sometimes it is more convenient to have the resistance expressed in terms of 1,000 feet of rail. Since 1,000 feet $= \frac{1000}{3}$ yards,

$$R' = \frac{.00254 \times \frac{1000}{3}}{W_y} = \frac{.848}{W_y} \qquad (4)$$

Rule II.—*The resistance, in ohms, per 1,000 feet of steel rail is equal to .848 divided by the weight, in pounds, per yard.*

If the resistance per mile is desired, we have

$$R_m = \frac{.00254 \times 1,760}{W_y} = \frac{4.48}{W_y} \qquad (5)$$

Rule III.—*The resistance, in ohms, per mile of steel rail is equal to 4.48 divided by the weight, in pounds, per yard.*

It should be particularly noted that these formulas are based on the assumption that the steel has a specific resistance 10 times that of copper.

45. For a special conductor rail with a resistance 8 times that of copper the formulas would become

$$R_y = \frac{.00204}{W_y} \qquad (6)$$

$$R' = \frac{.679}{W_y} \qquad (7)$$

$$R_m = \frac{3.59}{W_y} \qquad (8)$$

In the case of a single track, there are two rails in parallel; hence, the resistance for each unit length of track (two rails) would be one-half that given by the preceding formulas. For a double-track road (four rails in parallel) the resistance would be one-fourth that given by the formulas.

As shown later, under the subjects of rail joints and rail bonding, there is no reason why the resistance measured across, say, 3 feet of rail including a joint should not be as low as 3 feet measured across the solid rail if proper care is taken at the joints. Hence, for first-class construction, it is allowable to take the resistance calculated from the above formulas as representing the actual track resistance without the necessity of adding anything for extra resistance due to joints.

Table VI shows various values of rail and track resistance thus calculated; if provision is not made for thorough bonding, the values given would be exceeded by an amount depending on the conductivity of the joints as compared with an equal length of solid rail.

RAIL SECTIONS

46. Two kinds of rail are in common use for electric railways: **T rails** and **girder rails;** girder rails may be subdivided into two classes: *tram rails* and *groove rails.* There is no good reason why a **T** rail should not be called a girder rail; it resembles a girder fully as much as the rails commonly known by that name, and this is particularly so with the high **T** rails now so much used in paved streets.

TABLE VI

RAIL RESISTANCE

Weight	Area of Cross-Section	Track Rails, Resistance of Steel = 10 × Resistance of Copper										Conductor Rails, Resistance of Steel = 8 × Resistance of Copper						
			Ohms per Yard			Ohms per 1,000 Feet			Ohms per Mile				Ohms per Yard		Ohms per 1,000 Feet		Ohms per Mile	
Pounds per Yard	Square Inches	Equivalent Copper Cross-Section Square Inches	Single Rail	Two Rails in Parallel	Four Rails in Parallel	Single Rail	Two Rails in Parallel	Four Rails in Parallel	Single Rail	Two Rails in Parallel	Four Rails in Parallel	Equivalent Copper Cross-Section Square Inches	Single Rail	Two Rails in Parallel	Single Rail	Two Rails in Parallel	Single Rail	Two Rails in Parallel
40	4.0	.40	.0000635	.0000318	.0000159	.0212	.0106	.00530	.1120	.0560	.0280	.50	.0000510	.0000255	.0170	.00850	.0898	.0449
45	4.5	.45	.0000564	.0000282	.0000141	.0188	.00940	.00470	.0995	.0498	.0249	.56	.0000453	.0000227	.0151	.00755	.0798	.0399
50	5.0	.50	.0000508	.0000254	.0000127	.0169	.00845	.00423	.0896	.0448	.0224	.63	.0000408	.0000204	.0136	.00680	.0718	.0359
55	5.5	.55	.0000462	.0000231	.0000116	.0154	.00770	.00385	.0815	.0408	.0204	.69	.0000371	.0000186	.0123	.00615	.0653	.0327
60	6.0	.60	.0000423	.0000212	.0000106	.0141	.00705	.00353	.0747	.0374	.0187	.75	.0000340	.0000170	.0113	.00565	.0598	.0299
65	6.5	.65	.0000391	.0000196	.00000978	.0130	.00650	.00325	.0689	.0345	.0172	.81	.0000314	.0000157	.0104	.00520	.0552	.0276
70	7.0	.70	.0000363	.0000182	.00000908	.0121	.00605	.00303	.0640	.0320	.0160	.87	.0000291	.0000146	.0097	.00485	.0513	.0257
75	7.5	.75	.0000338	.0000169	.00000845	.0113	.00565	.00283	.0597	.0299	.0149	.94	.0000272	.0000136	.00905	.00453	.0479	.0239
80	8.0	.80	.0000318	.0000159	.00000795	.0106	.00530	.00265	.0560	.0280	.0140	1.00	.0000255	.0000128	.00849	.00424	.0449	.0224
85	8.5	.85	.0000299	.0000149	.00000748	.00998	.00499	.00249	.0527	.0264	.0132	1.06	.0000240	.0000120	.00799	.00399	.0422	.0211
90	9.0	.90	.0000282	.0000141	.00000705	.00942	.00471	.00236	.0498	.0249	.0124	1.12	.0000227	.0000114	.00754	.00377	.0399	.0199
95	9.5	.95	.0000267	.0000134	.00000668	.00893	.00447	.00223	.0472	.0236	.0118	1.18	.0000215	.0000108	.00715	.00358	.0378	.0189
100	10.0	1.00	.0000254	.0000127	.00000635	.00848	.00424	.00212	.0448	.0224	.0112	1.25	.0000204	.0000102	.00679	.00339	.0359	.0179
105	10.5	1.03	.0000242	.0000121	.00000605	.00808	.00404	.00202	.0427	.0214	.0107	1.31	.0000194	.00000970	.00647	.00324	.0342	.0171
110	11.0	1.10	.0000231	.0000116	.00000578	.00771	.00386	.00193	.0407	.0204	.0102	1.37	.0000186	.00000930	.00618	.00309	.0327	.0164
115	11.5	1.15	.0000221	.0000111	.00000553	.00737	.00369	.00184	.0389	.0195	.00973	1.43	.0000177	.00000885	.00590	.00295	.0312	.0156

In Fig. 43, (*a*) shows a **T** section, (*b*) a tram girder, and (*c*) a groove girder. In each case, *h* is the *head*, or *ball;* *w*, the *web;* and *f*, the *flange* or *foot*. A **T** rail is a *center-bearing rail*, because the center of the head is directly over the center of the web. The girder rail shown in (*b*) is called a *tram rail* because of the projecting tram *t*; in (*c*), the *groove o* is the distinctive feature; the projecting part *d*

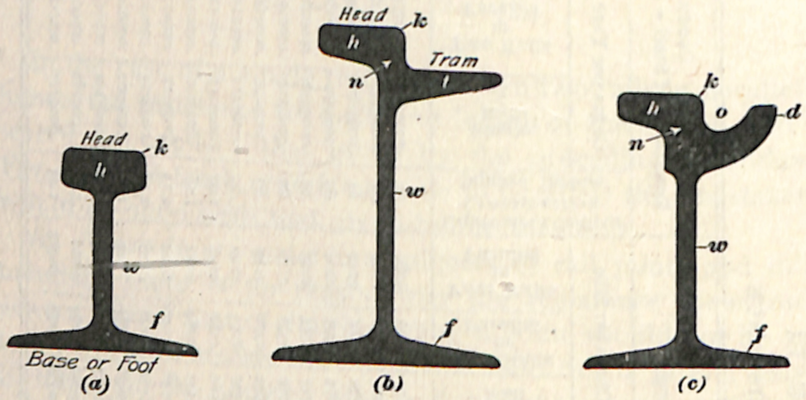


FIG. 43

is called the *lip*. *k* is the *gauge line*, or the part that the gauge touches when gauging the distance apart of the rails. The tram rail is the first in order of invention and it is still more used than any other type of girder rail. The tendency is to use long rails for electric-railway work in order to reduce the number of joints. Ordinary rails are 30 feet in length, but many roads are now using 60-foot rails even though they are more difficult to ship and handle.

47. T Rails.—The **T** rail is used on all steam roads and on electric roads wherever allowable. For suburban and interurban lines, it is the type universally employed; and even for city work in paved streets it is taking the place of the tram and groove rails. The **T** section gives a maximum amount of strength and stiffness with a minimum of material, and it has no groove or tram for the collection of dirt; the head remains clean, and a clean rail means less power for the propulsion of the cars. It is cheaper than the

tram or groove types and provides a track that is easier to lay and is fully as good, if not better, so far as running qualities are concerned. There has always been more or less opposition to the use of **T** rails in paved streets on the ground that they break up the surface of the pavement more than the tram or girder shapes, thus interfering with street traffic. However, with special paving bricks now used this objection is overcome to a large extent, and **T** sections are strongly advocated by many prominent street-railway engineers.

TABLE VII

WEIGHTS AND DIMENSIONS OF STANDARD T RAILS

(*A. S. C. E. Sections*)

Weight Pounds per Yard	Area of Cross-Section Square Inches	Width of Base and Height Inches	Thickness of Web Inches	Width of Head Inches
100	9.8	$5\frac{3}{4}$	$\frac{9}{16}$	$2\frac{3}{4}$
95	9.3	$5\frac{9}{16}$	$\frac{9}{16}$	$2\frac{11}{16}$
90	8.8	$5\frac{3}{8}$	$\frac{9}{16}$	$2\frac{5}{8}$
85	8.3	$5\frac{3}{16}$	$\frac{9}{16}$	$2\frac{9}{16}$
80	7.8	5	$\frac{35}{64}$	$2\frac{1}{2}$
75	7.4	$4\frac{13}{16}$	$\frac{17}{32}$	$2\frac{15}{32}$
70	6.9	$4\frac{5}{8}$	$\frac{33}{64}$	$2\frac{7}{16}$
65	6.4	$4\frac{7}{16}$	$\frac{1}{2}$	$2\frac{13}{32}$
60	5.9	$4\frac{1}{4}$	$\frac{31}{64}$	$2\frac{3}{8}$
55	5.4	$4\frac{1}{16}$	$\frac{15}{32}$	$2\frac{1}{4}$
50	4.9	$3\frac{7}{8}$	$\frac{7}{16}$	$2\frac{1}{8}$
45	4.4	$3\frac{11}{16}$	$\frac{27}{64}$	2

48. For suburban or interurban roads, standard **T** rails similar to those used on steam roads are suitable; no paving conditions have to be met and a rail of standard height can be used. Fig. 44 shows four of the standard sections for **T** rails and fish-plates adopted by the American Society of Civil Engineers and commonly known as A. S. C. E. sections. In all these, the height is equal to the width of the base; (*a*) is a 100-pound rail; (*b*) a 95-pound; (*c*) a 90-pound; and (*d*) an 85-pound. Table VII gives dimensions of the various A. S. C. E. sections; rails as small as 45 pounds per yard are given in the table, but those lighter than 60 pounds are seldom used for electric-railway work, except perhaps for light railways around industrial plants. Many of

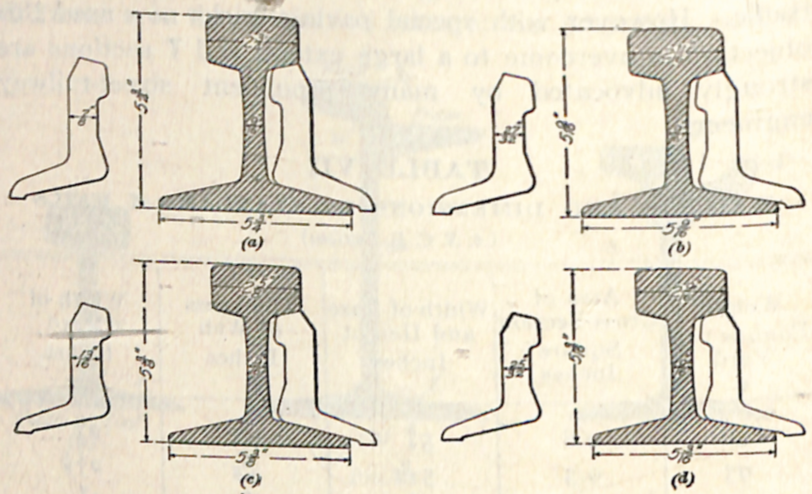
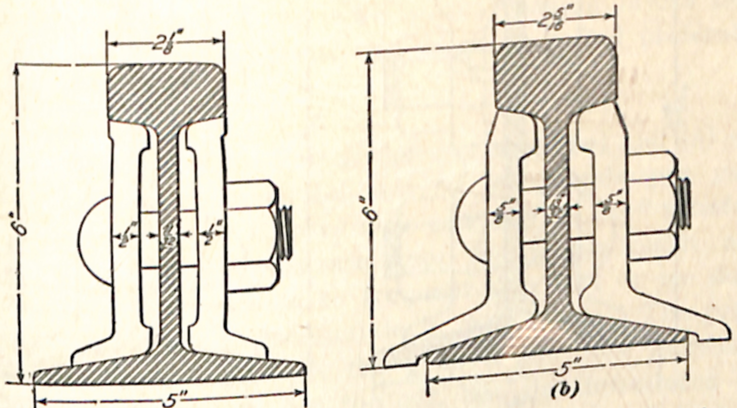


FIG. 44

the leading interurban electric roads use rails of standard A. S. C. E. section, and unless there is some good reason for using a special section it is advisable to install a standard rail wherever possible.

49. When **T** rails are used in paved streets, it is usually necessary to lay a rail higher than the standard; therefore, **T** rails 6 or 7 inches in height are much used for this class of work; they are sometimes called *shanghai rails.* Fig. 45 shows three typical high **T** sections; (*a*) and (*b*) are sections made by the Lorain Steel Company, (*a*) weighing 60 pounds per yard and (*b*) 72 pounds per yard. The one shown in (*c*) is recommended by the Committee on Standards of the American Street Railway Association. It weighs 95 pounds per yard and the distinctive feature is the width of tread, which is 3 inches as compared with $2\frac{1}{8}$ inches in (*a*) and $2\frac{5}{16}$ inches in (*b*). The object of the wide tread is

to allow interurban cars, having a 3-inch wheel tread, to operate over city tracks without interfering with the pavement. The splice bars, or fish-plates, are also made with an unusual amount of camber to prevent buckling when the bolts are drawn up. High **T** rails are strongly recommended,



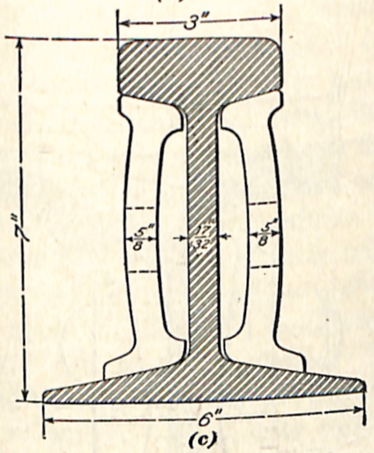


FIG. 45

by the committee just referred to, whenever the consent of the municipality can be obtained.

50. Girder Rails.—Girder rails of the tram or groove type are intended to provide a track that will interfere as little as possible with street traffic. A groove rail leaves the street surface unbroken and there is little tendency for vehicles to run along the rails. The rail head, or groove, does not present an attractive track for carriage or truck wheels, but with the tram rail, the surface of the street is more or less broken and the tram offers a good path for carriages and trucks. The tram rail should not, therefore, be used in places where there is dense city traffic. Vehicle traffic is not of so much importance in localities where it is

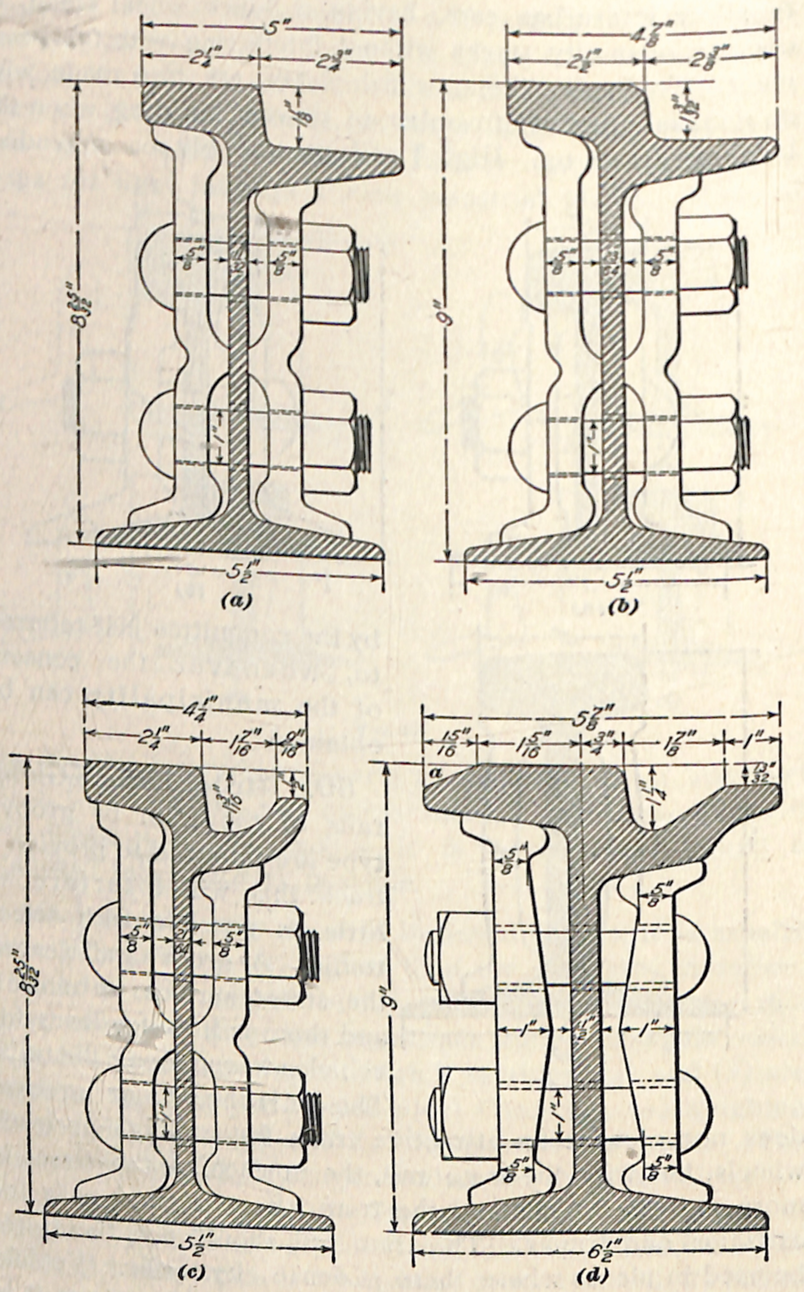


FIG. 46

not dense, but in large cities the wear on the track from this source may be considerable, and a tram rail not only attracts this traffic but makes it hard for vehicles to turn out of the way. For densely traveled districts, a grooved rail should be used; and for places where the street traffic is lighter, a high **T** rail with special paving bricks next the rail, as described later, will often be found preferable to the tram rail.

51. Fig. 46 shows four girder sections. (*a*) and (*b*) are standard tram sections; (*a*) weighs 90 pounds per yard and (*b*) 94 pounds. Groove rails can only be used satisfactorily where the streets are kept reasonably clean and where the car service is so frequent that dirt or ice does not have a chance to accumulate in the groove. The presence of foreign matter in the groove not only increases the power required to run the car, but also introduces an element of danger, as a small stone may be sufficient to throw the car off the track. It is now customary to make the groove flaring at the top, so that dirt can be pushed out sidewise by the wheel flange. Fig. 46 (*c*) shows an 88-pound grooved girder rail used in Boston. The lip is cut down ½ inch below the tread of the rail, and the section is to a certain extent a compromise between the tram rail and full-groove rail. The groove is wide and flaring so that dirt will be forced out at the side. (*d*) shows a very heavy grooved rail used for standard trackwork in Philadelphia in localities where the traffic is dense. For places where the traffic is lighter, the section shown in (*a*) is used. The rail shown in (*d*) weighs 137 pounds per yard and the lip is extended to the right, as shown, thus combining the tram feature with the groove. Another feature is the way in which the tread is cut off at (*a*), thus helping to keep the part of the tread, on which the wheel runs, cleaner than with ordinary girder rails. For a given groove, there is always a given shape of car-wheel flange that is best suited to that groove; so that in buying car wheels, due regard must be had for the shape and size of the groove that they are to run in, otherwise there will be excessive wear in the groove and on the wheel flange. A wheel flange must be of a certain depth in order to be safe; if the depth of the groove and the depth of the flange of the wheel are about the same, the least bit of wear in the tread of the wheel will let the weight of the car down on the flange, where it is not intended to be and which will not stand it; if the wheel flanges are deeper than the groove, the wheels cannot be used at all. A track of grooved rail must be gauged to exactness, because it offers two chances for the wheels to bind. If the gauge is too narrow, the outsides of the wheel flanges bind against the heads of the rails; if the rails are too far apart, the insides of the wheel flanges bind against the side of the groove.

52. **Standard Track Gauge.**—The standard track gauge is 4 feet $8\frac{1}{2}$ inches, as measured by means of a gauge such as that shown in Fig. 47 (*a*). The car wheels are pressed on the axle to 4 feet $8\frac{1}{4}$ inches by means of a gauge similar to that shown in Fig. 47 (*b*). To apply such a gauge correctly, one end of it should be free to move laterally about $2\frac{1}{2}$ inches, when both of the notches engage the flanges of the two wheels. T rails are much more economical from the operating point of view than girder rails, because however much the tread of the wheel may wear down or be ground down, there is nothing for the flange of the wheel to ride on.

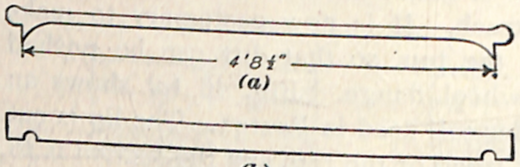


FIG. 47

53. **Rails With Conical Tread.**—The treads of wheels are conical; that is, the diameter of tread next to the flange is larger than its diameter at the outside edge. This is done to allow the car to center itself on the track when the two wheels on the same axle are of different sizes. The device probably performs its function when there is no greater difference in the wheels than is found on two wheels of the same make just as they come from the foundry; this difference

is, as a rule, not more than $\frac{1}{8}$ inch in the circumference. But the beveled tread cannot be expected to amount to very much as an equalizer where the difference in diameter of the two wheels is $\frac{3}{8}$ or $\frac{1}{2}$ inch. Such a state of affairs should not be allowed to exist, on account of the slippage it causes and for other reasons; but, unfortunately, in some cases it does exist. The general rule has been to make the top of the rail level, with the result that until there is a certain amount of wear in either the rail head or the wheel tread, the traction surface between the two is a straight line. Fig. 48 shows, in an exaggerated way, the point referred to. It is now becoming customary to roll girder rails with a conical tread, as shown in (*b*), thus providing a good traction surface between the wheel and rail from the start, and increasing the life of both by a considerable amount. The rails shown in Fig. 46 (*b*) and (*d*) have conical treads.

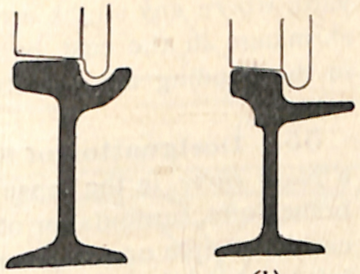


FIG. 48

SPECIAL WORK, GUARD RAILS, AND CURVES

54. **Special Work.**—All roads have a number of crossings, curves, branch-offs, cross-overs, etc., and since these are different from straight track, in that they involve special care and precautions in their installation, they are all included under the general name of **special work**. Important special work is made up complete at the steel works and shipped ready to install. As the construction of special work must be carried out with great precision (a difference of $\frac{1}{4}$ inch in the angle at which one arm of a frog or crossing sticks out may cause no end of trouble), it is done step by step, as follows: The site of the proposed work is first measured up carefully and a drawing of the survey made. This drawing is then carefully checked and is used as a means to lay the work out, in actual size, with chalk on

a hard, smooth, maple floor, known as the laying-out floor; if the job checks up all right, the floor lines and angles are used as a guide for making wooden templets to be used by the patternmaker and the rail bender. When the separate parts of the job are complete, it is set up in the laying-out yard, where any slight errors or inaccuracies due to uneven shrinkage in the cast parts of the job or to want of care in the bending are detected.

55. Designation of Special Work.—Fig. 49 (*a*) shows a *plain curve*, in the sense that it is not complicated by any branch-offs, turnouts, or other special features; such a curve can be simple or compound, single or double, right-hand or left-hand. (*b*) is a *left-hand branch-off* and (*c*) a *right-hand branch-off*: these are used where a branch road leaves the main line. Facing the point of departure of the branch from the main line a right-hand branch-off turns to the right and a left-hand branch-off to the left. (*d*) is known as a *connecting curve and crossing;* in the figure, the curve is a right-hand branch-off to the horizontal straight track and a left-hand branch-off to the vertical one. (*e*) is a *plain* Y; (*f*) is a *three-part* Y; and (*g*) a *through* Y; the three-part Y can be used instead of a loop to turn single-end cars at the end of the line. (*h*) is a *reverse curve*, and must often be used where a cross street is broken at the main street. (*k*) is a *right-hand* and (*l*) a *left-hand cross-over*, used to cross over from one track to the other; these are very convenient devices to place here and there in a main line to turn cars back, either when they are crippled or to get them on their time after a long delay. When it is practicable, a cross-over should be put in so that its switch points will lie in the direction of travel on the two tracks. (*m*) shows a *diamond turnout;* (*n*) an ordinary *siding;* and (*o*), a *thrown-over turnout*, seen very often in temporary work, where it is of the nature of a temporary cross-over to avoid a gang of workmen.

The names given to the different parts of special work vary considerably, and much confusion results therefrom. Fig. 50 shows a piece of special work that includes an example

of nearly all the crossings, switches, etc. commonly met with, and gives the names of the various parts as recommended by the Lorain Steel Company.

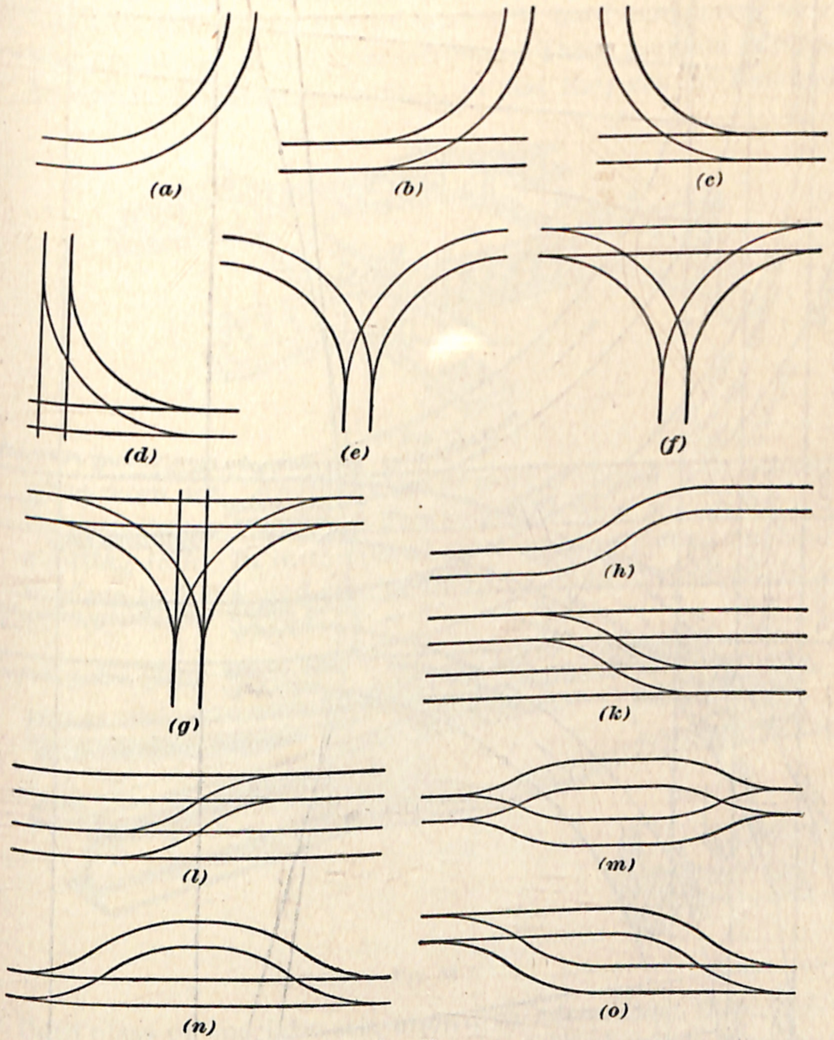


Fig. 49

56. Construction of Special Work.—In the switch, frog, and crossing part of the special work, the greatest wear takes place at the points and breaks, which are subjected to the pounding action of the wheels caused by the

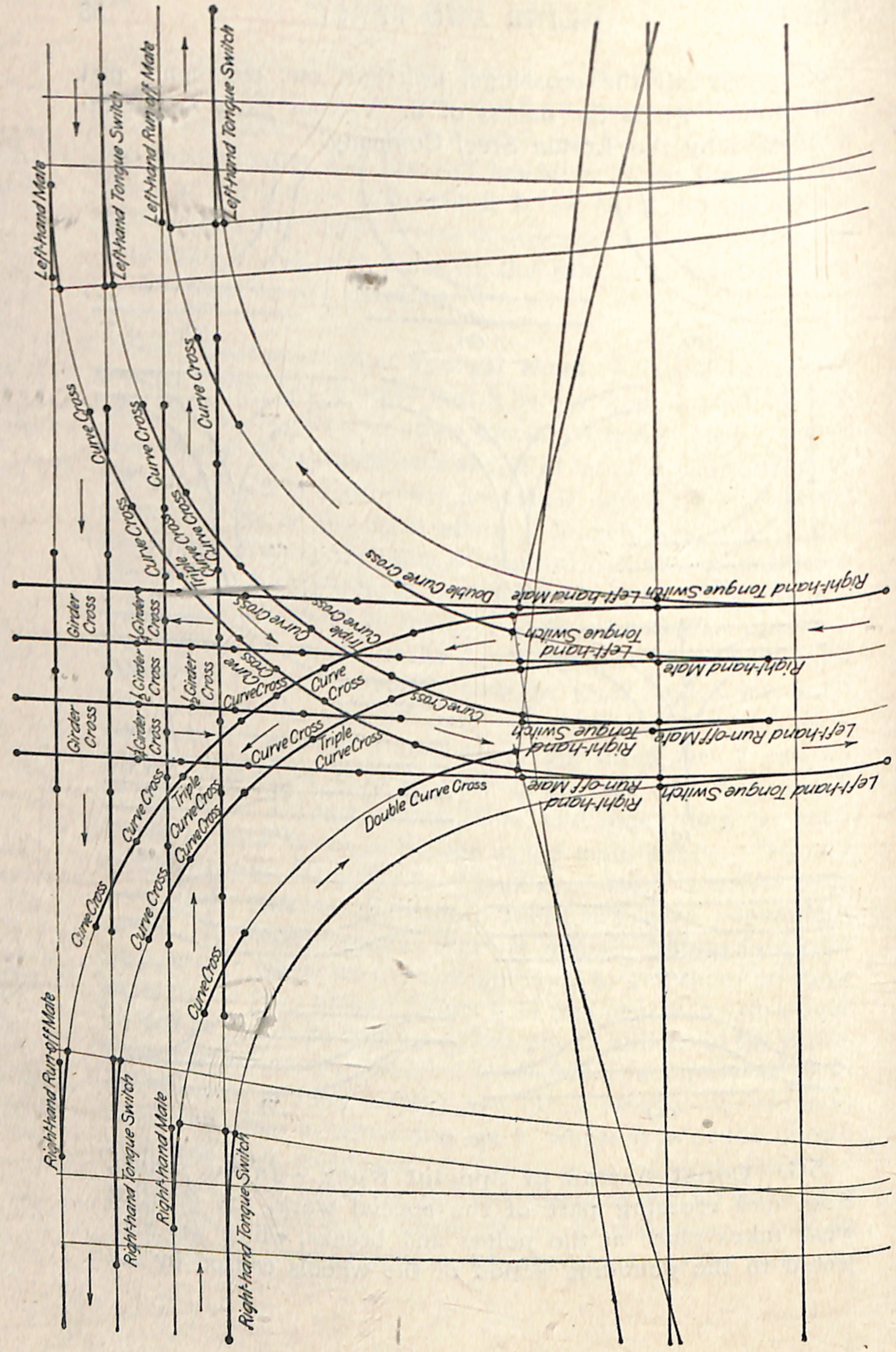


Fig. 50

breaks in the tread of the rail. On this account, methods have been adopted for inserting hard steel at the points and crossings. One make of special work, known as *manganese*, takes its name from special plates of hard manganese steel that are placed at the intersections. These are held in place by special bolts, or fastenings, so that they can be renewed

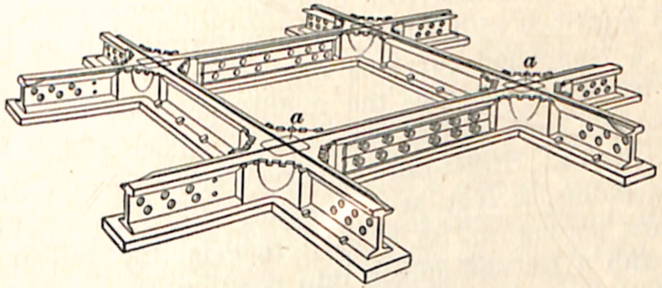


Fig. 51

when worn out. Another class of work is known as *guarantee*, because the crossings are guaranteed to wear as long as the abutting rail. In it, tempered steel wearing plates are held in place by keys, and zinc poured in around the piece. In a

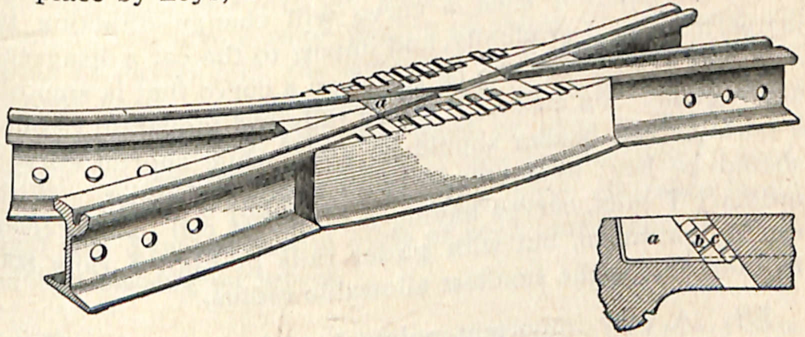


Fig. 52

third class of special work, known as *adamantine*, the crossings are made of steel castings. Fig. 51 shows a crossing of the guarantee type. Renewable hardened steel plates *a*, *a* are set in as shown; the joints are stiffened by a liberal use of cast iron, into which the ends of the rails are cast-welded at the crossings.

Fig. 52 shows a guarantee curve cross, showing how the renewable parts are arranged. The hardened-steel plate *a* is held in place by wedges *b*, *c* that are bedded in zinc, which prevents their working loose. In order to remove the plate, the wedges *b* are driven down.

57. **Curves.**—Curves are of two kinds, **simple** and **compound**, or **transition**, curves. A simple curve is one that is described with but one radius throughout its length, while a compound curve is one so constructed that the radii become shorter as the middle point of the curve is approached from either end and is easier riding than a simple curve. Street-railway curves are always designated by the radius, in feet, at the center. Long curves of light rail are sprung in, as a rule; that is, the rail is pried over with a bar and spiked into position, the paving being relied on to keep the track in place. The main objection to "springing in" a curve is, that if done on a curve of too short a radius or with heavy rail, the job in course of time will give trouble at the joints; the ends of the rails straighten out and make an angle at the joint. This means that the car trucks in rounding such a curve will change direction in jumps, instead of gradually, and impart to the car a disagreeable, jerky motion not to be found on a curve that is smooth and regular. On curves of heavy rails and moderate radius, a portable rail bender should be used, while shorter curves should be bent to a templet with a power bender. With ordinary **T** rails, curves having a radius of 500 feet or over can be sprung in, but with girder rails or high **T** rails 800 to 1,000 feet is the smallest allowable radius.

58. A very important point about laying out a single-track curve is to be certain that a car will go around it freely without either end overhanging the corner of the sidewalk or striking any obstruction. On double-track curves is also introduced the feature of two cars being able to pass each other without danger. It is not absolutely essential that the curves be such that two cars can pass each other on them, and in many existing cases it cannot be done. Very often,

however, it involves but small additional cost to so construct the curves, and in the long run it is the best thing to do. Whether or not a curve will allow cars to pass on it depends on the following: The length of the car; the width of the car; the amount that the ends overhang the wheel base; the distance between the track centers; the curvature; the elevation of the outside rail; the length of the wheel base; and, on double-truck cars, the distance between trucks. Also, the matter of fenders should be taken into account, as a fender increases the effective length of the car. As the trucks on a double-truck car are relatively nearer the ends of the car, the overhang in the center must be considered. The best plan is to lay out on paper and to scale a plan of the proposed curve; then, by means of a pasteboard dummy that scales the dimensions of the outside lines of the car, the actual clearance at all points can be readily determined. The positions of the car wheels may be indicated by holes through which the track can be seen, or transparent paper may be used, so that the dummy can be made to take the right path around the curve. Another point to be looked after in cutting out a dummy is to see that the widest part of the car is represented. To insure some degree of safety to the heads and arms of passengers, the clearance on both sides of the car should be at least 12 inches, if they are to pass each other on curves. Special attention must be paid to this feature where the center-pole method of line construction is used. There are many roads on which the curve clearance is not over 2 or 3 inches, but in most of such cases there is a rule against passing on curves.

59. **Transition, or Compound, Curves.**—These curves are formed by combining curves of different radii, so that the entrance of the car into the curve shall be gradual, and a sudden shock avoided. The curve at the point where it branches from the straight part of the track, or a tangent, as it is called, is of long radius and the radii are gradually decreased until the radius of the center of the curve is reached. Theoretically, the correct method would be to

make a true spiral connection between the tangent and the center of the curve, but this would be impracticable. Steel companies making a specialty of trackwork for electric railways have developed standard transition curves that approximate a spiral sufficiently close for all practical purposes. For example, the Lorain standard curve for a radius at the center of the curve varying from 40 feet to 62 feet 6 inches has an entrance radius of 432 feet.

At one time, curves for electric railways were made up of arcs of different radii struck from three or five different centers, thus giving a rough approximation to a spiral. Curves as now used are made up of a number of radii such that the length of arc of any one radius is not over 5 feet. This gives a curve that is practically as smooth riding as a true spiral.

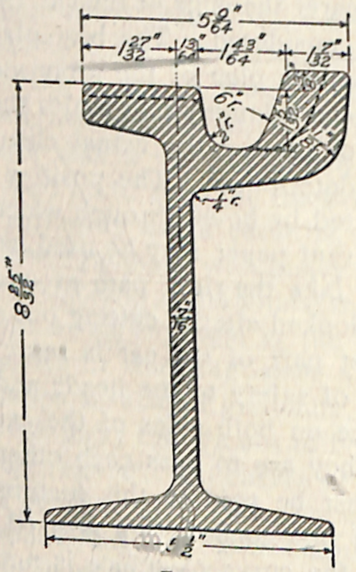
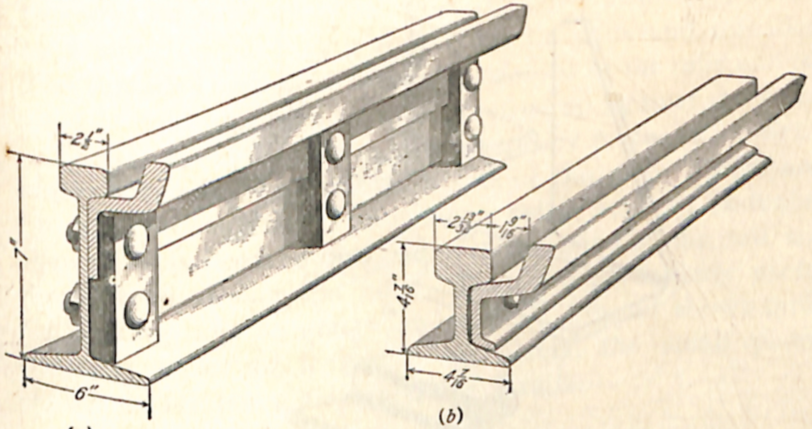


Fig. 53

60. Guard Rails.—Guard rails are rails provided with a protecting flange to prevent a car from climbing the rail on a curve; they may be solid or built up. Girder rails are, as a rule, solid; **T** rails are built up. Fig. 53 shows a section of a girder guard rail. It resembles a groove rail very closely except that the lip is heavier and projects above the tread of the rail. There is always considerable wear on the side of the groove and in time the lip and tread become worn, as shown by the dotted line. The **T** rail need only be provided with a regular guard where it is used in a paved street. In country work, the steam-road practice of laying a second line of **T** rail next to the inside-track rail is adopted. This practice is also adopted, as a rule, on bridges, where the guard rail is laid beside both track rails. The best authorities are inclined to the belief that a guard rail on

the inside, or short rail, of a curve affords ample protection, but it is common to see a guard on both the inside and outside rails of short curves. At any rate, it is not safe to rely on the wheel flanges alone to keep the car on the track, for



(a) (b)

Fig. 54

car wheels in street-railway service, on account of the heavy weight attached to the axle and also on account of the nature of the special work that they have to jolt over at times, are addicted to the trouble of broken or chipped flanges. A wheel with such a defect in the flange is almost certain to climb the rail if that wheel is on the front end of the car as a leader. As in the case of an ordinary grooved rail, a great deal of judgment must be used to select a groove that is adapted to the flanges of the wheels used. Fig. 54 shows two methods of attaching rail guards to **T** rails, (*a*) being used for high **T** rails and (*b*) for an ordinary rail, in this case a standard 65-pound A. S. C. E. section.

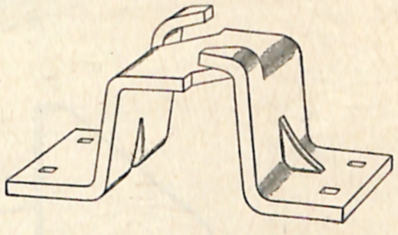


Fig. 55

61. Rail Chairs and Braces.—When a rail is not deep enough to accommodate the paving in a street, it can be raised on **chairs**. These are forged fittings on which the

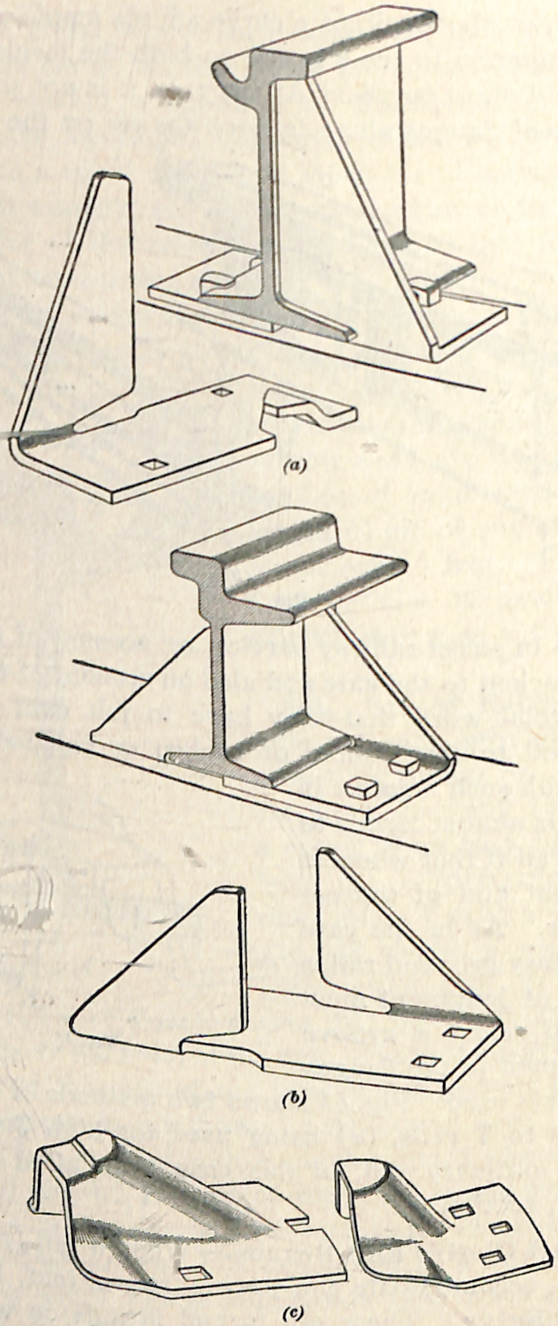


FIG. 56

rail rests and which raise it to the desired height. Fig. 55 shows a common form of chair.

In order to keep the track from spreading, either **tie-rods** or **braces** may be used. The former consist of rods threaded on each end; the most common form is $1\frac{1}{2}$ inches by $\frac{3}{8}$ inch forged $\frac{3}{4}$ inch round on the ends and threaded. The threaded ends pass through the webs of the rails and the track is held to gauge by nuts screwed up against the webs.

The track can also be held to gauge by means of tie brace plates that bear against the outside of the rail. These are, by many, considered a very much better form of fastening than tie-rods because they support the head of the rail and do not tend to cant the rails. They are particularly useful for holding rails to gauge on curves. Fig. 56 shows three common styles of forged brace plates, the small plates shown in (*c*) being designed for **T** rails.